

THERMODYNAMICS

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PREPARED BY: ENGR. YURI G. MELLIZA

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THERMODYNAMICS

Thermodynamics was derived from a Greek word “therme” that means HEAT and “dynamis” that means STRENGTH.

This subject is an area of Mechanical Engineering that deals with the transformation of energy or conversion of energy from one form to another.

This subject is comprehensive which emphasis throughout is the application of theories and principles to ideal or actual processes for the design of different types of power plant facilities and mechanical industrial equipment.

Founders of Thermodynamics



Albert Einstein (1879-1955), German-born American physicist and Nobel laureate, best known as the creator of the special and general theories of relativity and for his bold hypothesis concerning the particle nature of light. He is perhaps the most well-known scientist of the 20th century

Einstein was born in Ulm on March 14, 1879, and spent his youth in Munich, where his family owned a small shop that manufactured electric machinery. He did not talk until the age of three, but even as a youth he showed a brilliant curiosity about nature and an ability to understand difficult mathematical concepts. At the age of 12 he taught himself Euclidean geometry.



Isaac Newton (1642-1727), English physicist, mathematician, and natural philosopher, considered one of the most important scientists of all time. Newton formulated laws of universal gravitation and motion—laws that explain how objects move on Earth as well as through the heavens. He established the modern study of optics—or the behavior of light—and built the first reflecting telescope. His mathematical insights led him to invent the area of mathematics called calculus (which German mathematician Gottfried Wilhelm Leibniz also developed independently). Newton stated his ideas in several published works, two of which, *Philosophiae Naturalis Principia Mathematica* (Mathematical Principles of Natural Philosophy, 1687) and *Opticks* (1704), are considered among the greatest scientific works ever produced. Newton’s revolutionary contributions explained the workings of a large part of the physical world in mathematical terms, and they suggested that science may provide explanations for other phenomena as well.



Blaise Pascal (1623-62), French philosopher, mathematician, and physicist, considered one of the great minds in Western intellectual history. Pascal was born in Clermont-Ferrand on June 19, 1623, and his family settled in Paris in 1629. Under the tutelage of his father, Pascal soon proved himself a mathematical prodigy, and at the age of 16 he formulated one of the basic theorems of projective geometry, known as Pascal's theorem and described in his *Essai pour les coniques* (Essay on Conics, 1639). In 1642 he invented the first mechanical adding machine. Pascal proved by experimentation in 1648 that the level of the mercury column in a barometer is determined by an increase or decrease in the surrounding atmospheric pressure rather than by a vacuum, as previously believed. This discovery verified the hypothesis of the Italian physicist Evangelista Torricelli concerning the effect of atmospheric pressure on the equilibrium of liquids. Six years later, in conjunction with the French mathematician Pierre de Fermat, Pascal formulated the mathematical theory of probability, which has become important in such fields as

actuarial, mathematical, and social statistics and as a fundamental element in the calculations of modern theoretical physics. Pascal's other important scientific contributions include the derivation of Pascal's law or principle, which states that fluids transmit pressures equally in all directions, and his investigations in the geometry of infinitesimals. His methodology reflected his emphasis on empirical experimentation as opposed to analytical, a priori methods, and he believed that human progress is perpetuated by the accumulation of scientific discoveries resulting from such experimentation.



Robert Boyle (1627-1691), English natural philosopher and one of the founders of modern chemistry. Boyle is best remembered for Boyle's law, a physical law that explains how the pressure and volume of a gas are related. He was instrumental in the founding of the Royal Society, a British organization dedicated to the advancement of the sciences. Boyle was also a pioneer in the use of experiments and the scientific method to test his theories.

Boyle was born in Lismore Castle in Lismore, Ireland. His father was Richard Boyle, who was the first earl of Cork. Robert learned to speak French and Latin as a child and went to Eton College in England at the early age of eight.

In 1641 Boyle began a tour of Europe, returning to England in 1644. He settled there, because Ireland was in turmoil over colonization efforts by English protestants. Boyle had inherited parts of several estates upon his father's death in 1643, and income from these allowed him to live independently. He joined a group known as the Invisible

College, whose aim was to cultivate ideas called the "new philosophy." The new philosophy included new methods of experimental science, in which scientists sought to prove or disprove hypotheses through careful experiments. Boyle moved to Oxford, which was one of the meeting places of the Invisible College, in 1654. King Charles II granted a charter in 1663 that allowed the Invisible College to become the Royal Society of London for Improving Natural Knowledge, and Boyle was a member of its first council. (He was elected president of the Royal Society in 1680, but declined the office.) He moved to London in 1668 and lived with his sister until his death in 1691.



Joseph Louis Gay-Lussac (1778-1850), French chemist and physicist, known for his studies on the physical properties of gases. He was born in Saint Léonard and educated at the École Polytechnique and the École des Ponts et Chaussées in Paris. After holding several professorships he became professor of physics at the Sorbonne from 1808 to 1832. In 1804 he made balloon ascensions to study magnetic forces and to observe the composition and temperature of the air at different altitudes. In 1809 he formulated a law of gases that is still associated with his name. Gay-Lussac's law of combining volumes states that the volumes of the gases involved in a chemical reaction (both reactants and products) are in the ratio of small whole numbers. In connection with these studies he investigated, with German naturalist Baron Alexander von Humboldt, the composition of water and found it forms when two parts of hydrogen and one of oxygen unite. In 1809 Gay-Lussac worked on the preparation of potassium and boron and investigated the

properties of chlorine and hydrocyanic acid.



Amedeo Avogadro (1776-1856), Italian physicist and chemist who proposed a hypothesis that later became known as Avogadro's law. Avogadro was born in Turin and educated as a lawyer. He became interested in mathematics and physics and, after several years of study, was appointed to a professorship at the Royal College of Vercelli. From 1820 until his death, Avogadro was professor of physics at the University of Turin. Although he also conducted research on electricity and the physical properties of liquids, he is best known for his work with gases, which led him to formulate in 1811 the law that now bears his name.

Avogadro's law states that two equal volumes of gas at the same temperature and pressure contain an equal number of gas molecules. Now known to be true, this law was not universally accepted until the 1850s.



John Dalton (1766-1844), British chemist and physicist, who developed the atomic theory upon which modern physical science is founded. Dalton was born on September 6, 1766, in Eaglesfield, Cumberland County, England. He was the son of a weaver and received his early education from his father and at a Quaker school in his native town, where he began teaching at the age of 12. In 1781 he was appointed assistant to the Quaker school in Kendal and four years later became joint principal. In Kendal, Dalton came under the influence of scientist John Gough, who taught him mathematics, as well as meteorology and botany. He went to Manchester in 1793 and spent the rest of his life there as a teacher, first at New College and later as a private tutor. He died in Manchester on July 27, 1844. Dalton began a series of meteorological observations in 1787 that he continued for 57 years, accumulating some 200,000 observations and measurements on the weather in the Manchester area. Dalton's interest in meteorology led him to study a variety of

phenomena as well as the instruments used to measure them. He was the first to prove the validity of the concept that rain is precipitated by a decrease in temperature, not by a change in atmospheric pressure.



Daniel Bernoulli (1700-1782), Dutch-born Swiss scientist, who discovered basic principles of fluid behavior. He was the son of Johann Bernoulli and the nephew of Jakob Bernoulli, both of whom made major contributions to the early development of calculus.

Bernoulli was born in Groningen on January 29, 1700, and took an early interest in mathematics. Although he earned a medical degree in 1721, he became a professor of mathematics at the Russian Academy in Saint Petersburg in 1725. He later taught experimental philosophy, anatomy, and botany at the universities of Groningen and Basel, Switzerland.

Bernoulli pioneered in Europe in accepting the new physics of the English scientist Isaac Newton. He studied the flow of fluids and formulated the principle that the pressure exerted by a fluid is inversely proportional to its rate of flow (see Bernoulli's Principle). He used atomistic concepts in trying to develop the first kinetic theory of gases, accounting for their behavior under conditions of changing pressure and temperature in probabilistic terms. This work, however, did not gain wide notice at the time. Bernoulli died in Basel on March 17, 1782



Archimedes (287-212 BC), preeminent Greek mathematician and inventor, who wrote important works on plane and solid geometry, arithmetic, and mechanics.

Archimedes was born in Syracuse, Sicily, and educated in Alexandria, Egypt. In pure mathematics he anticipated many of the discoveries of modern science, such as the integral calculus, through his studies of the areas and volumes of curved solid figures and the areas of plane figures. He also proved that the volume of a sphere is two-thirds the volume of a cylinder that circumscribes the sphere.

In mechanics, Archimedes defined the principle of the lever and is credited with inventing the compound pulley. During his stay in Egypt he invented the hydraulic screw for raising water from a lower to a higher level. He is best known for discovering the law of hydrostatics, often called Archimedes' principle, which states that a body immersed in fluid loses weight equal to the weight of the amount of fluid it displaces. This discovery is said to have been made as Archimedes stepped into his bath and perceived the displaced

water overflowing.

Archimedes spent the major part of his life in Sicily, in and around Syracuse. He did not hold any public office but devoted his entire lifetime to research and experiment. During the Roman conquest of Sicily, however, he placed his gifts at the disposal of the state, and several of his mechanical devices were employed in the defense of Syracuse. Among the war machines attributed to him are the catapult and—perhaps legendary—a mirror system for focusing the sun's rays on the invaders' boats and igniting them.

After the capture of Syracuse during the Second Punic War, Archimedes was killed by a Roman soldier who found him drawing a mathematical diagram in the sand. It is said that Archimedes was so absorbed in calculation that he offended the intruder merely by remarking, "Do not disturb my diagrams." Several of his works on mathematics and mechanics survive, including *Floating Bodies*, *The Sand Reckoner*, *Measurement of the Circle*, *Spirals*, and *Sphere and Cylinder*. They all exhibit the rigor and imaginativeness of his mathematical thinking.

Kelvin, William Thomson, Baron

Born June 26, 1824, Belfast, County Antrim, Ire. [now in Northern Ireland], died Dec. 17, 1907, Netherhall, near Largs, Ayrshire, Scot

In full William Thomson, Baron Kelvin of Largs, also called (1866–92) Sir William Thomson Scottish engineer, mathematician, and physicist, who profoundly influenced the scientific thought of his generation.

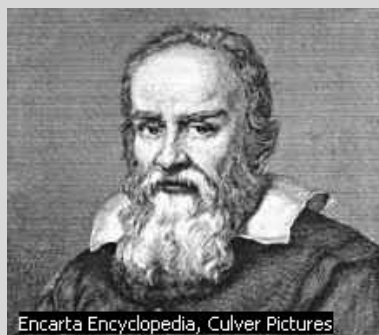
Thomson, who was knighted and raised to the peerage in recognition of his work in engineering and physics, was foremost among the small group of British scientists who helped to lay the foundations of modern physics. His contributions to science included a major role in the development of the second law of thermodynamics; the absolute temperature scale (measured in kelvins); the dynamical theory of heat; the mathematical analysis of electricity and magnetism, including the basic ideas for the electromagnetic theory of light; the geophysical determination of the age of the Earth; and fundamental work in hydrodynamics. His theoretical work on submarine telegraphy and his inventions for use on submarine cables aided Britain in capturing a preeminent place in world communication during the 19th century.

The style and character of Thomson's scientific and engineering work reflected his active personality. While a student at the University of Cambridge, he was awarded silver skulls for winning the university championship in racing single-seater rowing shells. He was an inveterate traveller all of his life, spending much time on the Continent and making several trips to the United States. In later life he commuted between homes in London and Glasgow. Thomson risked his life several times during the laying of the first transatlantic cable. Thomson's worldview was based in part on the belief that all phenomena that caused force—such as electricity, magnetism, and heat—were the result of invisible material in motion. This belief placed him in the forefront of those scientists who opposed the view that forces were produced by imponderable fluids. By the end of the century, however, Thomson, having persisted in his belief, found himself in opposition to the positivistic outlook that proved to be a prelude to 20th-century quantum mechanics and relativity. Consistency of worldview eventually placed him counter to the mainstream of science.

But Thomson's consistency enabled him to apply a few basic ideas to a number of areas of study. He brought together disparate areas of physics—heat, thermodynamics, mechanics, hydrodynamics, magnetism, and electricity—and thus played a principal role in the great and final synthesis of 19th-century science, which viewed all physical change as energy-related phenomena. Thomson was also the first to suggest that there were mathematical analogies between kinds of energy. His success as a synthesizer of theories about energy places him in the same position in 19th-century physics as Sir Isaac Newton has in 17th-century physics or Albert Einstein in 20th-century physics. All of these great synthesizers prepared the ground for the next grand leap forward in science.

Gabriel Daniel Fahrenheit (1686-1736)

Gabriel Daniel Fahrenheit (1686-1736), German physicist, born in Danzig (now Gdańsk, Poland). He settled in Holland and engaged in the manufacture of meteorological instruments. In 1714 he constructed the first thermometer employing mercury instead of alcohol. Using this thermometer he devised the temperature scale now known by his name and still used in the United States. Fahrenheit also invented a hygrometer of improved design. He discovered that other liquids besides water have a fixed boiling point and that these boiling points vary with changes in atmospheric pressure.



Encarta Encyclopedia, Culver Pictures

Galileo (1564-1642), Italian physicist and astronomer who, with German astronomer Johannes Kepler, initiated the scientific revolution that flowered in the work of English physicist Sir Isaac Newton. Galileo's main contributions were, in astronomy, the use of the telescope in observation and the discovery of sunspots, mountains and valleys on the Moon, the four largest satellites of Jupiter, and the phases of Venus. In physics, he discovered the laws of falling bodies and the motions of projectiles. In the history of culture, Galileo stands as a symbol of the battle against authority for freedom of inquiry.



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Max Planck (1858-1947), German physicist and Nobel laureate, who was the originator of the quantum theory.

Max Karl Ernst Ludwig Planck was born in Kiel on April 23, 1858, and educated at the universities of Munich and Berlin. He was appointed professor of physics at the University of Kiel in 1885, and from 1889 until 1928 filled the same position at the University of Berlin. In 1900 Planck postulated that energy is radiated in small, discrete units, which he called quanta. Developing his quantum theory further, he discovered a universal constant of nature, which came to be known as Planck's constant. Planck's law states that the energy of each quantum is equal to the frequency of the radiation multiplied by the universal constant. His discoveries did not, however, supersede the theory that radiation from light or matter is emitted in waves. Physicists now believe that electromagnetic radiation combines the properties of both waves and particles. Planck's discoveries, which were later verified by other scientists, were the basis of an entirely

new field of physics, known as quantum mechanics, and provided a foundation for research in such fields as atomic energy. See Atom; Quantum Theory.

Planck received many honors for his work, notably the 1918 Nobel Prize in physics. In 1930 Planck was elected president of the Kaiser Wilhelm Society for the Advancement of Science, the leading association of German scientists, which was later renamed the Max Planck Society. He endangered himself by openly criticizing the Nazi regime that came to power in Germany in 1933 and was forced out of the society, but became president again after World War II. He died at Göttingen on October 4, 1947. Among his

writings that have been translated into English are Introduction to Theoretical Physics (5 volumes, 1932-33) and Philosophy of Physics (1936).



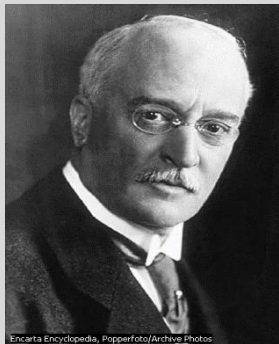
Nikolaus Otto (1832-1891), German inventor, who devised the Otto cycle engine—the first effective four-stroke internal-combustion engine.

Nikolaus August Otto was born in Holzhausen, Germany. He left school at age 16 and moved to Cologne. After seeing the coal-gas engine designed and built by French inventor Jean-Joseph-Étienne Lenoir in 1859, Otto began experimenting with internal-combustion engines. He built his first engine based on Lenoir's design in 1861. He joined forces with German industrialist Eugen Langen in 1864 to form a company near Cologne, and the firm turned out its first production-model engine in 1867.

The first engine produced by Otto's firm was a two-stroke engine that drew in a fresh air-fuel mixture on the same stroke it exhausted the spent mixture of the previous cycle. It was much more efficient than Lenoir's engine because the two-stroke engine compressed the gas before igniting it. In 1876 Otto and Langen announced a newer, much more efficient four-stroke engine.

In this engine the air-fuel mixture was drawn in on one stroke of the piston and then compressed and ignited on the next. The third stroke of the piston transferred the power of the exploding gases to the engine's crankshaft, and the fourth stroke of the piston was used to expel, or exhaust, the spent gases. The new engine, which was quiet and efficient, was named the Otto cycle engine. It caught on at once and remains the basic design of most modern internal-combustion engines.

Otto patented the Otto cycle in 1877 and formed a company that in a few years sold 35,000 engines, primarily for use in small factories. In 1886, however, Otto's competitors showed that French engineer Alphonse-Eugène Beau de Rochas had suggested the principle of the four-stroke engine in an obscure pamphlet before Otto developed his cycle engine. Although this invalidated Otto's patent, the Otto engines were still the only internal-combustion engines widely used. In 1890 Wilhelm Maybach and Gottlieb Daimler, two of the lead engineers in Otto's firm, launched their own firm to produce automobiles powered by Otto cycle engines. They refined the Otto cycle engine and went on to manufacture the first Mercedes automobile in 1899.



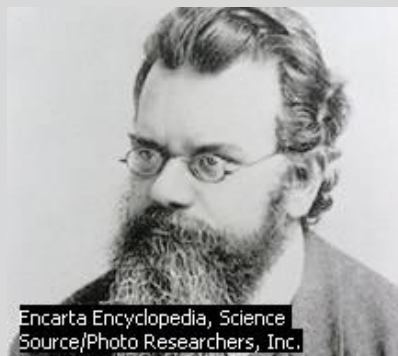
Rudolf Diesel, full name Rudolf Christian Karl Diesel (1858-1913), German engineer, who invented the diesel engine. born March 18, 1858, Paris, France, died September 29, 1913.

German thermal engineer who invented the internal-combustion engine that bears his name. He was also a distinguished connoisseur of the arts, a linguist, and a social theorist.

Diesel, the son of German-born parents, grew up in Paris until the family was deported to England in 1870 following the outbreak of the Franco-German War. From London Diesel was sent to Augsburg, his father's native town, to continue his schooling. There and later at the Technische Hochschule (Technical High School) in Munich he established a brilliant scholastic record in fields of engineering. At Munich he was a protégé of the refrigeration engineer Carl von Linde, whose Paris firm he joined in 1880.

Diesel devoted much of his time to the self-imposed task of developing an internal combustion engine that would approach the theoretical efficiency of the Carnot cycle. For a time he experimented with an expansion engine using ammonia. About 1890, in which year he moved to a new post with the Linde firm in Berlin, he conceived the idea for the diesel engine (q.v.). He obtained a German development patent in 1892 and the following year published a description of his engine under the title Theorie und Konstruktion eines rationellen Wärmotors (Theory and Construction of a Rational Heat Motor). With support from the Maschinenfabrik Augsburg and the Krupp firms, he produced a series of increasingly successful models, culminating in his demonstration in 1897 of a 25-horsepower, four-stroke, single vertical cylinder compression engine. The high efficiency of Diesel's engine, together with its comparative simplicity of design, made it an immediate commercial success, and royalty fees brought great wealth to its inventor.

Diesel disappeared from the deck of the mail steamer Dresden en route to London and was assumed to have drowned.



Encarta Encyclopedia, Science
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Ludwig Boltzmann (1844-1906), Austrian physicist, who helped lay the foundation for the field of physics known as statistical mechanics. Boltzmann was born in Vienna and educated at the universities of Vienna and Oxford. He was a professor of physics at various German and Austrian universities for more than 40 years. During the 1870s Boltzmann published a series of papers that showed that the second law of thermodynamics could be explained by statistically analyzing the motions of atoms. In these papers Boltzmann utilized the central principle of statistical mechanics: that large-scale, visible phenomena, such as the second law of thermodynamics, can be explained by statistically examining the microscopic properties of a system, such as the motions of atoms. Boltzmann also formulated the law of thermal radiation, named for him and the Austrian physicist Josef Stefan. The Stefan-Boltzmann law states that the total radiation from a blackbody, which is an ideal surface that absorbs all radiant energy that strikes it, is proportional to the fourth power of the

absolute temperature of the blackbody. Boltzmann also made important contributions to the kinetic theory of gases. Boltzmann's work was strongly attacked by scientists of his time. However, much of Boltzmann's work was substantiated by experimental data soon after he committed suicide in 1906.

Joseph Stefan

Joseph Stefan (1835-1893), Austrian physicist who succeeded in relating radiation to absolute temperature. Stefan was born at St Peter near Flagenfurt, the son of an illiterate shopkeeper. A brilliant experimenter, he became Professor of Physics at Vienna in 1863. Three years later he was appointed Director of the Institute for Experimental Physics in Vienna, founded by Christian Doppler. He remained there for the rest of his life. Stefan had a wide range of interests in physics, including electromagnetism, optical interference, and capillary action, but is especially noted for his work on the kinetic theory of gases. He developed a dia-thermometer to measure heat conduction, and worked on the diffusion of liquids and on the relationship between surface tension and evaporation. His most famous experiment was described in 1879. By analyzing measurements of a glowing platinum wire (measurements that had been made by John Tyndall), he demonstrated that the rate of radiation of energy from a hot body is proportional to the fourth power of its temperature. Subsequently his distinguished pupil Ludwig Boltzmann gave this relationship a theoretical foundation, the basis of the theory of gases by James Clerk Maxwell. This generalization is now known as the Stefan-Boltzmann Law, and was used to make the first satisfactory estimate of the sun's surface temperature.

Nicolas-Léonard-Sadi Carnot

Born June 1, 1796, Paris, Fr.

Died Aug. 24, 1832, Paris

In full Nicolas-léonard-sadi Carnot French scientist who described the Carnot cycle, relating to the theory of heat engines.

Carnot was the eldest son of the French Revolutionary figure Lazare Carnot and was named for a medieval Persian poet and philosopher, Sa'dī of Shīrāz. His early years were a period of unrest, and the family suffered many changes of fortune. His father fled into exile soon after Sadi's birth; in 1799 he returned to be appointed Napoleon's minister of war but was soon forced to resign. A writer on mathematics and mechanics as well as military and political matters, the elder Carnot now had the leisure to direct his son's early education.

Sadi entered the École Polytechnique in 1812, an institution providing an exceptionally fine education, with a faculty of famous scientists aware of the latest developments in physics and chemistry, which they based on a rigorous mathematics. By the time Sadi graduated in 1814, Napoleon's empire was being rolled back, and European armies were invading France. Soon Paris itself was besieged, and the students, Sadi among them, fought a skirmish on the outskirts of the city.

During Napoleon's brief return to power in 1815, Lazare Carnot was minister of the interior, but, following the emperor's final abdication, he fled to Germany, never to return to France.

Sadi remained an army officer for most of his life, despite disputes about his seniority, denial of promotion, and the refusal to employ him in the job for which he had been trained. In 1819 he transferred to the recently formed General Staff but quickly retired on half pay, living in Paris on call for army duty. Friends described him as reserved, almost taciturn, but insatiably curious about science and technical processes.

The mature, creative period of his life now began. Sadi attended public lectures on physics and chemistry provided for workingmen. He was also inspired by long discussions with the prominent physicist and successful industrialist Nicolas Clément-Desormes, whose theories he further clarified by his insight and ability to generalize.

The problem occupying Carnot was how to design good steam engines. Steam power already had many uses—draining water from mines, excavating ports and rivers, forging iron, grinding grain, and spinning and weaving cloth—but it was inefficient. The import into France of advanced engines after the war with Britain showed Carnot how far French design had fallen behind. It irked him particularly that the British had progressed so far through the genius of a few engineers who lacked formal scientific education. British engineers had also accumulated and published reliable data about the efficiency of many types of engines under actual running conditions; and they vigorously argued the merits of low- and high-pressure engines and of single-cylinder and multi-cylinder engines.

Convinced that France's inadequate utilization of steam was a factor in its downfall, Carnot began to write a nontechnical work on the efficiency of steam engines. Other workers before him had examined the question of improving the efficiency of steam engines

by comparing the expansion and compression of steam with the production of work and consumption of fuel. In his essay, *Réflexions sur la puissance motrice du feu et sur les machines propres à développer cette puissance* (Reflections on the Motive Power of Fire), published in 1824, Carnot tackled the essence of the process, not concerning himself as others had done with its mechanical details. He saw that, in a steam engine, motive power is produced when heat “drops” from the higher temperature of the boiler to the lower temperature of the condenser, just as water, when falling, provides power in a waterwheel. He worked within the framework of the caloric theory of heat, assuming that heat was a gas that could be neither created nor destroyed. Though the assumption was incorrect and Carnot himself had doubts about it even while he was writing, many of his results were nevertheless true, notably the prediction that the efficiency of an idealized engine depends only on the temperature of its hottest and coldest parts and not on the substance (steam or any other fluid) that drives the mechanism.

Although formally presented to the Academy of Sciences and given an excellent review in the press, the work was completely ignored until 1834, when Émile Clapeyron, a railroad engineer, quoted and extended Carnot's results. Several factors might account for this delay in recognition; the number of copies printed was limited and the dissemination of scientific literature was slow, and such a work was hardly expected to come from France when the leadership in steam technology had been centred in England for a century. Eventually Carnot's views were incorporated by the thermodynamic theory as it was developed by Rudolf Clausius in Germany (1850) and William Thomson (later

Lord Kelvin) in Britain (1851).

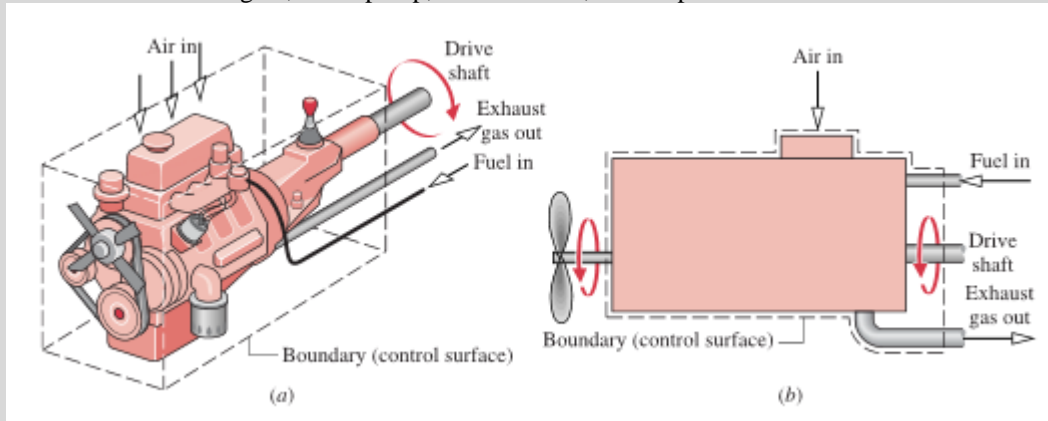
Little is known of Carnot's subsequent activities. In 1828 he described himself as a “constructor of steam engines, in Paris.” When the Revolution of 1830 in France seemed to promise a more liberal regime, there was a suggestion that Carnot be given a government position, but nothing came of it. He was also interested in improving public education. When absolutist monarchy was restored, he returned to scientific work, which he continued until his death in the cholera epidemic of 1832 in Paris.

TERMS AND DEFINITIONS

System: Is that portion in the universe an atom, a galaxy, a certain quantity of matter or a certain volume in space in which one wishes to study. It is enclosed by a specified boundary that may be imaginary, fixed or moving. The region all about the system is called the “surrounding or environment”

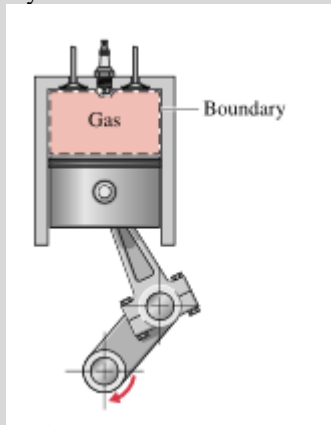
Open System: A system that open to matter flow or a system in which there’s an exchange of mass between the system and the surrounding.

Example: Internal combustion engine, water pump, steam turbine, air compressor.



Closed System: A system that is closed to matter flow or a system in which there’s no exchange of mass between the system and the surrounding.

Example: Piston-in-cylinder



Working Substance: A substance that is responsible for the transformation of energy.

Example:

1. air in an air compressor
2. water in a water pump

Pure Substance: A substance that is homogeneous in nature and is homogeneous. It is a substance that does not undergo chemical reaction or it is not a mixture of different species.

Example: Water (H_2O)

Property: It is a characteristic quality of a certain substance. By knowing the properties of a substance its state or condition may be determine. Certain group of state of a substance determines the phases of a substance.

Intensive Property: Property that is independent of the mass of a substance.

Extensive Property: Property that is dependent of the mass of a substance.

Extensive	Intensive
Volume, V [m^3]	Density, ρ [m^3/kg]
Mass, m [kg]	Pressure, p [N/m^2]
Enthalpy, H [J]	Temperature, T [K]
Entropy, S [J/K]	Specific enthalpy, h [J/kg]

In the right-hand column are **intensive** properties. In the left are **extensive** properties. Intensive properties are the same for any quantity of material being considered. Extensive properties depend on the amount of material. Intensive properties are mostly expressed per kg of material; this is a **specific** measure of an extensive property. Extensive is indicated by capital symbols, intensive by lowercase. In changing from extensive (the whole) to intensive (specific), H becomes h , S becomes s , V becomes v ; T , and p are inherently intensive and a specific measure cannot be stated. h , s , v are specific enthalpy, specific entropy and specific volume.

SPECIFIC TERMS TO CHARACTERIZED PHASE TRANSITION

- **Evaporation:** Change from liquid to vapor phase.
- **Condensation:** Change from vapor to liquid phase.
- **Freezing or Solidification:** Change from liquid to vapor phase.
- **Melting:** Change from solid to liquid phase.
- **Sublimation:** Change from solid directly to vapor phase without passing the liquid state.

Mass: It is the absolute quantity of matter in it.

m – mass, kg

1 kg = 2.205 lbs

Velocity: It is the distance per unit time.

$$v = \frac{d}{t} \frac{m}{sec}$$

Where

d – distance, m

t – time, sec

Conversion

1 meter = 3.28 ft = 100 cm = 1000 mm

1 ft. = 12 inches

Acceleration: Rate of change of velocity with respect to time.

$$a = \frac{dv}{dt}$$

where

a – acceleration in m/sec^2

Gravitational Acceleration: It is the acceleration due to gravity.

At standard condition or Sea level condition:

$$g = 9.81 \text{ m}/\text{sec}^2 = 32.2 \text{ ft}/\text{sec}^2$$

Force: It is the mass multiplied by the acceleration.

$$F = \frac{ma}{1000} \text{ KN (Kilo Newton)}$$

Newton: It is the force required to accelerate 1 kg mass at the rate of 1 m/sec per second.

Where:

m – mass in kg

a – acceleration in m/sec²

Weight: It is the force due to gravity.

$$W = mg \text{ N}$$

$$W = \frac{mg}{1000} \text{ KN}$$

where

g - gravitational acceleration, $\frac{\text{m}}{\text{sec}^2}$

$$g = 9.81 \frac{\text{m}}{\text{sec}^2} \rightarrow (\text{Standard gravitational acceleration})$$

Force of Attraction: From Newton's Law of Gravitation the force of attraction between two masses m_1 and m_2 is given by the equation:

$$F_g = \frac{Gm_1m_2}{r^2} \text{ Newton}$$

where:

m_1 and m_2 - masses in kg

r - distance apart in meters

G - Gravitational constant in N-m²/kg²

$$G = 6.670 \times 10^{-11} \frac{\text{N} \cdot \text{m}^2}{\text{kg}^2}$$

Table 2.1 SI Units for Mass, Length, Time, and Force

Quantity	Unit	Symbol
mass	kilogram	kg
length	meter	m
time	second	s
force	newton (= 1 kg · m/s ²)	N

Table 2.2 SI Unit

Prefixes

Factor	Prefix	Symbol
10 ¹²	tera	T
10 ⁹	giga	G
10 ⁶	mega	M
10 ³	kilo	k
10 ²	hecto	h
10 ⁻²	centi	c
10 ⁻³	milli	m
10 ⁻⁶	micro	μ
10 ⁻⁹	nano	n
10 ⁻¹²	pico	p

Table 2.3 Other Units for Mass, Length, Time, and Force

Quantity	Unit	Symbol
mass	pound mass	lb
	slug	slug
length	foot	ft
time	second	s
force	pound force	lbf
	(= 32.1740 lb · ft/s ²)	
	(= 1 slug · ft/s ²)	

PROPERTIES OF FLUIDS

DENSITY (ρ) - it is the mass per unit volume.

$$\rho = \frac{m}{V} \quad \frac{\text{kg}}{\text{m}^3}$$

where:

m - mass, kg

V - volume, m³

Conversion:

$$1 \frac{\text{lb}}{\text{ft}^3} = 16.0185 \frac{\text{kg}}{\text{m}^3}$$

$$1 \frac{\text{kg}}{\text{cm}^3} = 62,427.9606 \frac{\text{lb}}{\text{ft}^3}$$

$$1 \frac{\text{g}}{\text{liter}} = 1 \frac{\text{kg}}{\text{m}^3}$$

SPECIFIC VOLUME (v) - it is the volume per unit mass or the reciprocal of its density.

$$v = \frac{V}{m} \quad \frac{\text{m}^3}{\text{kg}}$$

$$v = \frac{1}{\rho} \quad \frac{\text{m}^3}{\text{kg}}$$

SPECIFIC WEIGHT (γ) - it is the weight per unit volume.

$$\gamma = \frac{W}{V} \quad \frac{\text{KN}}{\text{m}^3}$$

$$\gamma = \frac{mg}{1000V} \quad \frac{\text{KN}}{\text{m}^3}$$

$$\gamma = \frac{\rho g}{1000} \quad \frac{\text{KN}}{\text{m}^3}$$

SPECIFIC GRAVITY OR RELATIVE DENSITY (S):

FOR LIQUIDS: Its specific gravity or relative density is equal to the ratio of its density to that of water at standard temperature and pressure.

$$S_L = \frac{\rho}{\rho_w} = \frac{\gamma_L}{\gamma_w}$$

At standard condition:

$$\rho_w = 1000 \text{ kg/m}^3$$

$$\gamma_w = 9.81 \text{ KN/m}^3$$

FOR GASES: Its specific gravity or relative density is equal to the ratio of its density to that of either air or hydrogen at some specified temperature and pressure

$$S_G = \frac{\rho_G}{\rho_{AH}}$$

where:

ρ_{ah} - density of either air or hydrogen
at some value of P and T.

Equation of State for Gases

$$PV = mRT$$

$$\rho = \frac{P}{RT} \frac{\text{kg}}{\text{m}^3}$$

$$R = \frac{8.3143}{M} \frac{\text{KJ}}{\text{kg} \cdot ^\circ\text{K}}$$

Where:

P – absolute pressure in KPa

V – volume in m³

m – mass in kg

R – Gas constant in KJ/kg-K

T – absolute temperature in K.

M – molecular weight of gas, kg/kgmol

Specific gravities of some
substances at 0°C

Substance	SG
Water	1.0
Blood	1.05
Seawater	1.025
Gasoline	0.7
Ethyl alcohol	0.79
Mercury	13.6
Wood	0.3–0.9
Gold	19.2
Bones	1.7–2.0
Ice	0.92
Air (at 1 atm)	0.0013

TEMPERATURE: It is the measure of the intensity of heat.

FAHRENHEIT SCALE

Freezing Point = 32°F

Boiling Point = 212°F

CENTIGRADE SCALE

Freezing Point = 0°C

Boiling Point = 100°C

ABSOLUTE SCALE

$$^{\circ}\text{R} = \text{F} + 460$$

$$\text{K} = ^{\circ}\text{C} + 273$$

$$P = \frac{F}{A} \frac{\text{KN}}{\text{m}^2} \text{ or KPa (KiloPascal)}$$

$$1 \frac{\text{KN}}{\text{m}^2} = 1 \text{ KPa}$$

PRESSURE - is defined as the normal component of a force per unit area.

$$P = \frac{dF}{dA}$$

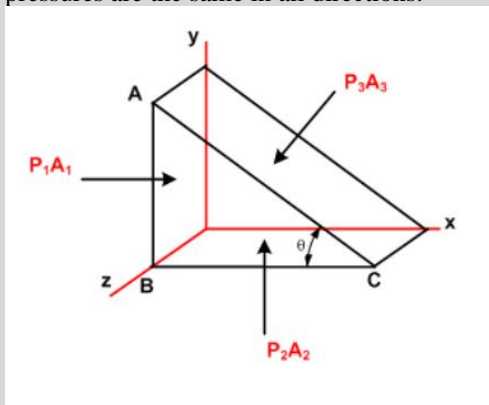
If a force dF acts on infinitesimal area dA the intensity of pressure P is

Conversion

$$^{\circ}\text{C} = \frac{^{\circ}\text{F} - 32}{1.8}$$
$$^{\circ}\text{F} = 1.8(^{\circ}\text{C}) + 32$$

PASCAL'S LAW

At any point in a homogeneous fluid at rest the pressures are the same in all directions.



$$\Sigma F_x = 0$$

$$P_1 A_1 - P_3 A_3 \sin \theta = 0$$

$$P_1 A_1 = P_3 A_3 \sin \theta \rightarrow \text{eq.1}$$

From Figure

$$\sin \theta = \frac{A_1}{A_3};$$

$$A_1 = A_3 \sin \theta \rightarrow \text{eq.2}$$

Equation 2 to equation 1

$$P_1 = P_3$$

$$\Sigma F_y = 0$$

$$P_2 A_2 - P_3 A_3 \cos \theta$$

$$P_2 A_2 = P_3 A_3 \cos \theta \rightarrow \text{eq.3}$$

$$\cos \theta = \frac{A_2}{A_3}$$

$$A_2 = A_3 \cos \theta \rightarrow \text{eq.4}$$

Equation 4 to equation 3

$$P_2 = P_3$$

therefore

$$P_1 = P_2 = P_3$$

ATMOSPHERIC PRESSURE (P_a): It is the average pressure exerted by the atmosphere.

At sea level (Standard Condition)

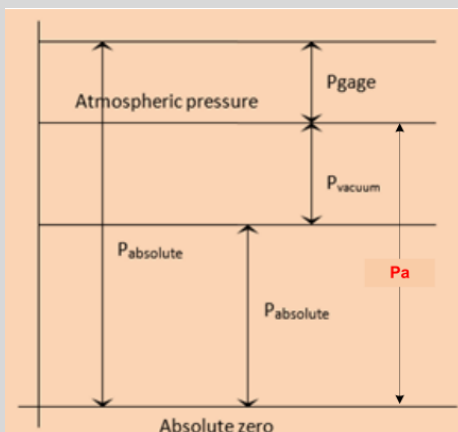
P_a	=	101.325	KPa
	=	0.101325	MPa
	=	760	mm Hg
	=	10.33	m of H_2O
	=	1.033	Kg/cm^2
	=	14.7	Lb/in ²
	=	29.921	in Hg
	=	33.88	Ft of H_2O

1Bar	=	100	KPa
1MPa	=	1000	KPa

ABSOLUTE AND GAGE PRESSURE

Absolute Pressure - is the pressure measured referred to absolute zero and using absolute zero as the base.

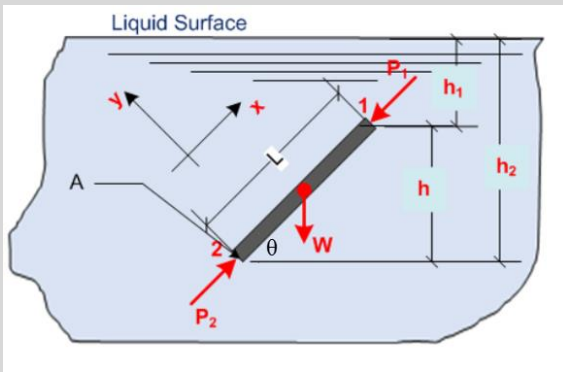
Gage Pressure - is the pressure measured referred to atmospheric pressure and using atmospheric pressure as the base.



$$P_{\text{abs}} = P_a + P_{\text{Gage}}$$

$$P_{\text{abs}} = P_a - P_{\text{vacuum}}$$

VARIATION OF PRESSURE WITH DEPTH OR ELEVATION



By applying equations for equilibrium

$$\sum F_x = 0$$

$$P_2 A - P_1 A - W \cos \theta = 0$$

$$P_2 A - P_1 A = W \cos \theta$$

$$(P_2 - P_1) A = W \cos \theta$$

But

$$W = \gamma V$$

$$V = AL$$

$$(P_2 - P_1) A = \gamma AL \cos \theta$$

from Figure

$$\cos \theta = \frac{h}{L}$$

$$h = L \cos \theta$$

$$(P_2 - P_1) A = -\gamma Ah$$

$$(P_2 - P_1) = -\gamma h$$

General Equation

$$dP = -\gamma dh$$

If the specific weight γ or density ρ is constant

$$\Delta P = -\gamma \Delta h$$

Note: Negative sign is used because pressure decreases with increasing elevation and increases with decreasing elevation.

h is positive if measured upward

h is negative if measured downward

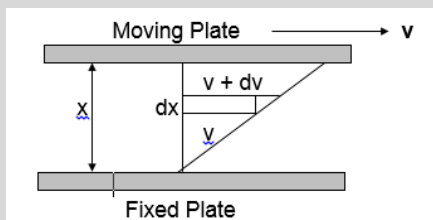
Where:

P – Pressure in KPa

γ – specific weight in KN/m^3

h – elevation in meters

VISCOSITY: It is the property of a fluid that determines the amount of its resistance to shearing stress.



Assumptions:

1. Fluid particles in contact with the moving surface moves with the same velocity of that surface.
2. The rate of change of velocity dv/dx is constant in the direction perpendicular to the direction of motion.
3. The shearing is directly proportional to the rate of change of velocity.
let S - shearing stress in Pa or N/m^2

$$S \propto \frac{dv}{dx}$$

$$S = \mu \frac{dv}{dx} = \mu \frac{v}{x}$$

$$\frac{dv}{dx} = \frac{v}{x}$$

$$\mu = S \left(\frac{x}{v} \right) \text{ Pa - sec or } \frac{\text{N - sec}}{\text{m}^2}$$

where: μ - absolute or dynamic viscosity in Pa – sec or N – sec/m²
 S - shearing stress Pa
 x - distance apart, m
 v - velocity , m/sec

KINEMATIC VISCOSITY: It is the ratio of the absolute or dynamic viscosity to the mass density.

$$\nu = \frac{\mu}{\rho} \frac{\text{m}^2}{\text{sec}}$$

ELASTICITY: If a pressure is applied to a fluid, it contracts; if the pressure is released, it expands, the elasticity of a fluid is related to the amount of deformation (expansion or contraction) for a given pressure change. Quantitatively, the degree of elasticity is equal to:

$$h = \frac{2\sigma \cos \theta}{\gamma r}$$

$$E_v = - dP/(dV/V)$$

Where negative sign is used because dV/V is negative for a positive dP .

$$E_v = dP/(d\rho/\rho) \quad \text{because } -dV/V = d\rho/\rho$$

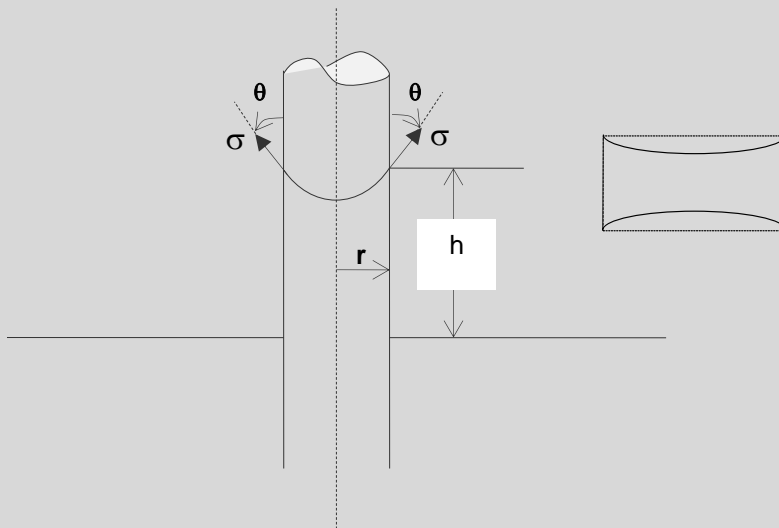
where: E_v - bulk modulus of elasticity

dV - is the incremental volume change

V - is the original volume

dP - is the incremental pressure change

SURFACE TENSION: Capillarity



Where:

σ - surface tension, N/m

γ - specific weight of liquid, N/m³

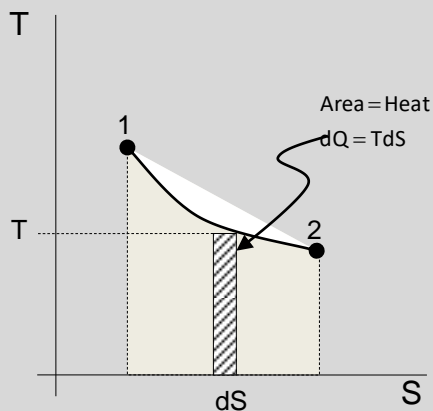
r - radius, m

h - capillary rise, m

Table 1. Surface Tension of Water

°C	σ
0	0.0756
10	0.0742
20	0.0728
30	0.0712
40	0.0696
60	0.0662
80	0.0626
100	0.0589

ENTROPY (S): It is a property of a fluid that determines the amount of its randomness and disorder of a substance. If during a process an amount of heat is taken at certain instant and is divided by the absolute temperature at which it is taken the result is called the “Change of Entropy”



$$dS = \frac{dQ}{T}$$

$$dQ = TdS$$

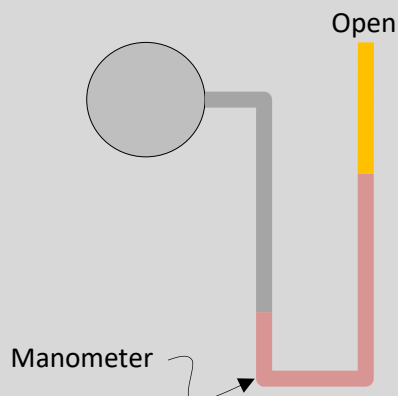
$$\Delta S = \int \frac{dQ}{T}$$

MANOMETERS

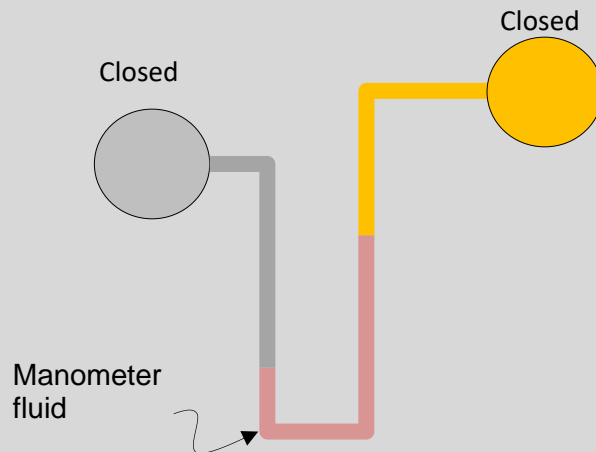
Manometer is an instrument used in measuring gage pressure in length of some liquid column.

1. Open Type Manometer : It has an atmospheric surface and is capable in measuring gage pressure.
2. Differential Type Manometer : It has no atmospheric surface and is capable in measuring differences of pressure.

Open Type



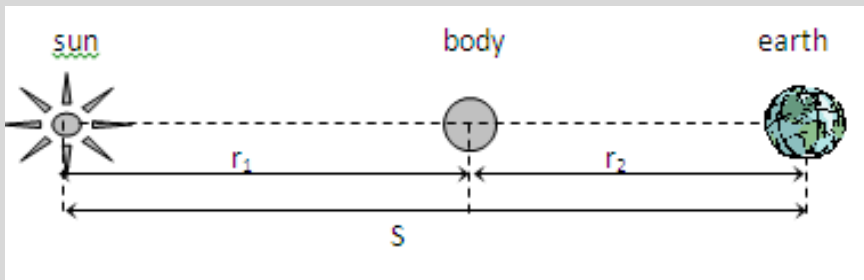
Differential Type



SAMPLE PROBLEMS

Problem No. 1 (Force of Attraction)

How far from the earth must a body be along a line toward the sun so that the gravitational pull of the sun balances that of the earth?
 Earth to sun distance is 9.3×10^7 mi; mass of sun is 3.24×10^5 times mass of earth. (1.63×10^5 mi.)



Given

$$S = 9.3 \times 10^7 \text{ miles}$$

$$m_s = 3.24 \times 10^5 m_e$$

m_b - mass of body

m_e - mass of sun

$$S = r_1 + r_2$$

$$F_{g1} = F_{g2}$$

$$F_{g1} = \frac{G m_s m_b}{r_1^2}$$

$$F_{g2} = \frac{G m_b m_e}{r_2^2}$$

$$F_{g1} = F_{g2}$$

$$\frac{G m_s m_b}{r_1^2} = \frac{G m_e m_b}{r_2^2}$$

$$\frac{(3.24 \times 10^5 m_e)}{r_1^2} = \frac{m_e}{r_2^2}$$

$$\frac{(3.24 \times 10^5)}{r_1^2} = \frac{1}{r_2^2}$$

$$S = r_1 + r_2$$

$$r_1 = (S - r_2)$$

$$\frac{(3.24 \times 10^5)}{(S - r_2)^2} = \frac{1}{r_2^2}$$

$$(S - r_2)^2 = (3.24 \times 10^5) r_2^2$$

$$(S - r_2) = r_2 \sqrt{(3.24 \times 10^5)}$$

$$r_2 = \frac{S}{1 + \sqrt{(3.24 \times 10^5)}} = 1.63 \times 10^5 \text{ miles}$$

Problem No. 2 (Measuring Temperature)

If the °F scale is twice the C scale, what will be the corresponding reading in each scale? (160° ; 320°)

$$^{\circ}\text{C} = \frac{^{\circ}\text{F} - 32}{1.8}$$

$$^{\circ}\text{F} = 1.8^{\circ}\text{C} + 32$$

$$^{\circ}\text{F} = 2^{\circ}\text{C}$$

$$2^{\circ}\text{C} = 1.8^{\circ}\text{C} + 32$$

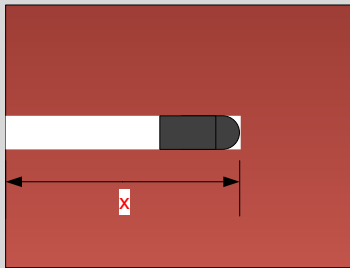
$$^{\circ}\text{C} = \frac{32}{2 - 1.8} = 160^{\circ}$$

$$^{\circ}\text{F} = 320^{\circ}$$

Problem No. 3 (Force, acceleration)

For a ballistic study, a 1.9 g bullet is fired into the soft wood. The bullet strikes the wood surface with a velocity of 380 m/sec and penetrates 0.15 m. Find:

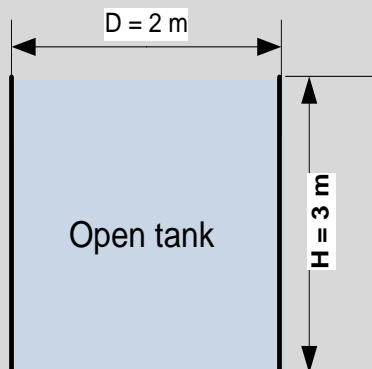
- the constant retarding force in N
- the time required to stop the bullet
- the deceleration in m/sec²



$$\begin{aligned}x &= v_1 t - \frac{1}{2} a t^2 \\v_2^2 &= v_1^2 - 2 a x \\a &= v_1^2 / 2 x \\a &= 481,333.33 \text{ m/sec}^2 \\F &= m a = 914.5 \text{ N} \\v_2 &= v_1 - a t \\t &= v_1 / a \\t &= 7.8 \times 10^{-4} \text{ sec}\end{aligned}$$

Problem No. 4 (Density, Specific gravity)

A cylindrical tank 2 m diameter, 3 m high is full of oil. If the specific gravity of oil is 0.9, what is the mass of oil in the tank? (8482.3 kg)



$$V_{\text{cylinder}} = \frac{\pi}{4} D^2 H = \frac{\pi}{4} (2^2) 3 = 3\pi \text{ m}^3$$

$$S = \frac{\rho}{\rho_{\text{water}}}$$

$$0.9 = \frac{\rho}{1000}$$

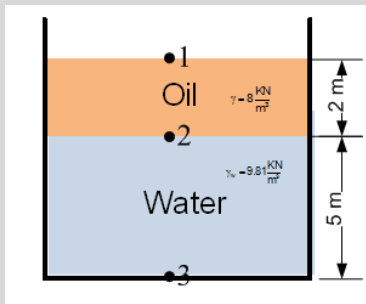
$$\rho = 900 \frac{\text{kg}}{\text{m}^3}$$

$$\rho = \frac{m}{V}$$

$$m = 900(3\pi) = 8482.3 \text{ kg}$$

Problem No. 5 (Variation in Pressure)

An open tank contains 5 m of water covered with 2 m of oil ($\gamma = 8 \text{ kN/m}^3$). Find the pressure at the interface and at the bottom of the tank.



$$P_2 = 0 + 8(2) = 16 \text{ KPa}$$

$$P_3 = 0 + 16 + 9.81(5) = 65.05 \text{ KPa}$$

ACTIVITY 1

- 10 liters of an incompressible liquid exert a force of 20 N at the earth's surface. What force would 2.3 Liters of this liquid exert on the surface of the moon? The gravitational acceleration on the surface of the moon is 1.67 m/sec^2 .

$$F = ma$$

$$\rho = \frac{m}{V}$$

$$m = \rho V = \rho(10.0) \left(\frac{1 \text{ m}^3}{1000 \text{ L}} \right) \text{ kg}$$

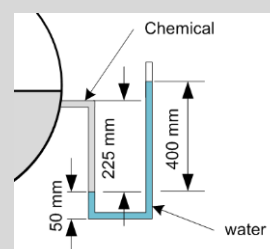
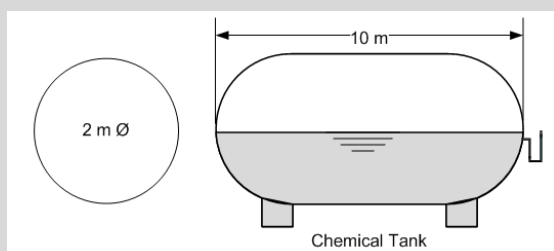
$$20 = \frac{\rho(10.0)}{1000} (9.81) \text{ N}$$

$$\rho = 203.874 \frac{\text{kg}}{\text{m}^3}$$

On the surface of the moon

$$F = 203.874 \left(\frac{2.3}{1000} \right) (1.67) = 0.783 \text{ N}$$

- An open manometer is used to measure the pressure in the tank. The tank is half filled with 50,000 kg of a liquid chemical that is not miscible in water. The manometer tube is filled with liquid chemical. What is the pressure in the tank relative to atmospheric pressure?



$$V = \left[\frac{4}{3} \pi r^3 + \pi r^2 (6) \right] \frac{1}{2} = \left[\frac{2}{3} \pi r^3 + \pi r^2 (3) \right] = \pi r^2 \left[\frac{2}{3} r + (3) \right] = 54.45 \text{ m}^3$$

$$\rho = \frac{m}{V} = \frac{50,000}{54.45} = 918.2 \frac{\text{kg}}{\text{m}^3}$$

$$\gamma = \frac{\rho g}{1000} = \frac{918.2(9.81)}{1000} = 9.008 \frac{\text{KN}}{\text{m}^3}$$

$$P + 9.008(0.225) - 0.350(9.81) = 0$$

$$P = 1.4067 \text{ KPa}$$

$$P_{a_{bs}} = 101.325 + 1.4067 = 102.73 \text{ KPa}$$

3. A 6 m x 6 m x 6 m cubical tank is half filled with water, the remaining space is filled with Oil (S = 0.8). What is the total force on one side of the tank?

Practice Problems

Weight, Density

Two liquids of different densities ($\rho_1 = 1500 \text{ kg/m}^3$; $\rho_2 = 500 \text{ kg/m}^3$) are poured together into a 100 L tank, filling it. If the resulting density of the mixture is 800 kg/m^3 , find the respective amounts of liquid used. Also find the weight of the mixture if $g = 9.675 \text{ m/sec}^2$. ($m_1 = 45 \text{ kg}$; $m_2 = 35 \text{ kg}$)

Temperature

If the temperature inside a furnace is 700 K, what is the corresponding reading in °F? (800.6)

Solution:

$$t = 700 - 273 = 427^\circ\text{C}$$

$$^\circ\text{F} = (427)(1.8) + 32$$

$$^\circ\text{F} = 800.6^\circ\text{F}$$

Absolute Pressure

The suction pressure of a pump reads 540 mm Hg vacuum. What is the absolute pressure in KPa? (29.33)

Solution:

$$P = 760 - 540 = 220 \text{ mm Hg absolute}$$

$$P = \frac{220}{760}(101.325) = 29.33 \text{ mm Hg}$$

Pressure Variation

A storage tank contains oil with a specific gravity of 0.88 and depth of 20 m. What is the hydrostatic pressure at the bottom of the tank in kg/cm^2 . (1.7)

Solution:

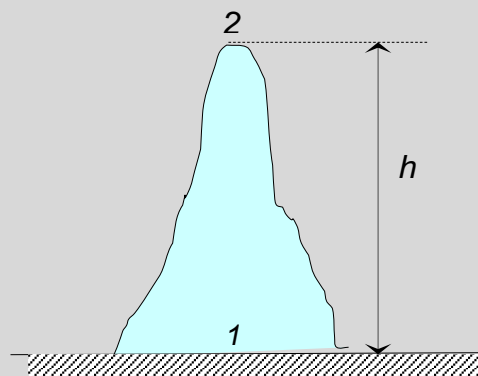
$$\text{Using: } g = 9.81 \text{ m/sec}^2$$

$$P = 0 + \frac{0.88(1000)(9.81)(20)}{1000} = 172.656 \text{ KPa}$$

$$P = 1.7 \text{ kg/cm}^2$$

Variation in Pressure Measuring Altitude of Mountain

A hiker carrying a barometer that measures 101.3 KPa at the base of the mountain. The barometer reads 85 KPa at the top of the mountain. The average air density is 1.21 kg/m^3 . Determine the height of the mountain.



$$dP = -\gamma dh$$

$$P_2 - P_1 = -\gamma(h_2 - h_1)$$

$$h_2 - h_1 = h$$

$$h = \frac{(P_1 - P_2)1000}{\rho g}$$

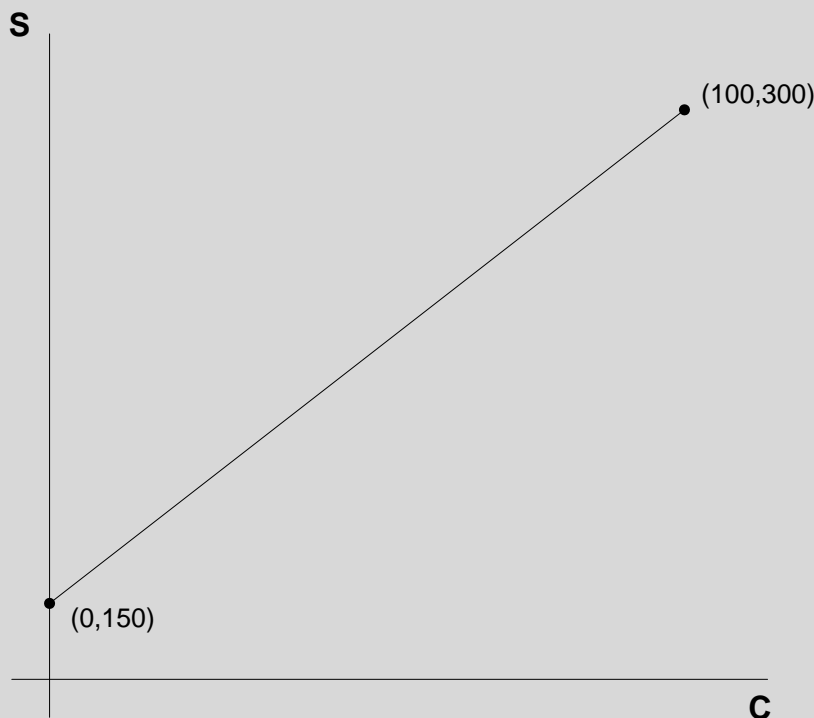
$$h = \frac{(101.3 - 85)1000}{1.21(9.81)}$$

$$h = 1373 \text{ m}$$

2.25 A gas initially at $p_1 = 1$ bar and occupying a volume of 1 liter is compressed within a piston–cylinder assembly to a final pressure $p_2 = 4$ bar.

- (a) If the relationship between pressure and volume during the compression is $pV = \text{constant}$, determine the volume, in liters, at a pressure of 3 bar. Also plot the overall process on a graph of pressure versus volume.
- (b) Repeat for a linear pressure–volume relationship between the same end states.

2.31 A new absolute temperature scale is proposed. On this scale the ice point of water is 150°S and the steam point is 300°S . Determine the temperatures in $^\circ\text{C}$ that correspond to 100° and 400°S , respectively. What is the ratio of the size of the $^\circ\text{S}$ to the kelvin?



$$m = \frac{300 - 150}{100 - 0} = 1.5$$

$$y = mx + b$$

$$S = 1.5C + 150$$

$$100 = 1.5C + 150$$

$$C_1 = -33.33$$

$$400 = 1.5C + 150$$

$$C_2 = 166.66$$

$$K = C + 273$$

$$C = K - 273$$

$$S = 1.5(K - 273) + 150$$

$$S = 1.5K - 409.5 + 150$$

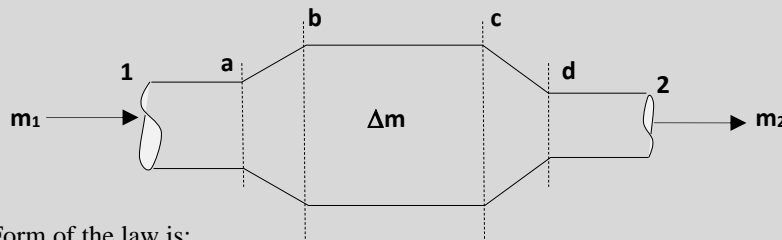
$$S = 1.5K - 259.5$$

2.18 The weight of an object on an orbiting space vehicle is measured to be 42 N based on an artificial gravitational acceleration of 6 m/s². What is the weight of the object, in N, on earth, where $g = 9.81 \text{ m/s}^2$?

2.19 The storage tank of a water tower is nearly spherical in shape with a radius of 30 ft. If the density of the water is 62.4 lb/ft³, what is the mass of water stored in the tower, in lb, when the tank is full? What is the weight, in lbf, of the water if the local acceleration of gravity is 32.1 ft/s²?

LAW OF CONSERVATION OF MASS

Mass is indestructible. In applying this law we must except nuclear processes during which mass is converted into energy.



The verbal Form of the law is:

Mass Entering - Mass Leaving = Change of Mass Stored in the system

In equation form:

$$m_1 - m_2 = \Delta m$$

But for a steady-state, steady flow system (OPEN SYSTEM) $\Delta m = 0$. Therefore:

$$m_1 - m_2 = 0 \text{ or } m_1 = m_2$$

CONTINUITY EQUATION:

For one dimensional flow where: m - mass flow rate in kg/sec

$$m = \rho A v = \frac{A v}{v}$$

From $m_1 = m_2 = m$

$$\rho_1 A_1 v_1 = \rho_2 A_2 v_2 = \rho A v$$

$$\frac{A_1 v_1}{v_1} = \frac{A_2 v_2}{v_2} = \frac{A v}{v}$$

where:

m - mass flow rate in kg/sec

A - cross sectional area in m²

v - velocity in m/sec

v - specific volume in m³/kg

ρ - density in kg/m³

FORMS OF ENERGY

WORK: It is the force multiplied by the displacement in the direction of the force.

$$W = \int_1^2 \mathbf{F} \cdot d\mathbf{x}$$

By convention:

(-)W - indicates that work is done on the system

(+)W - indicates that work is done by the system.

HEAT: It is a form of energy that crosses a system's boundary, because of a temperature difference between the system and the surrounding.

Q - Heat

By convention:

+Q - indicates that heat is added to the system

-Q - indicates that heat is rejected from the system.

INTERNAL ENERGY: It is the energy acquired due to the overall molecular interaction, or the total energy that a molecule has.

$$U = mu \text{ KJ}$$

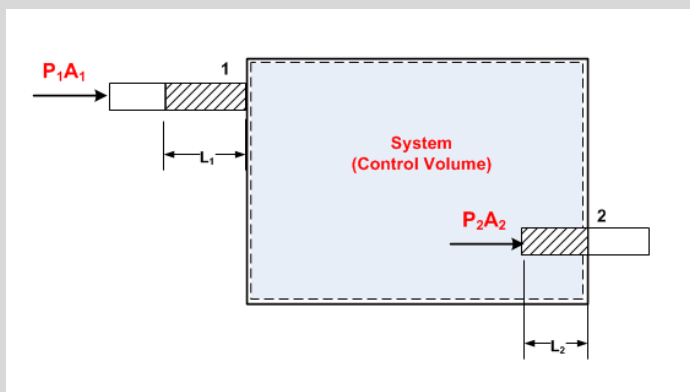
U - total internal energy KJ, KW

u - specific internal energy KJ/kg

ΔU - change of internal energy

m - mass kg, kg/sec

FLOW ENERGY OR FLOW WORK: It is the energy required in pushing a fluid usually into the system or out from the system.



Ef – Flow work or Flow energy

$$E_{f1} = F_1 L_1 = P_1 A_1 L_1 = P_1 V_1$$

$$E_{f2} = F_2 L_2 = P_2 A_2 L_2 = P_2 V_2$$

$$\Delta E_f = E_{f2} - E_{f1}$$

$$\Delta E_f = P_2 V_2 - P_1 V_1$$

$$\Delta E_f = \Delta(PV)$$

$$\Delta(PV) = P_2 V_2 - P_1 V_1 \quad \text{KJ; KW}$$

$$\Delta(Pv) = P_2 v_2 - P_1 v_1 \quad \frac{\text{KJ}}{\text{kg}}$$

$$\Delta KE = \int F \cdot dx$$

$$F = \frac{ma}{1000}$$

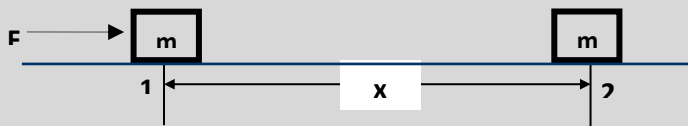
$$a = \frac{dv}{dt}$$

$$\Delta KE = \frac{m}{1000} \int_1^2 \frac{dv}{dt} \cdot dx$$

$$\Delta KE = \frac{m}{1000} \int_1^2 dv \cdot \frac{dx}{dt}$$

$$\frac{dx}{dt} = v$$

KINETIC ENERGY: It is the energy acquired due to the motion of a body or a system.



$$\Delta PE = \int W \cdot dz$$

$$W = \frac{mg}{1000}$$

$$\Delta PE = \frac{mg}{1000} \int_1^2 dz$$

$$\Delta PE = \frac{mg(z_2 - z_1)}{1000} \quad \text{KJ; KW}$$

$$\Delta PE = \frac{g(z_2 - z_1)}{1000} \quad \frac{\text{KJ}}{\text{kg}}$$

$$m - \text{kg; kg/sec}$$

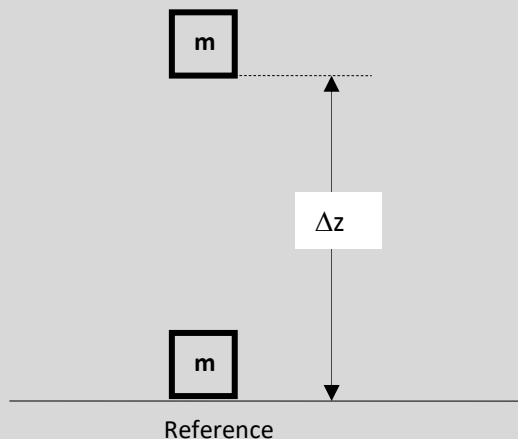
$$P - \text{KPa}$$

$$V = m^3; \frac{m^3}{\text{sec}}$$

$$v = \frac{m^3}{\text{kg}}$$

$$v = \frac{1}{\rho}$$

POTENTIAL ENERGY: It is the energy required by virtue of its configuration or elevation.



$$\Delta KE = \frac{m}{1000} \int_1^2 v \cdot dv$$

$$\Delta KE = \frac{m}{1000} \left[\frac{v^2}{2} \right]_1^2$$

$$\Delta KE = \frac{m(v_2^2 - v_1^2)}{2(1000)} \quad \text{KJ; KW}$$

$$\Delta KE = \frac{(v_2^2 - v_1^2)}{2(1000)} \quad \frac{\text{KJ}}{\text{kg}}$$

$$m - \text{kg; kg/sec}$$

Where:

Z - elevation in m, (+) if above datum and (-) if below datum
g - gravitational acceleration, m/sec²

ENTHALPY (h): It is the sum of the Internal Energy and the Flow Energy.

$$h = u + Pv \frac{\text{KJ}}{\text{kg}} \rightarrow \text{specific enthalpy}$$

$$H = mh \text{ KJ} \rightarrow \text{total enthalpy}$$

$$H = U + PV \text{ KJ}$$

$$\Delta h = \Delta u + \Delta(Pv)$$

$$\Delta H = \Delta U + \Delta(PV)$$

ZEROTH LAW OF THERMODYNAMICS

If two bodies are in thermal equilibrium with a third body, they are in thermal equilibrium with each other, and hence their temperatures are equal.

SPECIFIC HEAT: It is the amount of heat required to raise the temperature of a 1 kg mass, 1° K or 1° C.

$$C = \frac{dQ}{dt} = \frac{dQ}{dT} \frac{\text{KJ}}{\text{kg} \cdot ^\circ\text{C}} \text{ or } \frac{\text{KJ}}{\text{kg} \cdot \text{K}}$$

then $dQ = Cdt$

by integration, where C is constant

$Q = C\Delta T = C\Delta t$, considering the mass m:

$$Q = mC\Delta T = mC\Delta t$$

where:

T - absolute temperature in °K

t - temperature in °C

SENSIBLE HEAT: The amount of heat per unit mass that must be transferred (added or remove) when a substance undergoes a change in temperature without a change in phase.

$$Q = mC(\Delta t) = mC(\Delta T)$$

where:

m - mass, kg

C - heat capacity or specific heat, KJ/kg-°C or KJ/kg-K

t - temperature in °C

T - temperature in K

HEAT OF TRANSFORMATION (LATENT HEAT): The amount of heat per unit mass that must be transferred when a substance completely undergoes a phase change without a change in temperature.

$$Q = mh$$

A. Heat of Vaporization: Amount of heat that must be added to vaporize a liquid or that must be removed to condense a gas.

$$Q = mh_v$$

where

h_v - latent heat of vaporization, KJ/kg

B. Heat of Fusion : Amount of heat that must be added to melt a solid or that must be removed to freeze a liquid.

$$Q = mh_F$$

where

h_F - latent heat of fusion, KJ/kg

WATER EQUIVALENT: The water equivalent of a mass of a substance is the mass of water that would require the same heat transfer as the mass of that substance to cause the same change of temperature.

$$m_w = \frac{m_s C_{ps}}{C_{pw}}$$

IDEAL OR PERFECT GAS

1. CHARACTERISTIC EQUATION

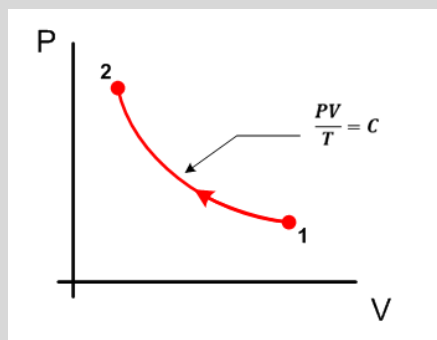
$$PV = mRT$$

$$Pv = RT$$

$$v = \frac{RT}{P}$$

$$\rho = \frac{P}{RT}$$

$$\frac{PV}{T} = C \quad \text{or} \quad \frac{Pv}{T} = C$$



where:

P - absolute pressure in KPa

V - volume in m³
m -mass in kg
R -Gas constant in KJ/kg-°K
T - absolute temperature in °K
v - specific volume in m³/kg
ρ - density in kg/m³

2. GAS CONSTANT

$$R = \frac{\bar{R}}{M} = \frac{8.3143}{M} \frac{\text{KJ}}{\text{kg} \cdot \text{K}}$$

$$\bar{R} = 8.3143 \text{ KJ/kgm-K}$$

\bar{R} - universal gas constant, KJ/kgm-°K

M - molecular weight, kg/kg mol

$$M = \frac{m}{n} \frac{\text{kg}}{\text{kg}_{\text{mol}}}$$

m – mass, kg

n - no. of moles

3. BOYLE`S LAW (T = C) Robert Boyle (1627-1691)

If the temperature of a certain quantity of gas is held constant, the volume V is inversely proportional to the absolute pressure P, during a quasi-static change of state.

$$V \propto \frac{1}{P} \text{ or } V = C \frac{1}{P}$$

$$PV = C \text{ or}$$

$$P_1 V_1 = P_2 V_2 = C$$

4. CHARLE`S LAW (P = C and V = C) Jacques Charles (1746-1823) and Joseph Louis Gay-Lussac (1778-1850)

A) At constant pressure (P = C), the volume V of a certain quantity of gas is directly proportional to the absolute temperature T, during a quasi static change of state.

$$V \propto T \text{ or } V = CT$$

$$\frac{V}{T} = C \text{ or } \frac{V_1}{T_1} = \frac{V_2}{T_2}$$

B) At constant volume (V = C), the pressure P of a certain quantity of gas is directly proportional to the absolute temperature T, during a quasi-static change of state.

$$P \propto T \text{ or } P = CT$$

$$\frac{P}{T} = C$$

or

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

5. AVOGADRO`S LAW: Amedeo Avogadro (1776-1856)

All gases at the same temperature and pressure, under the action of a given value of g, have the same number of molecules

per unit of volume. From which it follows that the the specific weight is directly proportional to its molecular weight.

At the same temperature and pressure for all gases

$$\frac{n_1}{V_1} = \frac{n_2}{V_2} = \frac{n}{V}$$

or

$$\frac{\gamma_1}{\gamma_2} = \frac{M_1}{M_2} = \frac{R_2}{R_1}$$

6. SPECIFIC HEATS

A. SPECIFIC HEAT AT CONSTANT PRESSURE (C_p)

$$Q = mC_p(\Delta T) = m\Delta h$$

considering m

$$\Delta h = h_2 - h_1$$

$$Q = m(\Delta h) = \Delta H$$

From

$$\text{From } C = \frac{dQ}{dT}$$

$$h = u + Pv$$

$$dh = du + Pdv + v dP$$

$$C_p = \frac{dQ}{dT} = \frac{dh}{dT} \rightarrow (C_p - \text{Specific heat at } P = C)$$

but

$$dQ = C_p dT$$

$$dQ = du + Pdv$$

$$Q = C_p(\Delta T) = C_p(\Delta t)$$

$$dh = dQ + v dP$$

At $P = C$ (Constant Pressure)

$$Q = \Delta H = mC_p(\Delta T) = mC_p(\Delta t)$$

$$dP = 0$$

$$dh = dQ$$

$$Q = \Delta h$$

B. SPECIFIC HEAT AT CONSTANT VOLUME (C_v)

From

From

$$dQ = du + Pdv$$

$$h = u + Pv$$

$$\text{at } v = C; dv = 0$$

$$Pv = RT$$

therefore

$$h = u + RT$$

$$dQ = du$$

$$dh = du + Rdt$$

$$Q = \Delta u = (u_2 - u_1)$$

$$C_p dT = C_v dT + Rdt$$

$$Q = \Delta U = m(u_2 - u_1)$$

dividing the equation by dT

$$C_p = C_v + R$$

From

$$C = \frac{dQ}{dT}$$

$$C_v = \frac{dQ}{dT} = \frac{du}{dT} \rightarrow (C_v - \text{specific heat at } V = C)$$

$$Q = mC_v \Delta T = m\Delta u$$

$$\Delta U = m(u_2 - u_1)$$

$$dQ = C_v(dT)$$

$$Q = C_v(\Delta T) = C_v(\Delta t)$$

$$Q = \Delta U = mC_v(\Delta T) = mC_v(\Delta t)$$

7. RATIO OF SPECIFIC HEATS

$$k = \frac{C_p}{C_v} = \frac{dh}{du} = \frac{\Delta H}{\Delta U}$$

$$C_p = kC_v$$

$$C_v = \frac{C_p}{k}$$

$$C_p = C_v + R$$

$$kC_v = C_v + R$$

$$C_v = \frac{R}{k-1}$$

$$C_p = C_v + R$$

$$C_p = \frac{C_p}{k} + R$$

$$R = \frac{Rk}{k-1}$$

8. ENTROPY CHANGE (ΔS)

Entropy is that property of a substance that determines the amount of randomness and disorder of a substance. If during a process, an amount of heat is taken and is divided by the absolute temperature at which it is taken, the result is called the

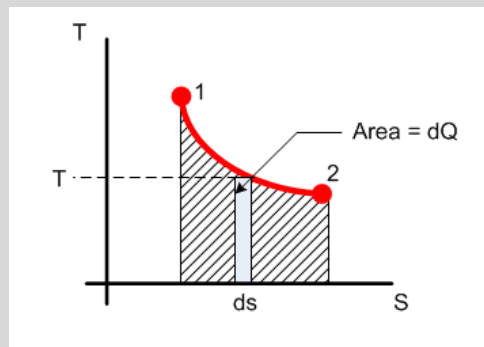
ENTROPY CHANGE.

$$dS = \frac{dQ}{T}$$

$$dQ = T(dS)$$

by integration

$$\Delta S = \int_1^2 \frac{dQ}{T}$$



From:

$$h = U + Pv$$

$$h = U + RT$$

$$dQ = dU + Pdv$$

$$P = \frac{RT}{v} \text{ and } dQ = TdS$$

$$TdS = C_v dT + \frac{RT}{v} dv$$

dividing by T

$$dS = C_v \frac{dT}{T} + R \frac{dv}{v}$$

By integration

$$\Delta S = C_v \ln \frac{T_2}{T_1} + R \ln \frac{v_2}{v_1}$$

From

$$dh = dQ + v dP$$

$$dQ = dh - \frac{RT}{P} dP$$

$$TdS = C_p dT - RT \frac{dP}{P}$$

dividing by T

$$dS = C_p \frac{dT}{T} - R \frac{dP}{P}$$

by integration

$$\Delta S = C_p \ln \frac{T_2}{T_1} - R \ln \frac{P_2}{P_1}$$

Actual – Gas equation of State

In actual gases the molecular collision are inelastic; at high densities in particular there are intermolecular forces that the simplified equation of the state do not account for. There are many gas equations of state that

attempt to correct for the non - ideal behavior of gases.
The disadvantage of all methods is that the equations are more complex and require the use of experimental coefficients.

a. Van der Waals Equation

$$\left(P + \frac{a}{\bar{v}^2} \right) (\bar{v} - b) = \bar{R}T$$

where :

a and b a coefficients that compensate for the nonideal behavior of the gas.

$$\bar{v} \text{ in } \frac{\text{m}^3}{\text{kg}_{\text{mol}}}$$

b. Beattie-Bridgeman Equation

$$\left(P + \frac{A}{\bar{v}^2} \right) \frac{\bar{v}^2}{(1 - \varepsilon)(\bar{v} + B)} = \bar{R}T$$

where :

$$A = A_0 \left(1 - \frac{a}{\bar{v}} \right)$$

$$B = B_0 \left(1 - \frac{b}{\bar{v}} \right)$$

$$\varepsilon = \frac{c}{\bar{v}T^3}$$

Compressibility Factor

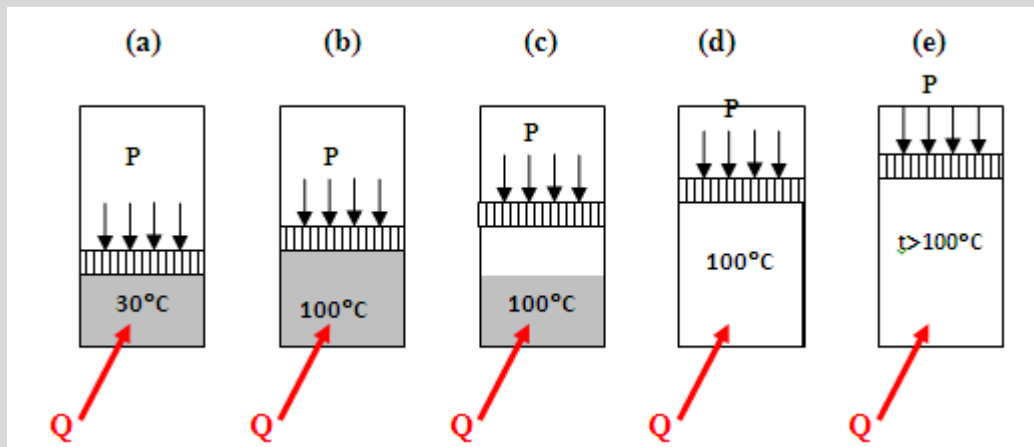
$$\frac{P\bar{v}}{RT} = 1$$

For nonideal behavior of gases

$$\frac{P\bar{v}}{RT} = Z$$

Where: Z – compressibility factor

PROPERTIES OF PURE SUBSTANCE



- a - sub-cooled liquid
- b - saturated liquid
- c - saturated mixture
- d - saturated vapor
- e - superheated vapor

Considering that the system is heated at constant pressure where $P = 101.325 \text{ KPa}$, the 100°C is the saturation temperature corresponding to 101.325 KPa , and 101.325 KPa pressure is the saturation pressure at 100°C .

Saturation Temperature (t_{sat}) - is the highest temperature at a given pressure in which vaporization takes place.

Saturation Pressure (P_{sat}) - is the pressure corresponding to the temperature.

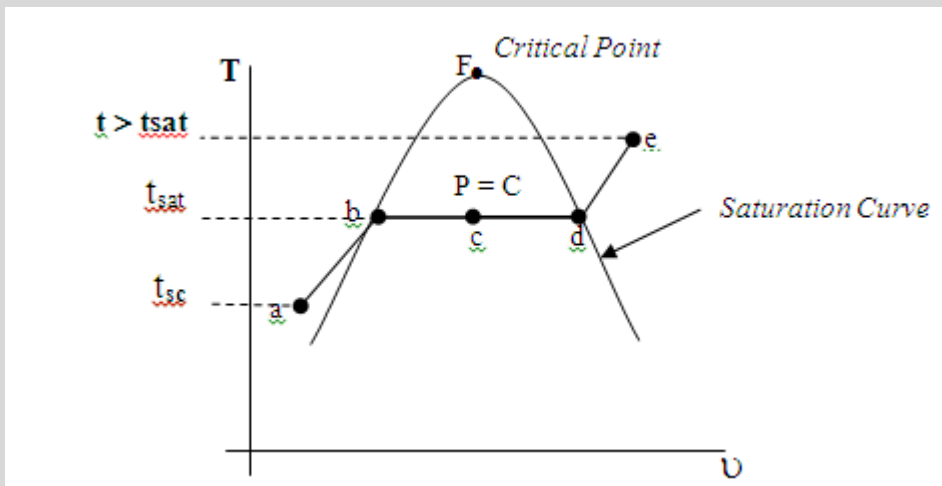
Sub-cooled Liquid - is one whose temperature is less than the saturation temperature corresponding to the pressure.

Compressed Liquid - is one whose pressure is greater than the saturation pressure corresponding to the temperature.

Saturated Mixture - a mixture of liquid and vapor at the saturation temperature.

Superheated Vapor - a vapor whose temperature is greater than the saturation temperature.

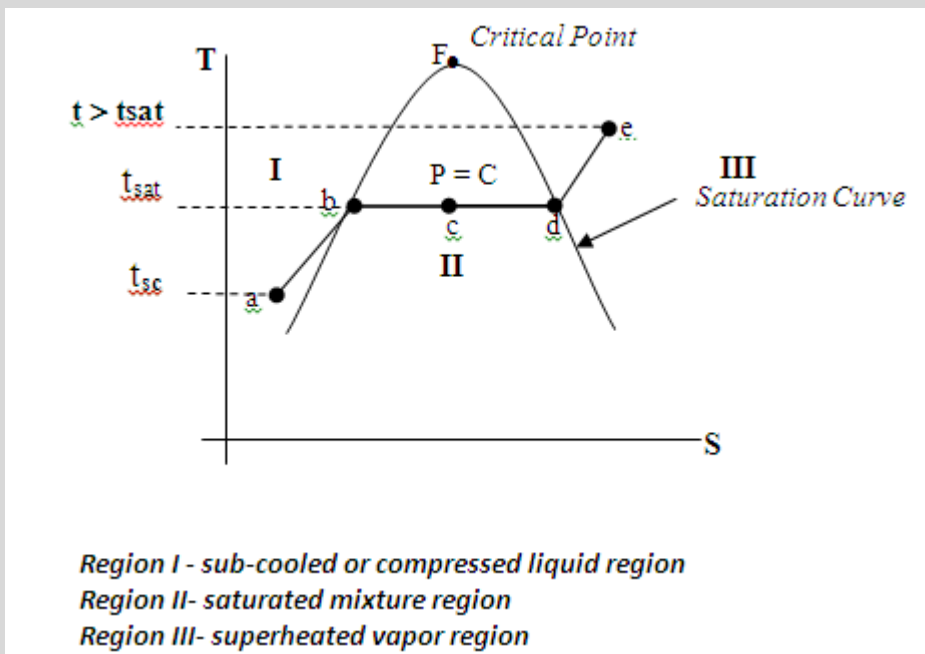
Temperature - Specific volume Diagram (T - v diagram)



F(critical point)- at the critical point the temperature and pressure is unique.

For Steam: At Critical Point, $P = 22.09 \text{ MPa}$; $t = 374.136^\circ\text{C}$

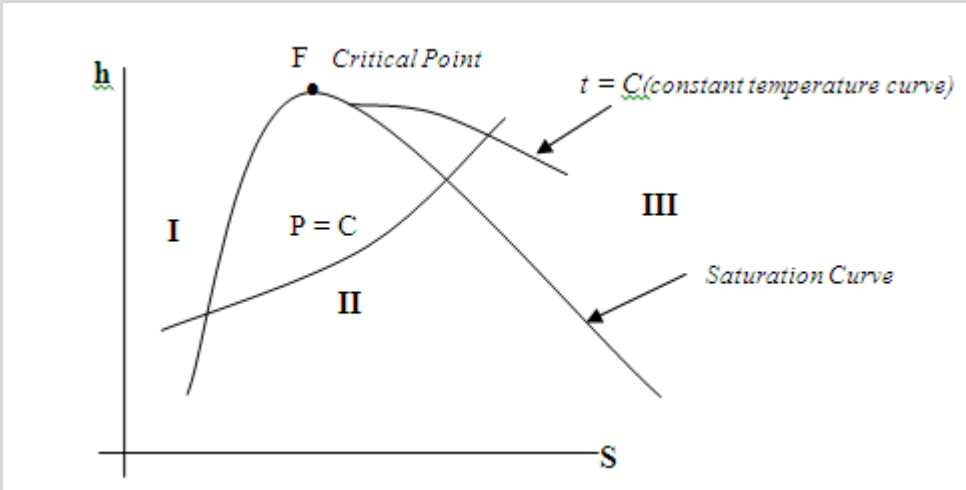
Temperature-Entropy Diagram (T-S Diagram)



Entropy (S): Is that property that determines the randomness and disorder of a substance. If during a process, an amount of heat is taken and is divided by the absolute temperature at which it is taken the result is called the “Change of Entropy”.

$$dS = \frac{dQ}{T} \quad \Delta S = \int \frac{dQ}{T}$$

Enthalpy-Entropy Diagram (h-S Diagram or Mollier Chart)



The properties $h, S, U,$ and v at saturated liquid, saturated vapor, sub-cooled or compressed liquid and superheated vapor condition, can be determined using the Steam Table.

For the properties at the saturated mixture condition, its properties is equal to

$$r = r_f + x r_{fg}$$

where r stands for any property, such as $h, S, U,$ and v , where subscript f refers to saturated liquid condition and fg refers to the difference in property between saturated vapor and saturated liquid and x is called the quality.

QUALITY

$$x = \frac{m_v}{m_v + m_l} = \frac{m_v}{m}$$

where:

m - mass

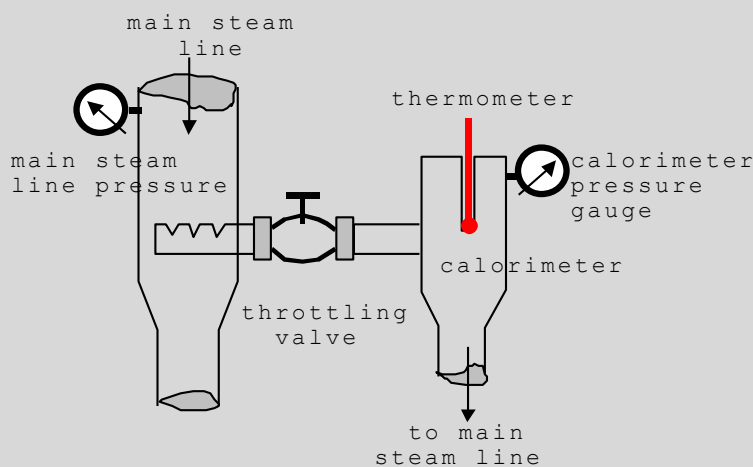
v - refers to vapor

l - refers to liquid

Note: For sub-cooled liquid, its properties are approximately equal to the properties at saturated liquid which corresponds to the sub-cooled temperature.

Throttling Calorimeter:

An apparatus that is used to determine the quality of a desuperheated steam flowing in a steam line.



A **throttling process** is a Steady State, Steady Flow Process in which $Q = 0$; $W = 0$; $\Delta KE = 0$; $\Delta PE = 0$ but the Enthalpy (h) remains constant ($h = C$).

From the figure, steam from the main steam line expands in the calorimeter to the calorimeter pressure and temperature at $h = \text{constant}$. A throttling calorimeter is an instrument used to determine the quality of steam.

THE FIRST LAW OF THERMODYNAMICS

(The Law of Conservation of Energy)

“Energy can neither be created nor destroyed but can only be converted from one form to another.”

With respect to any system (Open and Closed System)

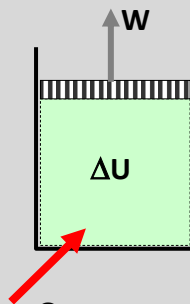
The Verbal form of the Law is:

Energy Entering - Energy Leaving = Change of Energy Stored within the system

In equation Form:

$$E_1 - E_2 = \Delta E_s$$

First Corollary: Is the application of the Law of Conservation of Energy principle to a Closed System. A system of Fixed mass.



For a Closed system (Nonflow system) the ΔKE and ΔPE are negligible and $\Delta(pv)$ doesn't exist.

$$Q - W = \Delta E_s$$

where

$$\Delta E_s = \Delta U$$

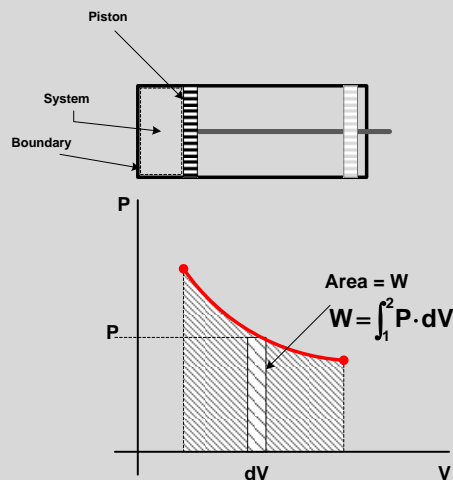
$$Q - W = \Delta U \rightarrow 1$$

$$Q = \Delta U + W \rightarrow 2$$

By differentiation:

$$dQ = dU + dW \rightarrow 3$$

Work for a Moving Boundary of a Closed System



$$W = \int_1^2 P \cdot dV \rightarrow 4$$

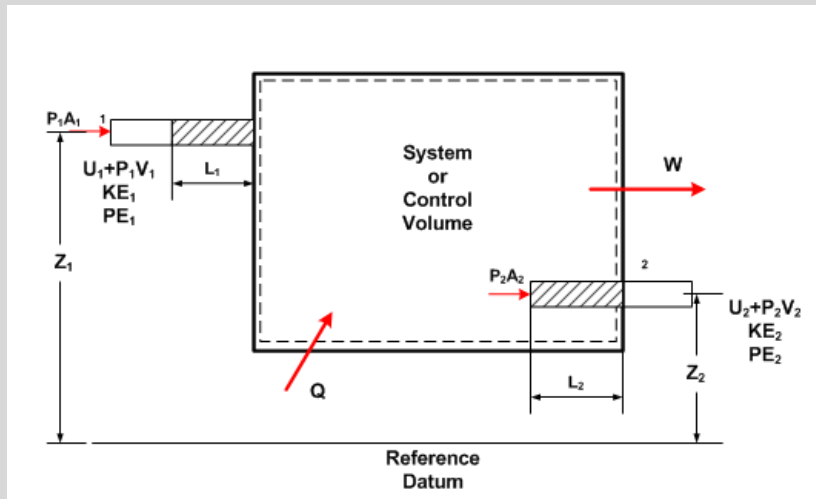
$$dW = P \cdot dV \rightarrow 5$$

$$dQ = dU + dW$$

$$dQ = dU + dW$$

$$dQ = dU + P \cdot dV \rightarrow 6$$

Second Corollary: Is the application of the Law of Conservation of Energy principle to an Open System (Steady-state, Steady Flow System) a system of Fixed space.



For an OPEN SYSTEM (Steady-State, Steady-Flow system)

$\Delta ES = 0$, therefore

Energy Entering = Energy Leaving,

In equation form

$$E_1 - E_2 = 0 \text{ or } E_1 = E_2$$

$$U_1 + P_1V_1 + KE_1 + PE_1 + Q = U_2 + P_2V_2 + KE_2 + PE_2 + W \rightarrow 1$$

$$Q = (U_2 - U_1) + (P_2V_2 - P_1V_1) + (KE_2 - KE_1) + (PE_2 - PE_1) + W \rightarrow 2$$

$$Q = \Delta U + \Delta PV + \Delta KE + \Delta PE + W \rightarrow 3$$

ENTHALPY (h): It is the sum of internal energy and flow energy.

$$h = U + PV \rightarrow 4$$

$$\Delta h = \Delta U + \Delta PV \rightarrow 5$$

$$Q = \Delta h + \Delta KE + \Delta PE + W \rightarrow 6$$

$$dh = dU + d(PV)$$

$$dh = dU + PdV + VdP \rightarrow 7$$

substituting eq. 5 to eq. 3

$$Q = \Delta h + \Delta KE + \Delta PE + W \rightarrow 8$$

$$dQ = dh + dKE + dPE + dW \rightarrow 9$$

substituting eq. 7 to eq. 9

$$dQ = dU + PdV + VdP + dKE + dPE + dW \rightarrow 10$$

but $dQ = dU + PdV$

$$0 = VdP + dKE + dPE + dW \rightarrow 11$$

$$dW = -VdP - dKE - dPE \rightarrow 12$$

by integration

$$W = -\int VdP - \Delta KE - \Delta PE \rightarrow 13$$

From Eq. 8

$$W = Q - \Delta h - \Delta KE - \Delta PE \rightarrow 14$$

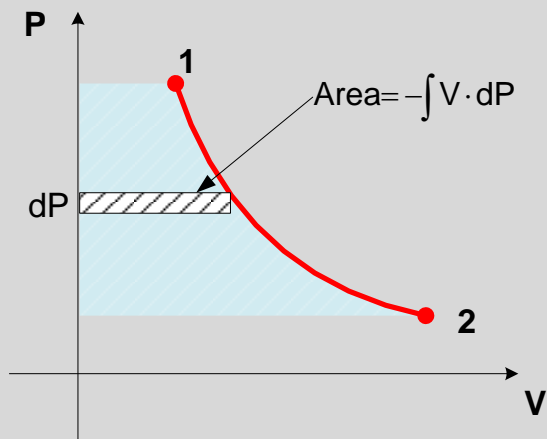
therefore

$$-\int VdP = Q - \Delta h \rightarrow 15$$

If $\Delta KE = 0$ and $\Delta PE = 0$ or negligible;

$$W = -\int V dP \rightarrow 16$$

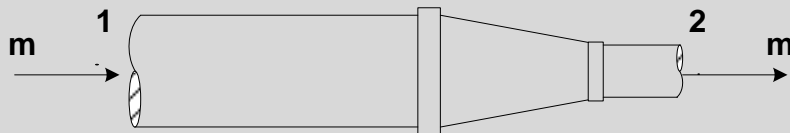
$$W = Q - \Delta h \rightarrow 17$$



SAMPLE PROBLEMS

(Law of Conservation of Mass)

Water runs through a water main of cross sectional area of 0.4 m^2 with a velocity of 6 m/sec . Calculate the velocity and mass flow rate of the water in the pipe when the pipe tapers down to a cross sectional area of 0.3 m^2 . ($\rho = 1000 \text{ kg/m}^3$)



$$m_1 = m_2 = m$$

$$\rho A_1 v_1 = m$$

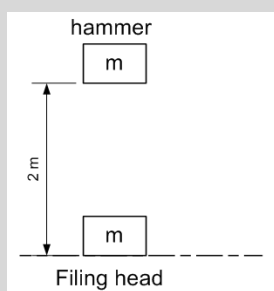
$$m = 1000(0.4)6 = 2400 \frac{\text{kg}}{\text{sec}}$$

$$\rho A_1 v_1 = \rho A_2 v_2$$

$$v_2 = \frac{A_1 v_1}{A_2} = 8 \frac{\text{m}}{\text{sec}}$$

Potential Energy

The 600 kg hammer of a pile driver is lifted 2 m above the piling head. What is the change in potential energy? If the hammer is released, what will be its velocity at the instant it strikes the piling? Local $g = 9.65 \text{ mps}^2$. (11.58 KJ; 6.21 mps)



Given:

$$m = 600 \text{ kg}$$

$$\Delta Z = 2 \text{ m}$$

$$g = 9.65 \text{ m/sec}^2$$

$$\Delta PE = \frac{mg\Delta Z}{1000} \text{ KJ}$$

$$\Delta PE = 11.58 \text{ KJ}$$

$$\Delta KE = \Delta PE$$

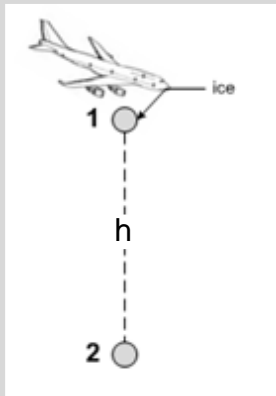
$$\frac{m(v_f^2 - v_i^2)}{2(1000)} = 11.58$$

$$v_i = 0$$

$$v_f = \sqrt{\frac{11.58(2000)}{600}} = 6.21 \frac{\text{m}}{\text{sec}}$$

Kinetic Energy

A lump of ice falls from an aero plane as it comes into land. If the ice hits the ground with a vertical speed of 85 m/sec, what was the height of the plane when the ice fell off? (use $g = 9.81 \text{ m/sec}^2$)



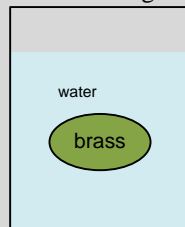
$$\Delta KE = \Delta PE$$

$$\frac{m(85^2 - 0)}{2(1000)} = \frac{mg(0 + h)}{1000}$$

$$h = 368.25 \text{ meters}$$

Zeroth Law of Thermodynamics

5 kg of brass of specific heat 0.39 KJ/kg $^{\circ}\text{C}$ at a temperature of 176°C is dropped into a 1.2 kg of water at 14°C . Find the resulting temperature of the mixture. ($C_{PW} = 4.187 \text{ KJ/kg } ^{\circ}\text{C}$)



$$m_w = 1.2 \text{ kg}$$

$$m_B = 5 \text{ kg}$$

$$C_{PB} = 0.39 \frac{\text{KJ}}{\text{kg } ^{\circ}\text{C}}$$

$$C_{PW} = 4.187 \frac{\text{KJ}}{\text{kg } ^{\circ}\text{C}}$$

Heat rejected by brass = Heat absorbed by water

$$Q_B = Q_W$$

$$m_B C_{PB} (t_{B1} - t) = m_w C_{PW} (t - t_{w1})$$

$$5(0.39)(176 - t) = 1.2(4.187)(t - 14)$$

$$t = 40.4^{\circ}\text{C}$$

(Sensible heat/Latent heat)

How much heat is removed to make ice of mass $m = 0.720 \text{ kg}$ at -10°C from a liquid at 15°C .

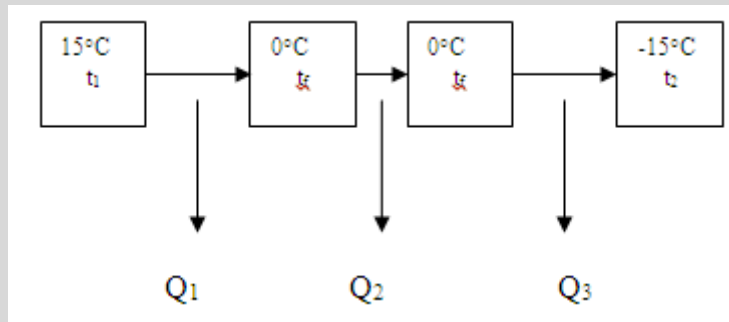
Specific heat of ice = $2.22 \text{ KJ/kg } ^{\circ}\text{C}$

Specific heat of water = $4.19 \text{ KJ/kg } ^{\circ}\text{C}$

Freezing point temperature of water = 0°C

h_F of ice = 334.9 KJ/kg

Answer: 302 KJ



$$Q = Q_1 + Q_2 + Q_3$$

$$Q_1 = mC_{pw}(15 - 0) \rightarrow \text{sensible heat}$$

$$Q_2 = m(h_F) \rightarrow \text{latent heat}$$

$$Q_3 = mC_{pi}(0 + 10) \rightarrow \text{sensible heat}$$

$$Q = 0.720[4.19(15 - 0) + (334.9) + 2.22(0 + 10)]$$

$$Q = 302 \text{ KJ}$$

(Law of conservation of energy/Open system)

A steam turbine receives superheated steam at 1.4 MPa and 400°C ($h_1 = 3257.5$ KJ/kg). The steam leaves the turbine at 0.101 MPa and 100°C ($h_2 = 2676$ KJ/kg). The steam enters the turbine at $v_1 = 15$ m/sec and exits at $v_2 = 60$ m/sec. The elevation difference between entry and exit ports is negligible. The heat loss through the turbine walls is 2 KW. Calculate the power output if the mass flow through the turbine is 0.5 kg/sec.

Given:

$$m = 0.5 \text{ kg/sec}$$

at 1.4 MPa and 400°C

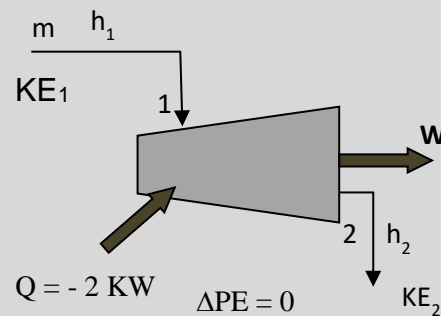
$$h_1 = 3257.5 \text{ KJ/kg}$$

At 0.101 MPa and 100°C

$$h_2 = 2676 \text{ KJ/kg}$$

$$v_1 = 50 \text{ m/sec} ; v_2 = 60 \text{ m/sec}$$

$$Q = -2 \text{ KW}$$



$$V_1 = 6 \text{ L} \times \frac{\text{m}^3}{1000 \text{ L}} = 0.006 \text{ m}^3$$

$$P_1 = 100 \text{ KPa}$$

$$V_2 = 2 \text{ L} = 0.002 \text{ m}^3$$

$$PV^2 = C$$

$$P_1 V_1^2 = P_2 V_2^2 = C$$

$$P = \frac{C}{V^2}$$

$$P_2 = \frac{P_1 V_1^2}{V_2^2} = 900 \text{ KPa}$$

$$W = \int P dV = \int \frac{C}{V^2} dV = C \int_1^2 \frac{dV}{V^2} = C \int_1^2 V^{-2} dV$$

$$W = C \left[\frac{V^{-2+1}}{-2+1} \right]_1^2 = -C \left[\frac{1}{V} \right]_1^2 = -C \left[\frac{1}{V_2} - \frac{1}{V_1} \right]$$

$$W = \left[\frac{C}{V_1} - \frac{C}{V_2} \right] = \left[\frac{P_1 V_1^2}{V_1} - \frac{P_2 V_2^2}{V_2} \right] = P_1 V_1 - P_2 V_2$$

$$W = -1.2 \text{ KJ}$$

$$W = 1.2 \text{ KJ} \rightarrow \text{work is done on the system}$$

(First Law/Closed System)

If 6 L of a gas at a pressure of 100 KPa are compressed reversibly according to $PV^2 = C$ until the volume becomes 2 L, Find the final pressure and the work.

$$Q = \Delta h + \Delta KE + \Delta PE + W$$

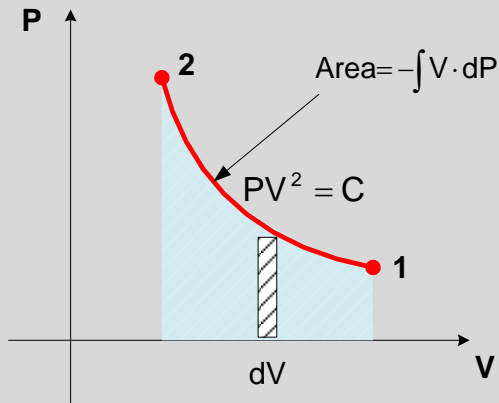
$$\Delta h = m(h_2 - h_1) = -290.75 \text{ KW}$$

$$\Delta KE = \frac{m(v_2^2 - v_1^2)}{2(1000)} = 0.275 \text{ KW}$$

$$\Delta PE = 0$$

$$Q = -2 \text{ KW}$$

$$W = 0 - \Delta h - \Delta KE - \Delta PE$$

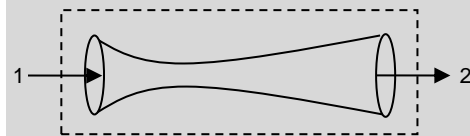


Problem No. 1 (Nozzle/Open system)

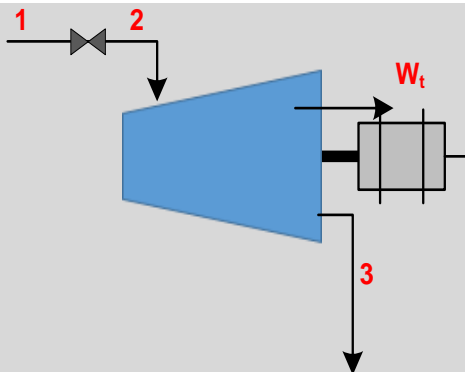
Steam with a flow rate of 1360 kg/hr enters an adiabatic nozzle at 1378 KPa, 3.05 m/sec with a specific volume of 0.147 m³/kg and with a specific internal energy of 2510 KJ/kg. The exit conditions are, P = 137.8 KPa, specific volume = 1.099 m³/kg, and internal energy = 2263 KJ/kg. Determine the exit velocity in m/sec.

Given:

$m = 1360 \text{ kg/hr} = 0.377 \text{ kg/sec}$ $P_2 = 137.8 \text{ KPa}$
 $P_1 = 1378 \text{ KPa}$ $v_2 = 1.099 \text{ m}^3/\text{kg}$
 $v_1 = 3.05 \text{ m/sec}$ $U_2 = 2263 \text{ KJ/kg}$
 $v_1 = 0.147 \text{ m}^3/\text{kg}$
 $U_1 = 2510 \text{ KJ/kg}$



For Adiabatic $Q = 0$ and
for a Nozzle $W = 0$



Problem No. 2 (Steam Turbine/Open system)

A small steam turbine operating at part load produces 110 KW output with a steam flow rate of 0.25 kg/sec. Steam at 1.4 MPa, 250°C is throttled to 1.1 MPa before entering the turbine, and the turbine exhaust pressure is 10 KPa. Find the steam quality (or temperature, if superheated) at the turbine outlet. ($x_2 = 96\%$)

From table 3 at 1.4 MPa and 250°C: $h = 2927.2 \text{ KJ/kg}$

From table 2 at 10 KPa (0.010 MPa): $h_f = 191.83 \text{ KJ/kg}$; $h_{fg} = 2392.8 \text{ KJ/kg}$

$$Q = \Delta h + \Delta KE + \Delta PE + W$$

$$0 = \Delta h + \Delta KE + 0 + 0$$

$$\Delta KE = -\Delta h$$

$$\frac{v_2^2 - v_1^2}{2(1000)} = -(h_2 - h_1)$$

$$v_2 = \sqrt{2(1000)(h_1 - h_2) + v_1^2}$$

$$h = U + P v$$

$$h_1 = 2510 + (1378)(0.147) = 2712.6 \text{ KJ/kg}$$

$$h_2 = 2263 + (137.8)(1.099) = 2401.9 \text{ KJ/kg}$$

$$v_2 = 788.3 \text{ m/sec}$$

$$m = 0.25 \frac{\text{kg}}{\text{sec}}$$

$$h_1 = h_2 = 2927.2 \frac{\text{KJ}}{\text{kg}}$$

$$Q = \Delta h + \Delta KE + \Delta PE + W$$

$$Q = 0; \Delta KE = 0 \text{ and } \Delta PE = 0$$

$$W = -\Delta h$$

$$110 = m(h_2 - h_3)$$

$$h_3 = h_2 - \frac{110}{m}$$

$$h_3 = 2487.2 \frac{\text{KJ}}{\text{kg}}$$

$$h = h_f + x(h_{fg})$$

$$x_3 = \frac{2487.2 - 191.83}{2392.8} = 0.96$$

$$x_3 = 96\%$$

Problem No. 3 (Throttling Process)

A throttling calorimeter is connected to the de-superheated steam line supplying steam to the auxiliary feed pump of a ship. The line pressure measures 2.5 MPa. The calorimeter pressure is 110 KPa and the temperature is 150°C. Determine the line steam quality.

From Superheated table, at 110 KPa and 150°C, $h_2 = 2775.6 \text{ KJ/kg}$

From Saturated liquid and saturated vapor table

$$h_{f1} = 962.11 \text{ KJ/kg}; h_{fg} = 1841.0 \text{ KJ/kg}$$

$$h_1 = h_{f1} + x_1(h_{fg1})$$

$$h_1 = h_2$$

$$x_1 = \frac{h_1 - h_{f1}}{h_{fg1}} = \frac{2775.6 - 962.11}{1841.0} = 0.985$$

$$x_1 = 98.5 \%$$

Problem No. 4 (Properties)

Find the enthalpy and specific volume of steam at 250 KPa and 50% quality.

From steam table the properties at saturated liquid and saturated vapor at 250 KPa are;

$$h_f = 535.37 \text{ KJ/kg}; h_g = 2716.9 \text{ KJ/kg}; h_{fg} = 2181.5 \text{ KJ/kg}$$

$$v_f = 0.001067 \text{ m}^3/\text{kg}; v_g = 0.7187 \text{ m}^3/\text{kg}$$

At 250 KPa and 50% quality

$$h = h_f + x h_{fg}$$

$$h = 535.7 + (0.50)(2181.5) = 1626.1 \text{ KJ/kg}$$

$$v = 0.001067 + (0.50)(0.7187 - 0.001067) = 0.3598 \text{ m}^3/\text{kg}$$

Problem No. 5 (Steam turbine)

Steam enters a turbine at 1400 KPa (468.18 K) and 320°C (593 K). The turbine isentropic efficiency is 70% and the actual power is 800 KW. The exhaust is to the back pressure system maintained at 175 KPa ($t_{\text{sat}} = 389.2\text{K}$). Find the steam flow rate. (2.58 kg/sec)

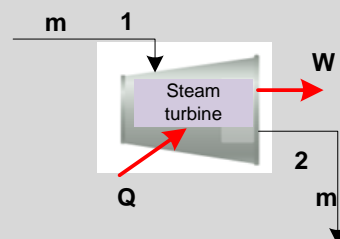
From table: at 1400 KPa and 320°C (593 K):

$$h = 3083.1 \text{ KJ/kg}; s = 7.0203 \text{ KJ/kg-K}$$

From table: at 175 KPa ($t_{\text{sat}} = 389.22 \text{ K}$):

$$h_f = 486.83 \text{ KJ/kg}; h_g = 2699.2 \text{ KJ/kg}$$

$$s_f = 1.4846 \text{ KJ/kg-K}; s_g = 7.1701 \text{ KJ/kg-K}$$



$$Q = \Delta h + \Delta KE + \Delta PE + W$$

$$m = 2.58 \text{ kg/sec}$$

$$Q = 0; \Delta KE = 0; \Delta PE = 0$$

$$W = -\Delta h$$

Isentropic Efficiency

$$e_s = \frac{h_1 - h_2}{h_1 - h_2}$$

$$W' = m(h_1 - h_2) = 800 \text{ KW}$$

$$h_1 = 3083.1 \frac{\text{KJ}}{\text{kg}}; S_1 = 7.0203 \frac{\text{KJ}}{\text{kg} \cdot \text{K}}$$

$$S_1 = S_2 = S_{f2} + x_2(S_{g2} - S_{f2})$$

$$x_2 = \frac{7.0203 - 1.4846}{7.1701 - 1.4846} = 0.974$$

$$h_2 = h_{f2} + x_2(h_{g2} - h_{f2}) = 486.83 + 0.974(2699.2 - 486.83)$$

$$h_2 = 2640.91 \frac{\text{KJ}}{\text{kg}}$$

$$(h_1 - h_2) = 0.70(3083.1 - 2640.91) = 309.53 \frac{\text{KJ}}{\text{kg}}$$

$$800 = m(309.53)$$

Problem No. 6 (Nonflow System)

During the execution of a non-flow process by a system, the work per degree temperature increase is $dW/dT = 170.9 \text{ J/K}$ and the internal energy may be expressed as $U = 27 + 0.68T$ Joules, a function of the temperature T in Kelvin. Determine the heat in KJ if the temperature changes from 10°C to 38°C .

(Continuity Equation)

Air of density 1.24 kg m^{-3} flows through a pipe at a mass-flow rate of flow of 3 kg s^{-1} . If the pipe diameter gradually changes from 300 to 200 mm calculate the flow velocity at the two sections and the pressure change that occurs.

Finding cross-sectional area of pipe where $d_1 = 300\text{ mm}$:

$$A_1 = \frac{\pi d_1^2}{4} = \frac{\pi \times 0.3^2}{4}$$

$$\mathbf{A_1 = 0.0707\text{ m}^2}$$

Finding flow velocity at this section

$$m = \rho A_1 v_1$$

$$v_1 = \frac{m}{\rho A_1} = \frac{3.0}{1.24 \times 0.0707}$$

$$\mathbf{v_1 = 34.2\text{ m s}^{-1}}$$

Finding cross-sectional area of pipe where $d_2 = 200\text{ mm}$

$$A_2 = \frac{\pi d_2^2}{4} = \frac{\pi \times 0.2^2}{4}$$

$$\mathbf{A_2 = 0.0314\text{ m}^2}$$

Finding flow velocity at this section

$$m = \rho A_2 v_2$$

$$v_2 = \frac{m}{\rho A_2} = \frac{3.0}{1.24 \times 0.0314}$$

$$\mathbf{v_2 = 77.0\text{ m s}^{-1}}$$

Potential Energy

It is required to lift five people on an elevator a distance of 100 m. The work is found to be 341.2 KJ and $g = 9.75\text{ m/sec}^2$. Determine the average mass per person. (69.99 kg)

Given:

$$\Delta Z = 100\text{ m}$$

$$\Delta PE = 341.2\text{ KJ}$$

$$g = 9.75\text{ m/sec}^2$$

$$\Delta PE = \frac{mg\Delta Z}{1000}$$

$$\mathbf{m = 349.95\text{ kg}}$$

the average mass per person is

$$m_{\text{ave}} = 69.99\text{ kg}$$

Question: Water enters a typical garden hose of diameter 1.6 cm with a velocity of 3 m/s. Calculate the exit velocity of water from the garden hose when a nozzle of diameter 0.5 cm is attached to the end of the hose.

Answer: First, find the cross-sectional areas of the entry (A_1) and exit (A_2) sides of the hose.

$$A_1 = \pi r^2 = \pi(0.008m)^2 = 2 \times 10^{-4} m^2$$

$$A_2 = \pi r^2 = \pi(0.0025m)^2 = 1.96 \times 10^{-5} m^2$$

Next, apply the continuity equation for fluids to solve for the water velocity as it exits the hose (v_2).

$$A_1 v_1 = A_2 v_2$$

$$v_2 = \left(\frac{A_1}{A_2} \right) v_1 = \left(\frac{2 \times 10^{-4} m^2}{1.96 \times 10^{-5} m^2} \right) (3 \frac{m}{s}) = 30.6 \frac{m}{s}$$

Solved example 1:

Water is flowing at a rate of 2m/s in a pipe of cross-sectional area 0.02m². If the cross-section is reduced to half, then find the rate of flow.

Solution:

Given $A_1 = 0.02m^2$, $v_1 = 2 m/s$, $A_2 = 0.02/2 m^2 = 0.01m^2$, $v_2 = ?$

From principle of continuity, $A_1 v_1 = A_2 v_2 = \text{constant}$ $0.02 \times 2 = 0.01 \times v_2$, $v_2 = 4m/s$

Mass/Volume

A cylindrical drum 60 cm diameter; 90 cm height, is filled with fluid whose density is 641 kg/m³. Determine

The total volume in m³

The total volume in liters

The total mass in kg

The specific weight in g = 9.62 m/sec²

Conservation of Mass

Two gaseous streams enter a combining tube and leave as a single mixture. These data apply at the entrance sections; for one gas,

$A_1 = 0.05 m^2$, $v_1 = 152.4 m/sec$, $\rho_1 = 0.6 m^3/kg$; for the m^3/kg . Find

a. the velocity at section 2

b. the flow and area at exit section

Given:

$A_1 = 0.05 m^2$; $v_1 = 152.4 m/sec$; $\rho_1 = 0.6 m^3/kg$

$A_2 = 0.032 m^2$; $m_2 = 7.6 kg/sec$; $\rho_2 = 1.9 kg/m^3$

$v_3 = 106.7 m/sec$; $\rho_3 = 0.44 m^3/kg$

$$m_1 + m_2 = m_3$$

$$\frac{A_1 v_1}{\rho_1} + m_2 = \frac{A_3 v_3}{\rho_3}$$

$$\frac{0.05(152.4)}{0.6} + 7.6 = \frac{A_3(106.7)}{0.44}$$

$$A_3 = 0.084 m^2$$

$$m_2 = \rho_2 A_2 v_2$$

$$v_2 = \frac{7.6}{1.9(0.032)} = 125 m/sec$$

$$m_3 = \frac{0.084(106.7)}{0.44}$$

$$m_3 = 20.37 kg/sec$$

Mass and Volume

A 3 m diameter by 4.5 m height vertical tank is receiving water ($\rho = 978 \text{ kg/m}^3$) at the rate of $1.13 \text{ m}^3/\text{min}$ and is discharging through a $150 \text{ mm } \phi$ with a constant velocity of 1.5 m/sec . At a given instant, the tank is half full. Find the water level and the mass change in the tank and the mass change in the tank 15 minutes later.

Given:

$$D = 3 \text{ m} ; H = 4.5 \text{ m}$$

$$Q = 1.13 \text{ m}^3/\text{min}$$

$$v = 1.5 \text{ m/sec}$$

V_i – initial volume of water in the tank

$$V_i = \left(\frac{1}{2}\right) \frac{\pi}{4} D^2 H$$

$$V_i = 15.9 \text{ m}^3$$

V_f = final volume of water in the tank after 15 minutes

V_{fd} – volume of outflow

$$V_{fd} = \frac{\pi}{4} (0.150)^2 (1.5)(60)15 = 23.88 \text{ m}^3$$

$$V_f = 15.9 + 1.13(15) - 23.88 = 8.97 \text{ m}^3$$

H_w – water level in the tank after 15 minutes

$$V_f = \frac{\pi}{4} D^2 H_w$$

$$H_w = 1.27 \text{ meters}$$

m_i – initial mass of water in the tank

m_f – final mass of water in the tank

$$m_i = V_i(\rho) = 15.9(978) = 15\,520.2 \text{ kg}$$

$$m_f = V_f(\rho) = 8.97(978) = 8772.66 \text{ kg}$$

$$\Delta m = m_f - m_i = -6747.54 \text{ kg}$$

Conservation of Mass

A certain fluid is flowing in a $0.5 \text{ m} \times 0.3 \text{ m}$ channel at the rate of $3 \text{ m}^3/\text{sec}$ and has a specific volume of $0.0012 \text{ m}^3/\text{kg}$. Determine the mass flow rate of water flowing in kg/sec .

$$A = 0.5(0.3) = 0.15 \text{ m}^2$$

$$m = \frac{Av}{v}$$

$$m v = Av = 3 \text{ m}^3 / \text{sec}$$

$$v = \frac{3}{0.15} = 20 \text{ m / sec}$$

$$m = \frac{0.15(20)}{0.0012} = 2500 \text{ kg / sec}$$

Zeroth Law

An engineering student wants to cool 0.25 kg of Omni Cola (mostly water) initially at 20°C by adding ice that is initially at -20°C . How much ice should be added so that the final temperature will be 0°C with all the ice melted, if the heat capacity of the container neglected.

$$C_{\text{water}} = 4.19 \text{ KJ/kg-}^\circ\text{C}$$

$$C_{\text{ice}} = 2.010 \text{ KJ/kg-}^\circ\text{C}$$

$$h_f \text{ of ice} = 334.9 \text{ KJ/kg}$$

$$Q_{\text{cola}} = Q_{\text{ice}}$$

$$0.25(4.19)(20 - 0) = m_{\text{ice}}[(2.010)(0 + 20) + 334.9]$$

$$m_{\text{ice}} = 0.056 \text{ kg} = 56 \text{ gram}$$

Zeroth Law

2.5 kg of brass of specific heat 0.39 KJ/kg-K at a temperature of 176°C is dropped into a 1.2 liters of water at 14°C . Find the resulting temperature of the mixture. (At 14°C density of water is 999 kg/m^3)

$$m_w = \frac{1.2}{1000} (999) = 1.1988 \text{ kg}$$

$$\text{Heat rejected by brass} = \text{Heat absorbed by water}$$

$$2.5(0.39)(176 - t) = 1.1988(4.187)(t - 14)$$

$$171.6 - 0.975t = 5.02t - 70.3$$

$$t = 40.4^{\circ}\text{C}$$

Pure Substance

Find the enthalpy and specific volume of steam at 200 KPa and 300°C. The condition of this steam is a superheated vapor, using superheated table, at 200 KPa

and 300°C;

$$h = 3071.8 \text{ KJ/kg}$$

$$v = 1.3162 \text{ m}^3/\text{kg}$$

Pure Substance

An 85 Liters drum contains saturated water and water vapor at 370°C.

a. Find the masses of each if their volumes are equal

b. Find the volume occupied by each if their masses are equal

From steam table at 370°C

$$v_f = 0.002222 \text{ m}^3/\text{kg}$$

$$v_g = 0.004193 \text{ m}^3/\text{kg}$$

a.

$$V_L = 0.0425 \text{ m}^3 ; V_V = 0.0425 \text{ m}^3$$

$$v_f = \frac{V_L}{m_L} = 0.002222$$

$$m_L = \frac{0.0425}{0.002222} = 19.13 \text{ kg}$$

$$v_g = \frac{V_V}{m_V} = 0.004193$$

$$m_V = \frac{0.0425}{0.004193} = 10.14 \text{ kg}$$

b.

$$V_L + V_V = 0.085$$

$$V_L = 0.085 - V_V \rightarrow \text{eq. 1}$$

$$v_f = \frac{V_L}{m_L}$$

$$m_L = \frac{0.085 - V_V}{0.00222} \rightarrow \text{eq. 2}$$

$$v_g = \frac{V_V}{m_V}$$

$$m_V = \frac{V_V}{0.004193} \rightarrow \text{eq. 3}$$

$$m_L = m_V$$

$$\frac{0.085 - V_V}{0.00222} = \frac{V_V}{0.004193}$$

$$V_V = \frac{0.085(0.004193)}{0.002222 + 0.004193}$$

$$V_V = 0.056 \text{ m}^3$$

$$V_L = 0.029 \text{ m}^3$$

Pure Substance (Steam Turbine)

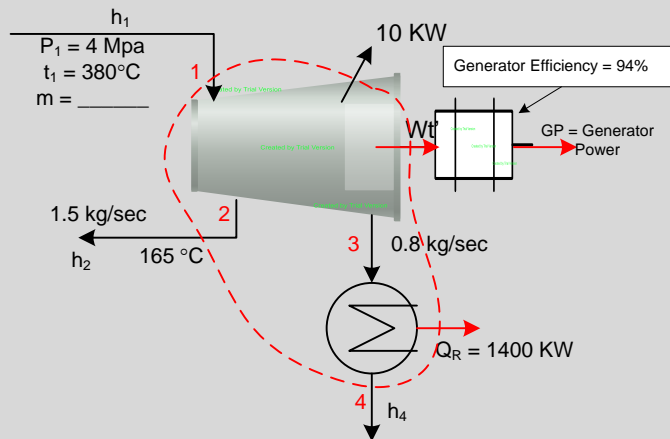
An industrial power plant requires 1.5 kg of dry saturated steam per second at 165°C for heating purposes. This steam may be supplied from an extraction turbine which receives steam at 4 MPa and 380°C and is exhausted to a condenser at the rate of 0.8 kg/sec at 0.0034 MPa while rejecting 1400 KW to the cooling water. If the mechanical efficiency of the turbine generator unit is 95% and the heat loss in the turbine casing is 10 KW, calculate the power generated by the plant.

($W_o = 1540 \text{ KW}$)

h at 4 MPa and 380°C = 3165.9 KJ/kg

h_g at 165°C = 2763.5 KJ/kg

h_f at 0.0034 MPa = 109.84 KJ/kg



By mass balance

$$m = 1.5 + 0.8 = 2.3 \frac{\text{kg}}{\text{sec}}$$

By energy balance condenser

$$Q_R = 0.8(h_3 - h_4)$$

$$1400 = 0.8(h_3 - 109.84)$$

$$h_3 = 1859.84 \frac{\text{KJ}}{\text{kg}}$$

By energy balance in the turbine

$$2.3(3165.9) - 10 - 1.5(2763.5) - 0.8(1859.84) = W_t$$

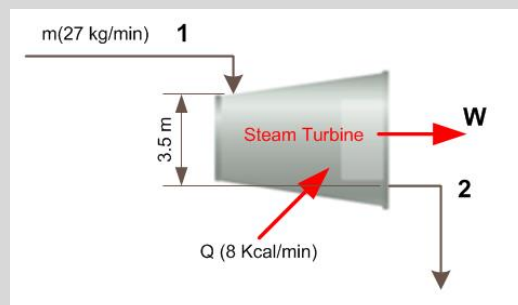
$$W_t = 1638.45 \text{ KW}$$

$$W_{\text{OUTPUT}} = 1540.14 \text{ KW}$$

Open system (Turbine)

Steam enters a turbine with a velocity of 1.5 m/sec and an enthalpy of 2093 KJ/kg and leaves with an enthalpy of 1977 KJ/kg and a velocity of 91.5 m/sec. Heat losses are 8 KCal/min and the steam flow rate is 27 kg/min. The inlet of the turbine is 3.5 m higher than its outlet. What is the work output of the turbine if the mechanical losses is 15%

- a) 32.4 KW b) 24.3 KW c) 34.2 K d) 48 KW



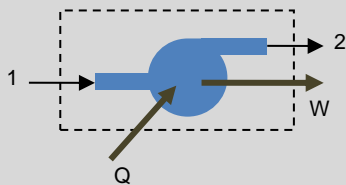
$$v_1 = 1.5 \frac{\text{m}}{\text{sec}}$$

$$v_2 = 91.5 \frac{\text{m}}{\text{sec}}$$

$$m = 27 \text{ kg} \quad 0.45 \text{ kg}$$

Open system (Air Compressor)

An air compressor handles 8.5 m³/min of air with a density of 1.26 kg/m³ and a pressure of 101 KPaa and discharges at 546 KPaa with a density of 4.86 kg/m³. The changes in specific internal energy across the compressor is 82 KJ/kg and the heat loss by cooling is 24 KJ/kg. Neglecting changes in kinetic and potential energies, find the work in KW.



$$\rho = \frac{m}{V}$$

$$m = \rho V = 1.26(8.5) = 10.71 \text{ kg/min} = 0.1785 \text{ kg/sec}$$

$$Q = \Delta U + \Delta(Pv) + \Delta KE + \Delta PE + W$$

$$W = Q - \Delta U - \Delta(Pv) - \Delta KE - \Delta PE$$

$$W = Q - (U_2 - U_1) - (P_2 v_2 - P_1 v_1) - 0 - 0$$

$$W = Q - (U_2 - U_1) - \left(\frac{P_2}{\rho_2} - \frac{P_1}{\rho_1} \right)$$

$$W = (-24) - (82) - \left(\frac{546}{4.86} - \frac{101}{1.26} \right) = -138.2 \frac{\text{KJ}}{\text{kg}}$$

In KW

$$W = 0.1785(-138.2) = -24.67 \text{ KW}$$

$$W = 24.67 \text{ KW (Work is done on the system)}$$

Open System

A steam turbine receives superheated steam at 1.4 MPa and 400°C. The steam leaves the turbine at 0.101 MPa and 100°C. The steam enters the turbine at 15 m/sec and exits at 60 m/sec. The elevation difference between entry and exit ports is negligible. The heat loss through the turbine walls is 2 KW. Calculate the power output in KW if the mass flow through the turbine is 0.5 kg/sec.

From Steam Table

At $P_1 = 1,400 \text{ KPa}$; $t_1 = 400^\circ\text{C}$

$h_1 = 3258.0 \text{ KJ/kg}$ (superheated vapor)

at $P_2 = 101 \text{ KPa}$; $t_2 = 100^\circ\text{C}$

$h_2 = 2344.9 \text{ KJ/kg}$ (saturated mixture)

$Q = 2 \text{ KW}$

$m = 0.5 \text{ kg/sec}$

System : Open System (Steam Turbine)

$$W = Q - \Delta h - \Delta KE - \Delta PE$$

If $\Delta PE = 0$

$$W = Q - \Delta h - \Delta KE$$

$$\Delta h = m(h_2 - h_1) \text{ KW}$$

$$\Delta KE = m \left[\frac{v_2^2 - v_1^2}{2(1000)} \right] \text{ KW}$$

Given:

$m = 0.5 \text{ kg/sec}$

$h_1 = 3258 \text{ KJ/kg}$

$h_2 = 2344.9 \text{ KJ/kg}$

$v_1 = 15 \text{ m/sec}$

$v_2 = 60 \text{ m/sec}$

$\Delta Z = 0$

$Q = 2 \text{ KW}$

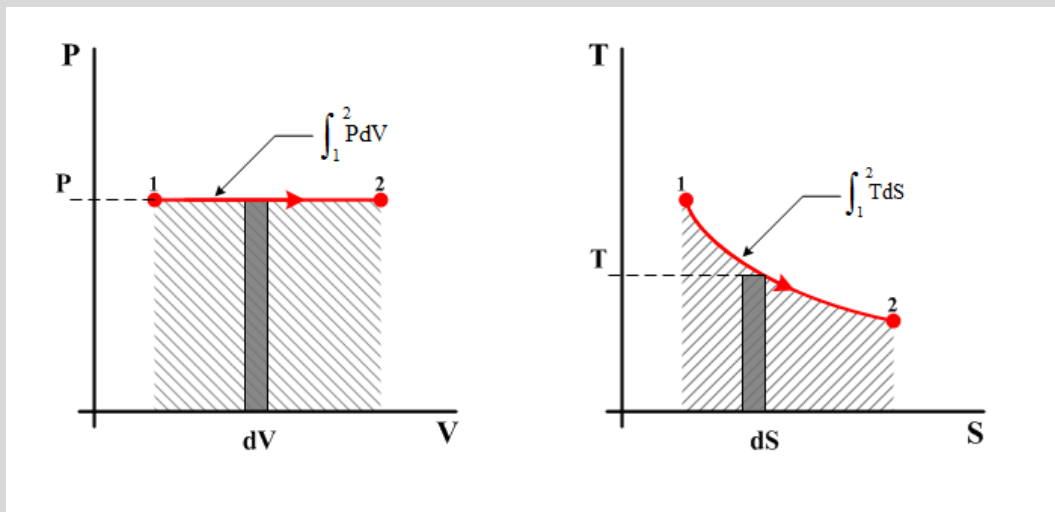
$\Delta h = -456.55 \text{ KW}$

$\Delta KE = 0.84375 \text{ KW}$

$W = 457.7 \text{ KW}$

PROCESSES OF FLUIDS

- **ISOBARIC PROCESS ($P = C$):** An Isobaric Process is an internally reversible Constant Pressure process.



CLOSED SYSTEM

For any substance

$$Q = \Delta U + W \rightarrow 1$$

$$W = \int P \cdot dV$$

At $P = C$

$$W = P(V_2 - V_1) \rightarrow 2$$

$$\Delta U = m(U_2 - U_1) \rightarrow 3$$

from

$$h = U + PV$$

$$dh = dU + PdV + VdP$$

$$dP = 0 \text{ at } P = C$$

$$dU + PdV = dQ$$

$$dQ = dh$$

$$Q = \Delta h$$

$$Q = m(h_2 - h_1) \rightarrow 4$$

For Ideal Gas

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} \rightarrow 1$$

$$W = P(V_2 - V_1) = mR(T_2 - T_1) \rightarrow 5$$

$$\Delta U = mC_v(T_2 - T_1) \rightarrow 3$$

$$Q = \Delta h = mC_p(T_2 - T_1) \rightarrow 6$$

ENTROPY CHANGE

For any substance

$$\Delta S = \int \frac{dQ}{T} = \int \frac{dh}{T} = S_2 - S_1 \rightarrow 7$$

For Ideal Gas

$$dQ = dh = mC_p dT$$

$$\Delta S = \int \frac{dQ}{T} = \int \frac{dh}{T} = mC_p \int_1^2 \frac{dT}{T}$$

$$\Delta S = mC_p \ln \frac{T_2}{T_1} \rightarrow 8$$

OPEN SYSTEM

$$Q = \Delta h + \Delta KE + \Delta PE + W \rightarrow 9$$

$$W = -\int VdP - \Delta KE - \Delta PE \rightarrow 10$$

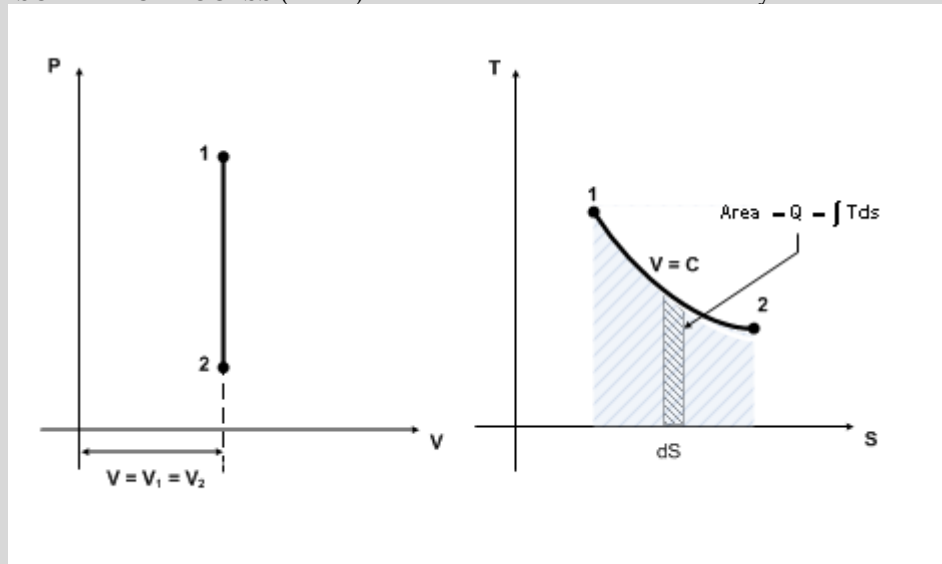
$$dP = 0 \text{ at } P = C \text{ and } Q = \Delta h; -\int V \cdot dP = 0$$

$$W = -\Delta KE - \Delta PE \rightarrow 11$$

If $\Delta KE = 0$ and $\Delta PE = 0$

$$W = 0 \rightarrow 12$$

- **ISOMETRIC PROCESS ($V = C$):** An Isometric Process is an internally reversible “Constant Volume” process.



CLOSED SYSTEM

For any substance

$$Q = \Delta U + W \rightarrow 1$$

$$W = \int P \cdot dV$$

At $V = C$

$$dV = 0$$

$$W = 0 \rightarrow 2$$

$$dQ = dU + PdV$$

$$dV = 0$$

$$dQ = dU$$

$$Q = \Delta U$$

$$Q = m(U_2 - U_1) \rightarrow 3$$

For Ideal Gas

$$\frac{P_1}{T_1} = \frac{P_2}{T_2} \rightarrow 4$$

$$Q = \Delta U = mC_v(T_2 - T_1) \rightarrow 5$$

ENTROPY CHANGE

$$\Delta S = \int \frac{dQ}{T} = mC_v \int \frac{dT}{T}$$

$$\Delta S = mC_v \ln \frac{T_2}{T_1} \rightarrow 6$$

OPEN SYSTEM

$$Q = \Delta h + \Delta KE + \Delta PE + W \rightarrow 7$$

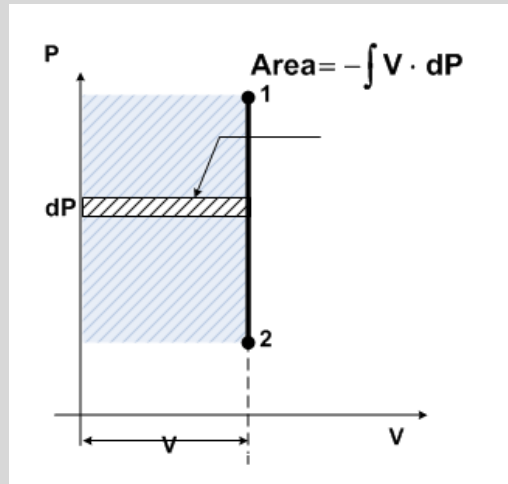
$$W = - \int V dP - \Delta KE - \Delta PE \rightarrow 8$$

$$- \int V \cdot dP = V(P_1 - P_2) \rightarrow 9$$

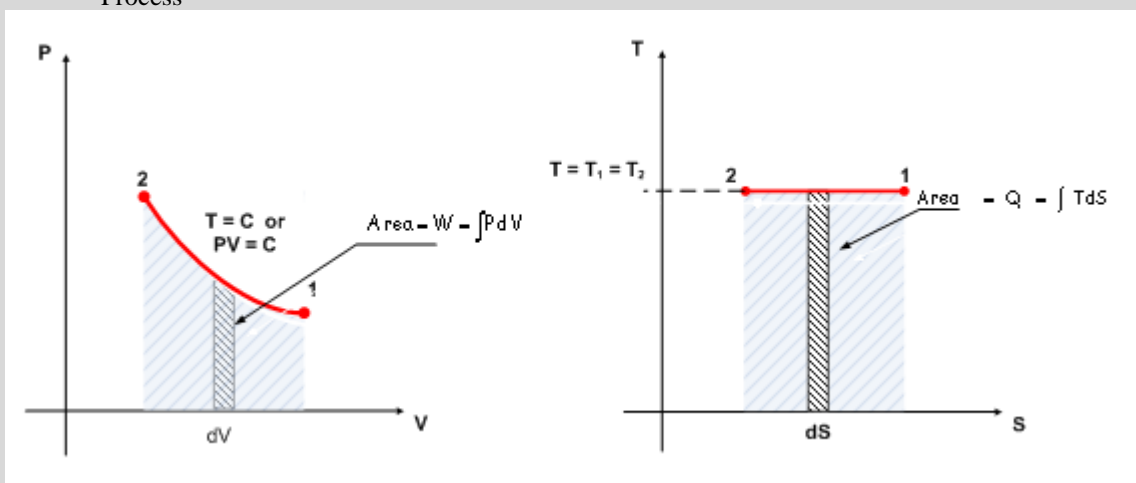
$$W = -\Delta KE - \Delta PE \rightarrow 11$$

If $\Delta KE = 0$ and $\Delta PE = 0$

$$W = 0 \rightarrow 12$$



- **ISOTHERMAL PROCESS ($T = C$ or $PV = C$):** An Isothermal Process is an internally reversible “Constant Temperature” Process



CLOSED SYSTEM

For any substance

$$Q = \Delta U + W \rightarrow 1$$

$$W = \int P \cdot dV \rightarrow 2$$

$$\Delta U = m(U_2 - U_1) \rightarrow 3$$

For Ideal Gas

$$PV = C \text{ or } P = \frac{C}{V}$$

$$P_1 V_1 = P_2 V_2 = C$$

$$\Delta U = mC_v(T_2 - T_1)$$

$$\text{But } T_1 = T_2$$

$$\Delta U = 0 \rightarrow 4$$

$$W = \int P dV = C \int \frac{dV}{V}$$

$$W = P_1 V_1 \ln \frac{V_2}{V_1} \rightarrow 5$$

$$W = mRT_1 \ln \frac{V_2}{V_1} \rightarrow 6$$

$$\frac{V_2}{V_1} = \frac{P_1}{P_2}$$

$$W = mRT_1 \ln \frac{P_1}{P_2} \rightarrow 7$$

ENTROPY CHANGE

For any substance

$$\Delta S = S_2 - S_1 \rightarrow 8$$

From

$$dQ = T ds$$

$$\text{At } T = C$$

$$Q = T \Delta S$$

$$\Delta S = \frac{Q}{T} \rightarrow 9$$

For ideal gas

$$\Delta U = 0, \text{ therefore}$$

$$W = Q \rightarrow 10$$

OPEN SYSTEM

$$Q = \Delta h + \Delta KE + \Delta PE + W \rightarrow 1$$

$$W = -\int V dP - \Delta KE - \Delta PE \rightarrow 2$$

$$\Delta h = m(h_2 - h_1) \rightarrow 3$$

For ideal gas

$$\Delta h = mC_p(T_2 - T_1)$$

$$\text{but } T_1 = T_2$$

$$\Delta h = 0 \rightarrow 4$$

From

$$PV = C \text{ or } V = \frac{C}{P}$$

$$P_1 V_1 = P_2 V_2 = C$$

$$-\int V dP = -C \int \frac{dP}{P}$$

$$-\int V dP = -P_1 V_1 \ln \frac{P_2}{P_1} \rightarrow 5$$

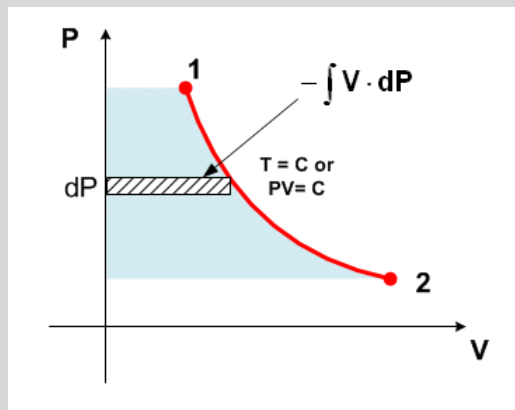
and applying laws of logarithm

$$-\int V dP = P_1 V_1 \ln \frac{P_1}{P_2} = mRT_1 \ln \frac{P_1}{P_2} \rightarrow 6$$

$$-\int V dP = mRT_1 \ln \frac{V_2}{V_1} \rightarrow 7$$

$$\text{If } \Delta KE = 0 \text{ and } \Delta PE = 0$$

$$W = -\int V dP = -P_1 V_1 \ln \frac{P_2}{P_1} \rightarrow 8$$



- **ISENTROPIC PROCESS ($S = C$):** An Isentropic Process is an internally “reversible adiabatic” process in which the entropy remains constant where $S = C$ (for any substance) or $PV^k = C$ (for an ideal or perfect gas)

From

$$dQ = dU + PdV$$

$$dQ = 0, \text{ for adiabatic}$$

$$dU = -PdV \rightarrow 1$$

$$dh = dQ + VdP$$

$$dQ = 0$$

$$dh = VdP \rightarrow 2$$

$$\frac{dh}{dU} = \frac{VdP}{-PdV} \rightarrow 3$$

but

$$\frac{C_p}{C_v} = \frac{dh}{dU} = k, \text{ hence}$$

$$k = \frac{-VdP}{PdV}$$

$$\frac{dP}{P} = -k \frac{dV}{V}$$

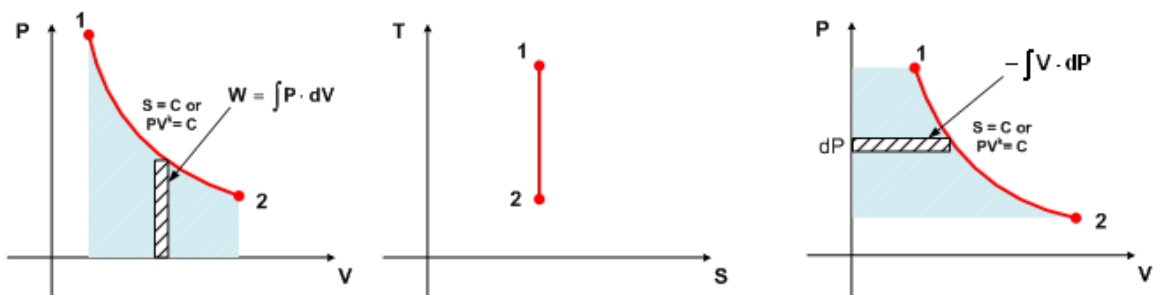
by integration

$$\int_1^2 \frac{dP}{P} = -k \int_1^2 \frac{dV}{V}$$

$$\ln \frac{P_2}{P_1} = -k \ln \frac{V_2}{V_1} = k \ln \frac{V_1}{V_2} = \ln \left(\frac{V_1}{V_2} \right)^k$$

taking antilog

$$\frac{P_2}{P_1} = \left(\frac{V_1}{V_2} \right)^k = \frac{V_1^k}{V_2^k} \text{ or } P_1 V_1^k = P_2 V_2^k \rightarrow 1$$



Using

$$PV^k = C \text{ and } \frac{PV}{T} = C$$

$$P_1 V_1^k = P_2 V_2^k \text{ and } \frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1} \right)^{\frac{k-1}{k}} = \left(\frac{V_1}{V_2} \right)^{k-1} \rightarrow 2$$

$$\text{From } PV^k = C$$

$$P = \frac{C}{V^k} \text{ and } V = \frac{C^{\frac{1}{k}}}{P^{\frac{1}{k}}} \rightarrow 3$$

By integration

$$\int_1^2 PdV = \frac{P_2 V_2 - P_1 V_1}{1-k} \rightarrow 4$$

$$-\int_1^2 VdP = \frac{k(P_2 V_2 - P_1 V_1)}{1-k} \rightarrow 5$$

$$-\int_1^2 VdP = k \int_1^2 PdV \rightarrow 6$$

$$P_1 V_1 = mRT_1 \rightarrow 7$$

$$P_2 V_2 = mRT_2 \rightarrow 8$$

CLOSED SYSTEM

For any substance

$$Q = \Delta U + W$$

$$Q = 0 \rightarrow 1$$

$$W = -\Delta U \rightarrow 2$$

For Ideal Gas

$$W = -\Delta U = -mC_v(T_2 - T_1) \rightarrow 3$$

$$W = \int PdV = \frac{P_2 V_2 - P_1 V_1}{1-k} = \frac{mR(T_2 - T_1)}{1-k} \rightarrow 4$$

$$\text{From } \frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}}$$

$$W = \int PdV = \frac{mR(T_2 - T_1)}{1-k} = \frac{mRT_1}{1-k} \left[\left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}} - 1 \right] = \frac{P_1 V_1}{1-k} \left[\left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}} - 1 \right] \rightarrow 5$$

ENTROPY CHANGE

$$\Delta S = 0$$

OPEN SYSTEM

$$Q = \Delta h + \Delta KE + \Delta PE + W$$

$$W = -\int VdP - \Delta KE - \Delta PE$$

$$Q = 0 \rightarrow 1$$

$$W = -\Delta h - \Delta KE - \Delta PE \rightarrow 2$$

$$-\int VdP = -\Delta h \rightarrow 3$$

For Ideal Gas

$$\Delta h = mC_p(T_2 - T_1) \rightarrow 4$$

If $\Delta KE = 0$ and $\Delta PE = 0$

$$W = -\int VdP = -\Delta h$$

$$-\int VdP = k \int PdV$$

$$-\int VdP = \frac{k(P_2 V_2 - P_1 V_1)}{1-k} = \frac{kmR(T_2 - T_1)}{1-k} = \frac{kmRT_1}{1-k} \left[\left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}} - 1 \right] = \frac{kP_1 V_1}{1-k} \left[\left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}} - 1 \right] \rightarrow 5$$

- **POLYTROPIC PROCESS ($PV^n = C$):** A Polytropic Process is an internally reversible process of an ideal or perfect gas in which $PV^n = C$, where n stands for any constants.

Using

$$PV^n = C \quad \text{and} \quad \frac{PV}{T} = C$$

$$P_1 V_1^n = P_2 V_2^n \quad \text{and} \quad \frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \rightarrow 1$$

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} = \left(\frac{V_1}{V_2} \right)^{n-1} \rightarrow 2$$

From $PV^n = C$

$$P = \frac{C}{V^n} \quad \text{and} \quad V = \frac{C^{\frac{1}{n}}}{P^{\frac{1}{n}}} \rightarrow 3$$

By integration

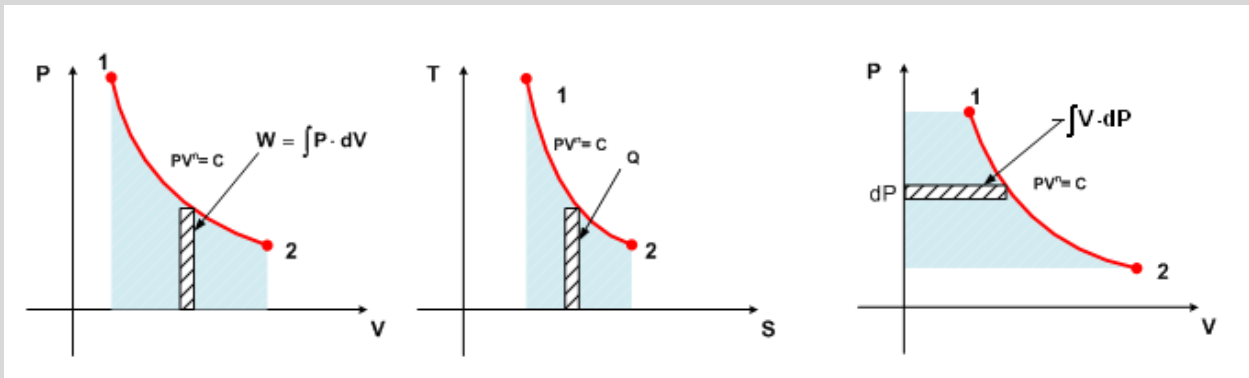
$$\int_1^2 P dV = \frac{P_2 V_2 - P_1 V_1}{1-n} \rightarrow 4$$

$$-\int_1^2 V dP = \frac{n(P_2 V_2 - P_1 V_1)}{1-n} \rightarrow 5$$

$$-\int_1^2 V dP = n \int_1^2 P dV \rightarrow 6$$

$$P_1 V_1 = mRT_1 \rightarrow 7$$

$$P_2 V_2 = mRT_2 \rightarrow 8$$



From

$$Q = \Delta U + W \rightarrow 9$$

$$W = \int P dv = \frac{P_2 v_2 - P_1 v_1}{1-n} = \frac{R(T_2 - T_1)}{1-n}$$

$$dW = \frac{RdT}{1-n} \rightarrow 10$$

$$dQ = dU + dW$$

$$dQ = C_v dT + \frac{RdT}{1-n}$$

$$R = C_p - C_v$$

$$C_p = kC_v$$

$$dQ = C_v dT + \frac{kC_v dT - C_v dT}{1-n}$$

$$dQ = C_v dT + C_v dT \left(\frac{k-1}{1-n} \right)$$

$$dQ = C_v dT \left(1 + \frac{k-1}{1-n} \right) = C_v dT \left(\frac{1-n+k-1}{1-n} \right)$$

$$dQ = C_v dT \left(\frac{k-n}{1-n} \right) = C_v \left(\frac{k-n}{1-n} \right) dT$$

$$\text{let: } C_n = C_v \left(\frac{k-n}{1-n} \right)$$

$$dQ = C_n dT$$

$$Q = C_n (T_2 - T_1) \rightarrow 10$$

Considering m

$$Q = mC_n (T_2 - T_1) \rightarrow 11$$

$$C_n = C_v \left(\frac{k-n}{1-n} \right) \rightarrow \text{Polytropic specific heat}$$

CLOSED SYSTEM

$$Q = \Delta U + W$$

$$Q = \Delta U \rightarrow 12$$

$$Q = mC_n (T_2 - T_1) \rightarrow 13$$

$$\Delta U = -mC_v (T_2 - T_1) \rightarrow 14$$

$$W = \int P dV = \frac{P_2 V_2 - P_1 V_1}{1-n} = \frac{mR(T_2 - T_1)}{1-n} \rightarrow 15$$

$$\text{From } \frac{T_2}{T_1} = \left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}}$$

OPEN SYSTEM

$$Q = \Delta h + \Delta KE + \Delta PE + W \rightarrow 18$$

$$W = -\int VdP - \Delta KE - \Delta PE \rightarrow 19$$

$$W = Q - \Delta h - \Delta KE - \Delta PE \rightarrow 20$$

$$h = U + PV$$

$$\Delta h = \Delta U + \Delta(PV)$$

$$\Delta(PV) = \Delta h - \Delta U$$

$$\Delta h = mC_p(T_2 - T_1) \rightarrow 21$$

$$Q = mC_n(T_2 - T_1) \rightarrow 22$$

$$-\int VdP = \frac{n(P_2V_2 - P_1V_1)}{1-n} = \frac{nmR(T_2 - T_1)}{1-n} = \frac{nmRT_1}{1-n} \left[\left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right] = \frac{nP_1V_1}{1-n} \left[\left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right]$$

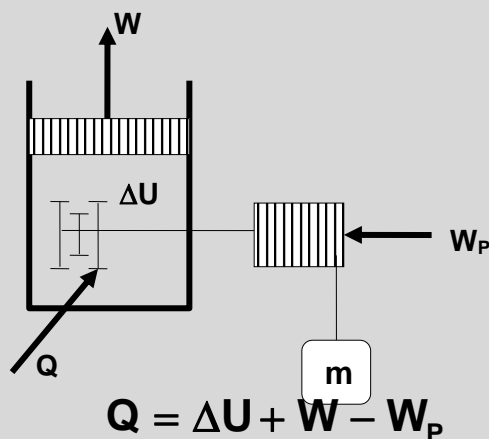
If $\Delta KE = 0$ and $\Delta PE = 0$

$$W = -\int VdP$$

- **ISOENTHALPIC PROCESS or THROTTLING PROCESS ($h = C$):** An Isoenthalpic Process is a steady state, steady flow, process in which $W = 0$, $\Delta KE = 0$, $\Delta PE = 0$, and $Q = 0$, where the enthalpy h remains constant.

$$h_1 = h_2 \text{ or } h = C$$

IRREVERSIBLE OR PADDLE WORK



Where:

W_P – irreversible or Paddle Work

SAMPLE PROBLEMS

1. Calculate the change of entropy per kg of air when heated from 300°K to 600°K while the pressure drops from 400 Kpa to 300 KPa.

$$(\Delta S = 0.78 \text{ KJ/kg-K})$$

Given;

$$R = 0.287 \text{ KJ/kg-K}$$

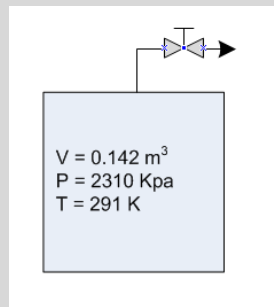
$$k = 1.4$$

$$T_1 = 300^\circ\text{K} ; T_2 = 600^\circ\text{K}$$

$$P_1 = 400 \text{ KPa} ; P_2 = 300 \text{ KPa}$$

$$\Delta S = C_p \ln \frac{T_2}{T_1} - R \ln \frac{P_2}{P_1}$$

2. A certain mass of sulfur dioxide (SO₂) is contained in a vessel of 0.142 m³ capacity, at a pressure and temperature of 2310 KPa and 18°C, respectively. A valve is open momentarily and the pressure falls immediately to 690 KPa. Sometime later the temperature is again 18°C and the pressure is observed to be 910 KPa. Estimate the value of specific heat ratio. (k = 1.29)



$$R = \frac{8.3143}{64} = 0.13$$

$$P_1 V_1 = m_1 R T_1$$

$$m_1 = \frac{2310(0.142)}{0.13(291)} = 8.67 \text{ kg}$$

At $V = C$

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

$$T_2 = \left(\frac{P_2}{P_1} \right) T_1 = 86.92^\circ\text{K}$$

2. Two unequal vessel A and B are connected by a pipe with a valve. Vessel A contains 150 L of air at 2760 KPa and 95°C. Vessel B contains an unknown volume of air at 70 KPa and 5°C. The valve is opened and when the properties have been

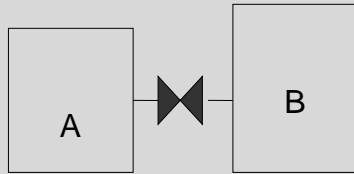
determined, it was found out that the pressure of the mixture is 1380 KPa and the temperature is 45°C. What is the volume of vessel B.(0.166 m³)

Given:

$$V_A = 0.150 \text{ m}^3 ; P_A = 2760 \text{ KPa} ; T_A = 95 + 273 = 368 \text{ K}$$

$$P_B = 70 \text{ KPa} ; T_B = 5 + 273 = 278 \text{ K}$$

$$P = 1380 \text{ KPa} ; T = 45 + 273 = 318 \text{ K}$$



$$V = V_A + V_B$$

$$m = m_A + m_B$$

$$m = \frac{PV}{RT} ; m_A = \frac{P_A V_A}{RT_A} ; m_B = \frac{P_B V_B}{RT_B}$$

$$\frac{1380(0.150 + V_B)}{R(318)} = \frac{2760(0.150)}{R(368)} + \frac{70(V_B)}{R(278)}$$

$$0.65 + 4.34V_B = 1.125 + 0.252V_B$$

$$V_B = \frac{(1.125 - 0.65)}{(4.34 - 0.252)} = 0.116 \text{ m}^3$$

3. An ideal gas with $R = 2.077 \text{ KJ/kg-K}$ and a constant $k = 1.659$ undergoes a constant pressure process during which 527.5 KJ are added to 2.27 kg of the gas. The initial temperature is 38°C. Find the ΔS in KJ/K.

Given:

$$R = 2.077 \text{ KJ/kg-K} ; k = 1.659$$

$$Q = 527.5 \text{ KJ} ; m = 2.27 \text{ kg}$$

$$T_1 = 38 + 273 = 311 \text{ K}$$

$$\text{Process: } P = C$$

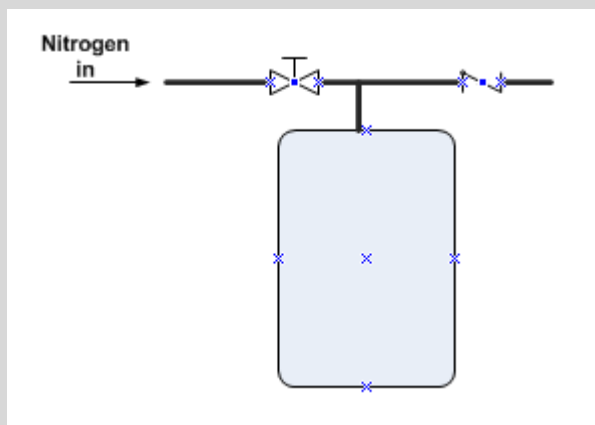
$$C_p = \frac{Rk}{k-1} = 5.72 \text{ KJ/kg-K}$$

$$Q = mC_p(T_2 - T_1) ;$$

$$T_2 = \frac{Q}{mC_p} + T_1 = 352^\circ\text{K}$$

$$\Delta S = mC_p \ln \frac{T_2}{T_1} = 1.6 \text{ KJ/K}$$

3. A vessel of volume 0.2 m³ contains nitrogen at 101.3 KPa and 15°C. If 0.2 kg of nitrogen is now pumped into the vessel, calculate the new pressure when the vessel has returned to its initial temperature. For nitrogen: $M = 28$; $k = 1.399$. (187 KPa)



Given :

$$V_1 = 0.2 \text{ m}^3; P_1 = 101.3 \text{ KPa}; T_1 = 15 + 273 = 288^\circ\text{K}$$

$m_a = 0.2 \text{ kg}$ (mass of N_2 added)

$$PV = mRT$$

$$m = \frac{PV}{RT}$$

$$R = \frac{8.3143 \text{ KJ}}{28 \text{ kg} \cdot \text{K}}$$

$$m_1 = \frac{101.3(0.2)28}{8.3143(15 + 273)} = 0.237 \text{ kg}$$

$$m_2 = 0.237 + 0.2 = 0.437 \text{ kg} \rightarrow \text{final mass}$$

$$T_2 = 15 + 273 = 288^\circ\text{K}$$

$$P = \frac{mRT}{V}$$

$$V_2 = V_1$$

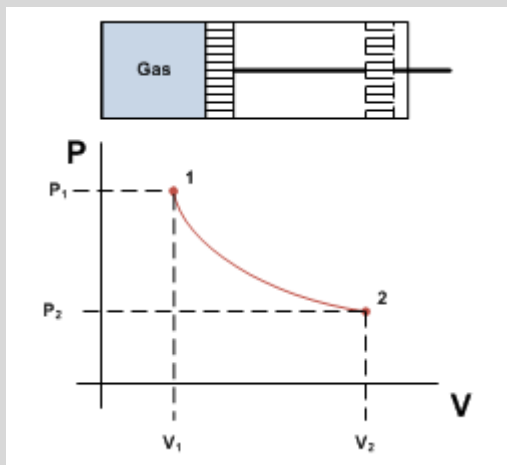
$$P_2 = \frac{0.437(8.3143)(15 + 273)}{28(0.2)} = 186.82 \text{ KPa}$$

4. A certain perfect gas of mass 0.1 kg occupies a volume of 0.03 m³ at a pressure of 700 KPa and a temperature of 131°C. The gas is allowed to expand until the pressure is 100 KPa and the final volume is 0.2 m³. Calculate;
- the molecular weight of the gas (16)
 - the final temperature

Given;

$$m = 0.1 \text{ kg}; V_1 = 0.03 \text{ m}^3; P_1 = 700 \text{ KPa}; T_1 = 131 + 273 = 404 \text{ K}$$

$$P_2 = 100 \text{ KPa}; V_2 = 0.2 \text{ m}^3$$



$$PV = mRT$$

$$R = \frac{P_1 V_1}{m T_1}$$

$$R = 0.52 \frac{\text{KJ}}{\text{kg} \cdot \text{K}}$$

$$R = \frac{8.3143}{M}$$

$$M = \frac{8.3143}{R} = 16 \frac{\text{kg}}{\text{kg}_{\text{mol}}}$$

$$\frac{PV}{T} = C$$

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

$$T_2 = \frac{T_1 P_2 V_2}{P_1 V_1} = 384.8^\circ\text{K}$$

$$t_2 = 111.8^\circ\text{C}$$

5. A perfect gas has a molecular weight of 26 kg/kmol and a value of $k = 1.26$. Calculate the heat rejected when 1 kg of the gas is contained in a rigid vessel at 300 KPa and 315°C, and is then cooled until the pressure falls to 150 KPa. (- 361 KJ)

$$R = \frac{8.3143}{26} = 0.32$$

$$C_v = \frac{R}{k-1} = 1.23$$

$$T_1 = 315 + 273 = 588$$

At $V = C$

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

$$T_2 = \frac{150(588)}{300} = 294$$

$$Q = mC_v(T_2 - T_1) = 1(1.23(294 - 588))$$

$$Q = 361.2 \text{ KJ (rejected)}$$

6. A closed gaseous system undergoes a reversible process in which 30 KJ of heat are rejected and the volume changes from 0.14 m³ to 0.55 m³. The pressure is constant at 150 KPa. Determine the change in internal energy of the system and the work done.

$$Q = \Delta U + W$$

$$W = \int P dV$$

at $P = C$

$$W = P \int dV = P(V_2 - V_1)$$

$$W = 150(0.55 - 0.14) = 61.5 \text{ KJ}$$

$$\Delta U = Q - W = -30 - 61.5 = -91.5 \text{ KJ}$$

8. An ideal gas has a mass of 1.5 kg and occupies 2.5 m³ while at a temperature of 300°K and a pressure of 200 KPa. Determine the ideal gas constant for the gas.

Given:

$$m = 1.5 \text{ kg}$$

$$V = 2.5 \text{ m}^3$$

$$T = 300^\circ\text{K}$$

$$P = 200 \text{ KPa}$$

$$PV = mRT$$

$$R = \frac{PV}{mT} = \frac{200(2.5)}{1.5(300)} = 1.11 \frac{\text{KJ}}{\text{kg} \cdot ^\circ\text{K}}$$

9. A 6 m³ tank contains helium at 400°K and is evacuated from atmospheric pressure to 740 mm Hg vacuum. Determine

a) the mass of helium remaining in the tank

b) the mass of helium pumped out

c) the temperature of the remaining helium falls to 10°C, what is the pressure in KPa

For Helium:

$$R = 2.077 \text{ KJ/kg} \cdot ^\circ\text{K}$$

$$C_p = 5.1954 \text{ KJ/kg} \cdot ^\circ\text{K}$$

$$C_v = 3.1189 \text{ KJ/kg} \cdot ^\circ\text{K}$$

Given:

$$P_1 = 101.325 \text{ KPa}$$

$$P_2 = 760 - 740 = 20 \text{ mm Hg} = 2.67 \text{ KPa}$$

$$V_1 = V_2 = 6 \text{ m}^3$$

$$T = 400^\circ\text{K}$$

$$V_1 = 0.5(2) = 1 \text{ kg}$$

$$V_2 = \left[\frac{P_1 V_1^{1.3}}{P_2} \right]^{1/1.3} = 2.9 \text{ m}^3$$

$$W = 91.7 \text{ KJ}$$

10. A closed system consisting of 2 kg of a gas undergoes a process during which the relationship between pressure and specific volume is $PV^{1.3} = C$. The process begins with $P_1 = 1 \text{ bar}$, $v_1 = 0.5 \text{ m}^3/\text{kg}$ and ends with $P_2 = 0.25 \text{ bar}$. Determine the final volume, in m^3 , and plot the process on a graph of pressure versus specific volume.

Given

$$m = 2 \text{ kg}$$

$$P_1 = 1 \text{ Bar} = 100 \text{ KPa} ; P_2 = 0.25 \text{ Bar} = 25 \text{ KPa}$$

$$v_1 = 0.5 \text{ m}^3/\text{kg}$$

$$\text{Process: } PV^{1.3} = C$$

$$P_1 V_1^{1.3} = P_2 V_2^{1.3} = C$$

$$P = \frac{C}{V^{1.3}}$$

$$W = \int P \cdot dV = \frac{P_2 V_2 - P_1 V_1}{1 - 1.3}$$

$$PV = mRT$$

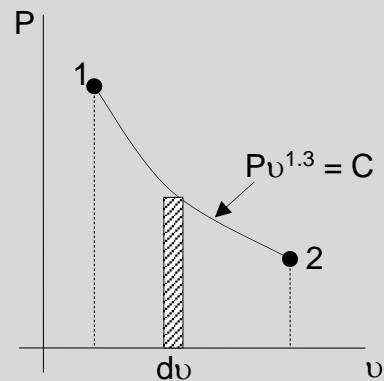
$$m_1 = \frac{101.325(6)}{2.077(400)} = 0.732 \text{ kg (original mass of helium in the tank)}$$

$$m_2 = \frac{2.67(6)}{2.077(400)} = 0.02 \text{ kg (mass of helium remaining in the tank)}$$

$$m_p = 0.732 - 0.02 = 0.712 \text{ kg (mass of helium pumped out)}$$

$$\text{If the temperature falls to } 283^\circ\text{K}$$

$$P = \frac{0.02(2.077)(283)}{6} = 1.96 \text{ KPa}$$



11. Four kilograms of a certain gas is contained within a piston–cylinder assembly. The gas undergoes a process for which the pressure - volume relationship is $PV^{1.5} = C$. The initial pressure is 3 bar, the initial volume is 0.1 m^3 , and the final volume is 0.2 m^3 . The change in specific internal energy of the gas in the process is $\Delta U = -4.6 \text{ kJ/kg}$. There are no significant changes in kinetic or potential energy. Determine the net heat transfer for the process, in kJ. ($Q = -0.8 \text{ KJ}$)

Given

$$m = 4 \text{ kg}$$

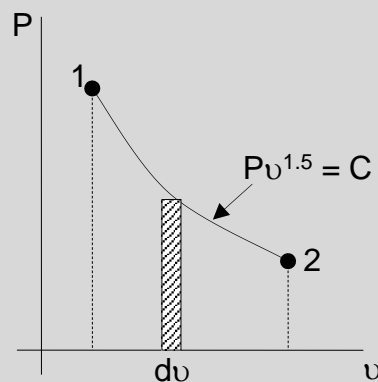
$$\text{Process: } PV^{1.5} = C$$

$$= 3 \text{ Bar} = 300 \text{ KPa} ; V_1 = 0.1 \text{ m}^3$$

$$P_2 = ? ; V_2 = 0.2 \text{ m}^3$$

$$\Delta U = -4.6 \text{ KJ/kg}$$

$$\Delta U = 4(-4.6) = -18.4 \text{ KJ}$$



For a closed system

$$Q = \Delta U + W$$

$$W = \frac{P_2 V_2 - P_1 V_1}{1 - 1.5}$$

$$P_1 V_1^{1.5} = P_2 V_2^{1.5} = C$$

$$P_2 = \frac{P_1 V_1^{1.5}}{V_2^{1.5}} = 106.07 \text{ KPa}$$

$$W = 17.6 \text{ KJ}$$

$$Q = -18.4 + 17.6 = -0.83 \text{ KJ}$$

$$Q = 0.83 \text{ KJ (heat is rejected from the gas)}$$

12. Calculate the change of entropy per kg of air ($R = 0.287 \text{ KJ/kg-K}$; $k = 1.4$) when heated from 300°K to 600°K while the pressure drops from 400 KPa to 300 KPa. ($\Delta S = 0.78 \text{ KJ/kg-K}$)

Given

$$T_1 = 300 \text{ K} ; T_2 = 600 \text{ K}$$

$$P_1 = 400 \text{ KPa} ; P_2 = 300 \text{ KPa}$$

$$\Delta S = C_p \ln \frac{T_2}{T_1} - R \ln \frac{P_2}{P_1}$$

$$C_p = \frac{Rk}{k-1} = \frac{0.287(1.4)}{1.4-1} = 1.0045 \frac{\text{KJ}}{\text{kg-K}}$$

$$\Delta S = 0.78 \frac{\text{KJ}}{\text{kg-}^\circ\text{K}}$$

13. A 5 kg quantity of oxygen ($M = 32$; $k = 1.395$) is heated from 250 K to 400 K at constant pressure.

Determine

- a) Δh
- b) ΔU
- c) ΔS
- d) $W = \int P dV$

Given

$$m = 5$$

Gas: Oxygen $M = 32$; $k = 1.395$

$$T_1 = 250^\circ\text{K} ; T_2 = 400^\circ\text{K}$$

Process: $P = C$

$$C_p = \frac{Rk}{k-1} ; C_v = \frac{R}{k-1} ; R = \frac{8.3143}{M}$$

$$R = 0.26 \frac{\text{KJ}}{\text{kg-}^\circ\text{K}}$$

$$C_p = 0.918 \frac{\text{KJ}}{\text{kg-}^\circ\text{K}} ; C_v = 0.658 \frac{\text{KJ}}{\text{kg-}^\circ\text{K}}$$

At Constant Pressure ($P = C$)

$$Q = m \Delta h = m C_p (T_2 - T_1) = 688.5 \text{ KJ}$$

$$\Delta U = m C_v (T_2 - T_1) = 493.5 \text{ KJ}$$

$$Q = \Delta U + W$$

$$W = Q - \Delta U = 195 \text{ KJ}$$

$$\Delta S = \int \frac{dQ}{T}$$

$$\Delta S = m C_p \ln \frac{T_2}{T_1} = 2.16 \frac{\text{KJ}}{^\circ\text{K}}$$

IDEAL GAS MIXTURE

TOTAL MASS OF A MIXTURE

$$m = \sum m_i$$

MASS FRACTION

$$x_i = \frac{m_i}{m}$$

TOTAL MOLES OF A MIXTURE

$$n = \sum n_i$$

MOLE FRACTION

$$y_i = \frac{n_i}{n}$$

EQUATION OF STATE

Mass Basis

For the Mixture

$$PV = mRT$$

For the Components

$$P_i V_i = m_i R_i T_i$$

Mole Basis

For the Mixture

$$PV = n\bar{R}T$$

For the Components

$$P_i V_i = n_i \bar{R} T_i$$

AMAGAT'S LAW

The total volume of a mixture of gases is equal to the sum of the volume occupied by each component at the mixture pressure P and temperature T .

1	2	3
V_1	V_2	V_3

P, T

$$P = P_1 = P_2 = P_3$$

$$T = T_1 = T_2 = T_3$$

$$n = n_1 + n_2 + n_3$$

$$n = \frac{PV}{\bar{R}T} ; n_1 = \frac{PV_1}{\bar{R}T} ; n_2 = \frac{PV_2}{\bar{R}T} ; n_3 = \frac{PV_3}{\bar{R}T}$$

$$\frac{PV}{RT} = \frac{PV_1}{RT} + \frac{PV_2}{RT} + \frac{PV_3}{RT}$$

$$\left[\frac{PV}{RT} = \frac{PV_1}{RT} + \frac{PV_2}{RT} + \frac{PV_3}{RT} \right] \left(\frac{\bar{RT}}{P} \right)$$

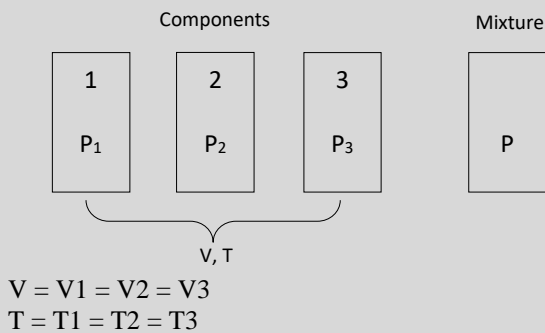
$$V = V_1 + V_2 + V_3$$

$$V = \sum V_i$$

$$y_i = \frac{n_i}{n} = \frac{V_i}{V}$$

Dalton's LAW

The total pressure of a mixture of gases P is equal to the sum of the partial pressure that each gas would exert at the mixture volume V and temperature T.



$$n = n_1 + n_2 + n_3$$

$$n = \frac{PV}{RT} ; n_1 = \frac{P_1 V}{RT} ; n_2 = \frac{P_2 V}{RT} ; n_3 = \frac{P_3 V}{RT}$$

$$\frac{PV}{RT} = \frac{P_1 V}{RT} + \frac{P_2 V}{RT} + \frac{P_3 V}{RT}$$

$$\left[\frac{PV}{RT} = \frac{P_1 V}{RT} + \frac{P_2 V}{RT} + \frac{P_3 V}{RT} \right] \left(\frac{\bar{RT}}{V} \right)$$

$$P = P_1 + P_2 + P_3$$

$$P = \sum P_i$$

$$y_i = \frac{n_i}{n} = \frac{P_i}{P}$$

MOLECULAR WEIGHT OF A MIXTURE (M)

$$M = \sum y_i M_i$$

$$M = \frac{\bar{R}}{R} = \frac{8.3143}{R} \frac{KJ}{kg - K}$$

GAS CONSTANT (R)

$$R = \sum x_i R_i$$

$$R = \frac{\bar{R}}{M} = \frac{8.3143}{M} \frac{KJ}{kg - K}$$

SPECIFIC HEAT OF A MIXTURE

At Constant Volume

$$C_v = \sum x_i C_{vi}$$

At Constant Pressure

$$C_p = \sum x_i C_{pi}$$

$$C_p = C_v + R$$

RATIO OF SPECIFIC HEAT

$$k = \frac{C_p}{C_v}$$

$$C_p = \frac{Rk}{k-1}$$

$$C_v = \frac{R}{k-1}$$

GRAVIMETRIC AND VOLUMETRIC ANALYSIS

Gravimetric analysis gives the mass fractions of the components in the mixture.

Volumetric analysis gives the volumetric or molal fractions of the components in the mixture.

CONVERSION

$$x_i = \frac{y_i M_i}{\sum y_i M_i} = \frac{y_i M_i}{M}$$

$$y_i = \frac{\frac{x_i}{M_i}}{\sum \frac{x_i}{M_i}}$$

1. A gaseous mixture has the following volumetric analysis: $O_2 = 30\%$; $CO_2 = 40\%$; $N_2 = 30\%$. Determine
 - a. the gravimetric analysis
 - b. the partial pressure of each component if the total pressure is 100 KPa and the temperature is $32^\circ C$
 - c. the molecular weight and gas constant of the mixture

For

O_2 : $M = 32$; $k = 1.395$

CO_2 : $M = 44$; $k = 1.288$

N_2 : $M = 28$; $k = 1.399$

Given

Volumetric analysis

$O_2 = 30\%$; $CO_2 = 40\%$; $N_2 = 30\%$; $P = 100$ KPa

$$x_i = \frac{y_i M_i}{M}$$

$$M = \sum y_i M_i$$

$$M = 0.30(32) + 0.40(44) + 0.30(28)$$

$$M = 9.6 + 17.6 + 8.4 = 35.6 \text{ kg/kg}_{\text{mol}}$$

$$x_{\text{O}_2} = \frac{9.6}{35.6} = 0.27 = 27\%$$

$$x_{\text{CO}_2} = \frac{17.6}{35.6} = 0.49 = 49\%$$

$$x_{\text{N}_2} = \frac{8.4}{35.6} = 0.24 = 24\%$$

$$R = \frac{8.3143}{M} = \frac{8.3143}{35.6}$$

$$R = 0.234 \frac{\text{KJ}}{\text{kg} \cdot ^\circ\text{K}}$$

From Dalton's Law

$$y_i = \frac{P_i}{P}$$

$$P_{\text{O}_2} = 0.30(100) = 30 \text{ KPa}$$

$$P_{\text{CO}_2} = 0.40(100) = 40 \text{ KPa}$$

$$P_{\text{N}_2} = 0.30(100) = 30 \text{ KPa}$$

d. A. How many kilograms of N_2 must be mixed with 3.6 kg of CO_2 in order to produce a gaseous mixture that is 50% by volume of each constituent.

B. For the resulting mixture, determine M and R, and the partial pressure of the N_2 if that of the CO_2 is 138 KPa.

Given

$$m_{\text{CO}_2} = 3.6 \text{ kg}; y_{\text{CO}_2} = 0.50$$

$$m_{\text{N}_2} = ?; y_{\text{N}_2} = 0.50$$

$$x_i = \frac{y_i M_i}{M}$$

$$M = 0.50(44) + 0.50(28)$$

$$M = 22 + 14 = 36 \text{ kg/kg}_{\text{mol}}$$

$$x_{\text{CO}_2} = \frac{22}{36} = 0.61$$

$$x_{\text{N}_2} = \frac{14}{36} = 0.39$$

$$x_{\text{CO}_2} = \frac{m_{\text{CO}_2}}{m} =$$

$$m = m_{\text{CO}_2} + m_{\text{N}_2}$$

$$0.61 = \frac{3.6}{m}$$

$$m = 5.9 \text{ kg}$$

$$m_{\text{N}_2} = 5.9 - 3.6 = 2.3 \text{ kg}$$

$$M = 36$$

$$R = \frac{8.3143}{36} = 0.231 \frac{\text{KJ}}{\text{kg} \cdot ^\circ\text{K}}$$

$$y_i = \frac{P_i}{P}$$

$$0.50 = \frac{138}{P}$$

$$P = 276 \text{ KPa}$$

$$P = P_{\text{CO}_2} + P_{\text{N}_2}$$

$$P_{\text{N}_2} = 276 - 138 = 138 \text{ KPa}$$

3. Assume 2 kg of O_2 are mixed with 3 kg of an unknown gas. The resulting mixture occupies a volume of 1.2 m^3 at 276 KPa and 65°C. Determine

a) R and M of the unknown gas constituent

b) the volumetric analysis

c) the partial pressures

$$\text{For } \text{O}_2: M = 32; k = 1.395$$

$$\text{Given; } m_{\text{O}_2} = 2 \text{ kg; } m_x = 3 \text{ kg}$$

$$V = 1.2 \text{ m}^3; P = 276 \text{ KPa; } T = 338 \text{ K}$$

a)

$$m = 5 \text{ kg}$$

$$x_{\text{O}_2} = 0.40; x_x = 0.60$$

$$R = 0.1361 \text{ KJ/kg-K}$$

$$R = .40(0.26) + 0.60(R_x)$$

$$R_x = 0.535 \text{ KJ/kg-K}$$

$$M_x = 15.54 \text{ kg/kgm}$$

b)

$$y_{O_2} = 0.245 ; y_x = 0.755$$

c)

$$P_{O_2} = .245(276) = 67.62 \text{ KPa} ; P_x = 0.755(276) = 208.38 \text{ KPa}$$

4. A gaseous mixture has the following volumetric analysis O_2 , 30%; CO_2 , 40% N_2 , 30%. Determine

a) the analysis on a mass basis

b) the partial pressure of each component if the total pressure is 100 KPa and the temperature is 32°C

c) the molecular weight and gas constant of the mixture

Gas	y_i	M	k	C_p	C_v	R	x_i	P_i	Mixture	
O_2	0.30	32	1.395	0.918	0.658	0.260	0.27	30	M	35.6
CO_2	0.40	44	1.288	0.845	0.656	189	0.494	40	R	.234
N_2	0.30	28	1.399	1.041	0.744	0.297	0.236	30	P	100

5. One mole of a gaseous mixture has the following gravimetric analysis:

$$O_2 = 16\% ; CO_2 = 44\% ; N_2 = 40\%$$

Find

a) the molecular weight of the mixture

b) the mass of each constituents

c) the moles of each constituents in the mixture

d) R

e) the partial pressures for $P = 207 \text{ KPa}$

Gas	$y_i(\%)$	M_i	$y_i M_i$	$x_i(\%)$	$m_i(\text{kg})$	$n_i(\text{moles})$	$P_i(\text{Kpa})$
O_2	16	32	5.12	14.3	5.12	0.16	33.12
CO_2	44	44	19.36	54.3	19.36	0.44	91.08
N_2	40	28	11.2	31.4	11.2	0.4	82.8

M	35.68
n	1
m	35.68
R	0.23302
P	207

6. A gaseous mixture composed of 25 kg of N_2 , 3.6 kg of H_2 , and 60 kg of CO_2 is at 200 KPa, 50°C . Find the respective partial pressure and compute the volume of each component at its own partial pressure and 50°C .

7. A 0.23 m^3 drum contains a gaseous mixture of CO_2 and CH_4 each 50% by mass at $P = 689 \text{ KPa}$, 38°C ; 1 kg of O_2 are added to the drum with the mixture temperature remaining at 38°C . For the final mixture, Find

a) the gravimetric analysis

b) the volumetric analysis

c) the C_p (For CO_2 ; $k = 1.288$; CH_4 ; $k = 1.321$; O_2 ; $k = 1.395$)

d) the total pressure P in KPa

8. A closed vessel of 0.7 m^3 internal volume contains a gas at 58 KPa and 18°C and with $R = 0.27$

KJ/kg- $^\circ\text{C}$. If now 0.35 kg of another gas at 18°C and $R = 0.29 \text{ KJ/kg-K}$ is also admitted into the vessel.

Calculate the final pressure of the mixture.

9. A mixture of gases has the following composition by volume: $O_2 = 6.3\%$; $SO_2 = 14.6\%$; $N_2 = 79.1\%$.

Calculate the composition by weight of this mixture. Assume gases will not react chemically. (6;27.9;66.1)

10. A mixture of gases has the following composition by weight: $O_2 = 10.7\%$; $CO = 0.9\%$; $N_2 = 88.4\%$. Calculate the composition by volume (volumetric analysis) of the mixture. (9.5; 0.9; 89.6)
11. Air having a total volume of 14 m³ at 100°C and 101 KPa contains
- 0.20 moles of O_2
 - 0.78 moles of N_2
 - 0.02 moles of H_2O
- a. What is the average molecular weight of the gas
 - b. What is the weight percent of the constituents?
 - c. What are the partial pressure of the constituents?
 - d. If the constituents were separated, what volume would they occupy at the same conditions of temperature and pressure
12. A boiler flue gas analysis shows after converting to percent composition by weight; $CO_2 = 0.1\%$; $O_2 = 6.2\%$; $CO = 0.1\%$ and $N_2 = 74.2\%$. Find the specific heat C_p and C_v of the mixture if the temperature is 260°C.

FUELS AND COMBUSTION

Fuel - a substance composed of chemical elements, which in rapid chemical union with oxygen produced combustion.

Combustion - is that rapid chemical union with oxygen of an element, whose exothermic heat of reaction is sufficiently great and whose rate of reaction is sufficiently fast, whereby useful quantities of heat are liberated at elevated temperatures. It is the burning or oxidation of the combustible elements.

TYPES OF FUEL

1) Solid Fuels

Example:

- a. coal
- b. charcoal
- c. coke
- d. woods

2) Liquid Fuels (obtained by the distillation of petroleum)

Example:

- a. Gasoline
- b. kerosene
- c. diesel
- d. Fuel oil
- e. alcohol (these are not true hydrocarbons, since it contains oxygen in the molecule)

3) Gaseous Fuels (a mixture of various constituents hydrocarbons, its combustion products do not Have sulfur components)

Example:

- a. Natural Gas (example: methane, ethane, propane)
- b. Coke oven gas -obtained as a byproduct of making coke
- c. Blast furnace gas - a byproduct of melting iron ore
- d. LPG
- e. Producer Gas - fuel used for gas engines

4) Nuclear Fuels

Example:

- a. Uranium
- b. Plutonium

COMBUSTIBLE ELEMENTS

1. Carbon (C)
2. Hydrogen (H_2)
3. Sulfur (S)

TYPES OF HYDROCARBONS

1) Paraffin - all ends in "ane"

Formula: C_nH_{2n+2}

Structure: Chain (saturated)

Example:

GAS

a. Methane(CH_4)

b. Ethane (C_2H_6)

LPG

a. Propane (C_3H_8)

b. Butane (C_4H_{10})

c. Pentane (C_5H_{12})

GASOLINE

a. n-Heptane (C_7H_{16})

b. Triptane (C_7H_{16})

c. Iso- octane (C_8H_{18})

FUEL OIL

a. Decane ($\text{C}_{10}\text{H}_{22}$)

b. Dodecane ($\text{C}_{12}\text{H}_{26}$)

c. Hexadecane ($\text{C}_{16}\text{H}_{34}$)

d. Octadecane ($\text{C}_{18}\text{H}_{38}$)

2) Olefins - ends in "ylene" or "ene"

Formula: C_nH_{2n}

Structure: Chain (unsaturated)

Example:

a. Propene (C_3H_6)

b. Butene (C_4H_8)

c. Hexene (C_6H_{12})

d. Octene (C_8H_{16})

3) DIOLEFIN - ends in "diene"

Formula: $\text{C}_n\text{H}_{2n-2}$

Structure: Chain (unsaturated)

Example:

a. Butadiene (C_4H_6)

b. Hexadiene (C_6H_{10})

4) NAPHTHENE - named by adding the prefix "cyclo"

Formula: C_nH_{2n}

Structure: Ring (saturated)

Example:

a. Cyclopentane (C_5H_{10})

b. Cyclohexane (C_6H_{12})

5) AROMATICS - this hydrocarbon includes the;

A. Benzene Series ($\text{C}_n\text{H}_{2n-6}$)

B. Naphthalene Series ($\text{C}_n\text{H}_{2n-12}$)

Structure: Ring (unsaturated)

Example:

a. Benzene (C_6H_6)

b. Toluene (C_7H_8)

c. Xylene (C_8H_{10})

6) ALCOHOLS - These are not true hydrocarbon, but sometimes used as fuel in an internal combustion engine. The characteristic feature is that one of the hydrogen atom is replaced by an OH radical.

Example:

a. Methanol (CH_4O or CH_3OH)

b. Ethanol ($\text{C}_2\text{H}_6\text{O}$ or $\text{C}_2\text{H}_5\text{OH}$)

Saturated Hydrocarbon - all the carbon atoms are joined by a single bond.

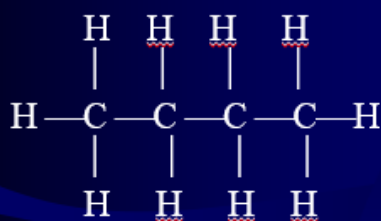
Unsaturated Hydrocarbon - it has two or more carbon atoms joined by a double or triple bond.

Isomers - two hydrocarbons with the same number of carbon and hydrogen atoms, but at different structure.

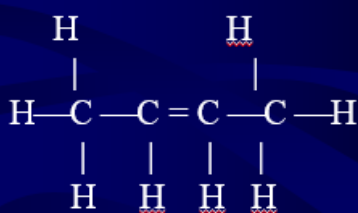
Family	Formula	Structure	Saturated
Paraffin	C_nH_{2n+2}	Chain	Yes
Olefin	C_nH_{2n}	Chain	No
Diolefin	C_nH_{2n-2}	Chain	No
Naphthene	C_nH_{2n}	Ring	Yes
Aromatic			
Benzene	C_nH_{2n-6}	Ring	No
Naphthalene	C_nH_{2n-12}	Ring	No
Alcohols		Note: Alcohols are not pure hydrocarbon, because one of its hydrogen atom is replace by an OH radical. Sometimes it is used as fuel in an ICE.	
Methanol	CH_3OH		
Ethanol	C_2H_5OH		

STRUCTURE OF HYDROCARBON

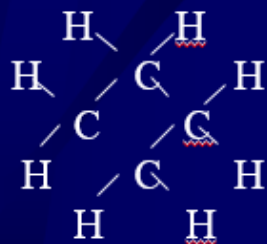
Chain structure Saturated



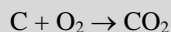
Chain Structure Unsaturated



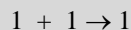
Ring structure Saturated



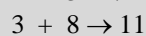
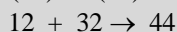
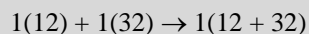
A. Oxidation of Carbon



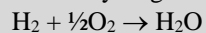
Mole Basis:



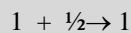
Mass Basis:



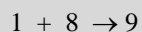
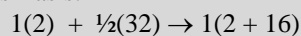
B. Oxidation of Hydrogen



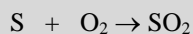
Mole Basis:



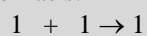
Mass Basis:



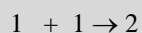
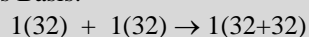
C. Oxidation of Sulfur



Mole Basis:



Mass Basis:



Complete Combustion: Occurs when all the combustible elements has been fully oxidized.

Example: $\text{C} + \text{O}_2 \rightarrow \text{CO}_2$

Incomplete Combustion: Occurs when some of the combustible elements have not been fully oxidized and it may result from;

a. Insufficient oxygen

b. Poor mixing of fuel and oxygen

c. the temperature is too low to support combustion.

Result: Soot or black smoke that sometimes pours out from chimney or smokestack.

Example: $\text{C} + \frac{1}{2}\text{O}_2 \rightarrow \text{CO}$

Composition of Air

a) Volumetric or Molal analysis

$\text{O}_2 = 21\%$

$\text{N}_2 = 79\%$

b) Gravimetric Analysis

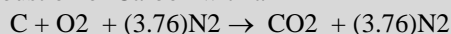
$\text{O}_2 = 23.3\%$

$\text{N}_2 = 76.7\%$

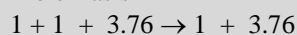
$$\frac{\text{Moles of } \text{N}_2}{\text{Mole of } \text{O}_2} = \frac{79}{21} = 3.76$$

COMBUSTION WITH AIR

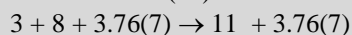
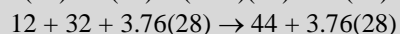
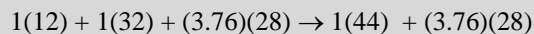
A) Combustion of Carbon with air



Mole Basis



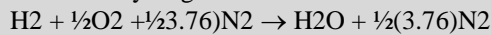
Mass Basis



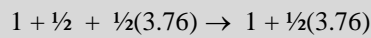
$$\frac{\text{kg of air}}{\text{kg of C}} = \frac{8 + 3.76(7)}{3}$$

$$\frac{\text{kg of air}}{\text{kg of C}} = 11.44$$

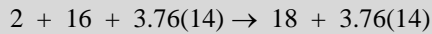
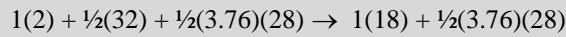
B) Combustion of Hydrogen with Air



Mole Basis:



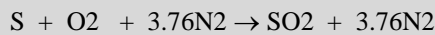
Mass Basis:



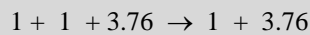
$$\frac{\text{kg of air}}{\text{kg of H}} = \frac{16 + 3.76(14)}{2}$$

$$\frac{\text{kg of air}}{\text{kg of H}} = 34.32$$

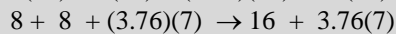
C) Combustion of Sulfur with air



Mole Basis:



Mass Basis:



$$\frac{\text{kg of air}}{\text{kg of S}} = \frac{8 + 3.76(7)}{8}$$

$$\frac{\text{kg of air}}{\text{kg of S}} = 4.29$$

THEORETICAL AIR

It is the minimum amount of air required to oxidized the reactants. With theoretical air no O₂ is found in the products.

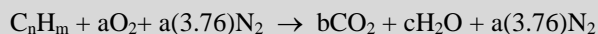
EXCESS AIR

It is an amount of air in excess of the theoretical air required to influence complete combustion. With excess air, O₂ is present in the products. Excess air is usually expressed as a percentage of the theoretical air. But in actual combustion, although there is an amount of excess air, the presence of CO and other hydrocarbon in the products cannot be avoided.

Example: 25% excess air is the same as 125% theoretical air.

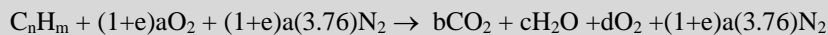
COMBUSTION OF HYDROCARBON FUEL(C_nH_m)

Combustion of C_nH_m with 100% theoretical air



$$\left(\frac{A}{F}\right)_t = \frac{a(32) + a(3.76)(28)}{12n + m} \frac{\text{kg of air}}{\text{kg of C}_n\text{H}_m}$$

Combustion with excess air



$$\left(\frac{A}{F}\right)_a = (1+e)\left(\frac{A}{F}\right)_t$$

$$\left(\frac{A}{F}\right)_a = (1+e) \frac{a(32) + a(3.76)(28)}{12n + m} \frac{\text{kg of air}}{\text{kg of C}_n\text{H}_m}$$

where:

e - excess air in decimal

(A/F)_t - theoretical air-fuel ratio

(A/F)_a - actual air-fuel ratio

SAMPLE PROBLEMS

Sample Problems No. 1 (Combustion of C_nH_m)

A hydrocarbon fuel represented by C₁₂H₂₆ is used as fuel in an IC engine and requires 25 % excess air for complete combustion.

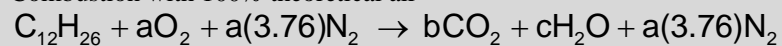
Determine

- The combustion equation
- The theoretical air – fuel ratio
- The actual air – fuel ratio
- The volumetric and gravimetric analysis of the products
- The molecular weight M and gas constant R of the products
- The kg of CO₂ formed per kg of fuel
- % C and %H in the fuel

Solution

Fuel: C₁₂H₂₆

Combustion with 100% theoretical air



Carbon balance

$$12 = b$$

Hydrogen balance

$$26 = 2c$$

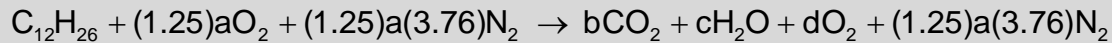
$$c = 13$$

Oxygen balance

$$2a = 2b + c$$

$$a = b + \frac{c}{2} = 18.5$$

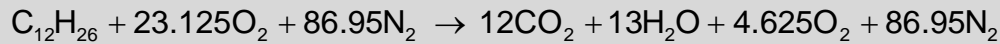
Combustion with excess air $e = 0.25$



By oxygen balance

$$1.25(2)a = 2b + c + 2d$$

$$d = \frac{1.25(2)a - 2b - c}{2} = 4.625$$



Gases	Mi	ni	yi	mi	xi	yiMi	yi(%)	xi(%)
CO ₂	44	12	0.103	528	0.158	4.529	10.3	15.8
H ₂ O	18	13	0.112	234	0.070	2.007	11.2	7.0
O ₂	32	4.625	0.040	148	0.044	1.270	4.0	4.4
N ₂	28	86.95	0.746	2434.6	0.728	20.884	74.6	72.8
total		116.575	1.00	3344.6	1.00	28.691	100.0	100.0

The combustion equation



The theoretical A/F ratio

$$\left(\frac{A}{F}\right)_t = \frac{a(32) + a(3.76)(28)}{12(12) + 26} = 14.94 \frac{\text{kg of air}}{\text{kg of } C_{12}H_{26}}$$

The actual A/F ratio

$$\left(\frac{A}{F}\right)_a = (1 + e)\left(\frac{A}{F}\right)_t = 14.94 (1.25) = 18.674 \frac{\text{kg of air}}{\text{kg of } C_{12}H_{26}}$$

The Volumetric and gravimetric Analysis

Gases	yi(%)	xi(%)
CO ₂	10.3	15.8
H ₂ O	11.2	7.0
O ₂	4.0	4.4
N ₂	74.6	72.8
Total	100.0	100.0

Molecular weight and Gas constant

$$M = \sum yiMi = 28.691 \frac{\text{kg}}{\text{kg}_m}$$

$$R = \frac{\bar{R}}{M} = \sum xiRi$$

$$R = \frac{8.3143}{28.691} = 0.2898 \frac{\text{KJ}}{\text{kg} \cdot \text{K}}$$

Kg of CO₂ per kg of fuel

$$\frac{\text{kg of } CO_2}{\text{kg of } C_{12}H_{26}} = \frac{528}{12(12) + 26} = 3.106$$

% C and % H in the fuel

$$\%C = \frac{12n}{12n + m} \times 100\%$$

$$\%C = \frac{12(12)}{12(12) + 26} \times 100 = 84.7\%$$

$$\%H = \frac{m}{12n + m} \times 100\%$$

$$\%H = \frac{26}{12(12) + 26} \times 100 = 15.3\%$$

Sample Problem No. 2 (Known Orsat analysis and Fuel type)

A fuel oil $C_{12}H_{26}$ is used in an internal combustion engine and the Orsat analysis are as follows: $CO_2 = 12.8\%$; $O_2 = 3.5\%$; $CO = 0.2\%$ and $N_2 = 83.5\%$. Determine the actual air-fuel ratio and the percent excess air.

Solution: (Basis 100 moles of dry flue gas)



By C balance

$$12a = 12.8 + 0.2$$

$$a = 1.0833$$

By N_2 Balance

$$b(3.76) = 83.5$$

$$b = 22.207$$

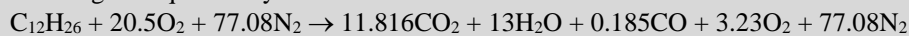
By H balance

$$26a = 2c$$

$$c = 26(1.0833)/2$$

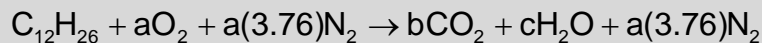
$$c = 14.083$$

Dividing the equation by a



$$\left(\frac{A}{F}\right)_a = \frac{20.5(32) + 77.08(28)}{12(12) + 26} = 16.56 \frac{\text{kg of air}}{\text{kg of fuel}}$$

Combustion of $C_{12}H_{26}$ with 100% theoretical air



$$12 = b$$

$$26 = 2c$$

$$c = 13$$

$$2a = 2b + c$$

$$a = 18.5$$

$$\left(\frac{A}{F}\right)_t = \frac{18.5(32) + (18.5)(3.76)(28)}{12(12) + 26} = 14.94 \frac{\text{kg of air}}{\text{kg of } C_{12}H_{26}}$$

$$\left(\frac{A}{F}\right)_a = (1 + e) \left(\frac{A}{F}\right)_t$$

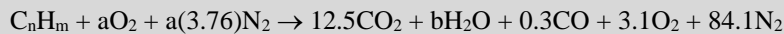
$$1 + e = \frac{\left(\frac{A}{F}\right)_a}{\left(\frac{A}{F}\right)_t}$$

$$e = \frac{\left(\frac{A}{F}\right)_a}{\left(\frac{A}{F}\right)_t} - 1 = 0.108 = 10.8\%$$

Sample Problem no. 3 (Unknown Fuel – Known Orsat analysis)

An unknown hydrocarbon is used as fuel in a diesel engine, and after an emission test the orsat analysis shows, $\text{CO}_2 = 12.5\%$; $\text{CO} = 0.3\%$; $\text{O}_2 = 3.1\%$; $\text{N}_2 = 84.1\%$. Determine

- the actual air-fuel ratio
- the percent excess air
- the fuel analysis by mass



By Carbon balance

$$n = 12.5 + 0.3$$

$$n = 12.8$$

By Hydrogen balance

$$m = 2b \rightarrow \text{eq. 1}$$

By Oxygen balance

$$2a = 2(12.5) + b + 0.3 + 2(3.1) \rightarrow \text{eq. 2}$$

By Nitrogen balance

$$a(3.76) = 84.1$$

$$a = 22.367$$

substituting a to eq. 2

$$b = 13.234$$

substituting b to eq. 1

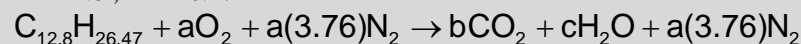
$$m = 26.47$$



$$\left(\frac{A}{F}\right)_a = \frac{22.367(32) + 84.1(28)}{12(12.8) + 26.47} = 17.05 \frac{\text{kg of air}}{\text{kg of fuel}}$$

Combustion with 100% theoretical air

$$n = 12.8 ; m = 26.47$$



$$12.8 = b$$

$$26.47 = 2c$$

$$c = 13.235$$

$$2a = 2b + c$$

$$a = 19.4175$$

$$\left(\frac{A}{F}\right)_t = \frac{19.4175(32) + 19.4175(3.76)(28)}{12(12.8) + 26.47} = 14.8 \frac{\text{kg of air}}{\text{kg of C}_{12}\text{H}_{26}}$$

$$\left(\frac{A}{F}\right)_a = (1+e)\left(\frac{A}{F}\right)_t$$

$$e = 0.152 = 15.2\%$$

$$\%C = \frac{12n}{12n+m} = \frac{12(12.8)}{12(12.8) + 26.47} = 85.3\%$$

$$\%H = \frac{m}{12n+m} = \frac{26.47}{12(12.8) + 26.47} = 14.7\%$$

Sample Problem No. 4

A diesel used dodecane ($C_{12}H_{26}$) for fuel. The fuel and the air enters the engine at 25°C and the products of combustion leave at 600 K . For 200% theoretical air required for combustion, determine

The combustion equation

The actual air – fuel ratio

The kg of H_2O formed per kg of fuel

The molecular weight and gas constant of the products

Fuel: $C_{12}H_{26}$ $n = 12$; $m = 26$

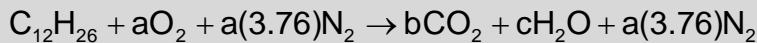
$T_{\text{air}} = 25 + 273 = 298\text{ K}$

$P = 101.325\text{ KPa} \rightarrow \text{assumed}$

$T_{\text{products}} = 600\text{ K}$

$(1 + e) = 200\% = 2$

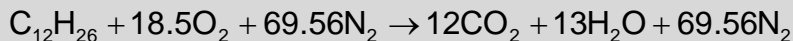
Combustion with 100% theoretical air



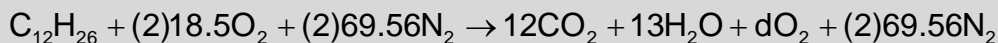
$$b = n$$

$$c = \frac{m}{2}$$

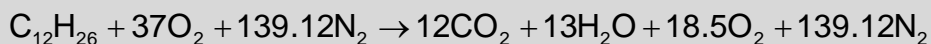
$$a = n + .25m$$



with 200% theoretical air



$$d = 18.5$$



$$\frac{A}{F} = \frac{37(32) + 139.12(28)}{12(12) + 26} = 29.88 \frac{\text{kg of air}}{\text{kg of } C_{12}H_{26}}$$

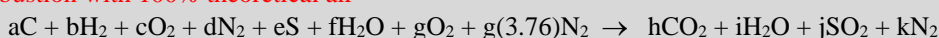
$$M = \frac{12(44) + 13(18) + 18.5(32) + 139.12(28)}{12 + 13 + 18.5 + 139.12} = 28.7$$

$$R = \frac{8.3143}{28.7} = 0.289 \frac{\text{KJ}}{\text{kg} \cdot \text{K}}$$

COMBUSTION OF SOLID FUELS

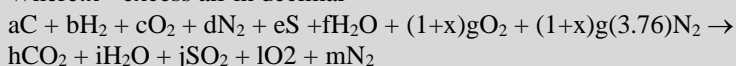
Components of Solid Fuels: C, H_2 , O_2 , N_2 , S, and Moisture

A) Combustion with 100% theoretical air



B) Combustion with excess air x

Where: x - excess air in decimal



The theoretical and actual air-fuel ratio of solid fuels can be computed based on their balance combustion equation above.

$$\left(\frac{A}{F}\right)_t = \frac{32g + 3.76(28)g}{12a + 2b + 32c + 28d + 32e + 18f}$$

$$\left(\frac{A}{F}\right)_a = (1 + x)\left(\frac{A}{F}\right)_t$$

DEW POINT TEMPERATURE

The Dew Point Temperature (tdp) is the saturation temperature corresponding the partial pressure of the water vapor in the mixture (products of combustion).

ULTIMATE ANALYSIS

Ultimate Analysis gives the amount of C, H₂, O₂, N₂, S and moisture in percentages by mass, sometimes the percentage amount of Ash is given.

$$\left(\frac{A}{F}\right)_t = 11.44C + 34.32\left(H - \frac{O}{8}\right) + 4.29S \frac{\text{kg of air}}{\text{kg of Fuel}}$$

where: C, H, O and S are in decimals obtained from the Ultimate Analysis

PROXIMATE ANALYSIS

Proximate Analysis gives the percentage amount of Fixed Carbon, Volatiles, Ash and Moisture.

$$100\% = \text{FC} + \text{Volatiles} + \text{M} + \text{A}$$

ORSAT ANALYSIS

Orsat Analysis gives the volumetric or molal analysis of the products of combustion or exhaust gases on a Dry Basis.

$$e = \frac{100 - \left[4.76 + 11.28 \frac{H}{C}\right] \text{CO}_2}{\left[4.76 + 14.28 \frac{H}{C}\right] \text{CO}_2}$$

$$\left(\frac{A}{F}\right)_a = \frac{11.44(1 + e) \left[1 + 3 \frac{H}{C}\right]}{\left[1 + \frac{H}{C}\right]} \frac{\text{kg of air}}{\text{kg of Fuel}}$$

where:

H and C are in % (by mass)

CO₂ is in % by volume from the exhaust gas analysis

MASS FLOW RATE OF FLUE GAS

a) Without considering Ash loss:

$$m_g = m_F \left(\frac{A}{F} + 1 \right)$$

b) Considering Ash loss

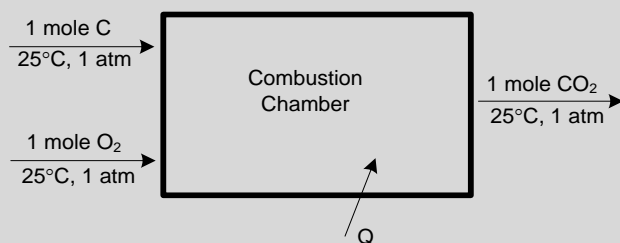
$$m_g = m_F \left(\frac{A}{F} + 1 - \text{Ash loss} \right)$$

where ash loss in decimal

PROPERTIES OF COMMON GASES						GAS
R	k	Cp	Cv	k	M	
0.260	1.395	0.918	0.658	1.395	32	O2
0.189	1.288	0.845	0.656	1.288	44	CO2
0.297	1.399	1.041	0.744	1.399	28	N2
0.320	1.232	1.698	1.378	1.232	26	C2H2
0.287	1.4	1.004	0.717	1.4	28.97	AIR
0.208	1.666	0.521	0.312	1.666	39.95	ARGON
0.297	1.399	1.041	0.744	1.399	28	CO
0.117	1.324	0.479	0.362	1.324	70.914	Cl2
0.277	1.187	1.759	1.482	1.187	30	C2H6
0.297	1.24	1.534	1.237	1.24	28	C2H4
2.079	1.666	5.200	3.121	1.666	4	He
4.157	1.4	14.550	10.393	1.4	2	H2
0.260	1.195	1.592	1.332	1.195	32	N2H4
0.520	1.321	2.138	1.619	1.321	16	CH4
0.412	1.666	1.030	0.619	1.666	20.183	Ne
0.189	1.127	1.677	1.488	1.127	44	C3H8
0.130	1.263	0.624	0.494	1.263	64	SO2
0.462	1.329	1.866	1.404	1.329	18	H2O
0.063	1.666	0.158	0.095	1.666	131.3	Xe

ENTHALPY OF FORMATION

The “Enthalpy of Formation of a compound is the enthalpy at the Arbitrary Reference State ($t = 25^{\circ}\text{C}$ and $P = 1 \text{ Atm}$).



Let;

HR – total enthalpy of Reactants

HP – total enthalpy of products

From 1st Law

$$Q + H_R = H_P$$

or

$$Q + \sum_R n_i \bar{h}_i = \sum_P n_i \bar{h}_i$$

but the enthalpy of all the reactants is Zero (for they are all elements)

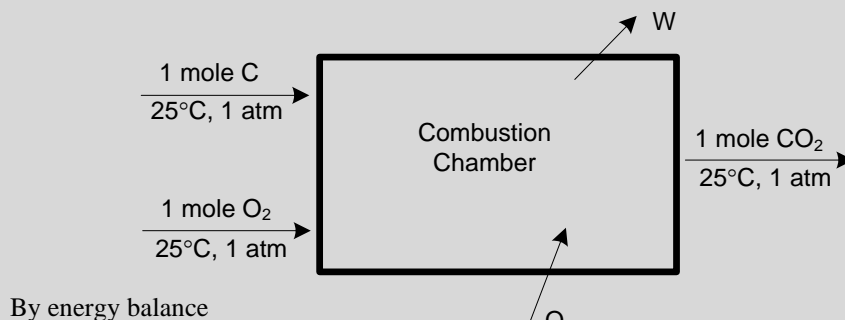
$$Q = H_P = -393,757 \text{ KJ}$$

therefore

$$(\bar{h}_f)_{\text{CO}_2} = -393,757 \frac{\text{KJ}}{\text{kg}_m} \rightarrow \text{Enthalpy of formation of CO}_2$$

Note : Negative sign is due to the reaction's being "Exothermic"

FIRST LAW ANALYSIS FOR STEADY STATE REACTING SYSTEM



$$Q + \sum_R n_i \bar{h}_i = W + \sum_P n_i \bar{h}_i$$

In most cases, neither the reactants nor the products are at the reference state ($t = 25^\circ\text{C}$ and $P = 1 \text{ Atm}$). In these case we must account for the property change between the reference state and the actual state. The change in enthalpy between the reference state and the actual state is

$$(\bar{h}^\circ - \bar{h}^\circ_{298})$$

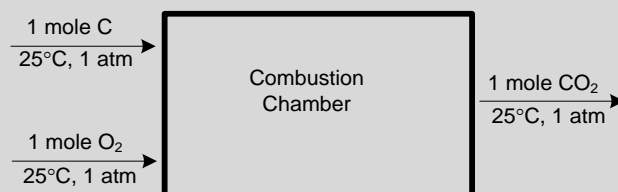
where

$^\circ$ – denotes that the pressure is 1 Atmosphere

General Equation for a Steady State, Steady flow reaction process

$$Q + \sum_R n_i [\bar{h}_{f,i} + (\bar{h}^\circ_i - \bar{h}^\circ_{298,i})] = W + \sum_P n_j [\bar{h}_{f,j} + (\bar{h}^\circ_j - \bar{h}^\circ_{298,j})]$$

ADIABATIC FLAME TEMPERATURE



If $Q = 0$; $W = 0$; $\Delta KE = 0$ and $\Delta PE = 0$, all the thermal energy would go into raising the temperature of the products of combustion. When the combustion is complete, the maximum amount of chemical energy has been converted into thermal energy and the temperature of the product is at its maximum. This maximum temperature is called the “Adiabatic Flame Temperature” (AFT)

$$H_R = H_P$$

ENTHALPY OF COMBUSTION OR HEATING VALUE

It is the difference between the enthalpies of the products and the reactants at the same temperature T and Pressure P.

$$\bar{h}_{RP} = H_P - H_R \quad \frac{\text{KJ}}{\text{kg}_{\text{mol}}}$$

$$\bar{h}_{RP} = \sum_P n_i [\bar{h}_{\text{of}} + (\bar{h}^\circ - \bar{h}^\circ_{298})] - \sum_R n_i [\bar{h}_{\text{of}} + (\bar{h}^\circ - \bar{h}^\circ_{298})] \quad \frac{\text{KJ}}{\text{kg}_{\text{mol}}}$$

$$\bar{h}_{RP} = \frac{(H_P - H_R)}{M} \quad \frac{\text{KJ}}{\text{kg}}$$

where

M - molecular weight

HEATING VALUE FORMULAS

Heating Value - is the energy released by fuel when it is completely burned and the products of combustion are cooled to the original fuel temperature.

Higher Heating Value (HHV) - is the heating value obtained when the water in the products is liquid.

Lower Heating Value (LHV) - is the heating value obtained when the water in the products is vapor.

For Solid Fuels

$$\text{HHV} = 33,820C + 144,212 \left(H_2 - \frac{O_2}{8} \right) + 9,304S \quad \frac{\text{KJ}}{\text{kg}}$$

where: C, H₂, O₂, and S are in decimals from the ultimate analysis

For Coal and Oils with the absence of Ultimate Analysis

$$\left(\frac{A}{F} \right)_t = \frac{\text{HHV}}{3,041} \quad \text{kg of air/kg of fuel}$$

$$\text{HHV} = 31,405C + 141,647H \quad \text{KJ/kg}$$

For Liquid Fuels

$$\text{HHV} = 43,385 + 93(\text{Be} - 10) \quad \text{KJ/kg}$$

Be - degrees Baume

For Gasoline

$$\text{HHV} = 41,160 + 93 (^\circ\text{API}) \quad \text{KJ/kg}$$

$$\text{LHV} = 38,639 + 93 (^\circ\text{API}) \quad \text{KJ/kg}$$

For Kerosene

$$\text{HHV} = 41,943 + 93 (^\circ\text{API}) \quad \text{KJ/kg}$$

$$\text{LHV} = 39,035 + 93 (^\circ\text{API}) \quad \text{KJ/kg}$$

For Fuel Oils

$$\text{HHV} = 41,130 + 139.6(^{\circ}\text{API}) \text{ KJ/kg}$$

$$\text{LHV} = 38,105 + 139.6(^{\circ}\text{API}) \text{ KJ/kg}$$

API - American Petroleum Institute

For Fuel Oils (From Bureau of Standard Formula)

$$\text{HHV} = 51,716 - 8793.8 (S)^2 \text{ KJ/kg}$$

$$\text{LHV} = \text{HHV} - \text{QL} \text{ KJ/kg}$$

$$\text{QL} = 2,442.7(9\text{H}_2) \text{ KJ/kg}$$

$$\text{H}_2 = 0.26 - 0.15(S) \text{ kg of H}_2/\text{kg of fuel}$$

$$S = \frac{141.5}{131.5 + ^{\circ}\text{API}}$$

$$S = \frac{140}{130 + ^{\circ}\text{Be}}$$

Where:

$$S @ t = S - 0.0007(t - 15.56)$$

S - specific gravity of fuel oil at 15.56 °C

H₂ - hydrogen content of fuel oil, Kg H/Kg fuel

QL - heat required to evaporate and superheat the water vapor formed by the combustion of hydrogen in the fuel, KJ/kg

S @ t - specific gravity of fuel oil at any temperature t

Oxygen Bomb Calorimeter - instrument used in measuring heating value of solid and liquid fuels.

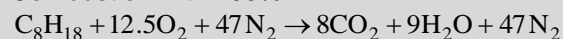
Gas Calorimeter - instrument used for measuring heating value of gaseous fuels.

SAMPLE PROBLEM NO. 1

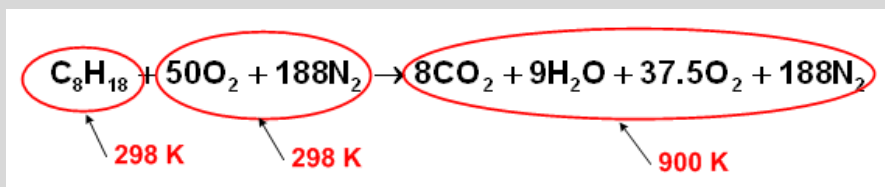
A small gas turbine uses C₈H₁₈ (liquid) for fuel and 400% theoretical air. The air and fuel enters at 25°C and the products of combustion leave at 900 K. The output of the engine and the fuel consumption are measured and it is found that the specific fuel consumption is 0.25 kg/sec of fuel per Megawatt output. Determine the heat transfer from the engine per kgmol of fuel. Assume complete combustion.

$$Q + \sum n_i [\bar{h}^{\circ}_f + (\bar{h}^{\circ} - \bar{h}^{\circ}_{298})]_i = W + \sum n_j [\bar{h}^{\circ}_f + (\bar{h}^{\circ} - \bar{h}^{\circ}_{298})]_j$$

Combustion with 100% TA



Combustion with 400% theoretical air or e = 300%



FUEL (CnHm) + AIR		MASS (kg)	h°f	(h°-h ₂₉₈)	h°f + (h°-h ₂₉₈)	n*(h°f + (h°-h ₂₉₈))	HR
n	8	6,978.00	-250,102.00	0.00	-250,102.00	-250,102.00	-250,102.00
m	18						
e	25						
(1+e)	4.00						
O2	50.00						
N2	188.00		0.00	0.00	0.00	0.00	
PRODUCTS		MASS (kg)	h°f	(h°-h ₂₉₈)	h°f + (h°-h ₂₉₈)	n*(h°f + (h°-h ₂₉₈))	HP
CO2	8	6,978.00	-393,757.00	28,041.00	-365,716.00	-2,925,728.00	-758,878.00
H2O	9		-241,971.00	21,924.00	-220,047.00	-1,980,423.00	
CO	0.00		0.00	0.00	0.00	0.00	
O2	37.50		0.00	19,246.00	19,246.00	721,725.00	
N2	188.00		0.00	18,221.00	18,221.00	3,425,548.00	
						-758,878.00	

$$Q + \sum_R n_i [\bar{h}^o_f + (\bar{h}^o - \bar{h}^o_{298})]_i = W + \sum_P n_j [\bar{h}^o_f + (\bar{h}^o - \bar{h}^o_{298})]_j$$

$$W = \frac{1000}{0.25} \left(114 \frac{\text{kg}}{\text{kgm}} \right) = 456,000 \frac{\text{KJ}}{\text{kgm}}$$

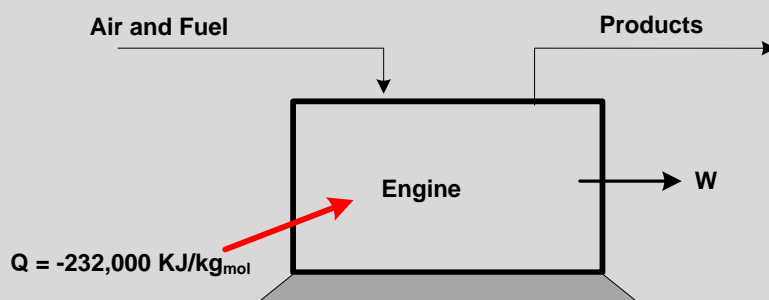
$$Q + \text{HR} = 456,000 + \text{HP}$$

$$Q = -52,776 \frac{\text{KJ}}{\text{kg}_{\text{mFuel}}}$$

$$Q = -463 \frac{\text{KJ}}{\text{kg}_{\text{Fuel}}}$$

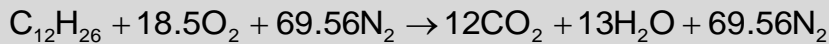
SAMPLE PROBLEM NO. 2

A diesel engine used gaseous Dodecane (C₁₂H₂₆) as fuel. The air and fuel enters the engine at 25°C and 100% excess air is required for combustion. The products of combustion leaves at 600 K and the heat loss from the engine is 232,000 KJ/kgm fuel. Determine the work for a fuel rate of 1 kgmfuel/hr.

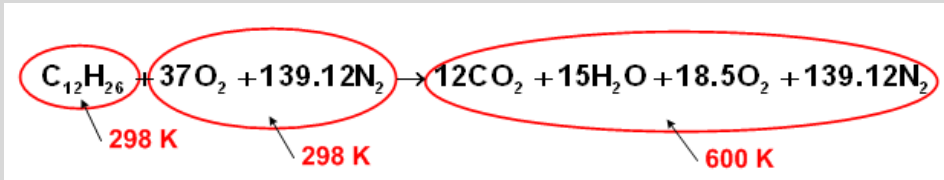


$$Q + \sum_R n_i [\bar{h}^{\circ}_f + (\bar{h}^{\circ} - \bar{h}^{\circ}_{298})]_i = W + \sum_P n_j [\bar{h}^{\circ}_f + (\bar{h}^{\circ} - \bar{h}^{\circ}_{298})]_j$$

Combustion with 100% theoretical air



Combustion with 400% theoretical air or $e = 300\%$



FUEL (CnHm) + AIR		MASS (kg)	h°_f	$(h^{\circ} - h_{298})$	$h^{\circ}_f + (h^{\circ} - h_{298})$	$n^{\circ}(h^{\circ}_f + (h^{\circ} - h_{298}))$	HR
n	12	5,249.36	-290,971.00	0.00	-290,971.00	-290,971.00	-290,971.00
m	26						
e	100						
(1+e)	2.00						
O2	37.00		0.00	0.00	0.00	0.00	
N2	139.12		0.00	0.00	0.00	0.00	
PRODUCTS		MASS (kg)	h°_f	$(h^{\circ} - h_{298})$	$h^{\circ}_f + (h^{\circ} - h_{298})$	$n^{\circ}(h^{\circ}_f + (h^{\circ} - h_{298}))$	HP
CO2	12	5,249.36	-393,757.00	12,916.00	-380,841.00	-4,570,092.00	-6,171,255.58
H2O	13		-241,971.00	10,498.00	-231,473.00	-3,009,149.00	
CO	0.00		-110,596.00	0.00	-110,596.00	0.00	
O2	18.50		0.00	9,247.00	9,247.00	171,069.50	
N2	139.12		0.00	8,891.00	8,891.00	1,236,915.92	
						-6,171,255.58	
						(HP - HR)	-5,880,284.58

$$Q + HR = W + HP$$

$$W = Q - (HP - HR)$$

$$W = -232,000 - (-5,880,284.58) =$$

$$W = 5,648,284.58 \frac{\text{KJ}}{\text{kg mol Fuel}}$$

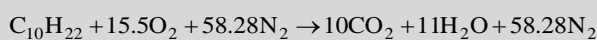
$$W = 5,648,284.58 \left(\frac{1}{3600} \right) = 1568.97 \text{ KW}$$

SAMPLE PROBLEM No. 3

A fuel oil represented by $\text{C}_{10}\text{H}_{22}$ is burned with 25% excess air in a laboratory to determine its heating value. Air and fuel enters at 25°C and the products of combustion leaves the apparatus at 500 K. Determine the higher heating value of the fuel considering; (assume $h^{\circ}_f(\text{C}_{10}\text{H}_{22}) = -289,402 \text{ KJ/kgmol Fuel}$)

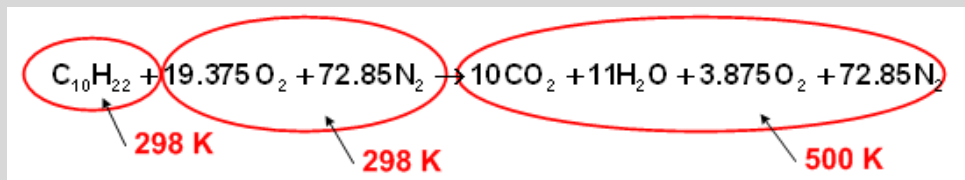
- Complete combustion with no CO in the products
- Incomplete combustion with 5% of the carbon atoms oxidizes to CO

Combustion with 100% TA



Combustion with EA ($e = 0.25$)

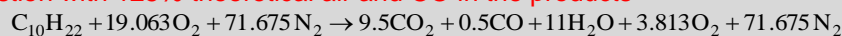




FUEL (CnHm) + AIR		MASS (kg)	h ^o f	(h ^o -h ₂₉₈)	h ^o f + (h ^o -h ₂₉₈)	n*(h ^o f + (h ^o -h ₂₉₈))	HR	MW of Fuel
n	10	2,801.80	-289,402.00	0.00	-289,402.00	-289,402.00	-289,402.00	142.00
m	22							
e	25							
(1+e)	1.25							
O2	19.38							
N2	72.85		0.00	0.00	0.00	0.00		
PRODUCTS		MASS (kg)	h ^o f	(h ^o -h ₂₉₈)	h ^o f + (h ^o -h ₂₉₈)	n*(h ^o f + (h ^o -h ₂₉₈))	HP	Mass Products
CO2	10	2,801.80	-393,757.00	8,314.00	-385,443.00	-3,854,430.00	-6,470,139.80	2,801.80
H2O	11		-286,010.00	6,920.00	-279,090.00	-3,069,990.00		
CO	0.00		-110,596.00	0.00	-110,596.00	0.00		
O2	3.88		0.00	6,088.00	6,088.00	23,591.00		
N2	72.85		0.00	5,912.00	5,912.00	430,689.20		
						-6,470,139.80		
						(HP - HR)	-6,180,737.80	KJ/kgmol
						(HP - HR)	-43,526.32	KJ/kgfuel

Incomplete Combustion

Combustion with 125% theoretical air and CO in the products

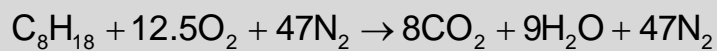


FUEL (CnHm) + AIR		MASS (kg)	h°f	(h°-h298)	h°f + (h°-h298)	n*(h°f + (h°-h298))	HR	MW of Fuel
n	10	2,758.90	-289,402.00	0.00	-289,402.00	-289,402.00	-289,402.00	142.00
m	22							
e	25							
(1+e)	1.25							
O2	19.063							
N2	71.675		0.00	0.00	0.00	0.00		
PRODUCTS		MASS (kg)	h°f	(h°-h298)	h°f + (h°-h298)	n*(h°f + (h°-h298))	HP	Mass Products
CO2	9.5	2,758.90	-393,757.00	8,314.00	-385,443.00	-3,661,708.50	-6,337,078.90	2,758.90
H2O	11		-286,010.00	6,920.00	-279,090.00	-3,069,990.00		
CO	0.50		-110,596.00	5,929.00	-104,667.00	-52,333.50		
O2	3.813		0.00	6,088.00	6,088.00	23,210.50		
N2	71.675		0.00	5,912.00	5,912.00	423,742.60		
						-6,337,078.90		
						(HP - HR)	-6,047,676.90	KJ/kgmol
						(HP - HR)	-42,589.27	KJ/kgfuel

SAMPLE PROBLEM NO. 3

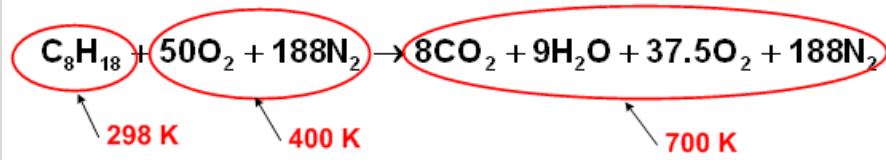
An internal combustion engine producing 600 KW of power uses Gasoline fuel (C_8H_{18}) at $25^\circ C$ and 400% theoretical air is used. Air and fuel enters the engine at 400 K and the products of combustion leaves the engine at 700 K. The heat loss from the engine is 146.5 KW. Determine the fuel consumption of the engine in kg/hr.

Combustion with 100% theoretical air



Combustion with 400% theoretical air or $e = 300\%$





CnHm	Kg (mole)	M (kg/kgm)	Mass (kg)	$(\bar{h}_f)_{298}$	$(\bar{h}_f - \bar{h}_{f,298})$	H	
n	8	114	114	-250,102.0	0	-250,102.0	REACTANTS
m	18						
O ₂	50	32	1600	0.0	3029.0	151,450.0	
N ₂	188	28	5264	0.0	2971.0	558,548.0	
n_{to CO}	0		6978			459,896.0	PRODUCTS
CO ₂	8	44	352	-393,757.0	17,761.0	-3,007,968.0	
CO	0	28	0	0.0	0.0	0.0	
H ₂ O	9	18	162	-241,971.0	14,184.0	-2,050,083.0	
O ₂	37.5	32	1200	0.00	12,502.0	468,825.0	
N ₂	188	28	5264	0.00	11,937.0	2,244,156.0	
e	3		6978			-2,345,070.0	
(1 + e)	4						

$$\sum_R n_i [\bar{h}_{of} + (\bar{h}^\circ - \bar{h}^\circ_{298})]_i = (-250,000) + 50(3,029) + 188(2,971)$$

$$H_R = 459,896.0 \frac{\text{KJ}}{\text{kg}_{\text{mfuel}}}$$

$$\sum_P n_j [\bar{h}_{of} + (\bar{h}^\circ - \bar{h}^\circ_{298})]_j = 8(-393,757 + 17,761) + 9(-241,971 + 14,184) + 37.5(12,502) + 188(11,937)$$

$$H_P = -2,345,070.0 \frac{\text{KJ}}{\text{kg}_{\text{mfuel}}}$$

By Energy Balance

$$Q + n_f (H_R) = 600 + n_f (H_P)$$

$$-146.5 + n_f (459,896) = 600 + n_f (-2,345,070)$$

$$n_f = \frac{600 + 146.5}{(459,896 + 2,345,070)} = 0.00027 \frac{\text{kg}_{\text{mfuel}}}{\text{sec}}$$

$$m_{\text{Fuel}} = 0.00027 [12(8) + 1(18)](3600) = 109.2 \frac{\text{kg}}{\text{hr}} \text{ of Fuel}$$

SAMPLE PROBLEM No. 4

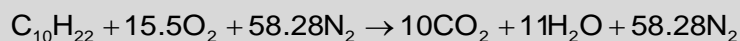
A fuel oil represented by C₁₀H₂₂ is burned with 25% excess air in a laboratory to determine its heating value. Air and fuel enters at 25°C and the products of combustion leaves the apparatus at 500 K. Determine the higher heating value of the fuel considering; (assume $\bar{h}^\circ_{f,298} = -289,402 \text{ KJ/kgmol Fuel}$)

Complete combustion with no CO in the products

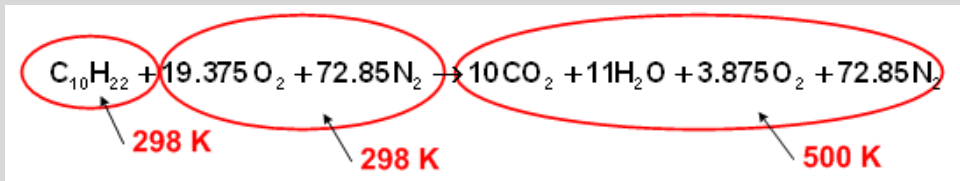
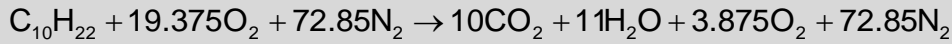
Incomplete combustion with 5% of the carbon atoms oxidizes to CO

Complete Combustion

Combustion with 100% theoretical air



Combustion with 125% theoretical air or $e = 25\%$

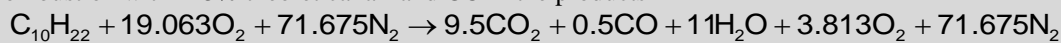


Given Fuel Composition (C_nH_m)							
C_nH_m	Kg (mole)	M (kg/kgm)	Mass (kg)	$(\bar{h}_f)_{298}$	$\bar{h}_f - \bar{h}_{f,298}$	H	
n	10	142	142	-289,404.0	0	-289,404.0	REACTANTS
m	22						
O ₂	19.375	32	620	0.0	0.0	0.0	
N ₂	72.85	28	2039.8	0.0	0.0	0.0	
n to CO	0		2801.8			-289,404.0	
CO ₂	10	44	440	-393,757.0	8,314.0	-3,854,430.0	PRODUCTS
CO	0	28	0	-110,596.0	0.0	0.0	
H ₂ O	11	18	198	-286,010.0	6,920.0	-3,069,990.0	
O ₂	3.875	32	124	0.00	6,088.0	23,591.0	
N ₂	72.85	28	2039.8	0.00	5,912.0	430,689.2	
e	0.25		2801.8			-6,470,139.8	
(1 + e)	1.25			(HP - HR)		-6,180,735.8	

$$\text{HHV} = \frac{6,180,735.8}{114} = 54,217 \frac{\text{KJ}}{\text{kg}_{\text{Fuel}}}$$

Incomplete Combustion

Combustion with 125% theoretical air and CO in the products



C_nH_m	Kg (mole)	M (kg/kgm)	Mass (kg)	$(\bar{h}_f)_{298}$	$\bar{h}_f - \bar{h}_{f,298}$	H	
n	10	142	142	-289,404.0	0	-289,404.0	REACTANTS
m	22						
O ₂	19.063	32	610	0.0	0.0	0.0	
N ₂	71.675	28	2006.9	0.0	0.0	0.0	
n to CO	0.5		2758.9			-289,404.0	
CO ₂	9.5	44	418	-393,757.0	8,314.0	-3,661,708.5	PRODUCTS
CO	0.5	28	14	-110,596.0	5,929.0	5,929.0	
H ₂ O	11	18	198	-286,010.0	6,920.0	-3,069,990.0	
O ₂	3.813	32	122	0.00	6,088.0	23,210.5	
N ₂	71.675	28	2006.9	0.00	5,912.0	423,742.6	
e	0.25		2758.9			-6,278,816.4	
(1 + e)	1.25			(HP - HR)		-5,989,412.4	

$$\text{HHV} = \frac{5,989,412.4}{114} = 42,179 \frac{\text{KJ}}{\text{kg}_{\text{Fuel}}}$$

SECOND LAW OF THERMODYNAMICS

Whenever energy is transferred, the level of energy cannot be conserved and some energy must be permanently reduced to a lower level.

When this is combined with the first law of thermodynamics, the law of energy conservation, the statement becomes:

Whenever energy is transferred, energy must be conserved, but the level of energy cannot be conserved and some energy must be permanently reduced to a lower level.

Kelvin-Planck statement of the second law:

No cyclic process is possible whose sole result is the flow of heat from a single heat reservoir and the performance of an equivalent amount of work.

For a system undergoing a cycle: The net heat is equal to the network.

$$\oint dW = \oint dQ \quad \text{or} \quad W = \Sigma Q$$

W - net work

ΣQ - net heat

CARNOT CYCLE

Nicolas Léonard Sadi Carnot (1796-1832), French physicist and military engineer, son of Lazare Nicolas Marguerite Carnot, born in Paris, and educated at the École Polytechnique. In 1824 he described his conception of the perfect engine, the so-called Carnot engine, in which all available energy is utilized. He discovered that heat cannot pass from a colder to a warmer body, and that the efficiency of an engine depends upon the amount of heat it is able to utilize. These discoveries led to the development of the Carnot Cycle, which later became the basis for the second law of thermodynamics.

A. Carnot Engine Cycle

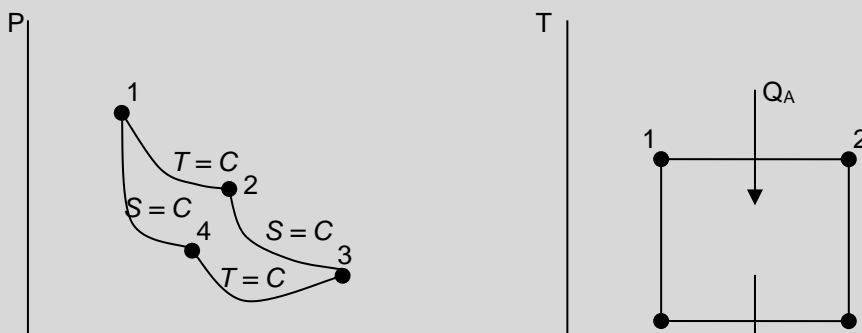
Processes:

1 to 2 - Heat Addition ($T = C$)

2 to 3 - Expansion ($S = C$)

3 to 4 - Heat Rejection ($T = C$)

4 to 1 - Compression ($S = C$)



Heat Added ($T = C$)

$$Q_A = T_H (\Delta S) \rightarrow 1$$

Heat Rejected ($T = C$)

$$Q_R = T_L (\Delta S) \rightarrow 2$$

$$\Delta S = S_2 - S_1 = S_4 - S_3 \rightarrow 3$$

Net Work

$$W = \Sigma Q = Q_A - Q_R \rightarrow 4$$

$$W = (T_H - T_L) (\Delta S) \rightarrow 5$$

Thermal Efficiency

$$e = \frac{W}{Q_A} \times 100\% \rightarrow 6$$

$$e = \frac{Q_A - Q_R}{Q_A} \times 100\% \rightarrow 7$$

$$e = \left[1 - \frac{Q_R}{Q_A} \right] \times 100\% \rightarrow 8$$

Eq. 5 to and Eq. 1 to Eq. 6

$$e = \frac{T_H - T_L}{T_H} \times 100\% \rightarrow 9$$

B. Carnot Refrigeration Cycle (Reversed Carnot Cycle)

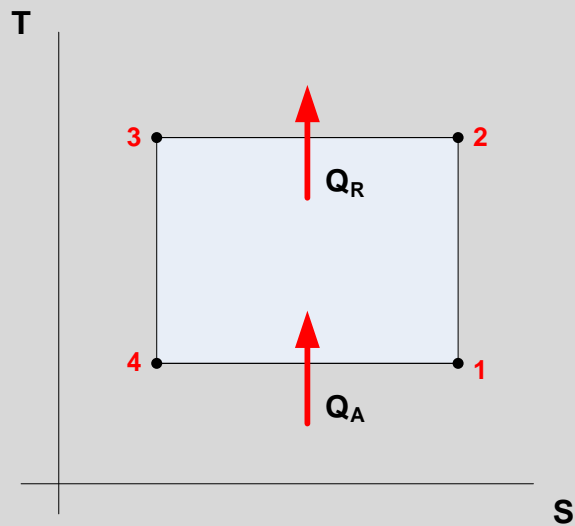
Processes:

1 to 2 - Compression ($S = C$)

2 to 3 - Heat Rejection ($T = C$)

3 to 4 - Expansion ($S = C$)

4 to 1 - Heat Addition ($T = C$)



Heat Added ($T=C$)

$$Q_A = T_L(\Delta S) \rightarrow 1$$

Heat Rejected ($T=C$)

$$Q_R = T_H(\Delta S) \rightarrow 2$$

$$\Delta S = S_1 - S_4 = S_2 - S_3 \rightarrow 3$$

Net Work

$$W = \Sigma Q \rightarrow 4$$

$$W = Q_R - Q_A \rightarrow 5$$

$$W = (T_H - T_L)(\Delta S) \rightarrow 6$$

COEFFICIENT OF PERFORMANCE

$$\text{COP} = \frac{Q_A}{W} \rightarrow 6$$

$$\text{COP} = \frac{Q_A}{Q_R - Q_A} \rightarrow 7$$

$$\text{COP} = \frac{T_L}{T_H - T_L} \rightarrow 8$$

C. Carnot Heat Pump:

A heat pump uses the same components as the refrigerator but its purpose is to reject heat at high energy level.

Performance Factor

$$\text{PF} = \frac{Q_R}{W} \rightarrow 11$$

$$\text{PF} = \frac{Q_R}{Q_R - Q_A} \rightarrow 12$$

$$PF = \frac{T_H}{T_H - T_L} \rightarrow 13$$

$$PF = COP + 1 \rightarrow 14$$

TON OF REFRIGERATION

It is the heat equivalent to the melting of 1 ton (2000 lb) of water ice at 0°C into liquid at 0°C in 24 hours.

$$TR = \frac{2000(144)}{24} = 12,000 \frac{\text{BTU}}{\text{hr}}$$

$$TR = 211 \frac{\text{KJ}}{\text{min}}$$

where 144 BTU/lb is the latent heat of fusion

1. A Carnot engine operating between 775 K and 305 K produces 54 KJ of work. Determine the change of entropy during heat addition. ($\Delta S_{12} = 0.115 \text{ KJ/K}$)

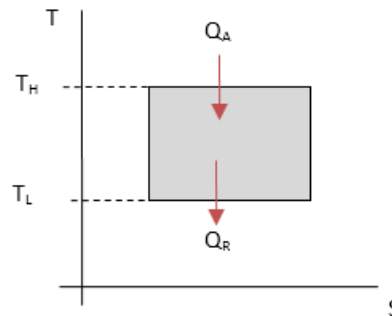
$$e = \frac{T_H - T_L}{T_H} = \frac{775 - 305}{775} = 0.606$$

$$e = \frac{W}{Q_A}$$

$$Q_A = \frac{54}{0.606} = 89 \text{ KJ}$$

$$Q_A = T_H \Delta S$$

$$\Delta S = \frac{89}{775} = 0.115 \frac{\text{KJ}}{^\circ\text{K}}$$



2. A Carnot engine operates between temperatures of 1000 K and 300 K. The engine operates at 2000 RPM and develops 200 KW. The total engine displacement is such that the mean effective pressure is 300 KPa. Determine:

- the thermal efficiency (71%)
- the heat added (286 KW)
- the total engine displacement in m³/cycle (0.02 m³/cycle)

$$e = \frac{1000 - 300}{1000} = 0.70$$

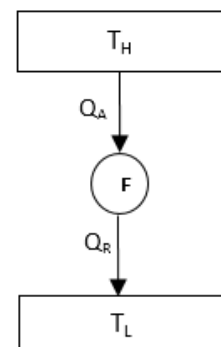
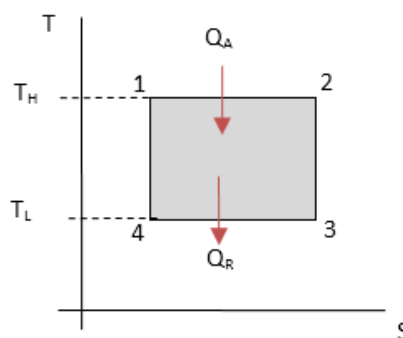
$$W = eQ_A$$

$$Q_A = \frac{200}{0.70} = 286 \text{ KW}$$

$$W = Pm(V_D)$$

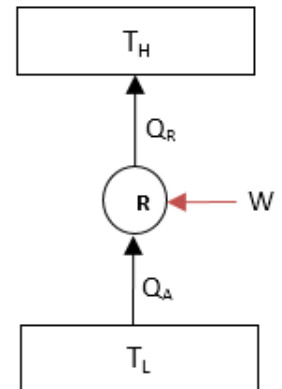
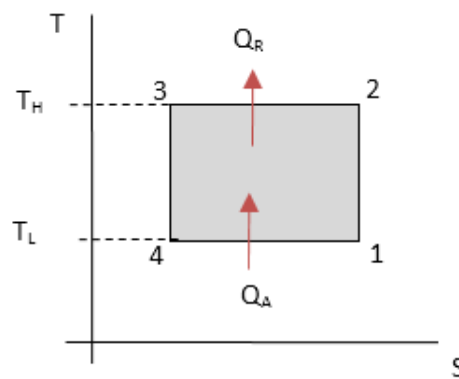
$$V_D = \frac{200}{300} = 0.67 \frac{\text{m}^3}{\text{sec}} \times \frac{\text{min}}{2000 \text{ rev}} \times \frac{60 \text{ sec}}{\text{min}} \times \frac{\text{rev}}{\text{cycle}}$$

$$V_D = 0.02 \text{ m}^3/\text{cycle}$$



3. A Carnot refrigerator rejects 2500 KJ of heat at 353 K while using 1100 KJ of work. Find
- the cycle low temperature
 - the COP
 - the heat absorbed or refrigerating capacity

$$\begin{aligned}
 W &= Q_R - Q_A \\
 1100 &= 2500 - Q_A \\
 Q_A &= 1400 \text{ KJ} \\
 COP &= \frac{Q_A}{W} = \frac{T_L}{T_H - T_L} \\
 \frac{1400}{1100} &= \frac{T_L}{353 - T_L} \\
 1100T_L &= 494,200 - 1400T_L \\
 T_L &= 197.7^\circ\text{K} \\
 COP &= 1.2727
 \end{aligned}$$



SAMPLE PROBLEMS

- A Carnot engine operating between 775°K and 305°K produces 54 KJ of work. Determine the change of entropy during heat addition. ($\Delta S_{12} = -0.12 \text{ KJ/K}$)
- A Carnot engine operates between temperature reservoirs of 817°C and 25°C and rejects 25 KW to the low temperature reservoir. The Carnot engine drives the compressor of an ideal vapor compression refrigerator, which operates within pressure limits of 190 KPa and 1200 Kpa. The refrigerant is ammonia. Determine the COP and the refrigerant flow rate. (4; 14.64 kg/min)
- A Carnot engine operates between temperatures of 1000 K and 300°K . The engine operates at 200 RPM and develops 200 KW. The total engine displacement is such that the mean effective pressure is 300 Kpa. Determine:
 - the thermal efficiency (71%)
 - the heat added (286 KW)
 - the total engine displacement in m^3/cycle (0.02 m^3/cycle)
- A Carnot engine operating between 775°K and 305°K produces 54 KJ of work. Determine the change of entropy during heat addition. ($\Delta S_{12} = -0.12 \text{ KJ/K}$)
- A Carnot engine produces 25 KW while operating between temperature limits of 1000 K and 300 K. Determine (a) the heat supplied in KW (b) the heat rejected in KW
- A Carnot heat engine rejects 230 KJ of heat at 25°C . The net cycle work is 375 KJ. Determine the cycle thermal efficiency and the cycle high temperature.
- A Carnot refrigerator operates between temperature limits of -5°C and 30°C . The power consumed is 4 KW and the heat absorbed is 30 KJ/kg. Determine; (a) the COP (b) the refrigerant flow rate

8. A non polluting power plant can be constructed using the temperature difference in the ocean. At the surface of the ocean in tropical climates, the average water temperature year round is 30°C. At a depth of 305 m, the temperature is 4.5°C. Determine the maximum thermal efficiency of such a power plant. (8.4%)
9. A heat is used to heat a house in the winter months. When the average outside temperature is 0°C and the indoor temperature is 23°C, the heat loss from the house is 20 KW. Determine the minimum power required to heat the heat pump.
10. A Carnot heat pump is being considered for home heating in a location where the outside temperature may as low as -35°C. The expected COP for the heat pump is 1.50. To what temperature could this unit provide?

INTERNAL COMBUSTION ENGINE CYCLE

Air Standard Cycle

- Otto Cycle
- Diesel Cycle
- Dual Cycle

AIR STANDARD OTTO CYCLE

Otto, Nikolaus August

Born: June 10, 1832, Holzhausen, Nassau

Died: Jan. 26, 1891, Cologne



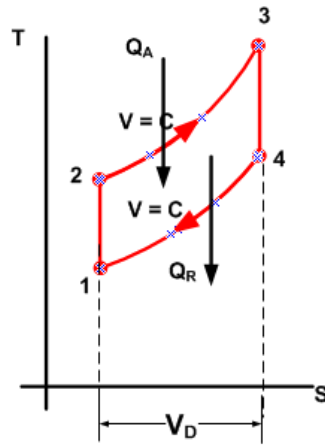
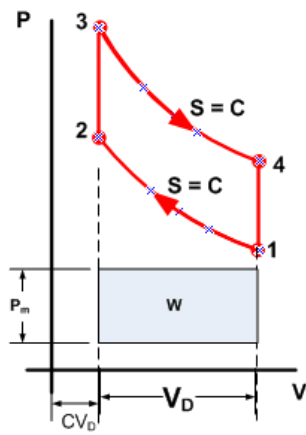
German engineer who developed the four-stroke internal-combustion engine, which offered the first practical alternative to the steam engine as a power source.

Otto built his first gasoline-powered engine in 1861. Three years later he formed a partnership with the German industrialist [Eugen Langen](#), and together they developed an improved engine that won a gold medal at the Paris Exposition of 1867.

In 1876 Otto built an internal-combustion engine utilizing the four-stroke cycle (four strokes of the piston for each ignition). The four-stroke cycle was patented in 1862 by the French engineer [Alphonse Beau de Rochas](#), but since Otto was the first to build an engine based upon this principle, it is commonly known as the Otto cycle. Because of its reliability, its efficiency, and its relative quietness, Otto's engine was an immediate success. More than 30,000 of them were built during the next 10 years, but in 1886 Otto's patent was revoked when Beau de Rochas' earlier patent was brought to light.

Processes

- 1 to 2 – Isentropic Compression ($S = C$)
- 2 to 3 – Constant Volume Heat Addition ($V = C$)
- 3 to 4 – Isentropic Expansion ($S = C$)
- 4 to 1 – Constant volume Heat Rejection ($V = C$)



Compression Ratio (r)

$$r = \frac{V_1}{V_2} = \frac{V_4}{V_3} \rightarrow 1$$

$$V_1 = V_4 \text{ and } V_2 = V_3$$

V_1 - volume at bottom dead center (BDC)

V_2 - volume at top dead center (TDC)(clearance volume)

Displacement Volume (V_D)

$$V_D = V_1 - V_2 \rightarrow \text{Eq. 2}$$

Percent Clearance (C)

$$C = \frac{V_2}{V_D} \rightarrow \text{Eq. 3}$$

$$r = \frac{1+C}{C} \rightarrow \text{Eq. 3'}$$

Heat Added (Q_A)

$$\text{At } V = C; Q = mC_v(\Delta T)$$

$$Q_A = mC_v(T_3 - T_2) \rightarrow \text{Eq. 4}$$

Heat Rejected (Q_R)

$$Q_R = mC_v(T_4 - T_1) \rightarrow \text{Eq. 5}$$

Net Work (W)

$$W = \Sigma Q$$

$$W = Q_A - Q_R \rightarrow \text{Eq. 6}$$

P,V and T Relations

At point 1 to 2 ($S = C$)

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2} \right)^{k-1} = (r)^{k-1} = \left(\frac{P_2}{P_1} \right)^{\frac{k-1}{k}}$$

$$T_2 = T_1(r)^{k-1} \rightarrow \text{Eq. 7}$$

At point 2 to 3 ($V = C$)

$$\frac{T_3}{T_2} = \frac{P_3}{P_2} \rightarrow \text{Eq. 8}$$

At point 3 to 4 ($S = C$)

$$\frac{T_3}{T_4} = \left(\frac{V_4}{V_3} \right)^{k-1} = \left(\frac{P_3}{P_4} \right)^{\frac{k-1}{k}} = (r)^{k-1}$$

$$T_3 = T_4(r)^{k-1} \rightarrow \text{Eq. 9}$$

At point 4 to 1 ($V = C$)

$$\frac{T_4}{T_1} = \frac{P_4}{P_1} \rightarrow \text{Eq. 10}$$

Entropy Change

a) ΔS during Heat Addition

$$S_3 - S_2 = mC_v \ln \frac{T_3}{T_2} \rightarrow \text{Eq. 11}$$

b) ΔS during Heat Rejection

$$S_1 - S_4 = mC_v \ln \frac{T_1}{T_4} \rightarrow \text{Eq. 12}$$

$$S_1 - S_4 = -(S_3 - S_2) \rightarrow \text{Eq. 13}$$

Thermal Efficiency

$$e = \frac{W}{Q_A} \times 100\% \rightarrow \text{Eq. 14}$$

$$e = \frac{Q_A - Q_R}{Q_A} \times 100\% \rightarrow \text{Eq. 15}$$

$$e = \left[1 - \frac{Q_R}{Q_A} \right] \times 100\% \rightarrow \text{Eq. 16}$$

$$e = \left[1 - \frac{(T_4 - T_1)}{(T_3 - T_2)} \right] \times 100\% \rightarrow \text{Eq. 17}$$

$$e = \left[1 - \frac{1}{(r)^{k-1}} \right] \times 100\% \rightarrow \text{Eq. 18}$$

Mean Effective Pressure

$$P_m = \frac{W}{V_D} \text{ KPa} \rightarrow \text{Eq. 19}$$

where:

P_m – mean effective pressure, KPa

W – Net Work KJ, KJ/kg, KW

V_D – Displacement Volume m^3 , m^3/kg , m^3/sec

Displacement Volume

$$V_D = V_1 - V_2 \text{ m}^3 \rightarrow \text{Eq. 20}$$

$$V_D = v_1 - v_2 \text{ m}^3/kg \rightarrow \text{Eq. 21}$$

Note:

For Cold Air Standar: $k = 1.4$

For Hot Air Standard: $k = 1.3$

AIR STANDARD DIESEL CYCLE

Diesel, Rudolf (Christian Karl)

Born: March 18, 1858, Paris, France

Died: September 29, 1913, at sea in the English Channel



German thermal engineer who invented the internal-combustion [engine](#) that bears his name. He was also a distinguished connoisseur of the arts, a linguist, and a social theorist.

Diesel, the son of German-born parents, grew up in Paris until the family was deported to England in 1870 following the outbreak of the Franco-German War. From London Diesel was sent to Augsburg, his father's native town, to continue his schooling. There and later at the Technische Hochschule (Technical High School) in Munich he established a brilliant scholastic record in fields of engineering. At Munich he was a protégé of the refrigeration engineer Carl von Linde, whose Paris firm he joined in 1880.

Diesel devoted much of his time to the self-imposed task of developing an internal combustion engine that would approach the theoretical efficiency of the Carnot cycle. For a time he experimented with an expansion engine using ammonia. About 1890, in which year he moved to a new post with the Linde firm in Berlin, he conceived the idea for the [diesel engine](#). He obtained a German development patent in 1892 and the following year published a description of his engine under the title Theorie und Konstruktion eines rationellen Wärmemotors (Theory and Construction of a Rational Heat Motor). With support from the Maschinenfabrik Augsburg and the Krupp firms, he produced a series of increasingly successful models, culminating in his demonstration in 1897 of a 25-horsepower, four-stroke, single vertical cylinder compression engine. The high efficiency of Diesel's engine, together with its comparative simplicity of design, made it an immediate commercial success, and royalty fees brought great wealth to its inventor.

Diesel disappeared from the deck of the mail steamer Dresden en route to London and was assumed to have drowned.

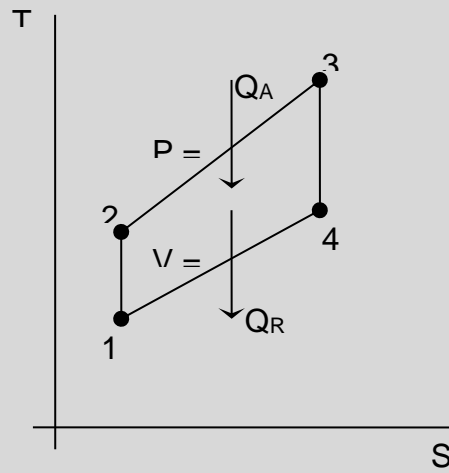
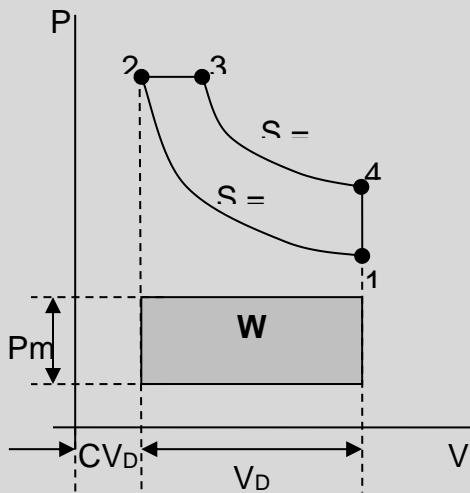
Processes:

1 to 2 – Isentropic Compression ($S = C$)

2 to 3 – Constant Pressure Heat Addition ($P = C$)

3 to 4 – Isentropic Expansion ($S = C$)

4 to 1 – Constant Volume Heat Rejection ($V = C$)



Compression Ratio

$$r = \frac{V_1}{V_2} = \frac{V_4}{V_3} \rightarrow 1$$

$$\frac{V_1}{V_2} \neq \frac{V_4}{V_3}$$

Cut-Off Ratio (r_c)

$$r_c = \frac{V_3}{V_2} \rightarrow 2$$

Percent Clearance

$$C = \frac{V_2}{V_D} \rightarrow 3$$

$$r = \frac{1+C}{C} \rightarrow 4$$

Displacement Volume (V_D)

$$V_D = V_1 - V_2 \rightarrow \text{Eq. 5}$$

Heat Added (Q_A)

$$\text{At } P = C ; Q = mC_p(\Delta T)$$

$$Q_A = mC_p(T_3 - T_2) \rightarrow \text{Eq. 6}$$

$$Q_A = mkC_v(T_3 - T_2) \rightarrow \text{Eq. 7}$$

Heat Rejected (Q_R)

$$Q_R = mC_v(T_4 - T_1) \rightarrow \text{Eq. 8}$$

Net Work (W)

$$W = \Sigma Q$$

$$W = Q_A - Q_R \rightarrow \text{Eq. 9}$$

$$W = mkC_v(T_3 - T_2) - mC_v(T_4 - T_1)$$

$$W = mC_v[k(T_3 - T_2) - (T_4 - T_1)] \rightarrow \text{Eq. 10}$$

P,V and T Relations

At point 1 to 2 ($S = C$)

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2} \right)^{k-1} = (r)^{k-1} = \left(\frac{P_2}{P_1} \right)^{\frac{k-1}{k}}$$

$$T_2 = T_1(r)^{k-1} \rightarrow \text{Eq. 11}$$

At point 2 to 3 ($P = C$)

$$\frac{T_3}{T_2} = \frac{V_3}{V_2} = r_c \rightarrow \text{Eq. 12}$$

$$T_3 = T_1(r)^{k-1}(r_c) \rightarrow \text{Eq. 13}$$

At point 3 to 4 ($S = C$)

$$\frac{T_4}{T_3} = \left(\frac{V_3}{V_4} \right)^{k-1} = \left(\frac{P_4}{P_3} \right)^{\frac{k-1}{k}}$$

$$T_4 = T_1(r)^{k-1}(r_c) \left(\frac{V_3}{V_4} \right)^{k-1}$$

$$T_4 = T_1 \frac{V_1^{k-1}}{V_2^{k-1}} \frac{V_3}{V_2} \frac{V_3^{k-1}}{V_4^{k-1}}$$

$$T_4 = T_1(r_c)^k \rightarrow \text{Eq. 14}$$

At point 4 to 1 ($V = C$)

$$\frac{T_4}{T_1} = \frac{P_4}{P_1} \rightarrow \text{Eq. 15}$$

Entropy Change

a) ΔS during Heat Addition

$$S_3 - S_2 = mC_p \ln \frac{T_3}{T_2} \rightarrow \text{Eq. 16}$$

b) ΔS during Heat Rejection

$$S_1 - S_4 = mC_v \ln \frac{T_1}{T_4} \rightarrow \text{Eq. 17}$$

$$S_1 - S_4 = -(S_3 - S_2) \rightarrow \text{Eq. 18}$$

Thermal Efficiency

$$e = \frac{W}{Q_A} \times 100\% \rightarrow \text{Eq. 19}$$

$$e = \frac{Q_A - Q_R}{Q_A} \times 100\% \rightarrow \text{Eq. 20}$$

$$e = \left[1 - \frac{Q_R}{Q_A} \right] \times 100\% \rightarrow \text{Eq. 21}$$

$$e = \left[1 - \frac{(T_4 - T_1)}{k(T_3 - T_2)} \right] \times 100\% \rightarrow \text{Eq. 22}$$

Substituting Eq. 11, Eq. 13 and Eq. 14 to Eq. 22

$$e = \left[1 - \frac{1}{(r)^{k-1}} \left(\frac{r_c^k - 1}{k(r_c - 1)} \right) \right] \times 100\% \rightarrow \text{Eq. 23}$$

Mean Effective Pressure

$$P_m = \frac{W}{V_D} \text{ KPa} \rightarrow \text{Eq. 24}$$

where:

P_m – mean effective pressure, KPa

W – Net Work KJ, KJ/kg, KW

V_D – Displacement Volume m^3 , m^3/kg , m^3/sec

Displacement Volume

$$V_D = V_1 - V_2 \text{ m}^3 \rightarrow \text{Eq. 25}$$

$$V_D = v_1 - v_2 \text{ m}^3/\text{kg} \rightarrow \text{Eq. 26}$$

AIR STANDARD DUAL CYCLE

Processes:

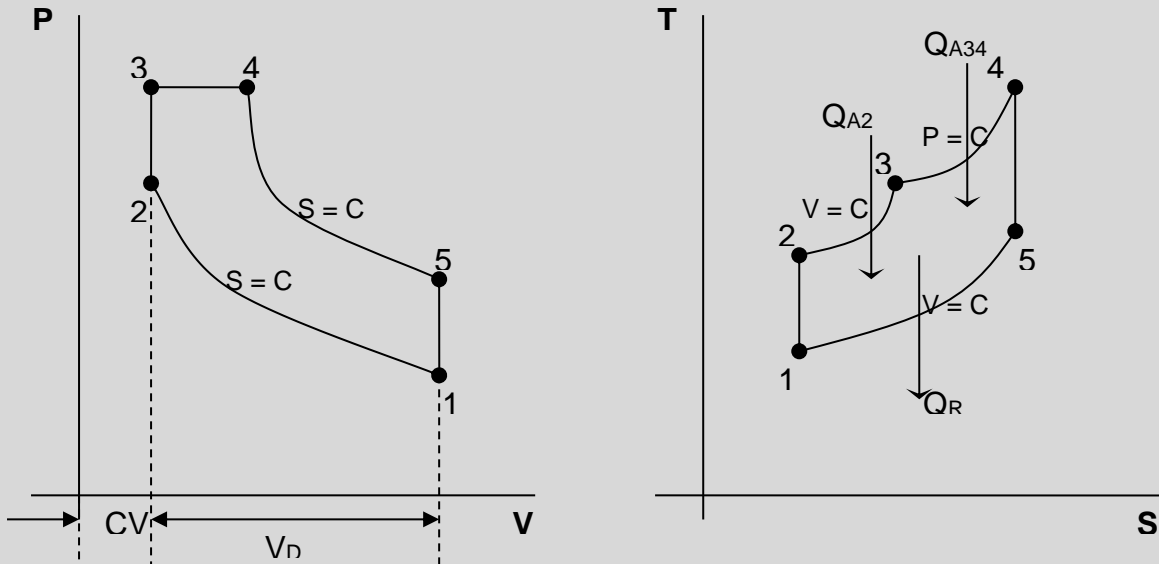
1 to 2 – Isentropic Compression ($S = C$)

2 to 3 – Constant Volume Heat Addition Q_{23} ($V = C$)

3 to 4 – Constant Pressure Heat Addition Q_{34} ($P = C$)

4 to 5 – Isentropic Expansion ($S = C$)

5 to 1 – Constant Volume Heat Rejection ($V = C$)



Compression Ratio

$$r = \frac{V_1}{V_2} \rightarrow \text{Eq. 1}$$

$$V_1 = V_5 \text{ and } V_2 = V_3$$

Cut-Off Ratio

$$r_c = \frac{V_4}{V_3} \rightarrow \text{Eq. 2}$$

Pressure Ratio

$$r_p = \frac{P_3}{P_2} \rightarrow \text{Eq. 3}$$

$$P_3 = P_4$$

Percent Clearance

$$C = \frac{V_2}{V_D} \rightarrow \text{Eq. 4}$$

$$r = \frac{1+C}{C} \rightarrow \text{Eq. 5}$$

Displacement Volume

$$V_D = V_1 - V_2 \text{ m}^3 \rightarrow \text{Eq. 6}$$

$$V_D = v_1 - v_2 \rightarrow \text{Eq. 7}$$

P, V, and T Relations

At point 1 to 2 ($S = C$)

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2} \right)^{k-1} = (r)^{k-1} = \left(\frac{P_2}{P_1} \right)^{\frac{k-1}{k}}$$

$$T_2 = T_1 (r)^{k-1} \rightarrow \text{Eq. 8}$$

At point 2 to 3 ($V = C$)

$$\frac{T_3}{T_2} = \frac{P_3}{P_2} = r_p \rightarrow \text{Eq. 9}$$

$$T_3 = T_1 (r)^{k-1} (r_p) \rightarrow \text{Eq. 10}$$

At point 3 to 4 ($P = C$)

$$\frac{T_4}{T_3} = \left(\frac{V_3}{V_4} \right) = r_c$$

$$T_4 = T_1 (r)^{k-1} (r_p) (r_c) \rightarrow \text{Eq. 11}$$

At point 4 to 5 ($S = C$)

$$\frac{T_5}{T_4} = \left(\frac{V_4}{V_5} \right)^{k-1}$$

$$T_5 = T_1 \frac{V_1^{k-1}}{V_2^{k-1}} (r_p) \frac{V_4}{V_2} \left(\frac{V_4^{k-1}}{V_1^{k-1}} \right) \rightarrow \text{Eq. 12}$$

$$T_5 = T_1 (r_c)^k (r_p) \rightarrow \text{Eq. 13}$$

At 5 to 1 ($V = C$)

$$\frac{T_5}{T_1} = \frac{P_5}{P_1} \rightarrow \text{Eq. 14}$$

Entropy change

a) At 2 to 3 ($V = C$)

$$S_3 - S_2 = mC_v \ln \frac{T_3}{T_2} \rightarrow \text{Eq. 15}$$

b) At 3 to 4 ($P = C$)

$$S_4 - S_3 = mC_p \ln \frac{T_4}{T_3} \rightarrow \text{Eq. 16}$$

$$S_4 - S_2 = (S_3 - S_2) + (S_4 - S_3) \rightarrow \text{Eq. 17}$$

c) At 5 to 1 ($V = C$)

$$S_1 - S_5 = mC_v \ln \frac{T_1}{T_5} \rightarrow \text{Eq. 18}$$

Heat Added

$$Q_A = Q_{A23} + Q_{A34} \rightarrow \text{Eq. 19}$$

$$Q_{A23} = mC_v(T_3 - T_2) \rightarrow \text{Eq. 20}$$

$$Q_{A34} = mC_p(T_4 - T_3) = mkC_v(T_4 - T_3) \rightarrow \text{Eq. 21}$$

$$Q_A = mC_v[(T_3 - T_2) + k(T_4 - T_3)] \rightarrow \text{Eq. 22}$$

Heat Rejected

$$Q_R = mC_v(T_5 - T_1) \rightarrow \text{Eq. 23}$$

Net Work

$$W = (Q_A - Q_R) \rightarrow \text{Eq. 24}$$

$$W = mC_v[(T_3 - T_2) + k(T_4 - T_3) - (T_5 - T_1)] \rightarrow \text{Eq. 25}$$

Thermal Efficiency

$$e = \frac{W}{Q_A} \times 100\% \rightarrow \text{Eq. 26}$$

$$e = \frac{Q_A - Q_R}{Q_A} \times 100\% \rightarrow \text{Eq. 27}$$

$$e = \left[1 - \frac{Q_R}{Q_A} \right] \times 100\% \rightarrow \text{Eq. 28}$$

$$e = \left[1 - \frac{(T_5 - T_1)}{(T_3 - T_2) + k(T_4 - T_3)} \right] \times 100\% \rightarrow \text{Eq. 29}$$

Substituting Eq. 8, Eq. 10 and Eq. 11 and Eq. 13 to Eq. 29

$$e = \left[1 - \frac{1}{(r)^{k-1}} \left(\frac{r_p r_c^k - 1}{(r_p - 1) + k r_p (r_c - 1)} \right) \right] \times 100\% \rightarrow \text{Eq. 30}$$

BRAYTON CYCLE

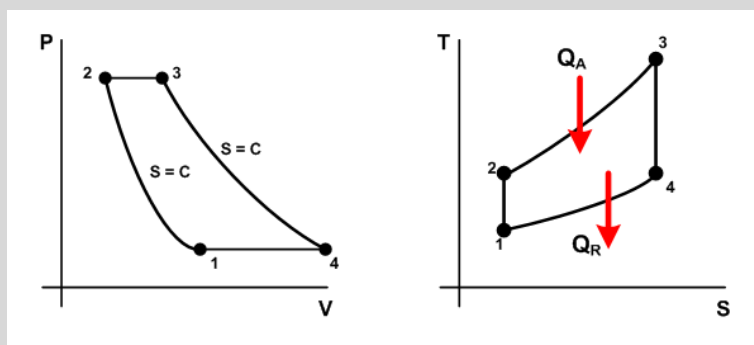
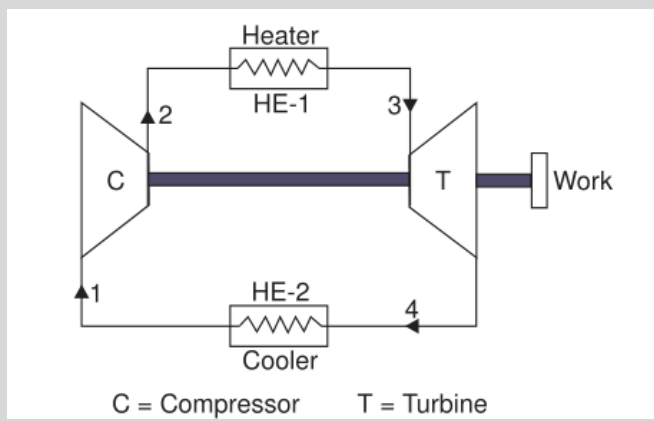
Basic Components

1. Air Compressor
2. Heater
3. Gas Turbine
4. Cooler

Processes

- 1 to 2 – Isentropic Compression
- 2 to 3 – Isobaric Heat Addition
- 3 to 4 – Isentropic Expansion
- 4 to 1 – Isobaric Heat Rejection

Figure 1: Closed Gas Turbine Cycle



Pressure Ratio

$$r_p = \frac{P_2}{P_1} = \frac{P_3}{P_4} \rightarrow \text{Eq. 1}$$

Compressor Work

$$W_c = mC_p(T_2 - T_1) \rightarrow \text{Eq. 2}$$

$$T_2 = T_1(r_p)^{\frac{k-1}{k}} \rightarrow \text{Eq. 3}$$

$$T_3 = T_4(r_p)^{\frac{k-1}{k}} \rightarrow \text{Eq. 4}$$

$$\frac{T_2}{T_1} = \frac{T_3}{T_4} = (r_p)^{\frac{k-1}{k}}$$

Heater

$$Q_A = mC_p(T_3 - T_2) \rightarrow \text{Eq. 5}$$

Turbine

$$W_t = mC_p(T_3 - T_4) \rightarrow \text{Eq. 6}$$

Cooler

$$Q_R = mC_p(T_4 - T_1) \rightarrow \text{Eq. 7}$$

Net Work

$$W = Q_A - Q_R \rightarrow \text{Eq. 8}$$

Thermal Efficiency

$$e = \frac{W}{Q_A} \times 100\% \rightarrow \text{Eq. 9}$$

$$e = \frac{Q_A - Q_R}{Q_A} \times 100\% \rightarrow \text{Eq. 10}$$

$$e = \left[1 - \frac{Q_R}{Q_A} \right] \times 100\% \rightarrow \text{Eq. 11}$$

$$e = \left[1 - \frac{(T_4 - T_1)}{(T_3 - T_2)} \right] \times 100\% \rightarrow \text{Eq. 12}$$

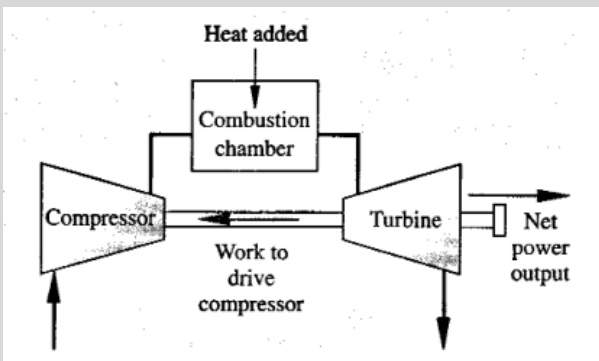
Substituting Eq. 3 and Eq. 4 to Eq. 12

$$e = \left[1 - \frac{1}{(r_p)^{\frac{k-1}{k}}} \right] \times 100\% \rightarrow \text{Eq. 13}$$

Work Ratio

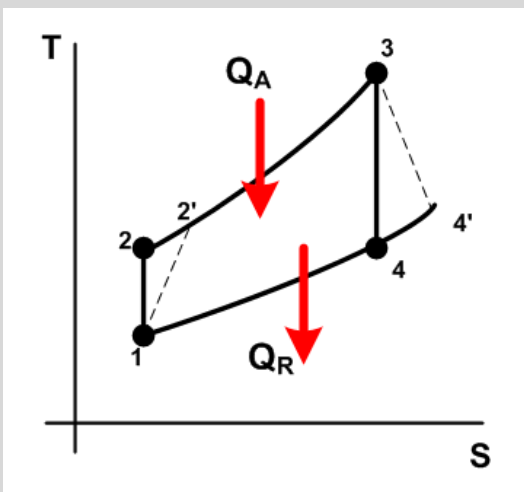
$$WR = \frac{\text{Net Work}}{\text{Turbine Work}}$$

Figure 2: Open Gas Turbine Cycle



$$W = W_{\text{Turbine}} - W_{\text{Compressor}}$$

ACTUAL BRAYTON CYCLE



Turbine Efficiency

$$\eta_{\text{Turbine}} = \frac{\text{Actual Turbine Work}}{\text{Ideal Turbine Work}} \times 100\%$$

$$W_{t'} = mC_p(T_3 - T_{4'}) \rightarrow \text{Actual Work}$$

$$W_t = mC_p(T_3 - T_4) \rightarrow \text{Ideal Work}$$

$$\eta_{\text{Turbine}} = \frac{(T_3 - T_{4'})}{(T_3 - T_4)} \times 100\%$$

Compressor Efficiency

$$\eta_{\text{Compressor}} = \frac{\text{Ideal Compressor Work}}{\text{Actual Compressor Work}} \times 100\%$$

$$W_c = mC_p(T_2 - T_1) \rightarrow \text{Actual Work}$$

$$W_{c'} = mC_p(T_{2'} - T_1) \rightarrow \text{Ideal Work}$$

$$\eta_{\text{Compressor}} = \frac{(T_2 - T_1)}{(T_{2'} - T_1)} \times 100\%$$

Actual Thermal efficiency

$$e_{t'} = \frac{\text{Net Work}}{\text{Heat added}} \times 100\%$$

Example No. 1

Air at 300 K and 100 kPa enters into the compressor of a gas turbine engine that operates on a Brayton cycle. The air mass flow rate is 5 kg/s and the maximum air temperature in the engine is 1200 K. If the pressure ratio of the cycle is $r_p = 4$,

- Find the efficiency of the engine, assuming ideal compression and expansion.
- Find the net power
- What are the exit temperatures from the turbine and the compressor if $\eta_{\text{Compressor}} = \eta_{\text{Turbine}} = 60.95\%$

given

$$T_1 = 300 \text{ K}$$

$$P_1 = 100 \text{ KPa}$$

$$T_3 = 1200 \text{ K}$$

$$r_p = 4$$

$$r_p = \frac{P_2}{P_1} = \frac{P_3}{P_4}$$

Open System

An air compressor handles 8.5 m³/min of air with $\rho = 1.26 \text{ kg/m}^3$ and $P = 101.325 \text{ KPa}$ and it discharges at $P = 445 \text{ KPa}$ with $\rho = 4.86 \text{ kg/m}^3$. The $\Delta U = 82 \text{ KJ/kg}$ and the heat loss by cooling is 24 KJ/kg . Neglecting ΔKE and ΔPE , find W in KJ/min .

Closed System

A closed system containing a gas expands slowly in a piston cylinder in accordance to $PV^2 = C$. If the initial pressure is 500 KPa , initial volume is 50 L and the final pressure is 200 KPa , find the work done by the system. (9.2 KJ)

Closed System

A closed gaseous system undergoes a reversible process in which 30 KJ of heat are rejected and the volume changes from 140 L to 550 L . The pressure is constant at 150 KPa . Determine W in KJ .

A steam turbine receives superheated steam at 1.4 MPa and 400°C ($h = 3121 \text{ KJ/kg}$). The steam leaves the turbine at 0.101 MPa and 100°C ($h = 2676 \text{ KJ/kg}$). The steam enters the turbine at 15 m/sec and exits at 60 m/sec . The elevation difference between entry and exit ports is negligible. The heat loss through the turbine walls is 2 KW . Calculate the power output if the mass flow through the turbine is 0.5 kg/sec . (220 KW)

A nozzle receives 10 kg/sec of steam at 4 MPa and 260°C ($h = 2836.3 \text{ KJ/kg}$; $v = 51.74 \times 10^{-3} \text{ m}^3/\text{kg}$) and discharges it at 1.4 MPa ($h = 2634.07 \text{ KJ/kg}$; $v = 129.72 \times 10^{-3} \text{ m}^3/\text{kg}$). If the velocity at inlet is negligible, find the diameter at exit in cm . (5.09 cm)

A centrifugal pump compresses 3000 L/min of water from 98 KPa to 300 KPa . The inlet and outlet temperatures are 25°C with $\rho = 997.1 \text{ kg/m}^3$. The inlet and discharge piping are on the same level, but the diameter of the inlet piping is 15 cm , whereas that of the discharge piping is 10 cm . Determine the pump work in KW . (-10.91 KW)

If 6 L of a gas at a pressure of 100 KPa are compressed reversibly according to $PV^2 = C$ until the volume becomes 2 L , Find the final pressure and the work.

Work is done by a substance in a reversible non-flow manner in accordance with $V = 700/P \text{ m}^3$, where P in KPa . Evaluate the work done on or by the substance as the pressure increases from 70 KPa to 700 KPa .

A fluid changes state from $P_1 = 103.4 \text{ LPa}$, $V_1 = 567 \text{ L}$ to $P_2 = 689.3 \text{ KPa}$, $V_2 = 57 \text{ L}$, the internal energy is the same in both states, Find Δh in KJ .

A closed gaseous system undergoes a reversible process during which 26.4 KJ are rejected, the volume changes from 0.14 m^3 to 0.06 m^3 , and the pressure remains constant at 345 KPa . Find the change of internal energy in KJ . $12.$ A closed system executes a reversible process wherein the pressure and volume vary in accordance with $PV^n = C$;
 $Q = 16.25 \text{ KJ}$; $\Delta U = 47.45 \text{ KJ}$. If $P_1 = 138 \text{ KPa}$; $V_1 = 142 \text{ L}$ and $P_2 = 827 \text{ KPa}$, find n and V_2 .

Let 100 kg of liquid water at 100°C be converted to steam at 100°C by boiling at standard atmospheric pressure. The volume changes from $1 \times 10^{-3} \text{ m}^3$ to 1.671 m^3 as steam. How much work is done by the system during this process. (169 KJ)

A fluid enters with a steady flow of 3.7 kg/sec and an initial pressure of 690 KPa , initial density of 3.2 kg/m^3 , initial velocity of 60 m/sec and an initial internal energy of 2000 KJ/kg . It leaves at 172 KPa , $\rho = 0.64 \text{ kg/m}^3$, $v = 160 \text{ m/sec}$, and $u = 1950 \text{ KJ/kg}$. The heat loss is found to be 18.6 KJ/kg . Find the work in KW . (-121.1 KW)

Steam with a flow rate of 1360 kg/hr enters an adiabatic nozzle at 1378 KPa , 3.05 m/sec with a specific volume of $0.147 \text{ m}^3/\text{kg}$ and with a specific internal energy of 2510 KJ/kg . The exit conditions are $P = 137.8 \text{ KPa}$, specific volume $= 1.099 \text{ m}^3/\text{kg}$ and internal energy $= 2263 \text{ KJ/kg}$. Determine the exit velocity. (772.2 m/sec)

A waterfall is 75 m high. If all of the gravitational potential energy of water were converted into heat energy, by how much would the temperature of the water increase in going from the top to the bottom of the falls? (consider 1 kg of water going over the falls)

A water storage tank contains liquid and vapor in equilibrium at 250°C , ($\rho_l = 799.23 \text{ m}^3/\text{kg}$; $\rho_v = 19.95 \text{ m}^3/\text{kg}$). The distance from the bottom of the tank to the liquid level is 10 m. What is the difference in pressure reading between the top of the tank and the bottom of the tank. (78.4 KPa)

Steam enters a turbine with a velocity of 1.5 m/sec and an enthalpy of 2093 KJ/kg and leaves with an enthalpy of 1977 KJ/kg and a velocity of 91.5 m/sec. Heat losses are 8 Kcal/min and the steam flow rate is 27 kg/min. The inlet of the turbine is 3.2 m higher than its outlet. What is the work output of the turbine if the mechanical losses is 15%.

- a) 32.4 KW b) 24.3 KW c) 34.2 K d) 42.3 KW

A fluid at 700 KPa, with $v = 0.25 \text{ m}^3/\text{kg}$ and $v = 175 \text{ m/sec}$ enters a device. Heat loss from the device by radiation is 23 KJ/kg. The work done by the fluid is 465 KJ/kg. The fluid exits at $P = 136 \text{ KPa}$, $v = 0.94 \text{ m}^3/\text{kg}$ and $v = 335 \text{ m/sec}$. Determine ΔU in KJ/kg. (-481.64 KJ/kg)

In a certain waterfall water drops vertically 400 m. Assuming specific heat of water to be 4.187 KJ/kg-K and neglecting evaporation (which would have a cooling effect) and other losses of heat, what would be the rise in temperature of the falling water after striking the rocks below.

If the specific heat for a certain process is given by the equation $C = 0.84 + 0.00021T$ KJ/kg-C, how much heat should be transferred to raise the temperature of 1 kg from 5°C to 850°C .

A water jacketed air compressor receives 8.5 m³/min of air at 101 KPa and 21°C and discharges the air at 482.5 KPa and 138°C . Cooling water enters the jacket at 16°C and leaves at 21°C for a flow rate of 10 kg/min. Determine the power in KW.

Estimate the steam flow rate required to drive a boiler feed pump which requires 75 KW at 5000 rpm. The turbine is a velocity compounded impulse turbine with two rows of moving blades. Steam is available at 3500 KPa and a temperature of 260°C . The turbine back pressure is 410 KPa. Assume a turbine efficiency of 95% and a stage efficiency of 80%.

If 2.2 m³/sec of air saturated at 35°C enters a four stage adiabatic compressor, having a compression ratio of 2.33 to 1, at atmospheric pressure, how much heat must be removed in the 1st stage intercooler.

A kg of a certain substance undergoes a change from state defined by a pressure of 60 KPa and a volume of 1.5 m³, to the state defined by a pressure 1034 KPa and a volume of 0.085 m³. with no change in internal energy, how much has the enthalpy increase?

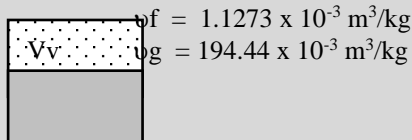
A steam turbine receives 0.5 kg/sec at 33.5 m/sec and $h = 3547.6 \text{ KJ/kg}$. The steam leaves at 245 m/sec and $h = 3024.2 \text{ KJ/kg}$. What is the KW power output.

SAMPLE EXERCISES

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in both states, Find Δh in KJ.

11. A closed gaseous system undergoes a reversible process during which 25 BTU are rejected, the volume changes from 5 ft³ to 2 ft³, and the pressure remains constant at 50 psi. Find the change of internal energy in BTU.
12. A closed system executes a reversible process wherein the pressure and volume vary in accordance with $PV^n = C$; $Q = 16.25$ KJ; $\Delta U = 47.45$ KJ. If $P_1 = 138$ KPa; $V_1 = 142$ L and $P_2 = 827$ KPa, find n and V_2 .
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a) 32.4 KW b) 24.3 KW c) 34.2 K d) 42.3 KW
19. A fluid at 700 KPa, with $v = 0.25$ m³/kg and $v = 175$ m/sec enters a device. Heat loss from the device by radiation is 23 KJ/kg. The work done by the fluid is 465 KJ/kg. The fluid exits at $P = 136$ KPa, $v = 0.94$ m³/kg and $v = 335$ m/sec. Determine ΔU in KJ/kg. (-481.64 KJ/kg)
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25. A kg of a certain undergoes a change from state defined by a pressure of 60 KPa and a volume of 1.5 m³, to the state defined by a pressure 1034 KPa and a volume of 0.085 m³. with no change in internal energy, how much has the enthalpy increase?
26. A steam turbine receives 0.5 kg/sec at 33.5 m/sec and $h = 3547.6$ KJ/kg. The steam leaves at 245 m/sec and $h = 3024.2$ KJ/kg. What is the KW power output.
27. A throttling calorimeter is attached to a steam line where the steam temperature reads 210°C. In the calorimeter the pressure is 100 KPa (0.10 MPa) and the temperature is 125°C. Determine the quality of the steam. ($x = 96.22\%$)
From table 3 at 0.10 MPa and 125°C: $h = 2726.6$ KJ/kg
From table 1 at 210°C: $h_f = 897.76$ KJ/kg; $h_{fg} = 1900.7$ KJ/kg
28. A vessel having a volume of 5 m³ contains 0.05 m³ of saturated liquid water and 4.95 m³ of saturated water vapor at 0.10 MPa. Heat is transferred until the vessel is filled with saturated vapor. Determine the heat transfer for this process in KJ. ($Q = 104\,940$ KJ)
From table 2 at 0.10 MPa : $v_f = 1.0432 \times 10^{-3}$ m³/kg; $v_g = 1694 \times 10^{-3}$ m³/kg
 $u_f = 417.36$ KJ/kg; $u_{fg} = 2088.7$ KJ/kg; $u_g = 2506.1$ KJ/kg
29. A tank contains exactly 1 kg of water consisting of liquid and vapor in equilibrium at 1 MPa. If the liquid and vapor occupy one half the volume of the tank, what is the enthalpy of the contents of the tank? ($h = 774.43$ KJ/kg)
From table 2 at 1 MPa:



30. A small steam turbine operating at part load produces 110 KW output with a steam flow rate of 0.25 kg/sec. Steam At 1.4 MPa, 250°C is throttled to 1.1 MPa before entering the turbine, and the turbine exhaust pressure is 10 KPa. Find the steam quality (or temperature, if superheated) at the turbine outlet. ($x_2 = 95.9\%$)
 From table 3 at 1.4 MPa and 250°C: $h = 2927.2$ KJ/kg
 From table 2 at 10 KPa (0.010 MPa): $h_f = 191.83$ KJ/kg; $h_{fg} = 2392.8$ KJ/kg
 $h_1 = 2927.2$ KJ/kg
 4
 0.8 kg/sec
31. Steam enters a turbine at 1.4 MPa and 320°C. The turbine internal efficiency is 70% and the load requirement is 800 KW. the exhaust is to the back pressure system maintained at 175 KPa. Find the steam flow rate. (2.6 kg/sec)
 From table 3 at 1.4 MPa and 320°C: $h = 3084.3$ KJ/kg ; $s = 7.0287$ KJ/kg-K
 From table 2 at 175 KPa (0.175 MPa): $h_f = 486.99$ KJ/kg ; $h_{fg} = 2213.6$ KJ/kg
 $sf = 1.4849$ KJ/kg-K; $s_{fg} = 5.6868$ KJ/kg-K
32. A feedwater pump in a supercritical power plant raises the pressure of water from 1.4 MPa and 175°C to 24.5 MPa isentropically. Determine the pump work in KJ/kg.
 From table 4 v at 1.4 MPa and 175°C = 1.1489×10^{-3} m³/kg
 $tsat$ at 1.4 MPa = 184.09°C
33. Steam at a pressure of 1200 KPa arrives at a steam turbine with a quality of 97%. For 1 kg. what is the work done by steam expands isentropically to a pressure of 20 KPa.
34. Two boilers discharges equal amount of steam in to the same main. The steam from one is at 1.4 MPa and 220°C, and from the other, at 1.4 MPa and 95% quality. What is the quality of steam after mixing. (.995)
35. Water at 21°C and atmospheric pressure is pumped into a boiler, evaporated at 2.1 MPa pressure and superheated to a total steam temperature of 320°C. How much heat must be supplied per kg of steam?
36. Saturated steam at 1400 KPa expands continuously through a throttling valve to 101.325 KPa. What are the state of expanded steam and the change of entropy for the process if no heat is lost to the surroundings, and if all the kinetic energy due any high velocity jets is dissipated?
37. Three kilograms of steam expands isentropically in a nonflow process from 2 MPa and 400°C to a temperature of 95°C. Find the quality and the work.
38. A vapor and liquid mixture with 95% quality and 100 KPa pressure enters the condenser and leaves at 90°C as a subcooled liquid at the same pressure. For a total heat load of 300 KW, determine the steam flow rate in kg/sec.
39. Water from a boiler at 1.14 MPa is blown down to a flash tank held at a pressure of 0.3 MPa. Neglecting pressure drop in the blowdown line and assuming the pipeline and flash tank to be perfectly insulated, how many kilograms of water flashed into vapor per kg of water fed to the tank.
40. Compute the work per kg of steam and the steam consumption in kg/KW-hr when steam is used in a Carnot Cycle between zero and 100% quality and 1 MPa and 20 KPa.
41. Air is contained in a cylinder fitted with a frictionless piston. Initially the cylinder contains 500 L of air at 150 KPa and 20°C. The air is then compressed in a polytropic process $PV^n = C$ until the final pressure is 600 KPa, at which point the temperature is 120°C. Determine the work W and the heat transfer Q.
42. A steady flow compressor handles 113.3 m³/min of nitrogen ($M = 28$; $k = 1.399$) measured at intake where $P_1 = 97$ KPa and $T_1 = 27^\circ\text{C}$. Discharge is at 311 KPa. The changes in ΔKE and ΔPE are negligible. For each of the following cases, determine the final temperature and the work if the process is:
 a) $PV^k = C$ (418.25 K ; $W = -253.1$ KW)
 b) $PV = C$ (300 K; $W = -213.4$ KW)
43. During a reversible process executed by a non-flow system the pressure increases from 245 KPa to 1378 KPa in accordance with $PV = C$ and the internal energy increases 22.6 KJ. The initial volume is 0.085 m³ Find Q in KJ.
 a) 28 b) 18 c) 38 d) 40
44. Calculate the change of entropy per kg of air when heated from 300°K to 600°K while the pressure drops from 400 Kpa to 300 KPa. ($\Delta S = 0.78$ KJ/kg-K)
45. One kg of oxygen are compressed polytropically from a pressure of 96.5 KPa and 21°C to 675.5 KPa. The ratio of the specific heat $k = 1.395$ and the compression is according to $PV^{1.3} = C$. Determine the change of entropy in KJ/K. ($\Delta S = -0.94$ KJ/K)
46. Two unequal vessel A and B are connected by a pipe with a valve. Vessel A contains 150 L of air at 2760 KPa and 95°C. Vessel B contains an unknown volume of air at 70 KPa and 5°C. The valve is opened and when the properties have been determined, it was found out that the pressure of the mixture is 1380 KPa and the temperature is 45°C. What is the volume of vessel B.(0.166 m³)
47. Calculate the change of entropy per kg of air when heated from 300°K to 600°K while the pressure drops from 400 Kpa to 300 KPa. ($\Delta S = 0.78$ KJ/kg-K)

48. During a reversible process executed by a non-flow system the pressure increases from 245 KPa to 1378 KPa in accordance with $PV = C$ and the internal energy increases 22.6 KJ. The initial volume is 0.085 m^3 . Find Q in KJ.
a) 28 b) 18 c) 38 d) 40
49. A closed gaseous system undergoes a reversible process during which 26 KJ are rejected. The volume changes from 0.142 m^3 to 0.057 m^3 and the pressure remains constant at 345 KPa. Find ΔU in KJ.
a) 4.95 b) 3.95 c) 5.95 d) 2.95
51. The decrease in internal energy of 1.36 kg of an ideal gas is -342.9 KJ when the pressure decreases from 689.3 KPa to 137.86 KPa and the volume increases from 0.0425 m^3 to 0.127 m^3 . $C_v = 1.047 \text{ KJ/kg-K}$. Determine k.
a) 1.034 b) 1.45 c) 1.432 d) 1.586
52. An ideal gas with $R = 2.077 \text{ KJ/kg-K}$ and a constant $k = 1.659$ undergoes a constant pressure process during which 527.5 KJ are added to 2.27 kg of the gas. The initial temperature is 38°C . Find the ΔS in KJ/K.
a) 2.687 b) 1.586 c) 8.64 d) 3.861
53. Calculate the volume occupied by 13.6 kg of chlorine at a pressure of 73 mm Hg and a temperature of 21°C . molecular weight of chlorine may be taken as 71. (4.7 m^3)
54. A 3.8 m^3 tank filled with acetylene at 103.4 KPa is supercharged with 1.95 kg of the gas. What would be the final pressure, assuming no change in temperature (16°C) that takes place during the charging period. (155 KPa)
55. A volume of gas having initial entropy of 5317.2 KJ/K is heated at constant temperature of 540°C until the entropy is 8165.7 KJ/K. How much heat is added and how much work is done during the process.
56. A perfectly insulated vessel is divided into two compartments, one holding 0.5 kg of H_2 at 1379 KPa and -1.1°C and the other holding 10 kg of N_2 at 670 KPa and -1.1°C . If the partition is removed, find the final pressure in KPa.
a) 847.7 b) 657.5 c) 746.9 d) 548.4
57. Helium gas ($R = 2.077 \text{ KJ/kg-K}$; $k = 1.667$) enters a steady state–steady flow expander at 800 KPa, 300°C and exits at 120 KPa. The mass flow rate is 0.2 kg/sec and the expansion process is $PV^{1.3} = C$. Calculate W of the expander in KW.
a) 365.7 b) 653.7 c) 465.7 d) 564.7
58. An air compressor receives $20 \text{ m}^3/\text{min}$ of air at 101.325 KPa and 20°C and compresses it to 10 000 KPa in an isentropic process. Calculate the power of the compressor.
a) 371 KW b) 317 K c) 358 KW d) 385 KW
59. There are 1.36 kg of gas for which $R = 0.377 \text{ KJ/kg-K}$ and $k = 1.25$ that undergo a non-flow constant volume process from $P_1 = 551.6 \text{ KPa}$ and $t_1 = 60^\circ\text{C}$ to $P = 1655 \text{ KPa}$. During the process the gas is internally stirred and there are also added 105.5 KJ of heat. Determine the paddle work in KJ.
a) 2160.4 b) 6120.4 c) 1260 d) 6210.4
60. Determine the value of ΔS of problem no. 20 in KJ/K.
a) 3.25 b) 5.23 c) 2.253 d) 3.225
61. A vessel of volume 0.2 m^3 contains nitrogen at 101.3 KPa and 15°C . If 0.2 kg of nitrogen is now pumped into the vessel, calculate the new pressure when the vessel has returned to its initial temperature. For nitrogen: $M = 28$; $k = 1.399$. (187 KPa)
62. A certain perfect gas of mass 0.01 kg occupies a volume of 0.03 m^3 at a pressure of 700 KPa and a temperature of 131°C . The gas is allowed to expand until the pressure is 100 KPa and the final volume is 0.02 m^3 . Calculate;
a) the molecular weight of the gas (16)
b) the final temperature (11.5°C)
63. A perfect gas has a molecular weight of 26 kg/kgm and a value of $k = 1.26$. Calculate the heat rejected
a) when 1 kg of the gas is contained in a rigid vessel at 300 KPa and 315°C , and is then cooled until the pressure falls to 150 KPa. (-361 KJ)
b) when 1 kg/sec mass flow rate of the gas enter a pipeline at 280°C and flows steadily to the end of the pipe where the temperature is 20°C . Neglect changes in kinetic and potential energies. (-403 KW)
64. A piston cylinder arrangement contains $0.02 \text{ m}^3/\text{min}$ of air at 50°C and 400 KPa. Heat is added in the amount of 50 KJ and work is done by a paddle wheel until the temperature reaches 700°C . If the pressure is held constant, how much paddle wheel work must be added to the air. ($W_p = 6.35 \text{ KJ}$)
65. If 300 KJ of heat are reversibly added to 0.2 kg of air at constant pressure and the initial temperature is 300°C , find the available energy of the heat added if the surrounding temperature $T_o = 303^\circ\text{K}$. ($AE = 222 \text{ KJ}$)
66. A Carnot engine operating between 775°K and 305°K produces 54 KJ of work. Determine the change of entropy during heat addition. ($\Delta S_{12} = 0.12 \text{ KJ/K}$)
$$e = \frac{T_H - T_L}{T_H} \frac{775 - 305}{775} = 60.6 \%$$

$$W = (T_H - T_L) \Delta S = 54$$

$$\Delta S = 0.115 \text{ KJ/K}$$
67. A Carnot engine operates between temperatures of 1000°K and 300°K . The engine operates at 200 RPM and develops 200 KW. The total engine displacement is such that the mean effective pressure is 300 KPa. Determine:
a) the thermal efficiency (71%)

- b) the heat added (286 KW)
 c) the total engine displacement in m³/cycle (0.02 m³/cycle)
 T_H = 1000 K; T_L = 300 K ; N = 200 RPM; W = 200KW

$$e = \frac{T_H - T_L}{T_H} = \frac{1000 - 300}{1000} = 70 \%$$

$$e = \frac{W}{Q_A} = 100\%$$

$$Q_A = \frac{W}{e} = \frac{200}{0.70} = 286 \text{ KW}$$

$$200 = 300V_D(200)/60$$

$$V_D = 0.20 \text{ m}^3$$

68. A Carnot engine produces 25 KW while operating between temperature limits of 1000 K and 300 K. Determine (a) the heat supplied in KW (b) the heat rejected in KW

$$e = \frac{T_H - T_L}{T_H} = \frac{1000 - 300}{1000} = 70 \%$$

$$e = \frac{W}{Q_A} = 100\%$$

$$Q_A = \frac{W}{e} = \frac{25}{0.70} = 38 \text{ KW}$$

$$W = Q_A - Q_R$$

$$Q_R = 38 - 25 = 13 \text{ KW}$$

69. A Carnot refrigerator operates between temperature limits of -5°C and 30°C. The power consumed is 4 KW and the heat absorbed is 30 KJ/kg. Determine; (a) the COP (b) the refrigerant flow rate

$$T_L = -5 + 273 = 268^\circ\text{K} ; T_H = 30 + 273 = 303^\circ\text{K}; W = 4 \text{ KW}$$

$$\text{COP} = \frac{268}{303 - 268} = 7.7$$

$$Q_A = \text{COP}(W) = 7.7(4) = 30.8 \text{ KW}$$

$$Q_A = m(30)$$

$$m = 30.8/30 = 1.03 \text{ kg/sec}$$

70. A Carnot engine operates between temperature reservoirs of 817°C and 25°C and rejects 25 KW to the low temperature reservoir. The Carnot engine drives the compressor of an ideal vapor compression refrigerator, which operates within pressure limits of 190 KPa and 1200 Kpa. The refrigerant is ammonia. Determine the COP and the refrigerant flow rate.(4; 14.64 kg/min)
71. It is required to compress air from ambient conditions of 100 KPa and 25°C, to a pressure of 800 KPa in a reversible steady-state, steady-flow process. Calculate the work, the heat transfer and the entropy change of the air, all per kg, for each of the following processes.
- Isothermal
 - Polytropic with $n = 1.25$
 - Isentropic
72. A certain perfect gas of mass 0.01 kg occupies a volume of 0.03 m³ at a pressure of 700 KPa and a temperature of 131°C. The gas is allowed to expand until the pressure is 100 KPa and the final volume is 0.02 m³. Calculate;
- the molecular weight of the gas
 - the final temperature

THERMODYNAMICS 1 (FINAL EXAM SERIES NO. 6)

Name of Student _____

Score _____

Course & Year _____

Multiple Choice

Instruction: Encircle the letter which corresponds to the correct answer in the questions below. If you want to change your answer cross-out your first choice and encircle the new one.

- A closed gaseous system undergoes a reversible process in which 40 KJ of heat are rejected and the volume changes 0.15 m^3 to 0.60 m^3 . The pressure is constant at 200 KPa. Determine the change of internal energy ΔU in KJ.
a. -130 b. 150 c. -90 d. 120
- Air in a piston - cylinder occupies 0.12 m^3 at 550 KPa. The air expands isentropically doing work on the piston until the volume is 0.25 m^3 . Determine the work W in KJ. For Air $R = 0.287 \text{ KJ/kg}^\circ\text{K}$ and $k = 1.4$.
a. 42 b. 59 c. 32 d. 69
- Air at 0.07 m^3 and 4000 KPa is expanded in an engine cylinder and the pressure at the end of expansion is 320 KPa. If the expansion is polytropic with $PV^n = C$ where $n = 1.35$, find the final volume.
a. 0.455 b. 0.565 c. 0.685 d. 0.255
- Gas at a pressure of 100 KPa, volume 0.20 m^3 and temperature 300°K , is compressed until the pressure is 320 KPa and the volume is 0.09 cu.m.. Calculate the final temperature in $^\circ\text{K}$.
a. 530 b. 432 c. 632 d. 730
- Helium gas ($R=2.077 \text{ KJ/kg}^\circ\text{K}$; $k= 1.667$) at 800 KPa and 300°K occupies a volume of 0.30 m^3 . Determine the mass of helium in kg.
a. 0.49 b. 0.39 c. 0.69 d. 0.59
- A rigid container containing 25 kg of nitrogen gas at 298°K receives heat and its temperature is increased to 370°K . Determine the amount of heat added in KJ. For N_2 : $R = 0.297 \text{ KJ/kg}^\circ\text{K}$; $k = 1.399$
a. 5338 b. 1334 c. 2556 d. 3885
- A 2 kg steam-water mixture at 1000 KPa and 90% quality ($U = 2401.41 \text{ KJ/kg}$; $h = 2576.57 \text{ KJ/kg}$) is contained in a rigid tank. Heat is added until the pressure rises to 3500 KPa and the temperature is 400°C ($U = 2926.4 \text{ KJ/kg}$; $h = 3222.3 \text{ KJ/kg}$). Determine the heat added.
a. 2598 b. 1292 c. 1045 d. 3467
- Calculate the pressure of 2 moles of air at 400°K , with a total volume of 0.5 m^3 .
a. 10.8 MPa b. 19.2 MPa c. 13.3 MPa d. 15.5 MPa
- A 100 Liters oxygen tank use in a hospital has a pressure of 1 atmosphere and a temperature of 16°C . For a molecular weight of $32 \text{ kg/kg}_{\text{mol}}$, determine the mass of oxygen in kilograms.
a. 0.245 b. 0.335 c. 0.135 d. 0.835
- An unknown gas has a mass of 1.5 kg and occupies 2.5 m^3 while at a temperature of 300°K and a pressure of 200 KPa. Determine the gas constant for the gas in $\text{KJ/kg}^\circ\text{K}$.
a. 3.111 b. 2.111 c. 1.111 d. 4.111

Problem Solving

- A steady flow compressor handles $113.3 \text{ m}^3/\text{min}$ of nitrogen ($M = 28$; $k = 1.399$) measured at intake where $P_1 = 97 \text{ KPa}$ and $T_1 = 27^\circ\text{C}$. Discharge is at 311 KPa. The changes in ΔKE and ΔPE are negligible. For each of the following cases, determine the final temperature and the work if the process is:
a) $PV^k = C$
b) $PV = C$
- Air is contained in a cylinder fitted with a frictionless piston. Initially the cylinder contains 500 L of air at 150 KPa and 20°C . The air is then compressed in a polytropic process ($PV^n = C$) until the final pressure is 600 KPa, at which point the temperature is 120°C . Determine the work W and the heat transfer Q . ($R = 0.287 \text{ KJ/kg}^\circ\text{K}$; $k = 1.4$)

ME 331

Midterm Exam (Special)

2nd Semester AY 08-09

Name of Student _____

Score _____

Course & Year _____

Date _____

Multiple Choice

Instruction: Encircle the letter which corresponds to the correct answer in the questions below. If you want to change your answer cross-out your first choice and encircle the new one.

I. Multiple Choice

1. A closed gaseous system undergoes a reversible process in which 40 KJ of heat are rejected and the volume changes 0.15 m^3 to 0.60 m^3 . The pressure is constant at 2000 KPa. Determine the change of internal energy ΔU in KJ.
a. -130 b. 50 c. -90 d. 320
2. Air in a piston - cylinder occupies 0.12 m^3 at 550 KPa. The air expands isentropically doing work on the piston until the volume is 0.25 m^3 . Determine the work W in KJ. For Air $R = 0.287 \text{ KJ/kg}^\circ\text{K}$ and $k = 1.4$.
a. 42 b. 59 c. 32 d. 69
3. Air at 0.07 m^3 and 4000 KPa is expanded in an engine cylinder and the pressure at the end of expansion is 320 KPa. If the expansion is polytropic with $PV^n = C$ where $n = 1.35$, find the final volume.
a. 0.455 b. 0.565 c. 0.685 d. 0.255
4. Gas at a pressure of 100 KPa, volume 0.20 m^3 and temperature 300°K , is compressed until the pressure is 320 KPa and the volume is 0.09 cu.m.. Calculate the final temperature in $^\circ\text{K}$.
a. 530 b. 432 c. 632 d. 730
5. Helium gas ($R=2.077 \text{ KJ/kg}^\circ\text{K}$; $k= 1.667$) at 800 KPa and 300°K occupies a volume of 0.30 m^3 . Determine the mass of helium in kg.
a. 0.49 b. 0.39 c. 0.69 d. 0.59
6. A rigid container containing 25 kg of nitrogen gas at 298°K receives heat and its temperature is increased to 370°K . Determine the amount of heat added in KJ.
For N_2 : $R = 0.297 \text{ KJ/kg}^\circ\text{K}$; $k = 1.399$
a. 5338 b. 1334 c. 2556 d. 3885
7. A 2 kg steam-water mixture at 1000 KPa and 90% quality ($U = 2401.41 \text{ KJ/kg}$; $h = 2576.57 \text{ KJ/kg}$) is contained in a rigid tank. Heat is added until the pressure rises to 3500 KPa and the temperature is 400°C ($U = 2926.4 \text{ KJ/kg}$; $h = 3222.3 \text{ KJ/kg}$). Determine the heat added.

- a. 2598 b. 1292 c. 1045 d. 3467

8. Calculate the pressure of 2 moles of air at 400°K, with a total volume of 0.5 m³.
 a. 10.8 MPa b. 19.2 MPa c. 13.3 MPa d. 15.5 MPa
9. A 100 Liters oxygen tank use in a hospital has a pressure of 1 atmosphere and a temperature of 16°C. For a molecular weight of 32 kg/kg_{mol}, determine the mass of oxygen in kilograms.
 a. 0.245 b. 0.335 c. 0.135 d. 0.835
10. An unknown gas has a mass of 1.5 kg and occupies 2.5 m³ while at a temperature of 300°K and a pressure of 200 KPa. Determine the gas constant for the gas in KJ/kg-°K.
 a. 3.111 b. 2.111 c. 1.111 d. 4.111

II Problem Solving

1. A steady flow compressor handles 113.3 m³/min of nitrogen (M = 28; k = 1.399) measured at intake where P₁= 97 KPa and T₁= 27° C. Discharge is at 311 KPa. The changes in ΔKE and ΔPE are negligible. For each of the following cases, determine the final temperature and the work if the process is:
 a) $PV^k = C$
 b) $PV = C$

2. Air is contained in a cylinder fitted with a frictionless piston. Initially the cylinder contains 500 L of air at 150 KPa and 20° C. The air is then compressed in a polytropic process ($PV^n = C$) until the final pressure is 600 KPa, at which point the temperature is 120° C. Determine the work W and the heat transfer Q. (R = 0.287 KJ/kg-°K ; k = 1.4)

Good Luck

Instructor: Engr. Yuri G. Melliza

ME 10E

Quiz No. 4

1. A piston cylinder arrangement contains 0.02 m³/min of air at 50° C and 400 Kpa.Heat is added in the amount of 50 KJ and work is done by a paddle wheel until the temperature reaches 700° C. If the pressure is held constant, how much paddle wheel work must be added to the air. (R = 0.287 KJ/kg-°K ; k = 1.4)
 (W_p = 6.35 KJ)
2. Calculate the change of entropy per kg of air when heated from 300°K to 600°K while the pressure drops from 400 Kpa to 300 KPa.
 ΔS = 0.78 KJ/kg-K)
3. An air compressor receives 20 m³/min of air at 101.325 KPa and 20°C and compresses it to 10 000 KPa in an isentropic process. Calculate the power of the compressor.

1. A closed gaseous system undergoes a reversible process in which 40 KJ of heat are rejected and the volume changes 0.15 m³ to 0.60 m³. The pressure is constant at 200 KPa. Determine the change of internal energy ΔU in KJ.

Given: $Q = -40 \text{ KJ}$; $V_1 = 0.15 \text{ m}^3$; $V_2 = 0.60 \text{ m}^3$; $P = 200 \text{ KPa}$

Solution: $Q = \Delta U + W$; $W = P(V_2 - V_1)$

$$W = 200(0.60 - 0.15) = 90 \text{ KJ}$$

$$\Delta U = -40 - 90 = -130 \text{ KJ}$$

2. Air in a piston - cylinder occupies 0.12 m³ at 550 KPa. The air expands isentropically doing work on the piston until the volume is 0.25 m³. Determine the work W in KJ. For Air $R = 0.287 \text{ KJ/kg-}^\circ\text{K}$ and $k = 1.4$.

Given: $V_1 = 0.12 \text{ m}^3$; $P_1 = 550 \text{ KPa}$; $V_2 = 0.25 \text{ m}^3$

$$W = \frac{P_1 V_1}{(1 - k)} \left[\left(\frac{V_1}{V_2} \right)^{k-1} - 1 \right] = 42 \text{ KJ}$$

3. Air at 0.07 m³ and 4000 KPa is expanded in an engine cylinder and the pressure at the end of expansion is 320 KPa. If the expansion is polytropic with $PV^n = C$ where $n = 1.35$, find the final volume.

Given: $V_1 = 0.07 \text{ m}^3$; $P_1 = 4000 \text{ KPa}$; $P_2 = 320 \text{ KPa}$; $PV^{1.35} = C$

$$P_1 V_1^n = P_2 V_2^n$$

$$V_2 = V_1 \left(\frac{P_1}{P_2} \right)^{\frac{1}{n}} = 0.455$$

4. Gas at a pressure of 100 KPa, volume 0.20 m³ and temperature 300°K, is compressed until the pressure is 320 KPa and the volume is 0.09 cu.m.. Calculate the final temperature in °K.

Given: $P_1 = 100 \text{ KPa}$; $V_1 = 0.20 \text{ m}^3$; $T_1 = 300^\circ\text{K}$; $P_2 = 320 \text{ KPa}$; $V_2 = 0.09 \text{ m}^3$

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

$$T_2 = 432^\circ\text{K}$$

5. Helium gas ($R = 2.077 \text{ KJ/kg-K}$; $k = 1.667$) at 800 KPa and 300°K occupies a volume of 0.30 m³. Determine the mass of helium in kg.

$$PV = mRT$$

$$m = 0.39 \text{ kg}$$

6. A rigid container containing 25 kg of nitrogen gas at 298°K receives heat and its temperature is increased to 370°K. Determine the amount of heat added in KJ.

For N₂: $R = 0.297 \text{ KJ/kg-}^\circ\text{K}$; $k = 1.399$

$$C_v = 0.7444 \text{ KJ/kg-}^\circ\text{K}$$

$$Q = mC_v \Delta T = 1334 \text{ KJ}$$

7. A 2 kg steam-water mixture at 1000 KPa and 90% quality ($U = 2401.41 \text{ KJ/kg}$) is contained in a rigid tank. Heat is added until the pressure rises to 3500 KPa and the temperature is 400°C ($U = 2926.4 \text{ KJ/kg}$). Determine the heat added in KJ.

$$Q = m(U_2 - U_1) = 1045 \text{ KJ}$$

8. Calculate the pressure of 2 moles of air at 400°K, with a total volume of 0.5 m³.

$$PV = mRT = nMRT = n\bar{R}T$$

$$P = 13.3 \text{ MPa}$$

9. A 100 Liters oxygen tank use in a hospital has a pressure of 1 atmosphere and a temperature of 16°C. For a molecular weight of 32 kg/kg_{mol}, determine the mass of oxygen in kilograms.

$$PV = mRT$$

$$T = 289^\circ\text{K}; P = 101.325 \text{ KPa}$$

$$m = 0.135 \text{ kg}$$

10. An unknown gas has a mass of 1.5 kg and occupies 2.5 m³ while at a temperature of 300°K and a pressure of 200 KPa. Determine the gas constant for the gas in KJ/kg-°K.

$$R = \frac{PV}{mT} = 1.111 \text{ KJ/kg-}^\circ\text{K}$$

PROBLEM SOLVING

1. A steady flow compressor handles 113.3 m³/min of nitrogen (M = 28; k = 1.399) measured at intake where P₁= 97 KPa and T₁= 27° C. Discharge is at 311 KPa. The changes in ΔKE and ΔPE are negligible. For each of the following cases, determine the final temperature and the work if the process is:
 - a) PV^k= C (418.25 K ; W= -253.1 KW)
 - b) PV = C (300 K; W = -213.4 KW)
2. Air is contained in a cylinder fitted with a frictionless piston. Initially the cylinder contains 500 L of air at 150 KPa and 20° C. The air is then compressed in a polytropic process (PVⁿ = C) until the final pressure is 600 KPa, at which point the temperature is 120° C. Determine the work W and the heat transfer Q.

ME 331D

Special Midterm Exam

January _____, 2008

Name of Student _____ Score _____

Course & Year _____

Multiple Choice

Instruction: Encircle the letter which corresponds to the correct answer in the questions below. If you want to change your answer cross-out your first choice and encircle the new one.

I. Multiple Choice

1. A 2 kg steam-water mixture at 1000 KPa and 90% quality ($U = 2401.41$ KJ/kg; $h = 2576.57$ KJ/kg) is contained in a rigid tank. Heat is added until the pressure rises to 3500 KPa and the temperature is 400°C ($U = 2926.4$ KJ/kg; $h = 3222.3$ KJ/kg). Determine the heat added.
a. 2598 b. 1292 c. 1045 d. 3467
2. Calculate the pressure of 2 moles of air at 400°K , with a total volume of 0.5 m^3 .
a. 10.8 MPa b. 19.2 MPa c. 13.3 MPa d. 15.5 MPa
3. A 100 Liters oxygen tank use in a hospital has a pressure of 1 atmosphere and a temperature of 16°C . For a molecular weight of $32\text{ kg/kg}_{\text{mol}}$, determine the mass of oxygen in kilograms.
a. 0.245 b. 0.335 c. 0.135 d. 0.835
4. An unknown gas has a mass of 1.5 kg and occupies 2.5 m^3 while at a temperature of 300°K and a pressure of 200 KPa. Determine the gas constant for the gas in KJ/kg- $^{\circ}\text{K}$.
a. 3.111 b. 2.111 c. 1.111 d. 4.111
5. Gas at a pressure of 100 KPa, volume 0.20 m^3 and temperature 300°K , is compressed until the pressure is 320 KPa and the volume is 0.09 cu.m. . Calculate the final temperature in $^{\circ}\text{K}$.
a. 530 b. 432 c. 632 d. 730
6. Helium gas ($R=2.077$ KJ/kg-K; $k= 1.667$) at 800 KPa and 300°K occupies a volume of 0.30 m^3 . Determine the mass of helium in kg.
a. 0.49 b. 0.39 c. 0.69 d. 0.59
7. A rigid container containing 25 kg of nitrogen gas at 298°K receives heat and its temperature is increased to 370°K . Determine the amount of heat added in KJ.
For N_2 : $R = 0.297$ KJ/kg- $^{\circ}\text{K}$; $k = 1.399$
a. 5338 b. 1334 c. 2556 d. 3885
8. A closed gaseous system undergoes a reversible process in which 40 KJ of heat are rejected and the volume changes 0.15 m^3 to 0.60 m^3 . The pressure is constant at 2000 KPa. Determine the change of internal energy ΔU in KJ.
a. -130 b. 50 c. -90 d. 320
9. Air in a piston - cylinder occupies 0.12 m^3 at 550 KPa. The air expands isentropically doing work on the piston until the volume is 0.25 m^3 . Determine the work W in KJ. For Air $R = 0.287$ KJ/kg- $^{\circ}\text{K}$ and $k = 1.4$.
a. 42 b. 59 c. 32 d. 69
10. Air at 0.07 m^3 and 4000 KPa is expanded in an engine cylinder and the pressure at the end of expansion is 320 KPa. If the expansion is polytropic with $PV^n = C$ where $n = 1.35$, find the final volume.
a. 0.455 b. 0.565 c. 0.685 d. 0.255

II Problem Solving

1. Two kilograms of helium operates on a three process cycle where the processes are constant volume (1 to 2); constant pressure (2 to 3); and constant temperature (3 to 1). Given that $P_1 = 100$ KPa, $T_1 = 300$ K, and $v_1/v_3 = 5$. Determine the pressure, specific volume and temperature around the cycle. For Helium: $R = 2.077$ KJ/kg-K ; $k = 1.666$
2. Air which is initially at 120 KPa and 320°K occupies 0.11 m^3 . It is compressed isothermally until the volume is halved and then compressed it at constant pressure until the volume decreases to $\frac{1}{4}$ of the initial volume. Sketch the process on the PV and TS diagrams. Then determine the pressure, the volume and temperature in each state.

ME 331

Special Quiz/Exam/

1. Two kilograms of helium operates on a three process cycle where the processes are constant

- volume (1 to 2); constant pressure (2 to 3); and constant temperature (3 to 1). Given that $P_1 = 100$ KPa, $T_1 = 300$ K, and $v_1/v_3 = 5$. Determine the pressure, specific volume and temperature around the cycle. For Helium: $R = 2.077$ KJ/kg-K ; $k = 1.666$
2. Air which is initially at 120 KPa and 320°K occupies 0.11 m³. It is compressed isothermally until the volume is halved and then compressed it at constant pressure until the volume decreases to ¼ of the initial volume. Sketch the process on the PV and TS diagrams. Then determine the pressure, the volume and temperature in each state.
-

SPECIAL EXAM

1. A steady flow compressor handles 113.3 m³/min of nitrogen ($M = 28$; $k = 1.399$) measured at intake where $P_1 = 97$ KPa and $T_1 = 27^\circ$ C. Discharge is at 311 KPa. The changes in ΔKE and ΔPE are negligible. For each of the following cases, determine the final temperature and the work if the process is:
- $PV^k = C$
 - $PV = C$
2. Air which is initially at 120 KPa and 320°K occupies 0.11 m³. It is compressed isothermally until the volume is halved and then compressed it at constant pressure until the volume decreases to ¼ of the initial volume. Sketch the process on the PV and TS diagrams. Then determine the pressure, the volume and temperature in each state.
-

Problem Set No. 1

NAME _____

Problem 1: Calculate the theoretical oxygen and air required to burn 1 kmol of carbon, and 1 kmol of Hydrogen.

ANSWER: a. _____ b. _____

Problem 2: Calculate the theoretical Oxygen--fuel ratio and Air--fuel ratio on a mass basis for the combustion of Methanol, CH₃OH.

ANSWER: a. _____ b. _____

Problem 3: Determine the moles of O₂ in the products of combustion when octane C₈H₁₈ is burned with 50% excess air.

ANSWER: a. _____

Problem 4: A certain fuel has the composition C₁₀H₂₂. If this fuel is burned with 50% excess air, what is the mole of CO₂ per mole of fuel.

ANSWER: a. _____

Problem 5: A sample of wood fuel has the following ultimate analysis, percent by mass: 5.6% H₂, 53.4% C, 0.1% S, 0.1% N, 37.9% O₂, and 2.9% ash. This fuel will be used as a fuel by burning it with no excess air in a furnace. Determine the air--fuel ratio on a mass basis and the heating value in KJ/kg.

ANSWER: a. _____ b. _____

Problem 6: Producer gas from bituminous coal contains following molar analysis.

CH₄ = 3.0%; H₂ = 14.0%; N₂ = 50.9%; O₂ = 0.6%; CO = 27.0% and CO₂ = 4.5%.

This is burned with 25% excess air, Calculate the air--fuel ratio on a volumetric basis and on a mass basis.

ANSWER: a. _____ b. _____

Problem 7: Coal from a mine, has the following ultimate analysis, percent by mass:

C = 79.2%, H₂ = 5.7%, O₂ = 10.0%, N₂ = 1.5%, S = 0.6%, and Ash 3.0%.

This coal is to be burned with 30% excess air. For a product pressure of 101 KPa and temperature of 350°C, Calculate cubic meter of CO₂ formed per kg of Fuel.

ANSWER: a. _____

Problem 8: There are 20 kg of flue gas formed per kg of fuel burned for the combustion of C₁₂H₂₆. What is the percent excess air.

ANSWER: a. _____

Problem 9: Butane (C₄H₁₀) is burned with air and a volumetric analysis of the combustion products on a dry basis yields the following composition.CO₂ = 7.8%, CO = 1.1%, O₂ = 8.2% and N₂ = 82.9%

Determine the percent of excess air used in this combustion process.

ANSWER: a. _____

Problem 10: A fuel represented by C_7H_{16} is oxidized with 20% excess air and the mass of fuel required for combustion is 50 kg/hr. Determine the dew point temperature of the products and the average heating value of the fuel.

ANSWER: a. _____ b. _____

A solid fuel is burned with air and the following volumetric analysis on a dry basis is obtained from the products of combustion.

$CO_2 = 10.5\%$, $O_2 = 5.3\%$ and $N_2 = 84.2\%$

Determine the composition of the fuel on a mass basis and the percent of excess air utilized in the combustion process.

Problem 12: An old boiler test provides the data as follows:

Fuel ultimate analysis:

$C = 57.5\%$; $N = 1.0\%$; $H = 3.7\%$

$S = 3.3\%$ & $O = 5.8\%$; $A = 16.5\%$

$M = 12.0\%$

$HHV = 25586 \text{ kJ/kg}$

Flue Gas analysis:

$CO_2 = 13.0\%$; $O_2 = 7.0\%$; $CO = 1.0\%$; $N_2 = 79.0\%$

Combustible solid refuse = 20% ; Flue gas temperature = 185°C :

Relative humidity of Air 64%. The radiation and unaccounted-for loss is assumed to be 3%. Calculate the boiler efficiency.

Problem 13:

Calculate the boiler heat balance on the dry basis for the data as follows:

Fuel ultimate analysis:

$C = 71.81\%$; $N = 1.2\%$; $H = 5.23\%$

$S = 3.34\%$; $O = 10.15\%$ & ; $A = 8.27\%$

HHV = 30428 kJ/kg

Flue Gas analysis:

$\text{CO}_2 = 14.2\%$; $\text{O}_2 = 4.3\%$; $\text{CO} = 0.3\%$ & $\text{N}_2 = 81.2\%$

Combustible Solid Refuse = 0.115 kg per kg of coal burned

Flue gas temperature = 240°C

Fuel and room temperature = 30°C

Relative humidity of Air = 50%.

Problem Set No. 2

Multiple Choice

Instruction: Encircle the letter, which corresponds to the correct answer in the questions below.

If you want to change your answer, cross-out your first choice and encircle the new one.

1. A hydrocarbon fuel represented by C_8H_{18} is burned with air. Its gas constant in KJ/kg-K is equal to;
a. 0.073 b. 0.286 c. 0.0826 d. 0.187
 2. A gaseous mixture has the following volumetric analysis O_2 , 30%; CO_2 , 40% N_2 , 30%. Determine its molecular weight in kg/kg_{mol}.
a. 25.6 b. 35.6 c. 28.9 d. 30.2
 3. The products of combustion of an automotive engine using a diesel fuel has an Orsat analysis as follows; $\text{CO}_2 = 12.5\%$; $\text{O}_2 = 3.5\%$; $\text{CO} = 0.5\%$; $\text{N}_2 = 83.5\%$. The gas constant of the dry flue gas is equal to;
a. 0.287 b. 1.0045 c. 0.1889 d. 1.007
 4. A newly designed high speed European car uses high grade gasoline fuel represented by C_8H_{18} . If this fuel is burned with 30% excess air, determine the actual air-fuel ratio.
a. 20.5 b. 10.87 c. 15.8 d. 19.6
 5. A fuel represented by C_7H_{16} is oxidized with 20% excess air and the mass of fuel required for combustion is 50 kg/hr. Determine the mass flow rate of the products in kg/hr.
a. 956.05 b. 906.05 c. 806.07 d. 856.07
 6. A coal fired steam boiler uses 3000 kg of coal per hour. Air required for combustion is 15 kg per kg of coal at barometric pressure of 95 KPa and temperature of 30°C . The flue gas has a temperature of 285°C and a volumetric analysis of as follows, $\text{CO}_2 = 15.53\%$; $\text{H}_2\text{O} = 3.53\%$; $\text{SO}_2 = 0.05\%$; $\text{O}_2 = 3.43\%$; $\text{N}_2 = 77.46\%$. Assuming an ash loss of 11%, determine the required stack height and diameter if the actual draft is 20.5 mm of water and draft losses of 10%.
a. 49 m ; 1.6 m b. 50 m; 1.8 m c. 64 m; 2.2 m d. 49 m; 2.2 m
 7. For a certain ideal gas mixture, $R = 0.270$ KJ/kg-k and $k = 1.3$. Determine the mass of the mixture in kg for 10 moles of the mixture.
a. 408 b. 308 c. 508 d. 208
 8. Determine the molecular weight of a products if $C_p = 1.1$ KJ/kg-K and $k = 1.3$.
a. 28.75 b. 26.75 c. 32.75 d. 39.75
 9. Determine the mass ratio C/H of a hydrocarbon fuel with a chemical formula of $\text{C}_{16}\text{H}_{32}$.
a. 8 b. 10 c. 4 d. 6
 10. The Dalton's Law of partial pressure is called the:
a. Law of additive volume
b. Law of additive mass
c. Law of additive moles
d. Law of additive pressure
7. Consider 2 kg of CO and 1 kg of CH_4 at 32°C that are in a 0.6 m³ rigid drum. Find:
a) the mixture pressure P in KPa

- b) the volumetric analysis
 - c) the partial pressures in KPa
 - d) the heat to cause a temperature rise of 50°C.
8. A gaseous mixture has the following volumetric analysis O_2 , 30%; CO_2 , 40% N_2 , 30%. Determine
- a) the analysis on a mass basis
 - b) the partial pressure of each component if the total pressure is 100 KPa and the temperature is 32°C
 - c) the molecular weight and gas constant of the mixture
9. A gaseous mixture has the following analysis on a mass basis, CO_2 , 30%; SO_2 , 30%; He, 20% and N_2 , 20%. For a total pressure and temperature of 101 KPa and 300 K, Determine
- a) the volumetric or molal analysis
 - b) the component partial pressure
 - c) the mixture gas constant
 - d) the mixture specific heats
10. A cubical tank 1 m on a side, contains a mixture of 1.8 kg of nitrogen and 2.8 kg of an unknown gas. The mixture pressure and temperature are 290 KPa and 340 K. Determine
- a) Molecular weight and gas constant of the unknown gas
 - b) the volumetric analysis
11. A mixture of ideal gases at 30°C and 200 KPa is composed of 0.20 kg CO_2 , 0.75 kg N_2 , and 0.05 kg He. Determine the mixture volume.

THERMODYNAMICS 1

QUIZ NO. 4 (February 2, 2017)

1. A 283 L drum contains a gaseous mixture at 690 KPa and 38°C whose volumetric composition is 30% O_2 and 70% CH_4 . How many kg of mixture must be bled and what mass of O_2 added in order to produce at the original pressure and temperature a mixture whose new volumetric composition is 70% O_2 and 30% CH_4 .
 MFor O_2 : $M = 32$; $k = 1.395$: For CH_4 ; $M = 16$; $k = 1.321$

Condition A	Condition B
$V = 0.283 \text{ L}$ $P = 690 \text{ KPa}$ $T = 311 \text{ K}$ $y_{O_2} = 0.30$ $y_{CH_4} = 0.70$	$V = 0.283 \text{ L}$ $P = 690 \text{ KPa}$ $T = 311 \text{ K}$ $y_{O_2} = 0.70$ $y_{CH_4} = 0.30$

Condition A

$$PV = mRT$$

$$R = \frac{8.3143}{M}$$

$$M = \sum y_i M_i$$

$$M_{O_2} = 32$$

$$M_{CH_4} = 16$$

$$M = 0.30(32) + 0.70(16)$$

$$M = 20.8 \frac{KJ}{kg \cdot K}$$

$$R = 0.40 \frac{KJ}{kg \cdot K}$$

$$m = \frac{690(0.283)}{0.40(311)} = 1.57 \text{ kg}$$

$$m = m_{O_2} + m_{CH_4}$$

$$x_i = \frac{m_i}{m}$$

$$x_i = \frac{y_i M_i}{M}$$

$$x_{O_2} = 46.2\%$$

$$x_{CH_4} = 53.8\%$$

$$m_{O_2} = 0.725 \text{ kg}$$

$$m_{CH_4} = 0.846 \text{ kg}$$

Condition B

$$PV = mRT$$

$$R = \frac{8.3143}{M}$$

$$M = \sum y_i M_i$$

$$M_{O_2} = 32$$

$$M_{CH_4} = 16$$

$$M = 0.70(32) + 0.30(16)$$

$$M = 27.2 \frac{KJ}{kg \cdot K}$$

$$R = 0.306 \frac{KJ}{kg \cdot K}$$

$$m = \frac{690(0.283)}{0.306(311)} = 2.054 \text{ kg}$$

$$m = m_{O_2} + m_{CH_4}$$

$$x_i = \frac{m_i}{m}$$

$$x_i = \frac{y_i M_i}{M}$$

$$x_{O_2} = 82.4\%$$

$$x_{CH_4} = 17.6\%$$

$$m_{O_2} = 1.692 \text{ kg}$$

$$m_{CH_4} = 0.362 \text{ kg}$$

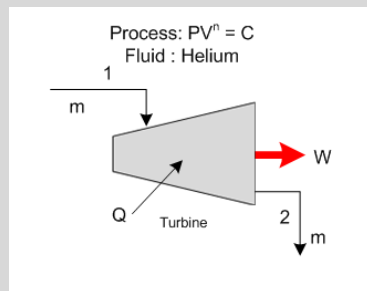
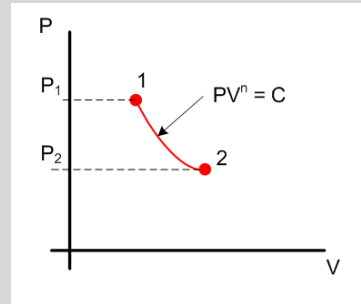
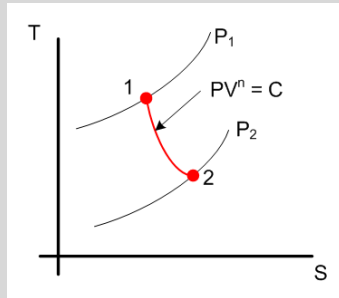
$$1.57 - (0.846 - 0.362) + (1.692 - 0.725 + m_{O_2 \text{ Removed}}) = 2.054$$

$$m_{O_2 \text{ Removed}} = 2.054 - (1.692 - 0.725) + (0.846 - 0.362) - 1.57 =$$

$$m_{\text{Bled}} = (0.846 - 0.362) + 0.001 = 0.485 \text{ kg}$$

$$m_{O_2 \text{ Added}} = (1.692 - 0.725) = 0.967 \text{ kg}$$

2. Helium (He; $M = 4$; $k = 1.666$) expands polytropically through a turbine according to the process $PV^{1.5} = C$. The inlet temperature is 1000 K, the inlet pressure is 1000 KPa, and the exit pressure is 150 KPa. The turbine produces 100 MW of power. Determine
- The exit temperature
 - The heat transfer Q in KW
 - The mass flow rate in kg/sec
 - The change of enthalpy in KW
 - The ΔPV in KW



$$P_1 = 1000 \text{ KPa} : T_1 = 1000 \text{ K}$$

$$P_2 = 150 \text{ KPa} : T_2 = 531.3 \text{ K}$$

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} = 531.3 \text{ K}$$

$$Q = \Delta h + \Delta KE + \Delta PE + W$$

$$W = Q - (\Delta h + \Delta KE + \Delta PE)$$

$$W = Q - (\Delta h + 0 + 0)$$

$$W = \frac{nmRT_1}{1-n} \left[\left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right] = 100,000 \text{ KW}$$

$$m = 34.2 \frac{\text{kg}}{\text{sec}}$$

$$Q = \Delta h + W$$

$$R = \frac{8.3143}{M} = 2.079$$

$$C_p = \frac{Rk}{k-1} = 5.2$$

$$C_v = \frac{R}{k-1} = 3.121$$

$$\Delta h = mC_p(T_2 - T_1) = -83,353.61 \text{ KW}$$

$$Q = -83,353.61 + 100,000 = 16,646.39 \text{ KW}$$

$$\Delta h = \Delta U + \Delta(PV)$$

$$\Delta U = mC_v(T_2 - T_1) = -50,027.93 \text{ KW}$$

$$\Delta(PV) = \Delta h - \Delta U = -33,325.68 \text{ KW}$$

3. A gas turbine generating unit uses liquid C_3H_8 as a fuel at 25°C and 101 KPa. 30% theoretical air is required for combustion at 310 K 101 KPa. The products of combustion leave at 700 K and 101 KPa. Determine
 - a. The combustion equation
 - b. The actual air fuel ratio
 - c. The volume of CO_2 in the products

Fuel: C_3H_8

$P = 101 \text{ KPa}$; $T = 25 + 273 = 298 \text{ K}$

Air

$e = 0.30$

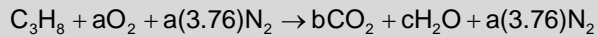
$P = 101 \text{ KPa}$; $T = 310 \text{ K}$

Products

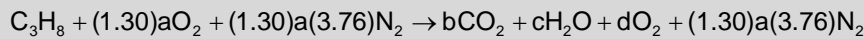
$P = 101 \text{ KPa}$

$T = 700 \text{ K}$

Combustion Equation with 100% theoretical air



Combustion with excess air $e = 0.30$



$$\frac{A}{F} = 20.28$$

$$PV = n\bar{R}T$$

$$V_{CO_2} = \frac{3(8.3143)(700)}{101} = 172.87 \text{ m}^3$$

14. Air is contained in a cylinder fitted with a frictionless piston. Initially the cylinder contains 500 L of air at 150 KPa and 20°C. The air is then compressed in a polytropic process $PV^n = C$ until the final pressure is 600 KPa, at which point the temperature is 120°C. Determine the work W and the heat transfer Q .

15. A steady flow compressor handles 113.3 m³/min of nitrogen ($M = 28$; $k = 1.399$) measured at intake where $P_1 = 97 \text{ KPa}$ and $T_1 = 27^\circ\text{C}$. Discharge is at 311 KPa. The changes in ΔKE and ΔPE are negligible. For each of the following cases, determine the final temperature and the work if the process is:

a) $PV^k = C$ (418.25 K; $W = -253.1 \text{ KW}$)

b) $PV = C$ (300 K; $W = -213.4 \text{ KW}$)

16. During a reversible process executed by a non-flow system the pressure increases from 245 KPa to 1378 KPa in accordance with $PV = C$ and the internal energy increases 22.6 KJ. The initial volume is Find Q in KJ.

17. A piston cylinder contains air at 600 KPa, 290 K and a volume of 0.01 m³. A constant pressure process gives 54 KJ of work out. Determine the heat transfer of the process.

Given:

$$P_1 = P_2 = 600 \text{ KPa}$$

$$T_1 = 290 \text{ K}$$

$$W = P(V_2 - V_1) = mR(T_2 - T_1)$$

$$P_1 V_1 = mRT_1$$

$$m = \frac{P_1 V_1}{RT_1} = 0.07 \text{ kg}$$

$$T_2 = \frac{W}{mR} + T_1 = 478.4 \text{ K}$$

$$V_1 = 0.01 \text{ m}^3$$

$$W = 54 \text{ KJ (work out)}$$

A spherical balloon contains 5 kg of air (ideal gas) at 200 KPa and 500 K. the balloon material is such that the pressure inside is always proportional to the square of the diameter. Determine the work done when the volume of the balloon doubles as result of heat transfer.

Given:

$$m = 5 \text{ kg}$$

$$P_1 = 200 \text{ KPa}$$

$$T_1 = 500 \text{ K}$$

$$P \propto D^2$$

$$V_{\text{sphere}} = \frac{\pi D^3}{6}$$

$$\frac{P_2}{P_1} = \frac{D_2^2}{D_1^2}$$

$$P_1 V_1 = mRT_1$$

$$V_1 = 3.6 \text{ m}^3$$

$$V_2 = 2(3.6) = 7.2 \text{ m}^3$$

As volume increases diameter also increases, therefore volume is directly proportional to diameter.

$$P = CV^2 ; C = \frac{P}{V^2}$$

$$\frac{P_2}{P_1} = \frac{V_2^2}{V_1^2}$$

$$W = \int_1^2 P dV = C \int_1^2 V^2 \cdot dV$$

$$W = \frac{P}{V^2} \left[\frac{V^3}{3} \right]_1^2 = \frac{1}{3} \left[\frac{P_2 V_2^3}{V_2^2} - \frac{P_1 V_1^3}{V_1^2} \right] = \frac{P_2 V_2 - P_1 V_1}{3}$$

$$P_2 = P_1 \left(\frac{V_2}{V_1} \right)^2 = 800 \text{ KPa}$$

A piston cylinder device, whose piston is resting on a set stops, initially contains 3 kg of air at 200 KPa and 27°C. The mass of the piston is such that a pressure of 400 KPa is required to move it. Heat is now transferred to the air until its volume doubles. Determine the work done by the air and the total heat transferred to the air during this process. Also show the process on a P-V diagram.

Given:

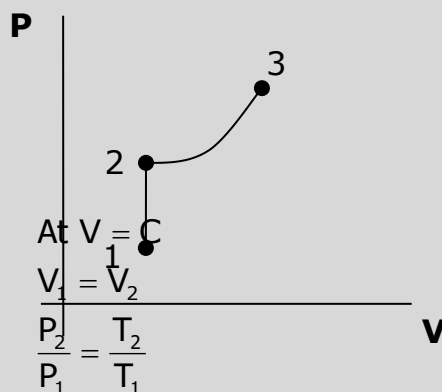
$$m = 3 \text{ kg}$$

$$P_1 = 200 \text{ KPa}$$

$$T_1 = 27 + 273 = 300 \text{ K}$$

$$P = 400 \text{ KPa}$$

$$V_2 = 2V_1$$

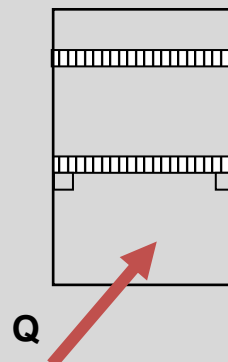


$$T_2 = 600 \text{ K}$$

$$Q_v = 3(0.7175)(600 - 300) = 645.75 \text{ KJ}$$

$$\text{At } P = C$$

$$V_3 = T_3$$



A piston cylinder assembly has 1 kg of propane gas at 700 KPa and 40°C. The piston cross – sectional area is 0.5 m², and the total external force restraining the piston is directly proportional to the cylinder volume squared. Heat is transferred to the propane until its temperature reaches 700°C. Determine the heat transfer during the process.

For Propane

$$C_p = 1.6683 \text{ KJ/kg-K}$$

$$m = 1 \text{ kg} ; P_1 = 700 \text{ KPa} ; T_1 = 313 \text{ K}$$

$$C_v = 1.4799 \text{ KJ/kg-K}$$

$$A = 0.5 \text{ m}^2 ; T_2 = 973 \text{ K}$$

$$k = 1.127$$

$$R = 0.1886 \text{ KJ/kg-K}$$

$$F \propto V^2$$

$$F = CV^2$$

$$P = \frac{F}{A} = \frac{CV^2}{A}$$

$$C = \frac{PA}{V^2} \rightarrow \text{Eq. 1}$$

$$W = \int PdV = \frac{C}{A} \int V^2 \cdot dV$$

$$W = \frac{C}{A} \left[\frac{V^3}{3} \right]_1^2$$

$$W = \frac{C}{3A} [V_2^3 - V_1^3] \rightarrow \text{Eq. 2}$$

$$C = \frac{PA}{V^2}$$

$$\frac{P_1 A}{V_1^2} = \frac{P_2 A}{V_2^2} = C$$

$$P_1 V_1 = mRT_1$$

$$V_1 = \frac{1(0.1886)(313)}{700} = 0.084 \text{ m}^3$$

$$P_2 = \frac{mRT_2}{V_2} = \frac{1(0.1886)(973)}{V_2} = \frac{183.5}{V_2} \rightarrow \text{Eq. 3}$$

$$\frac{700}{(0.084)^2} = \frac{183.5}{V_2^3}$$

$$V_2 = 0.123 \text{ m}^3$$

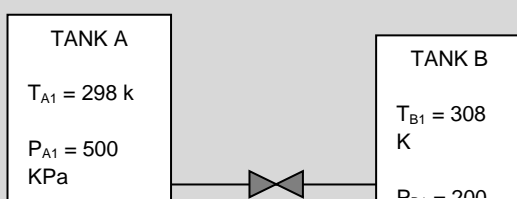
$$W = \frac{P_1}{3V_1^2} (V_2^3 - V_1^3) = 41.94 \text{ KJ}$$

$$Q = \Delta U + W$$

$$\Delta U = mC_v(T_2 - T_1) = 1(1.4799)(973 - 313) = 976.734 \text{ KJ}$$

$$Q = 976.734 + 41.94 = 1018.674 \text{ KJ}$$

One cu. m. rigid tank containing air at 25°C and 500 KPa is connected through a valve to another tank containing 5 kg of air at 35°C and 200 KPa. Now the valve is open, and the entire system is allowed to reach thermal equilibrium with surroundings which are at 20°C. Determine the volume of the second tank and the final equilibrium pressure of air. Assume air as an ideal gas with $k = 1.4$ and $R = 0.287 \text{ KJ/kg-K}$.



$$PV = mRT$$

$$m = \frac{PV}{RT}$$

$$m_A = \frac{500(1)}{0.287(298)} = 5.85 \text{ kg}$$

$$V = \frac{mRT}{P}$$

$$V_B = \frac{5(0.287)(308)}{200} = 2.21 \text{ m}^3$$

$$m = m_A + m_B = 5.85 + 5 = 10.85 \text{ kg}$$

A 0.5 m³ rigid tank containing hydrogen at 20°C and 600 KPa is connected by a valve to another 0.5 m³ rigid tank that holds hydrogen at 30°C and 150 KPa. Now the valve is opened and the system is allowed to reach thermal equilibrium with surroundings which are at 15°C. Determine the final pressure. Assume hydrogen as an ideal gas. (For hydrogen R = 4.125 KJ/kg-K)

Given:

Tank A

$$V_A = 0.5 \text{ m}^3$$

$$T_{A1} = 20 + 273 = 293 \text{ K}$$

$$P_{A1} = 600 \text{ KPa}$$

Tank B

$$V_B = 0.5 \text{ m}^3$$

$$T_{B1} = 30 + 273 = 303 \text{ K}$$

$$P_{B1} = 150 \text{ KPa}$$

$$m = \frac{PV}{RT}$$

$$m_A = \frac{600(0.5)}{4.125(293)} = 0.25 \text{ kg}$$

$$m_B = \frac{150(0.5)}{4.125(303)} = 0.06 \text{ kg}$$

At equilibrium state

$$V = 0.5 + 0.5 = 1 \text{ m}_3$$

$$m = 0.25 + 0.06 = 0.31 \text{ kg}$$

$$P = \frac{0.31(4.125)(15 + 273)}{1}$$

$$P = 368.28 \text{ KPa}$$

A piston-cylinder device contains 0.5 m³ of helium gas initially at 100 KPa and 25°C. At this position, a linear spring is touching the piston but exerts no force on it. Heat is now transferred to helium until both the pressure and the volume triple. Determine

The work done

The amount of heat transfer for this process. Also show the process on the PV diagram.

For Helium

$$R = 2.077 \text{ KJ/kg-K} ; C_p = 5.1984 \text{ KJ/kg-K} ; C_v = 3.1189 \text{ KJ/kg-K}$$

Given:

$$V_1 = 0.5 \text{ m}^3 ; P_1 = 100 \text{ KPa} ; T_1 = 298 \text{ K}$$

$$V_2 = 3(0.5) = 1.5 \text{ m}^3 ; P_2 = 3(100) = 300 \text{ KPa}$$

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

$$T_2 = \frac{298(300)(1.5)}{100(0.5)}$$

$$T_2 = 2682 \text{ K}$$

$$\text{From } PV^n = C$$

$$P_1 V_1^n = P_2 V_2^n = C$$

$$\left(\frac{P_1}{P_2} \right) = \left(\frac{V_2}{V_1} \right)^n$$

During some actual expansion and compression processes in piston cylinder devices, the gases have been observed to satisfy the relationship $PV^n = C$, where n and C are constants. Calculate the work done when a gas expands from a state of 150 KPa and 0.03 m³ to a final volume of 0.2 m³ for the case of $n = 1.3$. Also show the process on the PV diagram.

Given:

$$P_1 = 150 \text{ KPa} ; V_1 = 0.03 \text{ m}^3$$

$$V_2 = 0.2 \text{ m}^3$$

$$P_1 V_1^n = P_2 V_2^n$$

$$P_2 = \frac{P_1 V_1^n}{V_2^n} = P_1 \left(\frac{V_1}{V_2} \right)^n = 150 \left(\frac{0.03}{0.2} \right)^{1.3}$$

$$P_2 = 12.74 \text{ KPa}$$

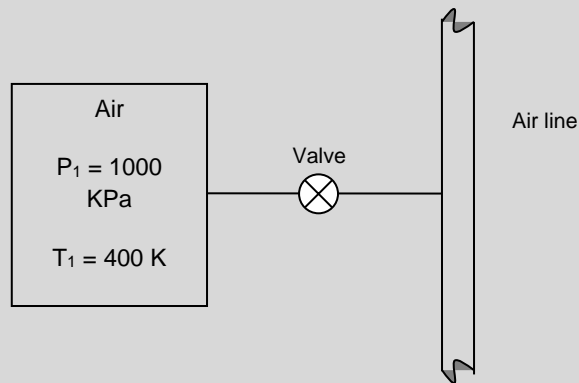
$$W = \int_1^2 P dV = \frac{P_2 V_2 - P_1 V_1}{1 - n} = \frac{12.74(0.2) - 150(0.03)}{1 - 1.3}$$

$$W = 6.533 \text{ KJ}$$

A 1 m³ rigid tank with air at 1 MPa and 127°C is connected to an air line as shown. The valve is opened and air flows into the tank until the pressure reaches 5 MPa, at which point the valve is closed and the temperature inside is 177°C.

What is the mass of air in the tank before and after the process

The tank eventually cools to room temperature at 27°C. What is the pressure inside the tank then.



Given:

Before charging

$$P_1 = 1 \text{ MPa} = 1000 \text{ KPa} ; T_1 = 400 \text{ K} ; V_1 = 1 \text{ m}^3$$

$$m_1 = \frac{P_1 V_1}{RT_1} = \frac{1000(1)}{400} = 2.5 \text{ kg}$$

After charging

$$P_2 = 5 \text{ MPa} = 5000 \text{ KPa} ; T_2 = (177 + 273) = 450 \text{ K} ; V_2 = V_1 = 1 \text{ m}^3$$

$$m_2 = \frac{P_2 V_2}{RT_2} = \frac{5000(1)}{450} = 11.11 \text{ kg}$$

Condition 3: After cooling to room temperature

$$T_3 = 27 + 273 = 300 \text{ K}$$

$$P_3 = \frac{11.11(0.287)(300)}{1} = 956.6 \text{ KPa}$$

At constant volume

$$\frac{P_2}{T_2} = \frac{P_3}{T_3}$$

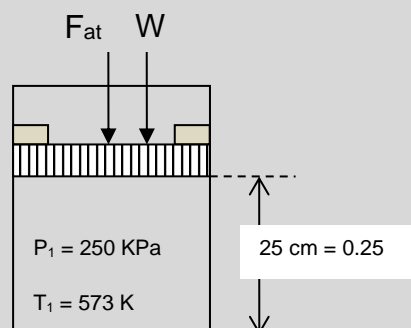
$$P_3 = \frac{300(5000)}{450} = 3333.33 \text{ KPa}$$

$$P_3 = 3.33 \text{ MPa}$$

A piston cylinder arrangement as shown below contains air at 250 KPa, 300°C. The 50 kg piston has a diameter of 0.1 m and initially pushes against the stops. The atmosphere is at 98 KPa and 25°C. The cylinder now cools as heat transferred to the ambient (surrounding).

At what temperature does the piston begin to move down?

How far has the piston dropped when the temperature reaches ambient?

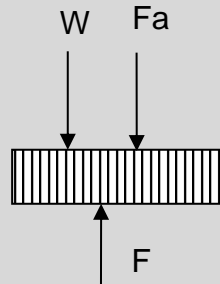


Given:

$$P_1 = 250 \text{ KPa} ; T_1 = 300 + 273 = 573 \text{ K}$$

$$V_1 = \frac{\pi}{4} (0.1)^2 (0.25) = 0.002 \text{ m}^3$$

$$m = \frac{250(0.002)}{0.287(573)} = 0.003 \text{ kg}$$



W – weight of piston

F_a – force exerted by atmospheric air on the piston

F – force exerted by air inside the cylinder after cooling in which the piston begin to move

$$W = \frac{mg}{1000} \text{ KN}$$

$$W = \frac{50(9.81)}{1000} = 0.4905 \text{ KN}$$

$$F_a = P_a A = 98 \left(\frac{\pi}{4} \right) (0.1)^2$$

$$F_a = 0.77 \text{ KN}$$

$$\Sigma F = 0$$

$$W + F_a = F$$

$$F = 0.4905 + 0.77$$

$$F = 1.2605 \text{ KN}$$

P₂ - pressure of air inside
when piston starts to move down

$$P_2 = \frac{F}{A} = \frac{1.2605}{\frac{\pi}{4} (0.1)^2}$$

$$P_2 = 160.5 \text{ KPa}$$

$$PV = mRT$$

T - temperature of air at the instant piston starts to move downward

$$T = \frac{PV}{mR} = \frac{160.5(0.002)}{0.003(0.287)} = 373 \text{ K}$$

Final condition; temperature of air reaches ambient

$$T_2 = 25 + 273 = 298 \text{ K (ambient)}$$

$$V_2 = \frac{0.003(0.287)(298)}{160.5} = 0.0016 \text{ m}^3$$

h – final position of piston

$$V = \frac{\pi}{4} D^2 h$$

$$h = \frac{4(0.0016)}{\pi(0.1)^2} = 0.204 \text{ m} = 20.4 \text{ cm}$$

x - distance travelled by piston

$$x = 25 - 20.4 = 4.6 \text{ cm}$$

SAMPLE PROBLEMS

1. A steady flow compressor handles 113.3 m³/min of nitrogen (M = 28; k = 1.399) measured at intake where P₁ = 97 KPa and T₁ = 27° C. Discharge is at 311 KPa. The changes in ΔKE and ΔPE are negligible. For each of the following cases, determine the final temperature and the work if the process is:

Isentropic

Isothermal

$P_1 = 97$	KPa	
$T_1 = 300$	K	
$P_2 = 311$	KPa	
$M = 28$		
$k = 1.399$		
$(k-1) = 0.399$		
ISENTROPIC		
$T_2 = 418.2$	K	
$W = -253$	KW	
ISOTHERMAL		
$T_2 = 300$	K	
$W = -213$	KW	

ISENTROPIC

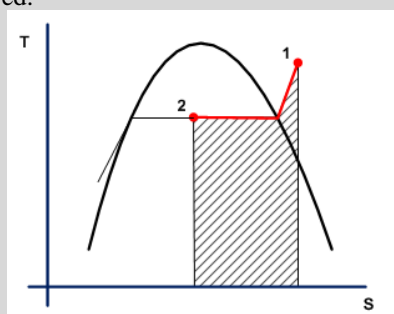
$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1} \right)^{\frac{k-1}{k}} = \left(\frac{V_1}{V_2} \right)^{k-1}$$

$$W = \frac{kP_1V_1}{1-k} \left[\left(\frac{P_2}{P_1} \right)^{\frac{k-1}{k}} - 1 \right]$$

ISOTHERMAL

$$W = -P_1V_1 \ln \frac{P_2}{P_1}$$

2. A cylinder fitted with a frictionless piston contains 5 kg of superheated water vapor at 1000 KPa and 250°C. The system is now cooled at constant pressure until the water reaches a quality of 50%. Calculate the work done and the heat transferred.



System : Closed System (cylinder - piston)

Process : Isobaric ($P = C$)

$$Q = m(h_2 - h_1) \text{ KJ}$$

$$W = mP(v_2 - v_1) \text{ KJ}$$

GIVEN

$m = 5$	kg
$P_1 = 1000$	KPa
$t_1 = 250$	C
$P_2 = 1000$	KPa
$x_2 = 0.5$	
$v_1 = 0.233$	m^3/kg
$h_1 = 2942$	KJ/kg
$h_{f2} = 762.24$	KJ/kg
$h_{g2} = 2774.9$	KJ/kg
$h_2 = 1768.57$	KJ/kg
$Q = -5867.15$	KJ
$W = -676.43$	KJ

$$h = h_f + x(h_g - h_f)$$

At Constant pressure

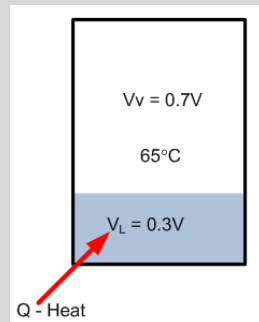
$$Q = m(h_2 - h_1)$$

$$v_2 = 0.097714 \text{ m}^3/\text{kg}$$

$$v_{f2} = 0.001128 \text{ m}^3/\text{kg}$$

$$v_{g2} = 0.1943 \text{ m}^3/\text{kg}$$

3. A rigid steel tank contains a mixture of vapor and liquid water at 65°C . The tank has a volume of 0.5 m^3 , the liquid phase occupying 30% of the volume. Determine the amount of heat added to the system to raise the pressure to 3.5 MPa.



$$v = \frac{V}{m}$$

$$m = \frac{V}{v}$$

$$V = V_L + V_v = 0.5 \text{ m}^3$$

$$m = m_L + m_v$$

L refers to liquid

v refers to vapor

$$V_L = 0.30(0.5) = 0.15 \text{ m}^3$$

$$V_v = 0.70(0.5) = 0.35 \text{ m}^3$$

$$m_L = \frac{V_L}{v_{f1}} = 147.07 \text{ kg}$$

$$m_v = \frac{V_v}{v_{g1}} = 0.0565 \text{ kg}$$

$$m = 147.13 \text{ kg}$$

$$x_1 = \frac{m_v}{m} = 0.000384$$

$$v_1 = v_{f1} + x_1(v_{g1} - v_{f1})$$

$$x_1 = \frac{m_v}{m} = 0.000384$$

$$v_1 = v_{f1} + x_1(v_{g1} - v_{f1})$$

$$v_1 = 0.0033984 \frac{\text{m}^3}{\text{kg}}$$

$$U_1 = U_{f1} + x_1(U_{fg1})$$

$$U_1 = 272.861 \frac{\text{KJ}}{\text{kg}}$$

$$v_2 = v_1 = 0.0033984 \frac{\text{m}^3}{\text{kg}}$$

$$v_2 = v_{f2} + x_2(v_{g2} - v_{f2})$$

$$x_2 = \frac{v_2 - v_{f2}}{(v_{g2} - v_{f2})} = 0.4838$$

$$U_2 = U_{f2} + x_2(U_{fg2})$$

$$U_2 = 1799.323 \frac{\text{KJ}}{\text{kg}}$$

$$Q = m(U_2 - U_1) = 224,587.86 \text{ KJ}$$

From Steam table

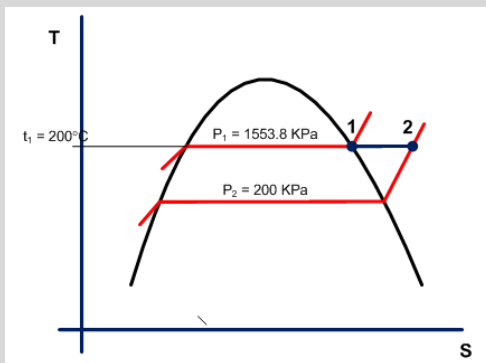
At 65°C

$v_{f1} = 0.0010199$
 $v_{g1} = 6.197$
 $u_{f1} = 272.02$
 $u_{g1} = 2463.1$
 $u_{fg1} = 2191.1$
 $V = 0.5$
 $V_L = 0.15$
 $V_v = 0.35$
 $m_L = 147.073242$
 $m_v = 0.05648$
 $m = 147.12972$
 $x_1 = 0.000384$
 $v_1 = 0.003398$
 $U_1 = 272.86110$

At 3500 Kpa

$v_{f2} = 0.0012347$
 $v_{g2} = 0.005707$
 $u_{f2} = 1045.43$
 $u_{g2} = 2603.7$
 $u_{fg2} = 1558.3$
 $v_2 = 0.00339836$
 $x_2 = 0.4838$
 $U_2 = 1799.323$
 $Q = 224,587.86$

4. Saturated vapor water at 200°C is contained in a cylinder fitted with a piston. The initial volume of the cylinder is 25 L. The steam then expands in a quasi-equilibrium isothermal process until the final pressure in the cylinder is 200 KPa, and in so doing does work against the piston. Determine the work done during the process. (Isothermal process is a constant temperature process)



System : Closed System

Process : Isothermal

$$T_1 = T_2$$

$$Q = \Delta U + W$$

$$Q = T(S_2 - S_1)$$

$$\Delta U = m(U_2 - U_1)$$

$$m = \frac{V}{v} = \frac{0.025}{0.12736} = 0.1963 \text{ kg}$$

From Steam Table

At $t_1 = 200^\circ\text{C}$ (saturated vapor)

$P_1 = 1553.8 \text{ Kpa}$
 $U_1 = 2595 \text{ KJ/kg}$
 $h_1 = 2793.2 \text{ KJ/kg}$
 $S_1 = 6.4323 \text{ KJ/kg-K}$
 $v_1 = 0.12736 \text{ m}^3/\text{kg}$
 $m = 0.1963 \text{ kg}$

At $P_2 = 200 \text{ Kpa}$ and $t_2 = 200^\circ\text{C}$
(Superheated Vapor)

$U_2 = 2654.4 \text{ KJ/kg}$
 $h_2 = 2870.5 \text{ KJ/kg}$
 $S_2 = 7.5066 \text{ KJ/kg-K}$
 $T = 473 \text{ K}$
 $Q = 99.75 \text{ KJ}$
 $\Delta U = 11.66 \text{ KJ}$
 $W = 88.09 \text{ KJ}$

5. A small steam turbine operating at part load produces 110 KW output with a steam flow rate of 0.25 kg/sec. Steam at 1.4 MPa, 250°C is throttled to 1.1 MPa before entering the turbine, and the turbine exhaust pressure is 10 KPa. Find the steam quality (or temperature, if superheated) at the turbine outlet.

System : Open System (Steam Turbine)

Process : Adiabatic (Actual)

$$W = Q - \Delta h - \Delta KE - \Delta PE$$

$$\Delta KE = 0$$

$$\Delta PE = 0$$

$$Q = 0$$

$$W = -\Delta h = m(h_2 - h_3)$$

$$h_3 = h_2 - \frac{W}{m} = 2487.2 \frac{\text{KJ}}{\text{kg}}$$

$$h_3 = h_{f3} + x_3(h_{fg3})$$

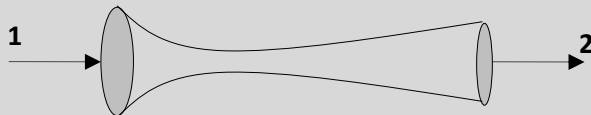
$$x_3 = 95.93\%$$

From Steam table			
At $P_1 = 1400 \text{ KPa}$; $t_1 = 250^\circ\text{C}$		$W = 110$	KW
$h_1 = 2927.2$	KJ/kg	$m = 0.25$	kg/sec
At $P_2 = 1.1 \text{ Mpa}$		$h_3 = 2487.2$	
$h_2 = 2927.2$		$x_3 = 0.9593$	
At $P_3 = 10 \text{ KPa}$			
$h_{f3} = 191.83$	KJ/kg		
$h_{fg3} = 2392.8$	KJ/kg		
$h_{g3} = 2584.7$	KJ/kg		

7. Oxygen expands in a reversible adiabatic manner through a nozzle from an initial pressure and initial temperature and with an initial velocity of 50 m/sec. there is a decrease of 38°K in temperature across the nozzle. Determine

a. the exit velocity

b. for inlet conditions of 410 KPa and 320 K, find the exit pressure.



Given:

$$v_1 = 50 \text{ m/sec}$$

$$\Delta T = 38 \text{ K}$$

$$P_1 = 410 \text{ KPa} ; T_1 = 320 \text{ K}$$

$$\text{For O}_2: C_p = 0.918 \text{ KJ/kg-K} ; k = 1.395$$

$$Q = \Delta h + \Delta KE + \Delta PE + W$$

$$Q = 0; W = 0; \text{ and } \Delta PE = 0$$

$$\Delta KE = -\Delta h = -C_p(T_2 - T_1)$$

$$\frac{v_2^2 - v_1^2}{2000} = -C_p(T_2 - T_1)$$

$$v_2 = \sqrt{v_1^2 - 2000C_p(T_2 - T_1)} \rightarrow \text{exit velocity}$$

$$v_2 = 259.4 \frac{\text{m}}{\text{sec}}$$

$$T_2 - T_1 = -38 \text{ K}$$

$$T_2 = 320 - 38 = 282 \text{ K}$$

$$\frac{P_2}{P_1} = \left(\frac{T_2}{T_1} \right)^{\frac{k}{k-1}}$$

$$P_2 = 262.4 \text{ KPa}$$

8. A throttling calorimeter is connected to the main steam line where the pressure is 1.75 MPa. The calorimeter pressure is 90 KPa and 105°C. Determine the main steam quality.

From steam table

At 1.75 MPa; $h_f = 878.50 \text{ KJ/kg}$; $h_g = 2796.4 \text{ KJ/kg}$

At 90 KPa and 105°C; $h = 2687.55 \text{ KJ/kg}$

$h_1 = h$ at 1.75 MPa and unknown quality

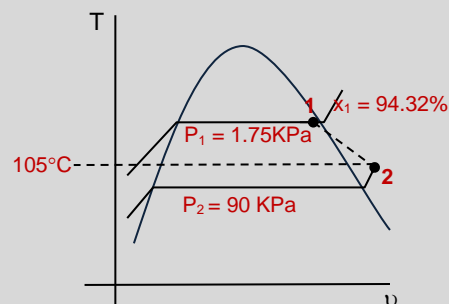
$h_2 = h$ at 90 KPa and 105°C

$h_1 = h_2$

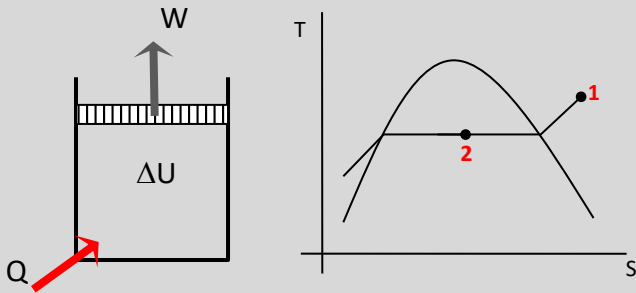
$h_1 = hf_1 + x_1(hfg_1) = h_2$

$2687.55 = 878.5 + x_1(2796.4 - 878.5)$

$x_1 = 0.9432 = 94.32\%$



9. A cylinder fitted with a frictionless piston contains 5 kg of superheated water vapor at 1000 KPa and 250°C. The system is now cooled at constant pressure until the water reaches a quality of 50%. Calculate the work done and the heat transferred.



From Steam Table:

At 1000 KPa and 250°C
(superheated)

$h = 2942.6 \text{ KJ/kg}$

$U = 2709.90 \text{ KJ/kg}$

$S = 6.9247 \text{ KJ/kg-}^\circ\text{C}$

$v = 0.2327 \text{ m}^3/\text{kg}$

At 1000 KPa and $x = 50\%$

$h = 1770.46 \text{ KJ/kg}$

$U = 1672.64 \text{ KJ/kg}$

$S = 4.3626 \text{ KJ/kg-}^\circ\text{C}$

10. A 0.5 m³ tank contains saturated steam at 300 KPa. Heat is transferred until the pressure reaches 100

$$U_1 = 2709.9 \text{ KJ/kg}; h_1 = 2942.6 \text{ KJ/kg}$$

$$U_2 = 1672.64 \text{ KJ/kg}; h_2 = 1770.46 \text{ KJ/kg}$$

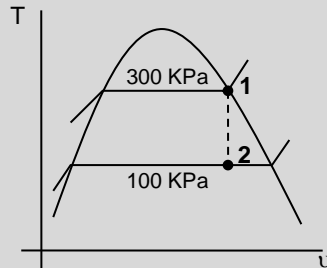
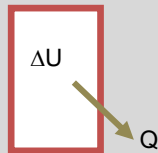
$$Q = \Delta U + W$$

$$\Delta U = m(U_2 - U_1) = 5(1672.64 - 2709.9) = -5186.3 \text{ KJ}$$

$$W = m \int_1^2 P dv = mP(v_2 - v_1) = 5(1000)(0.97784 - 0.2327) = -674.58 \text{ KJ (work is done on the system)}$$

$$Q = -5860.88 \text{ KJ (heat is rejected)}$$

KPa. Determine the heat transferred and the final temperature.



$$v = \frac{V}{m}$$

$$m = \frac{0.5}{0.6058} = 0.825 \text{ kg}$$

Process: Constant Volume

$$W = 0$$

$$Q = \Delta U$$

$$Q = m(U_2 - U_1)$$

From Steam Table at P = 300 KPa (saturated vapor)

$$U_1 = 2543.6 \text{ KJ/kg}$$

$$v_1 = 0.6058 \text{ m}^3/\text{kg}$$

From steam Table at 100 KPa

$$v_g = 1.694 \text{ m}^3/\text{kg}; v_f = 0.0010432 \text{ m}^3/\text{kg}$$

$$v_{fg} = v_g - v_f = 1.693 \text{ m}^3/\text{kg}$$

$$U_g = 2506.1 \text{ KJ/kg}; U_f = 417.36 \text{ KJ/kg}; U_{fg} = 2088.7 \text{ KJ/kg}$$

$$v_2 = v_1$$

$$v_2 = 0.0010432 + x_2(1.693) = 0.6058$$

$$x_2 = 0.357 = 35.7\%$$

$$U_2 = 417.36 + (0.357)(2088.7) = 1163.465 \text{ KJ/kg}$$

$$Q = 0.825(1163.465 - 2543.6) = -1138.6 \text{ KJ}$$

$$Q = 1138.6 \text{ KJ (Heat is rejected from the system)}$$

11. A reversible nonflow constant volume process decreases the internal energy by 316.5 KJ for 2.3 kg of a gas for which $R = 0.47 \text{ KJ/kg} \cdot ^\circ\text{K}$ and $k = 1.35$. For the process, determine

a. the work

b. the heat

c. the entropy change if the initial temperature is 478°K

Given:

$$\Delta U = -316.5 \text{ KJ}$$

$$m = 2.3 \text{ kg}$$

$$R = 0.47 \text{ KJ/kg} \cdot ^\circ\text{K}$$

$$k = 1.3$$

$$T_1 = 478^\circ\text{K}$$

Solution

$$\text{At } V = C; Q = \Delta U = mC_v(\Delta T)$$

$$C_v = \frac{R}{k-1} = \frac{0.47}{1.3-1} = 1.567 \text{ KJ/kg} \cdot ^\circ\text{K}$$

$$Q = -316.5 = 2.3(1.567)(T_2 - 478)$$

$$T_2 = 390^\circ\text{K}$$

a.

$$W = \int P dV = 0$$

b. $Q = -316.5 \text{ KJ}$

$$Q = 316.5 \text{ KJ (heat is rejected)}$$

c.

$$\Delta S = mC_v \ln \frac{T_2}{T_1} = 2.3(1.567) \ln \frac{390}{478} = -0.733 \frac{\text{KJ}}{^\circ\text{K}}$$

12. In a turbine 4500 kg/min of air expands polytropically from 425 KPa and 1360°K to 101 KPa. The exponent $n = 1.45$ for the process. Find the work done and the heat transfer.

Given:

$$m = 4500 \text{ kg/min}; P_1 = 425 \text{ KPa}; T_1 = 1360^\circ\text{K}; P_2 = 101 \text{ KPa}; PV^n = C$$

$$n = 1.45; \Delta KE \text{ and } \Delta PE \text{ are negligible}$$

$$\text{For Air: } R = 0.287 \text{ KJ/kg} \cdot ^\circ\text{K}; k = 1.4; C_p = 1.0045 \text{ KJ/kg} \cdot ^\circ\text{K};$$

$$C_v = 0.7175 \text{ KJ/kg} \cdot ^\circ\text{K}$$

$$W = Q - \Delta h = \frac{nmRT_1}{1-n} \left[\left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right]$$

$$Q = mC_n(T_2 - T_1); \quad C_n = C_v \left(\frac{k-n}{1-n} \right); \quad T_2 = T_1 \left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}}$$

$$W = \frac{1.45(4500)(0.287)(1360)}{60(1-1.45)} \left[\left(\frac{101}{425} \right)^{\frac{1.45-1}{1.45}} - 1 \right] = 33.938 \text{ KW}$$

$$Q = \frac{4500(0.7175)(1.4-1.45)(1360)}{60(1-1.45)} \left[\left(\frac{101}{425} \right)^{\frac{1.45-1}{1.45}} - 1 \right] = -2926 \text{ KW}$$

$$Q = 2926 \text{ KW (heat is rejected)}$$

13. Steam flows steadily through a turbine with a mass flow rate of 2.52 kg/sec. The inlet steam conditions are 7000 KPa and 500°C. The exit steam pressure is 20 KPa and the expansion is isentropic. Determine the turbine work in KW.

From Steam Table(superheated state)

At 7000 KPa and 500°C

$$h_1 = 3410.3$$

$$U_1 = 3073.4$$

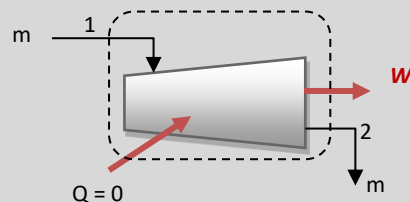
$$S_1 = 6.7975$$

At $S_1 = S_2$ to 20 KPa (saturated mixture region)

$$h_2 = 2239.45$$

$$U_2 = 2110.47$$

$$x_2 = 84.3\%$$



$$Q = \Delta h + \Delta KE + \Delta PE + W$$

$$Q = 0 \text{ (for adiabatic)}$$

ΔKE and ΔPE are negligible

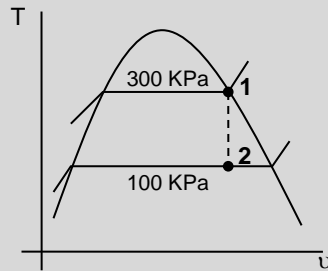
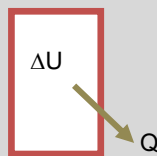
$$W = -\Delta h = -(h_2 - h_1) \text{ KJ/kg}$$

$$W = m(h_1 - h_2) \text{ KW}$$

where m is the mass flow rate in kg/sec

$$W = 2.52(3410.3 - 2239.45) = 2959.54 \text{ KW}$$

A 0.5 m³ tank contains saturated steam at 300 KPa. Heat is transferred until the pressure reaches 100 KPa. Determine the heat transferred and the final temperature.



$$v = \frac{V}{m}$$

$$m = \frac{0.5}{0.6058} = 0.825 \text{ kg}$$

Process: Constant Volume

$$W = 0$$

$$Q = \Delta U$$

$$Q = m(U_2 - U_1)$$

From Steam Table at $P = 300 \text{ KPa}$ (saturated vapor)

$$U_1 = 2543.6 \text{ KJ/kg}$$

$$v_1 = 0.6058 \text{ m}^3/\text{kg}$$

From steam Table at 100 KPa

$$v_g = 1.694 \text{ m}^3/\text{kg}; v_f = 0.0010432 \text{ m}^3/\text{kg}$$

$$v_{fg} = v_g - v_f = 1.693 \text{ m}^3/\text{kg}$$

$$U_g = 2506.1 \text{ KJ/kg}; U_f = 417.36 \text{ KJ/kg}; U_{fg} = 2088.7 \text{ KJ/kg}$$

$$v_2 = v_1$$

$$v_2 = 0.0010432 + x_2(1.693) = 0.6058$$

$$x_2 = 0.357 = 35.7\%$$

$$U_2 = 417.36 + (0.357)(2088.7) = 1163.465 \text{ KJ/kg}$$

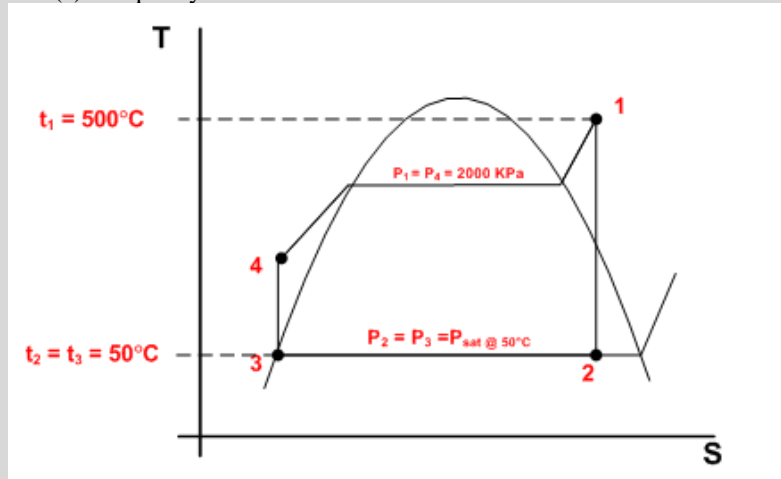
$$Q = 0.825(1163.465 - 2543.6) = -1138.6 \text{ KJ}$$

$$Q = 1138.6 \text{ KJ (Heat is rejected from the system)}$$

SAMPLE PROBLEMS

RANKINE CYCLE

A steam power plant operates on an ideal Rankine cycle. Superheated steam flows into the turbine at 2 MPa and 500°C with a flow rate of 100 kg/s and exits the condenser at 50°C as saturated water. Determine (a) the net power output, (b) the thermal efficiency, and (c) the quality of steam at the turbine exit.



m =	100	kg/sec
h ₁ =	3467.4	KJ/kg
S ₁ =	7.4349	KJ/kg-K
S ₂ =	7.4349	KJ/kg-K
h ₂ =	2383.8	KJ/kg
t ₂	50	C
x ₂	91.301	%
P ₂	12.338	KPa
P ₃ =	12.338	KPa
h ₃ =	209.19	KJ/kg
S ₃ =	0.7036	KJ/kg-K
S ₃ = S ₄	0.7036	KJ/kg-K
h ₄ =	211.21	KJ/kg
W _t =	108,360.00	KW
Q _A =	325,619.00	KW
W _p =	202.00	KW
W =	108,158.00	KW
e =	33.22	%

$$W_t = m_s (h_1 - h_2) \text{ KW}$$

$$Q_A = m_s (h_1 - h_4) \text{ KW}$$

$$W_p = m_s (h_4 - h_3) \text{ KW}$$

$$Q_R = m_s (h_2 - h_3)$$

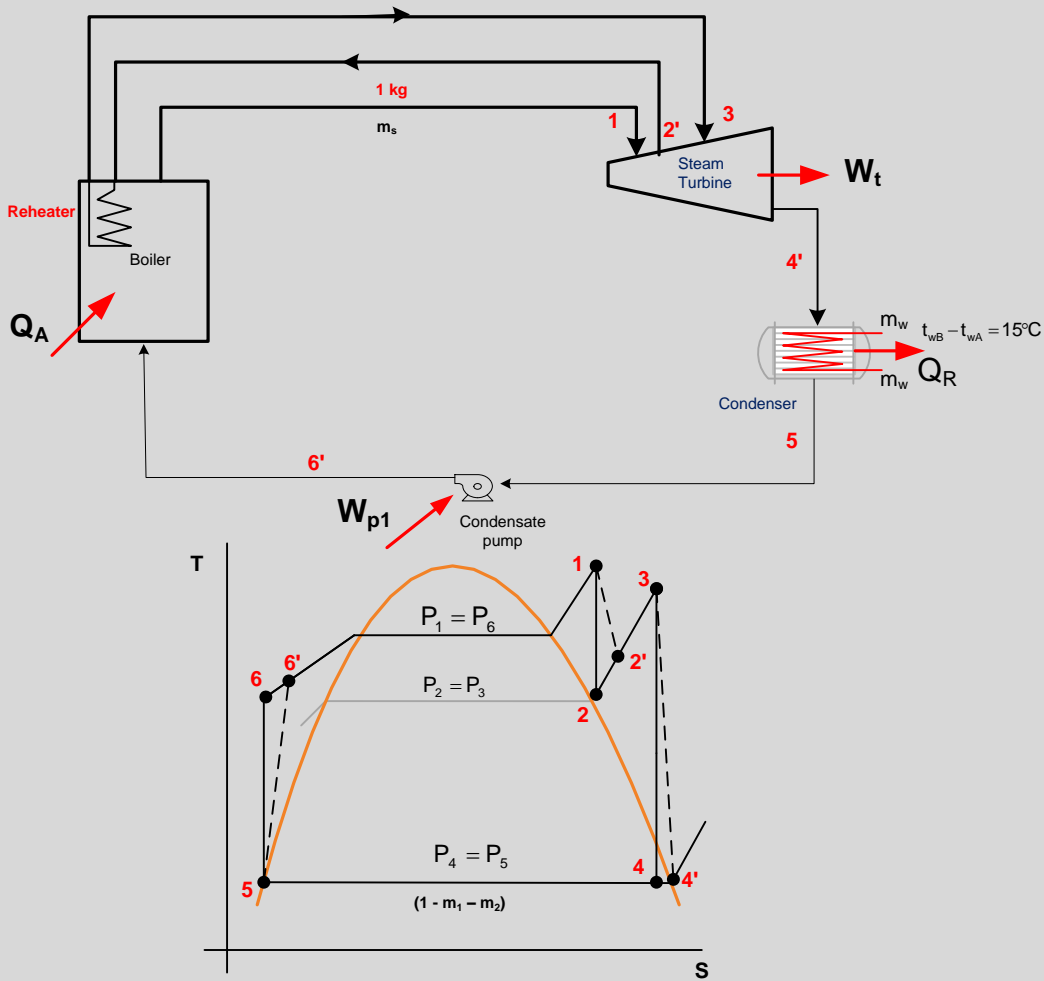
$$W = W_t - W_p$$

$$e = \frac{W}{Q_A} \times 100\%$$

Reheat Cycle

Steam power plant is operating on a reheat Rankine cycle with 80 MW of net output. Steam enters the HP turbine at 10 MPa and 500 °C and expands to 1000 KPa and is reheated at constant pressure to a temperature of 500 °C and re-expand to LP turbine. Steam leaves the condenser as a saturated liquid at 10 kPa. Isentropic efficiencies of the turbine and pump are 80 percent and 95 percent, respectively. Find:

- quality or temperature of steam at turbine exit
- thermal efficiency of the cycle
- mass flow rate of the steam
- condenser cooling water flow rate allowing a water temperature rise of 15 °C
- cycle steam rate kg/KW-hr
- cycle heat rate KJ/KW - hr



$$W_{t'} = (h_1 - h_{2'}) + (h_3 - h_{4'}) \frac{\text{KJ}}{\text{kg}}$$

$$W_{p'} = (h_{6'} - h_5) \frac{\text{KJ}}{\text{kg}}$$

$$W = W_{t'} - W_{p'} \frac{\text{KJ}}{\text{kg}}$$

$$80,000 = m_s (W) \text{ KW}$$

$$m_s = \frac{\text{kg}}{\text{sec}}$$

$$Q_R = m_s (h_{4'} - h_5) = m_w (4.187) (t_{wB} - t_{wA})$$

$$m_w = \frac{\text{kg}}{\text{sec}}$$

$$h_{4'} = h_{f4} + x_{4'} (h_{g4} - h_{f4})$$

$$x_{4'} =$$

$$e_{\text{turbine}} = \frac{h_1 - h_{2'}}{h_1 - h_2} = \frac{h_3 - h_{4'}}{h_3 - h_4} = \frac{W_{t'}}{W_t}$$

$$h_{2'} = h_1 - e_{\text{turbine}} (h_1 - h_2)$$

$$h_{4'} = h_3 - e_{\text{turbine}} (h_3 - h_4)$$

$$Q_{A'} = m_s (h_1 - h_{6'}) \text{ KW}$$

$$e_{\text{Pump}} = \frac{h_6 - h_5}{h_{6'} - h_5} = \frac{W_p}{W_{p'}}$$

$$h_{6'} = \frac{h_6 - h_5}{e_{\text{Pump}}} + h_5$$

$$W_{p'} = m_s (h_{6'} - h_5) \text{ KW}$$

$$\text{CSR} = \frac{m_s (60)}{W} \frac{\text{kg}}{\text{KW} \cdot \text{hr}}$$

$$\text{CHR} = \frac{Q_A (60)}{W} \frac{\text{kg}}{\text{KW} \cdot \text{hr}}$$

P1	t1	h1	S1	e(turbine)	e(pump)
10,000	500	3373	6.5906	0.8	0.95
P2	t2	h2	S2	(h1-h2)	(h6-h5)
1000	180.65	2279.4	6.5906	1093.6	10.08
P3	t3	h3	S3 = S4	h2'	h6'
1000	500	3478.3	7.764	2498.12	202.371
P4	t4	h4	x4 (%)	(h3-h4)	Wt' (KJ/kg)
10	45.83	2583.6	94.857	894.7	1590.64
P5	t5	h5	S5	h4'	Wp' (KJ/kg)
10	45.83	191.76	0.6492	2762.54	10.611
P6	t6	h6	S6	W (KW)	W (KJ/kg)
10000	46.072	201.84	0.6492	10000.000	1580.03
ms (kg/sec)	Wp' (KW)	QA (KW)	e (%)	QR (KW)	(twB-twA)
6.33	67.15	20066.9	49.83	16270.46	15
Cpw	mw(kg/sec)	CSR (kg/KW-hr)	CHR(KJ/KW-hr)		
4.187	259.06	0.038	120.40		

Reheat – Regenerative Cycle

Ideal reheat-regenerative Rankine cycle with one open feedwater heater. The boiler pressure is 10 MPa, condenser pressure is 15 kPa, reheater pressure is 1 MPa, and feedwater pressure is 0.6 MPa. Steam enters the high and low pressure turbines at 500 °C. Find:

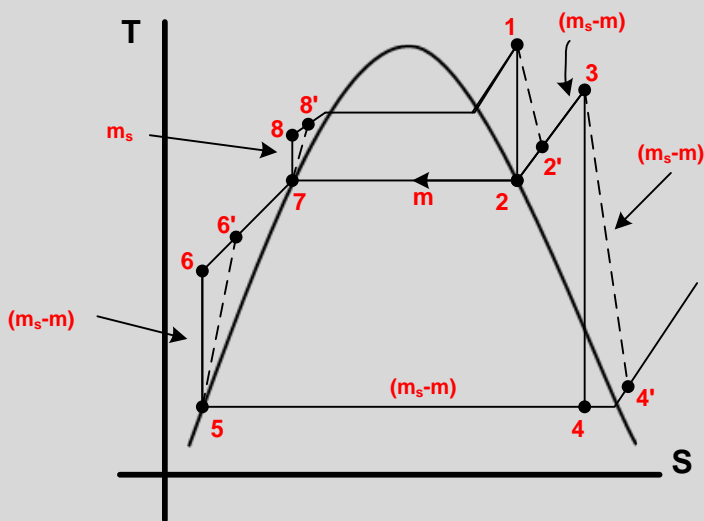
- fraction of steam extracted for regeneration
- thermal efficiency of the cycle.

Example 3

Calculate the power plant efficiency and the net work for a steam power plant that has turbine inlet conditions of 6 MPa and 500°C, bleed steam to the heater occurring at 800 KPa and exhausted to the condenser at 15 KPa. The turbine and pump have an internal efficiencies of 90%. The flow rate is 63 kg/sec. ($\eta = 35.6\%$; $\dot{W} = 60,511$ KW)

A steam power plant operates using the reheat Rankine cycle. Steam enters the high pressure turbine at 12.5 MPa and 550°C at a rate of 7.7 kg/s and leaves at 2 MPa. Steam is then reheated at a constant pressure to 450°C before it expands in the low pressure turbine. The isentropic efficiencies of the turbine and the pump are 85% and 90%, respectively. Steam leaves the condenser as a saturated liquid at 150 KPa. Determine

- the net power output, and
- the thermal efficiency.



P = 12.5 Mpa ; t = 550 C

h1	s1	
3473.7	6.6250	

P = 2000 Kpa ; S = 6.6250

h2	t2	tsat
2936.9	263.9	212.36

P = 2000 Kpa ; t = 450 C

h3	s3	
3357	7.2900	

P = 96 Kpa ; S = 7.2900

h4	tsat	
2631	96.712	

P =96 Kpa ; Sat. Liquid

h5	s5	
412.52	1.2896	

P = 2000 Kpa ; s = 1.2896		
h6	t6	
414.51	98.629	

P = 2000 Kpa ; Saturatted liq.		
h7	s7	
908.02	2.4465	

P = 12500 Kpa ; s = 2.4465		
h8	tsat	
920.35	214.14	

η_t	η_p
0.85	0.9
h2'	3017.42
h4'	2739.9
h6'	414.7311
h8'	921.72

$$\eta_t = \frac{h1 - h2'}{h1 - h2} = \frac{h3 - h4'}{h3 - h4}$$

$$\eta_p = \frac{h6 - h5}{h6' - h5} = \frac{h8 - h7}{h8' - h7}$$

A coal fired steam power plant produces 150 MW of electric power with a thermal efficiency of 35%. If the energetic efficiency of the boiler is 75%, heating value of coal is 30 MJ/kg, and the temperature rise of the cooling water in the condenser is 10°C, determine (a) the fuel consumption rate in kg/h, and (b) mass flow rate of cooling water.

A power plant operates on a simple Rankine cycle producing a net power of 100 MW. The turbine inlet conditions are 15 MPa and 600°C and the condenser pressure is 10 kPa. If the turbine and pump each has an isentropic efficiency of 85% and there is a 5% pressure drop in the boiler, determine (a) the thermal efficiency, (b) the mass flow rate of steam in kg/h, and (c) the back work ratio. How sensitive is the thermal efficiency on (d) boiler pressure drop, (e) pump efficiency, and (f) turbine efficiency?

ME 26 (Thermodynamics 2)

Quiz No. 6 – May 12, 2016

Name _____

A steam power plant operates on an ideal reheat-regenerative Rankine cycle with two feedwater heaters, one open and one closed. Steam enters the first turbine at 15 MPa and 500°C, expands to 1 MPa, and is reheated to 450°C before it enters the second turbine where it expands to 10 kPa. Steam is extracted from the first turbine at 3 MPa and sent to the closed FWH, where the feedwater

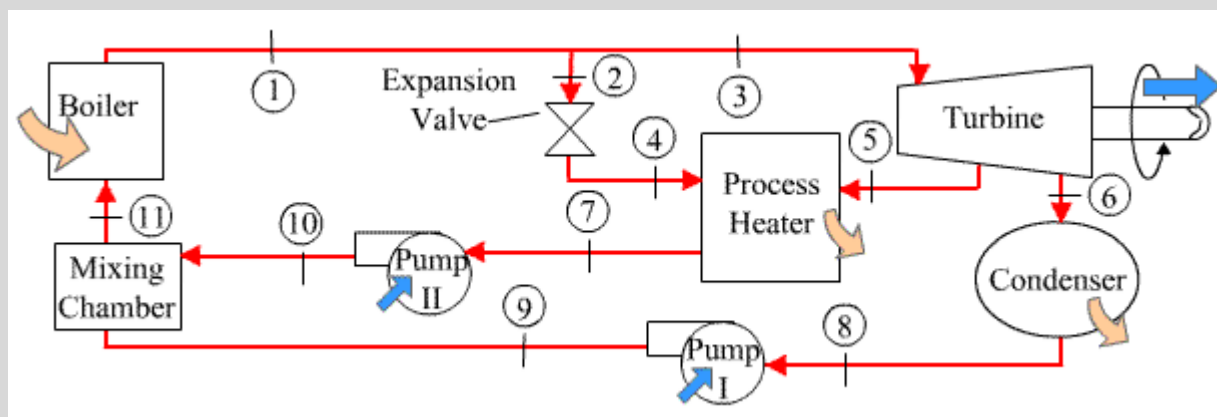
leaves at 5°C below the temperature at which the saturated condensate leaves. The condensate is fed through the trap to the open FWH, which operates at 0.5 MPa. Steam is extracted at 0.5 MPa from the second turbine and is fed to the open FWH. The flow out of the open FWH is saturated liquid at 0.3 MPa. If the power output of the cycle is 150 MW, determine (a) the thermal efficiency, (b) the mass flow rate through the boiler, (c) the bleeding rate from the first turbine, and (d) the bleeding rate from the second turbine. (Note: Draw the Schematic and TS diagram)

A steam power plant operates on an ideal reheat-regenerative Rankine cycle with two feedwater heaters, one open and one closed. Steam enters the first turbine at 15 MPa and 500°C , expands to 1 MPa, and is reheated to 450°C before it enters the second turbine where it expands to 10 kPa. Steam is extracted from the first turbine at 3 MPa and sent to the closed FWH, where the feedwater leaves at 5°C below the temperature at which the saturated condensate leaves. The condensate is fed through the trap to the open FWH, which operates at 0.5 MPa. Steam is extracted at 0.5 MPa from the second turbine and is fed to the open FWH. The flow out of the open FWH is saturated liquid at 0.3 MPa. If the power output of the cycle is 150 MW, determine (a) the thermal efficiency, (b) the mass flow rate through the boiler, (c) the bleeding rate from the first turbine, and (d) the bleeding rate from the second turbine. What would the thermal efficiency be if (e) the closed FWH were eliminated, (f) both the FWH's were eliminated?

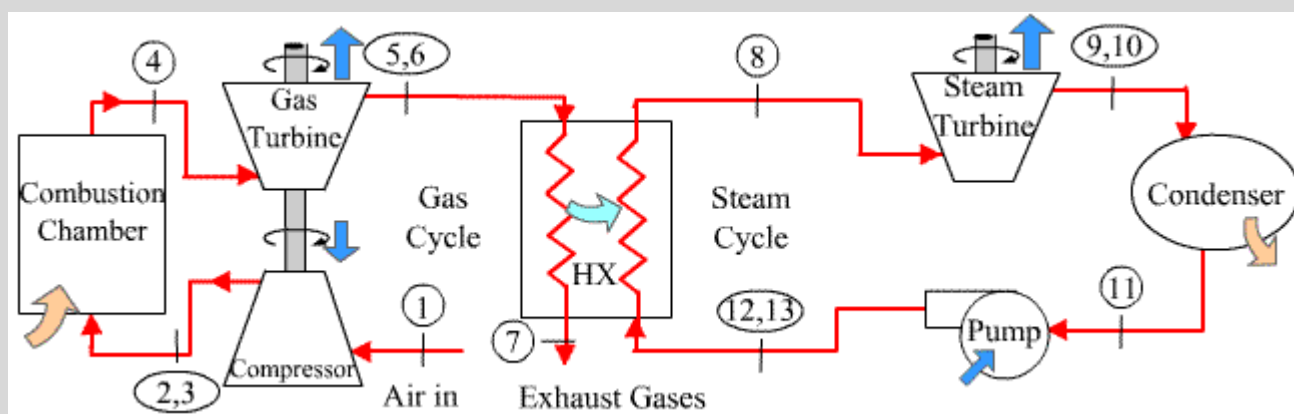
(a) 44.8%, (b) 116.13 kg/s, (c) , (d) , (e) 43.8%, (f) 41.4%

The cogeneration plant has a peak capacity of 25 MW for process heating. Steam leaves the boiler at 8 MPa and 600°C. The process heater and the condenser operate at a pressure of 400 kPa and 8 kPa respectively. Assuming ideal behavior of each component, determine (a) the mass flow rate of steam through the boiler and (b) the maximum turbine output. To meet a certain load condition,

10% of the steam is diverted to the expansion valve, and half the steam flowing through the turbine is extracted. Determine (c) the process heat load, and (d) the utilization factor.
 ANSWER: (a) 8.23 kg/s, (b) 11.9 MW, (c) 10.61 MW, (d) 71.8%,



A combined gas turbine-steam power plant has a net power output of 500 MW. Air enters the compressor of the gas turbine at 100 kPa, 300 K, and has a compression ratio of 12 and an isentropic efficiency of 85%. The turbine has an isentropic efficiency of 90%, inlet conditions of 1200 kPa and 1400 K, and an exit pressure of 100 kPa. The air from the turbine exhaust passes through a heat exchanger and exits at 400 K. On the steam turbine side, steam at 8 MPa, 400°C enters the turbine, which has an isentropic efficiency of 85%, and expands to the condenser pressure of 8 kPa. Saturated water at 8 kPa is circulated back to the heat exchanger by a pump with an isentropic efficiency of 80%. Determine (a) the ratio of mass flow rates in the two cycles, (b) the mass flow rate of air, and (c) the thermal efficiency. (d) What would the thermal efficiency be if the turbine inlet temperature increased to 1600 K?
 ANSWER: (a) 6.673, (b) 1107 kg/s, (c) 53.1%, (d) 54.8%



YURI G. MELLIZA

Water at 60 bar, 60°C and 50 kg/s is heated, vaporized and superheated to 500°C. This steam expands isentropically in a high pressure (HP) steam turbine to 10 bar. Thereafter the steam is brought back to the boiler and reheated under constant pressure to 500°C. A low pressure (LP) turbine expands this steam to 0.2 bar isentropically. What is the cycle efficiency neglecting the pump work?

Problem No. C1 (Ideal Reheat Rankine Cycle)

Consider a steam power plant operating on the ideal reheat Rankine cycle. Steam enters the high pressure turbine at 600°C and 15 MPa and is condensed in the condenser at a pressure of 10 kPa . Assume the steam is reheated to the same temperature as in inlet of the high-pressure turbine. If the moisture content of the steam at the exit of the low-pressure turbine is not to exceed 10.4% , determine

- the pressure at which the steam should be reheated
- the thermal efficiency of the cycle.

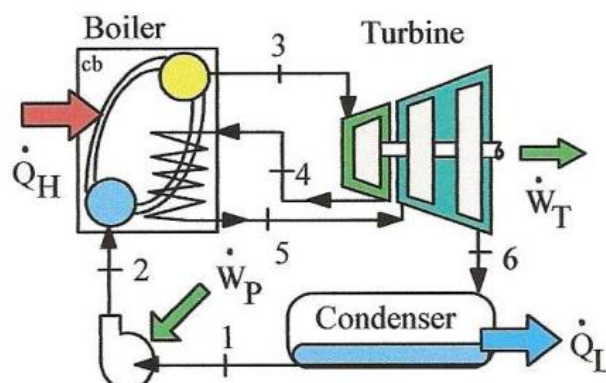
Problem No. C2 (ideal regenerative Rankine cycle with OFH)

Consider a steam power plant operating on the ideal regenerative Rankine cycle with one open feedwater heater. Steam enters the turbine at 600°C and 15 MPa and is condensed in the condenser at a pressure of 10 kPa . Some steam leaves the turbine at a pressure of 1.2 MPa and enters the open feedwater heater. Determine the fraction of steam extracted from the turbine and the thermal efficiency of this cycle.

Problem No. C3 (ideal reheat-regenerative Rankine)

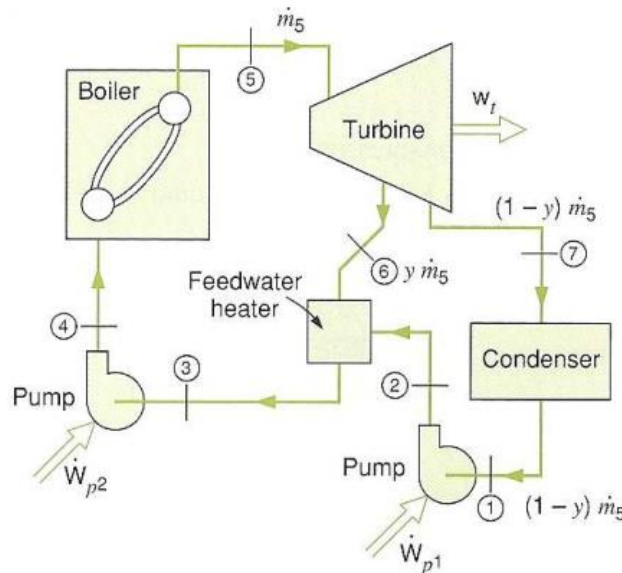
Consider a steam power plant operating on the ideal reheat-regenerative Rankine cycle with one open feedwater heater, one closed feedwater heater and one reheater. Steam enters the turbine at 600°C and 15 MPa and is condensed in the condenser at a pressure of 10 kPa . Some steam leaves the turbine at a pressure of 4 MPa for the closed feedwater heater while the rest of the steam under the same (4 MPa) pressure is reheated to 600°C . The extracted steam is completely condensed in the heater and is pumped to 15 MPa before it mixes with the feedwater at the same pressure. Steam for the open feedwater heater is extracted from the low-pressure turbine at a pressure of 0.5 MPa . Determine the fractions of steam extracted from the turbine and the thermal efficiency of this cycle.

Consider an ideal steam reheat cycle where steam enters the high-pressure turbine at 4.0 MPa , 400°C , and then expands to 0.8 MPa . It is then reheated to 400°C and expands to 10 kPa in the low-pressure turbine. Calculate the cycle thermal efficiency and the moisture content of the steam leaving the low-pressure turbine.



Consider a 600 MW reheat-Rankine cycle steam power plant. The boiler pressure is 1000 *psia*, the reheater pressure is 200 *psia*, and the condenser pressure is 1 *psia*. Both turbine inlet temperatures are 1000°F. The water leaving the condenser is saturated liquid. Determine the thermal efficiency of the power plant and the boiler mass flow rate in *lbm/hr*.

A power plant with one open feedwater heater has a condenser temperature of 45°C, a maximum pressure of 6 MPa, and a boiler exit temperature of 900°C. Extraction steam at 1 MPa to the feedwater heater is mixed with the feedwater line so the exit is saturated liquid into the second pump. Find the fraction of extraction steam flow and the two specific pump work inputs.



A steam power plant operates on an ideal reheat Rankine cycle between the pressure limits of 9 MPa and 10 kPa. The mass flow rate of steam through the cycle is 25 kg/s. Steam enters both stages of the turbine at 500°C. If the moisture content of the steam exiting the low-P turbine is not to exceed 10% determine (a) the reheat pressure, (b) total rate of heat input in the boiler and (c) the thermal efficiency of the cycle

A steam power plant operates in the ideal reheat-regenerative Rankine Cycle with one reheater and two feedwater heaters: one open and one closed. Steam enters the high P turbine at 15 MPa and 600°C and the low P turbine at 1 MPa and 500°C. The condenser pressure is 5 kPa. Steam is extracted from the turbine at 0.6 MPa for the closed feedwater heater and at 0.2 MPa for the open feedwater heater. In the closed feedwater heater the feedwater is heated to the condensation temperature of the extracted steam. The extracted steam leaves the closed feedwater heater as a saturated liquid which is subsequently throttled to the open feedwater heater. Show the cycle on a T-s diagram. Determine (a) the fraction of steam extracted from the turbine for the open feedwater heater, (b) the thermal efficiency of the cycle and (c) the net power output for a mass flow rate of 42 kg/s through the boiler.

Steam power plant that operates on a reheat Rankine cycle with 80 MW of net output. Steam enters the high pressure turbine at 10 MPa and 500 °C, and the low pressure turbine at 1 MPa and 500 °C. Steam leaves the condenser as a saturated liquid at 10 kPa. Isentropic efficiencies of the turbine and compressor are 80 percent and 95 percent, respectively.

a) quality or temperature of steam at turbine exit, b) thermal efficiency of the cycle, and c) mass flow rate of the steam. Draw the T-s diagram.

Reheat-Regenerative Rankine Cycle

Ideal reheat-regenerative Rankine cycle with one open feedwater heater. The boiler pressure is 10 MPa, condenser pressure is 15 kPa, reheater pressure is 1 MPa, and feedwater pressure is 0.6 MPa. Steam enters the high and low pressure turbines at 500 °C.

a) fraction of steam extracted for regeneration (y), and b) thermal efficiency of the cycle. Draw the T-s diagram.

1. (Problem 10.16 in the book) The turbine of a steam power plant operating on a simple Rankine cycle produces 1750 kW of power when the boiler is operated at 6 MPa, the condenser at 20 kPa, and the temperature at the turbine entrance is 500°C. Determine the rate of heat supply in the boiler, the rate of heat rejection in the condenser, and the thermal efficiency of the cycle.

2. (Problem 10.20 in the book) A simple Rankine cycle uses water as the working fluid. The boiler operates at 6000 kPa and the condenser at 50 kPa. At the entrance to the turbine, the temperature is 450°C. The isentropic efficiency of the turbine is 94%, pressure and pump losses are negligible, and the water leaving the condenser is subcooled by 6.3°C. The boiler is sized for a mass flow rate of 20 kg/s. Determine the rate at which heat is added in the boiler, the power required to operate the pumps, the net power produced by the cycle, and the thermal efficiency. (Answers: 59660 kW, 122 kW, 18050 kW, 30.3%)
3. (Problem 10.36 in the book) Consider a steam power plant that operates on the ideal reheat Rankine cycle. The plant maintains the boiler at 7000 kPa, the reheat section at 800 kPa, and the condenser at 10 kPa. The mixture quality at the exit of both turbines is 93%. Determine the temperature at the inlet of each turbine and the cycle's thermal efficiency. (Answers: 373°C, 416°C, 37.6%)
4. (Problem 10.38 in the book) A steam power plant operates on the reheat Rankine cycle. Steam enters the high-pressure turbine at 12.5 MPa and 550°C at a rate of 7.7 kg/s and leaves at 2 MPa. Steam is then reheated at constant pressure to 450°C before it expands in the low-pressure turbine. The isentropic efficiencies of the turbine and pump are 85% and 90%, respectively. Steam leaves the condenser as a saturated liquid. If the moisture content of the steam at the exit of the turbine is not to exceed 5%, determine (a) the condenser pressure, (b) the net power output, and (c) the thermal efficiency. (Answers: (a) 9.73 kPa, (b) 10.2 MW, (c) 36.9%)