1. Introduction

The air conditioner used in automobile works under vapour compression principle, for which a compressor is required. The power required for the air conditioner compressor is drawn from the engine, resulting in increased fuel consumption. The fuel economy of a vehicle drops when the compressor is coupled to the engine. So energy efficient air conditioning systems are getting attention from the automotive industry to improve the fuel economy. The ac compressor is powered by engine via belt drive (from crank shaft pulley to compressor pulley), which consumes about 20% engine power for normal cooling effect of AC. Due to this, fuel consumption of car increases.

Generally the exhaust from the engine takes away about 30% of the energy produced by the engine. This exhaust energy from the automobile is unutilized. The exhaust gases contain heat energy and pressure energy. The pressure energy can be used by converting it into kinetic energy by allowing the gases to pass through a restricted area.

Considering the above scenario, we used a turbine to convert the kinetic energy available in exhaust gases into mechanical energy. The turbine shaft power is used to run the car AC compressor by using a belt drive.

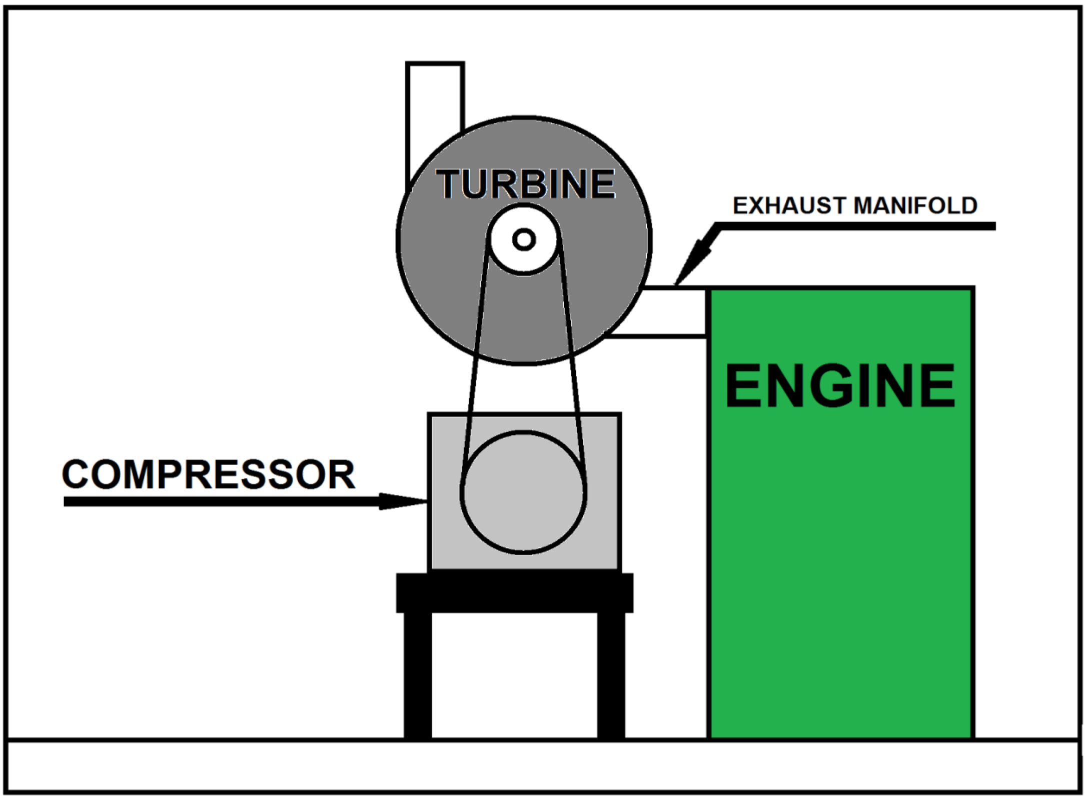

Figure 1: BLOCK DIAGRAM OF E.P.A.A.C.S.

2. Literature Review

2.1 IC Engine

The internal combustion engine is an engine in which the burning of a fuel occurs in a confined space called a combustion chamber. This exothermic reaction of a fuel with an oxidizer creates gases of high temperature and pressure, which are permitted to expand. The defining feature of an internal combustion engine is that useful work is performed by the expanding hot gases acting directly to cause movement, for example by acting on pistons, rotors, or even by pressing on and moving the entire engine itself.

Compression ignition systems, such as the diesel engine and HCCI (Homogeneous Charge Compression Ignition) engines, rely solely on heat and pressure created by the engine in its compression process for ignition. Compression that occurs is usually more than three times higher than a gasoline engine. Diesel engines will take in air only, and shortly before peak compression, a small quantity of diesel fuel is sprayed into the cylinder via a fuel injector that allows the fuel to instantly ignite. HCCI type engines will take in both air and fuel but will continue to rely on an unaided auto-combustion process due to higher pressures and heat. This is also why diesel and HCCI engines are also more susceptible to cold starting issues though they will run just as well in cold weather once started. Most diesels also have battery and charging systems however this system is secondary and is added by manufacturers as luxury for ease of starting, turning fuel on and off which can also be done via a switch or mechanical apparatus, and for running auxiliary electrical components and accessories. Most modern diesels, however, rely on electrical systems that also control the combustion process to increase efficiency and reduce emissions.

Once successfully ignited and burnt, the combustion products, hot gases, have more available energy than the original compressed fuel/air mixture (which had higher chemical energy). The available energy is manifested as high temperature and pressure which can be translated into work by the engine. In a reciprocating engine, the high pressure product gases inside the cylinders drive the engine's pistons.

Once the available energy has been removed, the remaining hot gases are vented (often by opening a valve or exposing the exhaust outlet) and this allows the piston to return to its previous position (Top Dead Center—TDC). The piston can then proceed to the next phase of its cycle, which varies between engines. Any heat not translated into work is normally considered a waste product, and is removed from the engine either by an air or liquid cooling system.

A four-cycle engine works with 4 basic steps to a successful rotation of the crankshaft: the intake, compression, power and exhaust stroke. Each engine cylinder has four openings for the intake, exhaust, spark plug and fuel injection. The piston is driven by the engine's crankshaft whereas the intake and exhaust valves are driven by the camshaft. The crankshaft and camshaft are connected by a timing belt/chain to maintain synchronization between them. The various processes comprising the cycles of a four-stroke engine are explained below:

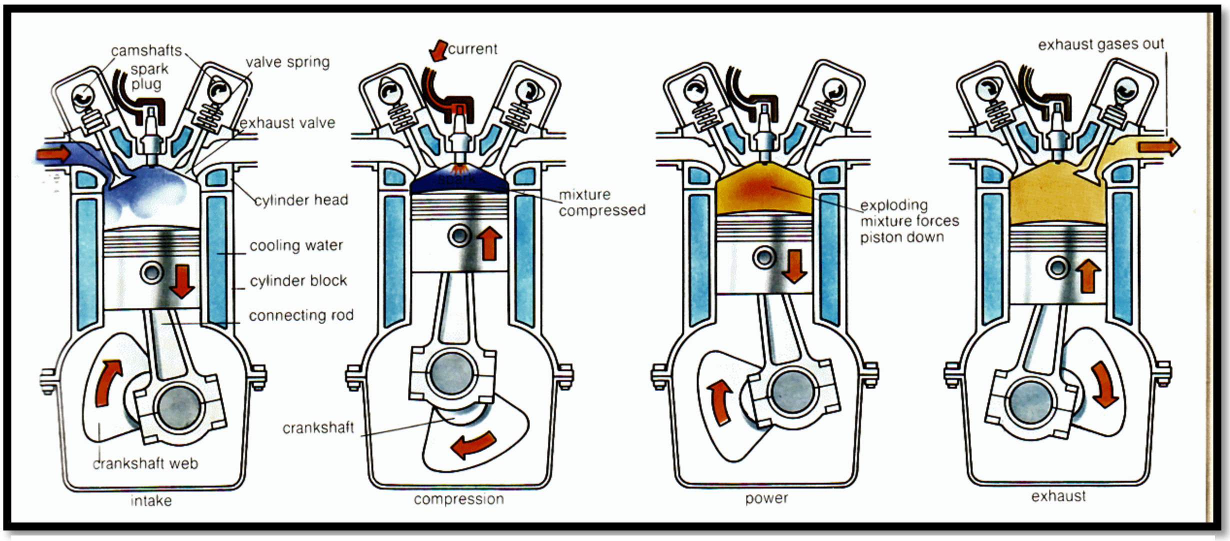

Figure 2: Working of 4 Stroke Engine

Intake Stroke

The engine cycle begins with the intake stroke as the piston is pulled towards the crankshaft. The intake valve is open, and fuel and air are drawn past the valve and into the combustion chamber and cylinder from the intake manifold located on top of the combustion chamber. The exhaust valve is closed and the electrical contact switch is open. The fuel/air mixture is at a relatively low pressure (near atmospheric) and is colored blue in this figure. At the end of the intake stroke, the piston is located at the far left and begins to move back towards the right. The cylinder and combustion chamber are full of the low pressure fuel/air mixture and, as the piston begins to move to the right, the intake valve closes.

Compression Stroke

With both valves closed, the combination of the cylinder and combustion chamber form a completely closed vessel containing the fuel/air mixture. As the piston is pushed to the right, the volume is reduced and the fuel/air mixture is compressed during the compression stroke.

During the compression, no heat is transferred to the fuel/air mixture. As the volume is decreased because of the piston's motion, the pressure in the gas is increased, as described by the laws of thermodynamics. In the figure, the mixture has been colored yellow to denote a moderate increase in pressure. To produce the increased pressure, we have to do work on the mixture, just as you have to do work to inflate a bicycle tire using a pump. During the compression stroke, the electrical contact is kept opened. When the volume is the smallest, and the pressure the highest as shown in the figure, the contact is closed, and a current of electricity flows through the plug.

Power Stroke

At the beginning of the power stroke, the electrical contact is opened. The sudden opening of the contact produces a spark in the combustion chamber which ignites the fuel/air mixture. Rapid combustion of the fuel releases heat, and produces exhaust gases in the combustion chamber.

Because the intake and exhaust valves are closed, the combustion of the fuel takes place in a totally enclosed (and nearly constant volume) vessel. The combustion increases the temperature of the exhaust gases, any residual air in the combustion chamber, and the combustion chamber itself. From the ideal gas law, the increased temperature of the gases also produces an increased pressure in the combustion chamber. We have colored the gases red in the figure to denote the high pressure. The high pressure of the gases acting on the face of the piston cause the piston to move to the left which initiates the power stroke.

Unlike the compression stroke, the hot gas does work on the piston during the power stroke. The force on the piston is transmitted by the piston rod to the crankshaft, where the linear motion of the piston is converted to angular motion of the crankshaft. The work done on the piston is then used to turn the shaft, and the propellers, and to compress the gases in the neighboring cylinder's compression stroke. Having produced the igniting spark, the electrical contact remains opened.

During the power stroke, the volume occupied by the gases is increased because of the piston motion and no heat is transferred to the fuel/air mixture. As the volume is increased because of the piston's motion, the pressure and temperature of the gas are decreased. We have colored the exhaust "molecules" yellow to denote a moderate amount of pressure at the end of the power stroke.

Exhaust Stroke

At the end of the power stroke, the piston is located at the far left. Heat that is left over from the power stroke is now transferred to the water in the water jacket until the pressure approaches atmospheric pressure. The exhaust valve is then opened by the cam pushing on the rocker arm to begin the exhaust stroke.

The purpose of the exhaust stroke is to clear the cylinder of the spent exhaust in preparation for another ignition cycle. As the exhaust stroke begins, the cylinder and combustion chamber are full of exhaust products at low pressure (colored blue on the figure above.) Because the exhaust valve is open, the exhaust gas is pushed past the valve and exits the engine. The intake valve is closed and the electrical contact is open during this movement of the piston. At the end of the exhaust stroke, the exhaust valve is closed and the engine begins another intake stroke.

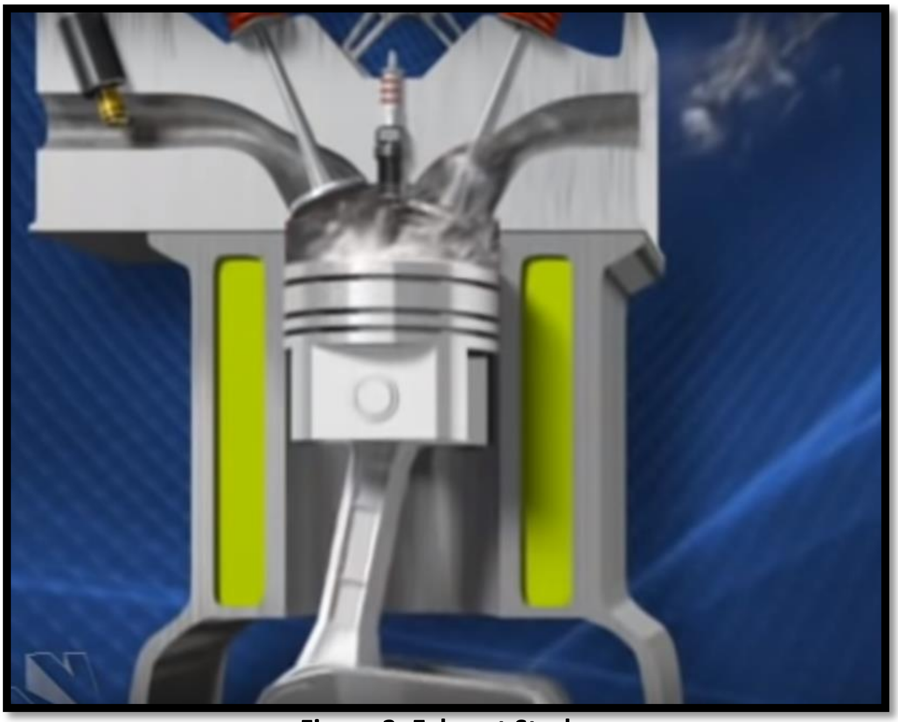

Figure 3: Exhaust Stroke

2.2 Turbine

A turbine is a rotary mechanical device that extracts energy from a fluid flow and converts it into useful work. The work produced by a turbine can be used for generating electrical power when combined with a generator. A turbine is a turbomachine with at least one moving part called a rotor assembly, which is a shaft or drum with blades attached. Moving fluid acts on the blades so that they move and impart rotational energy to the rotor. Early turbine examples are windmills and waterwheels.

Gas, steam, and water turbines have a casing around the blades that contains and controls the working fluid. Credit for invention of the steam turbine is given both to Anglo-Irish engineer Sir Charles Parson for invention of the reaction turbine, and to Swedish engineer Gustaf de Laval for invention of the impulse turbine. Modern steam turbines frequently employ both reaction and impulse in the same unit, typically varying the degree of reaction and impulse from the blade root to its periphery.

Impulse Turbine

An impulse turbine is a turbine that is driven by high velocity jets of water or steam from a nozzle directed on to vanes or buckets attached to a wheel. The resulting impulse (as described by Newton's second law of motion) spins the turbine and removes kinetic energy from the fluid flow. Before reaching the turbine the fluid's pressure head is changed to velocity head by accelerating the fluid through a nozzle. This preparation of the fluid jet means that no pressure casement is needed around an impulse turbine.

Blades: The number of blades is situated over the rotary. They are concave in shape. The exhaust jet strikes at the blades and change the direction of it. The force exerted on blades depends upon amount of change in direction of jet. So the blades are generally concave in shape.

Rotor: Rotor which is also known as wheel is situated on the shaft. All blades are pined into the rotor. The force exerted on blades passes to the rotor which further rotates the shaft.

Nozzle: A nozzle play main role of generating power from impulse turbine. It is a diverging nozzle which converts all pressure energy of gas into kinetic energy and forms the gas jet. This high speed gas strikes the blades and rotates it.

Casing: Casing is the outside cover which prevent the turbine from atmosphere. The main function of casing is to prevent discharge the exhaust from vanes to outlet.

Working:

The gas flows along the tangent to the path of the runner. Nozzle direct forceful streams of gas against a series of buckets mounted around the edge of a wheel. As gas flows into the bucket, the direction of the gas velocity changes to follow the contour of the bucket.

When the gas-jet contacts the bucket, the gas exerts pressure on the bucket and the gas is decelerated as it does a "u-turn" and flows out the other side of the bucket at low velocity. In the process, the gas's momentum is transferred to the turbine This "impulse " does work on the turbine. For maximum power and efficiency, the turbine system is designed such that the gas-jet velocity is twice the velocity of the bucket. Because gas and most liquids are nearly incompressible, almost all of the available energy is extracted in the first stage of the hydraulic turbine. Therefore, the Pelton wheel has only one turbine stage, unlike gas turbines that operate with a compressible fluid.

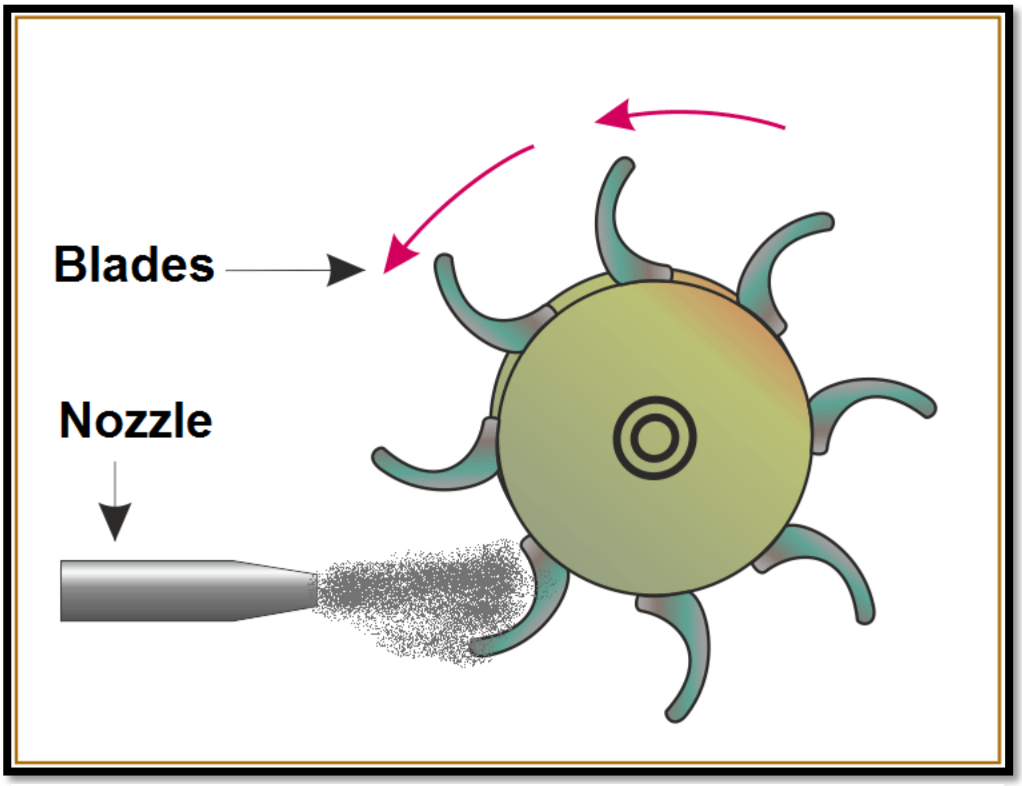

Figure 4: Impulse Turbine

2.3 Air Conditioning System

Air conditioning is the process of removing heat and moisture from the interior of an occupied space, to improve the comfort of occupants. Air conditioning can be used in both domestic and commercial environments. This process is most commonly used to achieve a more comfortable interior environment, typically for humans and other animals; however, air conditioning is also used to cool/dehumidify rooms filled with heat-producing electronic devices, such as computer servers, power amplifiers, and even to display and store some delicate products, such as artwork.

Air conditioners often use a fan to distribute the conditioned air to an occupied space such as a building or a car to improve thermal comfort and indoor air quality. Electric refrigerant-based AC units range from small units that can cool a small bedroom, which can be carried by a single adult, to massive units installed on the roof of office towers that can cool an entire building. The cooling is typically achieved through a refrigeration cycle, but sometimes evaporation or free cooling is used. Air conditioning systems can also be made based on desiccants (chemicals which remove moisture from the air). Some AC systems reject or store heat in subterranean pipes.

In the most general sense, air conditioning can refer to any form of technology that modifies the condition of air (heating, (de-) humidification, cooling, cleaning, ventilation, or air movement). In common usage, though, "air conditioning" refers to systems which cool air. In construction, a complete system of heating, ventilation, and air conditioning is referred to as HVAC.

Vapor-compression refrigeration:

Vapor-compression refrigeration or vapor-compression refrigeration system (VCRS), in which the refrigerant undergoes phase changes, is one of the many refrigeration cycles and is the most widely used method for air-conditioning of buildings and automobiles. It is also used in domestic and commercial refrigerators, large-scale warehouses for chilled or frozen storage of foods and meats, refrigerated trucks and railroad cars, and a host of other commercial and industrial services. Oil refineries, petrochemical and chemical processing plants, and natural gas processing plants are among the many types of industrial plants that often utilize large vapor-compression refrigeration systems.

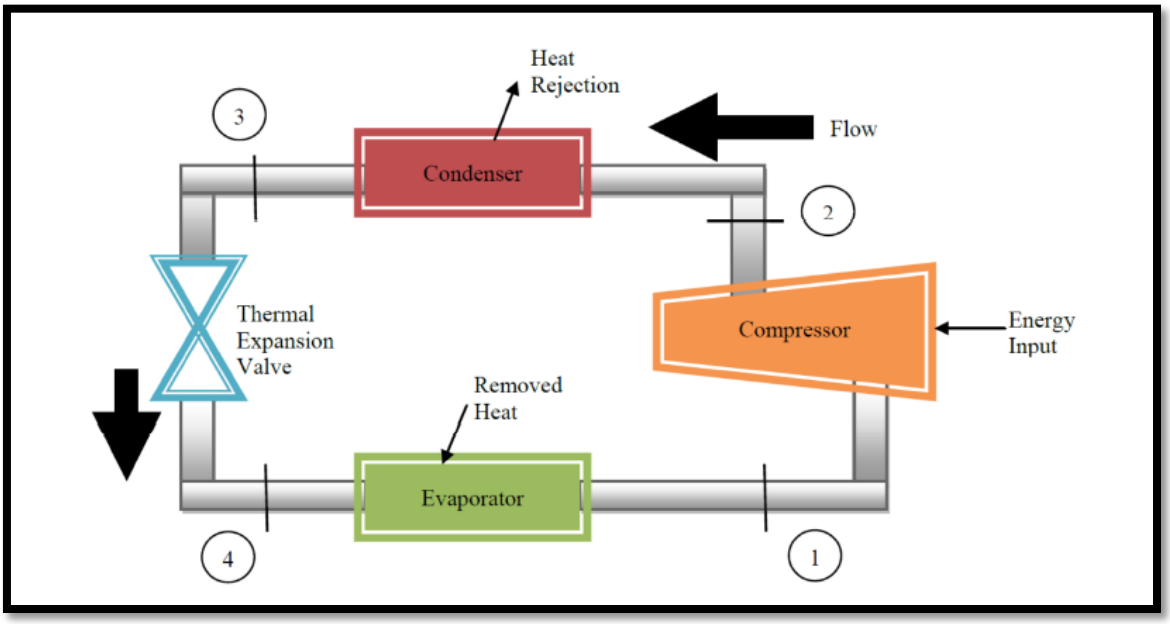

Figure 5: Vapour Compression Refrigeration

Refrigeration may be defined as lowering the temperature of an enclosed space by removing heat from that space and transferring it elsewhere. A device that performs this function may also be called an air conditioner, refrigerator, air source heat pump, geothermal heat pump or chiller (heat pump).

The components of a car's AC system is almost same as a room's AC but there are lots of modification made in an automobile AC to make it compact and to fit it with engine's component.

The components used in automobile AC are:

1. Compressor:

It is also known as the heart of the AC system, A compressor provide pressure rise to the refrigerant to convert the vapour refrigerant into liquid refrigerant which in turn enables the further flow of the refrigerant through condenser.

The compressor of the car air conditioning system is driven by the crankshaft of the engine through the belt drive.

2. Condenser:

It is the device looks like a small radiator and is used after the compressor as it provides condensing i.e. lowers the temperature, of the high pressure and high temperature liquid refrigerant sent by compressor through forced convection provided either by radiator fan or by separated fan used with condenser.

3. Expansion valve:

It is a device used in car air conditioning system to expand the high pressure, low temperature liquid refrigerant sent by the condenser in order to release pressure of the refrigerant before sending it to evaporator for the further process.

4. Evaporator:

It is a device that looks like another heat exchanger and is place just behind the AC vent over a dash board of a car, an evaporator takes heat from the passenger's compartment and convert the liquid refrigerant sent by the expansion valve into vapor, which in turn provides cooling through the fan inside a passenger's cabin

Note – Thermal expansion valve is used in vehicles that enable the passenger to change the temperature according to the requirement, by just adjusting the knob provided over a dash board in passenger's cabin.

5. Receiver-Dryer:

It is a safety catch used in an automobile or car air conditioning system as there is a chance that instead of vapors some liquid also flows towards the compressor which can damage the compressor, so the receiver dryer is used in between evaporator and compressor to convert that remaining liquid into vapors before sending it to compressor for compression.

6. Refrigerant:

It is the heat sensitive fluid with very low boiling point that is used in AC as a medium of heat exchanging.

Working

The working of an automobile AC system is also almost same as the normal AC but little difference is there:

1. The evaporator which is the another heat exchanger used in AC takes heat from the passenger's cabin which in turn converts the liquid refrigerant flowing through the evaporator into vapors which in turn provide cooling with the help of the blower fan.

2. This vapor having high temperature low pressure is then sent to compressor which in turn increases the pressure over the vapors and converts the vapor refrigerant into liquid refrigerant.

Now the refrigerant is in high pressure and high temperature liquid state.

3. This high pressure high temperature liquid refrigerant is then sent to the condenser which lowers the temperature of this refrigerant by forced convection provided by the radiator fan or by separated fan used.

Now the refrigerant is having low temperature but the pressure of the liquid is almost same.

4. This high pressure and low temperature refrigerant is than sent to expansion valve which in turn releases the pressure from the refrigerant and convert it into its original state.

5. This refrigerant is then again sent to the evaporator for the further cycle.

Note – Between evaporator and compressor a receiver dryer is used that convert the remaining liquid refrigerant from the evaporator into the vapors before sending it to the compressor.

Receiver dryer also provide filtering of the system by absorbing the contaminated foreign materials inside the AC system.

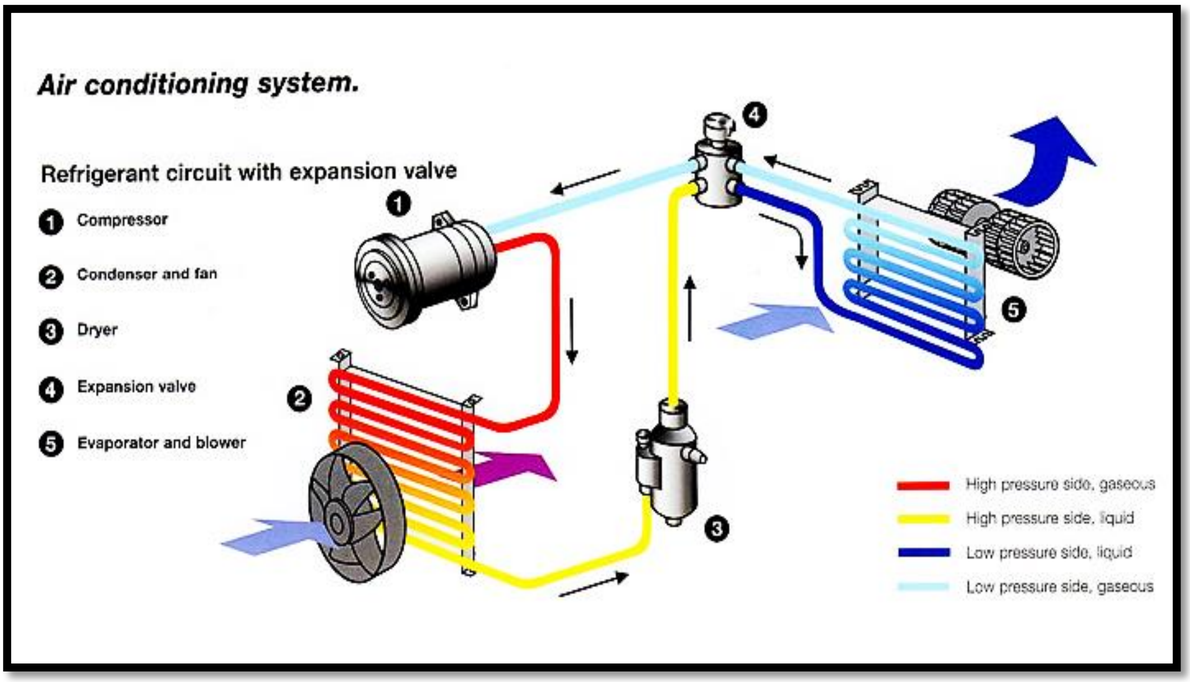

Figure 6: Car AC System

3. Design

3.1 Engine Specifications:

A. **Make:** Kirloskar Engines
B. **Engine type:** Reciprocating I.C. Engine
C. **Number of Strokes:** 4
D. **Number of Cylinder:** 1
E. **Fuel:** Diesel
F. **Power:** 3.5 KW
G. **RPM:** 1000
H. **Torque:** 30.4 Nm
I. **Number of Valves:** 2

3.2 Turbine Specifications:

A. **Turbine inlet pipe:**

Material: GI pipe (External Threads)

Diameter: 25 mm

Length: 150 mm

B. Casing:

a. **Pipe:**

Material: Iron

Internal Diameter: 210 mm

External Diameter: 220 mm

Width: 65 mm

b. **Plate:**

Material: Iron

Diameter: 220 mm

Thickness: 6 mm

C. **Bearing: 6201 RS**

Material: Standard SAE 52100

Internal Diameter: 12 mm

External Diameter: 32 mm

D. **Bearing Bush:**

Material: Iron

Internal Diameter: 32 mm

External Diameter: 40 mm

Width: 12 mm

E. **Shaft:**

Material: Mild steel

Diameter: 12 mm

Length: 160 mm

F. **Rotor:**

Material: Stainless Steel

Diameter: 86.88 mm

Thickness: 11.2 mm

G. **Blades:**

Material: Mild Steel

Height: 76 mm

Width: 61 mm

Thickness: 0.6 mm

3.3 AC Compressor Specifications:

A. **Type:** Reciprocating Piston
B. **Number of Cylinders:** 5
C. **Material:** Mild Steel
D. **Cooling Method:** Air Cooled
E. **No. of Stages:** Single Stage
F. **Voltage:** 12 V

3.4 Pulley:

A. **Material:** Cast Iron
B. **Internal Diameter:** 12mm
C. **External Diameter:** 50mm
D. **Groove:** Type A
E. **No. of Grooves:** 1

3.5 Belt:

A. **Material:** Rubber
B. **Cross Width:** A
C. **Top Width:** 13
D. **Height:** 8
E. **Angle:** 40 degree

3.6 Turbine Manufacturing Process:

1. Facing of pipe to 65 mm width. Drilling two holes of 31 mm on opposite sides of casing.
2. Turning the casing plates to 222 mm and giving counter of 6×2 mm. Drilling holes of 12 mm on both plates at center. Facing the plate at center to make a seat of 30 mm and 2 mm deep.
3. Welding the bush to plates from outer side. Turning the bushes internally to 32 mm diameter for bearing size.
4. Fitting the bearings in bushes.
5. Making slots on rotor 17 mm deep to fix the blades. Drilling a center hole of 12 mm.
6. Cutting the blades into 6 pieces of 76×61 mm each.
7. Making two grooves for circlip on shaft at a distance of 100 mm.
8. Brazing of blades on rotor and then brazing the rotor on shaft.
9. Welding of one plate on the 210 mm iron pipe.
10. Fixing the shaft on bearing.
11. Welding the second plate from other side.
12. Cutting the pipe in two pieces in different angles.
13. Welding of pipes on the casing.
14. Fixing circlips of 10.5 mm on the grooves of shaft.

3.7 Components

1. Engine

An engine or motor is a machine designed to convert one form of energy into mechanical energy. Heat engines, like the internal combustion engine, burn a fuel to create heat which is then used to do work. Electric motors convert electrical energy into mechanical motion, pneumatic motors use compressed air, and clockwork motors in wind-up toys use elastic energy. In biological systems, molecular motors, like myosin’s in muscles, use chemical energy to create forces and eventually motion.

Figure 7: Diesel Engine

2. Turbine

A turbine (from the Latin turbo, a vortex, related to the Greek τύρβη, tyrbē, meaning "turbulence") is a rotary mechanical device that extracts energy from a fluid flow and converts it into useful work. The work produced by a turbine can be used for generating electrical power when combined with a generator. A turbine is a turbomachine with at least one moving part called a rotor assembly, which is a shaft or drum with blades attached. Moving fluid acts on the blades so that they move and impart rotational energy to the rotor. Early turbine examples are windmills and waterwheels.

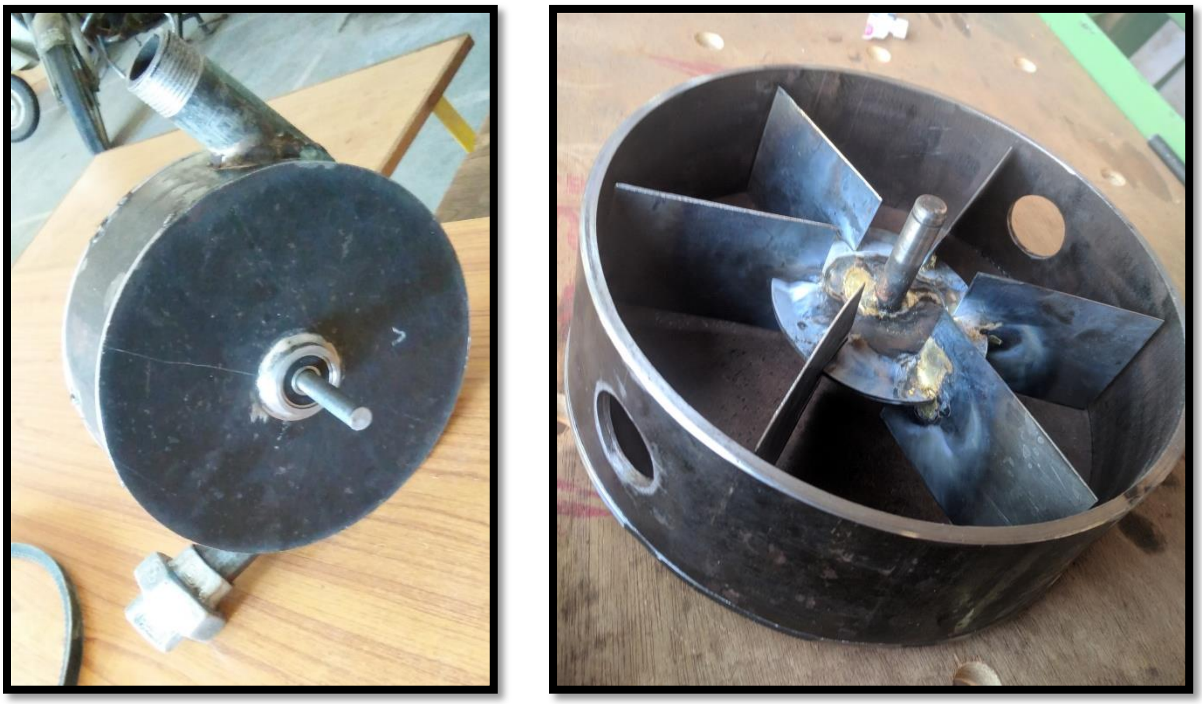

Figure 8: Turbine

3. Compressor

A compressor is a mechanical device that increases the pressure of a gas by reducing its volume. An air compressor is a specific type of gas compressor.

Compressors are similar to pumps: both increase the pressure on a fluid and both can transport the fluid through a pipe. As gases are compressible, the compressor also reduces the volume of a gas. Liquids are relatively incompressible; while some can be compressed, the main action of a pump is to pressurize and transport liquids.

Figure 9: Car AC Compressor

4. Pulley

A pulley is a wheel on an axle or shaft that is designed to support movement and change of direction of a taut cable or belt, or transfer of power between the shaft and cable or belt. In the case of a pulley supported by a frame or shell that does not transfer power to a shaft, but is used to guide the cable or exert a force, the supporting shell is called a block, and the pulley may be called a sheave.

A pulley may have a groove or grooves between flanges around its circumference to locate the cable or belt. The drive element of a pulley system can be a rope, cable, belt, or chain.

Figure 10: 2" Pulley

5. Belt

A belt is a loop of flexible material used to link two or more rotating shafts mechanically, most often parallel. Belts may be used as a source of motion, to transmit power efficiently or to track relative movement. Belts are looped over pulleys and may have a twist between the pulleys, and the shafts need not be parallel.

Figure 11: V Belt

4. Construction and Working:

Construction:

A turbine is connected to engine exhaust outlet with help of G.I. Pipe using Coupler. The turbine shaft has a pulley mounted on it with a V-groove on which a belt is fastened to transmit the rotations of turbine to AC Compressor having A2 V-groove.

Figure 12: Setup of E.P.A.A.C.S.

Principle:

Running the automobile AC compressor using pressure energy of exhaust gases by converting it into mechanical energy.

Working:

The exhaust gas comes out with a pressure from the engine. When this gas is passed through a restricted area (exhaust pipe), the pressure energy is converted into kinetic energy. This gas is passed on the blades of turbine, due to the kinetic energy of exhaust gas, the blades start to rotate with some velocity. This gas goes outside the turbine through the outlet. As the blades are mounted on the turbine shaft, when the blades rotate due to the gases striking on it, the turbine shaft also rotates. A pulley is mounted on the turbine shaft which drives the AC compressor's pulley through belt drive. Reduction in speed is done using smaller pulley on turbine shaft and larger pulley on the compressor by this more torque is obtained and required rpm for compressor is obtained. As the compressor runs, VCR cycle starts and required Air Conditioning effect is gained.

Observations:

Compressor Clutch Disengaged

Condition	Engine RMP	Turbine RPM	Compressor RPM
Idling	500	950	475
Normal	650	1600	800
Normal	750	2200	1100
Acceleration	950	3400	1700
Maximum	1100	3700	1850

Condition	Engine RMP	Turbine RPM	Compressor RPM
Idling	500		
Normal	650		
Normal	750		
Acceleration	950		
Maximum	1100		

5. Modifications:

Modifications required for implementing this system in Automobiles:

1. **Engine Exhaust Manifold:**

   Separate the exhaust manifold and tail pipe and attach the turbine inlet and outlet between these two.

2. **AC Compressor:**

   Longer belt required as the distance between compressor pulley and turbine pulley is more than the distance between compressor and engine crack shaft pulley.

3. **Mountings:**

   Separate mounting required to mount the turbine on the engine or chassis.

4. **Turbine:**
   1) Select inlet and outlet Pipe sizes according to the engine manifold and tail pipe.
   2) Use of stronger and light weight material to reduce the weight of the turbine.
   3) Reduce the size of the turbine to accommodate it inside engine bonnet.
   4) Select proper angle of entry of exhaust to gain more efficiency.
   5) Give angle to the blade so that the exhaust gas strikes on the blade covering maximum area.
   6) Mount the blades directly on the shaft to restrict more exhaust gases and reduce the weight.
   7) Minimum clearances should be given between the blades and the casing of the turbine for more efficiency.
5. **Pulley:**

   Select the pulley diameter according to the speed and torque available at the turbine shaft and the speed requirement to run the AC Compressor.

6. Merits

1. Decreased load on engine.
2. Waste exhaust power Utilized.
3. Increased Fuel Economy of engine.
4. Saving of money due to less fuel consumptions.
5. This system can be installed on any engine with some minor modifications.

7. Future Scope

1. The power available on turbine shaft can be used to run other systems of IC Engine like Battery charging system.
2. The shaft power can also be used to run the coolant pump, lubricant pump, etc.
3. More saving in fuel can be done by giving power to different components through the turbine shaft, as the load on engine will reduce.
4. Higher speeds of turbine shaft can be achieved by making some modifications in the design of turbine.
5. Better designs can be made to gain more efficiency of engine and reduction in fuel consumption.
6. Length of belt used to drive the AC compressor pulley can be reduced by reducing the distance between the AC compressor and turbine pulley.
7. More saving in cost of fuel required to run the engine can be made by improving the design of turbine.

Conclusion

The exhaust power which is wasted in current Automobiles is used by means of turbine to run the AC Compressor of the Automobiles. This decreases the consumption of fuel upto 25% to 30% to run the automobile as the load on engine is reduced by running the AC compressor using the energy available in exhaust.

References:

- Mathur and Sharma, IC Engine, 2014
- Kirpal Singh, Automobile Engineering, vol 1&2, ,2014
- R.K. Rajput, Thermal Engineering, 2008
- https://en.m.wikipedia.org/wiki/Turbine
- http://www.mechanicalengineeringsite.com/impulse-turbine-reaction-turbine-principle-working-difference/
- https://www.britannica.com/technology/belt-drive