KMOU Division of Marine System Engineering

Introduction to Internal Combustion Engine

국립한국해양대학교
NATIONAL KOREA MARITIME & OCEAN UNIVERSITY

Made by Minho Park (Ph.D.)
https://orcid.org/0000-0002-6900-4566

Lesson content for each week

Ch0_Introduction to the Class

Ch1_Overview of the Internal Combustion Engine

Ch2_Thermodynamics and Compressed Air System

Ch3_Marine Fuels and Internal Fuel Oil System

Ch4_Intake and Exhaust System

Ch5_Turbocharger

Midterm

Ch6_Piston Fittings and Crankshaft

Ch7_Lube Oil System

Ch8_Cooling Water System

Ch9_Introduction to the Main Engine

Ch10_Alternative Fuels and Alternative Fuel Systems

Ch11_Environmental Regulations and Exhaust Gas Aftertreatment Systems

Ch12_Tools, Apprentice Engineer Duties, and Career Direction

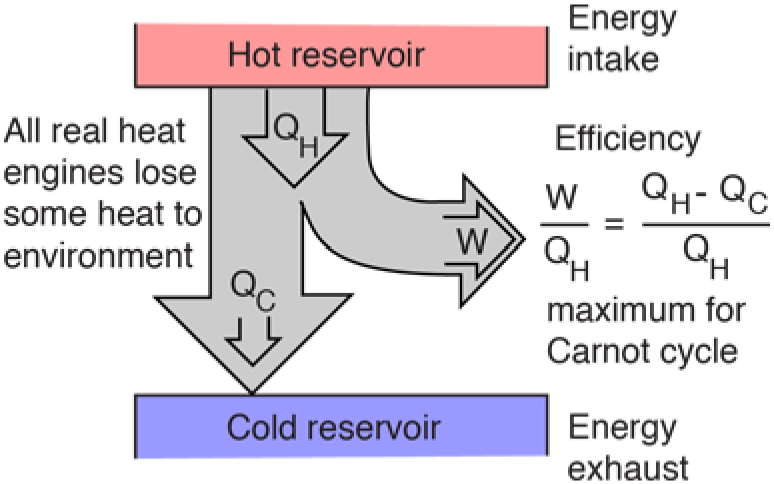
Final Exam

What is Heat Engine?

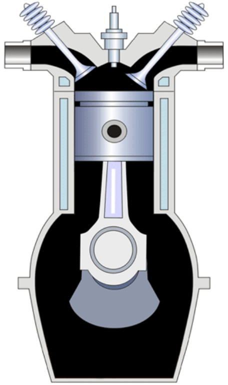
Heat Engine :

A machine that converts the heat energy generated by burning fuel into mechanical work to obtain power is called a heat engine.

Heat engines can be classified into internal combustion engines and external combustion engines depending on how they convert thermal energy into mechanical energy.



What is Internal Combustion Engine?



Internal Combustion Engine (ICE) :

Combustion occurs inside the engine.

A heat engine in which the combustion gases and the working substance are the same.

A heat engine that directly combusts fuel and air inside the engine and uses the high-temperature, high-pressure gas to perform effective work.

Internal combustion engines on board include the main engine (M/E) and diesel generator (G/E, it is also called as generator engine and auxiliary engine (A/E)).

M/E

G/E

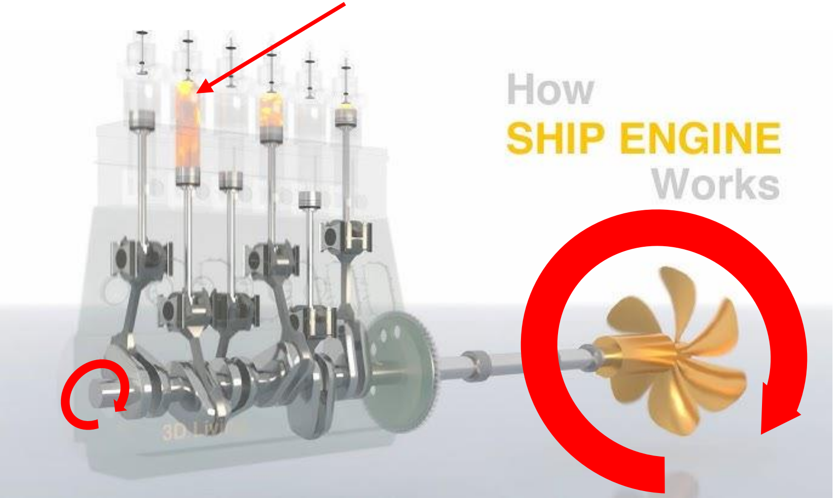
Where is M/E used?

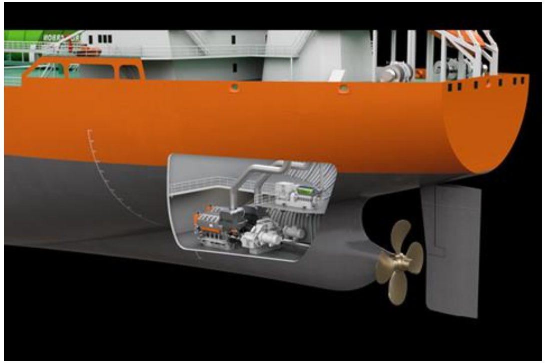
M/E is used to propel the ship.

How does M/E propel a ship?

The rotational force generated from the M/E rotates the propulsion shaft, and the propeller connected to the propulsion shaft rotates, thereby propelling the ship.

Combustion gases (Working substance) – Contribute directly to work

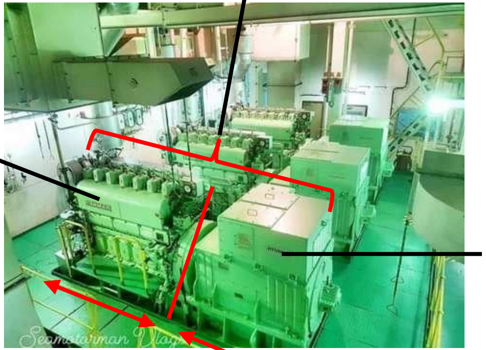




국립한국해양대학교
NATIONAL KOREA MARITIME & OCEAN UNIVERSITY

Where is G/E used?

G/E is used to generate electricity.



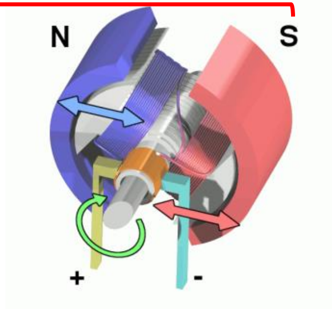
Where is the electricity generated from G/E used?

Electricity is mostly used to drive motors. (For container ship, refrigerant container.)

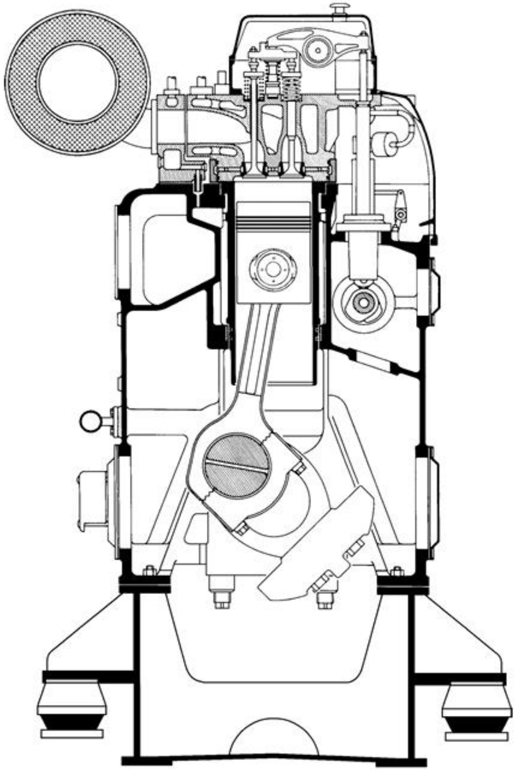
Connect the part to be driven to the motor shaft and use

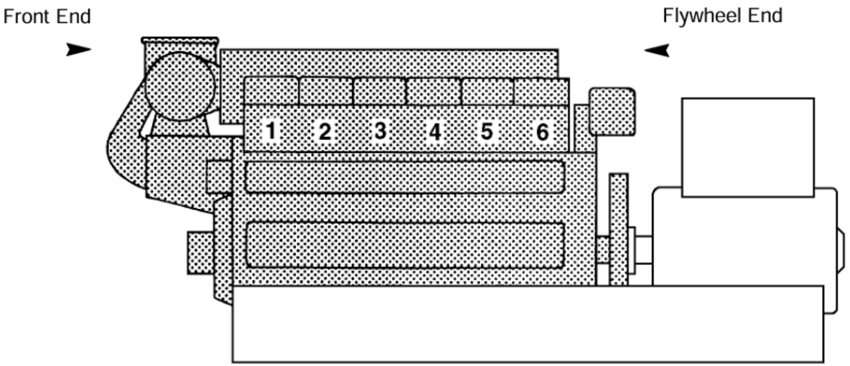
the rotational power of the shaft as mechanical work.

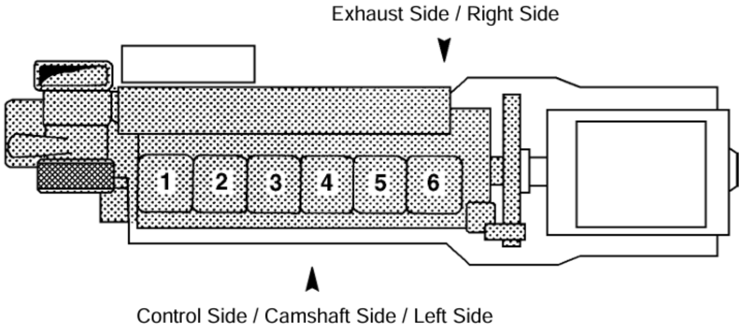
Motor

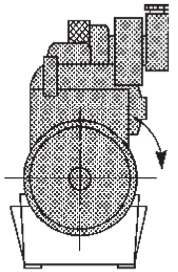


G/E

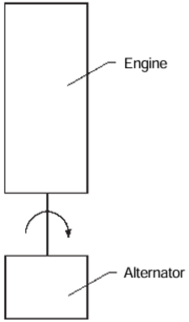






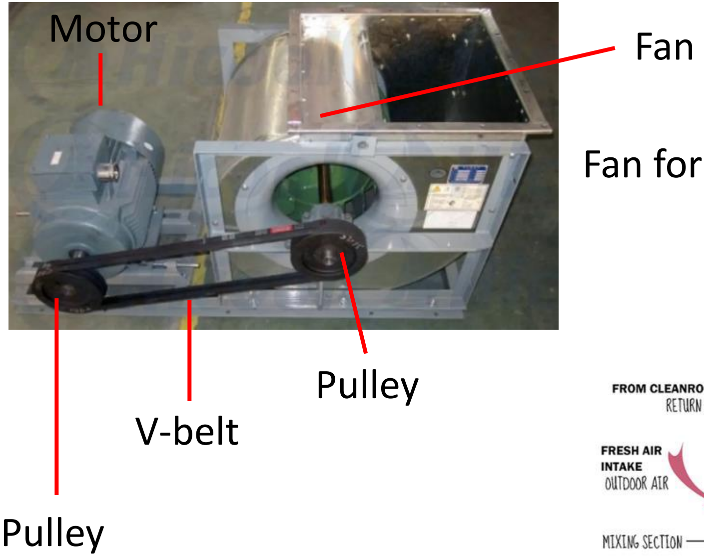


Normal direction "clockwise" of diesel engine seen from flywheel end

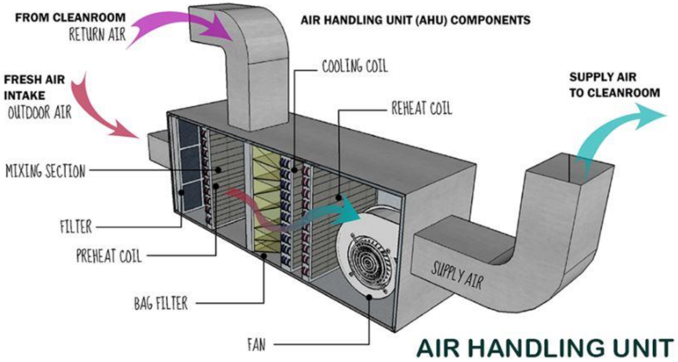


Where are motors used?

Motors are used in a variety of machinery, some of which include:



Fan for Air Handling Unit (AHU)



Where are motors used?

Motors are used in a variety of machinery, some of which include:

Air conditioning plant

Provision refrigerant plant

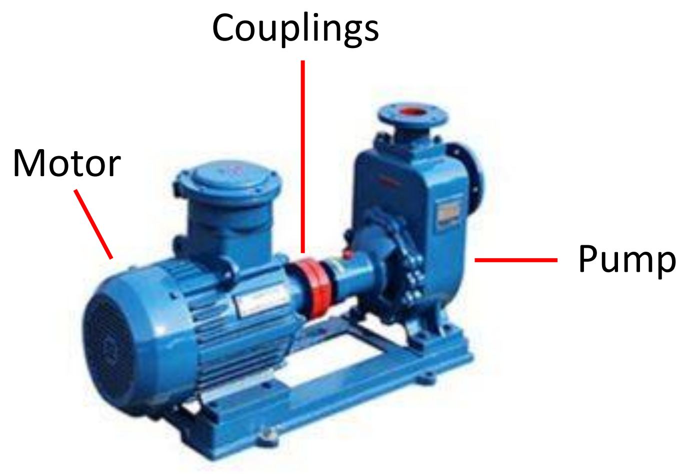
Those are almost looking same, but Air conditioning plant is bigger than Provision refrigerant plant.

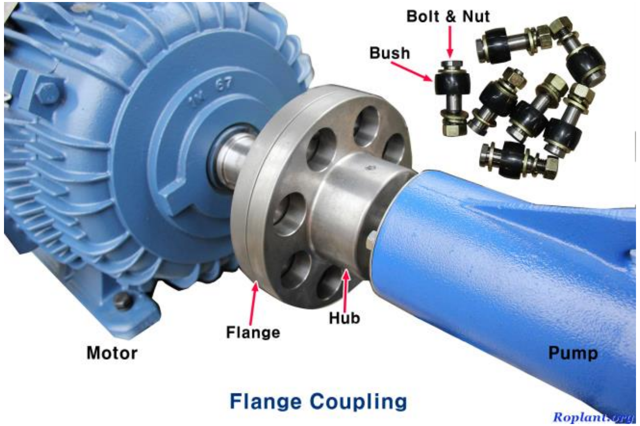
국립한국해양대학교
NATIONAL KOREA MARITIME & OCEAN UNIVERSITY

Where are motors used?

Motors are used in a variety of machinery, some of which include:

Fuel supply pump





What is External Combustion Engine?

External Combustion Engine (ECE) :

Combustion occurs outside the engine.

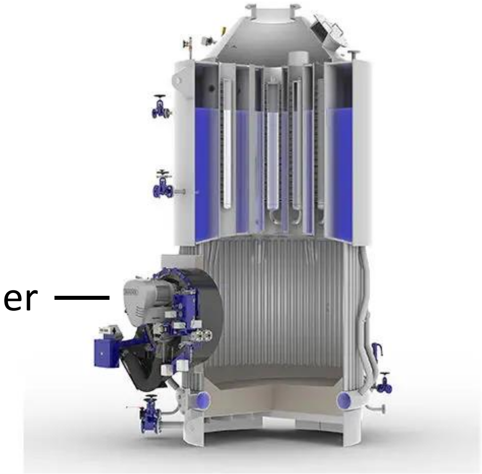
A heat engine in which the combustion gases and the working substance are different.

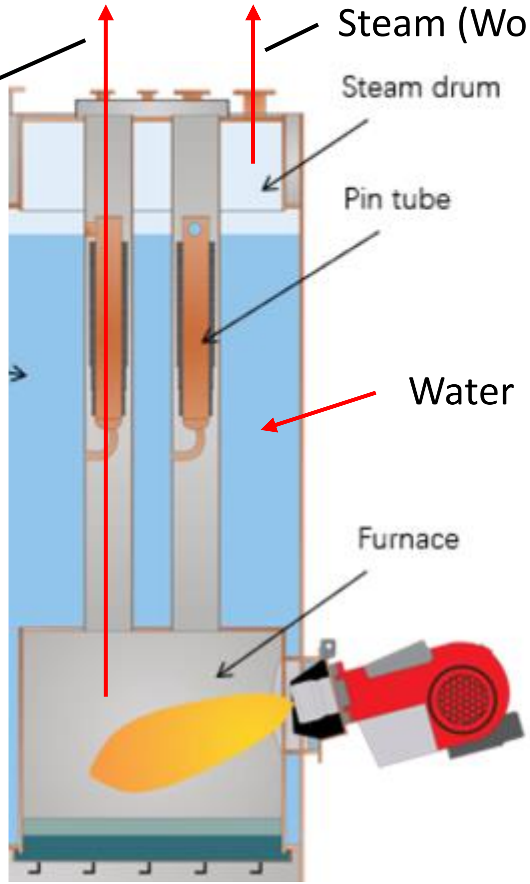
A heat engine in which combustion takes place outside the engine, such as a boiler, and the combustion gas and working substance (steam) are completely separate.

Boiler

What is External Combustion Engine?

External Combustion Engine (ECE) :



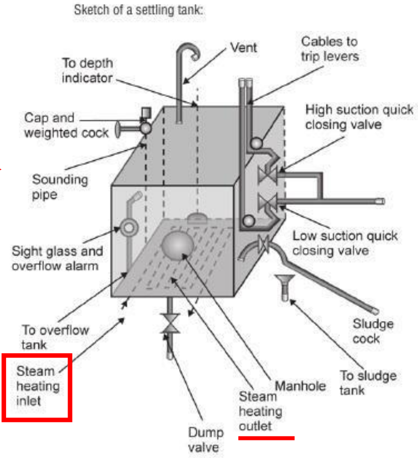


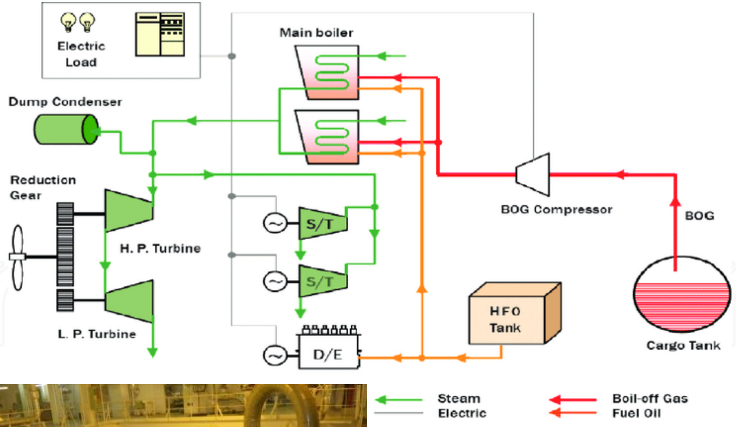
What is External Combustion Engine?

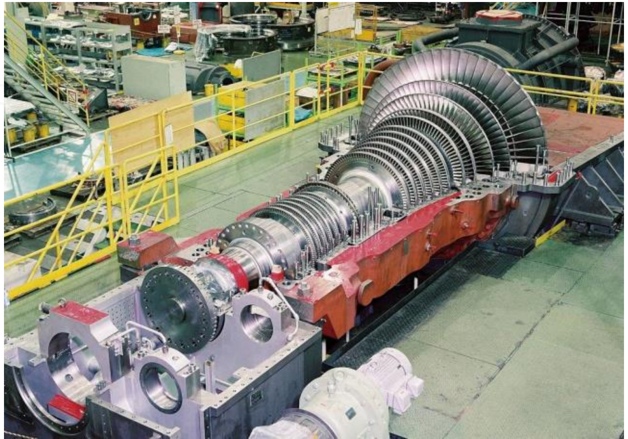
External Combustion Engine (ECE) :

Steam is mostly used for heating fuel tank.

Otherwise, steam is used to operate steam turbine.



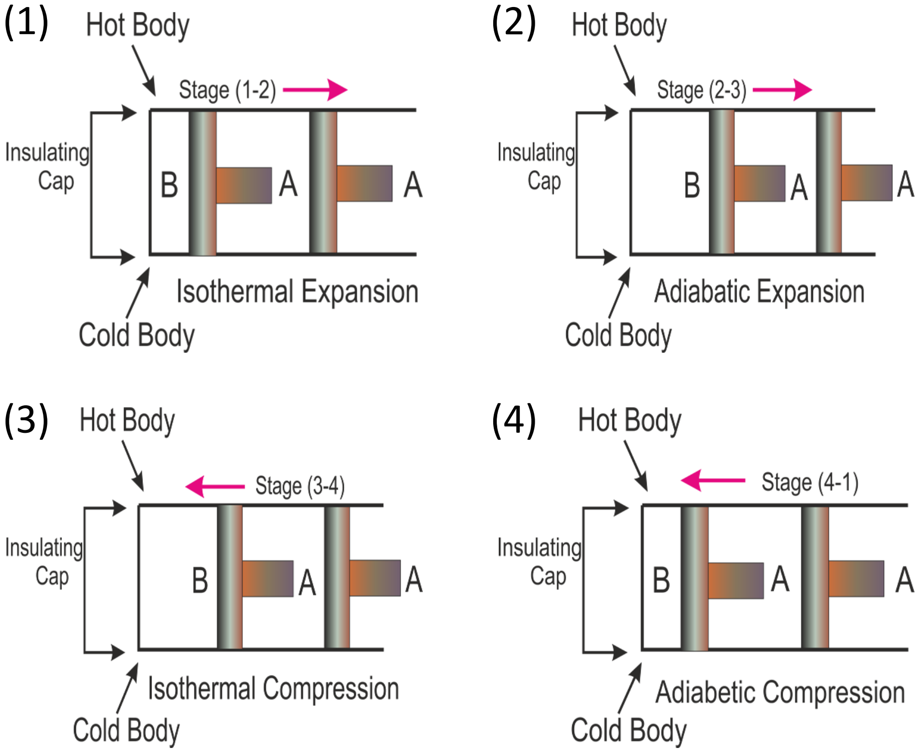


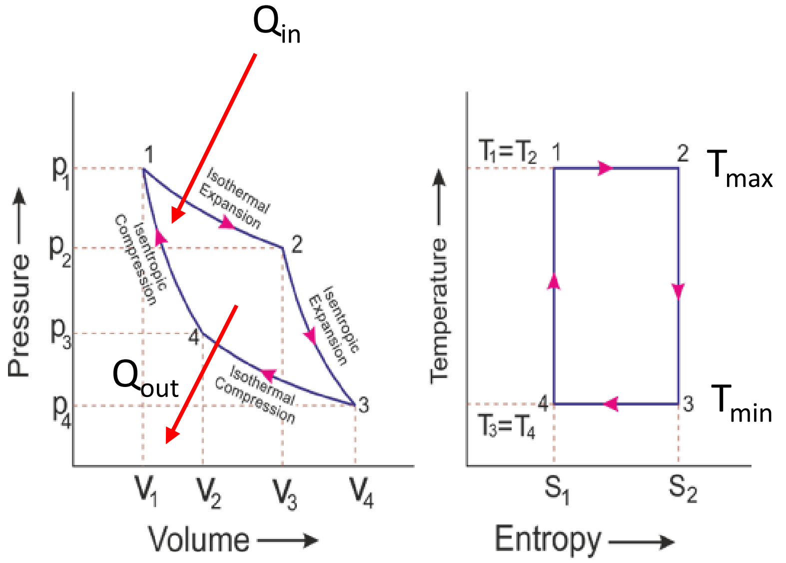


Steam directly contribute to work

Carnot Cycle

The Carnot cycle consists of four stages.





(a) p-v diagram (b) T-S diagram

Carnot Cycle

$dU = C_v dT$
U = Internal energy
C_v = Specific heat
T= Temperature

The Carnot cycle consists of four stages.

(1) **Isothermal expansion** (1 to 2) :

The gas expands as it absorbs heat Q_{in}, and there is no change in its internal energy.

(2) **Adiabatic expansion** (2 to 3) :

Gases expand without giving or receiving heat, and the temperature of the gas drops from T_{max} to T_{min}.

(3) **Isothermal compression** (3 to 4) :

The gas compresses while releasing heat as much as Q_{out}, and there is no change in internal energy.

(4) **Adiabatic compression** (4 to 1) :

The gas is compressed without giving or receiving heat, and the gas temperature rises from T_{min} to T_{max}.

Carnot Cycle

Proposed by Sadi Carnot in 1824.

Establishes the maximum possible efficiency any heat engine can achieve.

The efficiency depends only on the minimum and maximum temperatures:

$$\eta = 1 - \frac{T_{min}}{T_{max}}$$

where,

T_{min} = minimum temperature of the cycle

T_{max} = maximum temperature of the cycle

Quiz

Which of the following is a Carnot cycle?

1) Static compression -> Static expansion -> Adiabatic expansion -> Adiabatic compression

2) Adiabatic compression -> Constant pressure expansion -> Adiabatic expansion -> Constant pressure compression

3) Adiabatic compression -> Constant pressure expansion -> Adiabatic expansion -> Constant pressure compression

4) Isothermal expansion -> Adiabatic expansion -> Isothermal compression -> Adiabatic compression

Quiz

What is the process by which heat is released in the Carnot cycle?

1) Isothermal expansion

2) Adiabatic expansion

3) Isothermal compression

4) Adiabatic compression

Quiz

What is the Carnot cycle?

1) It consists of two isenthalpic changes and two adiabatic changes.

2) It consists of two isothermal changes and two adiabatic changes.

3) It consists of two isobaric changes and two adiabatic changes.

4) It consists of two isotropic changes and two adiabatic changes.

Quiz

What is the process of supplying heat from a high-temperature heat source in the Carnot cycle?

1) Adiabatic expansion process

2) Adiabatic compression process

3) Isothermal expansion process

4) Isothermal compression process

Types of ICE

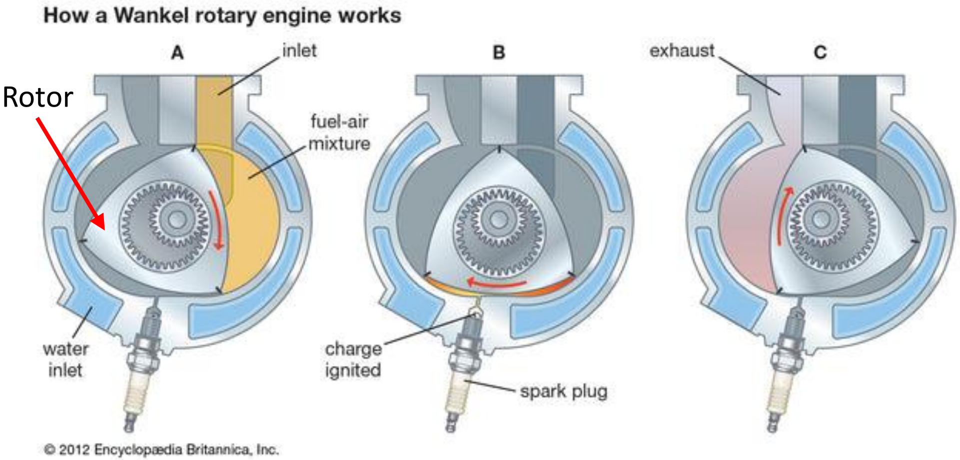
1) Rotary Engine
2) Gas Turbine Engine (Aerospace and Power Plant)
3) Piston Reciprocating Engine (M/E and G/E on ship)

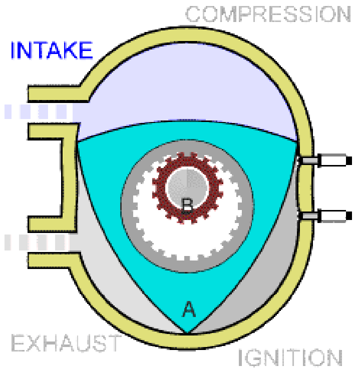
Rotary Engine

1) During one rotation of the rotor, one side performs each action of intake, compression, explosion, and exhaust every 90°.

2) Therefore, since the three sides move simultaneously, the work is done equivalent to that of the three cylinders of a reciprocating piston engine.

3) Compared to reciprocating internal combustion engines with piston rings, they have poor sealing and thermal efficiency, so they are rarely produced nowadays.



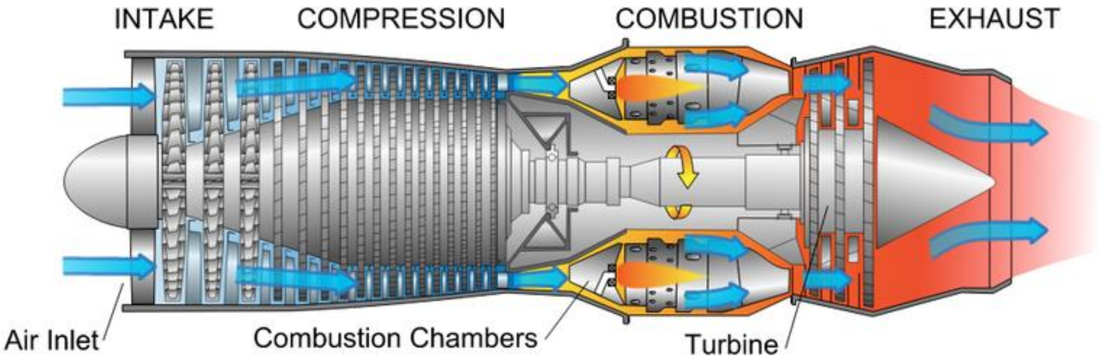


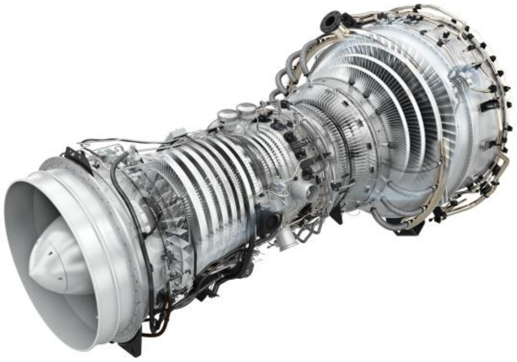
Gas Turbine

1) Combusts fuel in the combustion chamber, and injects the generated high-temperature gas at high speed to rotate the rotor shaft.

2) Light weight, low vibration, and good torque characteristics.

3) Thermal efficiency is lower than that of a reciprocating engine, and there are issues with price and durability because heat-resistant materials, bearings, and gears are required.

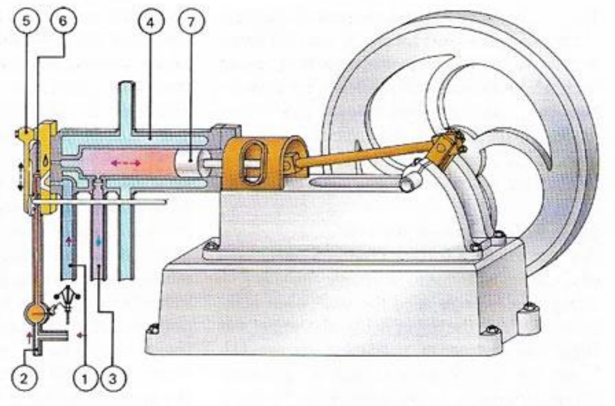


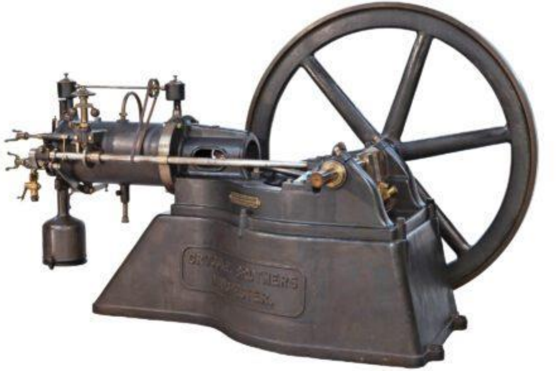


국립한국해양대학교
NATIONAL KOREA MARITIME & OCEAN UNIVERSITY

History of ICE

Nikolaus Otto (1832-1891, Germany)





Otto's engine of 1876 was the first successful internal combustion engine.

A four-stroke horizontal engine, it used a mixture of gas and air as fuel.

The charging stroke drew in air (1) and gas (2) through a slide valve (5) into the cylinder, pulled in by movement of the piston (7).

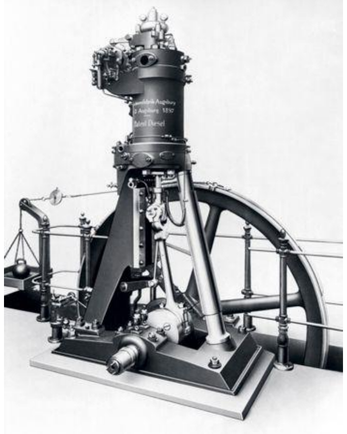
On the return stroke, the fuel mixture was ignited by a flame carried through a narrow opening in the slide valve from a continuously burning gas jet (6) outside the engine.

The expanding products of combustion produced the working stroke.

On the fourth and last stroke the exhaust gases were forced out of the engine (3).

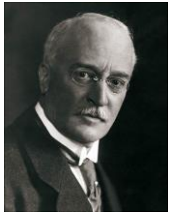
A jacket of cold water (4) surrounded the cylinder and kept the engine cool.

History of ICE



Diesel's third test engine used in the successful 1897 acceptance test

Rudolf Diesel (1858-1913, Germany)



In 1885, Diesel set up his first shop in Paris to begin development of a compression ignition engine.

From 1893 to 1897, Diesel further developed his ideas at Maschinenfabrik-Augsburg AG (later Maschinenfabrik-Augsburg-Nürnberg or MAN).

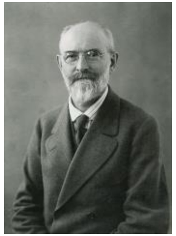
In addition to MAN, Sulzer Brothers of Switzerland took an early interest in Diesel's work, buying certain rights to Diesel's invention in 1893.

At MAN in Augsburg, prototype testing began with a 150 mm bore/400 mm stroke design on August 10, 1893.

While the first engine test was unsuccessful, a series of improvements and subsequent tests led to a successful test on February 17, 1897 when Diesel demonstrated an efficiency of 26.2% with the engine, under load—a significant achievement given that the then popular steam engine had an efficiency of about 10%.

The first Sulzer-built diesel engine was started in June 1898.

History of ICE



Robert Bosch (1861-1942, Germany)

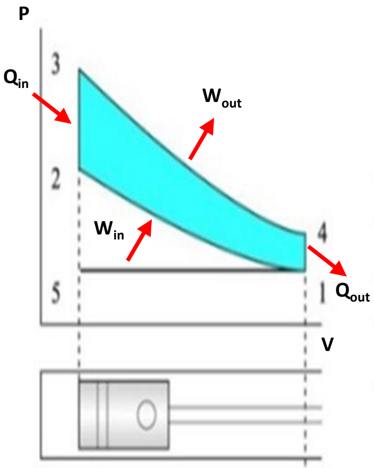
Many years in the making, in 1927 an innovation came to fruition that would last right up to this day — the diesel-injection pump.

This was the reaction of Bosch to the further development of diesel engines, which in contrast to gasoline engines required no magneto ignition.

Initially used only in trucks, the first diesel-injection pump for cars went to market in 1936.

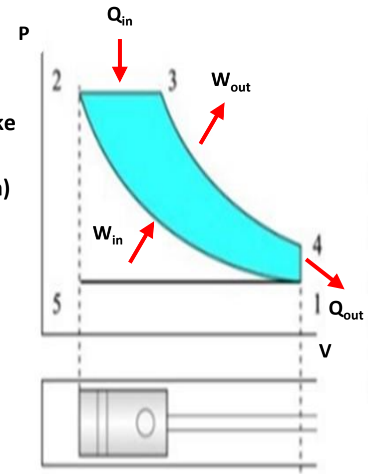
국립한국해양대학교
NATIONAL KOREA MARITIME & OCEAN UNIVERSITY

Classification by thermal cycle



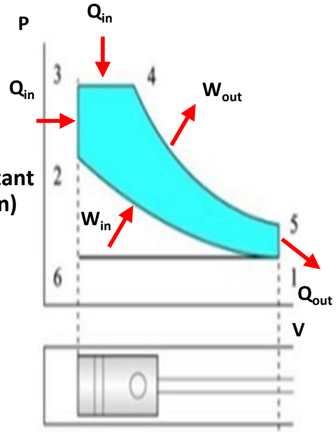
1→2 Compression stroke
2→3 Explosion (static combustion)
3→4 Expansion stroke
4→1 Exhaust start
1→5 Exhaust stroke
5→1 Intake stroke

Constant Volume Cycle Engine
(Otto Cycle)



1→2 Compression stroke
2→3 Fuel injection (constant pressure combustion)
3→4 Expansion stroke
4→1 Exhaust start
1→5 Exhaust stroke
5→1 Intake stroke

Constant Pressure Cycle Engine
(Diesel Cycle)



1→2 Compression stroke
2→3 Fuel injection (constant volume combustion)
3→4 Fuel injection (constant pressure combustion)
4→5 Expansion stroke
5→1 Exhaust start
1→6 Exhaust stroke
6→1 Intake stroke

Mixed/Dual Cycle Engine
(Sabathe Cycle)
(Airless injection system)

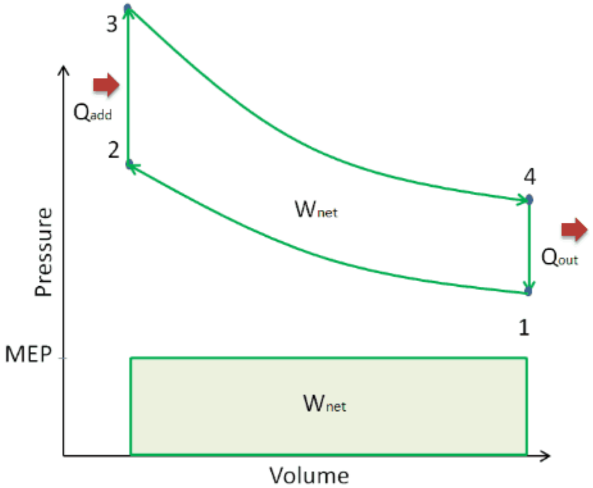
국립한국해양대학교
NATIONAL KOREA MARITIME & OCEAN UNIVERSITY

Mean effective pressure

What is the "Third Law of Thermodynamics"?

→ The mean effective pressure (MEP) is the constant theoretical pressure that would produce the same net work (W_{net}) as developed in one complete cycle if it acted on the piston during the power stroke.

$$MEP = \frac{Net\ work\ for\ one\ cycle\ (W_{net})}{Displacement\ volume\ (V_1 - V_2)}$$



Quiz

What is the basic thermal cycle of a reciprocating internal combustion engine where combustion occurs only under constant pressure?

1) Carnot Cycle

2) Sabathe Cycle

3) Otto Cycle

4) Diesel Cycle

Quiz

“In the thermal cycle, the Otto cycle is also called the ( ) cycle, and the Diesel cycle is also called the ( ) cycle.” Which of the following is correct for ( )?

1) Isothermal, Constant Volume

2) Constant Volume, Constant Pressure

3) Constant Volume, Mixed/Dual

4) Constant Pressure, Constant Volume

Quiz

Which of the following statements about the Otto cycle is incorrect?

1) The supply of calories occurs under Constant Volume conditions.

2) This is the basic cycle of a gasoline engine.

3) It is also called a Constant Volume Cycle.

4) Heat release occurs under Constant Pressure.

Quiz

What is the Otto cycle in an internal combustion engine?

1) Combustion occurs in a constant volume.

2) Combustion occurs at a constant pressure.

3) Combustion occurs at a constant temperature.

4) Combustion occurs at a constant pressure and volume.

Quiz

What is the thermal cycle of a diesel engine with an airless injection system?

1) Mixed/Dual Cycle

2) Constant Pressure Cycle

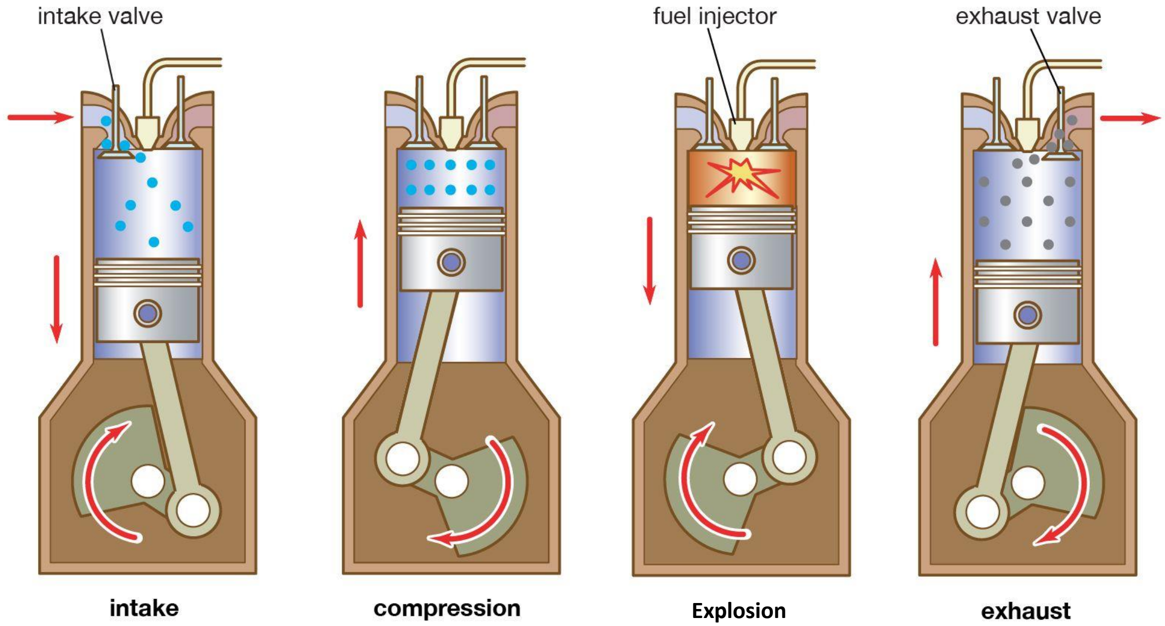
3) Constant Volume Cycle

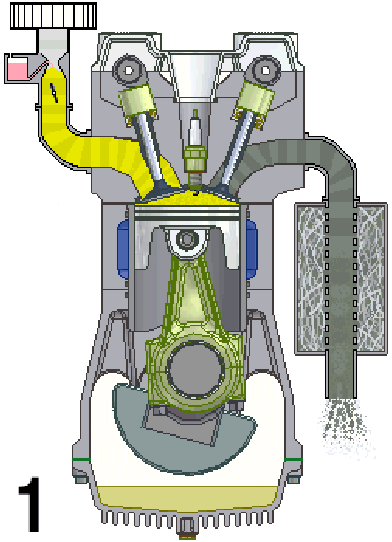
4) Constant Temperature Cycle

4-stroke ICE (G/E)

The engine of generator engine (G/E) on ship is a 4-stroke ICE.

What is 4-stroke ICE?



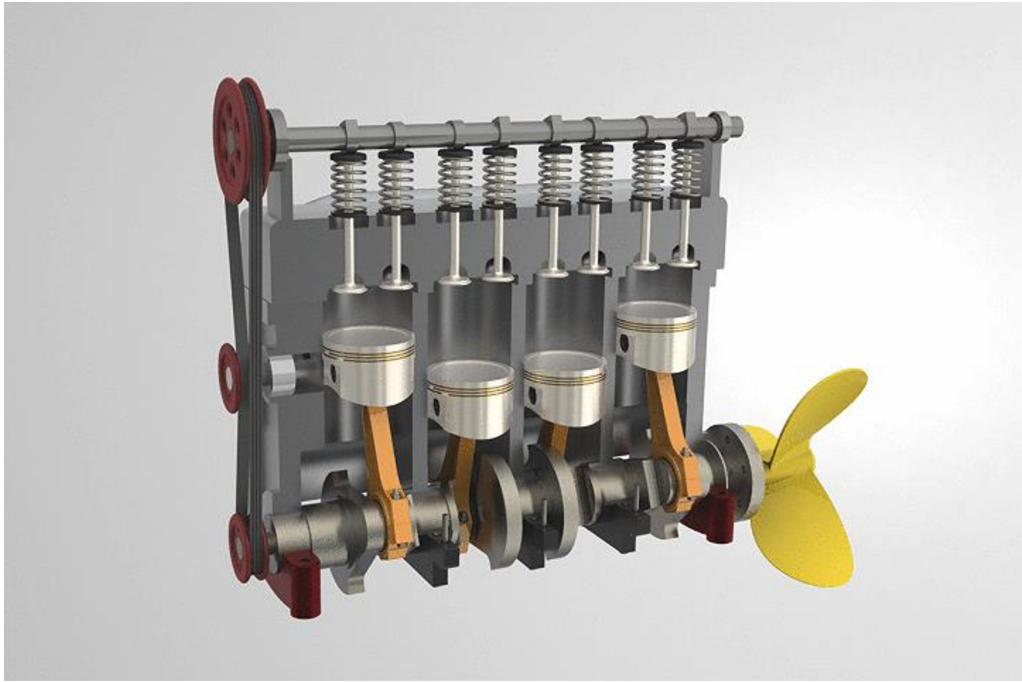


국립한국해양대학교
NATIONAL KOREA MARITIME & OCEAN UNIVERSITY

4-stroke ICE (G/E)

The engine of generator engine (G/E) on ship is a 4-stroke ICE.

What is 4-stroke ICE?



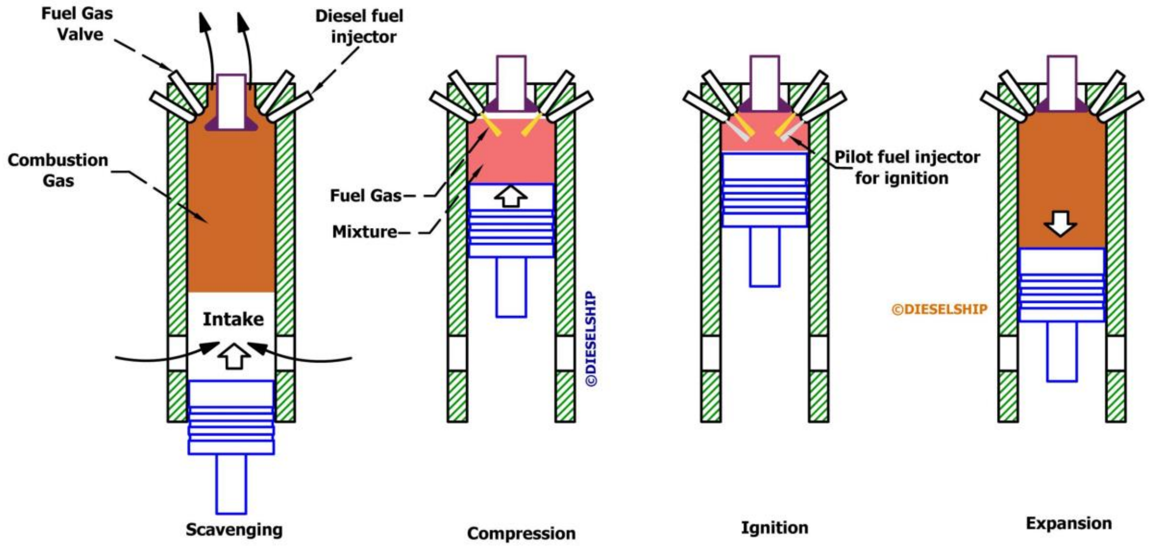
Real G/E is little bit different with left animation.

This animation is just for reference.

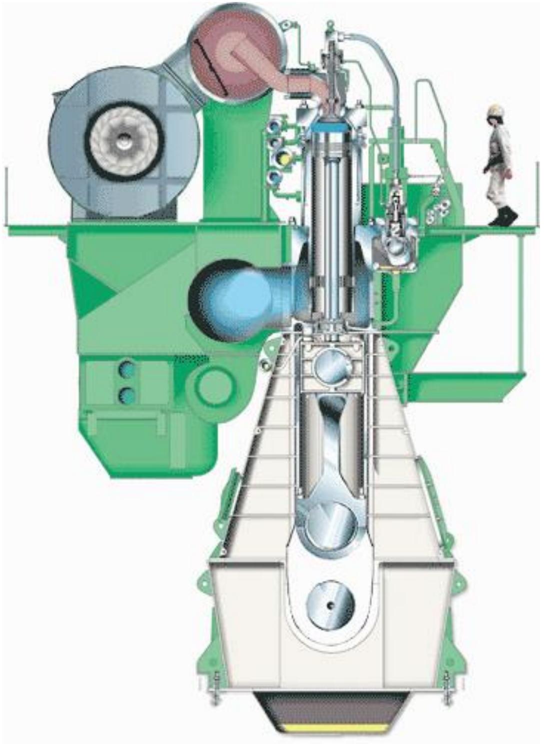
2-stroke ICE (M/E)

The main engine (M/E) on ship is a 2-stroke ICE.

What is 2-stroke ICE?



2-stroke dual fuel engine

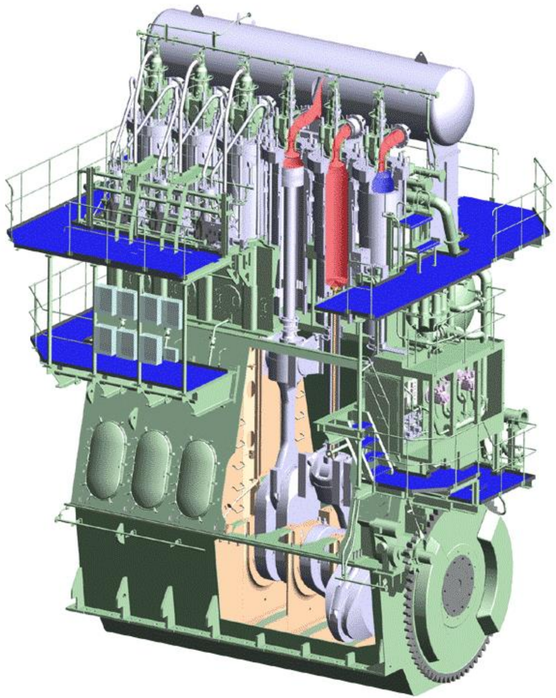


국립한국해양대학교 NATIONAL KOREA MARITIME & OCEAN UNIVERSITY

2-stroke ICE (M/E)

The main engine (M/E) on ship is a 2-stroke ICE.

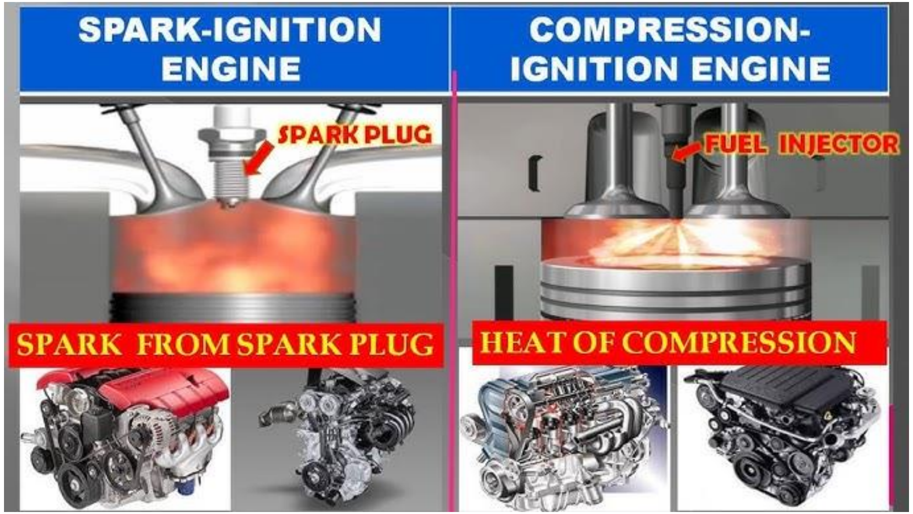
What is 2-stroke ICE?



Classification by ignition method

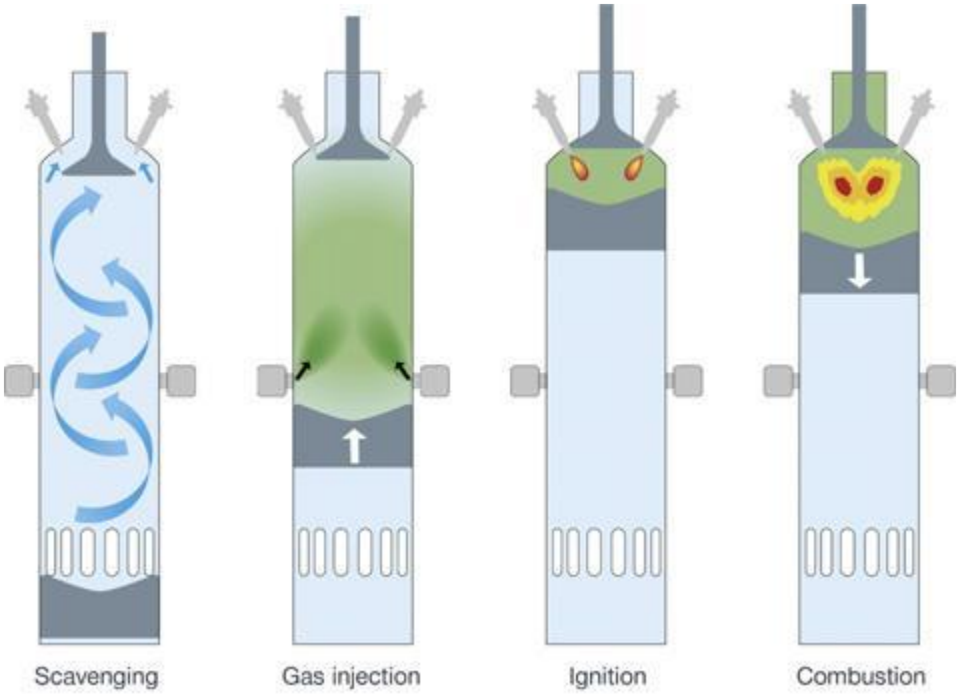
Spark Ignition (SI) Engine -> Not for ship / Famous for car

Compression Ignition (CI) Engine -> For ship (M/E and G/E)



Classification by ignition method

Pilot Injection Gas Engine -> For ship / Famous for dual fuel engine (Mainly for M/E)



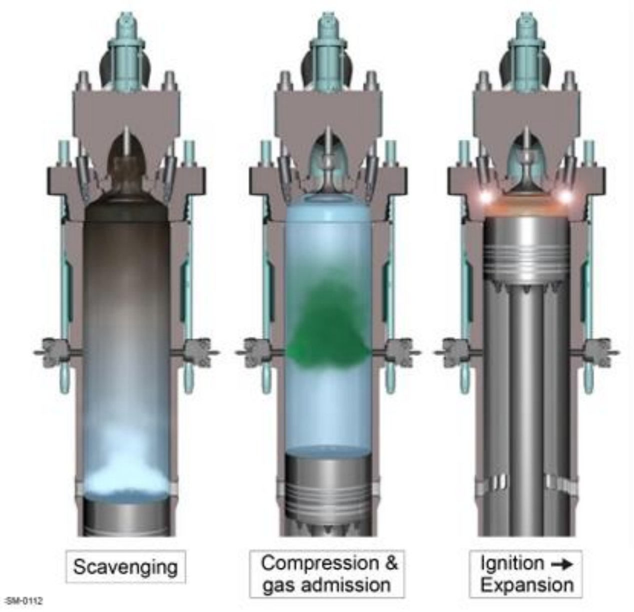


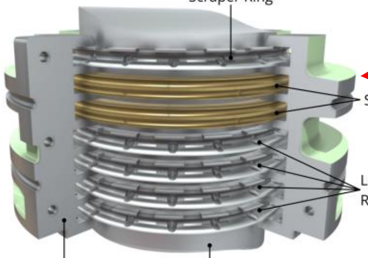
Figure 2-1 Lean burn with pilot ignition

국립한국해양대학교
NATIONAL KOREA MARITIME & OCEAN UNIVERSITY

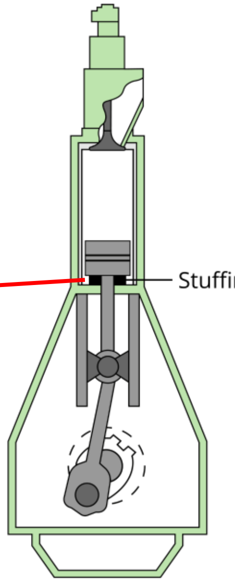
Classification by structure

Depending on the piston structure

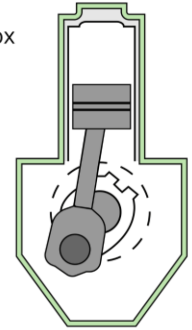
- Trunk Piston Type Engine (G/E)
- Cross-Head Type Engine (M/E)



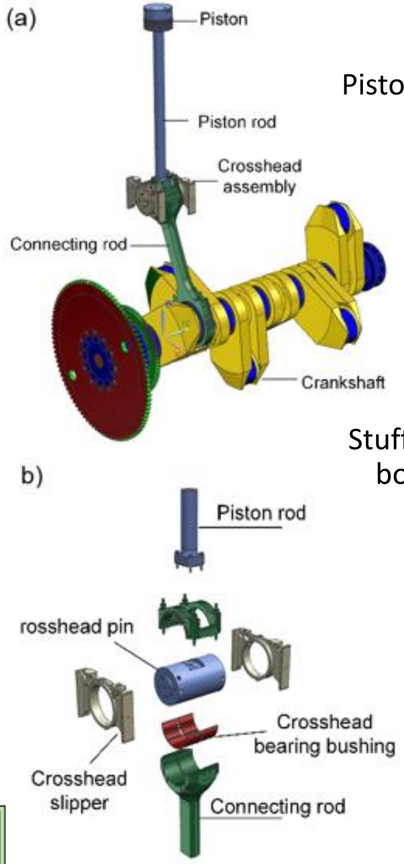
Stuffing Box

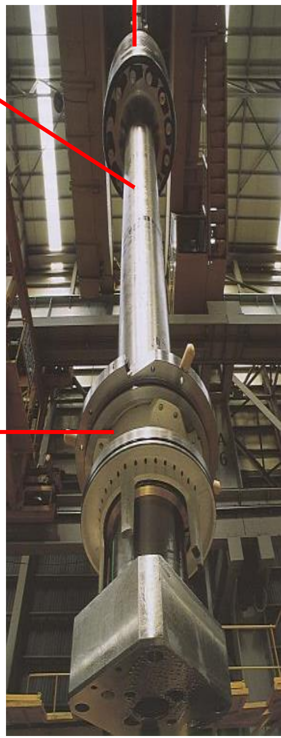


Crosshead Engine



Trunk Engine

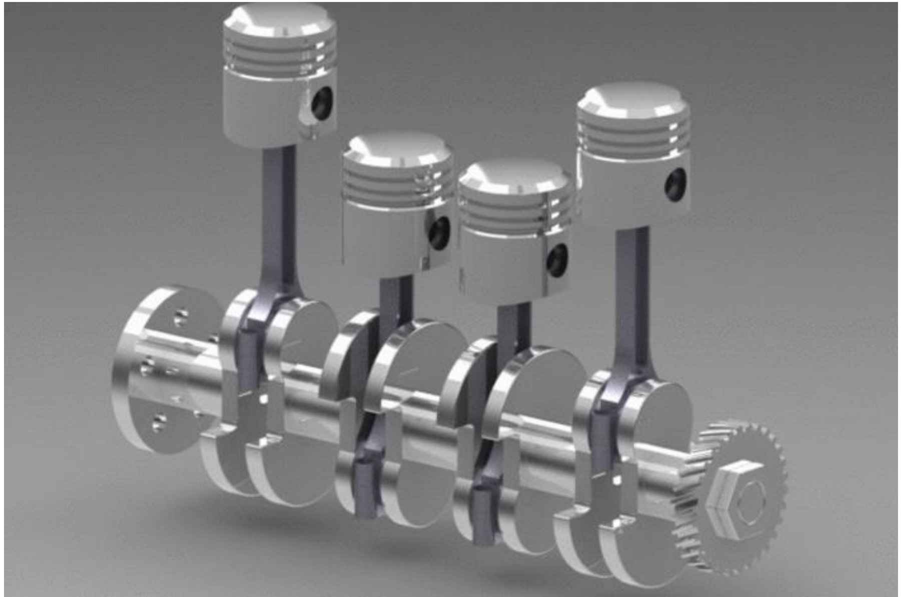


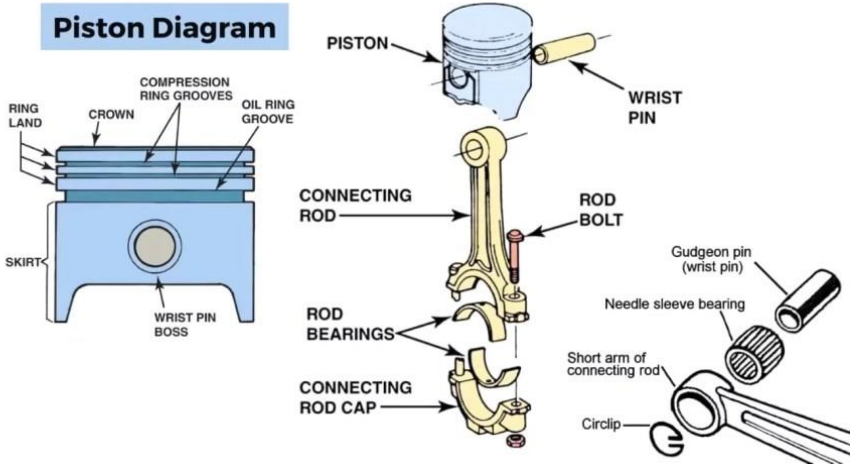


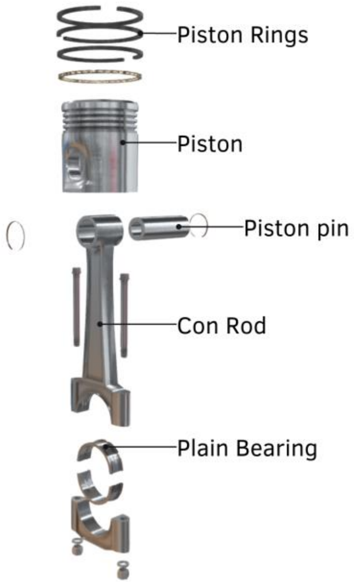
Classification by structure

Depending on the piston structure

- Trunk Piston Type Engine (G/E)

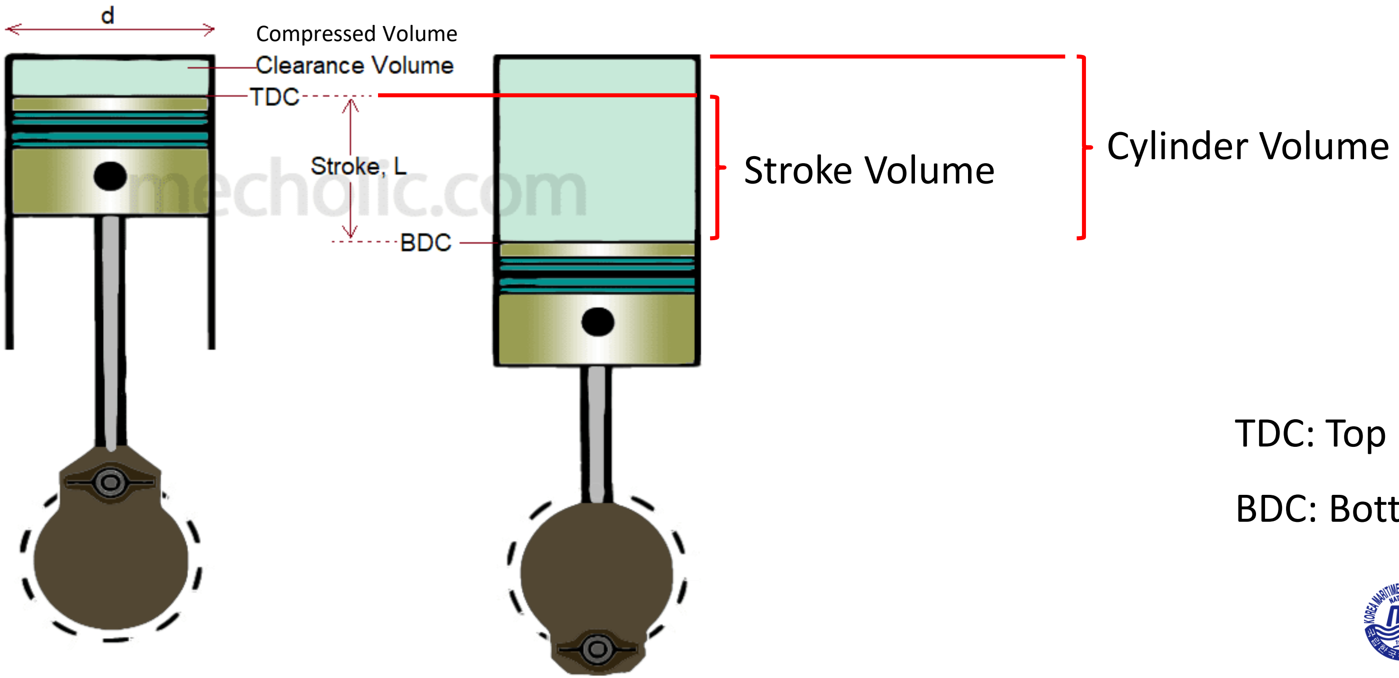






Terminology

$$Compression\ ratio = \frac{Cylinder\ volume}{Comprresed\ volume} = \frac{Comprresed\ volume + Stroke\ volume}{Comprresed\ volume} = 1 + \frac{Stroke\ volume}{Comprresed\ volume}$$



TDC: Top Dead Center

BDC: Bottom Dead Center

Advantages of 4-stroke and 2-stroke engines

4-stroke engine	2-stroke engine
Intake and exhaust operations are performed as separate strokes, resulting in high volumetric efficiency and mean effective pressure.	One explosion per revolution, resulting in less torque variation and smoother operation.
Easy starting and smooth low-speed operation give a wide operating range and great flexibility.	For the same cylinder volume, it is possible to produce 1.2 to 1.5 times the output (liter horsepower) of a 4-stroke engine (the engine capacity and weight are lower for the same output).
The fuel consumption rate is low because the air sucked into the cylinder does not escape to the exhaust.	The number of parts can be reduced because intake can be done through holes machined into the cylinder body.

Disadvantages of 4-stroke and 2-stroke engines

4-stroke engine	2-stroke engine
Since the number of explosions is once every two revolutions, the torque change is large and operation is not smooth when the number of cylinders is small.	It is difficult to design a sufficient replacement of the intake air and exhaust, and new intake air escapes.
Larger volume and weight of the engine compared to the same output.	The stable rotation speed range is narrow, low-speed rotation is unstable, low torque at low speeds, and starting is difficult.
It requires an intake and exhaust mechanism, has a complex structure, and generates a lot of shock and noise.	

Quiz

Which of the following is not an advantage of a four-stroke cycle diesel engine over a two-stroke cycle diesel engine?

1) The volumetric efficiency is better.

2) Low-speed driving is smooth.

3) Less interference between intake and exhaust.

4) There is little torque fluctuation.

Quiz

Which of the following is not an advantage of a two-stroke cycle diesel engine over a four-stroke cycle diesel engine?

1) Larger liter horsepower in cylinders of the same volume.

2) Small torque fluctuations.

3) Low capacity and weight per unit output.

4) There is little mixing of intake and exhaust.

References

1) http://hyperphysics.phy-astr.gsu.edu/hbase/thermo/heaeng.html

2) https://www.meoexamz.co.in/2019/02/de-rating-of-main-engine.html

3) https://www.linkedin.com/posts/nelson-miracle-b7531020b_a-generator-on-a-ship-is-known-as-the-heart-activity-7227398727093649411-bqAo/

4) https://www.youtube.com/watch?v=MNBsUaPYM4E

5) https://www.motorship.com/new-ship-power-concept-eliminates-traditional-2-stroke-propulsion-engine/1446503.article

6) https://hyundaiacmotor.com/product/hyundai-electric-motor-22kw/

7) https://commons.wikimedia.org/wiki/File:Electric_motor.gif

8) https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.hiqool.com%2Fmarine-air-conditioning-plant-operation-manual%2F&psig=AOvVaw1rofN1UJP7ZkyluJmURWoa&ust=1755652792469000&source=images&cd=vfe&opi=89978449&ved=0CBgQjhxqFwoTCMCexcTalY8DFQAAAAAdAAAAABAw

국립한국해양대학교
NATIONAL KOREA MARITIME & OCEAN UNIVERSITY

References

9) https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.cruisingjournal.com%2Fen%2Fcruise-industry%2Fcruise-industry-events%2Fhvac-systems-climate-control-on-board-ships&psig=AOvVaw0u_lkgB3gehqtj1VJ35E9r&ust=1755653360402000&source=images&cd=vfe&opi=89978449&ved=0CBgQjhxqFwoTCPiGh8rclY8DFQAAAAAdAAAAABAE

10) https://chiefengineerlog.com/2022/05/22/vessel-accommodation-air-conditioning-plant-explained/

11) https://chiefengineerlog.com/2022/05/29/vessel-domestic-refrigeration-system-explained/

12) https://www.goseamarine.com/marine-fuel-oil-supply-pump/

13) https://www.roplant.com/index.php/contents/platform/share?act=view&seq=536&bd_bcid=knowledge&q_wops=like&q_wcols=bd_subject&q_wvals1=&page=1

References

14) https://maritimepage.com/boiler-system-and-steam-systems-work-on-ships/

15) https://www.nauticexpo.com/prod/saacke/product-31562-191108.html

16) https://www.researchgate.net/figure/Basic-structure-of-Aalborg-OC-boiler-combined-boiler_fig1_366794613

17) https://commons.wikimedia.org/wiki/File:Costa_Pacifica_Funnel_Tallinn_8_June_2013.JPG

18) http://www.shipsbusiness.com/heating-of-fuel-oil-storage-tank.html

19) https://www.researchgate.net/figure/Simplified-schematic-of-a-steam-propulsion-system-9_fig2_331351046

20) https://www.team-bhp.com/forum/commercial-vehicles/278603-working-marine-steam-turbine-onboard-merchant-ship.html

21) https://maritimeducation.com/marine-steam-turbines/

References

22) https://www.britannica.com/technology/diesel-engine

23) https://commons.wikimedia.org/wiki/File:4-Stroke-Engine-with-airflows_numbers.gif

24) http://www.mechanicaltutorial.com/4-stages-of-carnot-cycle-improving-thermal-efficiency

25) https://en.wikipedia.org/wiki/Sadi_Carnot_%28statesman%29

26) https://mightycarmods.com/blogs/news/how-a-rotary-works-why-it-makes-the-most-engineering-sense-on-paper?srsltid=AfmBOorGBBE71df8SJ3n_moUwlbKreBBI4cRK6S5KXrPiWPfve4iHR8I

27) https://en.wikipedia.org/wiki/Wankel_engine

28) https://energyeducation.ca/wiki/images/thumb/3/3d/Natgasturb.png/800px-Natgasturb.png

29) https://press.siemens.com/global/en/pressrelease/siemens-introduces-38-mw-aeroderivative-gas-turbine-oil-and-gas-industry

References

30) https://www.daviddarling.info/encyclopedia/O/Otto.html

31) https://www.gasenginemagazine.com/gas-engines/oldest-otto-4-stroke-engine-zm0z22aszawar/

32) https://www.wikiwand.com/ko/articles/%EB%8B%88%EC%BD%9C%EB%9D%BC%EC%9A%B0%EC%8A%A4_%EC%98%A4%ED%86%A0

33) https://dieselnet.com/tech/diesel_history.php

34) https://www.bosch.us/news-and-stories/1926-1945-from-automotive-supplier-to-electrical-engineering-company/

35) https://en.wikipedia.org/wiki/Robert_Bosch

36) https://www.sciencedirect.com/science/article/pii/S0360544225018900

37) https://dieselship.com/marine-technical-articles/motor-engineering-knowledge/a-comparison-study-of-otto-diesel-cycles-and-suitability-of-natural-gas/

국립한국해양대학교
NATIONAL KOREA MARITIME & OCEAN UNIVERSITY

References

38) https://www.makita-corp.com/en/products/base/

39) https://grabcad.com/library/four-stroke-diesel-engine-1

40) https://www.youtube.com/watch?v=QcQNJIQvGDk

41) https://issuu.com/palladianpublications/docs/lng-august-2021/s/13040460

42) https://wingd.com/media/vvvop0qj/df-safety-concept_wingd-2s.pdf

43) https://savree.com/en/encyclopedia/marine-2-stroke-engine-stuffing-box

44) https://www.researchgate.net/figure/Details-of-the-six-cylinder-low-speed-marine-diesel-engine-a-main-moving-components_fig1_345721849

45) https://www.mendmotor.com/what-is-piston/

References

46) https://savree.com/en/encyclopedia/piston

47) https://idahospudsblog.blogspot.com/2017/10/cylinder-arrangements.html

48) https://www.marineinsight.com/main-engine/piston-skirt-piston-rod-and-trunk-piston/

49) https://www.mecholic.com/2018/09/nomenclature-ic-engine.html

50) https://www.nuclear-power.com/nuclear-engineering/thermodynamics/thermodynamic-cycles/otto-cycle-otto-engine/mean-effective-pressure-mep-otto-cycle/

51) https://en.wikipedia.org/wiki/Mean_effective_pressure

52) https://www.zichai.net/info/what-are-the-common-faults-of-marine-diesel-en-47329605.html