Text and Reference Book No. 53
July 1990

I.C. ENGINES
FUNDAMENTALS (I)

compiled by
Shinzo Yamamoto

Training Department
Southeast Asian Fisheries Development Center

CONTENTS

PREFACE

This text has been compiled for those trainees taking part in the six months Marine Engineering Course at SEAFDEC/TD, to be used in conjunction with the lectures and practical training on the subject of the Internal Combustion Engines for Fishing Boats.

The text deals with fundamentals of the prime mover in the form of heat engines, specifically the internal combustion engine, and has been based on the technical senior-high school level requirements in Japan. Further applications, including small automobile engines, rotary and diesel engines etc. will be explained in the next edition of this text series (I.C. Engine Fundamentals (II)) by the same author.

My experience has clearly shown that many trainees become hopelessly confused when they first encounter a formula or problem which requires some mathematical calculations. However, if the student carefully studies and follows this text, step by step, no such difficulties should occur. This manual thus includes many working examples to help the trainees and reinforces the concept that the most satisfactory way to learn is by doing.

I hope that by applying the theory to the problems in the text and comparing their solutions with the answers shown, the students will be able to gain a broader understanding of the subject.

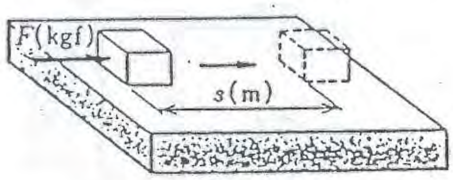
Shinzo YAMAMOTO
Instructor
July, 1990.

INTRODUCTION

A prime mover is a machine which uses energy existing in nature to generate power. There are substances found in nature, such as petroleum, which produce a large amount of heat when burned. By using those substances, it is possible to obtain power, as for instance, gasoline in an engine. Power can also be obtained from flowing water, as in a hydraulic turbine. In using these examples, we say that petroleum and water have "energy". In this study we will examine some fundamental principles regarding energy in prime movers.

* Work and Energy

When a force acts to move an object, the amount of work required is defined as the product of force F (kgf)1/ times the distance s (m) that the object moves in the direction of the force, that is, Fs (kgf.m)2/. In other words, $L = Fs$, where L represents the work. When an object has the capability of doing work, we say that the object has "energy".



Work L = Fs (kgf·m)

Fig. 1 Force and Work

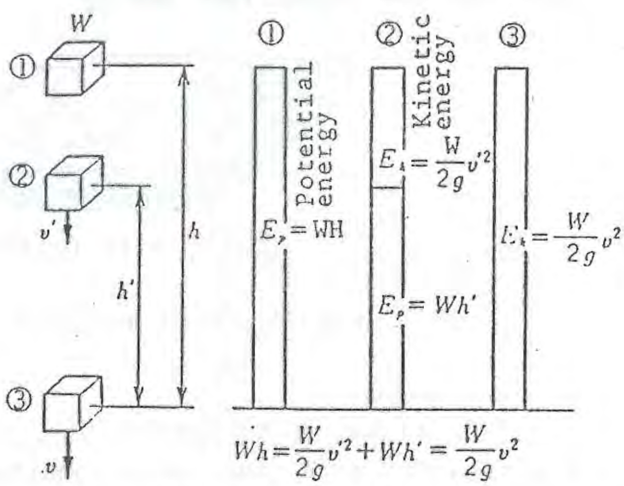
1/ In the international units system (SI), force is expressed in units of Newtons or N (the force required to give an acceleration of 1 m/s to an object with a mass of 1 kg, and 1 kgf = 9.8 N. Although SI has been incorporated in JIS, we will continue to use the traditional kgf system in this paper.

2/ In SI, work is defined in terms of joules J (1 J = 1 N.m) and 1 kgf.m = 9.8 J).

An object of weight W (kgf) moving at velocity v (m/s) has the capacity to do $Wv^2/2$ g (kgf.m) of work until it collides with another object and becomes still. In this case, we say that the moving object has "kinetic energy", whose value is expressed as $Wv^2/2$ g (kgf.m)1/.

If an object is lifted to a certain height and then dropped, it will generate a certain speed during the time it falls to its original position thus indicating that it has the capacity to do work. In this case, an object of weight W (kgf) at height h (m) is said to have "potential energy". The amount of that potential energy is equal to the work required to raise the object to h, and is expressed as Wh (kgf.m).

The general term for both kinetic and potential energy is "mechanical energy". If we take the example of a falling object, the object loses potential energy but gains kinetic energy as it falls, and the sum of its potential energy plus kinetic energy remains constant at a certain value.



(Potential energy) + (Kinetic energy) = a constant

Fig. 2 Mechanical Energy

1/ Energy has the same quality as work, so it is expressed in the same units as work.

Although there are various kinds of energy, for example; thermal, electrical, chemical, and optical, one form can be converted into another. For example, a generator converts mechanical energy into electrical energy. However, the essence of energy which has the capacity to do work does not change. This means that as long as no energy is gained or lost, the amount of energy never changes. This is called the Law of Conservation of Energy.

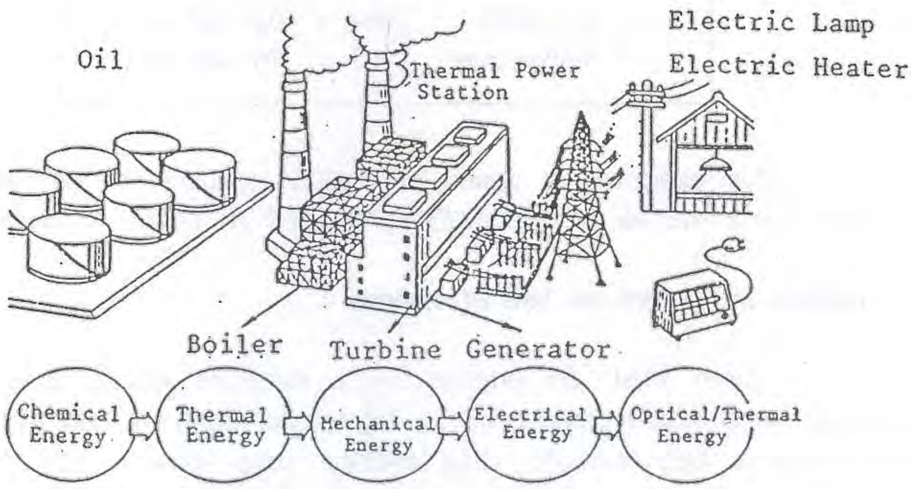


Fig. 3 Various Forms of Energy

*** Power**

The capacity of a prime mover is gerally expressed in terms of power. Power is defined as the amount of work that can be done in one unit of time (usually one second).

If machine A generates 100 kgf.m of work in 5 seconds and machine B generates 90 kgf.m of work in 3 seconds, calculations show that machine A produces 20 kgf.m/s while machine B produces 30 kgf./s. In other words, machine B produces 1.5 times more work than does machine A. If the work done in t seconds is L (kgf.m), the amount of work L is calculated in terms of Fs as shown in Figure 1 and the velocity of the object is v (m/s). If the power at this time is P, then the following equation is derived:

$$P = \frac{L\ (kgf.m)}{t(s)} = \frac{Fs}{t} = Fv\ (kgf.m/s)$$ 1/

The power of an engine is expressed in terms of kilowatts or horsepower.

1 Kilowatt	(kW)	=	102 kgf.m/s
1 horsepower	(PS)	=	75 kgf.m/s

For example, a power of 1,000 kgf.m/s is equivalent to 1,000/102 = 9.8 kW or 1,000/75 = 13.1 PS in terms of horsepower.

*** Degree of Effective Use of Energy**

Given that an engine is a machine which uses natural energy to produce power, it is important to know how effectively the engine can convert this energy into work. The degree of effective use of energy is called "efficiency", and can be expressed as follows:

$$\text{Efficiency} = \frac{\text{Work done by the engine}}{\text{Energy supplied to the engine}} \times 100(\%)$$

As we will learn later, the efficiency of an automobile gasoline engine has been calculated at about 30%. This means that only about 30% of the gasoline's thermal energy is converted into work, while about 70% is wasted. Thus, efficiency expresses the effective performance of an engine.

1/ In SI, 1 J/s is defined as 1 watt (W) and is used as the unit of power.

It is our job to make efficient use of nature's energy by making engines more efficient by minimizing energy wastage in operation. For example, in Japan, where energy resources are limited, an important aspect of design is the continuing research into the development of new resources, updating technologies and the introduction of countermeasures to save energy. These criteria are also important in our study of engines.

CHAPTER 1 THE USE AND CONVERSION OF ENERGY

Today's life style is maintained by using energy in various forms. For example, the electricity we use in our homes, schools, and factories is transmitted from power stations which convert water, thermal, or nuclear power found in nature into electrical energy.

The demand for energy is constantly increasing, and although we now depend on petroleum as our main energy source, we must bear in mind that this resource is limited. It is therefore essential to discover energy substitutes for petroleum and find ways to conserve fuel.

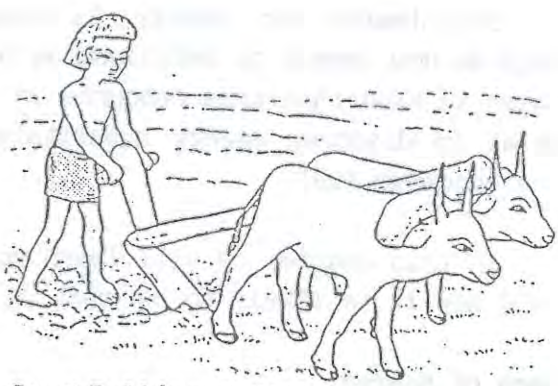
In this chapter we will learn how and why energy has been used and how it is likely to be used in the future.

1. Uses of Energy

Since primitive times, mankind has used natural resources for his clothing, food, and shelter. It is said that man is a unique animal because he makes tools for his survival. He started by making simple tools such as the lever, roller, wheel, and pulley all of which were operated by human power, then, gradually he harnessed domestic animals, the wind and water to work for him. With these developments from simple to more complicated machines, a larger power supply was required and mankind has steadily advanced into the age of sophisticated thermal power with the invention of the steam engine.

1.1 The Use of Human Power and Animal Power

The first power used by humans was their own physical labour. The construction of the pyramids in Egypt and the operation of galley ships on the Mediterranean Sea depended on human power. The ancient farmers also relied upon their own power alone, but they soon discovered that by domesticating wild animals, such as horses and cows, another power source became available. Until the time of the Industrial Revolution, animal power was widely used for cultivation and transportation as well as for pumping water and grinding flour. However, only a relatively small amount of energy can be obtained from humans and animals, and such energy could hardly be expected to provide a continuous source of power. Thus, with the development of the prime mover, our dependence on these early energy sources have all but disappeared.



Cows Pulling a Plow
(Egypt, 2000 B.C.)

Fig. 1-1 using Human and Animal Power

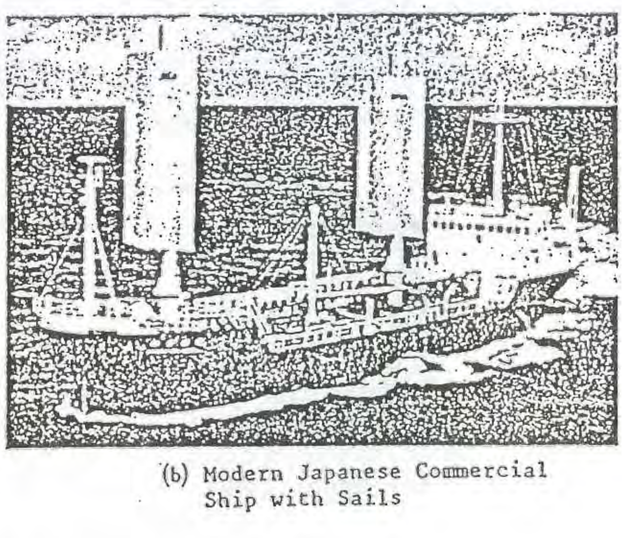
1.2 The Use of Wind Power

Wind power was first introduced on the sailing ships of Egypt around 3500 B.C. to supplement human effort. By around the 13th century sails had been developed to the point where they could be used as the ships' main source of power. In the 15th century large sailing vessels capable of crossing vast oceans appeared, and the age of big voyages of discovery and trade had started. With the invention of steamships in the 19th century, however, these massive sailing ships disappeared from the scene.

Windmills, which are used to convert wind power into rotary motion, were first used in ancient Egypt and were introduced into Europe in the 12th century where improvements were made in their design and efficiency throughout the 14th to 16th centuries. The well-known windmills of Holland were adapted for a wide variety of purposes, which included not only pumping and draining water, but also milling flour and sawing wood.

Because the direction and speed of the wind changes so often, wind power is unstable and cannot be relied upon as a constant source of energy. Furthermore, a large percentage of the wind's power is consumed by the windmill itself, and so the windmill's functions were largely displaced by the steam turbine. Following the energy crisis in the 1960's and early 70's, however, people started to reconsider wind-power as being capable of providing a non-polluting, inexhaustible, energy source. Using modern technology windmills and sailing ships are reappearing as a supplementary power source to conserve petroleum.

(a) Propeller-type Windmill in Denmark (Max. output:2,000KW)



(b) Modern Japanese Commercial Ship with Sails

Fig. 1-2 Uses of Wind-Power

1.3 Uses of Water Power

From about the 10th century B.C. along the Nile and Yellow Rivers, water wheels were used to draw water from the river to irrigate the land. The use of the water wheel as a power source was discovered by the Romans in the 1st century B.C. At first it was used for pumping water and irrigation and later for milling grains. From the 11th to the 18th century, the water wheel helped fuel the early industrial revolution in a variety of ways, including paper-making and sawing, spinning, the manufacture of alloys and steel, and in the mechanical industries, which explains why so many factories were built along river banks. The design of water wheel was gradually improved during this period, as shown in Figure 1-3 (a)-(b). The first wheels used only the kinetic energy of the water, but as wheels which could use the water's potential energy were developed, both efficiency and output were increased.

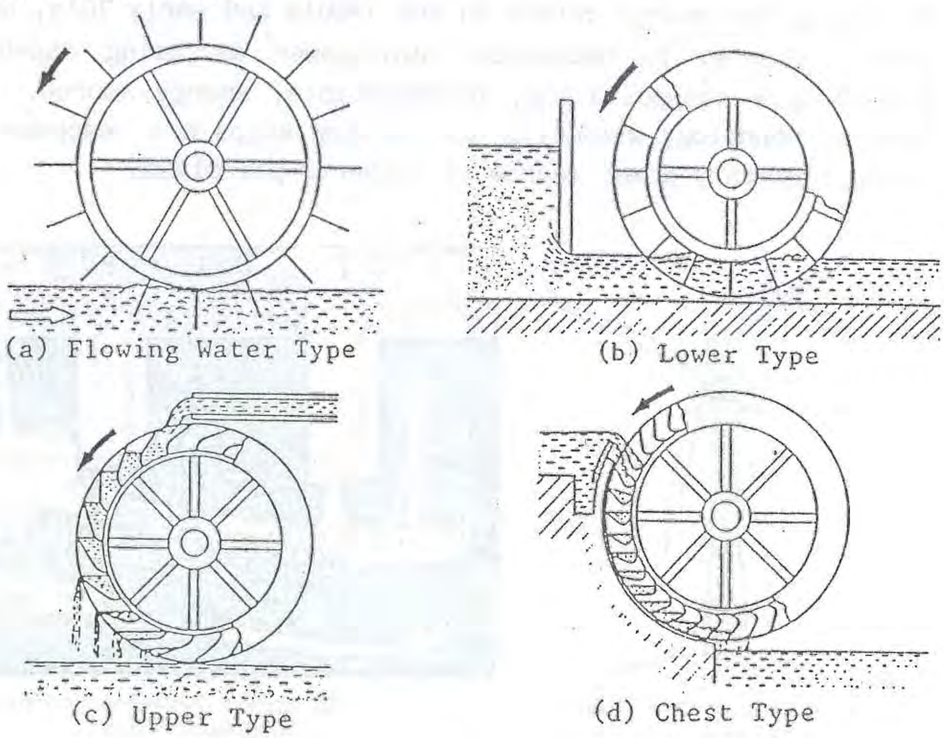


Fig. 1-3 Types of Water Wheels

In the latter half of the 18th century, advances were made in theoretical research and manufacturing techniques, and in the 19th century water wheels of iron and steel were devised to provide large outputs. This principle is now applied to modern hydraulic turbines. Thus old methods can still be adapted for use today, especially for generating electric power.

1.4 Uses of Thermal Energy

Mankind has been using fire as a source of energy since primitive times, although for many centuries it only provided a source of heat and light. It took up until the invention of the steam engine in the 18th century before man learned to convert heat into power.

In the following sections, let us see how thermal energy is harnessed in steam and internal combustion engines.

(1) Steam Engines

When industry started to flourish in the 18th century, waste water collected in the mines caused many severe problems and created the need for powerful pumps. People engaged in the mining industry attempted to use steam to power these pumps.

T. Savery of England and D. Papin of France both devised and built experimental pumps, but, in practice, they were not very successful.

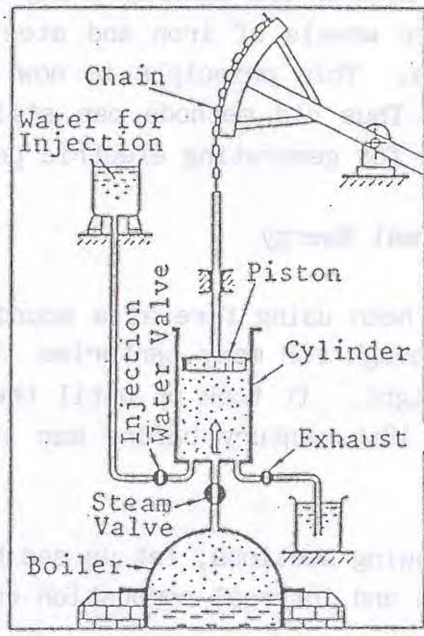


Fig. 1-4 The Newcomen Engine

The first practical steam engine was made in England in 1712 by T. Newcomen, and the Newcomen engine was soon in wide use. (Fig. 1-4)

James Watt (1736-1819) improved the Newcomen engine and, in 1769, obtained a patent for his own steam engine. In the Newcomen engine, the steam condensed inside the cylinders, but in Watt's engine condensation was carried out in a separate condenser. This improvement allowed the cylinders to be kept at a uniform high temperature and considerably reduced the consumption of fuel.

Later, Watt used the pressure created when the steam was expanding and converted it into reciprocating (up and down) motion through the pistons thereby putting steam pressure to work. The basic principles of this engine are shown in Fig. 1-5(a).

Watt also further converted reciprocating motion into rotary motion, devised a speed governor which kept the rotary speed constant, and made numerous other improvements to develop his engine to the stage shown in Fig. 1-5(b).

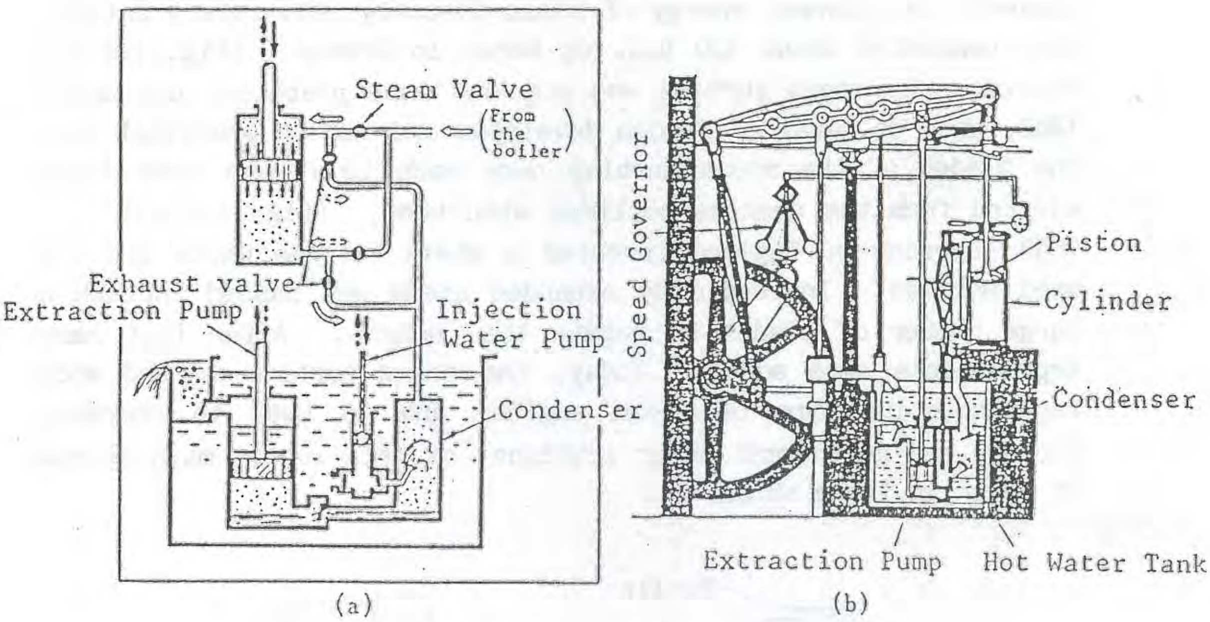


Fig. 1-5 Watt's Steam Engine

Besides being used for pumping out waste water for drainage, Watt's steam engine also became a powerful power source for factories. This engine made it possible to build factories wherever desired, and acted as a major force in the progress and expansion of the Industrial Revolution.

Many further refinements were made to the steam engine during the 19th century, eventually leading to a high-speed engine capable of producing high pressure and temperatures. Thus, the steam engine became the prime mover for transportation and for generating electric power. However, as engines with a higher thermal efficiency[1/] such as the steam turbine and internal combustion engine came on the scene, steam engines gradually lost their command in this field.

The first experiments with a steam turbine, which converts the thermal energy of steam directly into rotary motion, were conducted about 120 B.C. by Heron in Greece. (Fig. 1-6(a)) However, the steam turbine was not put into practical use until 1882, when de Laval of Sweden developed and made a practical one. The blades of the steam turbine were made to rotate when steam ejected from the nozzles collided with them. (Fig. 1-6(b)). In 1884, Parsons of England invented a steam turbine which did not need nozzles. Instead, the expanded steam was passed through a large number of blades to rotate the runners. After that many improvements were added. Today, the steam turbine is the most representative type of steam engine, and is used in thermal, nuclear and geothermal power stations, as well as the main source of power in large ships.

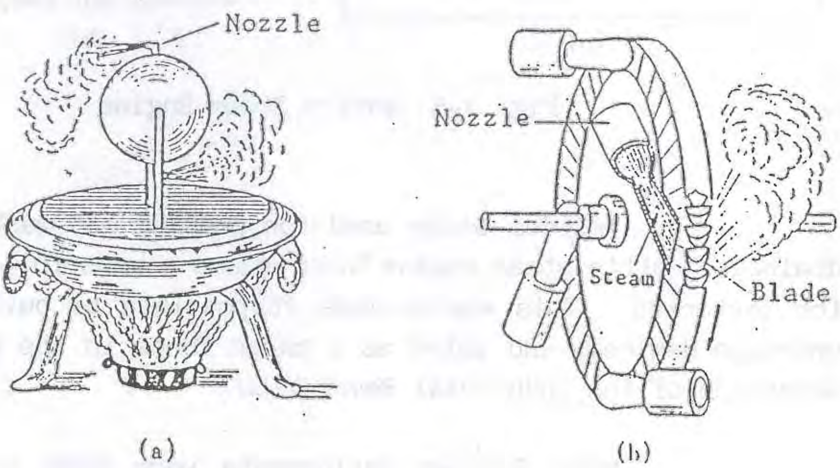


Fig. 1-6 Early Steam Turbines

1/ Thermal efficiency = Amount of heat used efficiently/Amount of heat supplied to the machine

(2) Internal-Combustion Engines

The first experiments with internal combustion engines, in which the fuel is burned directly in the cylinders to obtain power, were made by Huygens in the Netherlands around 1680. These experiments used gunpowder as the fuel, but did not succeed. The main advantage of the internal combustion engine is that it is smaller than the steam engine as it does not require a large boiler. Since internal combustion engines held the possibility of increasing thermal efficiency, various experiments were again conducted in the late 18th century, and by around 1820, using coal gas as the fuel the gas engine made its appearance. In 1860, J.J.E. Lenoir of France built an electrical-ignition type of gas engine (Fig. 1-7) which had a thermal efficiency of a mere 3-4%.

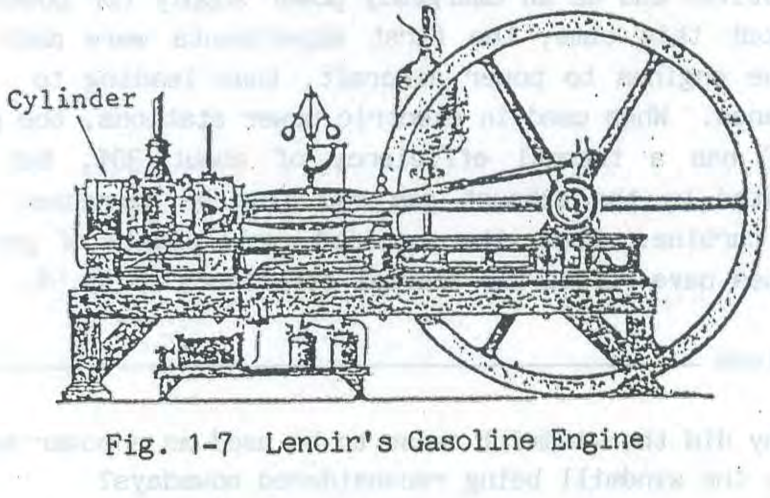


Fig. 1-7 Lenoir's Gasoline Engine

The gas engine, which was subsequently developed into today's gasoline engines, was first made by N.A. Otto of Germany in 1876. By compressing the absorbed gas these engines considerably increased the thermal efficiency, to about 14%. However, since gas was not a suitable fuel for moving vehicles or ships, the gasoline engine which uses vaporized gasoline was created. These small and light gasoline engines led to the introduction motorcycles, automobiles, and aircraft. Various kind of ignition devices were employed at this time. Some were operated by a flame or a long, thin burner was heated, or rudimentory electrical ignition systems were employed. However, in 1894 R. Diesel developed an engine with an ignition system which worked by compression. Diesel's engines could run on lower quality and, therefore, cheaper oil than gasoline engines, and has since been widely used in trucks and buses, trains, ships, construction machinery, and power stations. The development of the internal combustion engine has brought about a revolution in the area of transportation.

The concept of a gas turbine was first outlined in Germany by Stolze in 1872, but it was not until 1939 that a gas turbine which a thermal efficiency of 18% was built. Although not as efficient as the steam turbine, it is suitable for use in locomotives and as an emergency power supply for power stations. At about this time, the first experiments were made using gas turbine engines to power aircraft, thus leading to todays jet airplanes. When used in electric power stations, the gas turbine itself has a thermal efficiency of about 30%, but the steam generated by the exhaust gas can also be harnessed to drive a steam turbine. Thus, the combined cycle plants of gas and steam turbines have raised the thermal efficiency to 45.5%.

Questions ◎

1. Why did the windmill cease to be used as a power source? Why is the windmill being reconsidered nowadays?

2. What is the difference in the efficiency and the way that energy is harnessed between flowing water type wheels and upper type ones?

3. What kind of engines were used before the invention of the steam turbine? What were they mainly used for?

2. Engines and Conversion of Energy

As studied in the previous section, mankind has spent a long time discovering how to use nature's energy efficiently, and the result of this is the efficient engines we have today. As we move into an energy-saving age, more effort will be made to further improve thermal efficiency, reduce fuel consumption, make effective use of waste heat from factories, and develop new forms of energy such as nuclear fusion and solar heat.

2.1 Conversion of Energy

Fig. 1-8 shows an outline of the ways that energy may be converted through various kinds of machines and devices, in particular, the major engines used today.

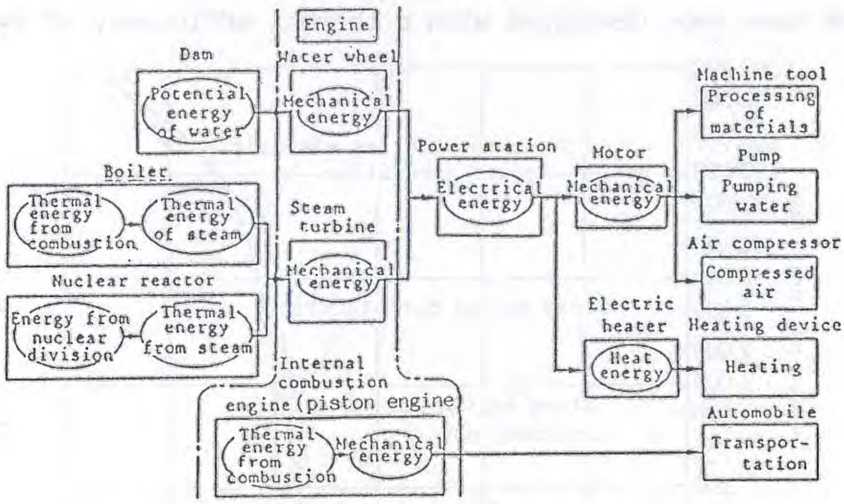


Fig. 1-8 Conversion of Energy and Its Uses

As shown in the table, most of the power we use today is obtained from the potential energy of water and from thermal energy through fuel combustion and nuclear fission.

Each of the engines in the figure uses its own active source to convert energy into power. The water wheel uses water, the steam turbine uses steam, and the internal combustion engine uses combustible gas as well as other active sources, which are termed "working fluids" or "substance".

2.2 Trends in the Development of Engines and Related Factors

Many technological developments have been introduced to increase the output and improve the efficiency of engines. As a result, the output per machine (unit output) has risen considerably to the point that todays hydraulic turbine can produce 500 MW (500,000 kW), a steam turbine can produce 1,300 MW, and a diesel engine can produce 41 MW. While the efficiency of a hydraulic turbine exceeds 90%, the thermal efficiency of a steam turbine used in a thermal power station exceeds 40%, and diesel engines have been developed with a thermal efficiency of 44%.

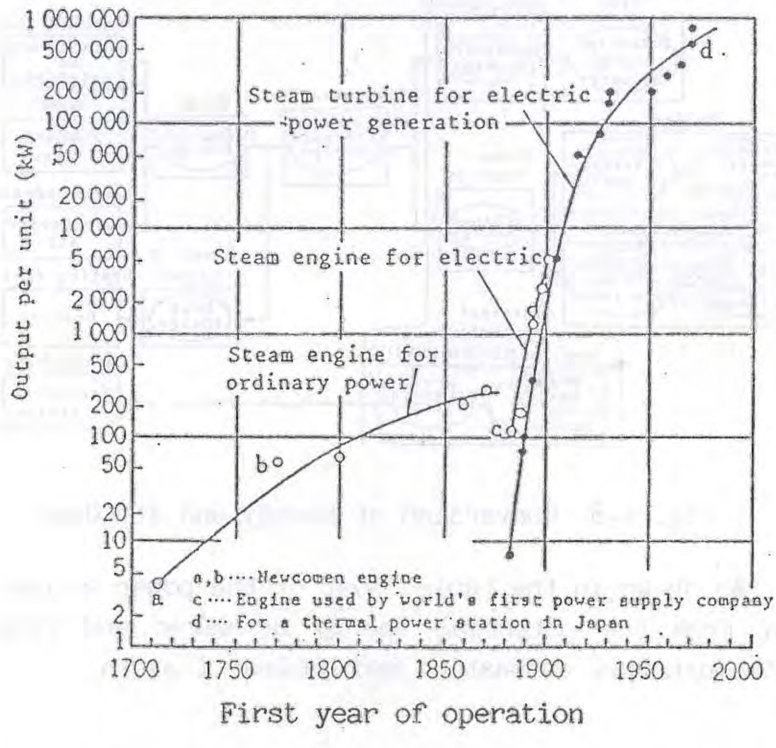


Fig. 1-9 Trend of Increasing output of Land Steam Engines

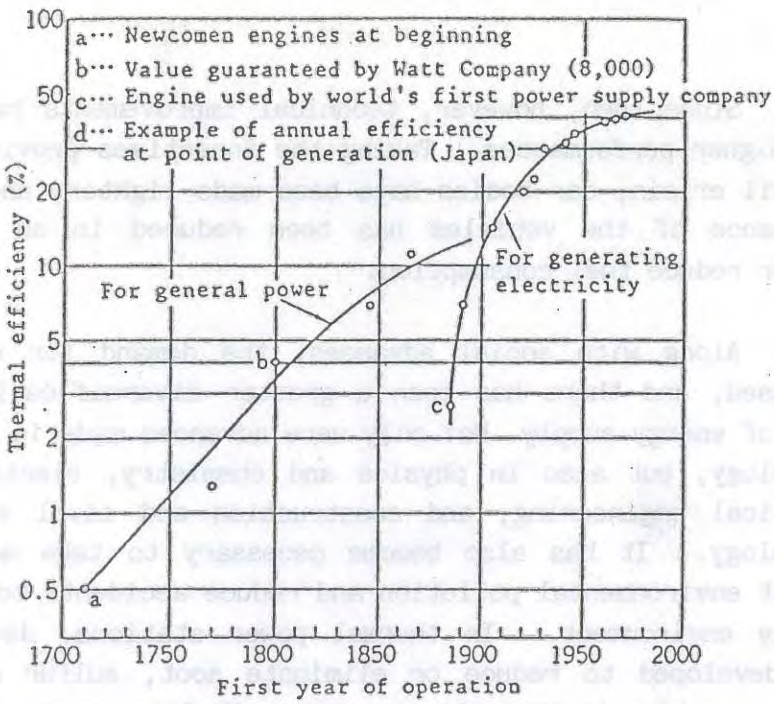


Fig. 1-10 Trends and Improvement of Thermal Efficiency of Steam Engines

Figs. 1-9 and 1-10 show the increasing trends in unit output and improvements in thermal efficiency, using the steam engine as an example. In both of these trends, the improvements were spectacular during the initial period of development, but have leveled off in recent years.

Recently, there have been not only increased in unit output itself but also in the amount of output for the size of the engine. Advances have been made in reducing the engine size while increasing output. These trends have been most noticeable in the internal combustion engines used in automobiles and airplanes. The gasoline engines used in automobiles were producing a greater output for their size up to about 1975 when, for a short period, output dropped and fuel consumption increased as measures were introduced to clean the exhaust gases and reduce environmental pollution.

Since then, however, technical improvements have led to even higher performances. Taking the incentives provided by the 1973 oil crisis, car bodies have been made lighter, and the wind resistance of the vehicles has been reduced in an effort to further reduce fuel consumption.

Along with social advances, the demand for energy has increased, and there has been a greater diversification in the forms of energy supply. Not only were advances made in mechanical technology, but also in physics and chemistry, electricity and electrical engineering, and construction and civil engineering technology. It has also become necessary to take measures to prevent environmental pollution and reduce accidents to provide a healthy environment. In thermal power stations, devices have been developed to reduce or eliminate soot, sulfur oxides and nitrogen oxides in the exhaust gases. Nuclear power plants have been provided with safety and protective measures to prevent exposure to radioactivity emitted from the fissionable material and radioactive waste materials. The future development of engines should take into consideration not only the requirements of efficiency, high output, and compact size but also be socially acceptable.

2.3 Energy Savings and the Future of Energy

Many large oil fields were discovered in the early 1960s, making it possible to obtain a plentiful supply of low priced fuel. When compared with coal, oil is easier to transport and store, can generate more heat, and contains less sulfur which pollutes the environment and therefore quickly became the preferred power source.

However, as shown in Fig. 1-11, the supply of oil will probably reach its peak in the year 2000, and if demand continues to grow at the present rate, there will be shortages and economic problems will result from soaring prices. Although experiments are taking place to obtain nuclear fusion from deuterium - 33 gf of deuterium is found in each cubic meter of seawater - it will take a considerable time to become economically viable. For this reason, it is necessary to develop other energy substitutes to conserve fossil energy, to be used in those areas which depend solely upon oil.

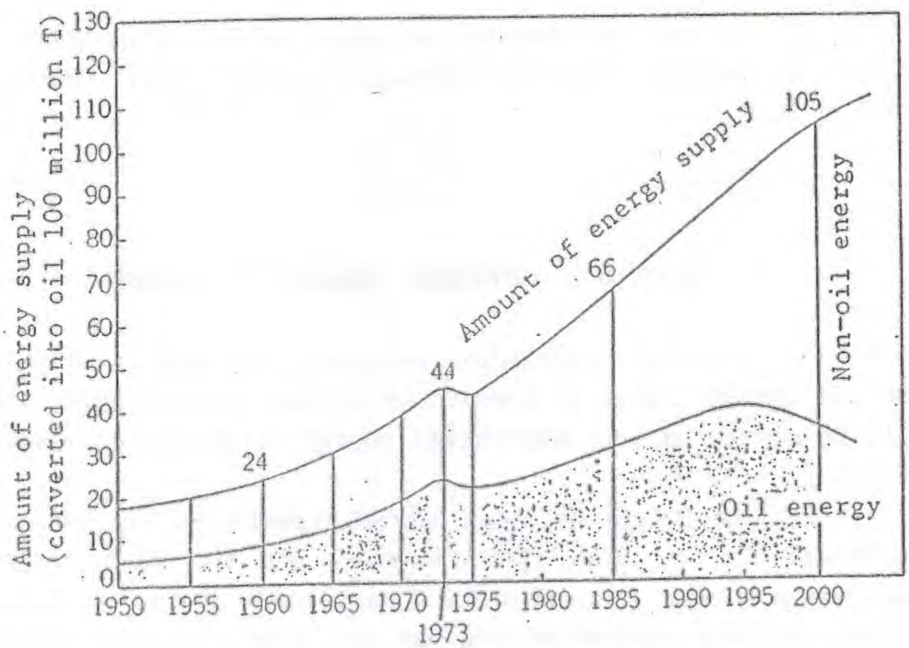


Fig. 1-11 World Energy Supply and Future forecast (Free World)

As a substitute for oil, coal is being reintroduced to generate electric power by means of gasification, liquefaction or coal-oil mixture (COM). Uranium 235 (Ur-235) fuels the present nuclear reactors. However, Ur-235 accounts for only 0.7% of natural uranium, the remaining 99.3% being uranium 238 (Ur-238) which was not suitable as a fuel. Advances have now been made by developing the fast breeder reactor (FBR) which can utilize uranium 238 by converting it into plutonium 239. Other developments of new energy technologies, such as solar and wind power generation, have also been progressing.

Questions ◎

1. In the following sentences, circle the appropriate value for saving energy:

   1) In winter, run the heater below (20°C, 18°C, 15°C).
   2) In summer, run the air-conditioner above (28°C, 25°C, 20°C).

CHAPTER 2 INTERNAL COMBUSTION ENGINES

An internal combustion engine is an engine in which the fuel is burned inside a chamber to produce heat energy, which in turn is converted into mechanical energy to generate power.

The prototype of the internal combustion engine was first conceived in the late 17th century, but the most spectacular developments took place in the second half of the 19th century. Today, internal combustion engines are widely used in transportation, agriculture, construction, and a variety of other fields in the form of gasoline engines, diesel engines, and gas turbines.

In this chapter we will study the relationships between heat and work, which represents the basic principles of internal combustion engines, and examine various kinds of internal combustion engines themselves.

1. Principles of Heat Engines

When two blocks are rubbed together the resulting friction will generate heat. However, this heat cannot be used to produce work. Thus, although we can say that mechanical work can be converted into heat relatively easily, it is not so easy to convert heat into mechanical work. In fact, the successful conversion of heat into mechanical work must be carried out according to certain definite laws, and the machine which does this most effectively is called a "heat engine". In this section, we will study the ways that heat works to produce heat engines.

1.1 Heat and Work

(1) The first law of thermodynamics

Though heat and work differ in form, they both have the same characteristics when converted to energy. When the law of conservation of energy is applied to heat and work, the following statement applies:

"Both heat and work are forms of energy, so it is possible to convert work into heat and heat into work".

This is called the first law of thermodynamics and it expresses the fundamental relationship between heat and work. From the law of conservation of energy, it is clear that in order for a machine to do work, it must consume some energy. Therefore in order for a heat engine to do mechanical work, it must consume an equivalent amount of heat energy.

When heat Q (kcal) and work L (kgf.m) are converted into each other, the ratio is a constant which can be expressed in the following equation.

$$Q = AL \qquad (4\text{-}1)$$

A is the coefficient for when work is converted into heat, and it is called the heat equivalent of work. The following value for A has been found from numerous experiments.

$$A = \frac{1}{427}\ \text{kcal/kgf.m}$$

These principles were discovered in 1840 by J.R. von Mayer and J.P. Joule.

- Equation 4-1 can also be expressed as L = JQ. J is called the mechnical equivalent of heat and is related to A as follows:
  J = 1/A. In other words, J = 427 kgf.m/kcal.

Ex. 1. How many kilocalories of heat are required to lift an object which weighs 5 kgf to height of 8 m?

(Solution)

In this case, work L = 5 x 8 = 40 (kgf.m)
Converting this to heat with equation (4-1),

$$Q = AL = \frac{1}{427} \times 40 = 0.0937 \text{ (kcal)}$$

(Answer 0.0937 kcal)

Q 1. With a force of 120 kgf, if the work used to move an object 4 m in the direction of force is converted into heat, how many kilocalories are used? (Ans. 1.12 Kcal)

Q 2. 1 kilowatt hour (kWh) is the amount of work done in one hour by a power of 1 kW. If this is converted into heat, what will its value be? (Ans. 860 Kcal)

(2) Internal energy

When a static substance is heated, the movement of the molecules which make up that substance becomes active, the kinetic energy of the molecules increases, and the temperature rises. When the temperature reaches a certain point, the substance changes form, from solid, to liquid, to gas by overcoming the mutual attraction between molecules and changing the collective shape of the molecules. If the distance between the molecules changes, the potential energy of the molecules will change. The combination of kinetic and potential energy of the molecules is called internal energy1/ and, in this case, the additional heat is used to increase the internal energy.

Furthermore, if that substance is in a state in which it can expand, part of the added heat will be consumed immediately to do external work in the form of increasing the volume.

If the added heat is Q (kcal), the internal energy before and after heating is U_1 and U_2 (kcal) respectively, and the heat equivalent to the work which acts externally is AL (kcal), this is expressed in the following equation.

$$Q = (U_2 - U_1) + AL \qquad (4\text{-}2)$$

This important fundamental equation expresses the relationship between the various kinds of energy in a static substance, and is expression of the first law of thermodynamics.

Q 3. If 8 kcal of heat is applied to a gas inside a cylinder and at the same time the gas is caused to expand to do 2,400 kgf.m of work, by how much will the $(U_2 - U_1)$ of the internal energy of the gas changed.

(Ans. 2.38 Kcal, increased)

(3) Work done by the expansion of a gas

Generally, if the expanded gas is forced against an external area, it works towards the outside. Fig. 4-1 (a), demonstrates the work which is exerted outside when the gas in the cylinder expands to push the piston from 1 to 2.

1/ In relation to internal energy, mechanical energy is called external energy.

For an arbitary condition along the stroke of travel, pressure p (kgf/m^2) acts on area S (m^2) of the piston, and if the piston is further pushed by Δx (m)[1/], the work ΔL (kgf.m) which the gas causes the piston to do at this time is expressed by the following equation.

$$\Delta L = pS\Delta x$$

In this equation, $S\Delta x$ is the increase in volume at ΔV, so this equation can be changed into the following equation.

$$\Delta L = p\Delta V \qquad (4\text{-}3)$$

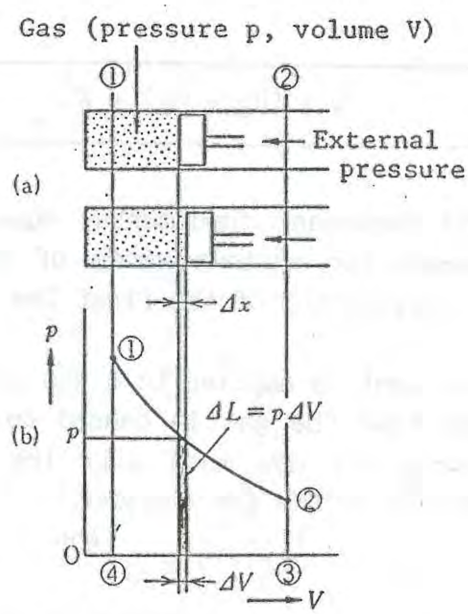


Fig. 4-1 Work Done by Expansion of Gas

1/ Δ (delta) represents a very small amount of change. The sum of all these changes is expressed by Σ (sigma).

When this equation is considered in reference to Fig. 4-1(b), it is clear that the shaded area represents the work ΔL. The total work L (kgf.m) done externally when the gas expands from 1 to 2 can be found by adding all of the continuous changes of ΔL from 1 to 2.

$$L = \Sigma\Delta L = \Sigma p\Delta V \qquad (4\text{-}4)$$

As shown in Fig. 4-1(b), the graph which represents the changes in state of the gas by plotting pressure p on the vertical axis and volume V on the horizontal axis is called a pV graph. In a pV graph, work can be expressed at points ①, ②, ③, and ④ in the graph[1/].

Q 4. In Fig. 4-1 (a), if the piston moves from 1 to 2 with no change in pressure inside the cylinder, what shape will the pV graph for this change have?

(4) Enthalpy

In Fig. 4-2 a certain amount of gas is allowed to enter a cylinder which contains a piston.

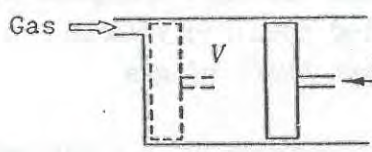


Fig. 4-2 Work done by Gas

1/ When the state changes from ② to ①, it indicates the work done from outside in order to compress the gas.

The gas with pressure p (kgf/m^2) exerts a force on the piston and does work pV ($kgf.m_2$) represented by cylinder volume V (m^3). In general, a gas which has pressure and volume has not only internal energy U (kcal) but also mechanical energy pV (kgf.m) needed to maintain its volume. If this is considered as an integral part of heat energy, the total heat energy H (kcal) of the gas can be expressed by the following equation:

$$H = U + ApV \qquad (4\text{-}5)$$

This H is called enthalpy.

- In thermodynamics, various measurements are often expressed in relation to 1 kgf of gas, and in these cases the equation (4-5) can be expressed as follows:

$$h = u + Apv, \quad H = Gh \qquad (4\text{-}6)$$

Where;

h : enthalpy (kcal/kgf) per 1 kgf of gas
u : internal energy (kcal/kgf) per 1 kgf of gas
v : volume (m^3/kgf) occupied by 1 kgf of gas (also called specific volume)
G : weight (kgf) of gas

Ex. 2. A gas with a pressure of 1.2 kgf/cm^2 and a volume of 0.5 m^3 changes state until it has a pressure of 4 kgf/cm^2 and a volume of 0.2 m^3. Assuming that no change has occurred in the internal energy of this gas over time, what would be the change in enthalpy?

(Solution)

If the enthalpy in the original condition is H_1, the internal energy is U_1, the pressure is pl, and the volume is V_1, enthalpy H_1 can be found as follows from equation (4-5).

$$H_1 = U_1 + Ap_1 V_1 \qquad (1)$$

In a similar way, when the gas has changed form, enthalpy H_2 can be found from the following,

$$H_2 = U_2 + Ap_2 V_2 \qquad (2)$$

Therefore, since $U_2 - U_1 = 0$, from equations (1) and (2)

$$H_2 - H_1 = A(p_2V_2 - p_1V_1) \qquad (3)$$

Substitute the following values into equation (3),

$$p_1 = 1.2(kgf/cm^2) = 1.2 \times 10^4(kgf/m^2)$$
$$p_2 = 4(kgf/cm^2) = 4 \times 10^4(kgf/m^2)$$
$$V_1 = 0.5(m^3),\ V_2 = 0.2(m^3)$$

$$\therefore H_2 - H_1 = \frac{10^4}{427}(4 \times 0.2 - 1.2 \times 0.5) = 4.68(kcal)$$

Since $H_2 - H_1$ is a positive value, the change in enthalpy increased.1/

(Answer Increase of 4.68 kcal)

Q 5. If a gas under a pressure of 0.4 kgf/cm^2 has a volume of 1.5 m^3 and an internal energy of 320 kcal, what is its enthalpy? (Ans. 334 Kcal)

1/ If $H_2 - H_1$ is negative, the change was a decrease in enthalpy

Q 6. A gas of 3 kgf under a pressure of 12 kgf/cm^2 and with a volume of 0.4 m^3 changes until the pressure is 0.6 kgf/cm^2 and the volume 3 m^3. If we assume that the internal energy of the gas does not change, how much will the enthalpy change for each 1 kgf of this gas?

(Ans. 23.4 Kcal, decreased)

1.2 Changes and State of Ideal Gases

The gases which serve as the working fluid in heat engines undergo various changes of state in order to perform work. For all practical purposes, these changes may be stated as following Boyle's Law and Charles' Law, although, in fact, there is no gas which completely follows these two laws. Generally, therefore, when checking the change of state of a gas, it is assumed that there is an ideal gas which follows these laws when various changes in state occur.

(1) Equation of State and Specific Heat of Ideal Gases

(a) Equation of state

The product (PxV) of volume v (m^3/kgf) and pressure p (kgf/m^2)1/ for a given quantity of gas is proportional to absolute temperature T (K)2/. This fact is known as Boyle's-Charles' law. According to this law, for 1 kgf of air, pv/T = a constant, and therefore, if the value of this constant is expressed with R,

$$pv = RT \qquad (4\text{-}7)$$

The volume of gas G (kgf) is V = Gv, therefore

$$pV = GRT \qquad (4\text{-}8)$$

1/ Pressure p used here is always the absolute pressure.

2/ Absolute temperature is the units of temperature used in SI where 1K equivalent to 1°C. The relationship between absolute temperature T (K) and Celsius temperature t (°C) is as follows: T = t + 273.

This R is a proportional constant determined by the kind of gas, and is called the "gas constant".

Thus, the equations which represents the relationships between the various quantities of state of the gas are called "equations of state", and equation (4-7) and equation (4-8) are equations of state for ideal gases. Oxygen, hydrogen, and air are be calculated as if they were ideal gases.

(b) Specific heat

The heat required to raise, by 1 K, the temperature of a substance which weighs 1 kgf is called specific heat. Thus, if the temperature of a substance weighing G (kgf) is raised from T_1(K) to T_2(K), the amount of heat Q (kcal) required for this is the specific heat c, thus:

$$Q = Gc(T_2 - T_1) \qquad (4\text{-}9)$$

In the case of a gas, if it is heated and the volume remains constant, no external work is done and all the added heat is used to increase the internal energy of the gas, as demonstrated by equation (4-2). On the other hand, if the pressure remains constant and the gas is heated, the gas will expand to do external work. The amount of heat required to do this will be greater by the amount required to do the work, than the amount of heat required when the volume remains constant.

Thus, even if the rise in temperature $(T_2 - T_2)$ is the same, the amount of heat required will differ depending upon the heating conditions and the specific heat at those times will vary. For that reason, the specific heat when the volume is constant is called specific heat at constant volume, c_v, and the specific heat for when the pressure is constant is called the specific heat at constant pressure c_p, c_p is always greater than c_v.1/ The ratio between c_p and c_v is called the ratio of specific heat and is expressed by K.

Table 4-1 Gas Constant, Specific Gravity, and Specific Heat for Selected Gases

Gas	Molecular formula	Gas constant R $\frac{(kgf.m)}{(kgf.K)}$	Specific gravity compared to air	Value of specific heat at 0°C and low pressure (kcal/kgf.k)		$K = \frac{C_p}{C_v}$
				Specific heat at constant pressure C_p	Specific heat at constant volume C_v	
Helium	He	211.8	0.1380	1.251	0.755	1.66
Hydrogen	H_2	420.57	0.0695	3.403	2.417	1.409
Nitrogen	N_2	30.27	0.967	0.2482	0.1774	1.400
Oxygen	O_2	26.50	1.105	0.2182	0.1562	1.399
Air	-	29.27	1.000	0.240	0.171	1.402
Carbon Monoxide	CO	30.27	0.967	0.2486	0.1775	1.400

$$\frac{C_p}{C_v} = K \quad (4\text{-}10)$$

Table 4-1 shows the values of the gas constant and specific heat for various gases.

1/ Because the degree of expansion of solids and liquids is so small, the specific heat at constant volume is not distinguished from the specific heat at constant pressure.

Ex. 3. What is the specific volume of air at 0^oC which is under apressure of 1.03 kgf/cm^2? Find the gas constant of air from Table 4-1.

(Solution)

From the equation of state (4-7) for an ideal gas, $v = RT/p$.

Substitute the following values into this equation.

$R = 29.27(kgf.m/kgf.K)$ (From Table 4-1.)
$p = 1.03(kgf/cm^2) = 1.03 \times 10^4 \ (kgf/m^2)$
$T = 273(K) \ (0^oC=273K)$

$$\therefore \quad v = \frac{29.27x273}{1.03 \times 10^4} = 0.776 \ (m^3/kgf)$$

(Answer 0.776 m^3/kgf)

Q 7. At a pressure of 7.5 kgf/cm^2 and a temperature of 18^oC, how much volume will be occupied by 3 kgf of air? Find the gas constant for air from Table 4-1. (Ans. 0.341 m^3)

Q 8. You want to introduce 20 kgf of oxygen at 23^oC into a container which has a volume of 120 liters. What will be the pressure of the oxygen? (The gas constant for oxygen will be found in Table 4-1). (Ans. 131 $kg.f/cm^2$)

(2) Changes of state of ideal gases

There are various circumstances in which an ideal gas may change its state. Let us examine how the equations of state are expressed depending on those various conditions, the relationship between the amount of heat and work, and the shape of the pV diagram for those changes.

(a) Isovolumetric change

When a change of state occurs while the volume remains constant, the change is expressed as shown in Fig. 4-3.

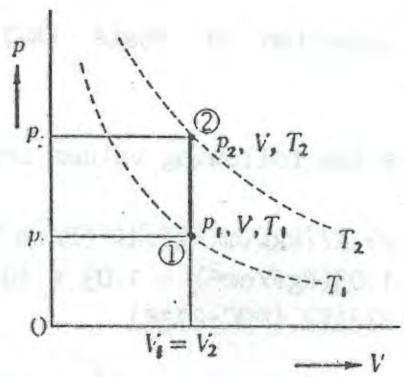


Fig. 4-3 Isovolumetric Change

Since V = a constant in equation 4-8,

$$\frac{p}{T} = \text{a constant} \quad (4\text{-}11)$$

Since the volume does not expand, no work is done externally and L = 0. Therefore, from equation 4-2, all of additional heat is converted to the internal energy of the gas. Also, specific heat c from equation 4-9 is in this case the specific heat at constant volume c_v. In other words:

$$Q = U_2 - U_1 = Gc_v\,(T_2 - T_1) \qquad (4\text{-}12)$$

Q 9. A gas weighing 15 kgf is heated from 10°C to 300°C while its volume remains constant. How much does the internal energy increase ($U_2 - U_1$)? Find the specific heat at constant volume for air from Table 4-1.

(Ans. 744 kcal, increased)

(b) Changes at constant pressure

When change of state occurs while the pressure remains constant, the change is expressed as shown in Fig. 4-4.

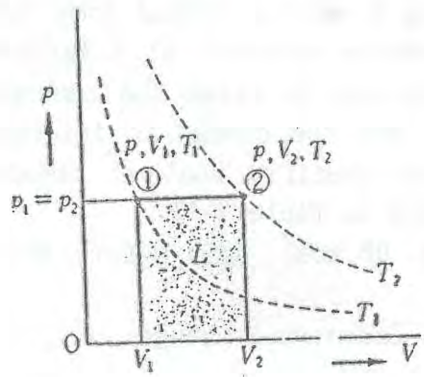


Fig. 4-4 Changes at Constant Pressure

Since p = a constant in equation 4-8,

$$\frac{V}{T} = \text{a constant} \quad (4\text{-}13)$$

The work done externally due to expansion can be found from equation 4-4,

$$L = p(V_2 - V_1) \qquad (4\text{-}14)$$

Thus, Equation 4-2 becomes $Q = U_2 - U_1 + Ap(V_2 - V_1)$, but if $H = U + ApV$ as expressed by Equation 4-5 is considered, $Q = H_2 - H_1$ is obtained, and it is clear that all the additional heat becomes an increase in enthalpy. Also, in this case, the specific heat c from Equation 4-9 is specific heat at constant pressure c_p. In other words:

$$Q = H_2 - H_1 = Gc_p(T_2 - T_1) \qquad (4\text{-}15)$$

Q 10. Air weighing 5 kgf is heated from 10°C to 50°C while the pressure remains constant at 5 kgf/cm^2. Find the amount of heat required to raise the temperature, the work done externally, and the change in internal energy. (The gas constant and specific heat at constant pressure of air will be found in Table 4-1).

(Ans. 48 kcal, 5854 kgf.m, 34.3 kcal increased)

(c) Isothermal change

When a change of state occurs at a constant temperature, the change is expressed as shown in Fig. 4-5.

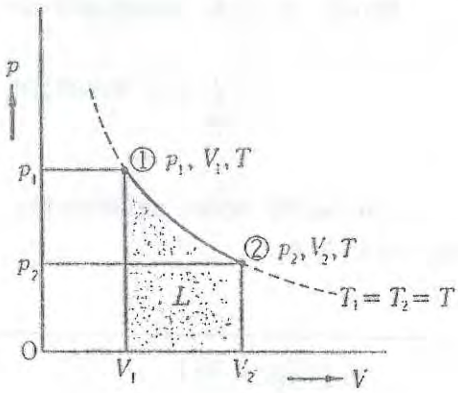


Fig. 4-5 Isothermal Change

Since T = a constant in equation 4-8,

$$pV = \text{a constant} \qquad (4\text{-}16)$$

As is clear from Equation 4-12 and Equation 4-15, the changes of the internal energy and enthalpy of an ideal gas are related only to changes in the temperature, and therefore the changes when the temperature is constant are $U_1 = U_2$, $H_1 = H_2$ Therefore, from Equation 4-2, all of the added heat is changed into external work. This work L can be found from $L = \Sigma p \Delta V$, but since $p = GRT/V$ is from the equation of state for ideal gases and since GRT is a constant, the following equation is obtained:

$$\left.\begin{array}{l} Q = AL \\ L = GRT \times 2.303 \log \frac{V_2}{V_1}{}^{1/} = GRT \times 2.303 \log \frac{p_1}{p_2} \end{array}\right\} \quad (4\text{-}17)$$

(d) Adiabatic change

An adiabatic change is one which occurs within a system without any transfer of heat energy to or from the system. This change is illustrated in Fig. 4-6.

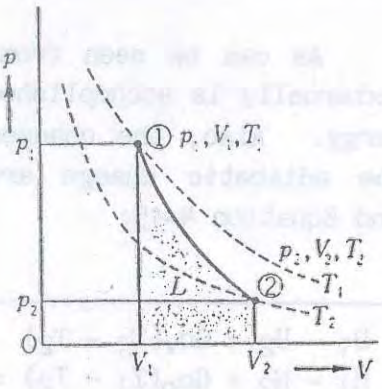


Fig. 4-6 Adiabatic Change

In this change, the following relationship holds between pressure p and volume V.

$$pV^k = \text{a constant} \quad (4\text{-}18)$$

1/ $L = \int_1^2 p\,dV = GRT \int_1^2 \frac{1}{V} dV = GRT \times 2.303 \log \frac{V_2}{V_1}$

K is called the adiabatic index and for an ideal gas it is the same as the ratio of specific heat. Next, the following equation holds to express the relationship with temperature T.

$$TV^{\kappa-1} = \text{a constant}$$

$$\frac{P^{\frac{\kappa-1}{\kappa}}}{T} = \text{a constant} \qquad (4\text{-}19)$$

Since there is no entry or loss of heat in an adiabatic change, Q = 0, therefore, from Equation 4-2:

$$AL = U_1 - U_2 \qquad (4\text{-}20)$$

As can be seen from this equation the work which is done externally is accomplished through the consumption of internal energy. Also, the changes of internal energy and enthalpy in the adiabatic change are as follows, based on Equation 4-12 and Equation 4-15:

$$U_1 - U_2 = Gc_v(T_1 - T_2)$$
$$H_1 - H_2 = Gc_p(T_1 - T_2) = \kappa AL \qquad (4\text{-}21)$$

(e) Polytropic change

The change in state of gases which actually occur are not ideal isothermic changes or adiabatic changes. In general, they can be approximately expressed through the following equation.

$$pV^n = \text{a constant} \qquad (4\text{-}22)$$

This change is called a polytropic change. Futher, n is called the Polytrop index and is an arbitrary value greater than 0 which is a constant for one particular change. Therefore, the polytropic change becomes a general expression for the change of state of a gas in special instances, i.e.,

when n = 1, pV = a constant and isothermal change occurs,
when n = K, pV^{K} = a constant and an adiabatic change occurs,
when n = 0, p = a constant and a constant pressure change occurs,
when n = ∞, V = a constant and a constant volume change occurs.

A comparison of these changes is shown in Fig. 4-7.

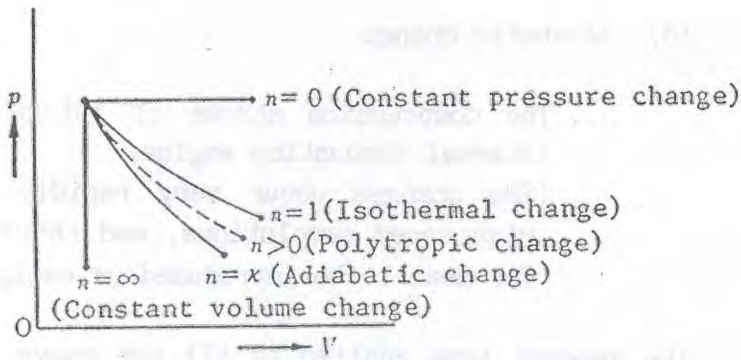


Fig. 4-7 Polytropic Change

- Among the changes described above, the changes from (a) to (d) are ideal changes considered from the viewpoint of an ideal gas. There are no ideal gases, but as approximations, the following changes can be considered as examples:

  (a) Constant volume change

  ... Heating something inside a pressure cooker. (In this case, it can be considered that the container is not subject to thermal expansion).

(b) Constant pressure change

... Boiling water in a kettle.
(The steam freely expands outside the kettle so that no change occurs in the pressure).

(c) Isothermal change

... In a water-cooled air compressor, air is compressed while being sufficiently cooled.
(An air compressor for starting a diesel engine).

(d) Adiabatic change

... The compression stroke of intake air in an internal combustion engine.
(The changes occur very rapidly because of high speed revolutions, and there is no time for heat to be introduced or escape).

The general term applied to all the above examples is called the polytropic change.

1.3 Cycles in Heat Engines

(1) Second law of thermodynamics

We have already learned from the first law of thermodynamics that heat and work can be converted into each other. But this law only makes clear the quantitative relationship between the heat and work. Actually, the conversion between heat and work will occur only under cantain conditions. The conversion of work into heat, as can be seen from the example of the heat generated by friction, is simply a natural phenomenon and can be carried out with ease. By contrast, the conversion of heat into work is not so easy. Work does not occur simply because there is heat. As, for instance, the fact that a water turbine will not turn simply because there is water, but requires that there is a flow of water from a high place to a low place. Therefore, in order to convert heat into work, both a high temperature object (high heat source) and low temperature object (low heat source) must be introduced for the heat to be transferred between them. Work can only be obtained from a flow of heat and a heat engine is a device which performs this work. The fact that heat naturally flows from a high heat source to a low heat source is a phenomenon which we often experience in our daily lives.

The law which clarifies these relationships is the second law of thermodynamics, discovered independently by R.J.E. Clausius of Germany and Lord Kelvin of England in 1851. This law can be expressed as follows.

"Heat cannot spontaneously flow from a colder to a hotter object."

"In order for a heat engine to do work, it is always necessary to have an object colder than the heat source."

(2) Cycles and thermal efficiency of heat engines

Heat engines use the changes in state of the gas which serves as the active component to convert heat into work. For example, let us consider Fig. 4-8. The gas inside the cylinder obtains heat Q_1 from the high heat source and increases its temperature and pressure, pushes the piston, and produces work L. However, this action is not made one time only, but must be continuous in order to do work. For that reason, when the gas reaches a given level of expansion, heat Q_2 must flow to the low heat source to reduce the temperature and pressure and allow the gas to be contracted and return to its original condition. By the repetition of this process, heat engines are capable of producing continuous work. However, because of this, it is not possible for all the heat obtained from the high energy source to be converted into effective work.

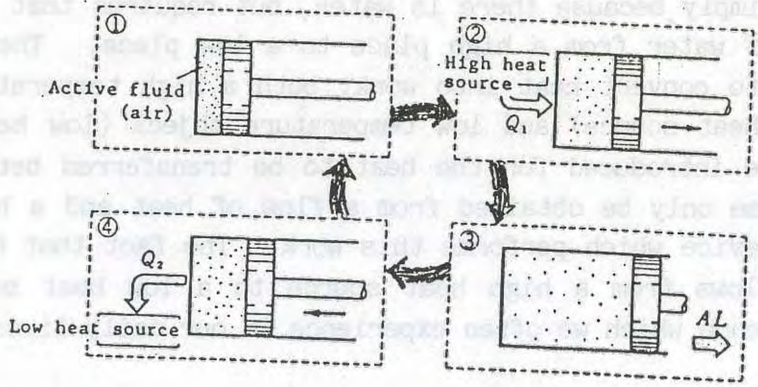


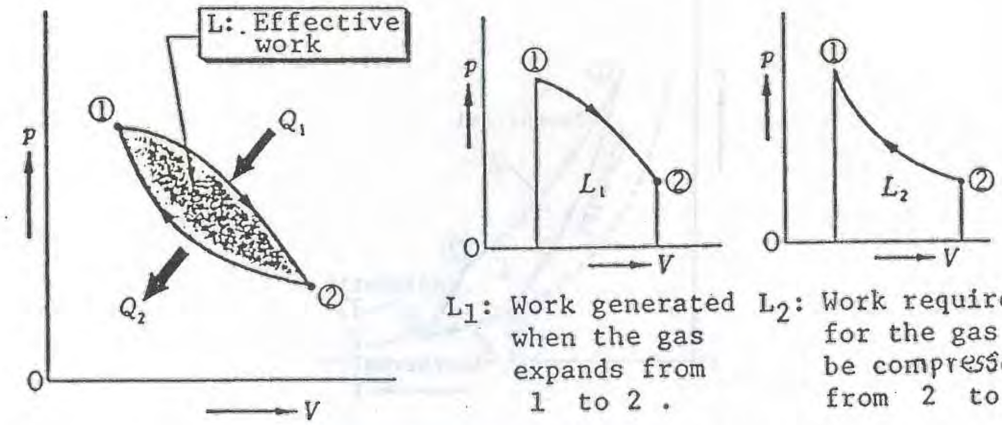
Fig. 4-8 Cycle of Heat Engine

The series of processes in a heat engine by which the active fluid returns to its original state after going through various changes is called a "cycle". If the active fluid obtains heat Q_1 from the high heat source and does work L and then discards heat Q_2 at the low heat source during each cycle, the following equation can be obtained, based on the first law of thermodynamics.

$$AL = Q_1 - Q_2 \qquad (4\text{-}23)$$

In a heat engine, the ratio of the amount of effective work L which can be converted from the heat Q_1 obtained from the high heat source is called the thermal efficiency, and, when this is represented by η:

$$\eta = \frac{AL}{Q_1} = \frac{Q_1 - Q_2}{Q_1} = 1 - \frac{Q_2}{Q_1} \qquad (4\text{-}24)$$



L_1: Work generated when the gas expands from 1 to 2 .

L_2: Work required for the gas to be compressed from 2 to 1 .

∴ Effective work $L = L_1 - L_2$

Fig. 4-9 pV Diagram of a Cycle

When the conditions of the change of state of the gas which goes through the cycle are expressed by a pV diagram, the shape of the curve will be as shown in Fig. 4-9. In this figure, the area which is under the line from (1) to (2) represents the work done externally because of expansion. Meanwhile, the area which is under the line from (2) to (1) represents the work required for compression. Therefore, in this case, the effective work L produced in one cycle is represented by the shaded area.

(3) Carnot cycle

When the temperatures of the high and low heat sources are determined, the cycle acting within that range may take various forms, but the ideal form, representing the highest thermal efficiency, is called the Carnot cycle. The Carnot cycle is a combination of the isothermal change in which all the heat is converted into work (Equation 4-17) and the adiabatic change in which work is done only by converting internal energy without intake or loss of heat (Equation 4-20). The Carnot cycle is equal to one cycle and its pV curve is shown in Fig. 4-10.

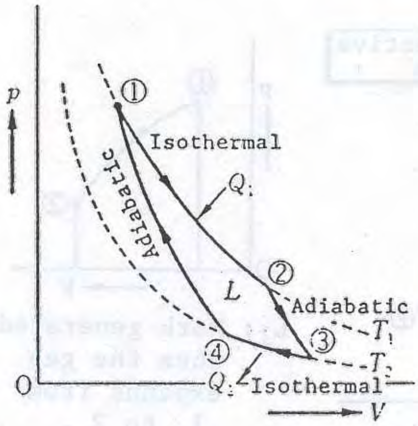


Fig. 4-10 Carnot Cycle

In the Carnot cycle, the following relation is seen between the incoming and outgoing heat Q_1 and Q_2 and the temperatures of the high and low heat sources T_1 and T_2.

$$\frac{Q_2}{Q_1} = \frac{T_2}{T_1} \qquad (4\text{-}25)$$

- If the active fluid in the Carnot cycle is an ideal gas, in Fig. 4-10, the line from 2 to 3 and from 4 to 1 are adiabatic changes and therefore, shown according to equation 4-19:

$$\frac{p_2}{p_3} = \left(\frac{T_1}{T_2}\right)^{\frac{\kappa}{\kappa-1}} \text{ and } \frac{p_1}{p_4} = \left(\frac{T_1}{T_2}\right)^{\frac{\kappa}{\kappa-1}}$$

$$\therefore \frac{p_1}{p_2} = \frac{p_4}{p_3} \cdots\cdots\cdots\cdots(1)$$

The lines from ① to ② and from ③ to ④ represent isothermal changes.

Therefore, from Equation 4-17:

$$Q_1 = AGRT_1 \times 2.303 \log \frac{P1}{P2}$$

$$\cdots\cdots\cdots\cdots (2)$$

$$Q_2 = AGRT_2 \times 2.303 \log \frac{P3}{P4}$$

From Equation 1 and 2 ,

$$\frac{Q_2}{Q_1} = \frac{T_2}{T_1}$$

From these facts, the thermal efficiency η_c of the Carnot cycle can be expressed by the following equation as based on Equation 4-24:

$$\eta_c = \frac{AL}{Q_1} = 1 - \frac{Q_2}{Q_1} = 1 - \frac{T_2}{T_1} \qquad (4\text{-}26)$$

In other words, the thermal efficiency of the Carnot cycle is not related to the kinds of active fluid, but is determined only by the temperatures of the high and low heat sources.

- In an ordinary heat engine (for example, an internal combustion engine), the low heat source can be ultimately be considered to be the atmosphere, and therefore that temperature cannot be lowered. Therefore, the higher the temperature of the high heat source the greater the thermal efficiency, although this factor is limited by the heat endurance of the materials used.

Ex. 4. Find the thermal efficiency for the Carnot cycle which acts between a high heat source of 120°C and a low heat source of 15°C. If the amount of heat supplied for each cycle is 6 kcal, how much work will be done?

(Solution)

In Equation 4-26,

$$T_1 = 120 + 273 = 393 \text{ K}$$
$$T_2 = 15 + 273 = 288 \text{ K}$$

Therefore,

$$\eta_c = 1 - \frac{T_2}{T_1} = 1 - \frac{288}{393} = 0.267$$

Also, from Equation (4-26), the work is

$$L = \frac{\eta_c Q_1}{A} = 427 \times 0.267 \times 6 = 684 (\text{kgf.m})$$

(Answer: Thermal efficiency 26.7%,
work per 1 cycle; 684 kgf.m)

Q 11. In an engine which is operating according to the Carnot cycle, you want to obtain 20 kgf.m of work per cycle. If the heat supplied per cycle is 0.11 kcal and the temperature of the high heat source 250°C, what must be the temperature of the low heat source? (Ans. 27°C)

Q 12. When the temperature of the low heat source is 20°C, calculate the thermal efficiency when the temperature of the high heat source is 100°C, 200°C, and 400°C, respectively. (Ans. 21.4%, 38.1%, 56.5%)

(4) Entropy

When a small amount of heat Q enters or is lost an object which is at on absolute temperature T, since no change in temperature occurs in the object, the following relationship holds:

$$\frac{\Delta Q}{T} = \Delta S \qquad (4-27)$$

Where ΔS is the change of entropy. Entropy is one measure of state and has important significance in thermodynamics For example, in the same way that the work is expressed by a pV curve which is the product of pressure p and volume V, the thermal energy is also expressed as the product of temperature T and and entropy S, and this relation is expressed as a TS curve (Fig. 4-11). The area which can be under the TS curve (the area surrounding by ①, ②, ③, and ④ in the figure) is an expression of the amount of heat Q introduced and lost.

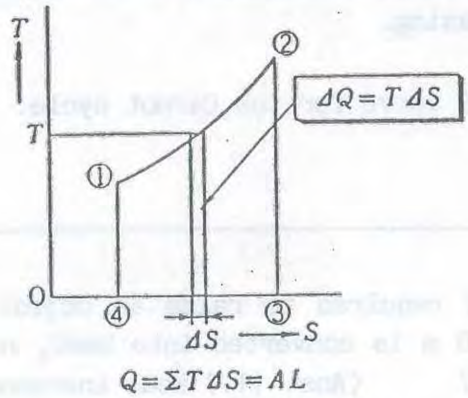


Fig. 4-11 TS diagram

Also, according to Equation 4-27, since T is an absolute temperature, it is always positive. Therefore;

1) When heat is added, ΔS is greater than 0, in other words, the entropy increases.

2) When heat is removed, ΔS is less than 0, in other words, the entropy decreases.

3) When no heat is introduced or lost, ΔS = 0, in other words the entropy is a constant.

When heat Q shifts from high heat source T_1 to low heat source T_2, the entropy S_1 of the hot object decreases and the entropy S_2 of the colder object increases. The difference in changes of entropy at this time are as follows:

$$\Delta S_2 - \Delta S_1 = \frac{Q}{T_2} - \frac{Q}{T_1} > 0 \qquad (T_1 > T_2) \qquad (4-28)$$

Thus overall, the entropy increases. The movement of heat from the high heat source to the low heat source is a natural phenomenon explained by the second law of thermodynamics, and as in all natural phenomenon, it can be said that the entropy is always increasing.

Q 13. Draw a TS curve for the Carnot cycle.

Questions ◎

1. If the work required to raise an object weighing 500 kgf a height of 10 m is converted into heat, how many kilocalories would it be? (Ans. 11.7 kcal increased)

2. 6.4 kcal of heat is applied to a gas inside a cylinder, and the volume of gas expands from 0.2 m^3 to 0.6 m^3. If an external pressure of 2 kgf/cm^2 acts on the piston, what will be the resulting external work done by the gas and what will be the change in internal energy?
(Ans. 8000 Kg.f.m, 12.3 kcal decreased)

3. A gas with a volume of 2.5 m^3 and under a pressure of 0.5 kgf/cm^2 changes volume until the pressure is 12 kgf/cm^2. If the increase in enthalpy was 25 kcal and there was no change in the internal energy of the gas, what will be the volume of the gas under the new conditions? (Ans. 0.193 m^3)

4. What is the volume of 2 kgf of air when the pressure is 15 kgf/cm^2 and the temperature is 28^oC? (Find the gas constant of air from Table 4-1.) (Ans. 0.117 m^3)

5. Helium weighing 3 kgf is heated from 15^oC to 120^oC without changing volume. Find the change in internal energy. Find the constant volume specific heat of helium in Table 1-4.
(Ans. 238 kcal increased)

6. The amount of work required to cause isothermal expansion so that 3 kgf of air in a cylinder changes in pressure from 12 kgf/cm^2 to 2 kgf/cm^2 was 55,000 kgf.m. Find the following values at this time. (Find the gas constant of air in Table 4-1.)

(a)	The original volume.	(Ans.	0.256 m^3)
(b)	The final volume.	("	1.54 m^3)
(c)	The original temperature.	("	77^oC)
(d)	The amount of heat added.	("	129 kcal)

7. You want to obtain 82 kgf.m of work per cycle in an engine which undergoes the Carnot cycle. If 0.3 kcal of heat is supplied per cycle and the low heat source is 25^oC, what must be the temperature of the high heat source? (Ans. 555^oC)