

## 2.2.7 Heat Pump, and Refrigeration Unit

### (1) Types of heat pump

Pump is an equipment for pumping liquid from a low place to a high place. A heat pump is an equipment for utilizing low temperature thermal energy by raising its temperature. It absorbs heat at the evaporator and releases the heat at the condenser. Among such equipment, an equipment for gathering heat at a temperature below the ordinary temperature with the purpose of obtaining low temperature is the refrigeration unit.

Recently, a unique type of dryer which uses a compression type refrigerator as a heat pump has been contrived. In this case, wet air which has taken moisture from the material to be dried in the dryer is introduced to the evaporator of the refrigerator, and after condensing and separating the moisture, it will be heated and its temperature will be raised in the condenser portion of the refrigerator, and returned to the dryer again. In other words, the thermal energy that is used for drying the material to be dried, is recovered as condensation latent heat of water at the evaporator of the refrigerator, then it is released to air again at the condenser portion. Consequently, it composes a thermally closed system, and what is discharged to the outside is only the moisture taken from the material to be dried.

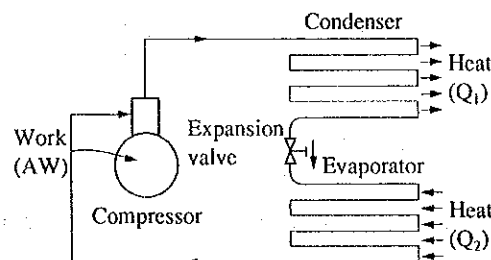
There are various methods of heat pump such as vapor compression type, steam ejector type, absorption type, and chemical type. However, from the standpoint of economics and performance, under current conditions, the vapor compression type and the absorption type are practical. The basic principle of these two systems is to transfer the heat by utilizing the process of evaporation and condensation of operating media.

### (2) Cycle of vapor compression system

The basic structure of vapor compression system is shown in Figure 2.43.

The operating media which have become high in temperature and pressure when they are compressed by the compressor, will emit heat to the outside by the condenser, and become liquid, then the pressure will be reduced after they pass through the expansion valve and enter the evaporator, where they absorb heat from the outside and become gas again, then enter the compressor.

**Figure 2.43 Vapor Compression Type Heat Pump Cycle**



During this cycle, the operating media receive workload in the compressor from the outside.

If we represent this workload by  $W$  kg-m, the heat amount absorbed by the evaporation by  $Q_2$  kcal, and that emitted from the condensor by  $Q_1$  kcal, the following relation will be obtained.

$$AW = Q_1 - Q_2$$

where

$$A = (1/427) \text{ kcal/kgf-m}$$

In order to know the various changes of the operating media in the cycle, there are the following charts used in general.

- a. Pressure-Enthalpy Chart (P-i Chart): A chart in which the Pressure  $P$  is taken on the Y axis (axis of ordinates), and enthalpy  $i$  is taken on the X axis (axis of abscissas).
- b. Temperature-Entropy Chart (T-s Chart): A chart that shows absolute temperature  $T$  on the Y axis, and Entropy  $s$  on the X axis.

P-i Chart is rather broadly used, because it is convenient in various design calculations and operation analysis.

Chart which indicates the cycle on the P-i Chart is Figure 2.44. Point A shows the condition in which the operating media are sucked into the compressor (low temperature and low pressure) and they will be compressed and become the condition of Point B (high temperature and high pressure).

At this time, theoretically, it is adiabatic compression and will be on the isoentropic line. The compression workload  $W$  (kgf-m/kg) will be

$$AW = i_B - i_A$$

where  $i_A$ : Enthalpy at the suction inlet of the compressor (kcal/kg)  
 $i_B$ : Enthalpy at the discharge outlet of the compressor (kcal/kg)  
A: 1/427 (kcal/kgf-m)

The refrigeration effect at the evaporator (refrigeration capacity per 1 kg of refrigerant)  $q_c$  will be

$$q_c = i_A - i_D \text{ (kcal/kg)}$$

where  $i_D$ : Enthalpy at the inlet of the evaporator (kcal/kg)

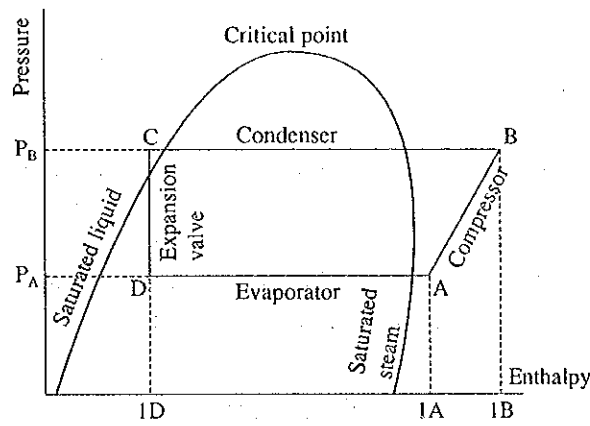
The ratio between the refrigeration effect and the compression workload is called the coefficient of performance, and if it is expressed by E,

$$E = (i_A - i_D)/(i_B - i_A)$$

In the case of heat pump, the coefficient of performance shall be the ratio between the amount of heat that was utilized at the condenser and the compression workload.

$$E_h = (i_B - i_C)/(i_B - i_A) = 1 + E$$

**Figure 2.44 P-i Diagram**



Besides the closed cycle vapor compression heat pumps mentioned above, there are also open cycle heat pumps which directly compress the vapor generated in the distillation tower or evaporator, and utilize this as heat source.

### (3) Compressor

Depending on the compression mechanism, the compressors can be divided into the reciprocating type, the centrifugal type and the rotary type.

The reciprocating type can be designed for small capacity ones as well as large capacity ones and can be used for almost any kind of temperature conditions. However, when the capacity becomes large, the centrifugal type will become cheaper. On the other hand, in case the compression ratio is large, the centrifugal type will be more expensive, and if the capacity is rather small, the efficiency will not be so good. (i.e. at 40 m<sup>3</sup>/min. or less)

As for the screw compressor which belongs to the rotary type, there is not much difference in efficiency as far as capacity is concerned, but as to the compression ratio, new types of screw compressor in which 1 stage equals 2 ~ 3 stages of the reciprocating type have been developed, and are being widely used.

In case the compressor is operated at high compression ratio, the volume efficiency drops and the discharge gas temperature rises. Consequently, degradation or carbonization of the lubricant occurs, and damages of the discharge valves are liable to occur. Normally, the 1 stage compression should have a compression ratio of 8 ~ 10 or less. In case the compression ratio exceeds this level, 2 stage or 3 stage compression should be adopted.

#### (4) Refrigerant

Refrigerants are media for thermodynamic changes inside of refrigerating cycle, and they are substances which possess the following special properties:

##### a. Physical properties

- 1) The critical temperature is higher than the ordinary temperature, and the freezing point is low.
- 2) Heat of vaporization is large (The circulation amount of the refrigerant can be less.)
- 3) The ratio of specific heat of the gas, that is, (constant pressure specific heat)/(constant volume specific heat) is small.
- 4) The coefficient of performance is large.
- 5) The specific volume of the gas is small. (The volume of the compressor may be designed small)
- 6) The condensation pressure and the vaporization pressure are suitable.

##### b. Chemical properties

- 1) Under the usage conditions, they are chemically stable.
- 2) They are inert and have no corrosiveness.
- 3) Solubility towards lubricants is small.
- 4) At both the gas and liquid state they have low viscosity.
- 5) The thermal conductivity is large.

As refrigerants, together with ammonia, a lot of halogenated hydrocarbons are broadly used. However, recently, it has become clear that most of the halogenated hydrocarbons become the cause of breaking the ozone layer in the stratosphere, and their use was prohibited.

The characteristic values of refrigerants that are not restricted are as shown in Tables 2.9 and 2.10. Furthermore, the P-i Charts of the refrigerants are shown in Figure 2.45.

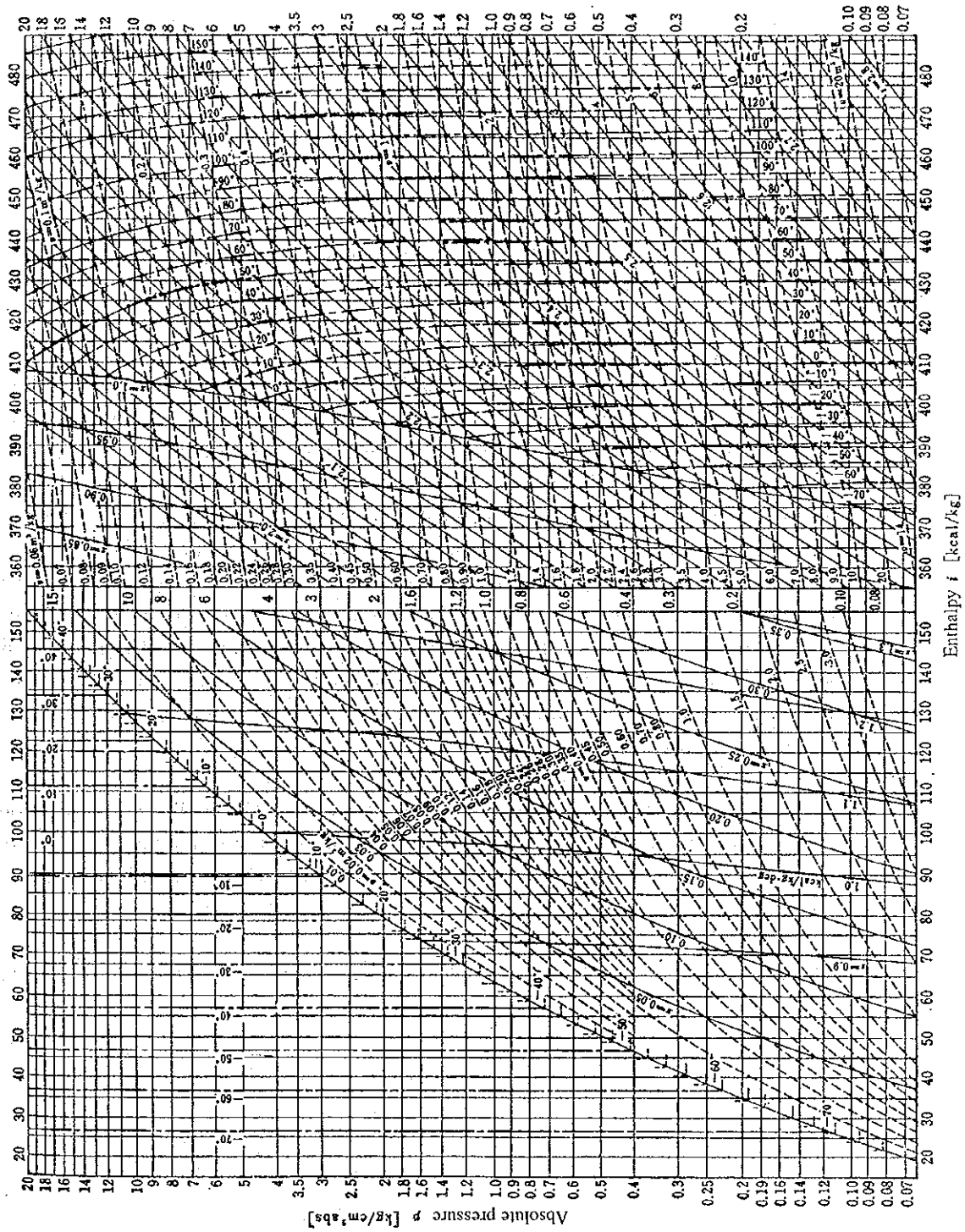
**Table 2.9 Refrigerant Properties (for High Temperature)**

Classification of refrigerants		Ammonia	Propane	Propylene	n-butane	i-butane
Chemical formula		NH <sub>3</sub>	C <sub>3</sub> H <sub>8</sub>	C <sub>3</sub> H <sub>6</sub>	C <sub>4</sub> H <sub>10</sub>	C <sub>4</sub> H <sub>10</sub>
Molecular weight		17.03	44.06	42.08	58.12	58.12
Boiling point (at atmospheric pressure)	°C	-33.3	-42.3	-41.0	-0.5	-11.7
Freezing point (at atmospheric pressure)	°C	-77.7	-189.9	-185.2	-135	-145
Critical temperature	°C	133	94.4	91.8	152.2	134.9
Critical pressure	kg/cm <sup>2</sup> (abs)	116.50	46.51	47.0	38.7	37.2
Evaporation pressure at -15 °C	"	2.410	2.946	3.70	0.576	0.921
Condensation pressure at 30 °C	"	11.895	10.918	13.10	2.92	4.18
Compression ratio at T <sub>e</sub> = -15 °C and T <sub>o</sub> = 30 °C		4.94	3.706	3.54	5.07	4.54
Heat of evaporation at -15 °C	kcal/kg	313.53	94.56	96.10	95.00	88.6
Refrigerating capacity at standard refrigerating cycle	"	269.03	70.68	72.8	74.2	65.3
Refrigerant circulation amount per ton of Japan refrigerating capacity	kg/h	12.34	46.97	45.6	44.7	50.8
Specific volume of saturated steam at -15 °C	m <sup>3</sup> /kg	0.5087	0.1548	0.142	0.623	0.400
Specific volume of saturated liquid at 25 °C	L/kg	1.6588	2.053	0.647	1.740	1.81
Compressor discharge temperature	°C	98	36.11	42.0	32.0	27.0
Theoretical piston displacement per ton of Japan refrigerating capacity	m <sup>3</sup> /h	6.278	7.272	6.48	27.8	20.3
Theoretical indicated horsepower per ton of Japan refrigerating capacity		1.08	1.079	1.09	1.02	1.14
Coefficient of performance		4.87	4.80	4.78	5.10	4.53

**Table 2.10 Refrigerant Properties (for Low Temperature)**

Classification of refrigerants		Ethane	Ethylene	Methane
Chemical formula		$C_2H_6$	$C_2H_4$	$CH_4$
Molecular weight		30.07	28.05	16.04
Boiling point (at atmospheric pressure)	°C	-88.6	103.90	-161.49
Freezing point (at atmospheric pressure)	°C	-172	-169.5	-182.48
Critical temperature	°C	32.3	9.2	-82
Critical pressure	kg/cm <sup>2</sup> (abs)	49.8	51.7	45.80
Evaporation pressure at -100 °C	"	0.536	1.28	26.60
Condensation pressure at -30 °C	"	10.86	19.7	Critical point or above
Compression ratio at $T_e = -100$ °C and $T_o = 30$ °C		20.3	15.4	—
Heat of evaporation at -100 °C	kcal/kg	121.7	113.4	72.8
Refrigerating capacity at standard refrigerating cycle $T_e = -100$ °C and $T_o = -30$ °C	"	77.0	69.3	—
Refrigerant circulation amount per ton of Japan refrigerating capacity	kg/h	43.1	47.9	—
Specific volume of saturated steam at -100 °C	m <sup>3</sup> /kg	0.880	0.378	0.022
Specific volume of saturated liquid at -30 °C	L/kg	2.17	2.27	—
Compressor discharge temperature	°C	36	49	—
Theoretical piston displacement per ton of Japan refrigerating capacity	m <sup>3</sup> /h	37.9	18.1	—
Theoretical indicated horsepower per ton of Japan refrigerating capacity		4.1	3.3	—
Coefficient of performance		1.7	1.6	—

Figure 2.45 P-i Diagram of Ammonia



Source: "JSME Data Book: Heat Transfer" by Japan Society of Mechanical Engineers

If refrigerants for high temperature use such as R-22 or ammonia are used at the vaporization temperature below  $-80\text{ }^{\circ}\text{C}$ , the saturation pressure at the vaporization temperature will be extremely low and very high vacuum will occur. As a result, the volume efficiency of the compressor will drop considerably. Thus, in this temperature range, in most cases, a two-refrigerant system is adopted where refrigerants which have comparatively high saturation pressure such as ethane and ethylene are used as the low temperature side refrigerant.

(5) Absorption type cycle

The absorption type heat pump utilizes the changes in partial pressure corresponding to the changes in concentration when the operating media are absorbed by the absorption liquid.

Although it is not necessary to mechanically compress the operating media, steam, warm water, combustion exhaust gas will be required as driving heat energy for evaporating the operating media from the absorption liquid, and concentrating the absorption liquid.

The structure of the absorption type heat pump is shown in Figure 2.46. The operating media gained heat from the brine and were vaporized at the evaporator, and were absorbed in the absorbing liquid in the absorber. The absorption liquid of which the concentration dropped will be sent to the regenerator via the heat exchanger where it is heated, and the operating media are vaporized, and absorbing liquid were concentrated, and returned to the absorber. The operating media that were evaporated will be cooled by the condenser and liquefied, and their pressures are reduced at the expansion valve, then sprayed on to the evaporator.

The absorption type heat pumps consist of the aforementioned Type 1 Absorption Heat Pumps which require heat source for high temperature driving and the Type 2 Absorption Heat Pumps which do not require high temperature heat source but require low temperature cooling water.

The cycle of each is shown in the Dühring Charts of Figure 2.47 and Figure 2.48.



Figure 2.46 Absorption Type Heat Pump

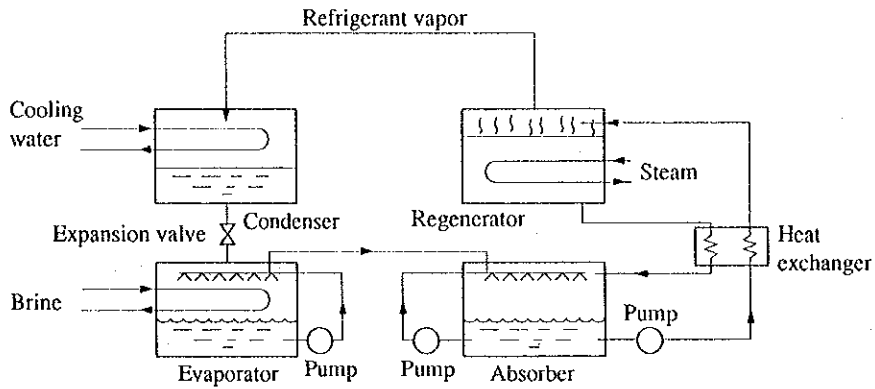


Figure 2.47 Dühring Chart for Heat Pump (Type 1)

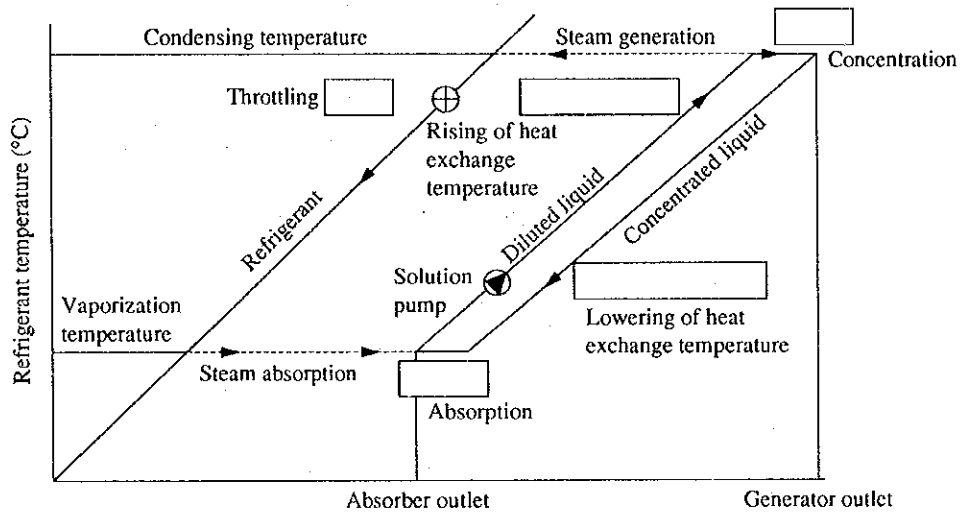
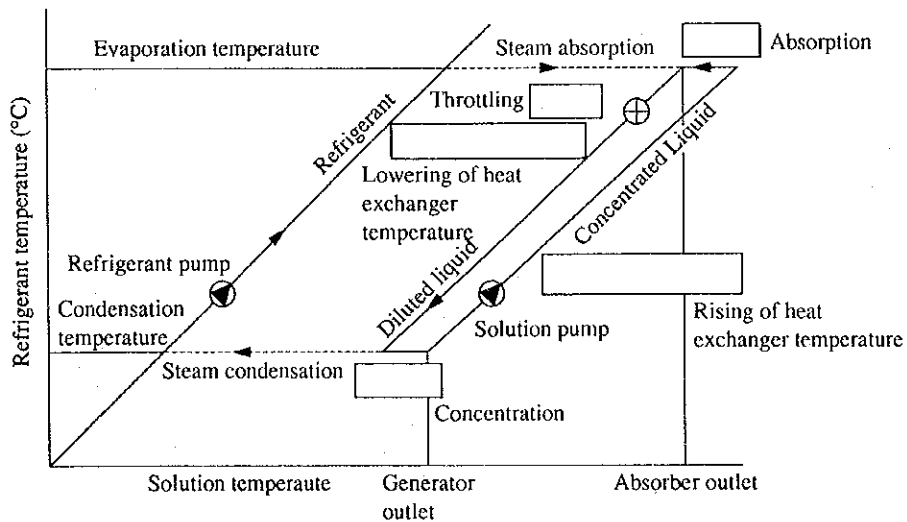


Figure 2.48 Dühring Chart for Heat Pump (Type 2)



In the case of Type 2 Absorption Heat Pump, the absorption heat generated at the time the operating media which were vaporized by the low temperature heat source such as warm effluent water are absorbed by the absorption liquid, is utilized.

Since heat of absorption liquid which has a temperature higher than the vaporization temperature by an amount equal to the boiling point rise will be utilized, a warm water having a temperature higher than the effluent temperature will be obtained.

For these absorption type heat pumps, as a combination of absorption liquid and operating media, there are aqueous solution of LiBr, LiCl, H<sub>2</sub>SO<sub>4</sub> and water, water and ammonia, tetra-ethylene glycol dimethyl ether and R22, LiBr and Methanol etc. The absorption type heat pumps are suitable for applications of comparatively large capacity.

(6) Brine

The salt solution which acts as an intermediary for cooling in the indirect freezing method is called brine. The most widely used type of brine is calcium chloride (CaCl<sub>2</sub>). Besides this, there are also sodium chloride (NaCl), magnesium chloride (MgCl<sub>2</sub>), methanol, ethanol, ethylene glycol, glycerine, etc. In Figure 2.49, the specific heat of brine is shown, and in Figure 2.50 the specific gravity and freezing temperature are shown.

Figure 2.49 Specific Heat of Brine

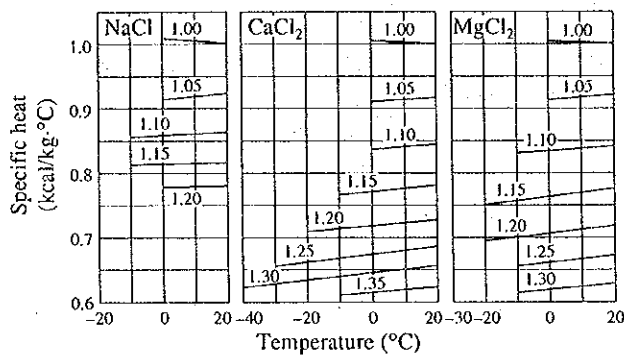
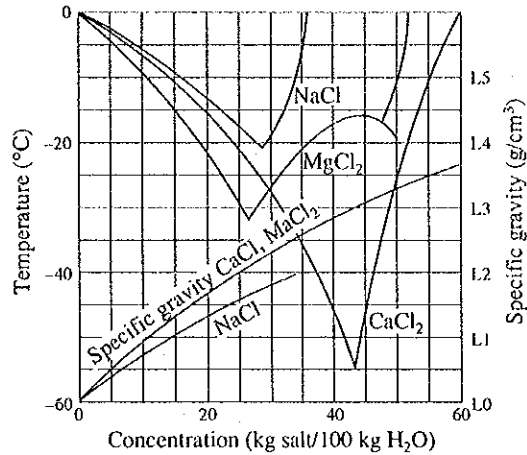


Figure 2.50 Freezing Temperature and Specific Gravity of Brine



(7) On the unit of refrigerating capacity

It is convenient to fix a unit to indicate the refrigerating capacity of refrigerator. However, since this varies with each country, it is necessary not to confuse them. Next, some examples are shown.

(Japan)

The refrigerating capacity to freeze 1 ton of 0 °C water into 0 °C ice in 24 hours is called 1 ton of refrigeration, and it is equivalent to 3,320 kcal/h.

(USA)

200 BTU/min. is called 1 ton of refrigeration. This is equivalent to heat quantity required to melt 2,000 pounds (lbs.) of 32 °F ice in 24 hours. (200 BTU/min. = 3,023 kcal/h)

(8) Rationalization of the use of refrigerating energy

In Table 2.11, the energy saving method of refrigerator and heat pump equipment is shown.

**Table 2.11 Energy Conservation Method of Refrigerator and Heat Pump Equipment**

Method of Energy Conservation	Freezer		Heat Pump	Remarks	
	Steam Comp.	Absorp.			
Decrease in Load Conv. Dr.	Decrease in Freezing (Heating) Load	○	○	○	
	Decrease in Conveying System Drive	○	○	○	
Improvement of Efficiency Cycle Improvement	Adoption of Supercooling-Economizer	○	—	○	
	Steam Temperature Rise	○	○	○	High Heat Transfer Pipe
	Condensation Temp, Drop	○	○	○	High Heat Transfer Pipe
	Selection of Optimum Refrigerant	○	△	○	Mixed Refrigerant, etc.
	Heat Transfer Promotion in Heat Exchanger	—	○	—	High Heat Transfer Pipe
	Decrease in Solution Circulation	—	○	—	
Improvement of Efficiency Others	Decrease in Auxiliary Equipment Power	○	○	○	
	Waste Gas Heat Recovery	—	○	—	Direct Firing
Partial Load Efficiency Increase	Division into Number of Units complying with Annual Load Conditions	○	○	○	
	Good Capacity Control System of Partial Load Characteristics	○	○	○	
	Volume Change of Cooling Water (Brine) Side	○	○	○	
	Inlet Temperature Control of Cooling Water (Brine)	○	○	○	
	Optimum Air Ratio Control	—	○	—	Direct Firing
Load Change Response Improvement	Optimum Operation by Microcomputer	○	○	○	
	Electronically Controlled Expansion Valve	○	—	—	For miniatures
	Microcomputer Control of Solution Circulation Amount	—	○	—	
	Cascade Control by Cycle Temperature	—	○	—	
	Decrease in Solution Retention	—	○	**	
Control	Fouling Countermeasure	○	○	○	Automatic Tube Cleaning
	Accurate Hot-Cold Switchover	—	**	○	Direct Firing
	Maintenance of Air-Tightness	○	○	○	

\*1) In case of absorption type heat pump 0.

a. Improvement of cycle

Install a supercooler next to the condenser, and by super cooling the operating media with the cooling water, increase the refrigerating effect and aim at decreasing the circulation amount of the media.

Make compression by two stages, and connect the intermediate stage with the economizer.

If the liquid pressure of the condenser outlet is reduced to the intermediate stage pressure by the economizer, a portion of it will vaporize, and the media temperature will drop to the saturation temperature equivalent to the intermediate stage pressure. Consequently, the refrigeration effect will be increased. As a result, although the second stage compression power will not change much, the compression power of the first stage can be reduced.

b. Capacity adjustment

In case the load is reduced, if the amount of cooling water is decreased in accordance with the load, the pump power can be reduced.

In case the amount of cooling water and the cooling water temperature entering the evaporator are kept constant, when the load is low, the cooling water temperature of the outlet, that is, the vaporization temperature will rise, and the compressor power will be decreased.

As a means to decrease the suction amount of the compressor, in case of the reciprocating compressor, the following methods are executed.

- 1) "Suction valve opening system" which makes the suction valves idle in accordance with the load, and makes the cylinder No-Load in steps, in case of the multi-cylinder type.
- 2) "Cylinder head by-pass system" in which by-pass valves are installed on each cylinder, and do not let the compression process take place.
- 3) "Hot gas by-pass system" in which high temperature exhaust gas is charged between the expansion valve and the evaporator.
- 4) "Clearance increment system" in which a clearance pocket is made to the cylinder, and the apparent volume efficiency is lowered.
- 5) "Motor speed control system" in which the drive motor speed is changed.

The systems of a, b, and e will be related to the reduction in power consumption. Since the power consumption remains unchanged in case of System c, it is preferable to utilize this for reducing the capacity to 0 ~ 25 %.

In the case of centrifugal compressor, the simplest method is to close the discharge valve. However, when it enters the surging zone, it will hinder the operation. In the "suction vane control system", several guide vanes are installed to the suction inlet, and the volume is varied by changing the tilting angle of the vanes. So it is a good system in which power consumption can be reduced without worrying about surging.

c. Purging of non-condensable gas

Sometimes non-condensable gases are mixed in the circulating refrigerant. The components of these non-condensable gases are  $N_2$ ,  $O_2$ ,  $H_2$ ,  $Cl_2$ , hydrocarbons, etc. The cause of such gases being mixed can be attributed to insufficient purging of the air in the equipment when the refrigerant is charged, decomposition of the lubricant, chemical reactions inside of the equipment, etc. In case non-condensable gases are mixed in the refrigerant, it will hinder the heat transfer of the condenser or occupy a certain space in the equipment and decrease the heat transfer surface. As a result, the condensation pressure will increase, and the input of the refrigeration unit will increase or the refrigerating capacity will lower.

In order to check whether non-condensable gas has been mixed or not, stop the equipment and run water through only the condenser. After sufficient time has elapsed, if the pressure at the time the water temperature and the refrigerant temperature have become equal is higher than the saturation vapor pressure of the refrigerant, it means that non-condensable gas has been mixed.

For instance, if there is a pressure difference corresponding to  $10\text{ }^\circ\text{C}$ , it is said that during actual operation, the condensation temperature will rise by about  $20\text{ }^\circ\text{C} \sim 25\text{ }^\circ\text{C}$ . The purging of the non-condensable gases is done by attaching special purging equipment to the upper portion or end portion of the condenser where the gases are liable to accumulate.

d. Fouling of the heat transfer

In case of the water cooled condensers, if hard well water or contaminated water is used for the cooling, scales will adhere to the heat transfer surface, and the heat transfer will be hindered. As a result, the condensation temperature and the pressure will rise (Figure 2.51). Consequently, the power consumption of the compressor will increase. (Figure 2.52)

Since the condensation pressure will be influenced the most by the cooling water temperature, we should confirm the relation between the cooling water temperature and the condensation pressure when the heat transfer surface is clean, and during the operation we should always compare the actual value with the normal value at clean condition and when the pressure difference becomes great, clean the heat transfer surface.

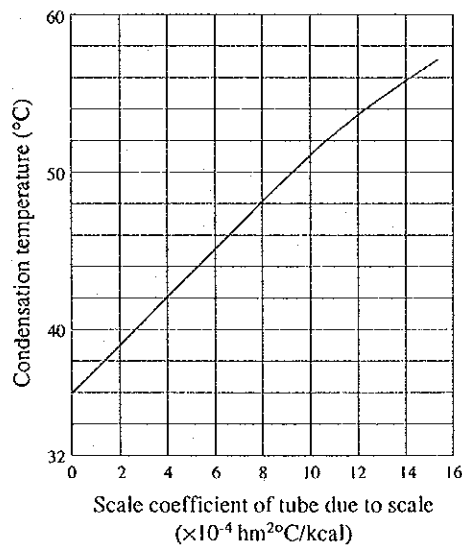
In the case of air-cooled condensers, since the temperature of the cooling air will have an influence on the consumption power, avoid installation near heat emitting equipment or indoors. Fresh outdoor air should be utilized.

In the case of evaporators, if the heat transfer surface becomes dirty, the vaporization temperature and pressure which gives the necessary coldness will drop (Refer to Figure 2.53). Since it will bring the increase in power consumption, attention should be paid to this matter during operation.

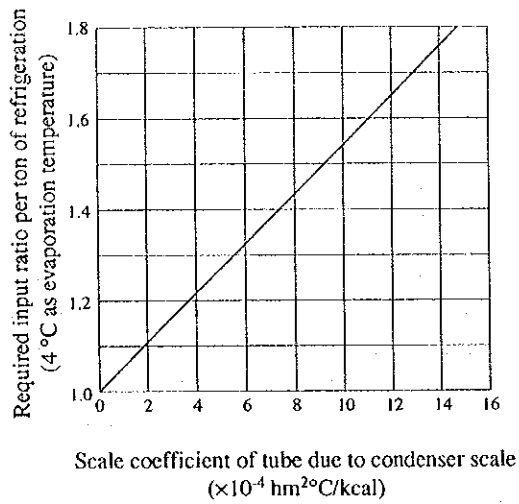
c. Cold insulation

In case the cold temperature portions of the equipment or piping is somewhat exposed, heat will enter and the freezing load will increase. Furthermore, the air in contact with the surface will reach dew point, and dew condensation will occur. As a result, the cold insulation material will absorb this moisture, the heat conductivity will become large, and the cold insulation effect will be lowered significantly. The cold insulation materials should be adhered to the surface by adhesives, and the outside should be covered completely with asphalt roofing (2 ~ 3 layers) so that the outside air cannot penetrate the cold insulation. With such structure, the decrease in cold insulation effect by the condensation of moisture in the air can be prevented.

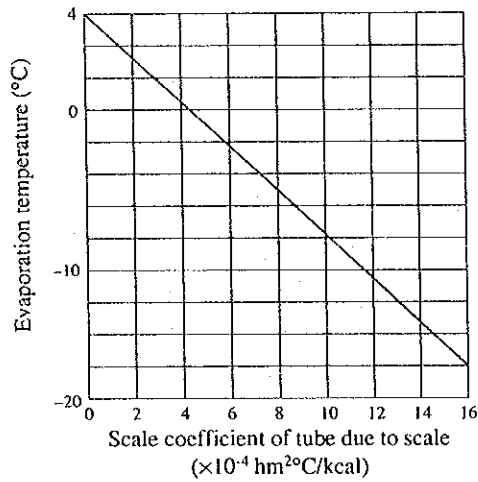
**Figure 2.51 Heat Transfer Surface Fouling and Condensation Temperature**



**Figure 2.52 Effect of Scale on Refrigeration Capacity**



**Figure 2.53 Effect of Scale on Evaporation Temperature**



### 2.2.8 Heating Furnace

In the chemical industry, there are many heating processes of the raw material for reaction or separation. The temperature range is also very broad, ranging from 100 °C to 1,000 °C or above.

By putting into consideration the safety against fires and the decomposition, in most cases steam is used as heat source, but combustion gas and heating oil are also used.



There are various types of heating furnace. Suitable ones will have to be selected depending on the condition of the material to be heated, heating temperature, amount to be treated, continuous or batchwise, etc. The heating furnaces are designed empirically, and they are classified by business types, by applications, by product conveying systems, by fuel types, by heating systems, by heat recovery systems, and by shapes. In this guideline, classification will be made mainly by applications such as heating, melting, or reacting, and heating methods such as direct or indirect, and furnace shapes such as vertical, horizontal, or tank type.

a. Fluid heating furnace

Boiler, pipe still, etc.

b. Solid melting furnace

Open hearth furnace, reverberatory furnace, crucible furnace, convertor etc.

c. Solid heating furnace

Direct heating type such as tunnel kiln, ring kiln, intermittent heating furnace, and indirect heating type such as retort furnace, muffle furnace, etc.

d. Rotary furnace

Internal heating cement kiln, external heating kiln, rotary type melting furnace

e. Vertical furnace

Gas producer, blast furnace, carbonization furnace, etc.

f. Fluidized bed furnace

Fluidized bed gas producer

g. Flash reaction furnace

Kopper's type gasification furnace

h. Multiple bed or rotary hearth type furnace

Herschhoff's furnace

i. Sintering furnace

j. Reaction furnace

Ammonia synthesis gas reformer, hydrogen chloride reactor, etc.

In the following paragraphs, as typical furnaces, pipe still and thermal media heating equipment will be described.

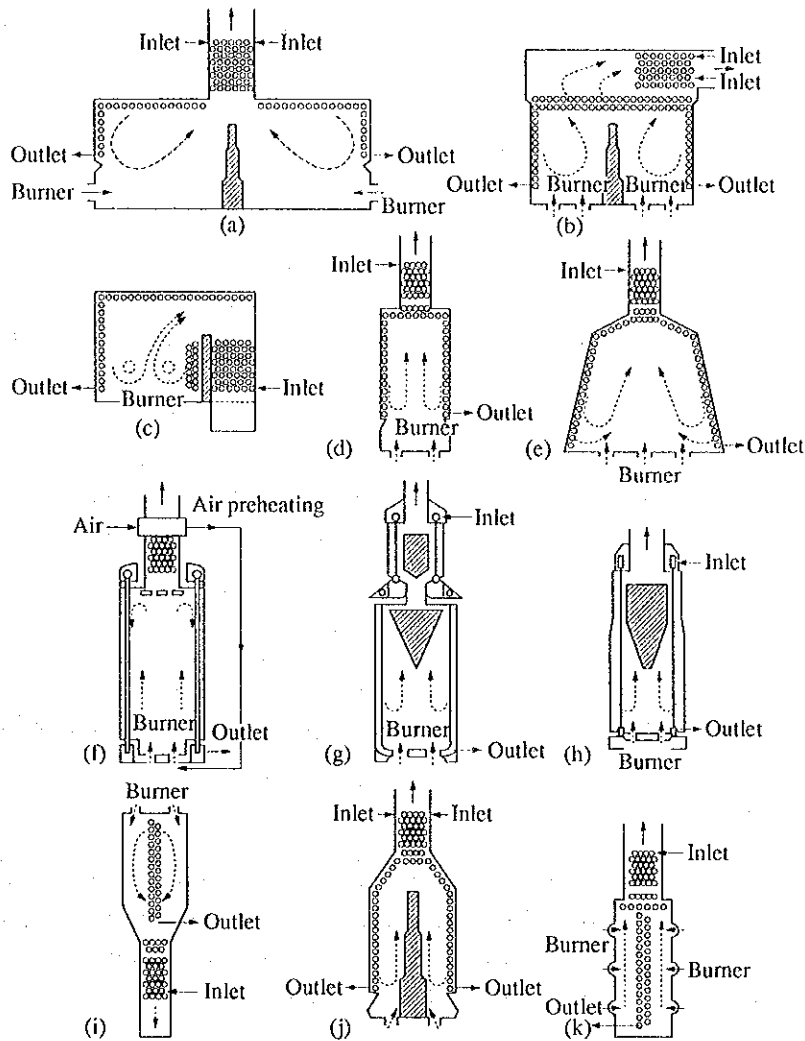
(1) Pipe still

In petroleum refining and in petrochemical industries, lots of pipe stills are utilized in the heating of petroleum. The pipe stills consist of the radiation portion and the convection portion. The radiation portion is the place where the radiation heat is absorbed directly from the flame, and the convection portion is the place where the heat is absorbed by convection heat transfer from the combustion gas.

Figure 2.54 shows a typical form of pipe stills. In the figures, the layout of the heating tubes and the flow direction of the combustion gases are illustrated.

The outstanding features and the drawbacks of each type are explained below.

Figure 2.54 Various Furnace Types of Pipe-Still



(a) Large box-type (b) Separate-convection (Lummus)  
 (c) Down-convection (d) Straight-up (Born) (e) A-frame (Kellogg)  
 (f) Circular (DeFelorez) (g) Large isoflow (Petrochem)  
 (h) Small isoflow (Petrochem) (i) Equiflux (UOP)  
 (j) Double-upfired (UOP) (k) Radiant-upfired (Selas)

a. Collision of flames

In case the flame is too large, the tubes will be easily damaged. In particular, the inlet of the convection portion of the (c) type and the bottom portions of the (j), (d) types will be easily damaged.

b. Heat distribution

Since the (a), (c) types have large empty spaces in the furnace, the heat distribution will easily become non-uniform. Other models have less problems.

c. 2 system heating

Since all types except the (c) type have symmetric shapes, if 2 systems are laid out in a similar way, it is possible to gain approximately uniform heating.

In case the heating amounts of the 2 systems vary, use the model having a partition.

d. Heating control

The (i) and (k) types can adjust the heating amount arbitrarily. In particular, it is suitable for high temperature heating in the range of 540 °C ~ 810 °C. In the case of cylindrical types such as (f), (g) and (h), and models having many radiation receiving surfaces, a low load operation is possible.

e. Models such as (c), (d), (h), (i), and (k) are suitable for small capacities and models such as (a), (b), (c), and (j) are suitable for large capacities.

f. Stacks

Models (a), (b), (c), and (i) require stacks, but in the case of other models, the furnace itself plays the role of stacks, and no stacks will be required.

g. Others

Since Models (g) and (h) use fin tubes at the convection portion, sometimes the amount of heat transfer at the convection portion will be greater than that of the radiation portion. In case the combustion gas is circulated, the flame temperature will drop, but the convection heat transfer will increase.

Furnaces having symmetric shapes will have uniform heat load, and it will have many advantages such as no coking, or no decomposition. Generally speaking, the radiation heat transfer amount is 16,000 ~ 54,000 kcal/m<sup>2</sup>h, but if the cokes accumulate, the heat transfer coefficient drops significantly. Thus, it is necessary to remove them periodically.

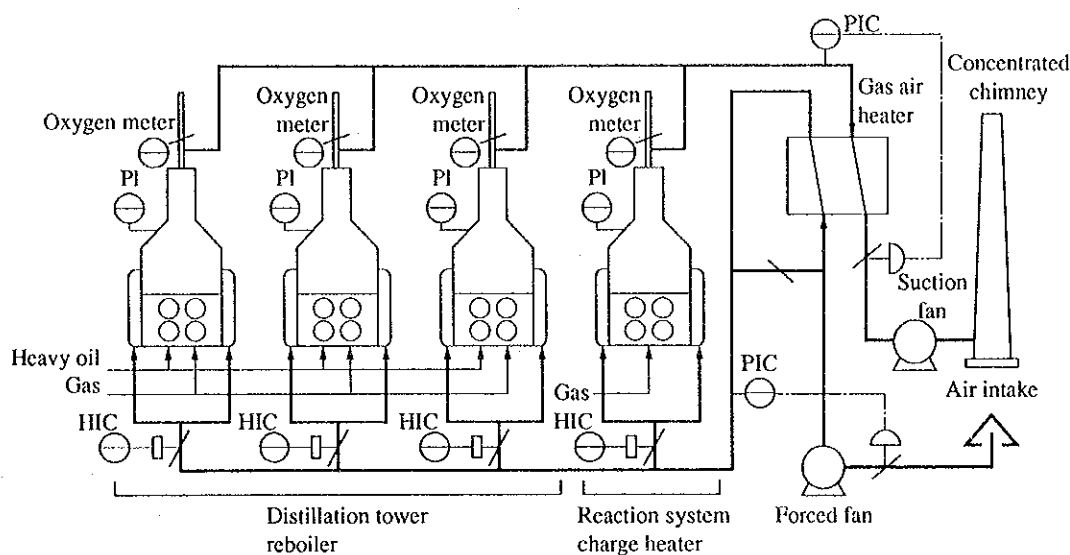
By lowering the exhaust gas loss, and by recovering the heat retained by the fluid, it is possible to raise the heat efficiency of the pipe still to 80 ~ 90 %.

As energy saving countermeasures of pipe still, an example case in Japan is shown.

- Improvement of efficiency by using stud tubes for the tubes of furnace convection portion
- Pre-heating of air (About 290 °C, Figure 2.55) by installation of heat exchanger for exhaust gas/combustion air

- Stable combustion at low excess air ratio (1.2 or less) by the adoption of low excess air burner and prevention of air ingress.

**Figure 2.55 Energy Conservation Measures for Pipe Still**



(2) Thermal media heating equipment

In the vacuum distillation of plasticizers, fatty acids, higher alcohol, and organic chemicals, in the vacuum deodorization of vegetable oil, and hardened oil, and in the various reactions such as esterization reaction, condensation reaction, hydrogenation and dehydrogenation reactions, in many cases operations at 250 ~ 350 °C are required. By the use of thermal media (thermal fluids), for instance, a heat source of 300 °C can be obtained at 1 atm, so it is a very convenient method in comparison with electric heating method, direct firing method, or hot water heating method. Besides the pressure being low, it possesses outstanding features such as uniform heating, precision temperature control, rapid heating and cooling. However, on the other hand, the capital investment and thermal media (thermal fluids) are expensive.

The thermal fluids which are used in general are shown in Table 2.12. At a temperature range of 250 ~ 350 °C, thermal fluids of the organic type are used. In the temperature range of 350 ~ 500 °C molten salts such as  $\text{KNO}_3$  and  $\text{NaNO}_2$  are used, and in the temperature range of 450 ~ 700 °C molten metals such as Na, K, and Hg are used.

As for the heating of the thermal fluids, can-type or tubular type heaters resembling a boiler are used. (Refer to Table 2.13)

In case air remains in the jackets, heating tubes, and the coils of the users, the heat transfer coefficient will drop significantly and the degradation of the thermal fluids owing to oxidation will be advanced. Thus, it is necessary to remove the air in the system completely. In case of the coils, it is very difficult to remove the air. Thus, in such a case, a vent box should be installed at the end of the coil to vent from this box or prior to charging the thermal fluids, it is preferable to make the system vacuum in order to remove the air as much as possible.

**Table 2.12 Physical Properties of Thermal Fluids**

Property	Dowtherm A*	Dowtherm B*	Fused salt Hi Tec †	Oil Mobilthem 600 ‡	Oil Mobilthem light ‡	Hydrothem § 750-200	Hydrothem § 700-160	Therminol ¶ FR-2	Mercury	NaK
Chemical formula	(C <sub>10</sub> H <sub>8</sub> ) <sub>2</sub> O	C <sub>10</sub> H <sub>8</sub> Cl <sub>2</sub> (C <sub>10</sub> H <sub>6</sub> ) <sub>2</sub>	NaNO <sub>2</sub>	NaNO <sub>2</sub> KNO <sub>3</sub>					Hg	44 wt. NaK
Molecular weight	165	147	92							
Specific gravity at 212°F	0.997	1.181	1.98(300 °F)	0.90	0.930	1.11	1.08	1.38	13.35	0.84(600 °F)
Melting point, °F.	53.6	-6.7	288	20(pour point)	-20(pour point)	5(pour point)	-40(pour point)	20(pour point)	-38.2	65
Boiling point, °F. (atm. pressure)	495.8	352		>600	>400		644	674.4	1.518	
Flash point, COC.°F	255	155		360	250	475		379		
Specific heat of liquid, B.t.u./(lb.)(°F.)	0.526(496°F)	0.412(352°F)	0.373(300°F)	0.580(500°F)	0.58(300°F)	0.56(600°F)	0.64(500°F)	0.333(500°F)	0.033(212°F)	0.25(600°F)
Heat of vaporization, B.t.u./lb.	125.0	119.0							117.0	
Heat of fusion, B.t.u./lb.	64	38	35						5.1	
Cubical expansion coefficient	0.00043		0.00020	0.00035			0.00039	0.000101		
Absolute viscosity of liquid, centipoise	0.30(600°F)	0.30(400°F)	1.7(800°F)	0.595(500°F)	0.873(300°F)	0.572(600°F)	0.605(500°F)	0.63(500°F)	1.23(200°F)	0.24(600°F)
Surface tension (contact with air), (contact with air), dynes/cm	43	37				37			487	105
Thermal conductivity liquid, B.t.u./(hr.)(sq.ft.)(°F./ft.)	0.076	0.064	0.35	0.067	0.0652	0.0590	0.072	0.057	4.85	15.6

\* The Dow Chemical Company.

† E. I. du Pont de Nemours & Co., Explosives Department, Wilmington, Del.

‡ Mobil Oil Corp.

§ American Hydrothem Corp.

¶ Monsanto Co.

**Table 2.13 Thermal Fluids Heaters**

Type	Vertical type	Horizontal multi-tube type	Marine type	Water tube type
Heat capacity (kcal/hr)	50,000 ~ 2000,000	50,000 ~ 15,000	100,000 ~ 6000,000	600,000 or more
Thermal efficiency (%)	50 ~ 55	50 ~ 55	about 70	70 ~ 75
Radiant section thermal load (kcal/m <sup>2</sup> ·hr)	15,000	—	15,000	—
Convection section thermal load (kcal/m <sup>2</sup> ·hr)	8,000	8,000	1,000	15,000~20,000
Construction	Simple-Small	Simple-Large	Simple-Medium	Dual drum water tube type
Thermal fluid	Small quantities	Large quantities	Large quantities	1 m <sup>3</sup> /10,000 kcal
Natural circulation system	Unsuitable	Suitable	Suitable	Unsuitable
Burner	Short flame burner	Fore-fire burner	Short flame burner	Easily adjustable burner
Applications	for small capacity	for small capacity	for general purposes	for large capacity

## 2.3 Energy Conservation in Each Manufacturing Process

### 2.3.1 Coal Tar Distillation

#### (1) Coal Tar Distillation Process

Coal tar is obtained through coal carbonization in the steel, city gas, and chemical industries. It was developed as a base resource for synthesized dyes, pharmaceuticals, and other synthetic organic chemical industries. The purpose of coal tar distillation is to concentrate and separate naphthalene and tar acids, refine washing oil, and to separate pitch. Distillation is carried out by a continuous distillation unit that uses pipe still heating, and the following are its 4 representative methods.

#### 1) Normal Pressure 1 Step Distillation

- a. **Wilton Process:** This is a process that circulates and heats pitch, which is shown in Figure 2.56 (A). A soda ash solution or caustic soda solution is added to raw tar, which is then preheated in a heat exchanger, economizer, inserted into the mixing part of the distillation column's mid step, and heated in the pipe still and mixed with pitch to let the volatile content evaporate, and finally exits the column bottom, and is circulated to the pipe still.
- b. **Abderhaldenn Process:** This process adopts a steam distillation unit, which is shown in Figure 2.56 (B). Raw tar is dewatered in a dewatering column and preheated in a pipe still, then enters a re-boiler that is installed at the high temperature part of the same pipe still, where hot steam is blown into it, then the pitch is sent into the heat exchanger, and the vaporized oil that is generated goes into the fractionating column, where it is steam-distilled, and with each fraction being drawn out as a bypass current, it is a complete reboil type distilling process.

#### 2) Vacuum 1 Step Flash Distillation

A representative type is the single column distillation unit of Germany's OTTO Corporation, which is shown in Figure 2.56 (C). Sodium carbonate solution is added to raw tar, which is then dewatered before it enters the pipe still, and then it enters the main column. For dewatering, many heat exchangers are used to recover the waste heat as a measure to economize heat. The main column is kept at a vacuum pressure of 100 to 200 Torr, and volatile matter less volatile than anthracene oil is sent to the column bottom, and is rectified by means of reflux of carbol oil from the column top.



### 3) Normal Pressure & Vacuum 2 Step Flash Distillation

The 2 column distillation unit of Germany's KOPPERS Corporation is representative, which is shown in Figure 2.56 (D). Raw tar is preheated in a heat exchanger, and enters the pipe still via a pressure dewatering vessel. The tar that was heated in the pipe still is sent to the normal pressure column, while the soft pitch that flows out of the normal pressure column is reheated in the heat exchanger, then sent to the vacuum column, and fractionated into light oil, carbol oil, mixed oil, and soft pitch. Pressure in the vacuum column is lowered to 60 to 70 Torr, and the reheated soft pitch is separated into naphthalene oil, washing oil, anthracene oil, and pitch.

### 4) Normal Pressure & Vacuum Multi-Step Flash Distillation

In order to raise the quality of fractionated tar oil, especially to raise the quality and recovery ratio of naphthalene oil, the new KOPPERS process, which has various support columns further installed to the previously mentioned 2-step flash distillation, among other processes, has been developed. It is shown in Figure 2.57.

Figure 2.56 Flow Sheet for Tar Distillation Equipment

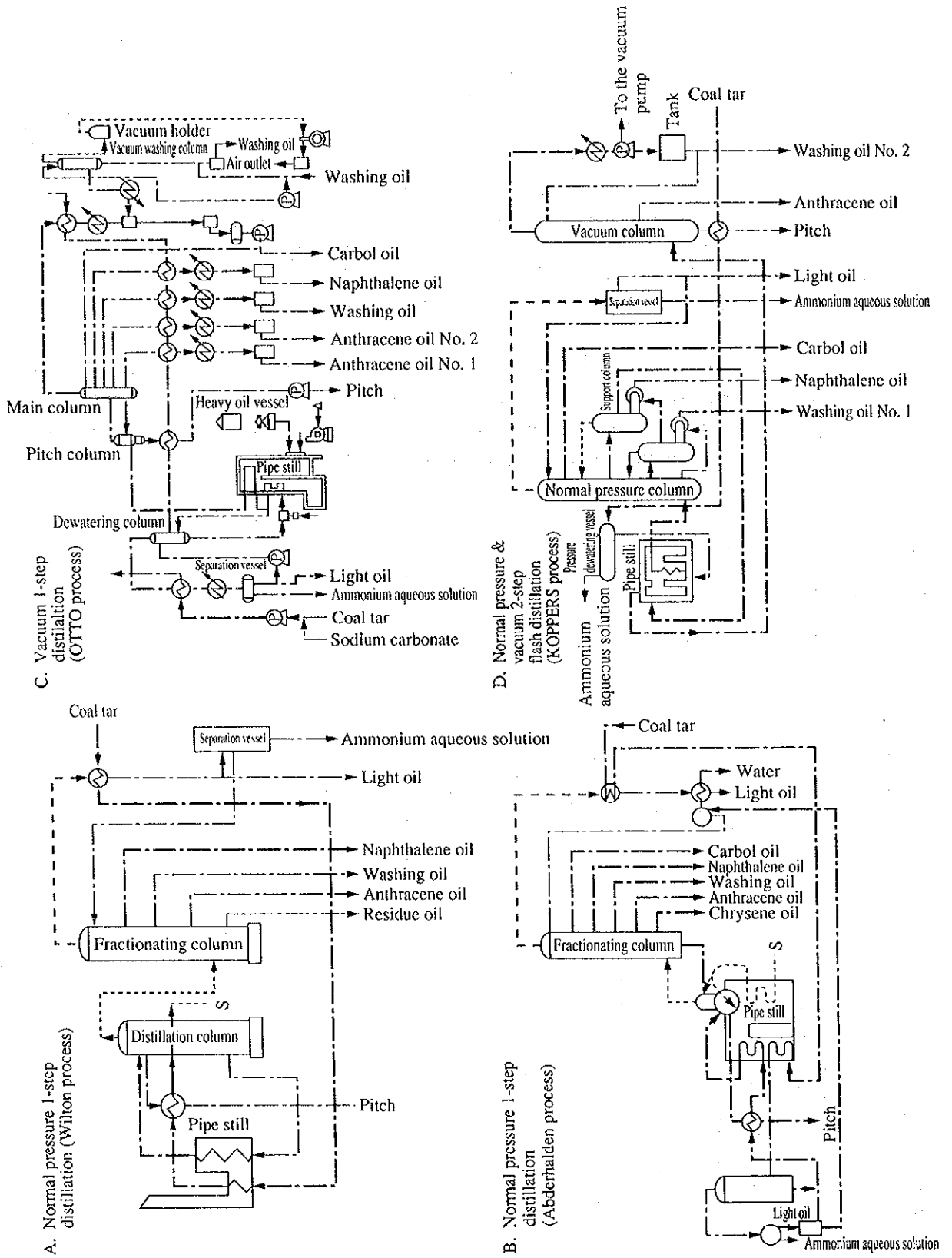
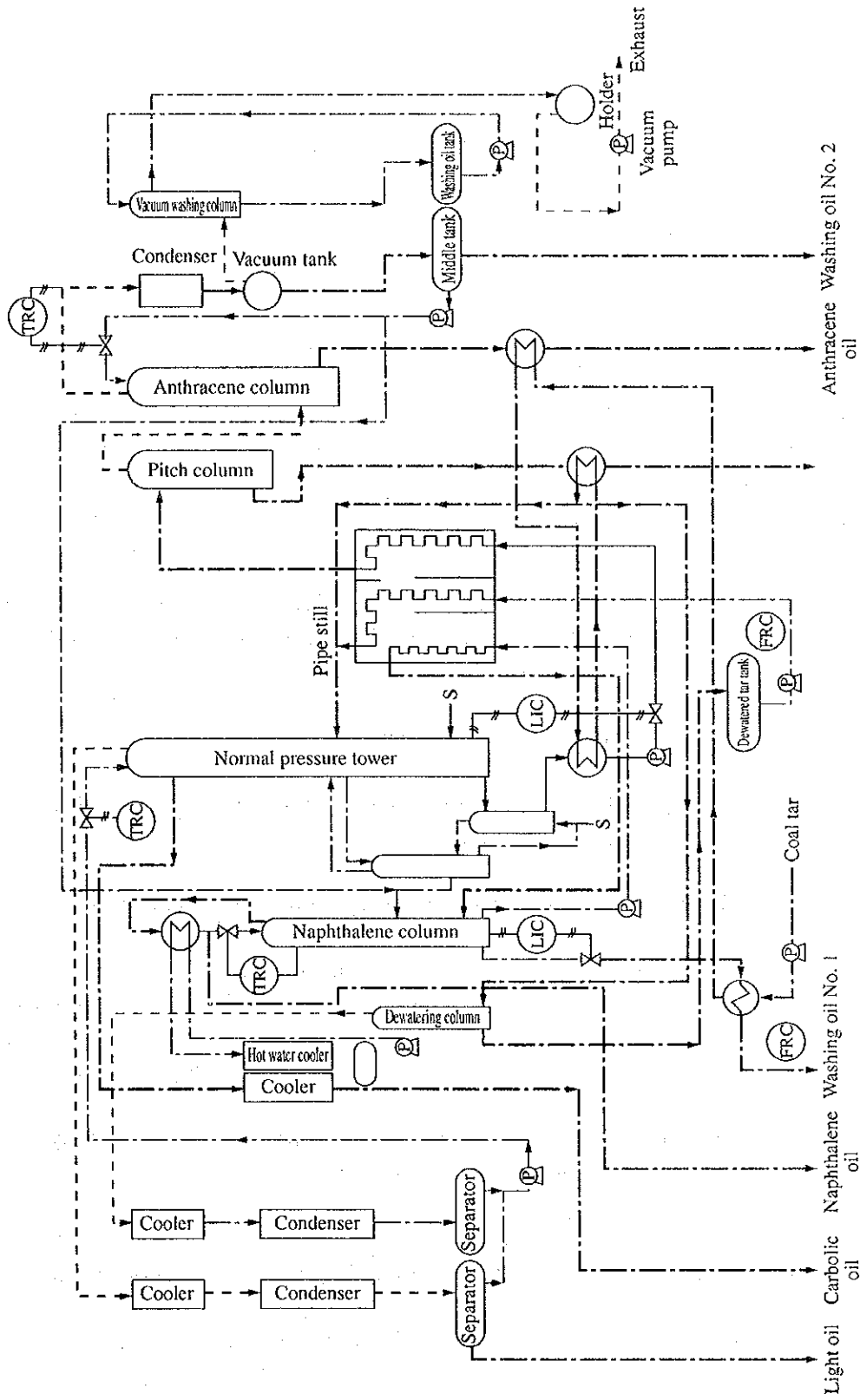


Figure 2.57 Flow Sheet for a Continuous Distillation Equipment (New KOPPERS process)



(2) Energy Conservation by Improvement of Operation and Equipment

1) State of Energy Use by Process

The energy intensity of the various processes are shown in Table 2.14. Differences in energy intensity arise depending on the plant's production capacity.

**Table 2.14 Energy Intensity for Each Process**

Type	Unit	Otto	Otto	Koppers
Capacity		200 t/d	500,000 t/y	
Fuel (COG)	(kcal/t-tar)	200,000	79,500	204,200
Electricity	(kWh/t-tar)	21	6.9	
Cooling water	(m <sup>3</sup> )	5	-	1.8
Steam for ejector	(kg/t-tar)	65	193	125
Steam for heating	(kg/t-tar)	175	193	125

The facilities that consume a large amount of energy in the tar distillation process are the pipe stills that heat the tar, and the distillation column that fractionates the tar.

2) Energy Conservation for Pipe Still Facilities

Coke oven gas (COG) is often used as the fuel for tar heating pipe stills, and among others, offgas within the factory is used.

The following items can be raised as energy conservation measures.

- Installation of fuel facilities that are compatible with the fuel
- Heat transfer by radiation and convection, thus allowing the heat efficiency to be improved
- Reinforcement of combustion management schemes such as optimizing the air ratio
- Prevention of heat loss by sealing gaps and openings in furnace body
- Reinforcement of furnace body insulation
- Waste heat recovery
- Prevention of fuel leakage
- For other measures, refer to the part on heating furnaces in Section 2.2.8.

3) Energy Conservation for Tar Distillation Columns

In the distillation of tar, moisture and light oil are separated by the dewatering column, and the fraction except pitch remaining in the column enters the fractionating column that is made up of about 30 steps, where it is fractionated by means of superheated steaming.

The following items can be raised as energy conservation measures.

- Establishment and reinforcement of heat insulation due to the high column and many steps
- Control of the reflux ratio that enables the temperature at the column top to remain constant
- Reinforcement of complete shutoffs and heat insulation of unnecessary distillate discharge tubes when changing the distillate discharge step along with a change in the target product ratio

For other measures, refer to the part on distillation equipment in Section 2.2.4.

#### 4) Waste Heat Recovery by Heat Exchangers

Pitch is separated and rectified at approximately 350 °C in tar distillation. As the boiling point of carbol oil is in the range of 180 to 220 °C, and that of anthracene oil is 300 to 360 °C, there is a great temperature difference between one fractionated product to another.

For energy conservation measures, see the part on heat transfer devices in Section 2.2.2.

### 2.3.2 Benzene Distillation

#### (1) The Benzene Distillation Process

As aromatic hydrocarbon sources, pyrolytic gasoline, modified oil, and tar derived crude light oil are available. Besides aromatic hydrocarbons, these raw materials also contain paraffin, naphthene, and olefin, etc., and they not only possess boiling points close to those of aromatic compounds, but create azeotropes with aromatic compounds; therefore it is not industrially possible to obtain high purity aromatic hydrocarbon by means of distillation only. Methods that are currently adopted by industry are the sulforane extractive distillation process, and a process called the MHC Process (Mitsubishi Hydro-Cracking and Dealkylation Process) which directly hydrocracks and dealkylates a raw material that contains benzene, toluene, xylene, and C9-aromatic compounds, etc., and manufactures benzene.

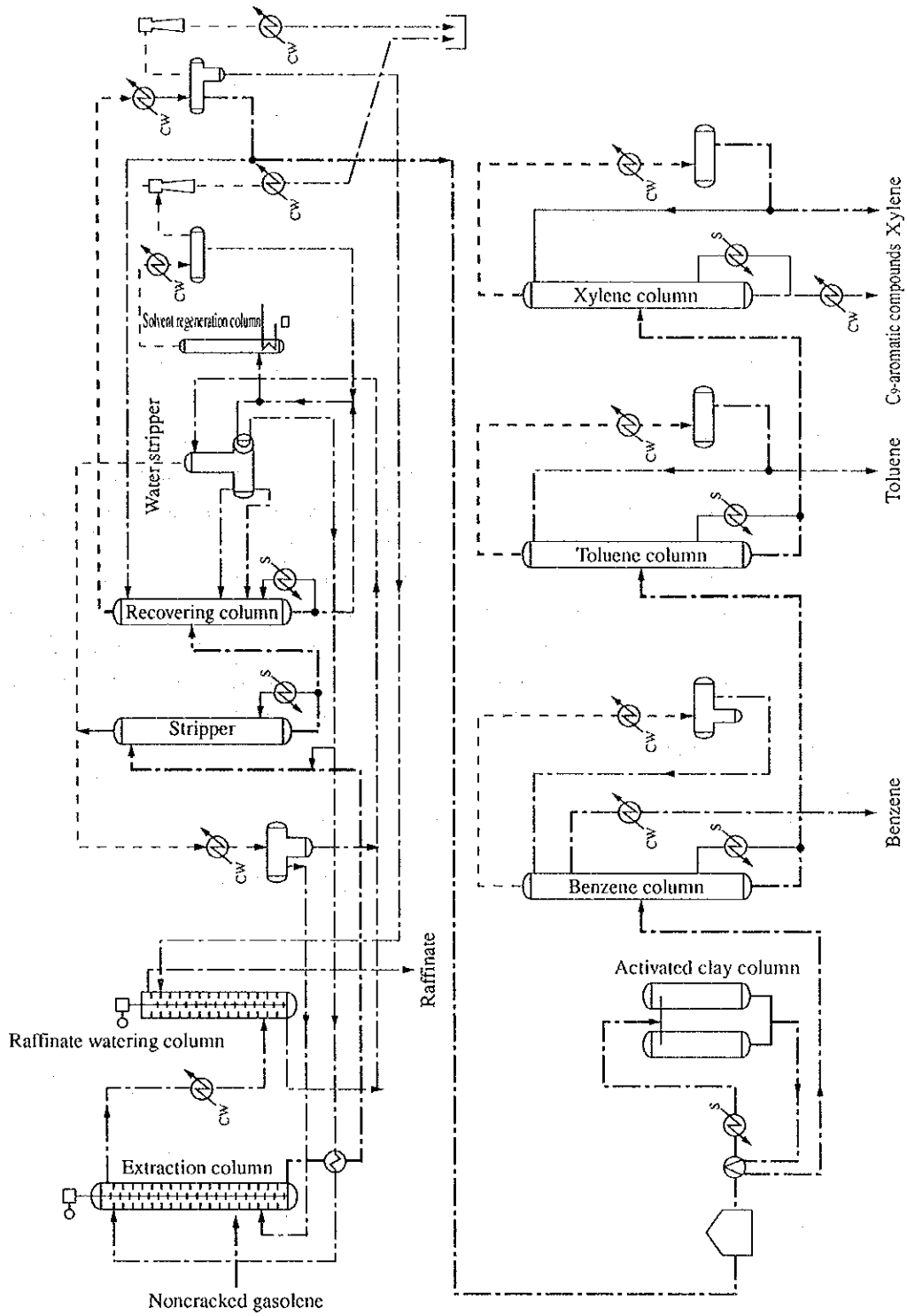
#### 1) Sulforane Method

The raw material enters the lower part of the extraction column, and aromatic compounds are selectively extracted with the use of a sulforane solvent that comes from the column top. The extracted matter enters the extractive distillation column (stripper), and the fractionated matter from the bottom of the extractive distillation column is sent to nearly the middle section of the recovering column, where it is distilled and separated into the desired aromatic compounds and solvents. Since the sulforane solvent and aromatic compounds have widely different boiling points, it is easy to separate them. The aromatic compounds are then further fractionated in the benzene column, toluene column, and xylene column.

The process flow sheet is shown in Figure 2.58.

The mass balance of the sulforane method is shown in Table 2.15.

Figure 2.58 BTX Process Flow Sheet (Shell sulfolane process)



**Table 2.15 Material Balance of Sulforane Method**

Raw material		Products	
Name	Quantity (BPSD)	Name	Quantity (BPSD)
Benzene	3,500	Benzene	3,500
Toluene	2,000	Toluene	1,980
Xylene	1,500	Xylene	1,440
Non-aromatics	3,000	Raffinate	3,080
Total	10,000	Total	10,000

2) MHC Process

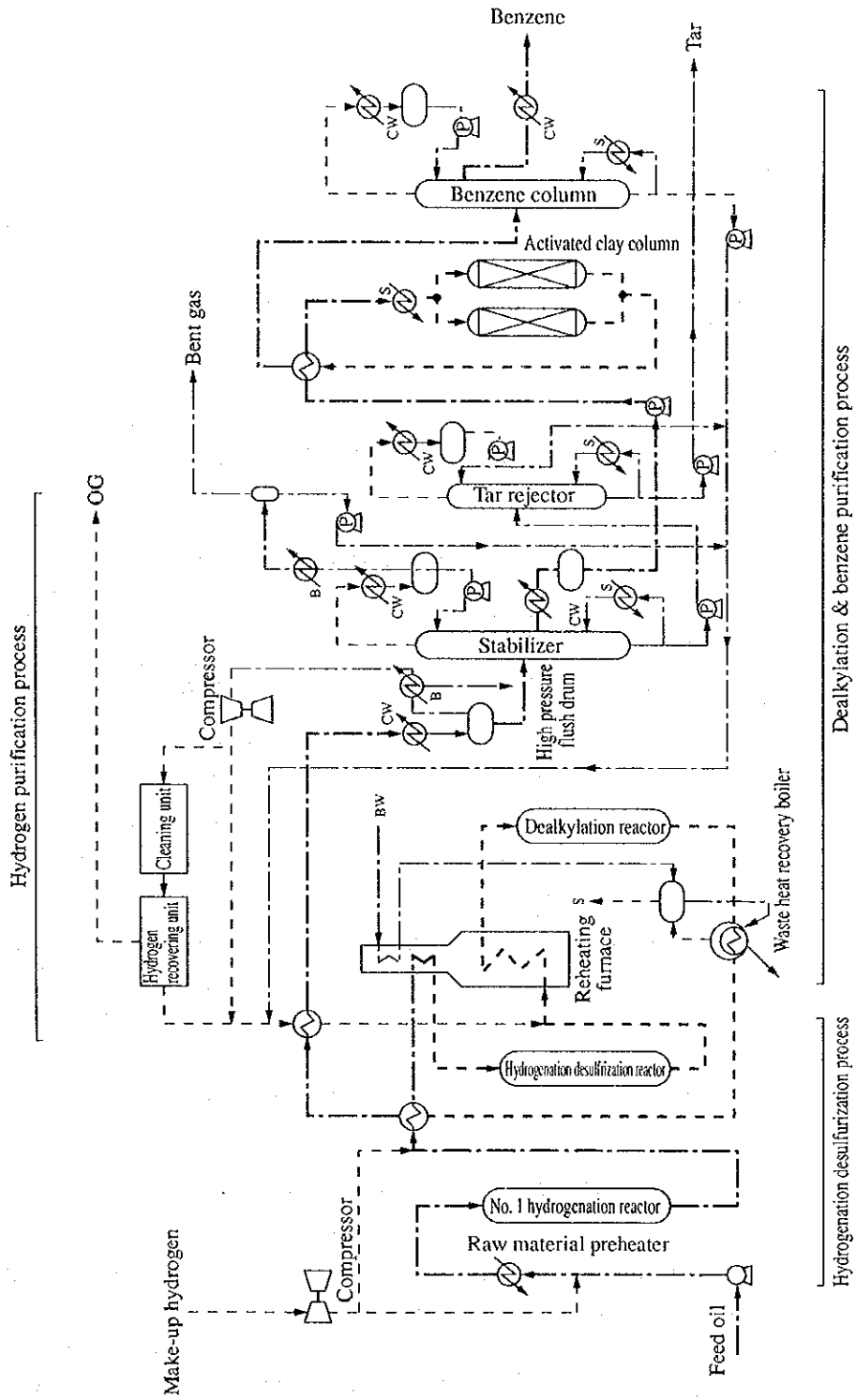
Feed oil is hydrodesulfurized, and the hydrodesulfurized oil, along with hydrogen and recycled oil, is heated in the heating furnace, and then inserted into the reactor, where dealkylation and hydrocracking take place simultaneously. The dealkylation reaction process takes place under a pressure level of 10atm or above, and temperature of 500 to 800 °C, in a draft of hydrogen. Because it is an exothermic reaction, how to control the temperature rise caused by the reaction is important. After it is processed by activated clay, the crude benzene enters the benzene column, and the product benzene is drawn out from the top of the benzene column, while the oil at the bottom of the column that contains toluene, and xylene, etc., are recycled to the dealkylation system.

The process flow sheet is shown in Figure 2.59.

The mass balance of this process is shown in Table 2.16.



Figure 2.59 Benzene Process Flow Sheet (MHC method)



**Table 2.16 Material Balance of MHC Process**

Raw material			Products		
Name	Unit	Quantity	Name	Unit	Quantity
Benzene	1,000 t/y	29.6	Benzene	1,000 t/y	100
Toluene	1,000 t/y	85.3	Tar	1,000 t/y	1.4
Non-arom	1,000 t/y	29.6	Off-gas	10 <sup>6</sup> m <sup>3</sup> /y	53.1
Hydrogen	10 <sup>6</sup> m <sup>3</sup> /y	49.2			

(2) Energy Conservation by Improvement of Operation and Equipment

1) State of Energy Use of the Process

A comparison of energy consumption between the sulforane method and the MHC process is shown in Table 2.17.

**Table 2.17 Energy Consumption in Sulforane and MHC Method**

	Unit	Sulforane	Sulforane	MHC
		10,000 BPSD	460 t-BTX/d	100,000 t/y 333 d/y
Electricity	(kWh/t)	700 kWh (12)	(55)	610 kWh (48.8)
Steam	(Mcal/t)	100 t/h (1,147)	(500)	0
Fuel	(Mcal/t)		(85)	8 Mcal/h (640)
				Dealkylation & benzene refinery

The facility with the largest consumption of energy in the benzene distillation process is the distillation facility. This facility consists of the extractive distillation column (stripper), recovering column, and the benzene, toluene, and xylene distillation columns. The MHC process is a process that transforms a benzene derivative into benzene by means of hydrodesulfurization, and is not a so called benzene distillation process.

2) Energy Conservation for the Benzene Distillation Column

Because of the strict quality standards for benzene, toluene, and xylene, a multi-step method is adopted in benzene distillation.

See the part on distillation units in Section 2.2.4 for reference on energy conservation measures.

### 3) Waste Heat Recovery Using Heat Exchangers

The fractionating temperatures for benzene is 80 °C, while that of toluene is 111 °C, and xylene 139 °C and thus, there is approximately a 30 °C temperature difference between them. The recovering column becomes about 140 °C since it has to fractionate all of the fractions.

See the part on heat transfer devices in section 2.2.2 for energy conservation measures.

### 2.3.3 Ethylbenzen Synthesis

#### (1) Ethylbenzen Synthesis Process

Ethylbenzen is manufactured through a process that alkylizes benzene by means of direct contact with ethylene. In industry, it can be called one of the processes that manufactures the synthetic raw material form of styrene monomers.

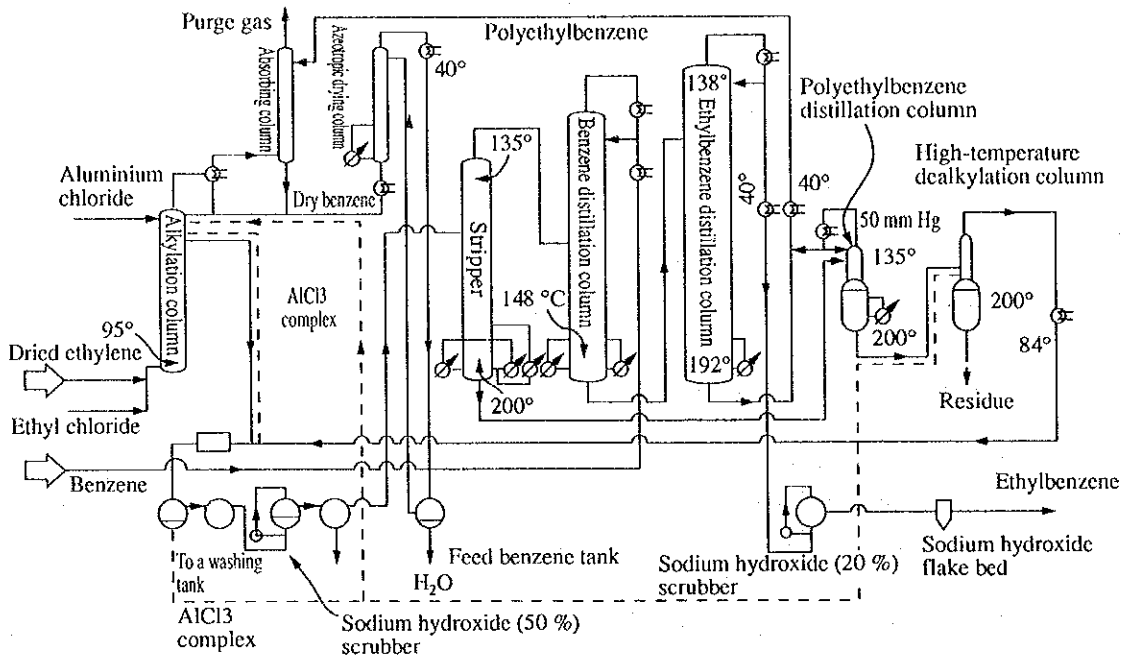
##### 1) Aluminum Chloride Process

The alkylation reaction generates about 27kcal/mol of heat, and is prone to reverse reaction in the atmosphere of high temperature, and therefore it is advantageous to carry out the reaction under low temperature using a catalyst.

Alkylation is carried out by a reactor with stirring machine or a filling column, and in the alkylation column, alkylation and dealkylation of polyethylbenzene take place simultaneously. The crude components from the alkylation column enter the distillation column after being subject to alkaline washing, and ethylbenzene is fractionated while benzene and polyethylbenzene are recycled to the alkylation column.

The process flow sheet is shown in Figure 2.60.

Figure 2.60 Ethylbenzene Process Flow Sheet (DOW process)



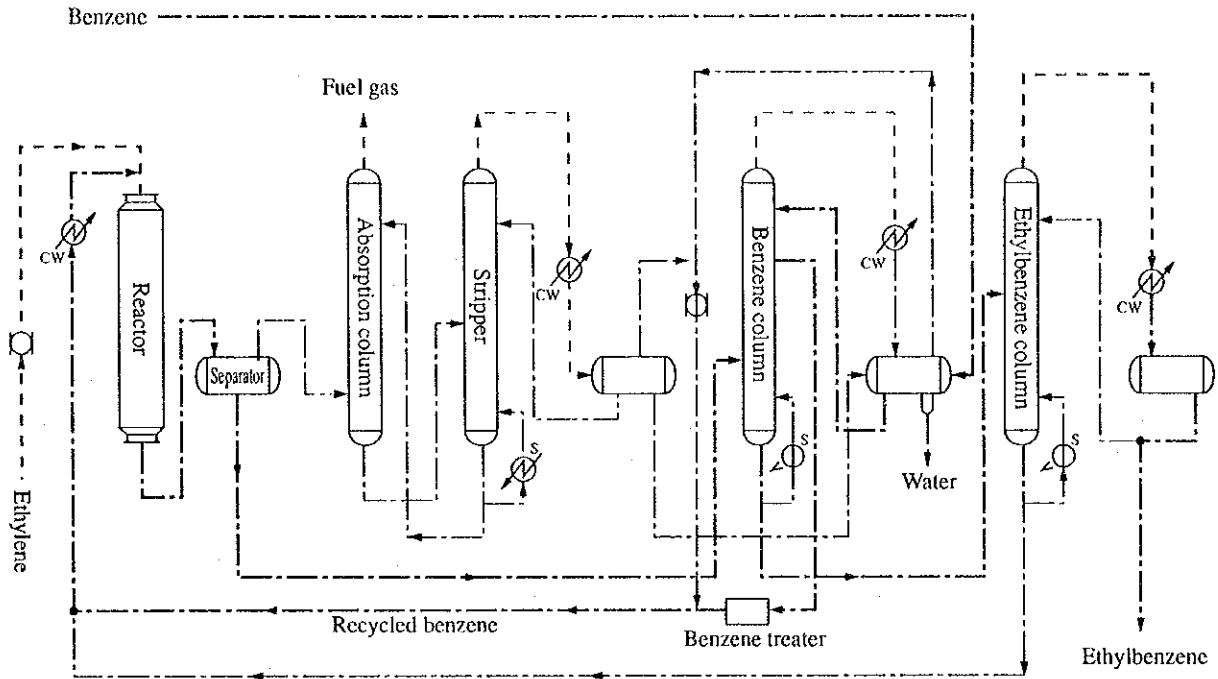
## 2) Alkar Process

The reactor is filled with an Alkar catalyst, which is stable with respect to both alkylation reactions and transalkylation reactions. After being compressed, the raw material ethylene is, along with circulated benzene, subjected to heat exchange, and then enters the reactor. In the reactor part, alkylation and transalkylation take place separately.

The distillate from the reactor enters the benzene column, and the non-reacting benzene, along with raw material benzene, is recycled to the reactor, while the matter at the bottom of the benzene column enters the ethylbenzene column, and a high purity ethylbenzene is fractionated from the top of the column. The polyethylbenzene at the bottom of the column, along with recycled benzene, enters the reactor, and is transalkylated.

The process flow sheet is shown in Figure 2.61.

**Figure 2.61 Ethylbenzene Process Flow Sheet (Alkar process)**



The material balance and energy consumption for the Alkar process are shown in Table 2.18 and Table 2.19, respectively.

**Table 2.18 Material Balance of Alkar Process**

Raw material			Products		
Name	Unit	Quantity	Name	Unit	Quantity
Ethylene	(t/y)	15,080	Offgas	(t/y)	10
Benzene	(t/y)	41,860	Ethylbenzene	(t/y)	56,720
			Polyethylbenzene	(t/y)	210
<b>Total</b>	<b>(t/y)</b>	<b>58,940</b>	<b>Total</b>	<b>(t/y)</b>	<b>58,940</b>

**Table 2.19 Energy Consumption in Alkar Process**

Unit		Alkar	
		EB: 56,720 t/y	Intensity
Electricity	(kWh/t)	690 kWh	97
Steam	(Mcal/t)	0	0
Fuel	(Mcal/t)	$19 \times 10^6$ BTU/h	675

(2) Energy Conservation by Improvement of Operation and Equipment

a. State of Energy Use in Processes

An example of reaction conditions, heat input, and cooling heat gain is shown (Ethylbenzene 1 kg).

Unit operation	Temperature [°C]	Heat inlet [kcal/kg]	Cooling [kcal/kg]
① Alkylation reactor	95	260 (Exotherm)	210 (CW: 25 °C)
② Washing filter	40	63 (Electricity)	
③ Benzene distillation	150	247 (Steam)	167 (CW: 25 °C)
④ Benzene drying column	40	170 (Steam)	146 (CW: 25 °C)
⑤ Ethylbenzene distillation	190	315 (Steam)	274 (CW: 25 °C)

(Note) The difference between heat input and cooling heat value is due to radiation heat, and also due to the ethylbenzene being sent to the styrene monomer synthesis process unchanged from its high temperature state.

Source: Energy analysis of 108 industrial processes, DOE, USA.

The heat of reaction in ethylbenzene synthesis reaction is approximately 27 kcal/mol (MW: 106). Therefore, the heat generated in this reaction is as follows:  
 $27 \times 106 \times 1,000 = 255$  [kcal/kg]. A difference in the process causes no significant difference in heat value required for distillation, not to mention reaction heat. In the example shown above, cooling water of normal temperature is used, while 1.15 kg of steam is used per kg of ethylbenzene.

In some cases of a new process using a molecular sieve catalyst, 1.5 ton of steam can be generated per ton of ethylbenzene.

The facility which generates a large amount of energy in the ethylbenzene synthesis process is alkylation equipment, while on the other hand major energy consumers include benzene, ethylbenzene and polyethylbenzene distillation facilities.

Based on One Metric Ton of EB

	Fixed-bed, liquid phase, zeolite catalyst technology	Fixed-bed, catalytic distillation technology with zeolite catalyst
Ethylene [kg]	266	266
Benzene [kg]	740	740
Electricity [kWh]	32	27
Water, Cooling [m <sup>3</sup> ]	9	9
Steam [tons] (export)	1.8	1.5
Hot oil (106) [kcal]	0.8	0.7

\* Hydrocarbon Processing/March 1997

b. Recovery of alkylation reaction heat for use

The methods of recovery and use include the following:

- Recovering alkylation reaction heat as in the form of steam (2 kg/cm<sup>2</sup>)
- Utilizing the steam as a heat source for distillation facilities

To this end

- Upgrading steam heating boilers
- Upgrading and reinforcing heat insulation

c. Energy conservation for distillation facilities

Distillation facilities include benzene, ethylbenzene and polyethylbenzene distillation columns.

For the energy conservation measures, refer to Section 2.2.4 Distillation Equipment.

d. Recovery of waste heat by heat exchangers

There are heat exchangers utilizing the steam recovered from reaction heat in the fuel heating system, and waste heat recovery available.

For energy conservation measures, refer to the heating equipment in Section 2.2.2.

### 2.3.4 Energy Conservation in the Dyestuff Industry

(1) Manufacturing Process

a. Types of synthetic dyestuff

There are two types of categorizing synthetic dyestuff: category by dye-affinity and that by chemical structure. Practically, the dyestuff is categorized by dye affinity. There is also classification by Colour Index, common to the world, which is jointly published by SDC (The Society of Dyers and Colourists) and AATCC (The American Association of Textile Chemists and Colourists). In Colour Index 3rd Edition (1971), dyestuff is classified by section name for each application, color and No. The dyestuff is provided with CI name and a 5-digit C.I. No. based on the chemical structure.

Table 2.20 shows classification by dye affinity.

**Table 2.20 Classification by Dye Affinity**

	Dye name	Ionicity	Bond with fibers	Major applications
Water-soluble dyestuff	Acid dye	Anion	Ion bond	Wool, silk, nylon
	Direct dye	Anion	Hydrogen bond, Fanderwals force	Cellulose (Cotton, linen, rayon)
	Mordant dye, acid mordant dye	Anion	Ionic bond, complex salt formation	Wool, silk, nylon
	Reactive dye	Anion	Covalent bond	Cellulose, wool
	Basic dye (cation dye)	Cation	Ionic bond	Wool, silk (Acryl)
Non-water- soluble dyestuff	Disperse dye	Non-ion	Hydrogen bond, Fanderwals force	Polyester, acetate
	Vat dye (?????)	Non-ion	Pigment formation	Cellulose
	Sulfur dye, sulfur vat dye	Non-ion	Pigment formation	Cellulose
	Azo dye (naphthol dye)	Non-ion	Pigment formation	Cellulose
	Solvent dye (oil color)	Non-ion	–	Plastic, paint, ink

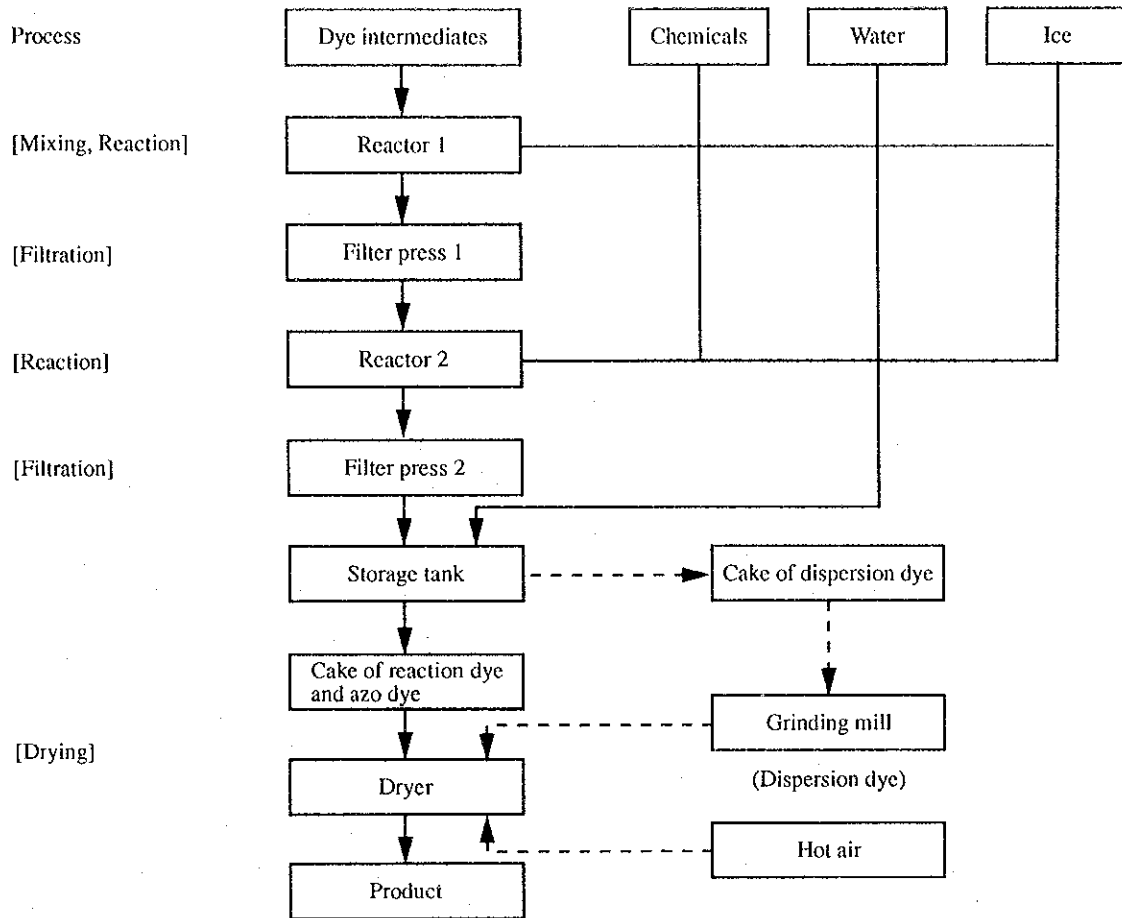
**b. Manufacturing process**

In the manufacturing processes, batch system is used for synthetic reaction, while both batch system and continuous system are used for drying. While there are a wide variety of dyestuff, their production process is common. Disperse dye is water-soluble and has a characteristic of requiring atomization.

Figure 2.62 shows the manufacturing process.



Figure 2.62 Manufacturing Process



Intermediates used for manufacturing dyestuff are reaction byproduct produced during nitration, sulfonation and halogenation processes using toluene, benzene, and anthracene as raw materials, and these intermediates are used as raw materials for the dye manufacturing process.

In the manufacturing process, reactive chemical is added to an intermediate appropriate for the product to perform diazotization or coupling reaction. For reaction, solid-liquid separation is conducted upon the completion of 1 step, but this solid-liquid process differs depending on the reaction condition; in some cases it is performed after finishing reaction in 2 steps, while in other cases it is carried out after 1 step reaction. Reaction is performed in water solution phase, and ice is used to maintain the reaction temperature (around 10 °C) because of the exothermic reaction.

A filter press and compressed air are used for solid-liquid separation.

Water and additives are added to reaction byproducts after solid-liquid separation, to be made into liquid products or they are dried to be made into powder products. Steam or fuel combustion gas is used as the heat source for drying.

For disperse dye, wet-process pulverizing by means of a mill or semi-wet process pulverizing by means of rolls is performed using electricity.

Waste water generated in solid-liquid separation is treated by the activated sludge method and then discharged in the water or it is discolored through the active carbon treatment, then to be discharged.

(2) Energy conservation by operation and equipment improvement

a. Sales expansion of liquid products

When the sale target is intended for the domestic market, products are not necessarily made in the powder form. Selling products in the form of liquid can eliminate the drying process and reduce the percentage occupied by steam for processing in the production cost, which is thus expected to improve the market competitiveness. This, however, requires the composition matching the dyeing process and quality control to maintain the stability. Particularly 30 % to 40 % of black and dark blue dyestuff, which account for about 50 % of the entire dyestuff, is sold in the liquid form in Japan, mainly with major users as their targets for another purpose of preventing pollution or skin trouble.

b. Reaction equipment

The reaction temperature is the room temperature or lower and in some cases coolant may be passed through the jacket, but in either case, cold insulation is required. By automatic feeding of ice or reaction chemicals depending on the reaction characteristic, product quality and yield can be improved. Additionally, components and slurry concentration are adjusted by controlling the reaction, to omit the filtration process before drying, thus contributing to energy conservation.

Following is typical reaction.

The reaction process of reactive dyestuff (Reactive Yellow 3) and an example of product yield in a Japanese factory are as follows:

(Reaction) diazotization → coupling → cyanuration → amination → filtration [overall yield]  
95 %      90 %      98 %      95 %      90 %      70

Coupling reaction in particular has a significant effect on the product yield in terms of the reaction temperature, acid concentration, chemicals feeding speed, etc. If the yield of coupling reaction is 90 % or lower, there is an allowance for improvement of the yield. In the reaction requiring a strict reaction temperature control, a chemicals table feeder is, in some cases, used to supply a specified amount of chemicals, thereby reducing the labor cost and improving the yield by 10 %.

c. Filtration equipment

Since compressed air is used in many cases, pressure tanks and piping system need to be maintained carefully to prevent any leakage. Using an enclosed type of treatment for waste/drain water from the filter press can eliminate floor cleaning and also reduce the waste water treatment load.

The current prevailing trend is that the filtration process is omitted and direct drying method is used to improve the product yield and achieve energy conservation in terms of electricity used for manufacturing compressed air. This requires setting appropriate reaction conditions and process control.

d. Drying equipment

Most of heat is consumed by the drying equipment in the dye manufacturing process. In this respect, therefore, it is of utmost importance to make the effort for energy conservation.

1) Improvement of air heater

Because high pressure steam is used, troubles such as breakage due to a distortion of a steam pipe or breakage due to water hammer phenomenon caused by the residual drain in the pipe may occur, thus wasting steam. In this regard, care should be taken to the structure and welding of a steam pipe.

2) Installation of individual drain traps

Installing a steam trap and a drain discharge pipe at individual air heaters allows preventing a pressure fluctuation in the drain discharge lines of the air heater, and back flow of drain due to siphon phenomenon, etc. This can also prevent a breakage of steam pipe.

For other information, refer to Section 2.2.6 Drying Equipment.

### 2.3.5 Method of supplying steam, ice and compressed air

Steam, ice and compressed air are all important energy sources, and thus due consideration should be taken to the method of supplying them to the factory. In case of their long-distance transportation, it is important to prevent radiation heat loss of piping with regard to steam, and to prevent the leakage of piping with regard to compressed air. Additionally, in some factories, the lines involving ice are integrated to store ices made into flakes, and fit them into the reaction tank by means of a screw feeder and belt conveyor. Thus a certain amount of ice is supplied by the on-off control of the screw feeder as required, thereby improving the product yield by an about 2 %.

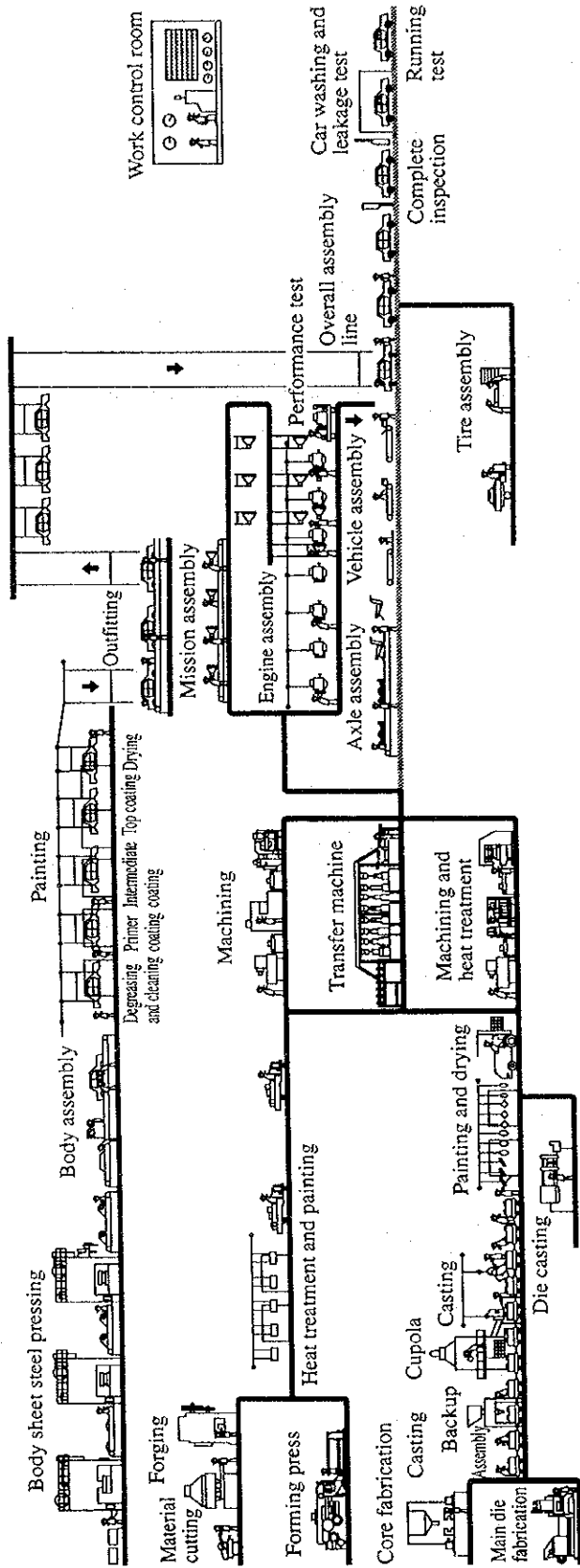
### 3. ENERGY CONSERVATION IN THE MACHINE MANUFACTURING INDUSTRY

### **3. ENERGY CONSERVATION IN THE MACHINE MANUFACTURE INDUSTRY**

#### **3.1 Energy and Energy Intensity in General Manufacturing Processes**

While the production flow from raw material to finished product in the general machinery industry, such as in truck manufacturing and tractor manufacturing, can be divided into a few main processes as shown in Figure 3.1, it does not necessarily mean that production takes place in-house within each process, but rather, a combination of outsourcing and in-house production is carried out in a way that is compatible with the manufacturer's technological and cost related capabilities. Additionally, since the energy intensity for finished goods produced in each process differs completely from one another, and the energy intensity that needs to be managed is also different, it is impossible to compare all processes using identical measurements of energy intensity; therefore it is important to manage energy used in each process independently when trying to grasp the overall energy intensity per final good produced.

Figure 3.1 General Production Process for Trucks and Tractors



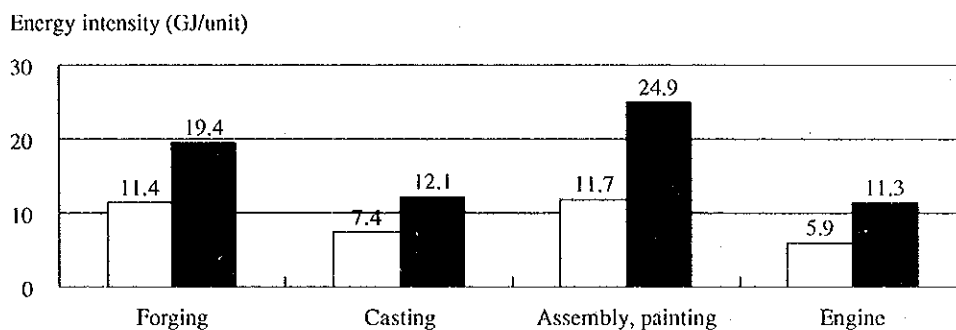
Source: "The Motor Industry of Japan" by Japan Automobile Manufacturers Association, Inc.

**Table 3.1 Example of Internal/External Fabrication (Make or Buy) of Trucks and Tractors by Process**

Manufacture	Internal/External fabrication (○ ... In-plant fabrication, × ... Purchasing/outsourcing)								
	Manufacture of material/part material				Intermediate process			Finishing	
	Casting	Forging	Machining	Heat treatment	Instrumentation	Engine	Mission	Press	Assembly
Company A	○	○	○	○	×	○	○	○	○
Company B	×	×	○	○	×	○	○	○	○
Company C	×	×	○	○	×	×	×	○	○

The energy intensity for each principal process is indicated in terms of factories that have (A) good energy management, and those where (B) management is inadequate.

**Figure 3.2 Energy Intensity by Process**



Hereafter, the type of energy used, and the energy intensity that needs to be managed to promote energy conservation, are summarized for the casting, mechanical fabrication, and assembly and coating processes.

Since forging and casting are often outsourced in the machinery industry, the guidelines for the “Steel-Making Industry” should be referred to for these processes.

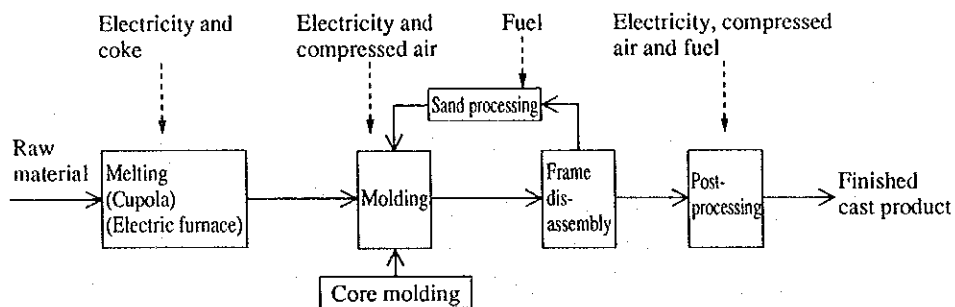
## 3.2 Energy Conservation and Control Indices for each Process

### 3.2.1 Casting

#### (1) Example of a typical process

While the casting process can be divided into “melting,” “core making,” “forming,” “sand processing,” and “post process” (Figure 3.3), generally it is more convenient to divide it into the 2 categories, “melting” and “other processes,” from the standpoint of energy consumption.

Figure 3.3 General Casting Process and Major Energy Consumption by Process



#### (2) Characteristics related to Energy Consumption

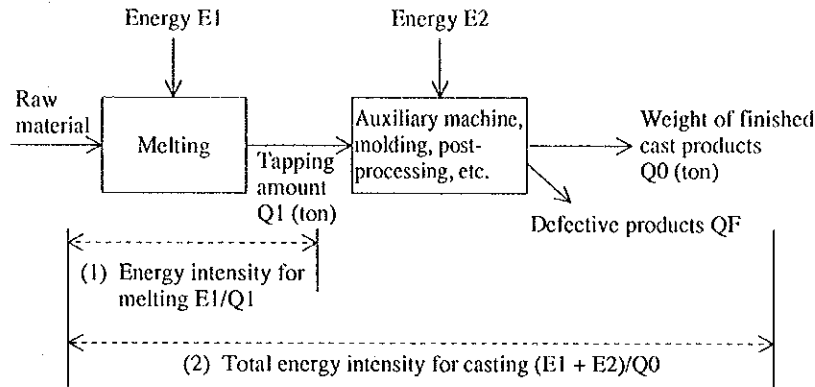
“Melting” consumes substantial amounts of energy in the casting process. Cupola melting using coke is the principal form of melting. While electric furnaces are used when multiple types of materials are produced, nearly 60 % of the electricity used in such casting process goes to power for melting. In processes other than melting, such as forming and sand processing, a lot of the consumption is made by environmental facilities such as dust collectors and fans. Additionally, energy consumption in these forms are so called “fixed energy” that is not influenced that much by production quantity. Thus a reduction in production becomes a factor that substantially increases the energy intensity in casting.

#### (3) Approach to Dealing with Energy Intensity within Processes

As mentioned before, it is crucial to manage the 2 forms of consumption rates, “melting” and “overall casting,” since they take up over half of the energy consumed in casting.



**Figure 3.4 Energy Intensity of the Casting Process**



a. Melting Energy Intensity

The energy consumed by melting is important as a measure of energy intensity that fluctuates with production quantity, and is expressed as an amount of energy consumed by melting per ton of molten metal output. For electric furnaces, it is expressed in terms of  $E1/Q$  (kWh/ton) in Figure 3.4, or coke ratio (%) in case of cupola melting. The management target, although it differs depending on the type of facility used, it is generally 640kWh/ton or less for electric melting, and a coke ratio of 12 % or less for cupolas.

b. Overall Casting Energy Intensity

In non-melting processes such as forming and sand processing, the amount of electric power consumed by environmental facilities like dust collectors and fans, and by hydraulic pumps and other drives, is substantial. Such facilities often continue to run, and thus consume energy, even while production is not taking place, increasing the fixed portion of their energy consumption. As far as the management of the entire casting process is concerned, it is necessary to grasp the overall energy intensity in consideration of how many finished cast products were produced by consuming these amounts of energy. This energy intensity is characterized by how it is influenced by fluctuations in production.

Overall casting energy intensity is expressed as = (total energy for casting process)/ (mass of final finished casting product), which, in Figure 3.4, turns out to be  $(E1+E2)/Q0$  (kJ/ton).

(4) Energy Management Items and Energy Conservation Items

a. Energy Management Items and Energy Conservation Items in Management and Operation Aspects

1) Cupola Operation Matched to Production Volume (Concentrated Operation)

An optimized operating method should be determined, from the perspective of the production plan for the cupola, and the production capacity of the casting line (line speed), and the production system should be as much concentrated as possible. If operation is carried out on a continuous basis, the coke ratio will be reduced as a result of improved efficiency, and energy consumption can be reduced by that much.

However, it should be noted that once the necessary amount is produced, concentrated production should come to a complete halt until the next production, keeping in mind that a production halt lacking unhesitating determination will only invite needless energy consumption.

b. Energy Conservation through Equipment Improvement

Energy conservation measures generally performed are summarized here.

- 1) Hydraulic pumps for the forming line are unloaded while the line is not running.
- 2) The cooling tower's fan is run or stopped depending on the level of water temperature.
- 3) The dust collector should be turned ON-OFF synchronously with the sand processing conveyor, or the number of revolutions should be controlled so that it can run according to the amount of load.
- 4) A "calendered timer" should be installed to devices, such as the chimney fan, that may be overlooked, and not turned off when they should be so that their ON-OFF operations can be performed automatically.
- 5) The power should be turned on immediately before running a line.

c. Energy Conservation through Process Improvement

Reference should be made to the guidelines for steel-making industry, as for details on the casting process, while comparisons on "melting" processes are mentioned here. Needless to say, not only energy consumption, but quality and cost are also examined.

1) Modernizing Melting Furnaces

Melting furnaces should be distinguished not only by cost, but also by the categories according to required quality level and operating mode as shown in the table below. As the overall efficiency of a cupola is realized when a material of constant composition is mass produced continuously, an optimal melting furnace should be introduced with targets set on long term production items and production quantity forecast.

The energy intensity of different types of melting furnaces are compared in Table 3.2.

**Table 3.2 Comparison of Energy Resources and Consumption by Type of Melting Furnace**

Type of furnace	Heat source	Energy efficiency per ton of iron		
Cold air cupola	Coke	150 kg	(4,520 MJ)	27 ~ 32 %
Hot air cupola	Coke	100 kg	(3,010 MJ)	38 ~ 45 %
Arc furnace	Electricity	550 ~ 660 kWh	(5,640 ~ 6,770 MJ)	59 ~ 65 %
Low-frequency furnace	Electricity	500 ~ 630 kWh	(5,120 ~ 6,460 MJ)	62 ~ 70 %
High-frequency furnace	Electricity	600 ~ 650 kWh	(6,150 ~ 6,660 MJ)	60 ~ 65 %

Additionally, along with the table above, an example in which the furnace is modified is shown below.

① Feasibility of Deploying a High Frequency Furnace

Presumed conditions	Monthly melting quantity 1,600 tons
Furnace introduced	High frequency furnace 3 tons × 3 units
Investment	Per 1 unit Approximately 7,500,000 PLN
Heat source	Since electricity is used, the initial power receiving will increase by about 5,000 kW. (Amount of increase; 5,400k W, Heat retaining furnace power for the amount of reduction; 400 kW) However, since receiving capacity is adequate, accommodations can be made with the existing receiving facility
Operating mode	Operation per day was made 8 hours, or the same as the line that pours molten metal. By dividing among 3 units the per hour melting quantity = 9 tons, the holding furnace is made unnecessary.
Energy	Current cupola

Melting coke	81,000 GJ/y (1,600 × 0.14 × 12 × 30,144 kJ/t)
Ele power for holding furnace	8,700 GJ/y (400 kW × 8 h × 22 d × 12 m)
Total	89,700 GJ/y

In the case of a high frequency furnace

Melting power	118,000 GJ/y (1,600 × 600 kWh × 12)
Energy effect	+28,300 GJ/y (An increase when only looking at energy quantity)

Other effects

- Quality stabilizes.
- Nail scrap can be used (results in reduction of raw material)
- Reduction of maintenance cost
- Since a small scale facility will do, facility space can be reduced (reducing energy for illumination, etc.)
- Unlike cupolas, specialized skills become unnecessary for workers.
- Becomes a measure to improve the environment
- Production can take place efficiently even if operating time is changed.

② Feasibility of introducing hot blast cupola

Presumed condition	Monthly melting quantity 1,600 tons
Furnace introduced	Hot blast cupola 3 tons × 3 units, or 10 tons × 1 unit
Volume of investment	Per 1 unit Approximately 9,500,000 PLN (about 300 million yen)
Operating mode	Equivalent to current one. (Holding furnace is the same, too)
Energy	Current cupola
	Melting coke 81,000 GJ/y (1,600 × 0.14 × 12 × 30,144 kJ/t)
	Hot blast cupola
	Melting coke 57,800 GJ/y (1,600 × 0.10 × 12 × 30,144 kJ/t)
	Energy effect -23,200 GJ/y

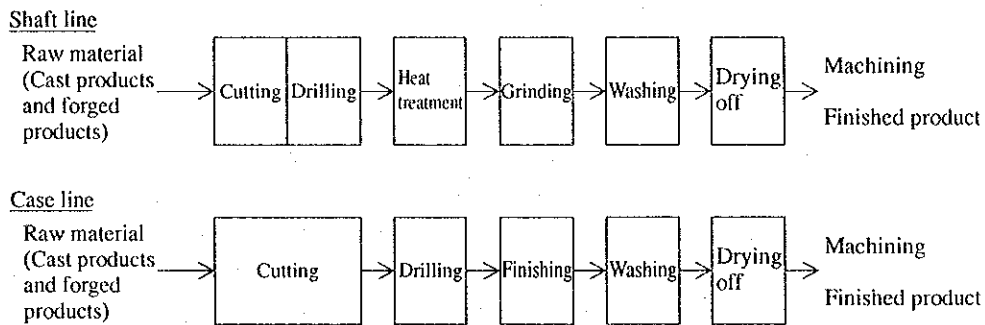
### 3.2.2 Machining

#### (1) Example of a typical process

A process that carries out “cutting,” “grinding,” and “cleaning,” etc. of raw materials produced in the casting and forging processes, it is usually arranged in 1 line for each type of part, from injection of raw material to completion of the part.

Figure 3.5 is an example of a fabrication line for an automobile part.

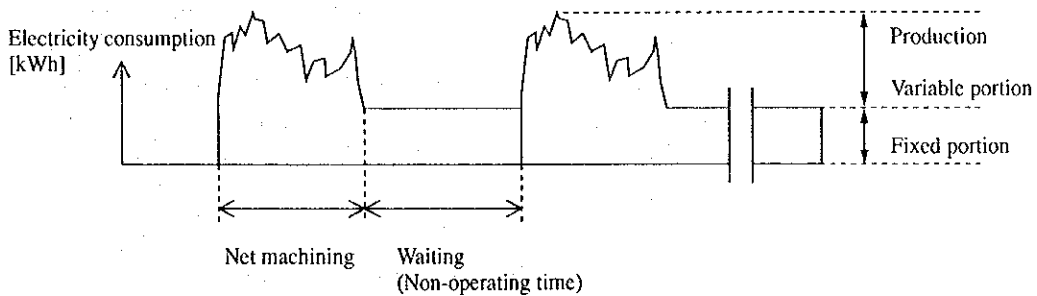
**Figure 3.5 Example of Machining**



#### (2) Characteristics Related to Energy Consumption

The energy consumed here is almost entirely electric power for drives and compressed air as a secondary energy source. Additionally, each facility has auxiliary facilities such as hydraulic pumps, coolant pumps, and dust collectors, and as seen in Figure 3.6, the amount of electric power consumed by these is also substantial. Also as evident from the figure, the fact that the “fixed portion” of energy consumption is large is another characteristic.

**Figure 3.6 Electricity Consumption during 1 Cycle of Machining (For cutting machine)**



(3) Approach to Dealing with Energy Consumption Rates within a Process

As shown in Figure 3.6, the amount of electric power consumed during non-operating time, in other words, while waiting for the next work, is also significant, and "total energy per 1 unit of a product" including these is subject to control.

In other words, the energy intensity of 1 line becomes as follows.

Consumption rate =  $E_t/P_t$  (kJ/unit)

$E_t$  = (Total energy use of an entire line during a given period [electric power, compressed air, fuel])

$P_t$  = (Number of units of completed parts per line during a given period)

However, when almost all of the energy consumed is electric power, and the amount of fuel is negligible, management is sometimes conducted using only the consumption rate (kWh/unit) of electric power for the sake of simplicity.

Additionally, total electric power consumption summed up for a single line can be difficult to grasp in reality, and in such case, the energy used by 1 unit of a typical facility in that line is grasped instead, and based on the figures for that typical facility, a conversion ratio is determined based on the number of facilities in the line and the facility's scale, to estimate consumption for the entire line.

(4) Energy Management Items and Energy Conservation Items

a. Energy Management Items and Energy Conservation Items in Aspects of Management and Operation

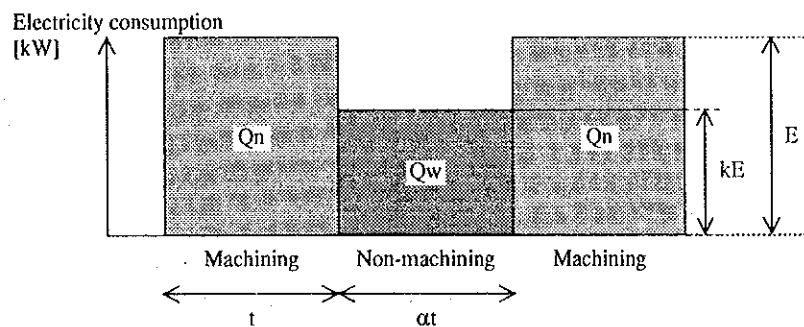
1) "Concentrated production" and "Uncompromising shutdown during non-producing periods"

Generally speaking, there is a "fixed portion" of energy consumed regardless of actual fabrication, which takes up about 40 to 60 % of the total in machine fabrication. This fixed portion is the  $Q_w$  part in Figure 3.7, consisting of "coolant pumps," "hydraulic pumps," "lubrication pumps," "mist collectors," "oil temperature adjusters," "chip conveyors," and "control panel cooling fans," etc., and these are energy portions by equipment that runs regardless of whether fabrication is taking place or not once the facility's power is turned ON, and they are fundamentally energy portions that are unnecessary when fabrication is not taking place.

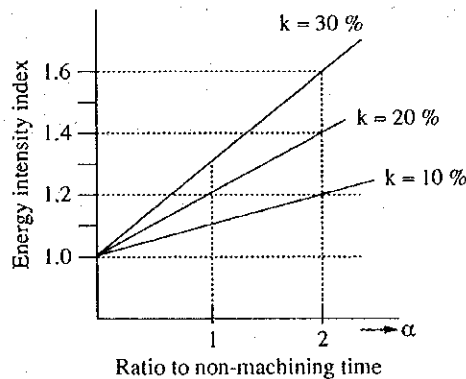
Because the energy intensity ( $I$ ) of producing a product includes these non-fabricating portions as well, it becomes as shown in the equation below, and as shown in Figure 3.8, and the energy intensity is worsened by  $Q_w$ , or the product of non-fabricating time,  $\alpha t$ , and the amount of fixed energy used during that time,  $kE$ .

- Energy intensity  $I = E (1 + \alpha \cdot k)$  [J/unit]
- $Q_n$  : Net electric power consumed in 1 cycle of fabrication ( $E \times t$ ) kWh
- $Q_w$  : Amount of electricity consumed while waiting kWh
- $E$  : Average electric power during fabrication kW
- $k$  : Ratio of average electric power during waiting with respect to that during fabricating
- $t$  : Fabrication time minutes
- $\alpha$  : Ratio of waiting time as a proportion of fabrication time

**Figure 3.7 Comparison between Energy Consumption during Machining and That during Non-machining**



**Figure 3.8 Energy Intensity Index including that during Non-machining**



For example, if production decreases and the same amount of time waiting for work is generated as the net amount of fabrication time,  $\alpha = 1$  becomes true; therefore for a facility or line whose fixed portion  $k$  is 30 %, the energy intensity worsens to 1.3 times net fabrication. In other words, in this example in which production volume is small and time waiting for work is great, a 30 % energy conservation is possible by conducting concentrated production, and then completely turning OFF the power after the production. To calculate the effect of concentrated production, it is convenient to use a table like the one shown below.

**Table 3.3 Effect after Improvement by Concentrated Production for Each Unit Item**

Item	Unit	Before improvement	After improvement by centralized production	Effect
(1) Production volume per month	piece	150	150	
(2) Machining time for a work piece (t)	min	30	30	
(3) Average waiting time ( $\alpha t$ )	min	31	2	29
(4) Energy consumption during machining ( $Q_n$ )	kWh	12	12	
(5) Energy consumption during waiting for a work piece ( $Q_w$ )	kWh	4	0.2	-3.8
(6) Time during which equipment is ON	min	9,500	4,800	4,700
(7) Power consumption per month (7) = (1) × ((4) + (5))	kWh/m	2,400	1,830	-570
(8) No. of machines in a line	unit	20	20	
(9) Power consumption for the entire line per year (9) = (7) × (8) × 12	kWh/y	576,000	439,200	-136,800
(10) Electricity unit price	PLN/kWh	0.16	0.16	
(11) Electric charge per year	PLN/y	92,160	70,202	-21,958

2) **Maintaining Facility Function (Reduction of time loss due to malfunctions)**

If a facility malfunctions, not only that facility, but the facilities before and after it, or even the entire line, could stop, wasting the fixed amount of energy during that time. Preventing malfunctions by thoroughly maintaining facilities not only cuts energy costs, but is an important activity in terms of preventing all kinds of waste such as waste in labor cost. In machining processes, it is necessary to implement a facility maintenance program that restricts the proportion of idle time (idle ratio) due to facility malfunction to under a few %.

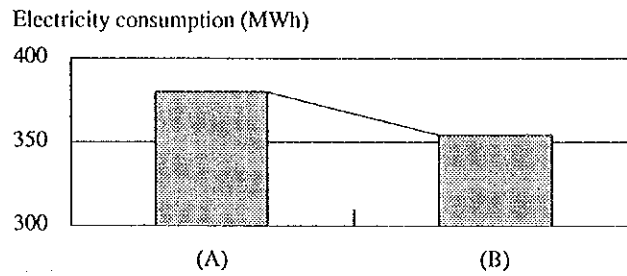
In Table 3.4 and Figure 3.9, the difference in energy consumption due to facility malfunction related idleness at a part fabrication factory is shown.

**Table 3.4 Relationship between Rate of Downtime due to Troubles and the Difference in Monthly Power Consumption**

	Troubles occur frequently	Troubles occur less frequently	Trouble reduction effect
Rate of downtime due to troubles	20 %	5 %	
Power consumption per month	380 MWh	354 MWh	-26 MWh



**Figure 3.9 Relationship between Rate of Downtime due to Troubles and Difference in Monthly Power Consumption**



- 3) Stabilizing Quality of Facilities (Reducing product failures by reducing facility malfunctions ... improved throughput)

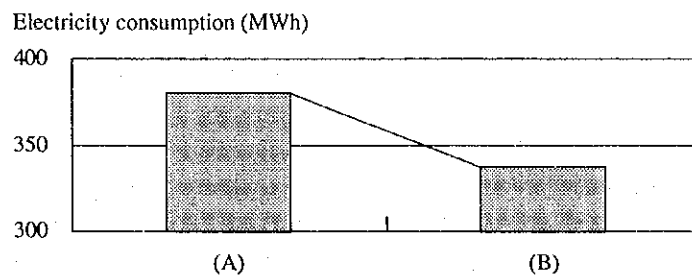
When a product failure occurs due to facility trouble, all the energy that was consumed in the previous processes go to waste. Not only that, but a great amount of waste is generated, such as material cost and labor cost incurred for rebuilding that unit. Determining the cost of loss for 1 incident of product failure, and billing the sector that generated that failure, is an effective way to instill awareness for reducing failures.

In Table 3.5 and Figure 3.10, the difference in energy consumption due to the generation of product failure at a part fabrication factory is shown.

**Table 3.5 Relationship between Defective Product Rate and the Difference in Monthly Power Consumption**

	Many defective products occur	Few defective products occur	Effect of defective product reduction
Defective product rate	20 %	5 %	
Monthly power consumption	380 MWh	337 MWh	-43 MWh

**Figure 3.10 Relationship between Defective Product Rate and the Difference in Monthly Power Consumption**



4) Adjusting Production between Processes (Waste free energy distribution)

If many processes run simultaneously, substantial amounts of energy such as electricity, compressed air, and water, etc. become necessary, and the capacity of energy supplying facilities becomes great too.

At the same time, if the production levels fall simultaneously, only small amounts of energy will be supplied from large energy supplying facilities, resulting in reduced efficiency.

Additionally, signing on to a higher basic fee in the contract with the power company just to meet demands for a few instances will increase energy cost. It is therefore desirable to plan production in a way that energy consumption is as even as possible. To do this, the energy management section should be involved in production coordination for the entire factory in order to reduce energy cost.

5) Synchronizing Production

Synchronizing production means to "produce what is needed when needed only in the needed amount," and by doing so, excess inventory can be reduced.

The presence of excess inventory requires space, which incurs facility maintenance costs such as illumination, and air conditioning, etc. Moreover, there are many undesirable aspects when a product failure occurs in concentrated production, such as the presence of a large quantity of continuous failures by the time it is discovered in the next process. Thus there are many advantages to synchronizing production.

6) Selecting Inexpensive Energy

Electric power is priced differently for different time periods, and the price difference is quite substantial. The cheapest pricing for power should be selected, especially for facilities that consume large amounts of electricity, since the power bill for the same amount of energy consumed can be 30 to 50 % less. Moreover, such measure can contribute to the power supplier's ability to provide a stable supply as the burden on the supplier will become more even.

7) Standardization of Work: Reduction of product failure due to human error

If the speed and accuracy of work differs from one worker to another, the amount of energy consumed will differ too. Setting optimal work methods, and standardizing, and thus producing at the fastest speed, with the greatest accuracy, is by itself improving the energy intensity. In order to raise workers' awareness, and promote failure reductions with vigor, it is also important to adopt a system that makes the output and failure rate of individual workers evident.

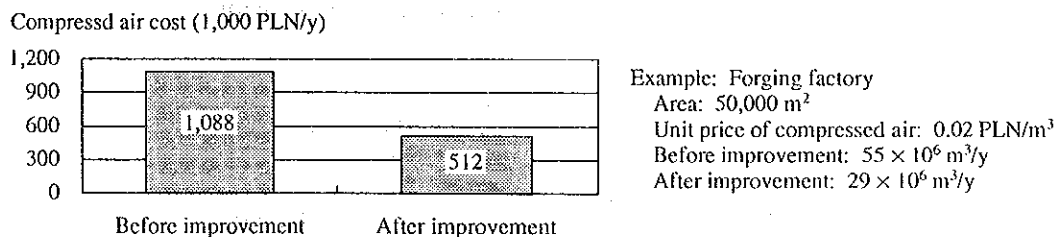
b. Energy Conservation through Equipment Improvement and Other Measures

1) Reducing Leakage of Compressed Air

One of the most representative forms of energy loss in machining is leakage of compressed air. While many of them are caused by leakage from connecting parts such as hose joints, because each leakage is not so large individually, they are often ignored. Yet, because such leakage of compressed air occurs even during production, they accumulate into a substantial cost over the course of a year. Therefore checks and prevention of leakage are very important as basic energy conservation activities. The amount of energy loss due to leakage can be grasped, along with the amount of compressed air leakage itself, by finding out the amount of power consumed by the compressor when the facility is not used, and by measuring the pressure reduction speed when the main valve is shut. The easiest way to find out is to leave the main valve of the header for each compressed air line open on a holiday when the facility is not running, and to measure the actual amount of power consumed by the compressor when production is not taking place. Since the result of this measurement is the amount that is always leaking while production is taking place on a weekday, it can be grasped as the amount of energy loss that is generated continuously over 24 hours.

The effect of streamlining a large amount of compressed air leakage that was left unattended at an actual factory is shown in Figure 3.11.

**Figure 3.11 Energy Consumption Effect of Air Leakage Measures**



(Example) Forging factory  
 Area : 50,000 m<sup>2</sup>  
 Unit price of compressed air: 0.02 PLN/m<sup>3</sup>  
 Before correction : 55 × 10<sup>6</sup> m<sup>3</sup>/y  
 After correction : 29 × 10<sup>6</sup> m<sup>3</sup>/y

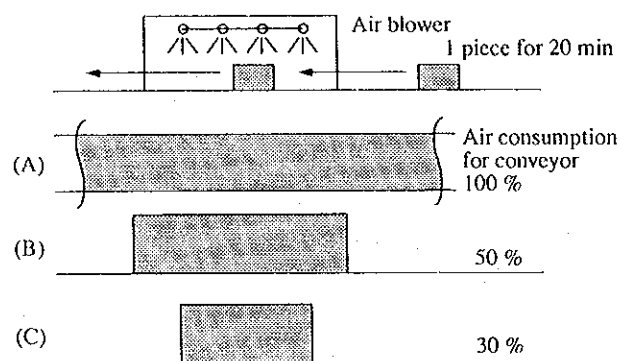
## 2) Improving air blow efficiency

Removing residual water after cleaning consumes a lot of compressed air. Yet, the amount of compressed air that actually contributed to the removal of water is surprisingly small, with more than half of it just being released into the atmosphere. There are the following ways to reduce this compressed air that gets released without accomplishing anything, that will enable a 30 to 50 % reduction in compressed air.

### ① One Cycle Blow

It is important to blow at only the location that needs the air blow, and to stop the air once the job is done. If the work is fixed, only the necessary location should be blown accurately by a robot. If the work is mobile, it is important to accurately detect the work, and to set the timing of the blow accurately. A cycle in which the blow starts when the work enters the air blow device, and stops when it exits, releases a meaningless amount of air inside the device, and thus still has room for improvement. To accurately attain the timing at which the location that needs to be blown passes the nozzle tip is what makes the difference. Since the air blow time for a part is generally about 5 to 10 minutes, except for cases where several hundred parts are fabricated in 1 day, the waiting time is longer so that a reduction of 50 % or more in compressed air consumption can be achieved at facilities implementing continuous blows. The example in Figure 3.12 compares the amount of compressed air consumed by one cycle blows.

Figure 3.12 Air Consumption during Air Blowing



(Condition)

Production quantity : 1 per 20 minutes

Time passing through air blow device: 10 minutes

Net effective blow time : 6 minutes

(A) When air is blown regardless of presence or absence of work

(B) Blown only when passing device

(C) Blown only when passing under nozzle

② Adoption of Energy Conserving Nozzle

Using energy-saving type nozzles with small diameters and good aiming performance is a good way to achieve strong air blows that concentrate only on the location that needs water removed. (Figure 3.13) Since the amount of compressed air blown is proportional to the second power of nozzle diameter, it is effective to blow with the smallest hole diameter, and smallest number of nozzles, possible.

Figure 3.13 Shape of an Air Blow Nozzle

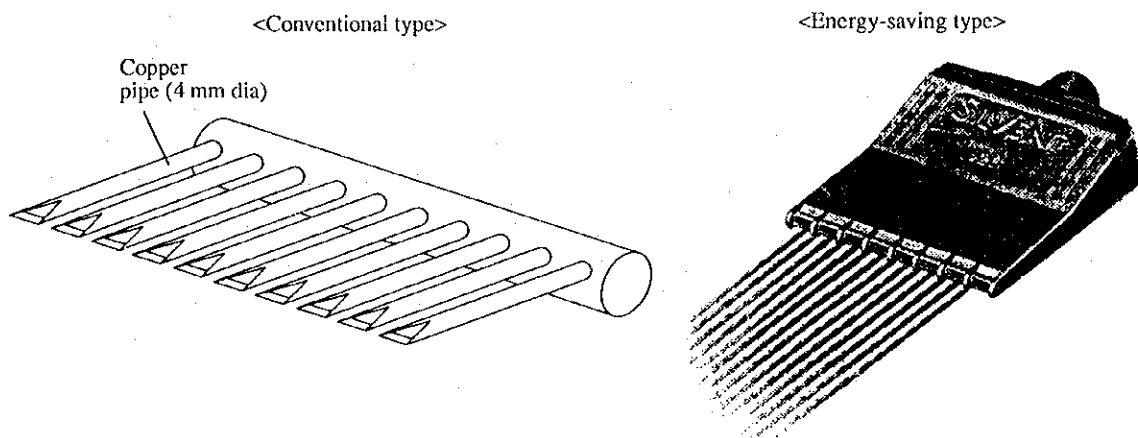
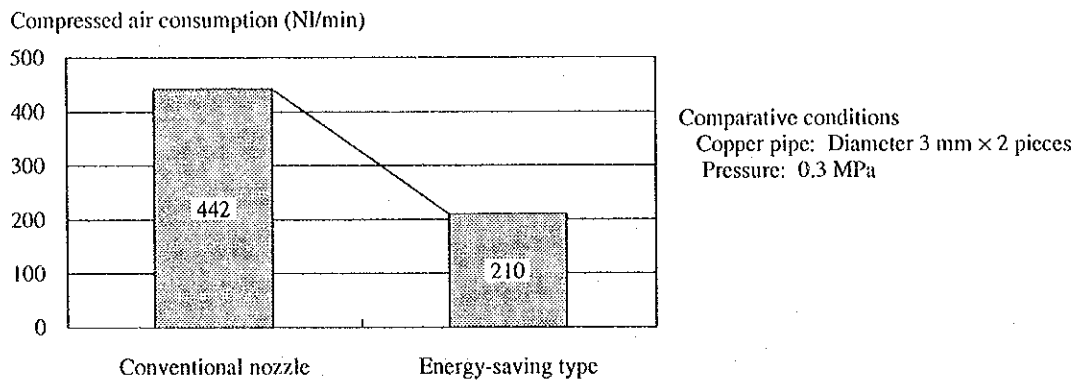


Figure 3.14 is a comparison of air consumption, between a conventional copper pipe nozzle and the latest energy conserving type nozzle, in which not only air consumption is over 50 % less, but the noise level was reduced as well.

**Figure 3.14 Comparison of Compressed Air Consumption between a Conventional Copper Nozzle and an Energy-saving Nozzle**



(Conditions of comparison)  
 Copper pipe diameter: 3 mm x 2 units  
 Pressure : 0.3 MPa

### 3) Reducing Facility Failures

As mentioned before, facility failures often cause processes that precede and follow to stop, creating great energy losses. Thoroughly analyzing the causes of failures for facilities prone to failure, and taking corrective measures to remedy them, are energy conservation activities that have great effects.

Although such improvements cost much, as mentioned in (4)-a.-2 where energy conservation through maintaining facility functions was explained, large benefits can be expected from such measures. Besides, reductions in labor cost and repair cost can also be achieved.

### 4) Optimizing Capacity and Volume of Auxiliary Facilities

Auxiliary facilities of fabrication facilities include hydraulic pumps, coolant pumps, dust collectors, and chip conveyors, and the amount of energy they consume while fabricating and waiting combined is nearly 70 % of the total. Upon selecting these auxiliary facilities, a careful study on necessary volumes should be made, and along with the use of power saving circuits explained in the next section, it is important to restrict the amount of energy consumed by auxiliary facilities as much as possible. A difference in energy consumption between 30 and 50 % generates between a facility with no energy conservation scheme and one for which energy conservation is implemented.

5) Implementing Controls that are Compatible with Loads on Auxiliary Facilities

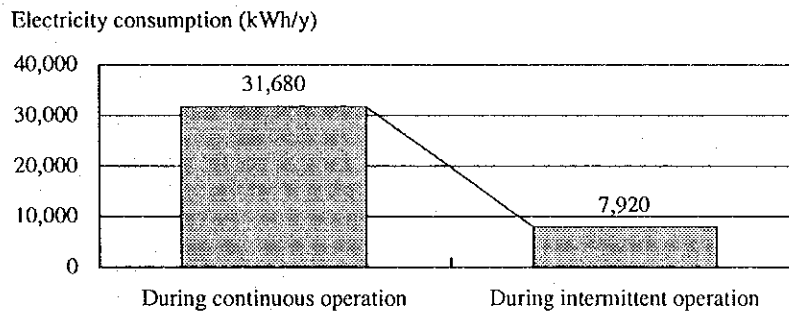
Even if the volume of an auxiliary facility is optimized, if it is run when it does not need to be, there will still be energy consumed that goes to waste.

There is a method of control that best suits each case, and principal ones are shown below.

Auxiliary Facility Name	Energy Conservation Control Method
Chip conveyor	Either run when needed depending on the amount of grinding burrs created, or control the number of revolutions.
Hydraulic pump	Stop hydraulic pumps when waiting. Or, install a small scale hydraulic pump, and switch over to it to maintain pressure.
Coolant pump	Link it to the rotation of the main shaft so that the pump goes ON only while cutting is taking place.
Dust collector	Link it to the rotation of the main shaft so that the dust collector goes ON only while cutting is taking place.

The effect introduced in Figure 3.15 is from an example in which a 5.5kW chip conveyor, which was operating 24 hours continuously, was reset so that it goes ON for 5 minutes and OFF for 10 minutes in a way matched to the amount of debris generated.

**Figure 3.15 Comparison of Power Consumption for Chip Conveyor**



6) Managing Energy Consumption Rates of Facilities Individually to Raise Energy Conservation Awareness, and Achieve Positive Results.

To achieve energy conservation improvements with a facility, it is important to begin with grasping the amount of wasted energy consumption at that facility. Additionally, devices like watt-hour meters should be installed to principal facilities that consume a lot of energy in order to learn the effects of an improvement.

Also, the amount of energy required to produce 1 unit of a representative product should be known.

Some specific management methods are introduced here.

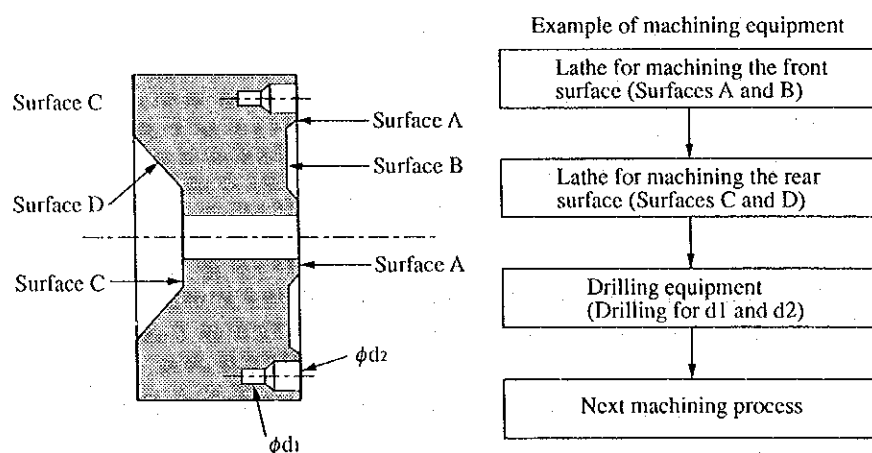
- ① When introducing a new facility, incorporate into the facility's specification a requirement to install kWh power meters to facilities that have power capacities greater than 50kVA.
- ② When accepting a new facility, request the submission of the amount of electricity consumed to fabricate 1 unit of a representative product.
- ③ Install status lamps so that workers can know whether a facility is fabricating or in waiting, so that unnecessary waiting time can be avoided.

c. Energy Conservation through Process Improvement

Rather than tinkering with a facility, by being innovative with the material or fabricating method, the number of processes can be reduced. While reducing the amount of energy consumed by a facility is one way to go, by reducing the size of production space, reduction in energy for heating and air conditioning becomes possible, and a more effective use of buildings and land becomes possible, resulting in beneficial effects.

Hereafter, details of such an improvement will be introduced using the example of a part fabrication shown in Figure 3.16.

**Figure 3.16 Example of Machining Parts and Machining Process (Flywheel)**





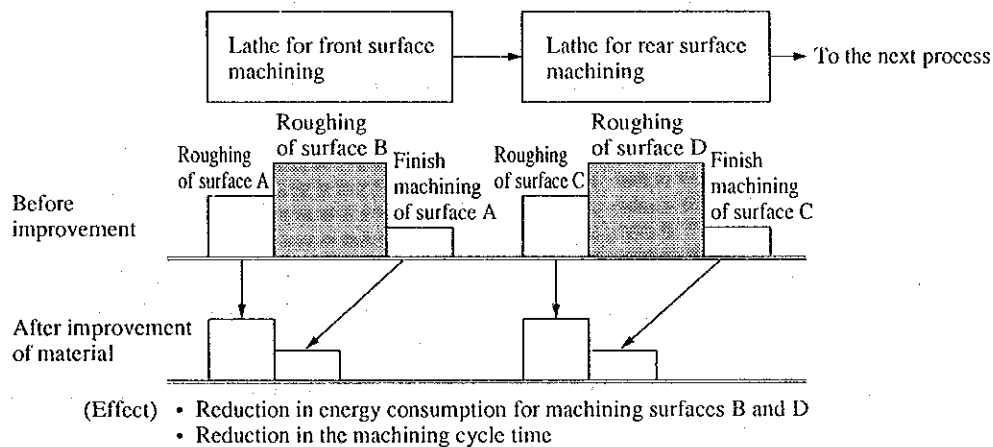
1) Reducing the Number of Processes by Improving the Material

By taking measures to improve the material's pre-fabrication state, such as improving the quality of a material, the number of processes can be reduced, and energy consumption can be reduced by that much.

For example, while the flywheel in Figure 3.16 was conventionally fabricated from face B to D, since the fabrication becomes unnecessary if the casting surface is clean, the fabrication process can be eliminated, and the number of facilities can also be reduced.

Additionally, by achieving a steady level of raw material quality, and thus reducing the size of grinding area, even the remaining fabrication requirements can be reduced, resulting in energy conservation as processes and cycle time are reduced.

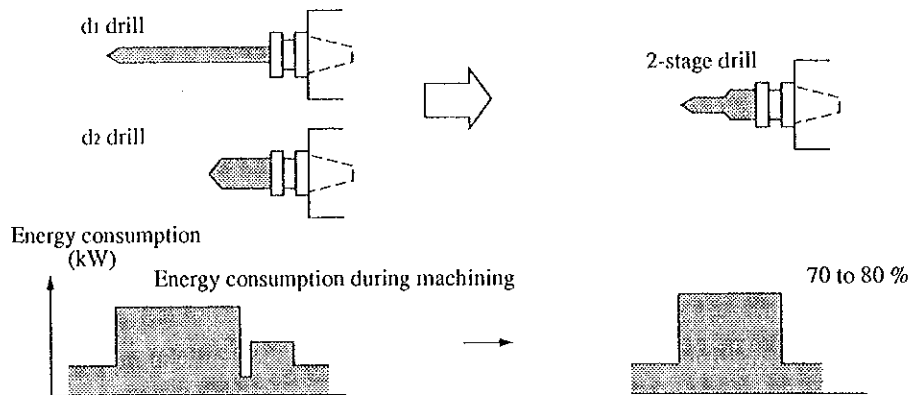
**Figure 3.17 Energy Conservation through Reduction of Processes by Material Improvement**



2) Reducing Processes by Streamlining Fabrication Methods

Even for areas that need fabrication, if it can be completed in 1 try instead of 2, only half the amount of energy will be consumed. For example, in Figure 3.16, D was fabricated with a d1 diameter drill, and then drilled with a d2 diameter drill. By improving the tool to one with a 2-step diameter arrangement, as shown in Figure 3.18, 1 drill can perform both tasks, and thus only 1 fabrication will do the job.

**Figure 3.18 Reduction of Processes by Improvement of Tools**

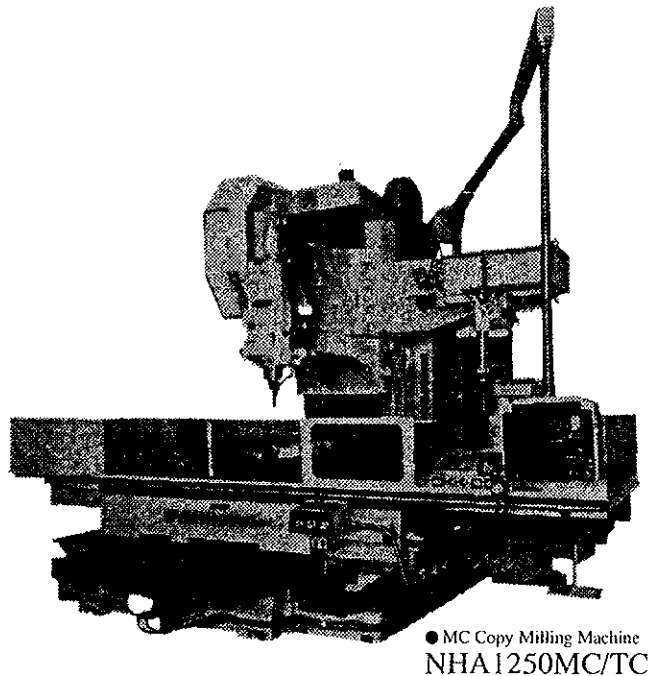


Such streamlining measures are numerous as shown below, and therefore optimal fabrication methods should be studied, while assuring quality, through discussions with production engineers responsible for process designs.

- ① Clarify the minimum level of quality required, and do not perform finishes that are better than what is needed.  
(Reduce the number of fabrication processes required up to the last finish)
  - ② Improve the tool to achieve a larger grinding area in one try.
  - ③ Improve tools and work methods so that fabrications worth several processes can be performed simultaneously (multi-axis hole drilling, etc.)
- 3) Reducing the Number of Facilities by Introducing Multi-process Facilities

Recently, facilities that can carry out several processes, from drilling to machining, in 1 unit are being developed (Figure 3.19). Deploying such innovations will not only save energy, but will also have the following benefits. Their effects are especially great where the production quantity is small.

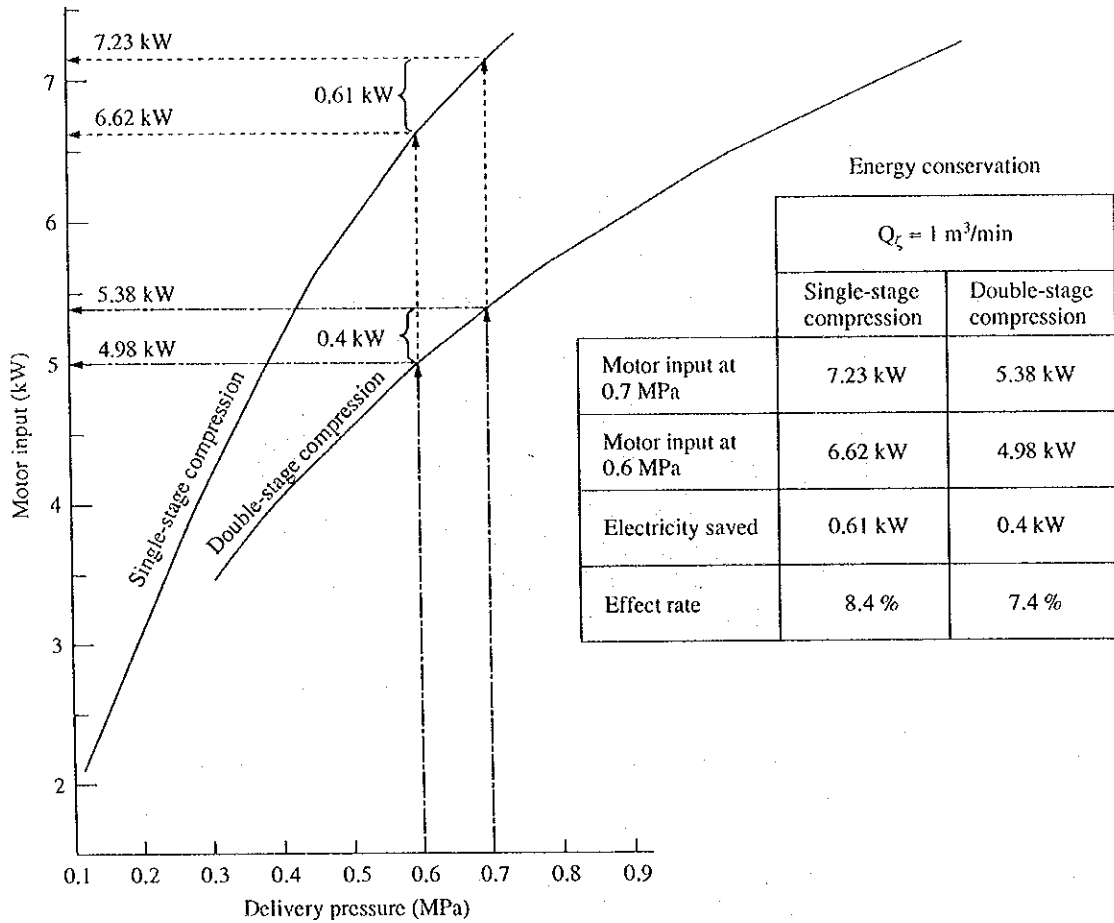
Figure 3.19 Combined Machine Tool



- ① The number of facility units, and the amount of energy consumed, can be reduced.
  - ② The number of facility units, and the amount of space devoted to production, can be reduced.
  - ③ The operation rate of each facility increases.
  - ④ Unmanned operations over long periods of time become possible, and heating costs can be reduced. It also leads to savings in man power.
  - ⑤ Quality control becomes easier.
- 4) Energy Conservation Through Resetting Compressed Air Pressure

Lowering a factory's pressure setting for compressed air by 0.1MPa reduces the amount of electricity that compressors consume by 7 to 8 % (Figure 3.20). Thus, it is desirable to use compressed air at the lowest pressure level that meets requirements. Yet, several problems can be anticipated if the pressure of compressed air is reduced, such as malfunctions of air cylinders and reduced torque levels in pneumatic screw fasteners. Discussions should be held with the sectors that use compressed air, and it is important to lower the pressure in small increments of about 0.01MPa at a time, making sure no problem arises.

Figure 3.20 Energy Required for Generating Compressed Air of  $Q = 1 \text{ m}^3/\text{min}$



5) Energy Conservation through the "Elimination of Processes" by Improving Quality

Among production processes, there are some that are not really necessary, but are implemented in order to maintain "quality." There may be more cleaning machines than needed during the course of a process, or an "intermediate fabrication" may be performed between rough fabrication and finish fabrication.

Many of these can be eliminated if quality assurance can be made with certainty in the earlier processes, thus, improving quality contributes greatly to energy conservation as well.

### 3.2.3 Assembly (Engine assembly and body assembly), Painting and Drying Processes

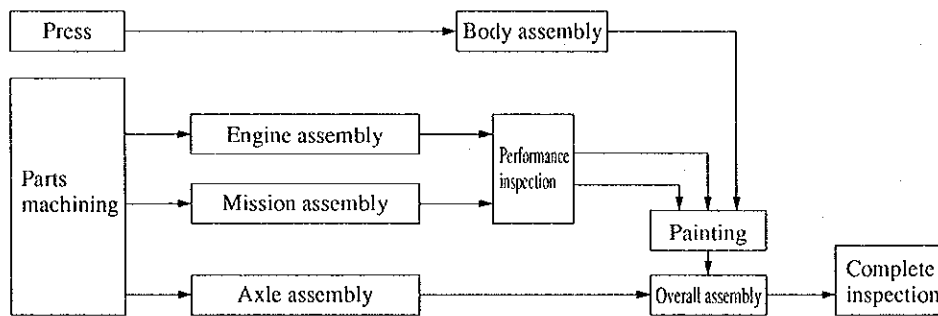
#### (1) Example of a Typical Process

Assembling consists of component assembly, such as those for engines and transmissions, and body assembly, which completes the vehicle's body, or a main line and sub assembly lines for different units, and energy consuming facilities consist of individual facilities and the transfer lines that link them.

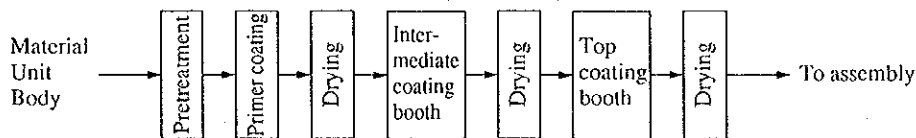
Additionally, the coating process consists of a number of large scale general purpose facilities such as "drying furnaces" and "painting booths" that are linked together.

An example of a representative process for each of these is shown in Figure 3.21 and Figure 3.22.

**Figure 3.21 Overview of the Assembly Process**



**Figure 3.22 Overview of the Painting Process**

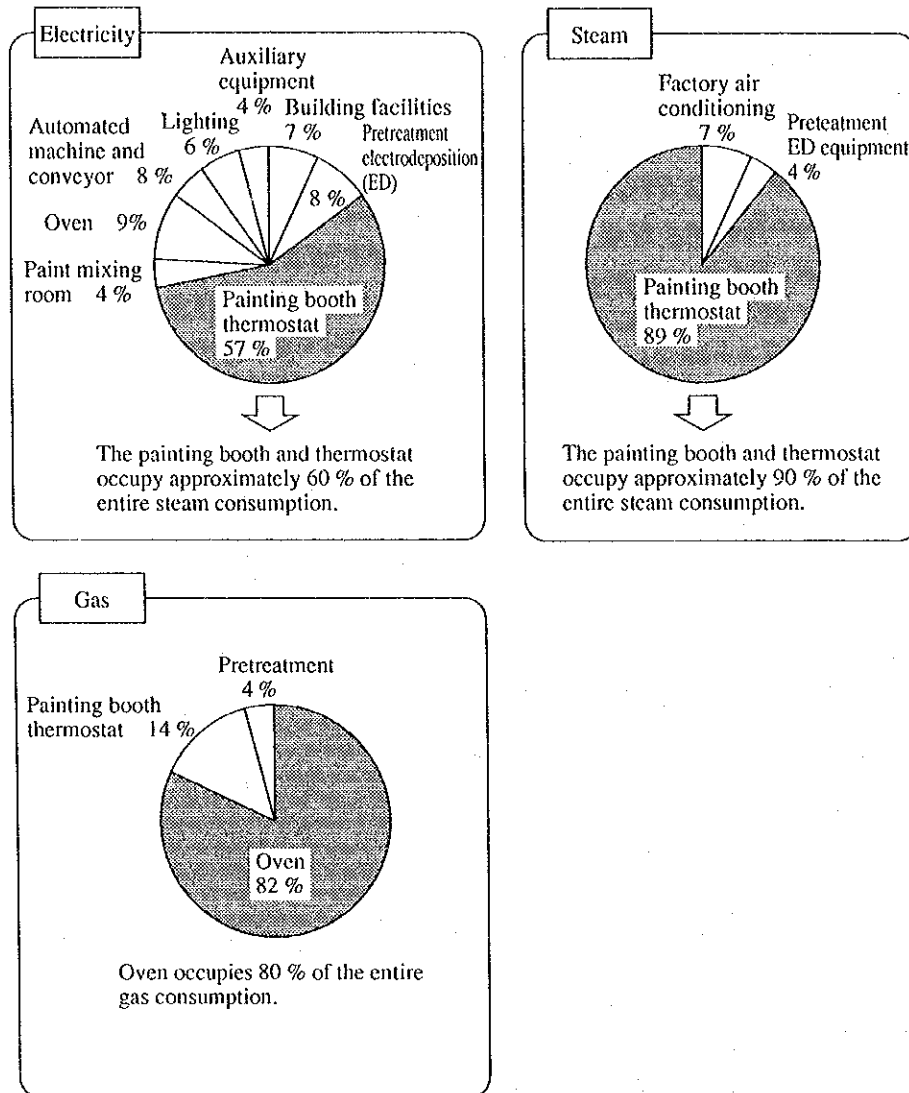


#### (2) Energy Consumption Characteristics

Almost all of the energy consumed by the assembly process is electricity, and most of it is for welding and other facility drives. While the amount of electricity for welding is more or less proportional to production quantity, most of the power for facility drive purposes, such as air conditioning, lighting, ventilation, cooling water pumps, is consumed even during non-operating times, and thus, contain much room for improvement.

On the other hand, electricity, steam (hot water), and gas are the principal forms of energy consumption in the coating process. Figure 3.23 shows where each form of energy is being used.

**Figure 3.23 Percentages of Energy Consumption by Equipment  
(Example of Company A in the cold region)**



Source: "Energy Minimizing Manual in Toyota", The Energy Conservation Center, Japan

(3) Approach to Energy Consumption Rate

Generally, the energy intensity for assembling and coating processes for vehicles like trucks and tractors is managed in terms of the "consumption rate per 1 product unit." While electric consumption by most production facilities is easy to measure since most of them are relatively large scale general purpose facilities, some are small scale and spread out, such as air conditioning, ventilation, and lighting, etc. Although it is not easy to grasp the real amount of energy consumption for the entire factory, it is necessary to grasp the energy intensity per unit of product based on the amount of energy consumed by each building that houses the assembly and coating processes.

(4) Energy Management Items and Energy Conservation Items

a. Energy Management Items and Energy Conservation Items in Management and Operation Aspects

1) Energy Conservation through Completely Stopping Facilities during Non-Operating Times

As mentioned earlier, energy consumption in assembly and coating processes is characterized by the fact that they include “many facilities that make up the fixed portion of consumption that takes place even during non-operating times.”

In other words, distinguishing operating and non-operating times, and completely stopping these facilities during non-operating times, results in the greatest amount of energy conservation.

The ideal way to do this is to reduce the length of non-operating time by implementing concentrated production, and as soon as the necessary production quantity is obtained, to completely turn OFF the facilities including air conditioning, lighting, and ventilation. Since this procedure is the same as in (4)-a.-1) of the previous section, 3.3.2, see the previous section for reference.

2) Training and Education in Optimal Running of Facilities

Workers are focused on their work without having a sense of “waste” even if elements of their given environment, or the temperature and brightness, are excessive.

It is customary for air conditioning and lighting to operate wherever a facility is installed. However, it is important to educate workers to promote energy conservation activities by “instilling an awareness in energy conservation” as described below.

- ① Adjust lighting and air conditioning to optimal levels according to the temperature and brightness of the day.
- ② Start air conditioning, ventilation, lighting, and pumps right before production starts, and stop them at once when production ends.
- ③ Make it habitual to turn off facilities and equipment, such as lights, that are present for the worker whenever he or she leaves that area.
- ④ Since a leakage of compressed air will not only lead to energy loss, but also affect quality as it causes the torque level in screw fastening processes to become unstable, workers should be educated never to leave it unattended.

- ⑤ Workers should be made aware that partial operations during off hours and holidays generate a lot of energy loss in air conditioning, and lighting, etc., and such partial operations should be minimized.

b. Energy Conservation through Equipment Improvement

1) Minimize Gaps at Inlets and Outlets of Drying Furnaces

As loss in the form of “radiation heat” at inlets and outlets of drying furnaces is great, energy conservation can be achieved by making these gaps as small as possible.

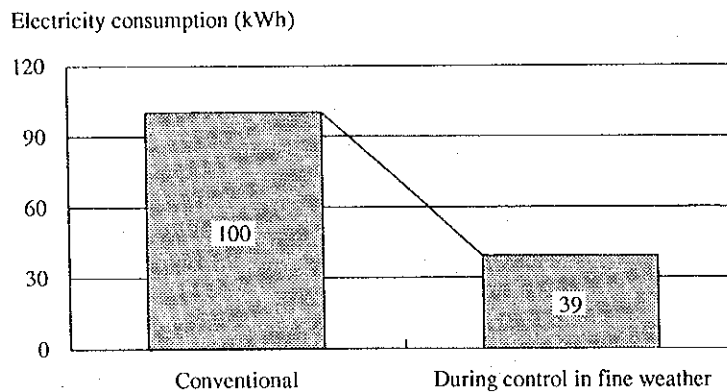
Specifically, there are the following methods.

- ① Make the gap as small as possible by designing its configuration to match that of the work.
- ② Install an automatic door that opens only when a work passes through.

2) Automatic Control of Drying Air Blow Facilities (Control according to weather)

Although the air blow process for preventing unevenness in wax coatings on vehicles is usually operated in a constant setting, the amount of blow really necessary differs between sunny days and rainy days. There are cases in which energy conservation of 60 % had been achieved by finding the amount of blow necessary to dry when it is “sunny,” “cloudy,” while verifying quality, and “raining,” and controlling the number of revolutions accordingly (Figure 3.24).

**Figure 3.24 Electricity Consumption for Air Blow Motor for Drying**





3) Reducing Air Blows

As with the measures taken in fabrication processes, energy conservation can be achieved in air blows that follow cleaning in assembly processes, and air blows during drying processes, by reducing the amount of time set for air blows, and minimizing the blows by changing the start blow detection position.

On this matter, refer to (4)-b.-2) in the previous section, 3.2.2.

4) Reducing the Number of Facilities by Increasing the Range of a Facility's Use

In pre-assembly cleaning, such as for engines, transmissions, and other components, different cleaning machines are often installed depending on the size and configuration of the work. Yet, they can sometimes be covered by the same cleaning machine just by modifying the conveyor or nozzle of the facility, which may lead to energy conservation through reduction in the number of facilities. Moreover, secondary effects such as reduced facility space, and increased facility operation rate, can also be great.

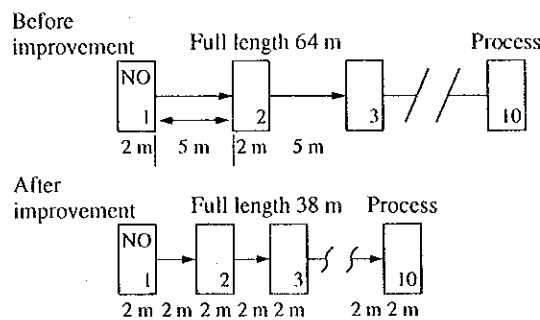
c. Energy Conservation through Process Improvement

1) Reducing Distances Between Processes

Assembly and coating are generally processes that progress at constant speeds or in constant amounts of time by means of conveyors or other such device. Lengthening the distance between processes and facilities only leads to waste in energy consumption, since it increases the amount of space subject to air conditioning, lighting, and ventilation, etc. While making sure that "ease of work," "safety," and "quality" are assured, the distance between processes in such assembly lines should be minimized to achieve energy conservation.

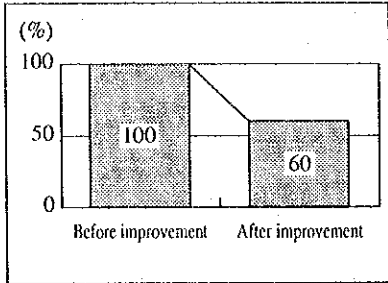
Figure 3.25 and Figure 3.26 are examples of the effects attained by shortening the distance between 10 processes in an assembly line from 5m to 2m.

**Figure 3.25 Example of Rearrangement for Reduction of Assembly Process Interval**

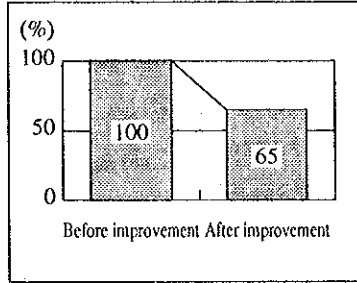


**Figure 3.26 Example of Improvement Effect of Rearrangement for Reduction of Assembly Process Interval**

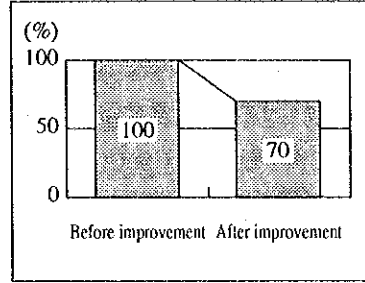
(1) Area effect



(2) Heating energy consumption



(3) Lighting energy consumption



### 3.3 Energy Conservation Items Common throughout the Machinery Industry

#### (1) Energy Management Items and Energy Conservation Items in Management and Operation Aspects

##### a. Systematic Energy Conservation Activities

Compared to steel and chemical industries, the machinery industry, which has a lot of workers who are directly involved in production processes, is characterized by the fact that the “awareness and skills of workers” can make a difference in energy consumption. In other words, to use energy effectively, “systematic energy conservation activities” are required, and their results are greater than those obtained from investing in improvements of individual facilities and processes.

These activities that are generally called “energy conservation activities involving everyone,” these activities specifically carry out the following kinds of activities, and support facility improvements and process improvements with the aim of raising awareness in energy conservation and achieving energy conservation.

##### Items Implemented by Energy Conservation Teams

- 1) An Energy Manager is assigned at both user and supplier sections, and they are made responsible for the efficient use of energy.
- 2) “Indices” are set to implement energy management, and monthly results are tabulated and made public.
- 3) Energy consumption patrols are carried out, to point out wastes and give instructions to make improvements.
- 4) Workers are trained and educated to use energy efficiently.

Additionally, the following focus points are introduced to facilitate these activities.

- 1) “Don’t” (Example : Fabricate faces that do not require finishes)
- 2) “Reduce” (Example : Flow rate of cooling water, Number of lighting equipment)
- 3) “Lower” (Example : Pressure setting of factory’s compressed air, Temperature setting for drying)
- 4) “Stop” (Example : Lighting on sunny days, Supply of compressed air on holidays)
- 5) “Switch” (Example : Change from electricity to gas, Material of work, Insulation material of furnace)
- 6) “Fix” (Example : Leakage of compressed air)

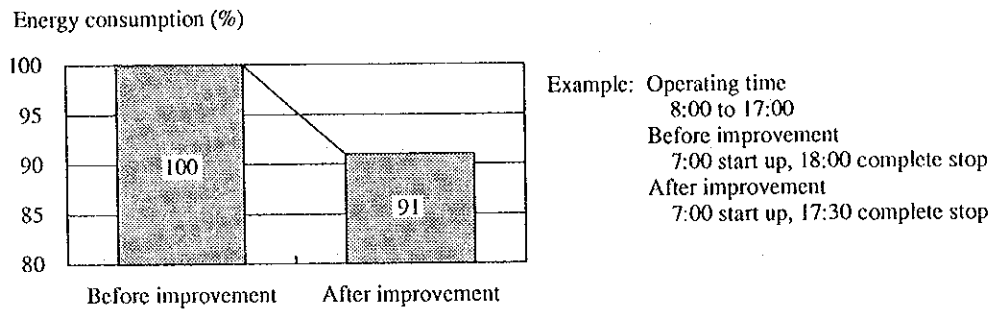
#### (2) Energy Conservation through Streamlining Facilities

##### a. Optimizing Startup Time and Stop Time of Individual Facilities

The startup of pumps, compressors, air conditioning, lighting, and ventilation, etc., at the beginning of the week are often set earlier than necessary.

Installing “calendered timers” to these so that they can be managed to start just before operation will result in energy conservation. Figure 3.27 shows an example in which the startup and stop times were squeezed by 30 minutes each in a 1-shift operation, and an approximately 9 % energy conservation effect was achieved.

**Figure 3.27 Energy Conservation by Improvement of Start-up and Halt Time**



(Example)

Operating hours : 8:00 to 17:00

Conventionally : 7:00 startup, 18:00 complete stop

After improvement: 7:30 startup, 17:30 complete stop

## 2) Energy Conservation at Waste Water Processing Facility

The amount of energy consumed by “waste water processing facilities” that process waste water from coating booths and other such places is substantial in the machinery industry. Especially the amount of air consumed by the aeration tank for air blows and compressed air is great. Quantity of air consumption by these can be reduced by about 20 to 40 % by improving the stirring method and improving the structure of dispersion pipes.

Methods of improving should be studied paying close attention to the latest waste water processing technology.

## 3) Optimal Control of Compressor (Optimal type and limiting the number of units)

In the machinery industry, about 10 to 15 % of the electricity is consumed to power the compressor for making compressed air.

While there are “reciprocating,” “screw,” and “turbo” type compressors, the screw type and turbo type are currently the mainstream.

These 2 types have the following features, and by using them in combinations that are compatible to load fluctuations, operations can be carried out with efficient energy consumption.

① Screw type

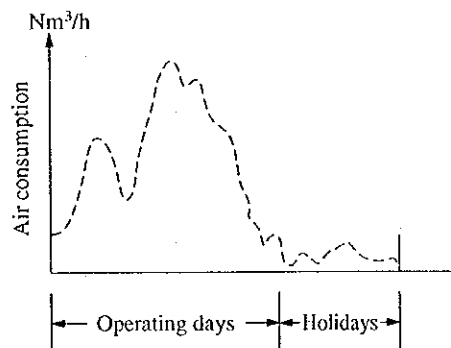
Since the amount of electricity consumed by the motor goes down when air consumption drops, this type is suited where fluctuation in loads is great.

② Turbo type

While there is a cost advantage in the large capacity range compared to the screw type, and the noise level is also small, energy consumption is constant regardless of the amount of air consumed. Therefore it is not suited where quantity of air consumption fluctuates.

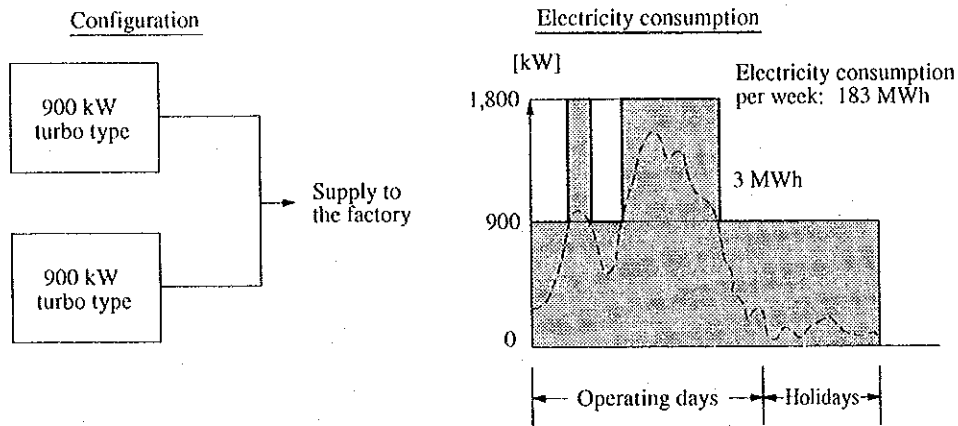
While Figure 3.28 depicts fluctuation in compressed air consumption at a production factory, and Figure 3.29 shows an example of comparisons in electricity consumption between different compressor combinations, if the optimal combination is used, and the number of units is limited, energy conservation of about 19 % can be achieved.

**Figure 3.28 Fluctuation in Air Consumption in a Factory**

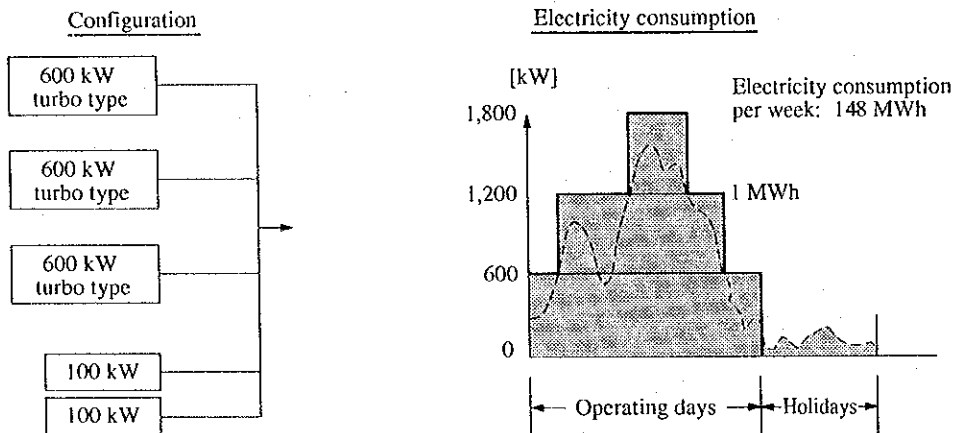


**Figure 3.29 Compressor Combination Patterns and Electricity Consumption**

(A) When two large compressors are used



(B) When three large turbo compressors and two small screw compressors are used



(3) Energy Conservation through Process Improvements

a. Appropriate settings

In production processes, there are various "settings" for each of its facilities. While these settings differ depending on facility, type of work, and facility environment, etc., the items that need to be reviewed from an energy conservation standpoint are listed below.

Upon reviewing settings, it is important to make sure "quality," "safety," and "ease of work" are assured, and to implement the changes in small increments.

Energy conservation can be achieved by reviewing these settings.

- 1) Pressure of compressed air
- 2) Flow rate of air blows, and blow time
- 3) Temperature and flow rate of cooling water
- 4) Steam pressure
- 5) Cleaning fluid temperature
- 6) Cleaning shower quantity (size and number of nozzles)
- 7) Drying temperature and drying fan operating speed
- 8) Time of facility startup and stop
- 9) Temperature, humidity, and brightness of workplace
- 10) Temperature of heat treating furnace
- 11) Fabrication accuracy
- 12) Oil control and pressure of hydraulic pumps
- 13) Pressure, quantity, and time of coolant pumping
- 14) Gas quantity of other supply and exhaust fans

### 3.4 Level of Energy Consumption Rate in Japanese Machinery Industry

As mentioned at the beginning, manufacturers of trucks and tractors, who represent the machinery industry, have processes such as forging, casting, and heat treatment, etc, performed in-house or outsourced, depending on the particular technology and cost advantages they have. It is therefore difficult to grasp their energy use with the same yardstick, but taking this into consideration, the energy intensity for each process at a representative factory with competent energy management is introduced in Figure 3.30 as an example.

**Figure 3.30 Energy Intensity by Process in Middle-size Tractor Manufacturing in Japan (GJ/unit)**

