JICA-SMEDA

ENERGY EFFICIENCY MANAGEMENT PROJECT FOR INDUSTRIAL SECTOR IN PAKISTAN

ESCO MANUAL

December, 2016

Prepared by

Energy Efficiency Management Project, JICA

Content

Chapter 1 Energy audit for factories

1. Introduction

Energy audit for factories (hereinafter referred to as Factory) is to clarify the energy utilization situation in Factory firstly, improve energy utilization efficiency and reduce energy loss by strengthening energy management, remodeling the equipment and changing the process.

In order to grasp to the energy utilization situation in Factory, it is necessary to get the following data, such as the consumption amount of the fuel and the electricity, the temperature of materials be heated and the element of exhaust gas etc. And it is possible to be read and recorded by the measurement instrument in Factory. However, in some Factories, though the measurement instrument to measure the production and operation is installed, the measurement instrument concerning energy management is not installed fully. And in the energy audit, it is necessary to offer measuring data gained from Factory to the audit team and obtain all data from measurement instrument in the Factory. In the measurement period of Factory, it is necessary to obtain accurate measurements within a limited time, and it is very important to install measurement instruments and sensors, confirm and record the data, and confirm the reliability of the data.

This audit and measurement section includes mainly procedure of energy auditing of Factory, measurement technology for Factory, analysis technique of the data, method to conduct the audit report. It is expected that the engineer in Pakistan is able to promote the energy conservation by referring to this manual.

2. Procedure of energy audit

Figure 2.1 shows the general procedure of energy audit for Factories.

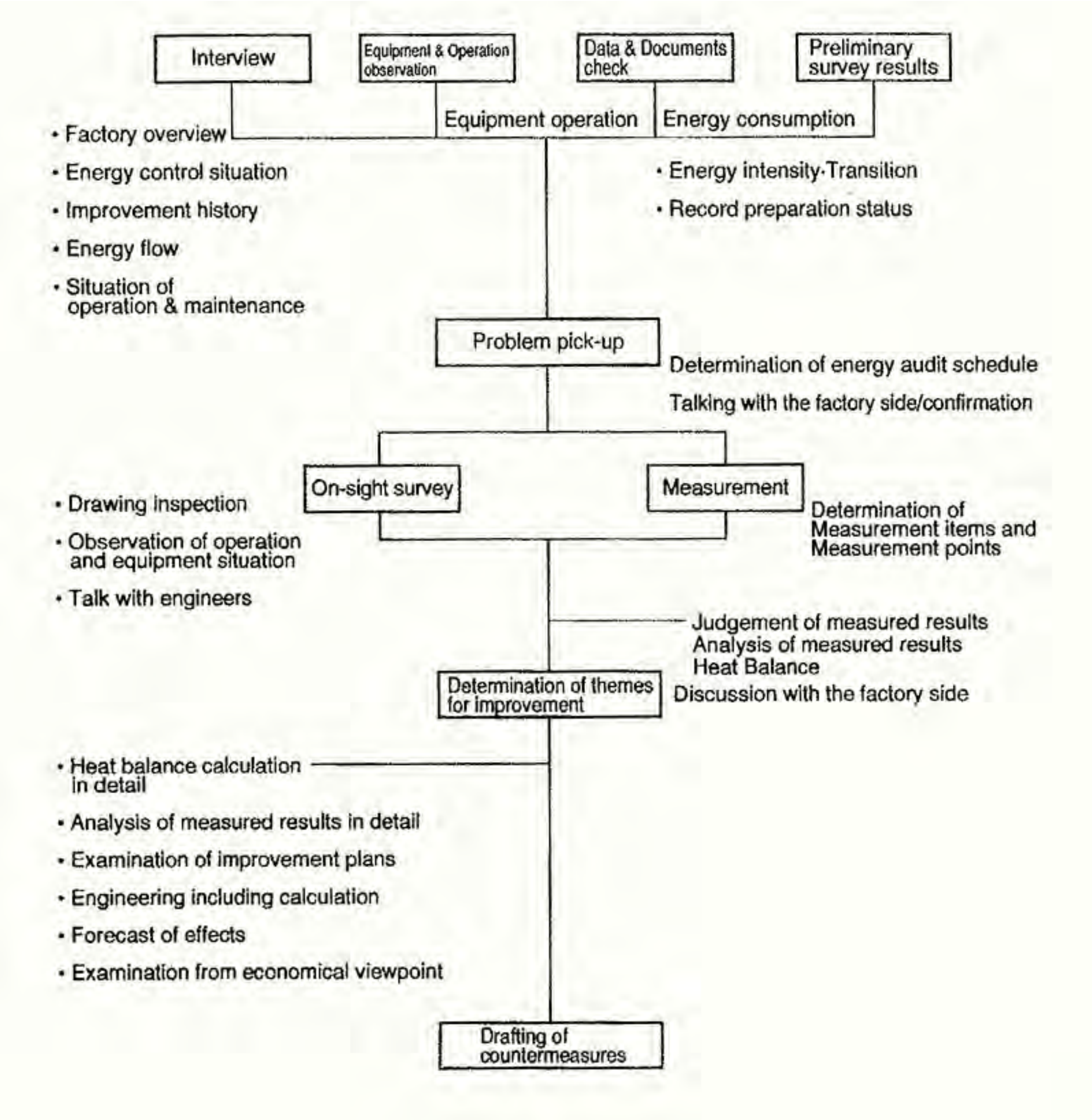


Figure 2.1 Flow chart of energy audit for Factory

2.1 Outline of Factory

The auditor must understand the matter described as follow; the scale, production, and energy consumption of Factory, etc. through questionnaire before energy audit (Table 2.1 2-2). At the same time, the auditor must grasp the manager's stance for energy conservation, current approach, problems and basic strategy of the Factory.

(1) Outline of the Factory

a. Outline of the Factory (Name, category, capital, sales, number of employees, organization, share in their filed and locations, etc.)

b. Production of the main product in past five years

c. Energy consumption in past five years

d. Manufacturing process charts of the main products

e. Capacity and operation situation of the main energy consumption equipment such as boilers

f. Energy flow in the factory

g. Chart of single-line diagram for electrical system and the situation of the power receiving equipment specifications

h. Layout of the factory

i. Problems of the factory and request of audit items

j. Past implemented items for energy conservation

k. Implementation plan for energy conservation in the future

l. Condition of the factory and the same industrial filed, as well as the obstruction factors of energy conservation

2. 2 Conduct the energy audit plan

(1) Preparation of checklist

The auditor lists up the items to be measured and investigated in the Factory firstly, so that the deficit of information should not occur; and should make the checklist based on the preliminary auditing sheet and the data be obtained from the Factory manager by prior interviewing. The checklist is distributed to the member of audit team (sector specialist of process, heat, electricity and measurement), and the policy and the work participation of the measurement and the audit are discussed at an internal meeting. Table 2.1 and Table

2.2 show the example of the energy audit check items of the factory and the commercial buildings

(2) A general inspection is done by hearing the explanation of the Factory. At the same time, the follwing contents should be grasped by the preliminary auditing sheet and the record data on the production and consumption of energy.

- Problems in equipment and operation
- Point which should be given priority in energy audit
- Technical level of factory
- Level of aging and maintenance of equipment
- Fluctuation of operation rate
- Energy intensity and its trend

(3) Determination of energy audit program

The auditor should revise and add the content in the checklist according to the above-mentioned, then accept some advice from the audit team and decide the following contents

- Measurement and auditing schedule
- Equipment or process which should be given priority in energy audit
- Measuring point, measuring items, measuring schedule
- Work participation

(4) The audit plan is explained to the Factory and the following cooperation is requested also from the Factory.

- Adjustment with production plan
- Preparation of the hole to insert measuring sensor and collect sample.
- Power supply preparation
- Attendance person's nomination of the Factory

2.3 The measurement and investigation are executed based on the audit plan.

- Selection and arrangement of measurement instruments

- Setting of measurement condition in the measuring instrument
- Check the proceeding of datacollection
- Investigation of detailed structure and dimention of equipments by equipment drawing or actual measurement
- Grasping problem by observation of operation
- Hearing from engineers
- Investigation on the necessary data to evaluate economic effect of improvement measures（energy prices, fund, and cost, etc.）

2.4 When the measurement result and the investigation data are collected, energy conservation measures in the future are analysed. And the measures are explained to the Factory and to be finalised.

2.5 Study of improvement measures

Based on the following information such as the data in the checklist, the measurement record form, the data logging memory (SD card, CDR, and USB memory, etc.) and the drawings, etc, the heat management and the electric management analyses such as the calculation of heat balance, heat transfer and the fluid conveying power are made. The energy conservation measures by the modification or the addition of equipment should be made. The most reasonable measures should be decided.

At the same time, the economic analysis for each improvement measures and the expected effect is estimated. Based on the above estimation results, the economy for each improvement measure is evaluated by using a common index and method. And their practicability and priority are clarified.

Moreover, the environmental influence with the improvement measure execution is examined and the point to be noted in execution should be shown.

3 Check list for energy audit

Table3.1 Check List for Energy conservation audit in Factory

(1) General management items	
1. Energy management system	• Development of organizational structure and human resource education • Goals for energy conservation and investment budget • Establishment of management standards • Implementation status of energy conservation • Annual plans, and medium-and long-term plans • PDCA management cycle
2.Implementation status of measurement and recording	• Status of installation of measuring equipment and its operation • Status of maintenance of measuring equipment and its inspection • Status of implementation of measurement and recording • Status of introduction of measurement and control systems
3. Management of energy consumption	• Status of recording of daily report • Daily consumption and daily load curve • Visualization • Monthly consumption • Comparison with previous fiscal year
4. Maintenance management of equipment	• Periodical inspection and daily check • Management of equipment performance • Leak repair (water, air, and steam) • Cleaning of filters and strainers • Management of system performance • Heat retention, heat insulation
5. Management of specific energy consumption	• Management of specific consumption (consumption/production) • Management of cost (cost/production) • Specific consumption and cost by process • Specific consumption and cost by product
6. Management related to the environment	• Status of implementation of global warming prevention measures • Status of implementation of CO_2 emission reduction measures
(2) Air conditioning and refrigerating facilities	
1. Operation management of air conditioning facilities	• Optimization of preset temperature and humidity • Control of outdoor air intake volume • Multiple Unit control of heat source equipment • Changing the setting of chilled water outlet temperature • Scheduled operations • Status of shielding of the outdoor air and ventilation • Shielding of radiation heat released from high-temperature equipment
2. Energy-saving measures for air conditioning system	• Heat insulation reinforcement of buildings and solar radiation shading • Utilization of outdoor air • Satratified air conditioning and reduction of air conditioning volume • Rotation speed control of conveying equipment (pumps and air blowers) • Recovery and utilization of waste heat, and heat pumps • Local cooling and local exhaust

3. Operation management of cooling facilities	• Motors for refrigerating equipment • Refrigerant inlet and outlet pressure • Water inlet and outlet temperature and pressure
4. Operation management of auxiliary cooling facilities	• Motors for cooling towers • Water quality control (electrical conductivity) • Pump operation control（water volume and pump head）
5. Cold storage and refrigerating facilities	• Management of entrance and exit • Heat retention management • Efficiency improvement
(3) Pumps, Fans and Compressors	
1. Operation management of pumps and fans	• Status of opening and closing of valves • Improvement of routes (pipe fittings and ducts) • Control of rotation speed and multiple unit control • Flow rate and operating pressure • Check of design margin
2. Operation management of compressors	• Review of types • Matching of capacity and types • Reduction of discharge pressure and terminal working pressure • Segmentation of high/low pressure lines • ventilating facilities and ambient air temperature • Review of pipe diameters and piping routes • Installation of air receivers
(4) Boilers, industrial furnaces , steam systems, heat exchangers, waste heat, and waste water	
1. Combustion control of furnaces	• Management of air ratio and exhaust gas • Burners, fuels, and ventilation systems • Combustion control devices
2. Operation and efficiency management	• Load factor and status of start-Up/ shutdown • Multiple unit control • Heat efficiency, heat balance, and heat distribution • Water quality management, and blow control
3. Heat insulation / retention and prevention of heat loss	• Temperature of exterior furnace surface and ducts • Heat insulating materials • Sealing of the opening and furnace pressure
4. Exhaust gas temperature control and waste heat recovery	• Exhaust gas temperature • Heat recovery (water feed and air preheat) • Exhaust gas circulation
5. Operation management of steam systems	• Dryness and carry-over • Preset steam pressure and temperature of facilities • Steam flowrate
6. Management of steam leak and heat retention	• Piping system and tanks • Load systems
7. Optimization of piping systems	• Routes and pipe size • Removal of unnecessary piping • Integration of multiple steam systems
8. Steam load leveling	• Installation of accumulators • Load-side measures
8. Steam pressure, and recovery and use of drain-off	• Drain-off recovery units and recovery systems • Use of flash steam • Steam trap management
9. Management of heat exchangers	• Appropriateness of the model • Appropriateness of usage and heat media • Maintenance condition (contamination and pressure loss) • Heat media and heated object temperature • Temperature efficiency

10. Reduction of waste heat and waste water	• Heat recovery from hot water • Stream lining of exhaust air ducts • Cyclical use of cooling water • Concentration management of impurities in water
12. Other	• Use of surplus gas
(5) Power receiving/ transforming facilities, electrical motors, lighting systems, and electrical heating equipment	
1. Management of power receiving/transforming facilities	• Adjustment of electrical voltage • Management of power factor • Transformer capacity • Demand factor and load adjustment • Shut off of Unnecessary transformers • Optimization of demand • Management of consumption • Utilization of night-time power • Control of power factor improvement • Demand control • Low-loss transformers • Multiple unit control of transformers
2. Management of electrical motors	• Equipment capacity, Voltage, and number of units • Rotation speed control • Cease of no-load running
3. Management of lighting systems	• Adoption of highly efficient lamps and fixtures • Adoption of automatic lighting and local lighting systems • Mounting position of lamp fittings and circuit partitioning • Management of optimum illumination • Lights-out and use of daylight during hours when lighting is unnecessary • Cleaning and replacement of lighting apparatus
4. Management of electrical heating equipment	• Improvement of supply voltage and power factor • Transfer of products into and from equipment, and preheating of materials • Temperature management and heating management • Heat insulation management • Load factor improvement • Continuous operations • Reuse of exhaust heat
(6) Others	
1. Load leveling measures	• Review of operation forms (operation hours, operating rate, load factor, etc.) • Introduction of equipment (thermal storage equipment, gas-fired absorption-type water chiller, heaters, etc.)
2. Co-generation	• Operation management (dependence rate, power generation efficiency, Utilization rate of waste heat, total efficiency, etc.)
3. New energies	• Fuel cells • Photovoltaic power generation • Solar heat • Wind power generation
Source: Guidebook on Energy Conservation for Factories 2010 / 2011, Energy Conservation Center, Japan (ECCJ)	

4 Questionnaire

Table 4.1 Questionnaire before energy audit

Sheet No.		Company Name	
Item		**Description**	**Comments**
Starting year of Operation			
Products			
Annual Production Capacity			
Production Volume in 2014			
Annual days operated (days)			
Number of Employees			
Number of Engineers			
Electricity (Line) per year (kWh)			
Electricity Charges per year (Rs/y)			
Electricity (Captive) per year (kWh)			
Natural gas Consumption per year (m3)			
Natural gas Charge per year (Rs/y)			
Diesel Oil Consumption per year (L)			
Diesel Charges per year (Rs/y)			
Others (LPG) (kg)			
Others Charges per year (Rs/y)			
Total energy Charge per year (Rs/y)			
Key Equipment	Air compressor		
	Air receiver		
	Pump		
	Fan, Blower		
	Chiller		
	Melting furnace		
	HP Die Cast Machine		
	Injection mold machine		
	Horizontal MC		
	Vertical MC		
	Main Transformer		
	Vacuum evaporation unit		
	Paint curing furnace		
	Power Generator		

Chapter 2 Power Receiving and Distribution Facilities

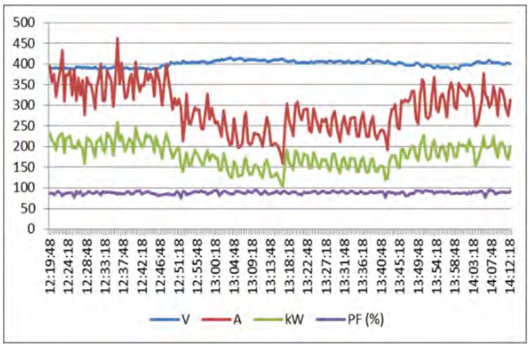
1. Proper voltage control

In Pakistan voltage level of factories are fluctuating generally. The main causes are fluctuating voltage at power receiving point and small cable size which causes big voltage drop on the cable. Allowable voltage level for electrical equipment is generally ±5% of equipment rated voltage (sometimes ± 10%). In case voltage imposed on electrical equipment is beyond allowable voltage level, efficiency of the equipment will be lower and equipment life will be also shortened.

1-1 Measuring and recording electricity data by power analyzer

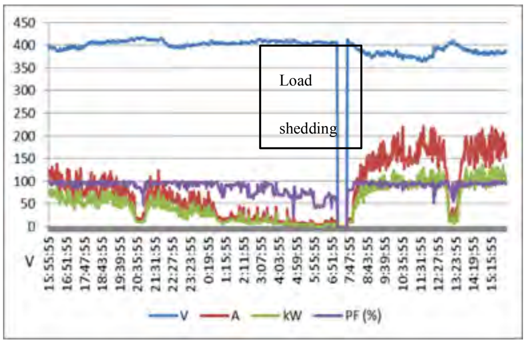
Measuring and recording electricity data (V, A, kW, Pf, etc.) for a few hours or several hours is necessary. It is recommendable to take 24 hour data at power receiving point once a month in Pakistan because of voltage fluctuation. Then prepare tables showing maximum, minimum, average values for analysis.

a) 2hour data sample



	V	A	kW	PF (%)
MAX	414.0	462.4	258.8	95.0
MIN	383.7	158.6	104.6	75.0
AVERAGE	400.0	294.1	179.9	88.4

b) 24hour data sample



	V-n	V-V	A	kW	PF (%)
MAX	241.0	417.5	221.9	136.1	100.0
MIN-1	222.8	385.9	3.3	1.0	23.7
MIN-2	210.2	364.1	11.4	6.6	51.7
AVERAGE-1	233.5	404.5	47.0	30.6	86.3
AVERAGE-2	222.0	384.6	141.7	87.5	92.6

1-2 Improvement proposal

(1) At power receiving point

In case receiving voltage fluctuation is too big and beyond allowable equipment voltage level, factory management should discuss with power company for improvement based on recorded voltage data of above a) and b).

(2) Inside factory

Following methods should be reviewed and considered.

1) Voltage setting shall be suitable for electrical equipment/motors.
2) Proper setting of transformer taps
3) Proper setting of generator voltage
4) Installation and proper control of power improvement capacitors
5) Proper cable size selection
6) Installation and proper control of AVR (Automatic Voltage Controller)

1-3 Reference

Problems of unstable voltage/overvoltage/under voltage

1) Inefficiency of electrical equipment /motors --- Energy loss !
2) Electrical equipment/motors are deteriorating and burning out due to overvoltage/overcurrent at last.

Rewinding

Efficiency and power factor becomes lower without proper rewinding skill.

Energy loss !

Note: Allowable voltage tolerance

±5% --- IEC (International Electrotechnical Commision)

±10% --- JIS (Japanese Industry Standards)

<u>Photos: Data gathering by Power Analyzer (Samples)</u>

2. Power factor control

Improvement of power factor contributes to followings.

a) Decreasing voltage drop (I --> smaller, $\Delta V = IR$ --> smaller)
b) Decreasing distribution loss (I --> smaller, I^2R --> smaller)
c) Increasing distributing capacity ($\cos\Theta$ --> bigger, $P = IV\cos\Theta$ --> bigger)
d) Reduction of electricity charge (In Pakistan low power factor penalty is imposed in case monthly power factor is lower than 0.9.)

2-1 Improvement of low power factor (lagging)

In case monthly power factor is less than 0.9, power factor improvement capacitors should be (additionally) installed.

Required capacitor size (Qc) is calculated as below.

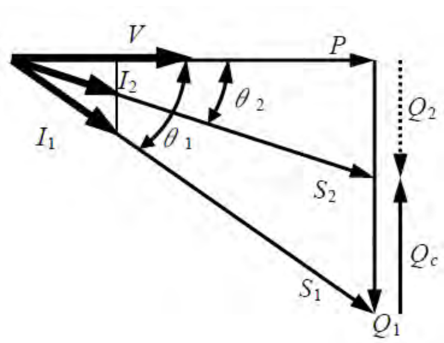
$Qc\ (kVAR) = Q_1 - Q_2 = P\ (kW) \times (\tan\Theta_1 - \tan\Theta_2) = P\ (kW) * \Delta\tan$

($\Delta\tan = \tan\Theta_1 - \tan\Theta_2$)

I_1, S_1, Q_1, Θ_1 : Before improvement

I_2, S_2, Q_2, Θ_2 : After improvement

Qc : Required Capacitor



Original Power Factor	Desired Power Factor				
	0.800	0.850	0.900	0.950	1.000
0.50	0.982	1.112	1.248	1.403	1.732
0.55	0.768	0.899	1.034	1.190	1.518
0.60	0.583	0.714	0.849	1.005	1.333
0.65	0.419	0.549	0.685	0.840	1.169
0.70	0.270	0.400	0.536	0.692	1.020
0.75	0.132	0.262	0.398	0.553	0.882
0.80	0.000	0.130	0.266	0.421	0.750
0.85	...	0.000	0.135	0.291	0.620
0.90	...	...	0.000	0.156	0.484
0.95	...	...	...	0.000	0.329
1.00	...	...	...	...	0.000

<u>kW Coefficient ($\Delta\tan$) for power factor improvement</u>

Original Power Factor : $\cos\Theta_1$

Desired Power Factor : $\cos\Theta_2$

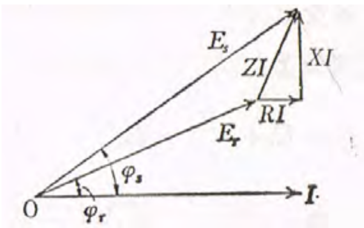
2-2 Leading power factor issue

In Pakistan power factor improvement capacitors are installed at power receiving point for avoiding low power factor penalty (<0.9) by power company. For avoiding the penalty, factories tend to install excess capacity of capacitors. But if automatic power factor controller is not installed or doesn't function properly, excess capacity of capacitors causes leading power factor ("-" values). In case of leading power factor, following disadvantages occur.

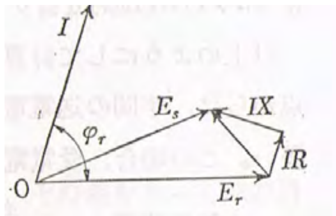
1) Leading reactive current generate generates unnecessary energy loss.
2) Leading power factor ("-" values) seems to be converted into lagging power factor ("+" same values) in Pakistan. In this case higher leading power factor (PF (%)) is equivalent to lower lagging power factor (Pfo (%)).

   --- Low power factor penalty is imposed if total power factor is less than 0.9.
3) High leading power factor may cause higher receiving voltage (Er) rise than source voltage (Es), which may damage electrical equipment in factories.

Lagging power factor : Er < Es



Leading power factor : Er > Es



Recommendation

Automatic power factor controller (APFC) should be installed and properly set.

In case harmonics level is high, APFC may malfunction.

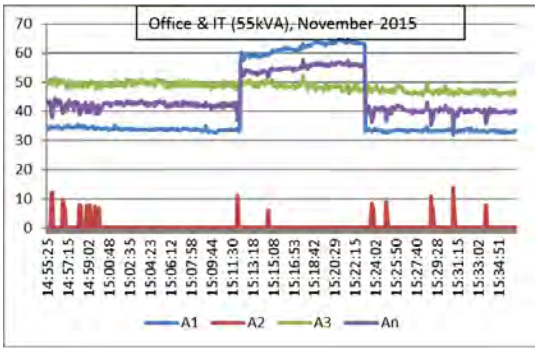
Harmonics and solution of harmonics are explained separately.

3. Rectification of phase imbalance

3-1 Current phase imbalance

There are many single phase loads in factories and offices such as lighting, heaters, rectifiers, office/laboratory equipment, etc. If single phase loads are not equally balanced on three phases, three phase currents are imbalanced. Imbalance current contains negative phase current which causes excess increase of temperature, noise, vibration, decreasing efficiency, etc.

Imbalance current sample

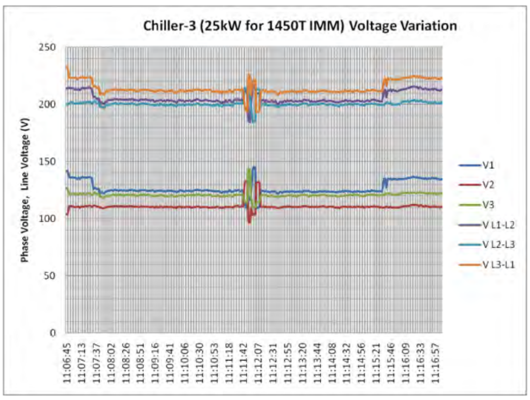


	A1	A2	A3	An	Imbalance (Av)
MAX	64.8	13.8	52.5	57.8	61.3%
MIN	32.5	0.0	45.5	32.0	98.5%
AVERAGE	41.2	0.4	48.4	44.9	30.0

3-2 Voltage phase imbalance

Voltage imbalance occurred because voltage taps of unit transformer for chilling unit were set wrongly.

Imbalance voltage sample



at 11:06:50 : V1 142.2(V), V2 103.8(V), V3 126.1(V)

at 11:11:54 : V1 116.4(V), V2 96.6(V), V3 143.2(V)

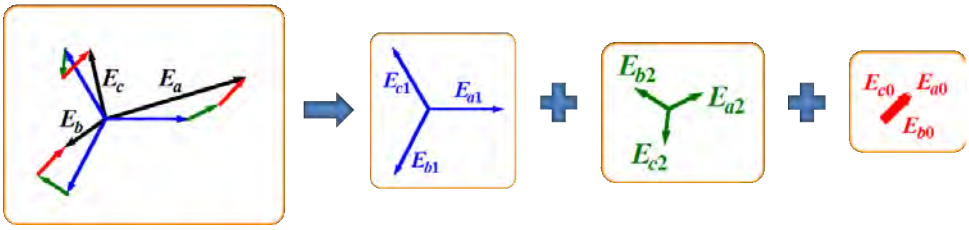
3-3 Improvement proposal

1) Transformer taps shall be properly set.
2) Generator 3 phase voltage shall be properly set.
3) Single phase load (lighting, heaters rectifiers, office/laboratory equipment, etc.) shall be equally distributed to each three phase.
4) Open-phase operation shall be avoided.
   (Open phase occurs because of blowing fuses, malfunction of disconnecting switches, circuit breakers, etc.)

3-4 Reference

(1) Method of Symmetric Coordinate

Any type of three phase imbalance situation (Voltage, Current) can be described by summation of three type of vectors.



Imbalance (Black) Positive Phase Negative Phase Zero Phase

- Zero phase appears only at earth leakage accident.
- Usual Imbalance situation is described by summation of Positive Phase and Negative Phase.

(2) Definition of imbalance ratio

1) Theoretical definition

a) Imbalance Voltage Rate (IEC, BS) = (Negative phase)/(Positive phase) x 100 (%) <= 2%

IEC : International Electrotechnical Commission) & BS :British Standards

b) Imbalance Current Rate for generators (JEC) < 10 %

JEC : Japanese Electrotechnical Committee

2) Practical definition and guideline

a) Imbalance voltage rate (NEMA) = ((Max. or Min. voltage) – (Average voltage)) / (Average voltage)

b) Imbalance voltage rate for motors < = 2.8 % (NEMA)

c) Imbalance voltage rate at motor terminals should be 1% or less for longer life.

NEMA : National Electrical Manufacturers Association (US)

Chapter 3 Application of Inverters

4. General description

In factories generally 60% electricity is consumed by motors. So reducing motor consumption is important for energy efficiency. For this purpose, identifying necessary energy and unnecessary energy by measuring and analyzing operation data (by power analyzer) is required. Unnecessary energy can be usually reduced by following methods.

1) Application of inverters for motors
2) Replacing existing motors with smaller size motors

In case of above 2) following inconvenience situation could occur.

a) After replacing motors, output cannot be increased, when necessary, such as changing product in future.
b) Selection of best capacity motor is not possible because motor output capacity is standardized, not continuous.

For avoiding above inconvenience, above 1) is effective for energy efficiency of motors. Introduction of high efficiency motors is effective but less effective compared to above 1) and they are expensive.

So in this manual "Application of inverters for motors" is explained.

Photos: Data gathering by Power Analyzer (Samples)

5. Type of inverters

1) CVCF (Constant Voltage Constant Frequency) with batteries as UPS (Uninterruptible Power Supply) --- Factory/office/home utilization during power outage
2) Hf inverter (High frequency) for Hf fluorescent lamp
3) Hf inverter for Hf welding --- for manufacturing pipe from sheet metal
   (around 100---500kHz, skin effect & proximity effect)
4) AVAF (Adjustable Voltage Adjustable Frequency)
   = VVVF (Variable Voltage and Variable Frequency: in Japan)
   = VFD (Variable Frequency Drive)
5) Others

(Note) Inverter : DC -→ AC, Converter : AC -→ DC

6. Theory/Principle

How to save energy of motors which usually consume most energy in factories.

--- Application of Inverters for motors is most effective !

(Inverter varies frequency then motor/pump/fan speed varies.)

3-1 Pump, fan/ blower

For pumps, fans/blowers following relations are applied.

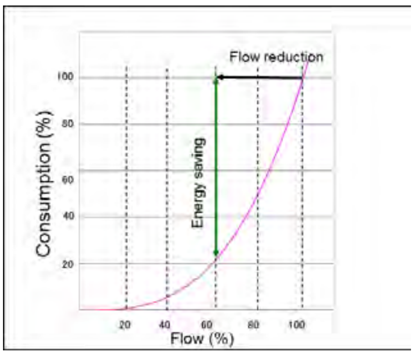
Water/air volume (Q : m^3/s) $\propto$ f (Hz) ($\propto$: in proportion to)

Water/air pressure (H: N/m^2) $\propto$ f^2

Motor Consumption (P : kWh) $\propto$ f^3

Ex) f : 50 Hz → 40 Hz (80%)

Q → 0.8 Q, P → 0.8 x 0.8 x 0.8 P = 0.51 P (HALF !)



Energy saving Performance (Cubic function curve)

Reference

Cooling Water

a) Operation situation

- Water quantity can be varied according to season, weather, surrounding temperature.
- Operating cooling water system under same conditions through years --- Wasting Energy !
- The system is usually designed for the hottest temperature.
- Except the hottest time cooling water system is Wasting Energy & Money continuously !
- Water volume is usually adjusted by valves. --- Wasting Energy.

b) Design Procedure of Cooling Water System

- Process Engineer calculates required cooling water quantity and temperature with some Margin considering
  - Future deterioration of the system
  - Worst temperature condition
  - Uncertain risk
- Mechanical Engineer selects pumps based on Manufacturers Standard Capacity --- Margin !
- Electrical Engineer selects motors based on manufacturers Standard Capacity --- Margin !
- Margins are accumulated so much and reduced by valves on operation ! --- Wasting energy !

c) How to lower inverter frequency

- Required water quantity shall be obtained by calculation, past operating data or testing using valves/temporary inverters.

  (Inverter supplier may lend demonstration inverter free of charge or with lower cost.)

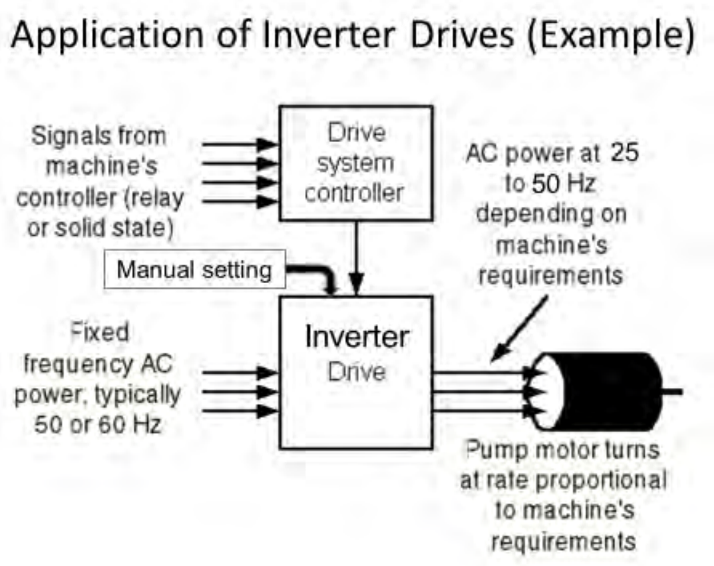
Notes:

1) Valves in cooling water piping system are wasting Energy.

   All valves shall be 100% open ! (Need to check.)

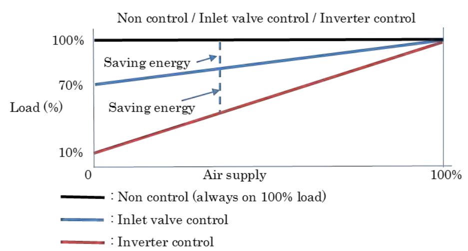
2) Inverter specialist involvement is required for setting parameters at initial stage since the setting is complicated.

   (Inverter suppliers usually support the setting.)

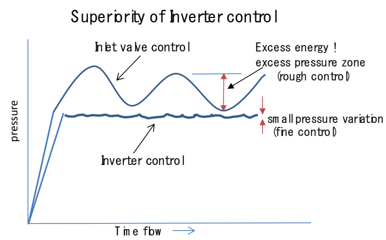


3-2 Compressor

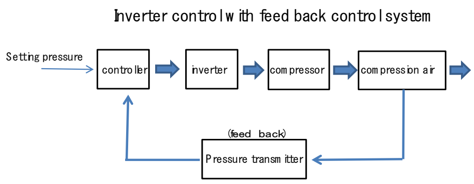
As compressor control Load-Unload control system has been commonly applied since On-Off control system requires frequent restarting of the compressor, which results in damaging equipment and equipment life. But Load-Unload control system is not preferable from energy saving point of view since on the control system compressor consumes nearly 70% energy even non-air-supply period. Therefore, inverter controlled compressor system has been introduced in the industry.



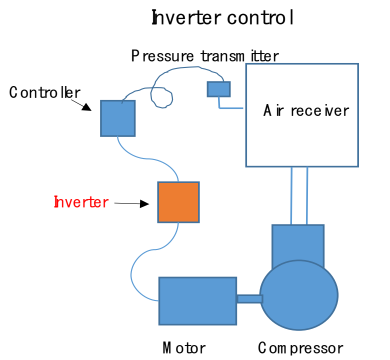
Energy Saving Performance



Control Characteristics



Inverter control system



Inverter control outline

3-3 Remarks on application of inverters

(1) Frequency control range of 25 --- 50 Hz is practical for inverters

At lower frequency operation becomes unstable.

- V/f (: constant) characteristics.

  f -> small, V-> small then Motor torque T -> small (T $\propto$ V[2)]

  Torque boost characteristics are usually set in low frequency area.

- Performance of cooling fan on motor is lowered. --- Motor temperature rises.
- Mechanical resonance may occur especially for compressor system.

  Mechanical resonance frequency value shall be obtained from the manufacturer and the frequency operation setting shall be avoided in case inverter is installed to existing compressor system.

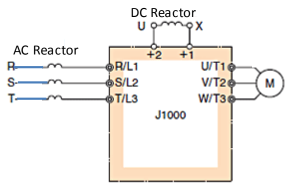
  (Compressors with built in inverters have presetting of operation frequency avoiding resonance frequency by the manufacturer.)

- In case vibration is observed, countermeasures such as rubber sheet to be added to the machinery base.

(2) Following accessories should be installed on inverters.

- DC reactors or AC reactors for suppressing harmonics

  DC reactors are more effective than AC reactors for suppressing harmonics.

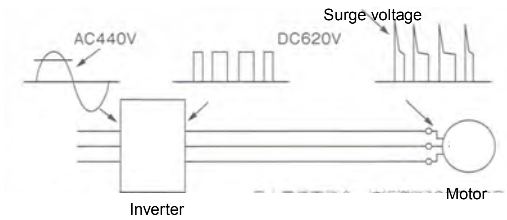


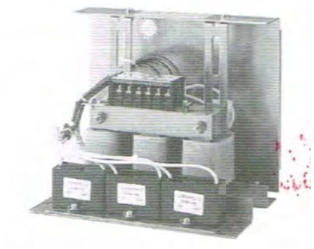
Inverter

DC reactor

(Note) Suppression effect of harmonics is explained separately in "Harmonics" chapter.

- Surge suppressors for protecting motor insulation (especially for 400V motors)





Output filter

Chapter 4 Harmonics

In Pakistan harmonics level has been increasing in industrial area recently because almost factories use equipment and machinery which generate harmonics. But at this stage almost factories don't realize harmonics and effect of harmonics.

1. Measuring harmonics

At first measure harmonics level by suitable power analyzer (or harmonics analyzer).

Harmonics level (sample)

	V	A	PF(%)	Pfo(%)	kW	THD L2(%V)
MAX	421.2	424.0	121.9	98.8	212.3	11.0
MIN	382.8	243.8	58.6	58.6	145.4	3.5
AVERAGE	408.3	292.2	110.5	83.4	171.7	9.2

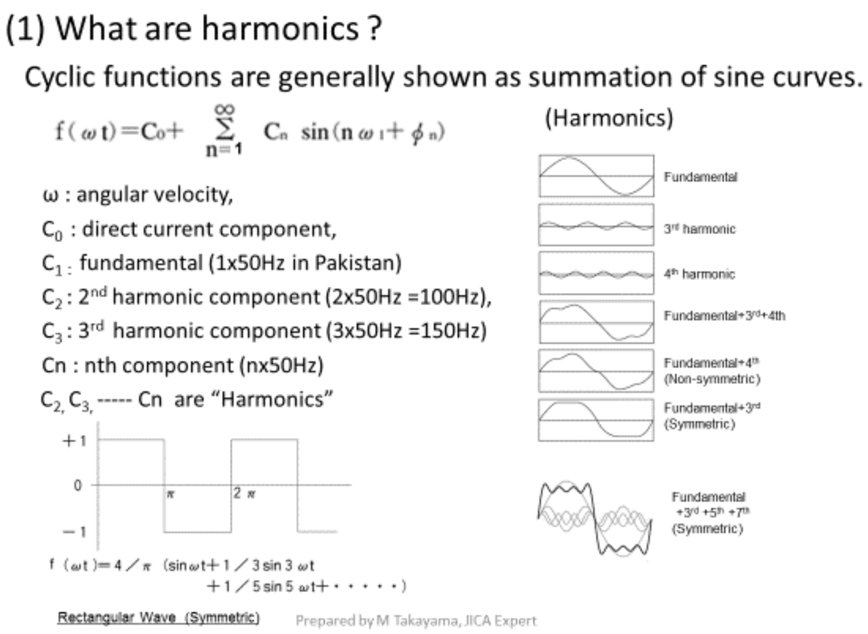
THD L2(%V) : Total Voltage Harmonics Distortion, Line 2 (%)

2. Recommendation

In case THD (V) exceeds 5%, survey on equipment damage or system malfunction and periodical monitoring should be carried out.

Typical effects of harmonics are equipment damage/burning and malfunction of control system.

3. Theory/principle



Harmonics on electrical equipment/circuit

In almost electrical circuit "+"half cycle and "-" half cycle are symmetric.

That means harmonics are odd number (3,5,7---).

Note : Transformer magnetizing rush current contains 2^{nd} harmonic.

(2) What generates harmonics ?

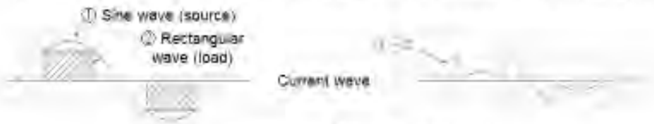
1) Non-Linear Circuit (analogue)

   Ex. Transformer magnetizing current, Capacitor charging current

2) Switching Circuit (digital)

   Ex. Inverter, Rectifier, Furnace, Heater, Electronics equipment

Note : Some load doesn't require sine wave current. The balance current (①−②) contains harmonics and flows out to power system.



(3) What are the effects of harmonics ?

- All equipment are designed to operate under rated frequency (50Hz).
- Harmonics (150Hz, 250Hz, 350Hz---) cause equipment unnecessary and unstable movement, vibration, noise and excess heat which may damage equipment and/or cause malfunction of control system.
- Capacitors are weak for harmonics.

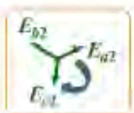
  $Zc = 1/\omega C = 1/2\pi fC$, $Ic = V/Zc = 2\pi fCV$, f -> large, Ic -> large : **damaged !**

  Zc : Impedance of capacitor, C : Capacitance, f : frequency,

  Ic : Capacitor current

- Vector rotation of harmonics

Positive phase rotation
n = 1, 7, 13, 19, ---



Negative phase rotation
n =5, 11, 17, ---

Cause worse effect !

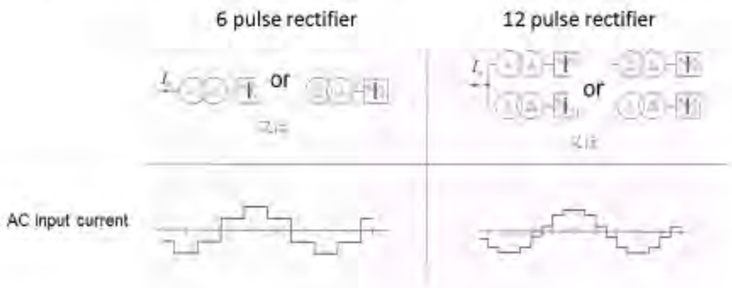
(4) How to protect harmonics effect ?

1)Devices/Control System, not generating/suppressing harmonics

a) Increasing number of pulses for rectifiers

→ AC side wave distortion becomes smaller (reducing harmonics)

(THD (%V) by 12 pulse rectifier is nearly half of THD (%V) by 6 pulse rectifier.)



Theoretical generating quantity of harmonics by 3 phase bridge rectifiers per pulses

Input current $I = 2\sqrt{3}I_d/\Pi$ (sinωt + 1/5sin5 ωt + 1/7sin7 ωt + -----)

Order	6 pulses	12pulses	24 pulses
5	20.0	–	–
7	14.3	–	–
11	9.1	9.1	–
13	7.7	7.7	–
17	5.9	–	–
19	5.3	–	–
23	4.3	4.3	4.3
25	4.0	4.0	4.0

Ratio (%) for fundamental

Prepared by M Takayama, JICA Expert

b) Thyristor Cycle Control

--- Non harmonics, but possibility of causing flicker problem

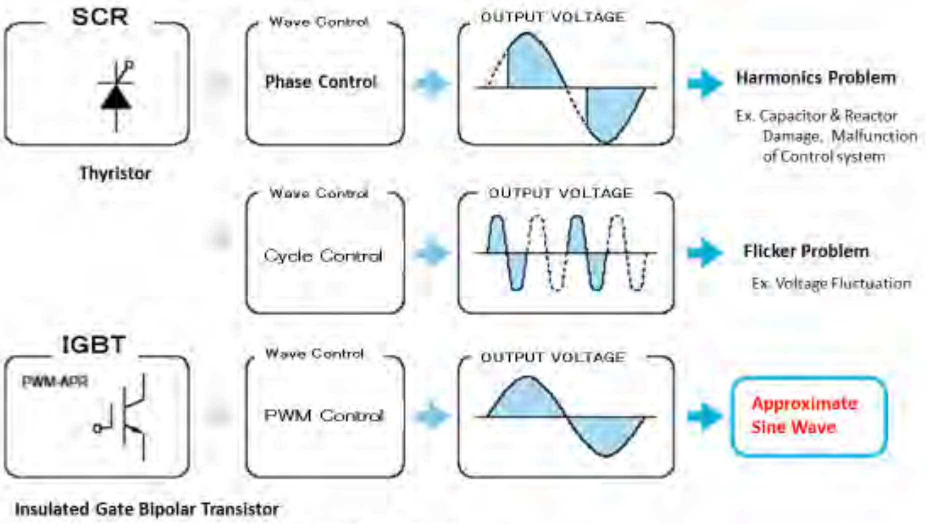
(cyclic voltage fluctuation) depending on factory electrical system.

To be studied carefully in case of application for big load.

c) Pulse Width Modulation (PWM) Control

---High speed switching of pulses makes output approximate sine wave.

Wave Control Method

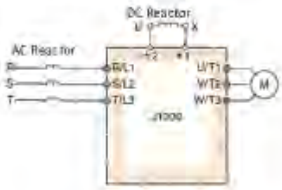


Note : Some factories may have harmonics problem.
Application of "Cycle Control" or "PWM" is a good solution.

d)DC Reactor for Inverter

Inverter has many switching devices which generate a lot of harmonics.

- DC Reactor should be installed for suppressing harmonics from the Inverter.
- AC reactor on inverter primary side also suppress harmonics to power system, but DC reactor is more effective.



Inverter

(Notes)

1. Reactor is effective for suppressing harmonics
   $Z_L = \omega L = 2\pi f L$, $I_L = V/Z_L = V/2\pi f L$, f -> large, I_L -> small (Suppression effect)
   Z_L : Impedance of reactor, I_L : Reactor current
2. (Ex) Generated quantity of 5^{th} harmonics
   (Inverter of 3 phase bridge with capacitance filter)

DC reactor

a) Without reactor : 65%, b) With AC reactor : 38%, c) With DC reactor : 30%
d) With AC & DC reactors : 28%

2) Devices protecting equipment/system from harmonics

a) Series reactor

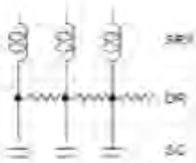
Series Reactor for Power factor Improvement Capacitor is effective.

In Pakistan Static Capacitors (SC) are well installed near power receiving point for avoiding fine/penalty from power company.

But Series Reactors (SRX) are not installed in almost factories.

So Static Capacitors (SC) are suffered from harmonics.

Series Reactors (SRX) should be installed for protection of capacitors and preventing harmonics to flow out from capacitors.



Selection of series reactor capacity

For suppressing harmonics impedance (Zn) shall be inductive :

$Z_1 = \omega L - 1/\omega C$

$Z_5 = 5\omega L - 1/5\omega C = 5(\omega L - 1/5^2\omega C) > 0$

$\omega L > 1/5^2\omega C = 0.04\omega C$

Considering tolerance, 6% series reactor is applied against 5th and higher harmonics as JIS.

In case 3rd harmonics are measured, 13% series reactor can be applied.

(Note)

3 phase bridge rectifiers don't generate 3rd, 6th, 9th --- harmonics.

1 phase bridge rectifiers generate 3rd harmonics.

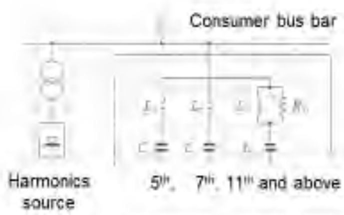
(Even if 3rd harmonics are generated, 3rd harmonics flow inside Δ connection of transformers and not flow out to power system.)

Prepared by M Takayama, JICA Expert

b) AC Filter for suppressing harmonics

Absorbing harmonics and suppressing them by L-C resonance characteristics.

Ex. 5^{th}, 7^{th} tunable filters and high pass filter (11^{th} and above)

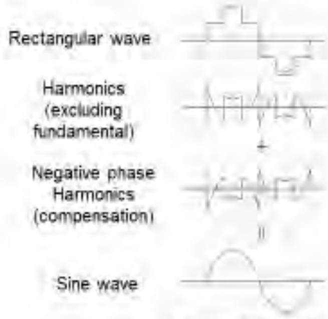


(Note) : AC filters are designed for certain circuit condition. If the circuit condition changes due to factory facilities/circuit modification and other reasons, the filters will be less effective.

c) Active filter

Eliminating/reducing harmonics by providing negative phase harmonics (compensation)

--- It is effective but still expensive.



Operating principle

(5) Harmonics Guideline

1) System voltage distortion rate target (%) : Japanese guideline

Harmonics	3rd	5th	7th	11th	13th	17th	19th	23rd	25th~39th	Total
6.6kV	3.0	4.0	3.0	2.0	2.0	1.5	1.5	1.0	1.0	5.0
>=22kV	2.0	2.5	2.0	1.5	1.5	1.0	1.0	0.5	0.5	3.0

Total Harmonic Distortion (THD) is shown as below

$$\mathrm{THD} = \frac{\sqrt{V_2^2 + V_3^2 + V_4^2 + \cdots + V_n^2}}{V_1} \quad \text{X 100 (\%)}$$

V_1 : Effective value of basic component

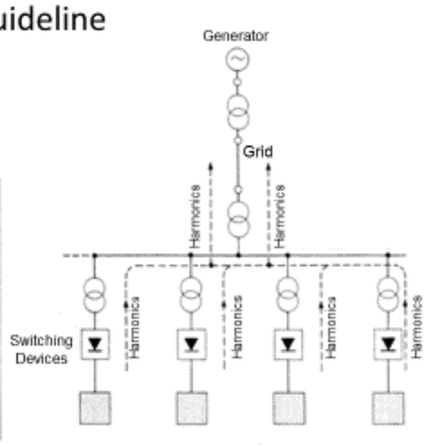
V_2, V_3, V_4, Vn : Effective value of harmonic component

2) Harmonics current emission limit/ 1kW (Installed capacity) : Japanese Guideline

Unit (mA/kW)

Receiving voltage	5th	7th	11th	13th	17th	19th	23rd	>=25th
受電電圧	5次	7次	11次	13次	17次	19次	23次	23次超過
6.6kV	3.5	2.5	1.6	1.3	1.0	0.9	0.76	0.70
22kV	1.8	1.3	0.82	0.69	0.53	0.47	0.39	0.36
33kV	1.2	0.86	0.55	0.46	0.35	0.32	0.26	0.24
66kV	0.59	0.42	0.27	0.23	0.17	0.16	0.13	0.12
77kV	0.50	0.36	0.23	0.19	0.15	0.13	0.11	0.10
110kV	0.35	0.25	0.16	0.13	0.10	0.09	0.07	0.07
154kV	0.25	0.18	0.11	0.09	0.07	0.06	0.05	0.05
220kV	0.17	0.12	0.08	0.06	0.05	0.04	0.03	0.03
275kV	0.14	0.10	0.06	0.05	0.04	0.03	0.03	0.02

(Note) Current emission is calculated based on type and capacity of equipment.



Harmonics generated by switching devices flow inside factory electrical system and flow out to grid network.

3)Allowable harmonics voltage level on low voltage system (IEC 1000-2-2)

Harmonics odd number

ν	5	7	11	13	17	19	23	25	>25
$U_{\nu VT}$(%)	6.0	5.0	3.5	3.0	2.0	1.5	1.5	1.5	$0.2+0.5\times\frac{25}{\nu}$
ν	3	9	15	>15					
$U_{\nu VT}$(%)	5.0	1.5	0.3	0.2					

Harmonics even number

ν	2	4	6	8	10	>10
$U_{\nu VT}$(%)	2.0	1.0	0.5	0.5	0.2	

Chapter 5 Lighting Part 1 Artificial light

2.1 Basic knowledge of lighting:

2.1.1 Intensity of Light:

Intensity of light is the light energy from the light source. Its unit is candela (cd).

2.1.2 Luminous flux:

Luminous flux is the ratio of light energy passes through the light receiving surface.

Its unit is lumen (lm)

2.1.3 Illuminance:

Illuminance is Luminous Flux per unit area (lm/m^2).It is used as standard of room brightness. Its unit is (lx).

2.1.4 Brightness:

It is light intensity per unit area of the light source. Its unit is a (cd / m^2)

2.2 Illuminance calculation of lighting:

The illuminance calculations is done by two methods

1-Method of point-by-point

2-Method of Luminous flux

Usually method of Point-by-point is used when the light source is single.

Method of Luminous flux is used when light source is more than one.

2.2.1 Method of Point-by-point:

(1) In case of vertical distance from light source

$$E = I / L^2$$

E: Illuminance (lx)

I: Intensity of light

L: Distance from light source to working surface (m)

(2) In case of not vertical distance form light source

$$E' = 1 / L^2 * \cos \theta$$

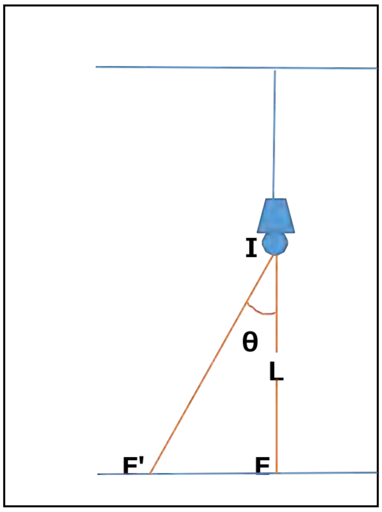
E: Illuminance (lx)

I: Intensity of light

L: Distance from light source to working surface (m)

Θ: Angle between light source and work surface

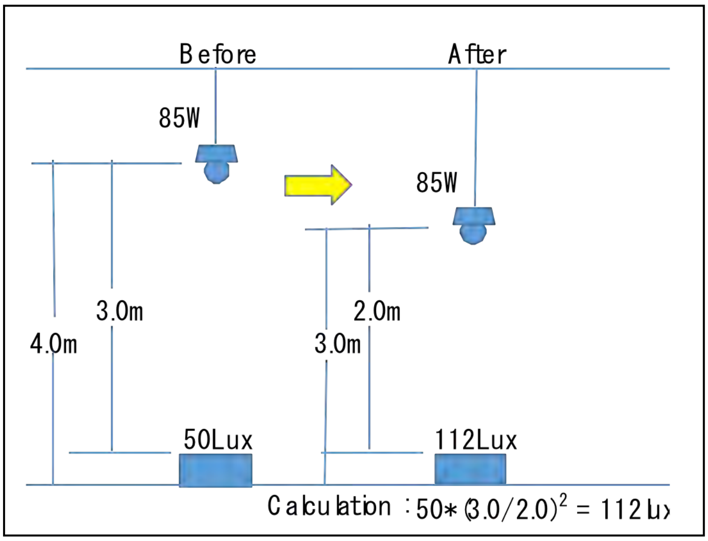
Fig1



(3) Calculation by point by point method:

Fig 2 shows which illuminance increased from 50lxto 112lx by lowering lamp to 1m..

Fig2



Calculation:

$50 = I / 3^2$ $I = 50 * 9 = 450(CD)$ $E = I / 2^2 = 450/4 ≒ 112lx$

I: Intensity of light (CD)

2.2.2-Method of Luminous flux:

Method of Luminous flux is used for lighting design when light source is more than one in the room.

Calculation by the method of illuminous flux.

E = N * F * U * M / A

E= Illuminance (lx)

N: Number of light source

F: Luminous flux

U: Utilization factor

M: Maintenance factor

A: Area of the room

Note): In case of light source design, ratio of maximum luminance and minimum luminance on the working surface is should be more than 1/3.

2.2.3 How to calculate maintenance factor and utilization factor

2.2.3.1Maintenance Factor(M)

Maintenance factor is maintenance rate of luminance flux against light aging. Maintenance factor of LED is more excellent than other lighting .It can keep 80% of new luminance flux even after 10 years installation. Therefore, in case of introduce LED maintenance factor is 90%.

2.2.3.2 Utilization Factor(U)

Utilization factor is ratio of luminous flux on the work surface. If the utilization factor is high efficiency of luminous flux is also high. Utilization factor is function for room constant and reflectivity.

1) **Room Constant**:

k = a*b / h (a + b)

K: room constant

A: Vertical and horizontal length of room (m)

B: Horizontal Length of room (m)

H: Height from work surface to light source (m)

2) **The reflectivity**:

Reflectivity shows the reflective degree of wall surface and ceiling surface. If room reflectivity is high utilization is also high. Standard reflectivity is as follows:

In case of office having white base wall and ceiling: Ceiling: 70%, Wall: 50%, Floor: 10%

In case of old factory: Celling: 10%, Wall: 10%, Floor: 10%

<u>3) Calculation of utilization:</u>

After decide of room constant and reflectivity, decide utilization by use fig 3 table

Fig 3

The table for the utilization factor

ceiling	70	70	70	70	50	50	50	50	30	30	30	30	10	10	10	10	0
Wall	70	50	30	10	70	50	30	10	70	50	30	10	70	50	30	10	0
Floor	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	0
0.60	.41	.33	.28	.24	.39	.32	.28	.24	.37	.31	.27	.24	.36	.31	.27	.24	.23
0.80	.47	.40	.35	.31	.45	.39	.34	.31	.43	.38	.34	.31	.42	.37	.33	.30	.29
1.00	.52	.45	.40	.37	.50	.44	.40	.36	.48	.43	.39	.36	.46	.42	.38	.36	.34
1.25	.56	.50	.46	.42	.54	.49	.45	.42	.52	.48	.44	.41	.50	.46	.43	.41	.40
1.50	.59	.54	.50	.46	.57	.52	.49	.46	.55	.51	.48	.45	.53	.50	.47	.45	.43
2.00	.63	.59	.56	.53	.61	.58	.55	.52	.59	.56	.53	.51	.57	.55	.52	.50	.49
2.50	.66	.62	.59	.57	.64	.61	.58	.56	.62	.59	.57	.55	.60	.58	.56	.54	.53
3.00	.68	.65	.62	.60	.65	.63	.61	.59	.63	.61	.59	.58	.62	.60	.58	.57	.56
4.00	.70	.67	.65	.63	.67	.66	.64	.62	.65	.64	.62	.61	.64	.62	.61	.60	.59
5.00	.71	.69	.67	.65	.69	.67	.66	.64	.67	.65	.64	.63	.65	.64	.63	.62	.61

Reflectivity in room

The room constant

The utilization factor

<u>2.2.3.3 Calculation example of Utilization:</u>

Condition:

1)-Office having white base wall and ceiling

2)-Dimension:

Vertical dimensions of the work surface (10m)

Horizontal dimension of the work surface (20m)

The height from light source to work place (3m)

Calculation:

Room constant (K) = 10*20 / 3 (10 + 20) ≒ 2.22

Reflectivity: Ceiling:70% , Wall:50%, Floor:10%

Utilization: 0.6 about (see fig 3)

Chapter 6   Lighting Part 2 : Natural sky light

2.3 Natural lighting and Illuminance calculation:

Natural lighting used solar radiation as room lighting. Usually install transparent plastic sheet on roof. In fine weather Sunbeam to transparent plastic sheet is about 70000lx .

2.3.1calculation of illuminance of natural lighting by method of luminous flux:

Condition:

1)Solar radiation to transparent plastic sheet is 70000Lx

2) New transparent plastic sheet

3) Transmittance ratio of solar radiations is 0.8

Therefore illuminance from the factory side is 56000Lx (70000Lx *0.8)

4) factory area and dimension :

Vertical dimension: 50m

Horizontal dimension: 30m

Area of factory:30*50=1500m2

Height from the work surface to transparent plastic sheet =5m

5) Reflectivity:

Reflectivity from ceiling wall and floor is each 10%

6) Utilization:

Room constant (K) = 30*50 / 5(30 + 50) ≒ 3.75

Therefore utilization is about 0.59 by fig 3 table.

7) Maintenance factor:

Maintenance factor is lowered to 0.3 because clear plastic sheet is easy to become dirty by dust.

8).Luminance flux from clear plastic sheet:

Area of clear plastic sheet:1.5*1.0=1.5m^2

Therefore luminance flux per one clear plastic sheet=56,000lx*1.5m^2 = 84,000lm

9)Illuminance of work surface:

Average illuminance of factory is intend to 500Lx.

Calculation: by method of luminance flux:

E = N * F * U * M / A

N = E * A / F * U * M = 500*1500/84000*0.59*0.3≒50, 4(50sheets)

2.3.2.1 The light rate:

The light rate is the ratio of illuminance between solar radiation and indoor constant points. If solar radiation change light rate is remain constant.

Calculation of the light rate:

Condition:

1) Solar radiation 20000Lx

2) Indoor Illuminance 1000Lx

3) The light rate= 1000*20000/100=5%

Question:

If the solar radiation is 10000Lx

Indoor illuminance ?

Answer:

Indoor illuminance=10000/0.05=500lux

2.3.2.2 Cleaning interval of clear plastic sheet:

The cleaning interval of clear plastic sheet should be small in too much dusty area.

It's better to clean the plastic sheet once with in the 6 months.

If clear plastic sheet become dirty then the light rate also decrease.

Condition:

1)-solar radiation 10000Lx

2) In case of the light rate is 5%

Indoor Illumination=10000*0.05=500Lux

1) In case of the light rate is 2%

Indoor illuminance =10000*0.02=200Lux (lighting is necessary)

2.4 Installation example of Natural sky light

Clear plastic sheet

Lighting off

Before installation

After installation

2.5 Energy-saving method of calculating the lighting

2.5.1 LED introduction:

Condition:

1)-change energy saver type (85W) to LED type(Tube light type 18w)

2)-luminance flux of Energy saver type (85W) and LED (18W) type are equal

3) The number of exchange: 100。

4) Price of LED=800Rs / piece * 100 = 80,000Rs(without construction cost)

5)-Lighting time 24 hours / day, 300 days in a year

6)-The electricity rates around 17Rs / kWh.

Calculation:

Annual cost savings (kwh)=(0.085－0.018)*100*24*300 = 48,240kWh

Annual cost savings (Rs) = (0.085－0.018)*100*24*300*17 ≒ 820,000Rs

2.5.2: Improvement of natural lighting:

Condition:

1)-Lighting : energy saver type (85W)

2)-Amount of lighting: 100

3) Lighting time in day time: 9 hours

4) Working day per year: 300 days

Calculation of energy saving:

1) 0.085*100*9*300=22950kw

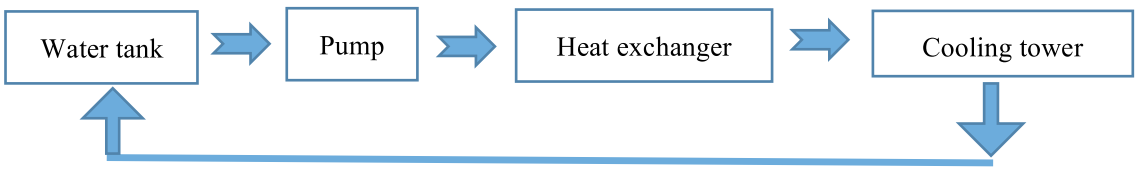
0.085*100*9*300*17 ≒ 390,000Rs

Chapter 7 Cooling Water system

1.1 Overview of the cooling water system:

In general cooling water systems consist of water tank, pump, heat exchanger, cooling tower and a pipe which connects the cooling tower and the respective.

This is expressed in block diagram as follows:



Cooling water in water tank is supplied to heat exchanger by pump and exchanges heat with the coolant of the production plant. Cooling water raised up temperature is send to the cooling tower and returned again to the water tank. The purpose of cooling water system is heat exchange to coolant circulation in the production plant.

Examples of coolant:

Cooling water of induction furnace. Oil of the Die-casting machines and hydraulic press, such as R22 circulating in the chiller.

1.2 Theory of heat exchange:

Heat Exchange is exchange of heat between cooling water and cooling. In Fig1, coolant side is cold from $t3 \rightarrow t4$, and cooling water side is rise up from $t1 \rightarrow t2$.

Theoretically the heat (H1) which coolant give and the heat (H2) which cooling water received are equal.

$H1 = H2$

$H1 = H1 = Q1 * s1 * (t2 - t1)$ $\quad\quad$ $H2 = Q2 * s2 * (t4 - t3)$

$Q1 * s1 * (t2 - t1) = Q2 * s2 * (t4 - t3)$

In case of coolant is water : $S1 = s2 \fallingdotseq 4.2 kJ/kg \cdot {}^\circ C$

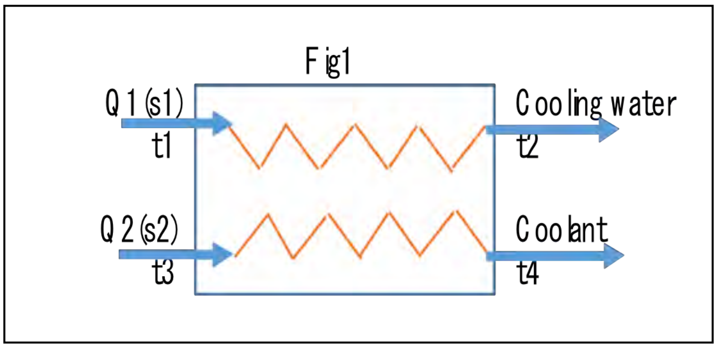
$Q1 * (t2 - t1) = Q2 * (t4 - t3)$

Q1 ($m3 / h$): Flow Quantity of cooling water

Q2 ($m3 / h$): Flow Quantity of coolant

S1 ($kJ / kg \cdot degC$): Specific heat of cooling water

S2 ($kJ / kg \cdot degC$): specific heat of coolant



Heat exchanger

1.3: Investigation method of cooling water system for energy saving

1.3.1: To check the piping in the factory and to make system diagram

1.3.2: To measure temperature, pressure and current. (To use a thermocouple thermometer for measuring temperature).

(1) Measuring points of temperature: Heat Exchanger, inlets outlet temperature of cooling water side and coolant side. Inlet and outlet of the cooling tower, the temperature of the water tank, Dry bulb temperature, Wet bulb temperature

(2) Measurement points of pressure: the suction side and discharge side of pump

1.3.3: To check power consumption (kW) of pump and fan, and operation time.

1.4 Energy saving improvement proposal

1.4.1 Point of checking

1.4.1.1 Checking of the heat exchanger: Cooling water side and coolant side difference between inlet side and outlet side is about 3-5°C.

(1)If this difference is too high, it shows flow quantity become too little or clogging.

(2)In case of small difference, it shows too much flow quantity or heat inside dirty.

1.4.1.2 Checking of the cooling tower:

The temperature difference between the cooling water inlet and outlet is “range”

The temperature difference between the cooling water outlet and wet-bulb is “approach”.

In general, both of range and approach are design by 5°C.

Cooling tower which range is large and approach is small, its efficiency is effective. (See 1.6.2).

If the range is 2 °C or less the approach is greater than 7 °C, following trouble occurs:

(1) Trouble of shower condition

(2) Trouble of bad air flow

(3) Bad wind direction or installation location. For example if install in low ground, possibility of mist from fan coming flowing around inside of cooling tower.

(4) Trouble of filler or adhesion of scale

(5) Shortage of cooling tower capacity

1.4.1.3: Checking of high coolant temperature:

In the inlet of heat exchanger if coolant temperature is above than 40degC, the flow possibility is too small.

To check the following items:

(1) To check series connection of coolant piping of production plant. In case of series connection piping, flow resistance increases and cause in flow shortage.

(2).To check the reduced point of pipe diameter.

(3)To check heat exchanger.

Result of the temperature measurement, If difference temperature between inlet and outlet is too high, it shows following

a) Flow quantity become too little or clogging.

b) There is a possibility of shortage of the heat exchanger capacity.

(4)To check the cooling water pump capacity.

.1.4.2 Improvement proposal

1.4.2.1 Improvement for heat exchangers and cooling towers.

As a results of the checking, if there is problem occurs in heat exchanger or cooling tower, purpose maintenance and capacity increasing

1.4.2.2 Proposal of operation time of the cooling tower fan:

Fan is necessary for the evaporating of the water drop in shower, but in winter season or night time air temperature become lower, and no necessary of operation or possibility of ON and OFF operation, if install temperature sensor in lower water tank we can operate by ON-OFF mode.

For example:

Condition

(1) One month production (fan operation): 400 hours/month

(2) No fan operation in 3months of winter season (Nov' Dec' Jan' Feb')

(3) Half hour (200 hours /month) operation in 4 months (Mar' Apr' Sep' Oct')

(3) Power consumption of the fan: 2.0kw

(4) 1kwh = 17Rs

Calculation of energy saving is as follows:

2.0kW*3*400 = 2,400kwh

2.0kW*4*200 = 1,600kwh Total: 4,000kwh

4,000*17 = 68,000Rs

1.4.3.1 Install inverter for Pump or size down:

Results of the checking, if water flow is big more than required and more than 10kW of pump capacity, consider the introduction of the inverter.

If the load is less than 50%, consider size down of pump capacity because pump selection is inappropriate (See electrical department Energy saving calculation by inverter introduction)

1.5 Cooling water pump

1.5.1 Overview of the cooling water pump:

Most of the pumps used in the cooling water system are “centrifugal pump". As in fig3,

Simple structure composed of the impeller and the casing, water flow take speed energy by rotation of impeller, and the speed energy changed to pressure energy by flow in the spiral casing, and water flow make water pressure.

Fig 3

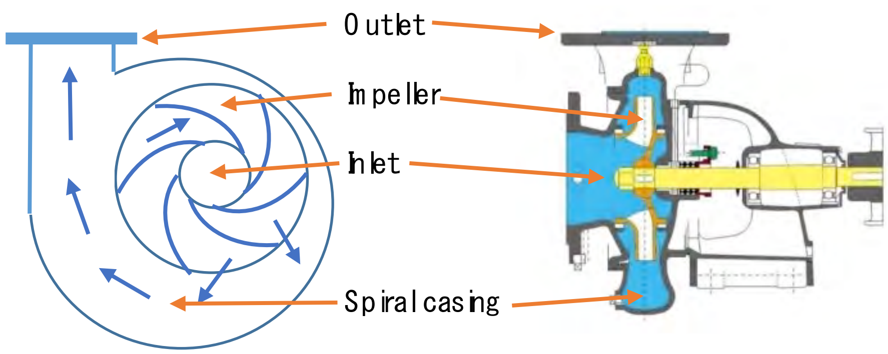


Fig 4

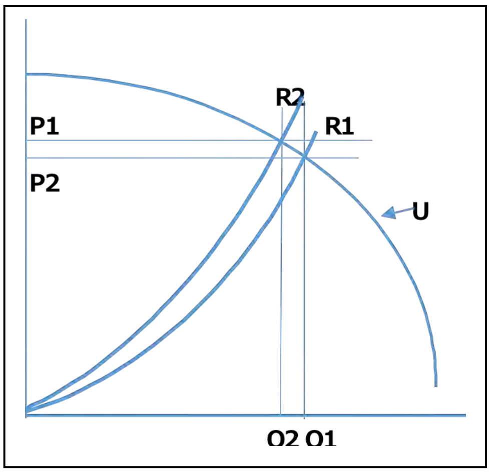
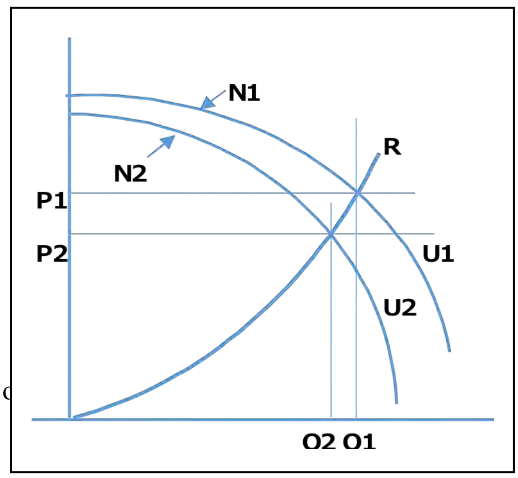


Fig 5



It's possible to express the performance of the pump in a head curve and a system loss curve
A head curve (U) is the function of the flow rate (Q) and the discharge pressure (P).
A system loss curve (R) changes by resistance of laying of the pipes and a speech
Fig4 shows that resistance rises from R1 to R2 by to reduce the divergence of the valve
Water flow decrease from Q1 to Q2, discharge pressure rises from P2 to P1.
Fig5 shows that the flow decrease by decrease of the number of rotations (N).
When decreases the number of rotations from N1 to N2, head-capacity curve changes from U1 into U2. On the other hand, resistance curve (R) doesn't change, so the flow rate decreases from Q1 to Q2, and discharge pressure decreases from P1 to P2.

1.5.2 Maintenance
1.5.2.1 Ball Bearing:
Ball baring according to long term use, wear, as a result generate noise and vibration also increase in power consumption and require one exchange in 3 years.
1.5.2.2 Gland packing
Small amount of water leakage from the gland packing is important because it is serve as, cooling and smoothness. However it is used for a long time so water leakage become increase for wearing. If this type of trend happened, you will replace the gland packing.
Performance curve of the pump:
Performance of pump is expressed by head discharge curve (U) resistance curve(R).Head discharge curve (u) is function of flow rate(Q) and discharge pressure(P).Resistance curve(R) changed according to resistance of the pipe or wall.

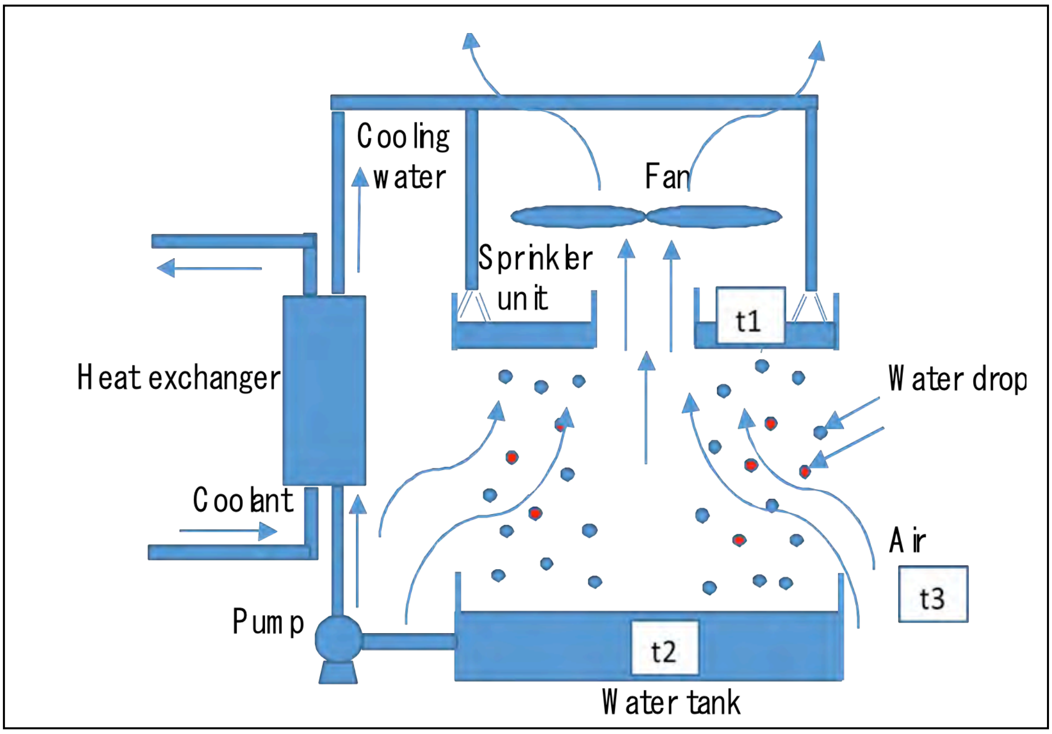
According to the fig 4 reduction of opening of the pipe valve, Rise in Resistance is shows as R1→R2.and its results flow rate is decrease from Q1→Q2, discharge pressure rise from P2→P1.
In fig (5) according to decrease in rotational speed (N), express decrease in flow rate. If we reduced rotational speed from N1→N2 discharge curve u changed from U1→U2.On the other hand resistance curve(R) is not changed flow rate is decreased from Q1→Q2. And Discharge pressure decrease from P1→P2.

1.6 cooling tower
1.6.1 Overview of the cooling tower:
Cooling tower is a device for cooling the cooling water, its principle is water droplet sprayed from top and air flow blow from below is efficient and well together. And evaporating a portion of the water droplets. So according to this vaporization heat, and cool the surrounding water drops. For the evaporation of 1kg of water, 2260kJ of amount of heat is required. It refers to the heat as ("heat of

vaporization"). Because it would be to take the heat from the surrounding water droplets and cooled the surrounding water drops.

In Fig 6 (t1) : cooling water inlet temperature,(t2) : cooling water outlet temperature, (t3) : wet bulb temperature of incoming air, (t1－t2) is called as (Range)and (t2－t3) is called as (approach).

Fig 6



Range : t1 – t2 Approach : t2－t3

1.6.2 Efficiency of the cooling tower

Efficiency of cooling tower (%) = (range) / (range + approach) * 100

(1) The range increase → The efficiency increase The

range decrease → The efficiency decrease

(2) The approach increase → The efficiency decrease

The approach decrease → The efficiency increase

1.6.3 The improvement of cooling tower efficiency

1.6.3.1 Condition for the efficiency improvement

Parameters for the cooling tower efficiency is the amount of evaporation of the water droplets.

The condition of evaporation is as follows:

1) To make smaller size of water droplet

2) Well contact between water drop and air flow up draft

Filler is important for well contact between water drop and air flow up draft (see1.6.6)

1.6.3.2 Maintenance for efficiency improvement

(1) Clogging prevention of water spray piping

(2) Prevention of scale to filler

3) Prevention of filler breakage

4) To keep the efficiency of fan operation (cleaning of fan blade)

1.6.4 Reason for cooling tower water temperature does not decrease

1.6.4.1 Too much sprinkling water

1.6.4.2 Air volume reduction (the resistance of air flow increase by scale to filler)

1.6.4.3 Sprinkler unit failure (water hole clogging)

1.6.4.4 The position of cooling tower is not good installed.

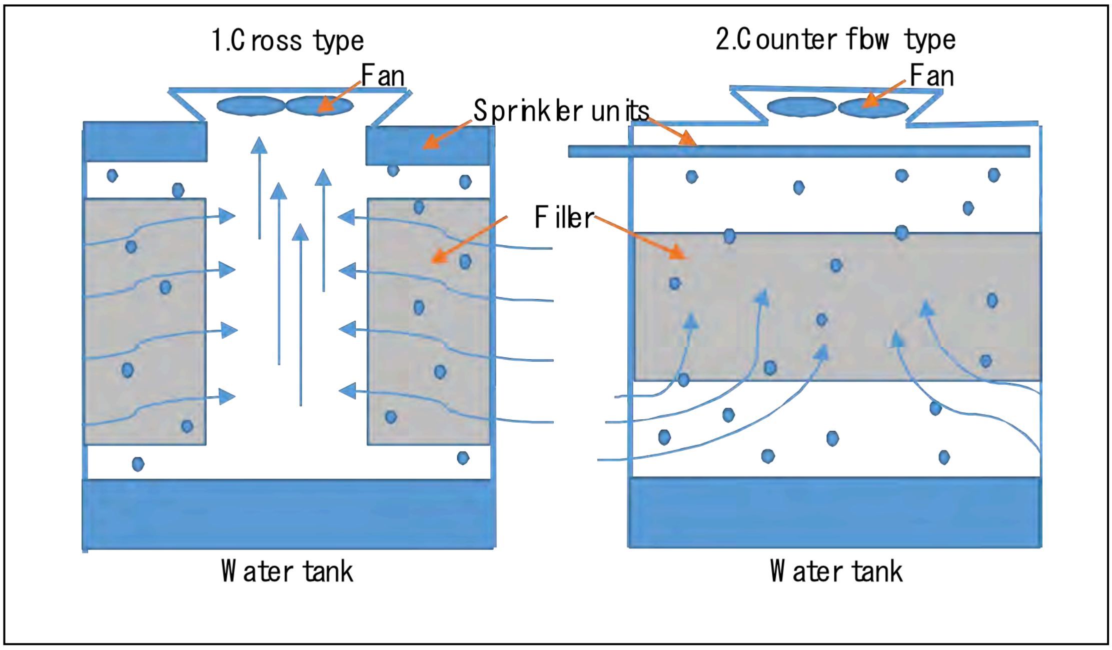
1.6.4.5 Filler is broken or damage

1.6.5 Energy saving of cooling tower

1.6.5.1 Cooling tower fan:

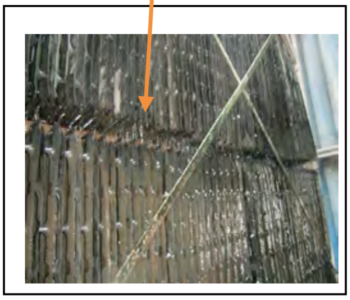
The cooling tower is effective for contact the air flow and water droplets and increase evaporation. There are two types of air flow

1- "cross flow type"
2- "Counter flow type".

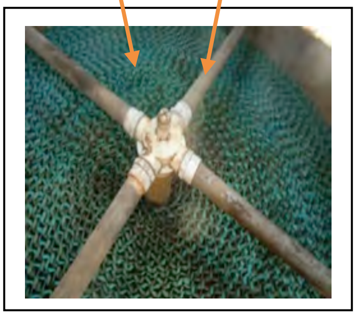


In Pakistan "counter flow type" is more used then cross type.

Cross flow type　　Filler　　Water tank



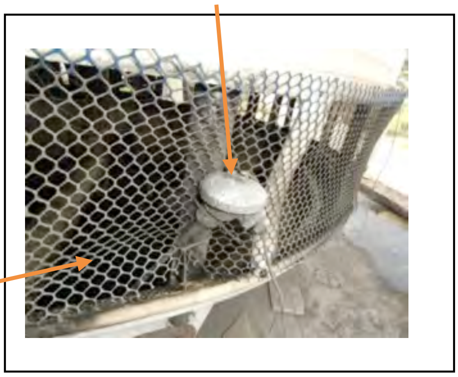
Counter flow type　　Filler　Sprinkler　　Fan



1.6.5.2 Energy saving of cooling tower fan:

In Pakistan there are many factory production for 24-hour throughout the year. In such production cooling water temperate decrease due to continuous operation of cooling tower fan in winter season and night time. Therefore, introduction of on off control for fan is big energy saving. The Setting temperature of fan is off by 25 °C and on by 28 °C.

Thermocouple



Water tank of cooling tower

1.6.6 Example for cooling tower failure (Counter flow type)

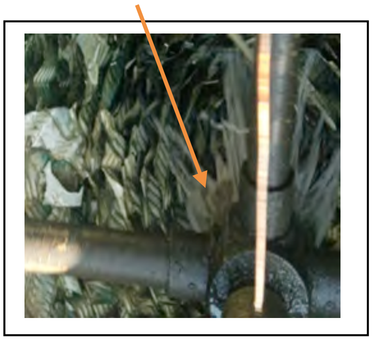
Damage of air in let louver

Good shower condition

too much water flow

Bad shower

same as left



Leakage from shower head

Chapter 8 Power generator engine

(1) Outline of power generation unit

1) Generator: kVA, Engine: kW (unit)

Scale of the generators installed in factories in Pakistan: 100kVA – 650kVA

2) Type of engines and fuel

(Type of engine)	(Kind of fuel)
a) Diesel engine	Light oil (High speed diesel oil)
b) Gas engine	Natural gas
c) Hybrid type engine	Blending of light oil and natural gas

3) Operation principle

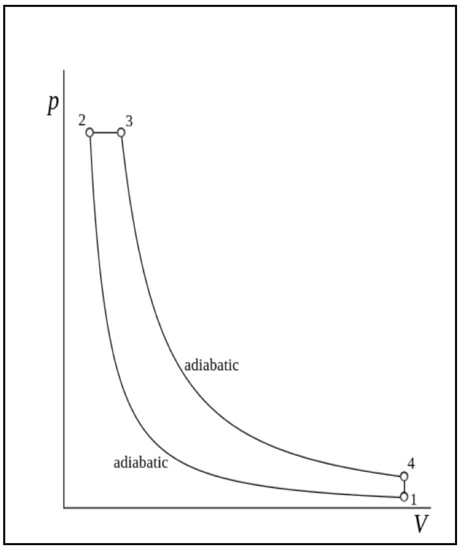
a) Diesel engine (Diesel cycle P-V Diagram)

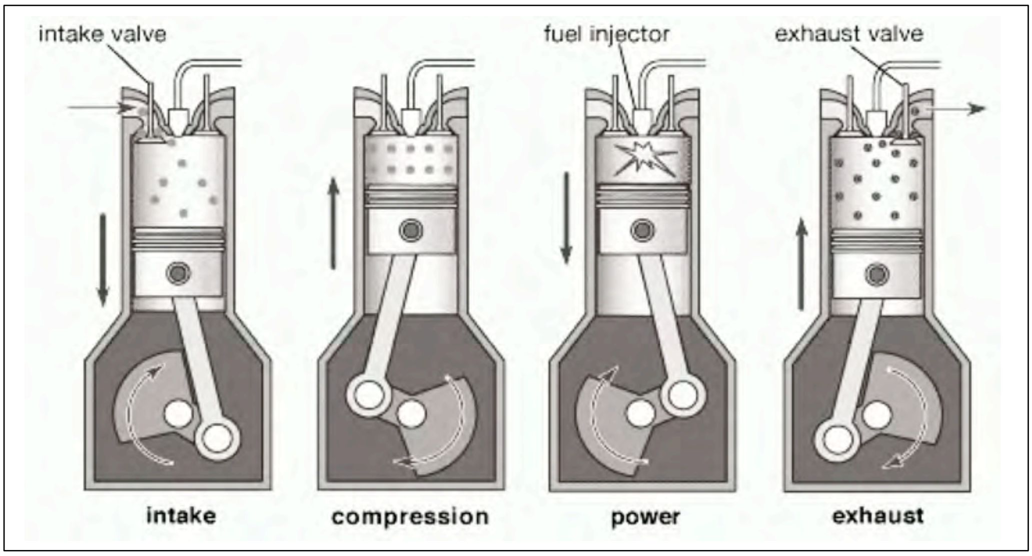
1-2: Adiabatic compression

2-3: Fuel injection and combustion

3-4: Adiabatic expansion

4-1: Exhaust and Air intake





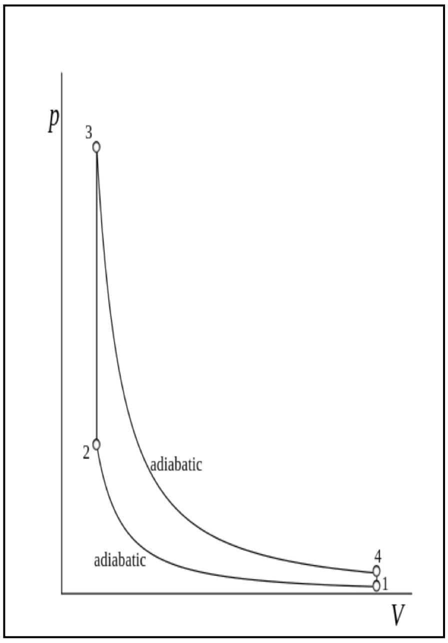
b) Gas engine (Otto cycle P-V Diagram)

1-2 : Adiabatic compression

2-3 : Ignite up fire and explosive combustion

3-4 : Adiabatic expansion

4-1 : Exhaust and air intake and fuel supply



(Note)

Comparison of gas engine and gasoline engine

1) Same point

Operation principle has Otto cycle.

It is Igniting up fire system.

2) Different point

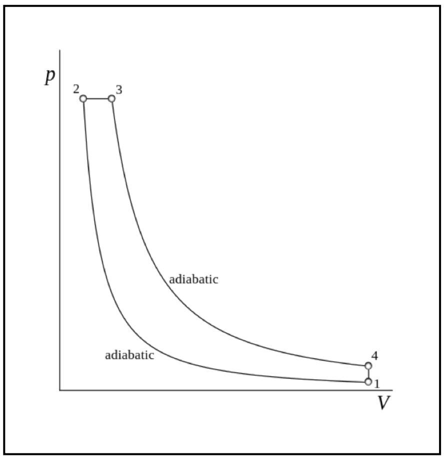
Gas engine : Carburetor is not required.

Gasoline engine : Carburetor is required.

c) Hybrid type engine

What is Hybrid type engine ?

Hybrid type engine is the engine which burns blended fuel of light oil (high speed diesel oil) and natural gas.

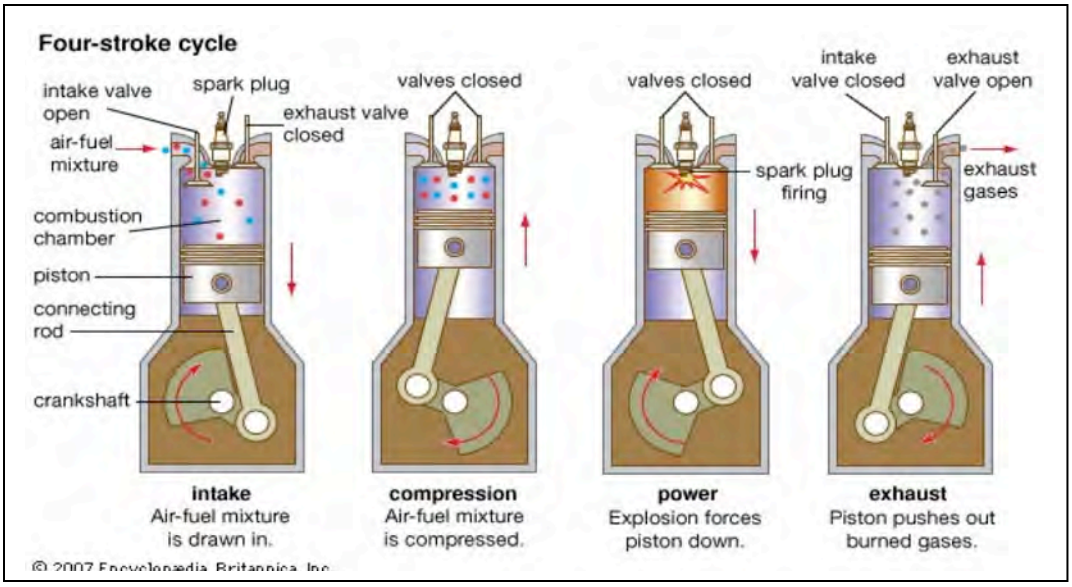


1-2 : Adiabatic compression

2-3 : light oil injection and combustion

3-4 : Adiabatic expansion

4-1 : Exhaust and intake air / natural gas



4) Classification of the engine by cooling method of water and oil

A small size - medium size engine: Air-cooling (Radiator is required.)

A Big size engine: Water cooling (Heat exchanger and cooling tower are required.)

Radiator Heat exchanger Cooling tower

(2) Maintenance management

1) Maintenance checkpoints

Are the pressure and temperature of the lubricant oil normal ? Is there any lubricant oil leakage ?

Are there any clogging of the fuel oil filter ? Is there any fuel oil leakage ?

c) Are the pressure and temperature of the coolant normal ?

d) Is the exhaust gas temperature normal? Is there any leakage of the exhaust gas?

e) Is the turbocharger stable ? Any abnormal noise or vibration ?

f) Is the number of engine revolution normal ?

2) Importance of the maintenance

The maintenance is extremely important and shall be periodical to extend the service life of the engine. Currently high speed diesel oil (HSDO) and natural gas have been used as fuel. However utilization of light diesel oil (LDO)should be investigated from the viewpoint of saving energy cost. Maintenance interval is shown below table about using HSDO and LDO.

The engine is defiled faster in the case of using LDO than the case of using HSDO. Therefore, maintenance interval is shortened in the case of using LDO.

No	Maintenance item	Maintenance interval	
		Use of high speed diesel oil	Use of light diesel oil
1	Draining water from the fuel service tank	?	Every day
2	Cleaning inside of the service tank	?	Every one year
3	Replacement of fuel oil filter	300hrs	200hrs
4	Replacement of lubricant oil filter	300hrs	200hrs
5	Washing filter of the turbocharger	300hrs	200hrs
6	Replacement of lubricant oil	300hrs	200hrs
7	Washing the oil cooler	At oil temperature rise (Max. 110-120 ℃)	
8	Washing the outside of radiator	1,000hrs	1,000hrs
9	Washing the inside of radiator	4,000hrs	4,000hrs
10	Opening maintenance of the turbocharger	6,000hrs	4,000hrs
11	Opening maintenance of the cylinder head	8,000hrs	6,000hrs
12	Overhaul (pulling out pistons)	16,000hrs	12,000hrs

The equipment and component of engine

Radiator

Cooling fan for radiator

Turbo charger

Blower f

Chapter 9 AC Arc Welder

1. Energy conservation measures of AC arc welder

Energy conservation measures of AC arc welder are to reduce stand-by power..

2. Outline of AC arc welder

AC arc welder generates low voltage and large current by a transformer which input voltage is 200V or 400V and output voltage is 50V, and implement arc welding work.

Overview of AC arc welder is shown in Figure 1. Circuit diagram is shown in Figure 2.

Arc welding work starts by close of Switch S1 and generation of arc between welding rod and base metal. Switch S1 is opened after finish of arc welding work.

Figure 1 Overview of AC arc welder

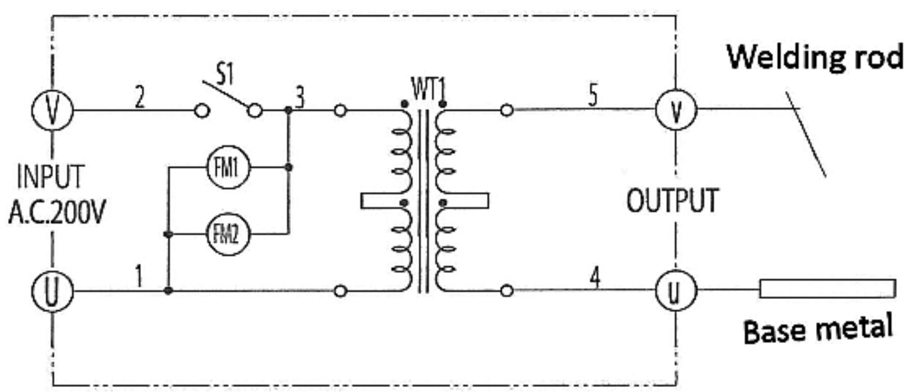


Figure 2 Circuit diagram of AC arc welder

3. Stand-by power of AC arc welder

Stand-by power is large as shown in Table 1. The stand-by power is no-load power of a transformer when Switch S1 is closed.

Table 1 Example of stand-by power of AC arc welder

4. Measures of improvement of stand-by power

Welder model No.	Rated output current	Stand-by power (Reference)
B-300 (Non voltage reducing device)	300 A	450 W
B-500 (Non voltage reducing device)	500 A	1000 W
BS250M (with built-in voltage reducing device)	250 A	380 W (Input frequency of 50Hz)
BS300M (with built-in voltage reducing device)	300 A	530 W (Input frequency of 50Hz)
BP-300 (with built-in voltage reducing device)	300 A	450 W
BP-400 (with built-in voltage reducing device)	400 A	80 W
BP-500 (with built-in voltage reducing device)	500 A	100 W
BPR-500 (with built-in voltage reducing device)	500 A	120 W
Source: Website of DAIHEN Corporation, Japan		

4.1 Measures by welding operators

(1) Switch off of Switch S1 and NFB after welding work is finished and during idle time.

4,2 Measures by machines

(1) New welders with automatic switch-off devices by timer are introduced.

5. Procedure of energy conservation measures of steam boiler and steam system

Energy conservation measures of steam boiler and steam system are implemented as the following procedure. Flowchart of steam boiler and steam system is shown in Figure 1-1.

1st step: Measurement and improvement of exhaust heat loss of boiler

2nd step: Measurement and improvement of heat radiation loss of boiler body

3rd step: Inspection of heat balance of steam system

4th step: Inspection and improvement of steam leakage of piping and equipment

5th step: Inspection and improvement of recovery of steam condensate

6th step: Inspection and improvement of heat radiation loss of steam piping

7th step: Preparation and implementation of energy management standards to keep energy conservation activities

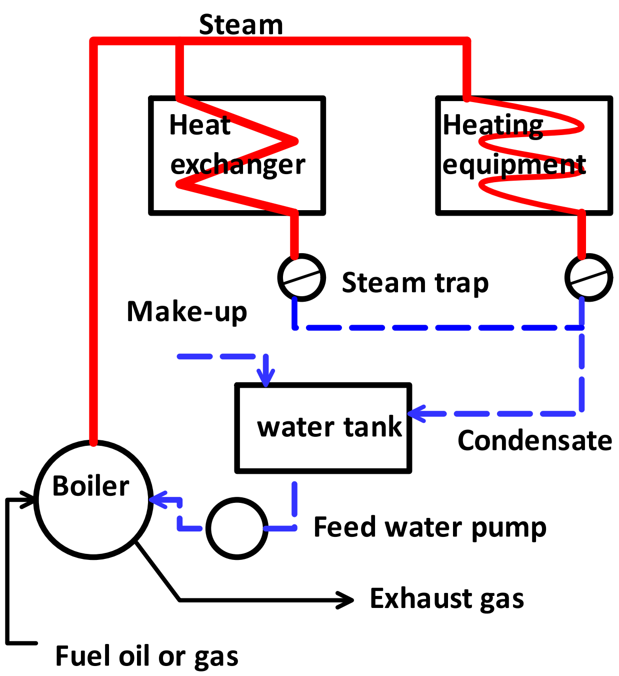


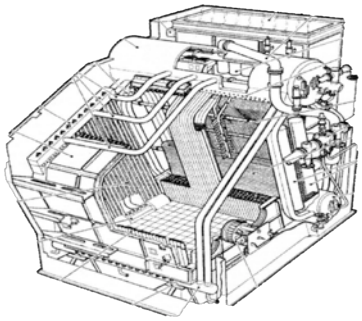
Figure 1-1 Flowchart of Steam system

6. Measurement and improvement of exhaust heat loss

6.1 Steam boiler

2.1.1 Type of steam boiler

Steam boilers using in factories are Water tube boilers, flue tube boilers and small-sized once-through boilers as shown in Figure 2.1, 2.2 and 2.3.



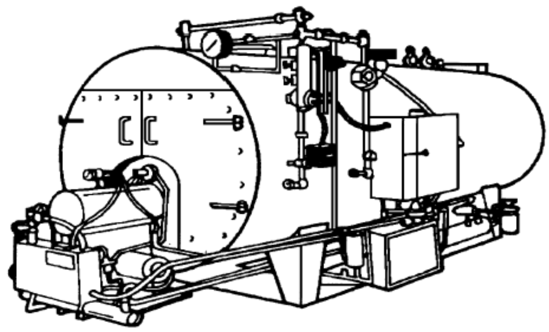


Figure 2-1 Water tube boiler **Figure 2-2 Flue tube boiler**

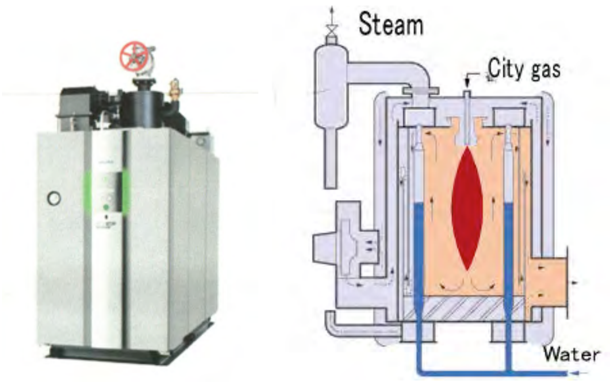


Figure 2-3 Small-sized once-through boiler

2.1.2 Heat flow and thermal efficiency of boiler

Heat flow of steam boiler is shown in Figure 2-4.

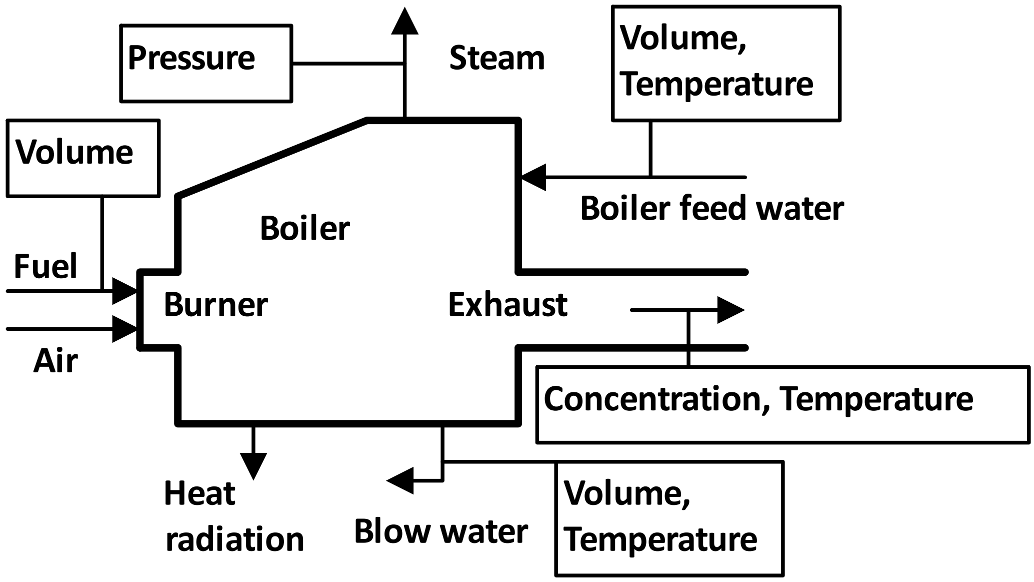


Figure 2-4 heat flow of steam boiler

Boiler thermal efficiency is calculated with the following methods:

- Input and output heat method (Direct method)
- Heat loss method (Indirect method)

Figure 2-5 shows an example of heat balance of boiler. Exhaust heat loss is most of heat loss of boiler.

(1) Input and output heat method (Direct method)

Direct method is calculated from input energy of fuel volume and output energy of generated steam volume.

Equation of boiler efficiency is as follows:

$$\text{Boiler efficiency E (\%)} = \frac{\text{Steam generated heat Qs (kcal)}}{\text{Fuel combustion heat Qf (kcal)}}$$

$$= \frac{W \times (hs - hw)}{F \times HL}$$

W: Generated steam volume (kg)

hs: Enthalpy of steam (kcal/kg)

hw: Enthalpy of water supply (kcal/kg)

F: Volume of fuel (L or m3)

HL: Low calorific value (kcal/L)

Generated steam volume is measured with steam flowmeter or feed water meter.

Consumed fuel volume is measured with fuel flowmeter.

(2) Heat loss method (indirect method)

Indirect method is calculated from exhaust heat loss and radiation heat loss.

Equation of boiler efficiency is as follows:

Boiler efficiency E (%) = 100 - (Le + Lr + Lo)

Le: Exhaust heat loss (%)

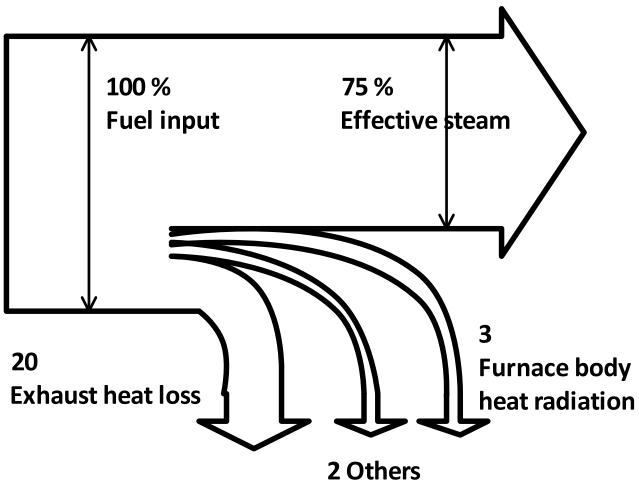
Lr: Furnace body heat radiation loss (%)

Lo: Percentage of other heat losses (%)

Exhaust heat loss is calculated with measurement of temperature and oxygen concentration of exhaust gas.

Furnace body heat radiation loss is calculated with surface temperature and circumstance temperature of furnace body

Other heat losses are blow water loss, steam leakage etc..



Boiler efficiency = 75%

Figure 2-5 An example of heat balance of boiler

2.1.3 Exhaust heat loss of boiler

Exhaust heat loss is caused by excess air volume or incomplete combustion in combustion chamber.

Excess air ratio is calculated from oxygen concentration (%) of exhaust gas. Oxygen concentration of exhaust gas is measured by flue gas analyzer.

Excess air ratio is calculated with the following equation.

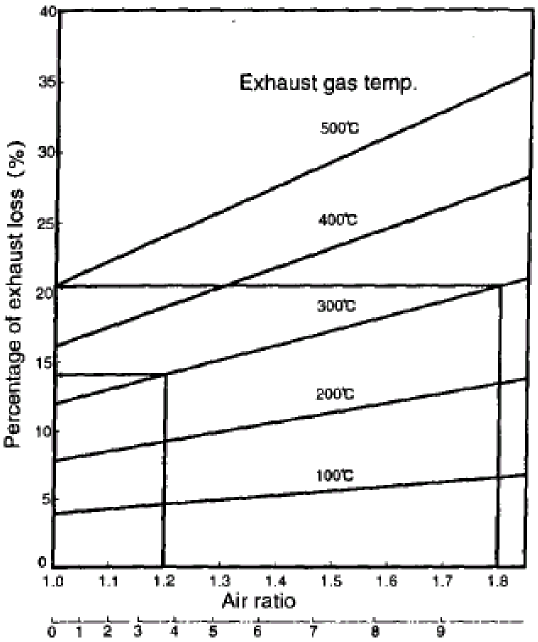
$$\text{Air ratio } m = \frac{\text{Actual volume of combustion air } (m^3)}{\text{Theoretical air volume } (m^3)}$$

$$= \frac{21}{21 - (\text{Percentage of } O_2 \text{ in the exhaust})}$$

(1) Exhaust heat loss from graph

Figure 2-6 shows exhaust heat loss calculated from air ratio.

When Air ratio is improved from 1.8 to 1.2, exhaust heat loss is reduced by 7% as shown in Figure 2-6.



Concentration (%) of O2 in exhaust gas

Figure 2-6 Air ratio and exhaust heat loss

(2) Exhaust heat loss calculation from elemental analysis of fuel

Equation of exhaust heat loss (Qe) is as follows:

Qe = G * Cp * (T exgas – T ambient)

Where,

G = Actual exhaust gas volume (Calculation from elemental analysis and oxygen %)

Cp = Specific heat of exhaust gas (Source: Thermal dynamics handbook)

T exgas = temperature of exhaust gas (Measurement data)

T ambient = ambient temperature (Measurement data)

Actual exhaust gas volume (G) is calculated from the following equation.

G = Go + (m-1) Ao

Where,

Go = Theoretical combustion exhaust gas volume for fuel gas calculated by elemental analysis of fuel

m = Air ratio

Ao = Theoretical combustion air volume calculated by elemental analysis of fuel

(3) Exhaust heat loss calculation when elemental analysis of fuel is not given

Equation of exhaust heat loss (Qe) is as follows:

Qe = G * Cp * (T exgas – T ambient)

G = Go + (m-1) Ao

Theoretical combustion exhaust gas (Go) and air volume (Ao) are calculated by the following simplified equation from heat value of fuel as shown in Table 2.1, when elemental analysis of fuel is not given.

Table 2.1 Simplified equation of Go and Ao

Fuel	Go	Ao
Solid fuel	0.904 * HL / 1000 + 1.67 (m^3N / kg)	1.01 * HL / 1000 + 0.56 (m^3N / kg)
Liquid fuel	15.75 * HL / 10000 – 3.91 (m^3N / kg)	12.38 * HL / 10000 – 1.36 (m^3N / kg)
Gas fuel	12.25 * HL / 10000 (m^3N / m^3N)	11.20 * HL / 10000 (m^3N / m^3N)

Note: HL is lower heat value of fuel (kcal/kg or kcal/m^3N)

Source: Boie's equation, Japan Industrial Standard (JIS B8222 - 2011)

2.1.4 Recovery of exhaust heat loss

Exhaust heat loss is recovered by economizer and air heater as shown in Figure 2-7.

Energy saving effect of installation of an economizer is 1% of fuel conservation, when difference in the feed water temp. at the inlet and outlet of the economizer = 7℃

Energy saving effect of installation of an air heater is 1% in boiler efficiency increase, when difference in the exhaust temp. at the inlet and outlet of the air heater = 20℃

Figure 2-8 shows an example of improved heat balance of boiler. Exhaust heat loss is reduced from 20% to 8% by improvement of air ratio and recovery of exhaust heat loss compared with Figure 2-5.

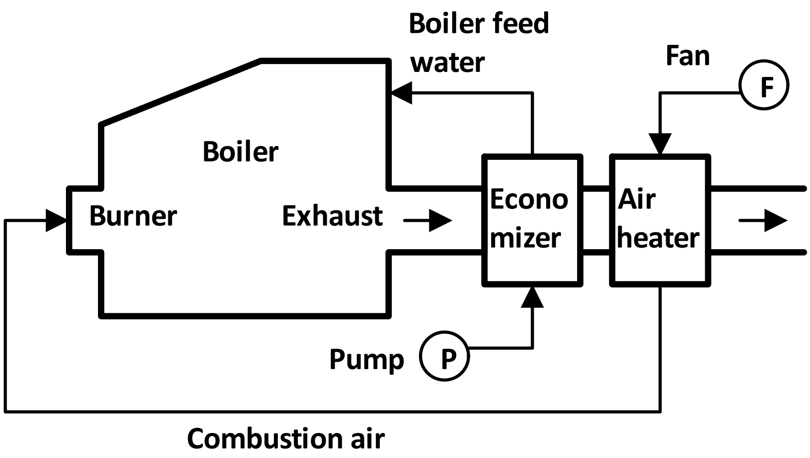


Figure 2-7 Recovery of exhaust heat

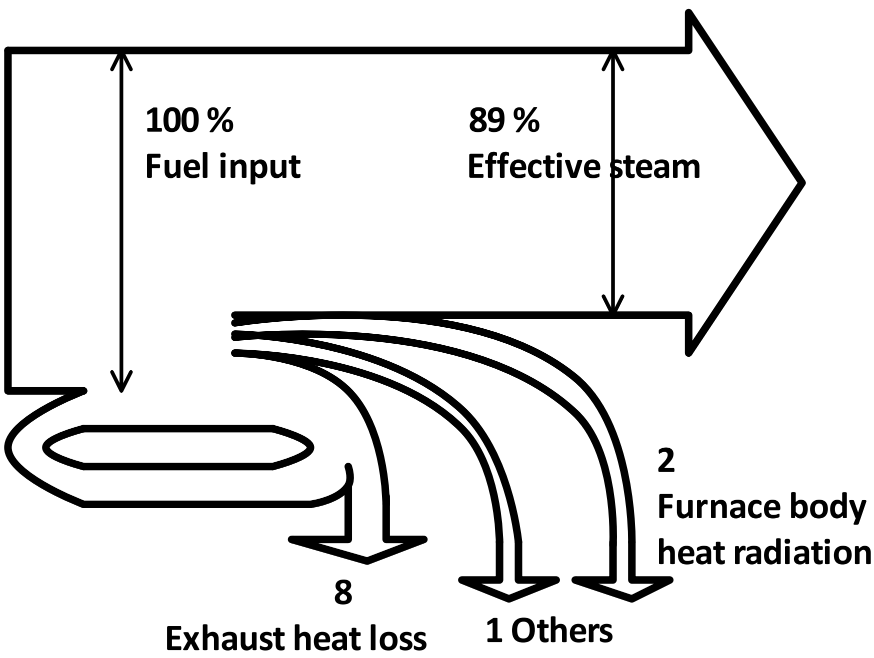


Figure 2-8 an example of improved heat balance

7. Measurement and improvement of heat radiation loss of boiler body
   Radiation volume Q (kcal/m^2h) through radiation from the furnace wall

$$Q = 4.88\varepsilon \left\{ \left(\frac{t + 273}{100} \right)^4 - \left(\frac{a + 273}{100} \right)^4 \right\}$$

t: Furnace wall surface temp. (℃)

a: Air temp. surrounding the furnace (℃)

ε: Furnace wall surface radiation rate

Table 3.1 shows percentage of radiation heat loss (at t-a=28℃) of boiler body after enforcement of insulation.

Table 3.1 Percentage of radiation heat loss of boiler body at circumstance temperature of 28℃

Boiler capacity t/h	5	10	50	100
Percentage of radiation heat loss %	2.0	1.4	0.7	0.4

8. Inspection of heat balance of steam system

Generated steam is sent to production equipment, but a part of the steam is useless steam.

Figure 4-1 shows that generated steam of 100 is sent heat exchanger and heating equipment and consumed in heat exchanger of 45 and heating equipment of 40. Steam of 15 is unclear loss.

Steam volume loss includes steam leakage, blow in steam trap etc.

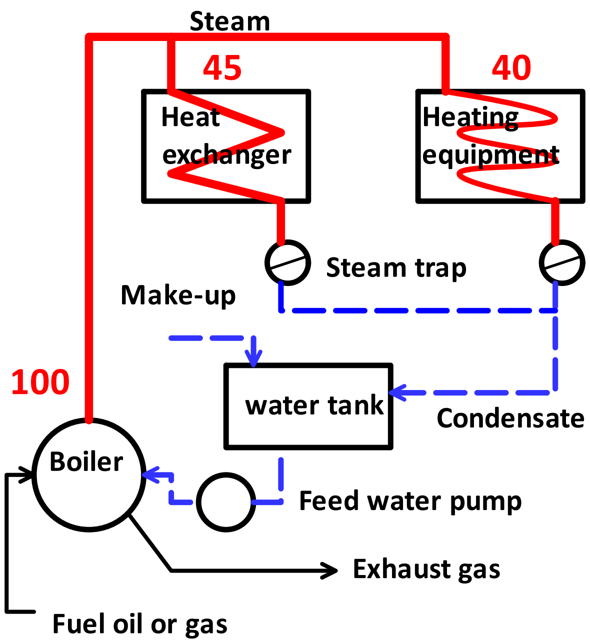


Figure 4-1 Check of steam balance

9. Inspection and improvement of steam leakage of piping and equipment

Steam leakage is checked and repaired as maintenance work to prevent energy loss.

Figure 5-1 shows steam leakage volume from a small hole.

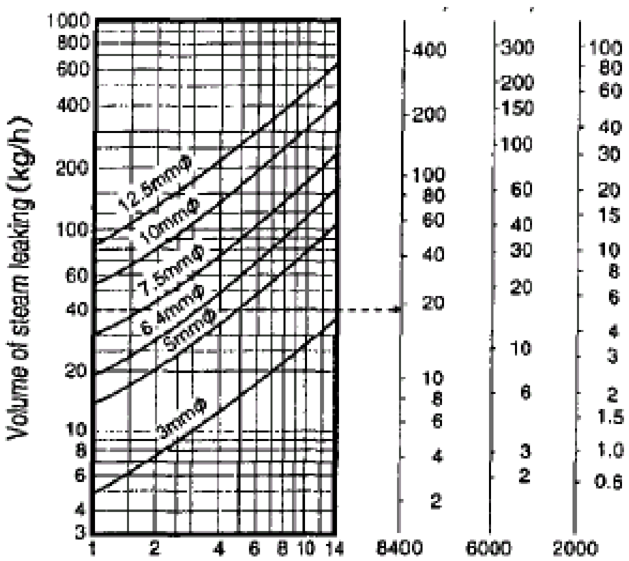


Figure 5-1 Volume of steam leak from a small hole

10. Inspection and improvement of recovery of steam condensate

    Steam condensate is recovered through steam traps and used to feed water of boiler and hot water of operation.

6.1 Type of steam trap

Types of steam traps are float type, thermo-dynamics type and orifice type. Types are selected by use and steam volume.

6.2 Steam trap operation and troubles

Operation condition of steam traps are shown in Table 6-1. Periodical inspection, overhauling and replacement of steam traps are necessary for heating operation.

Table 6-1 operation condition of steam traps

Operation condition	Material from drain port	Troubles
Normal	Drain only	No
Leakage of steam trap	Steam and drain	Steam loss
Locking of steam trap	Decrease of drain	Decrease of heating effects
Full locking of steam trap	No drain	Stop of heating operation

11. Inspection and improvement of heat radiation loss of steam piping

    Surface temperature of steam piping is more than 100 degC and so radiation heat loss is large. Radiation heat loss of steam piping is reduced by 90% with heat insulation work such as glass wool and slag wool as shown in Figure 7-1.

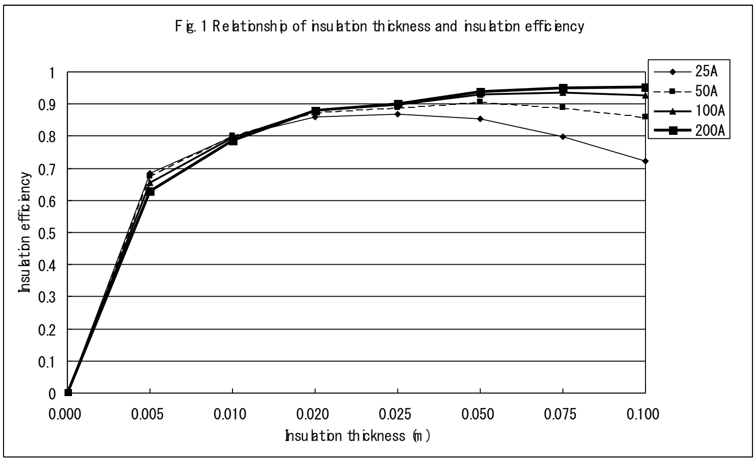


Figure 7-1 Relationship of insulation thickness and insulation efficiency

12. Preparation and implementation of energy management standards to keep energy conservation activities

    After implementation of energy saving measures, energy management standards should be perpetrated and implemented to keep high energy conservation conditions.

    Table 8-1 shows examples of energy management standards of steam boiler and steam system.

Table 8-1 Examples of management standards of steam boiler and steam system

Energy consuming elements	**Energy consuming cause**	**Examples of management criteria**
Steam boiler: Air ratio	Excess air causes exhaust heat loss	Flue tube boiler: 1.2 -1.3
Steam boiler: Temperature of exhaust gas	High temperature of exhaust gas causes exhaust heat loss	Flue tube boiler: 150 to 200 degC
Steam trap	Steam leakage causes heat loss. Plugging causes to decrease heating effects.	No leakage No plugging
Heat insulation of steam piping	Non insulation piping causes radiation heat loss	Thickness of insulation: 20 to 30mm of glass wool

Chapter 11 Compressed air system

13. Procedure of energy conservation measures of compressed air system

Energy conservation measures of compressed air system are promoted as the following procedure. Flowchart of compressed air system is shown in Figure 1.

1st step: Measurement and improvement of air leakage and air blow from piping and equipment

2nd step: Measurement and improvement of air pressure loss of piping and clean equipment

3rd step: Inspection and measures of required air pressure for operation of production equipment

4th step: Change of set air pressure of air compressors

a. Confirmation of variable pattern of compressed air consumption

b. Study of replacement and gathering of air compressors

5th step: Study of specifications and installation of multiple compressor control panels

a. Improvement of specific power consumption and delete of meaning –less operations

6th step: Preparation and implementation of management standards of compressed air system to keep energy conservation activities

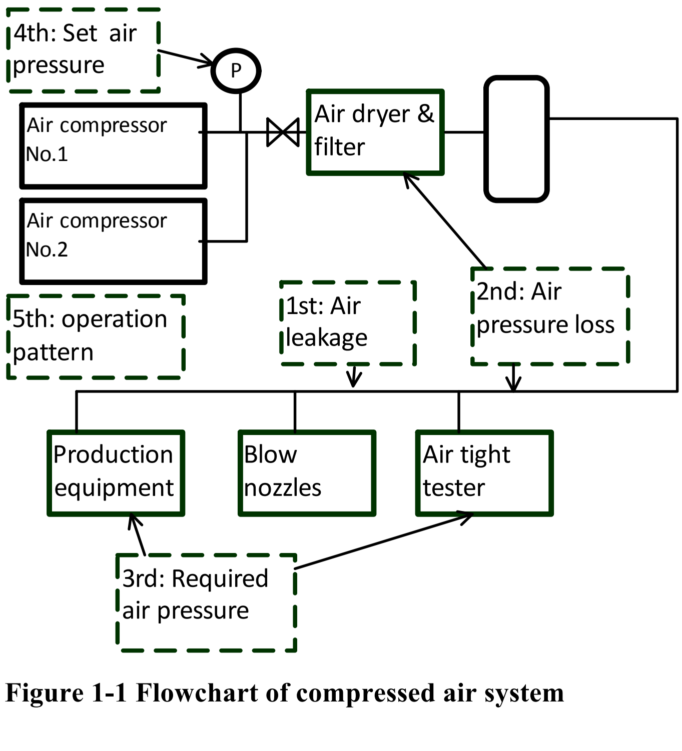


Figure 1-1 Flowchart of compressed air system

14. Measurement and improvement of air leakage and air blow from piping and equipment

14.1 Measurement method of air leakage

Air leakage from piping and equipment are measured with load ratio of air compressors and pressure reduction of piping and equipment.

a. Load ratio of an air compressor

Under the condition which all production equipment are stopped, a small-sized air compressor having capacity of 20% to 30% of all air compressors is operated and measured load ratio of the small-sized air compressor. Air leakage volume is delivery air volume of the small-sized air compressor which is calculated from load ratio of the compressor.
Load ratio of an air compressor is measured by suction air pressure, input current of motor and on-load time.

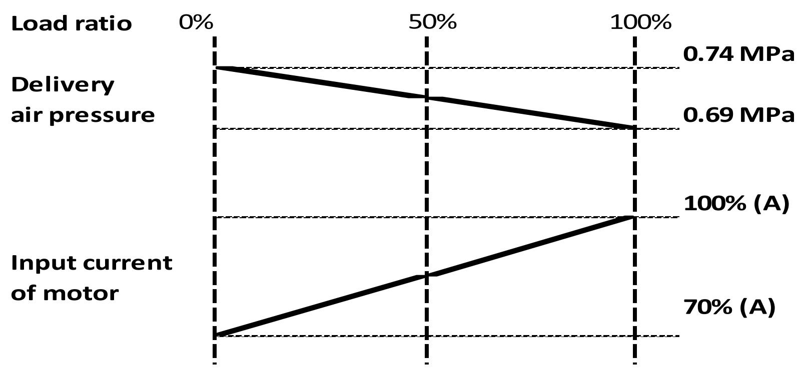


Figure 2-1 Load ratio of screw type air compressor

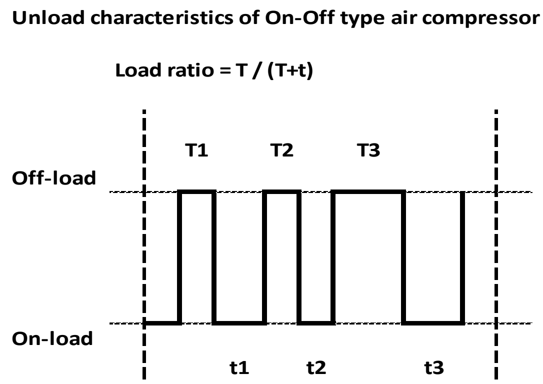


Figure 2-2 Load ratio of On-Off type air compressor

b. Air pressure reduction rate of piping and equipment

Under the condition which all production equipment are stopped, air pressure is raised to normal pressure and delivery air valves are closed, air pressure reduction speed of piping is measured during pressure reduction for 1 bar.
Air leakage volume is calculated from air pressure reducing speed per minutes.

When air pressure reduces by 1 bar for 50 seconds, air leakage volume is calculated as follows:

Air leakage volume (Q)

= (P1 - P2) * V / t /P0 = 3.72 m^3/min

Where,

P1 = 7.32 bar abs, P2 = 6.35 bar abs,

V= Inner volume of piping = 3.1 m^3

t = time = 0.833 min, P0 = 0.97 bar abs.

Delivery air volume of compressors= 6.2 + 6.6 = 12.8 m^3/min

Air leakage ratio = 29 % = 3.72/12.8*100

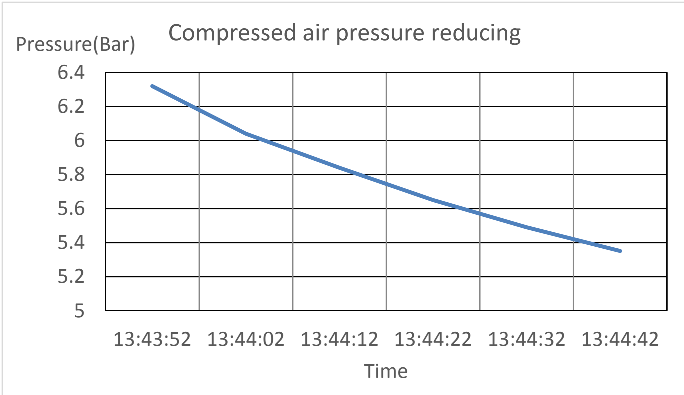


Figure 2-3 Example of pressure reduction curve

14.2 Inspection of air leakage points

Air leakage points are inspected with soap water test, noise detection test and supersonic detector

a. Soap water test

Soap water is made from washing soap and water.

When soap water is sprayed to joints and valves of piping under the normal operation, soap bubbles are generated at air leakage point.

Figure 2-4 Spraying soap water **Figure 2-5 Soap bubbles of leaked joint**

b. Noise detection test

When all equipment are stopped and air pressure is raised to normal pressure, inspectors can catch noise of air leakage from air leakage points.

c. Supersonic air leak detector

When a detector of supersonic wave is used to joints and valves of piping under the normal operation, the detector can catch supersonic wave from air leakage points.

Supersonic wave detector is difficult to use in small building of a factory, because the detector catches reflected supersonic from building walls other than supersonic wave of air leakage points.

Figure 2-6 Air leak detect by supersonic detector

14.3 Improvement of air leakage and air blow

2.3.1 Improvement of air leakage

a. Repairing of air leakage point
   - Replace sealing material of joint of piping and tighten threads
   - Replace parts and proper of valves of air leakage

b. Maintenance and inspection
   - Close the main air valves when production equipment is stopped.
   - Target value of air leakage ratio is 5% in factories of manufacturers.

2.3.2 Improvement of air blow

Air blow is used in many processes such as cleaning of products, preparation of cast iron mold, blowing metal scrap of milling machine with rubber hoses and air blow guns. Introduction of air blow gun with smaller diameter nozzle is very effective to energy saving instead of rubber hoses and large diameter blow gun.

Table 2.1 shows energy saving effects by change of nozzle diameter.

Figure 2.7 and 2.8 show air blow work and air blow gun.

Table 2.1 Effects of diameter of air blow nozzles

Air nozzle	Nozzle diameter	Air consumption at present	Air consumption after improvement	Change of impact pressure at 300mm
Air blow gun	8 mm to 6 mm	3.3 m3/min	1.8 m3/min	0.017 Mpa to 0.01 MPa
Air hose	10 mm to 8 mm	1.56 m3/min	1 m3/min	0.026 Mpa to 0.17 MPa
Total		4.86 m3/min	2.8 m3/min	

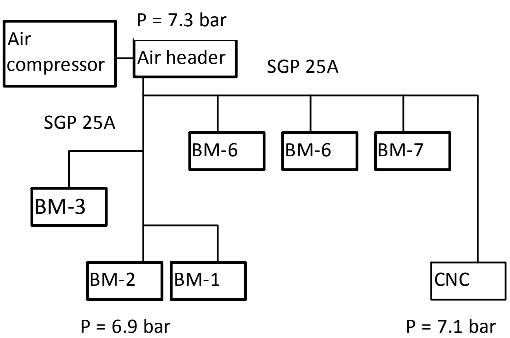
Figure 2.7 Air blow work **Figure 2.8 Air blow gun**

15. Measurement and improvement of air pressure loss of piping and air treatment units

15.1 Measurement of air pressure loss of piping and air treatment units

Air pressure loss of piping and air treatment units is shown as the deference of air pressure between delivery pressure of air compressors and inlet air pressure of each production equipment. Figure 3-1 shows delivery air pressure and inlet air pressure of machines BM-1 and CNC, which are measured simultaneously at 3 points by 3 persons.

Condensate drains cause air pressure loss in piping and air receivers.



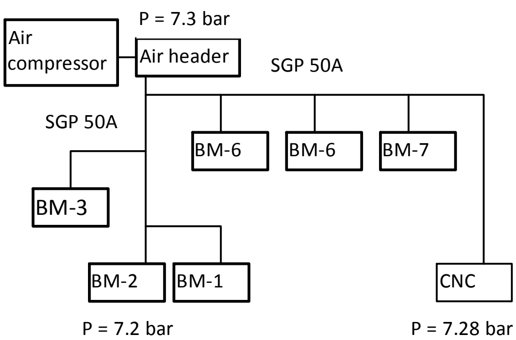


Figure 3-1 Existing air pressure **Figure 3.2 Improved pressure loss**

15.2 Improvement of air pressure loss of piping

Measures for reduction of air pressure loss of piping are as follows:

1) To replace air piping to larger size

Figure 3-2 shows a proposal of pressure loss improvement by replacement of piping from SGP25A to SGP50A. As a result of replacement of piping, air pressure loss is improved by 0.2 bar.

2) To make loop piping
3) Introduction of automatic drain trap and daily inspection of drain valves
4) Design standards of pressure loss of compressed air piping is 0.1 bar/100m of 2” piping.

15.3 Maintenance of air treatment units

Air treatment units are installed between air compressors and air headers or air receivers and consist of air filters, air dryers and mist separators.

1) Air dryers

Refrigerated air dryers are used in many factories. Pressure loss of refrigerated air dryer is constant.

2) Air filter and mist separator

Pressure loss of air filters and mist separators increases in proportion to operation hours Filter elements of air filters and mist separators are to be cleaned and replaced according to increase of deferential pressure

16. Inspection and measures of required air pressure of production equipment

16.1 Inspection of required air pressure of production equipment

Required air pressure is shown in Instruction manuals and specifications of equipment.

Minimum required air pressure is to be inspected through operation of machining, press machines etc. Examples of required air pressure are shown in Table 4-1.

Table 4-1 Examples of required air pressure

Equipment	Required air pressure	Equipment	Required air pressure
CNC machine	5 to 6 bar	Air blow	2 to 4 bar
Air cylinder	4 to 6 bar	Control circuit	3 to 4 bar
Air tight tester	6 to 10 bar	Air motor	6 to 10 bar

16.2 Measures of required air pressure of production equipment

1) Delivery air pressure of compressor is reduced by reducing of require air pressure.

2) Booster air compressor is installed for high pressure use such as air tight tester.

3) Air blower is installed for low air pressure use of 3 bar such as air blow nozzles.

17. Change of set air pressure of air compressors

17.1 Measurement of delivery air pressure of air compressors

1) Delivery air pressure of air compressor is decided the following equation:

Delivery air pressure = Required air pressure of production equipment + pressure loss of piping and air treatment units.

2) Required power of air compressor is calculated with the following equation:

$$La = \frac{mK}{K-1} \times \frac{PsQs}{6120} \times \left\{ \left[\frac{Pd}{Ps} \right]^{\frac{K-1}{mK}} - 1 \right\}$$

K: Specific heat ratio, K=1.4 for air
Qs: Air volume on suction state, m 3/min
Ps: Suction pressure absolute, kg/m2
Pd: Delivery pressure absolute, kg/m2
m: Compression stage

Required power La decreases in proportion to delivery pressure and air volume.

Therefore lower set air pressure of air compressor is important for power saving.

Figure 5-1 shows power reduction ratio by reducing of delivery pressure. When delivery air pressure is reduced to 6 bar from 7 bar, theoretical power of air compressor is reduced by 10%.

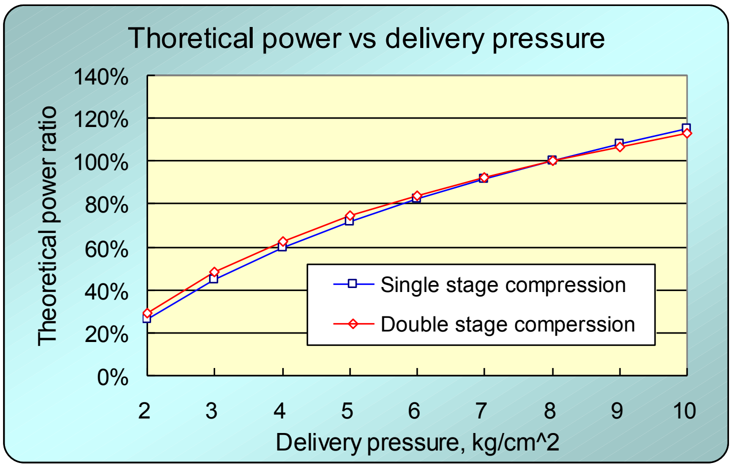


Figure 5-1 Theoretical power reduction by delivery air pressure

18. Study of specifications of multiple unit control panel and introduction of inverter control

18.1 Improvement of specific power consumption ratio

Specific power consumption ration is shown as input power per delivery air volume (kW/m3/min). Table 6-1 shows an example of specific power consumption ratio of screw type air compressor. Specific power consumption ratio is efficiency of air compressor. Efficiency is the highest at 100% load operation and lower by low load operation.

Table 6-1 Example of specific power consumption ratio of screw type air compressor

Load (%)	Specific power consumption ratio (kW/m3/min)	Input power (kW)	Delivery air volume (m3/min)
100	6.55	80.6	12.3
80	7.72	75.7	9.8
70	8.52	73.3	8.6
50	11.2	68.5	6.1
30	17.7	63.6	3.6
20	25.5	61.2	2.4

18.2 Multiple unit control of air compressors

When more than 3 sets of air compressors are installed, operation with multiple control is effective to save power and prolong machine life. Main air compressor with large capacity is operated at 100% load, that is power saving.

18.3 Inverter control of air compressor

Screw type air compressor with inverter control is operated at high specific power consumption ratio of 5 to 7 kW/m3/min between 100% and 30% load.

Air compressor with built-in inverter control unit is recommendable.

When an inverter unit is assembled in an existing air compressor, inverter unit is selected and installed according to instruction of manufacturer of air compressor.

Figure 6-1 shows partial load performance of air compressors. Screw type air compressor with inverter control has same characteristics as theoretical ideal curve.

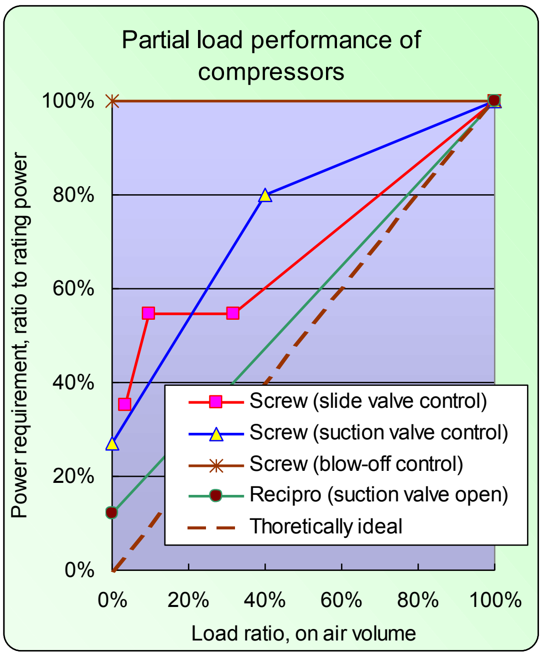


Figure 6-1 partial load performance of air compressors

19. Preparation and implementation of energy management standards to keep energy conservation activities

    After implementation of energy saving measures, energy management standards should be perpetrated and implemented to keep high energy conservation conditions.

    Table 7-1 shows examples of energy management standards of compressed air system.

Table 7-1 Examples of management standards of compressed air system

<table>
<tr><th>Energy consuming elements</th><th colspan="3">Energy consuming cause</th><th>Examples of management criteria</th></tr>
<tr><td>Air leakage</td><td colspan="3">Air leakage from piping, joints of equipment, inside of equipment, nozzles and valves</td><td>Less than 5% of capacity of air compressors</td></tr>
<tr><td rowspan="5">Reduction of deferential pressure of dryers and filters</td><td>Unit</td><td>Initial</td><td>Criteria</td><td rowspan="5">1)Maximum deferential pressure = 0.9 bar
2)Change of filter element at 0.35 bar of deferential pressure</td></tr>
<tr><td>Dryer</td><td>0.2 bar</td><td>0.2 bar</td></tr>
<tr><td>Filter</td><td>0.05 bar</td><td>0.35 bar</td></tr>
<tr><td>Mist separator</td><td>0.2 bar</td><td>0.35 bar</td></tr>
<tr><td>Total</td><td>0.45 bar</td><td>0.9 bar</td></tr>
<tr><td>Cleaning and replacement of suction air filter element</td><td colspan="3">Reduction of suction air volume:
Specific power ratio
Useless operation</td><td>1)Periodical measurement of deferential pressure
2)Deferential pressure:
- Cleaning at 60mmHg
- Change at 70mmHg</td></tr>
<tr><td>Change of oil separator element</td><td colspan="3">Increase of deferential pressure causes increase of useless power.</td><td>Change of element at more than 0.07MPa of deferential pressure</td></tr>
<tr><td>Set pressure of air compressors</td><td colspan="3">Reduction of set pressure
= energy saving</td><td>Reduction of deferential pressure</td></tr>
<tr><td>Load ratio of air compressors</td><td colspan="3">Reduction of specific energy consumption ratio</td><td>Recommendation of multiple unit control and inverter control</td></tr>
</table>

Chapter 12 ABC of combustion of gas fuel

1 Fuel gas

Fuel gas is any one of a number of fuels that under ordinary conditions are gaseous. Many fuel gases are composed of hydrocarbons (such as methane or propane), hydrogen, carbon monoxide and other gases. Such gases are sources of potential heat energy or light energy that can be readily transmitted and distributed through pipes directly to the place of consumption.

Some fuel gases are liquefied for storage and transport. While their gaseous nature has advantages, avoiding the difficulty of transporting solid fuel and the dangers of spillage inherent in liquid fuels. It is possible for a fuel gas to be undetected and collect in certain areas, leading to the risk of a gas explosion. For this reason, odorizers are added to most fuel gases so that they may be detected by a distinct smell.

The most common type of fuel gas in current use is natural gas. And LNG is popular, too. LPG is a fossil fuel closely linked to oil. About two thirds of the LPG people use is extracted directly from the Earth in the same way as ordinary natural gas. The rest is manufactured indirectly from petroleum (crude oil) drilled from the Earth.

There are some manufactured fuel gases such as follows:
Coal gas, Water gas, Producer gas, Syngas, Wood gas, Biogas, Blast furnace gas, Acetylene and others.

2 Fuel gas composition and amount of heat generation

2.1 Natural gas

The most common and widely used fuel gas is natural gas. Composition of natural gas is not common. Typical analysis and their range is shown in Table 2.1. Physical properties of natural gas are shown in Table 2.2.

Table 2.1 Composition of natural gas

Component	Typical Analysis (mole %)	Range (mole %)
Methane (CH_4)	95.0	87.0 - 97.0
Ethane (C_2H_6)	3.2	1.5 - 7.0
Propane (C_3H_8)	0.2	0.1 - 1.5
iso – Butane (C_4H_{10})	0.03	0.01 - 0.3
normal – Butane (C_4H_{10})	0.03	0.01 - 0.3

iso – Pentane (C_5H_{12})	0.01	trace - 0.04
normal – Pentane (C_5H_{12})	0.01	trace - 0.04
Hexanes plus (C_6H_{14})	0.01	trace - 0.06
Nitrogen (N_2)	1.0	0.2 - 5.5
Carbon Dioxide (CO_2)	0.5	0.1 - 1.0
Oxygen (O_2)	0.02	0.01 - 0.1
Hydrogen (H_2)	trace	trace - 0.02

(Source: https://www.uniongas.com/)

Table 2.2 Physical property of natural gas

Physical property	Typical value	Range
Specific Gravity	0.58	0.57 - 0.62
Gross Heating Value(dry basis)	38.0 (MJ/m^3)	36.0 - 40.2
Ignition Point	593 (^oC)	--
Flammability Limits	4-16% (vol% in air)	--

(Source: https://www.uniongas.com/ and http://www.engineeringtoolbox.com/)

Natural gas is exploited at many places worldwide. Table 2.3 shows the composition and properties of natural gas mined in some places on the earth.

Table 2.3 Data of natural gas world wide

Production Area	CH_4	CmHn	CO_2	O_2	N_2	Specific Gravity*	GHV**	NHV***
Niigata	**97**	**2**	**1**			**0.57**	**40.5**	**36.9**
Alaska	**99.8**	**0.1**			**0.1**	**0.56**	**39.7**	**35.7**
Brunei	**89.8**	**10.2**				**0.63**	**44.5**	**39.8**
Lacq	**97.4**	**2.3**			**0.3**	**0.57**	**40.5**	**36.5**
Groningen	**81.5**	**3.2**	**0.8**		**14.5**	**0.64**	**34.6**	**31.6**
Texas	**71.5**	**12.4**			**16.1**	**0.71**	**30.0**	**35.5**

* Standard: air = 1.0

** Gross Heat Value (MJ/m^3_N)

*** Net Heat Value (MJ/m^3_N)

(Source: ECCJ; Theory and Practice of Gas Incineration)

2.2 LPG

Chemically, LPG is a mixture of two flammable but nontoxic gases called propane (C_3H_8) and butane (C_4H_{10}). Both of these are hydrocarbons, and composition of these two hydrocarbons are very wide. LPG sometimes contains a variation of butane called isobutene and small amount of other hydrocarbons. The composition of components gases in LPG is various at production sites of LPG. Physical properties are shown in table 2.4.

Table 2.4 Physical property of LPG

Physical property	Range
Specific Gravity	1 – 1.5 (Air: 1)
Gross Heating Value(dry basis)	100 - 125 (MJ/m^3)
Flammability Limits	2 - 95% (vol% in air)

3 Combustion of natural gas

Reaction of gas fuel and oxygen and amount of heat generation is shown in table 3.1.

Table 3.1 Reaction of combustion and amount of heat generation

Gas	Incineration reaction	GHV(MJ/m^3_N)	NHV(MJ/m^3_N)
H_2	$H_2 + 0.5O_2 = H_2O$	12.78	10.83
CO	$CO + 0.5O_2 = CO_2$	12.61	12.61
CH_4	$CH_4 + 2O_2 = CO_2 + 2H_2O$	39.94	36.06
C_2H_6	$C_2H_6 + 3.5O_2 = 2CO_2 + 3H_2O$	70.47	64.55
C_3H_8	$C_3H_8 + 5O_2 = 3CO_2 + 4H_2O$	101.40	93.39
C_3H_6	$C_3H_6 + 4.5O_2 = 3CO_2 + 3H_2O$	93.73	87.76
C_4H_{10}	$C_4H_{10} + 6.5O_2 = 4CO_2 + 5H_2O$	134.3	124.1

GHV: Gloss Heating Value

NHV: Net Heating Value

Stoichiometric oxygen consumption in gas combustion is shown in table 3.1. Air requirement for gas combustion can be calculated with the data in Table 3,1. There shows an example of air consumption of gas combustion below.

Table 3.2 Composition of a fuel gas and oxygen and air use in combustion

A sample of gas composition							Oxygen use	Air Use (m^3/m^3)
H_2	CO	CH_4	C_2H_6	C_3H_8	C_4H_{10}	O_2		
0.41	0.026	0.257	0.015	0.032	0.006	0.03	0.954	4.54

Calculation of oxygen use in combustion of a fuel gas in Table 3.2

Theoretical Oxygen Use = 0.41 x 0.5 + 0.026 x 0.5 + 0.257 x 2 + 0.015 x 3.5 + 0.032 x 5 + 0.006 x 6.5 - 0.03 x 1 = 0.954

Theoretical Air Use = 0.954 / 0.21 = 4.54 (m^3/m^3)

A gas of special composition is used in above calculation. Generally speaking most natural gas contains methane (CH_4) mainly as shown in Table 2.3.

3 Theoretical amount of air and air ratio

Theoretical air volume required for perfect combustion of 1 m^3 gas fuel is called theoretical air volume. In actual combustion more air than theoretical air volume is necessary. This actual air volume for combustion of fuel $1m^3$ is called "Air ratio" and indicated with the letter of " α ".

$\alpha = A / Ao$

where

Ao: theoretical air volume (m3/m3)

A: practical air volume (m3/m3)

Air more than theoretical air volume is called "excess air", and the ratio is called "excess air ratio". It is indicated by percent of theoretical air.

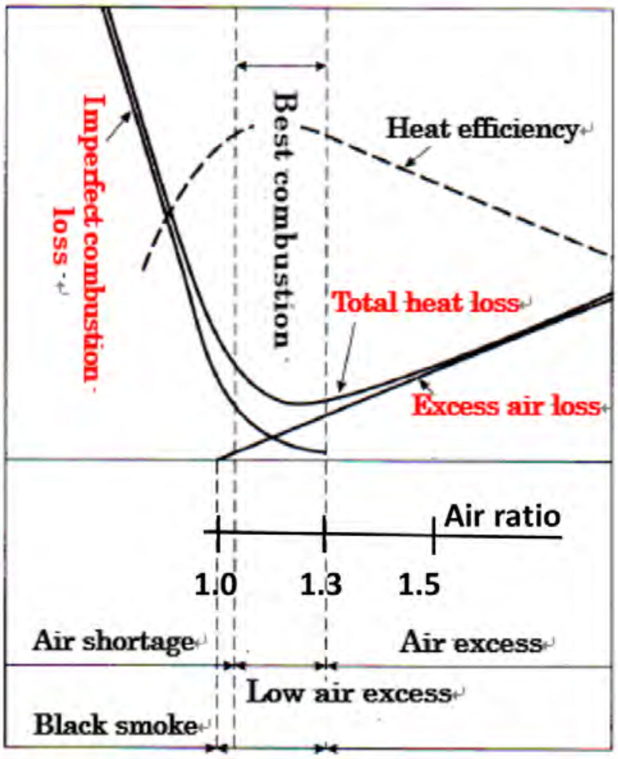


Figure 3.1 Relation of air ratio and heat efficiency

Figure 3.1 shows relation of air ratio and heat efficiency. In air shortage unburnt combustible content is generated, and heat efficiency decreases. On the contrary heating of excess air is required, and heat efficiency decreased, too. Therefore low air ratio without unburnt combustible content is required. For the purpose selection of adequate burner, daily maintenance, and prevention against invading air into furnace are necessary.

Following tables show standard air ratio and strictly controlled air ratio for boilers and industrial furnaces.

Table 3.1 Standard and target air ratio for gas fuel boiler

Boiler size	**Standard air ratio**	**Target air ratio**
10 – 30 t/h	1.15 – 1.3	1.15 – 1.25
Smaller than 5 t/h	1.2 – 1.3	1.15 – 1.25

Table 3.2 Standard and target air ratio for gas fuel industrial furnace

Furnace	Standard air ratio		Target air ratio	
	Continuous furnace	Intermittent furnace	Continuous furnace	Intermittent furnace
Metal melting furnace	1.25	1.35	1.05 – 1.205	1.05 – 1.25
Continuous steel heating furnace	1.20	--	1.05 – 1.15	--
Meta heating furnace	1.25	1.35	1.05 – 1.15	1.05 – 1.30
Meta heat treatment furnace	1.20	1.25	1.05 – 1.15	1.05 – 1.25

4 Measurement of air ratio

4.1 Flue gas analyzer

Furnaces, heaters, and boilers burn fuel in the presence of oxygen to produce heat. Achieving an intelligent balance of fuel and air will provide the most efficient combustion and highest cost savings. Measuring the exhaust gas is an excellent way to optimize fuel and air input. Usually oxygen, carbon mono oxide can be measured by the instruments.

4.2 Calculation of air ratio

Oxygen in flue gas (%) is an index of air balance in combustion. Oxygen concentration (%) in flue gas can be measured with flue gas analyzer or oxygen concentration meter.
Then the air ratio is calculated from oxygen concentration (%) with following equation.

$$\text{Air ratio} = \frac{21}{21 - \text{Oxygen}(\%)}$$

5 Exhaust heat recovery

Among exhaust heat recovery technologies recuperater is the most popular in industrial furances. Installing a recuperater on stack, and implementing heat exchange of low temperature combustion air and high temperature flue gas. This is to use the heat which flue gas has and to preheat combustion air.

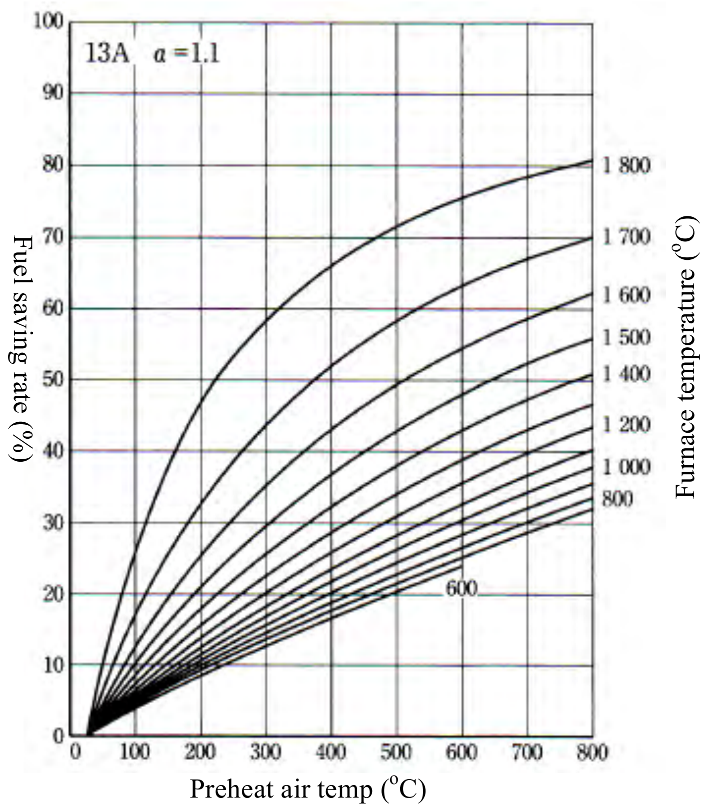


Figure 5.1 Preheat air temperature and fuel saving rate

Figure 5.1 shows the relation of preheat air temperature and fuel saving rate. For example, if furnace temperature is 1200 °C and preheat air temperature is 500 °C, fuel saving rate is more than 30%.

Chapter 13 Industrial furnace and Energy saving

1 Cupola furnace

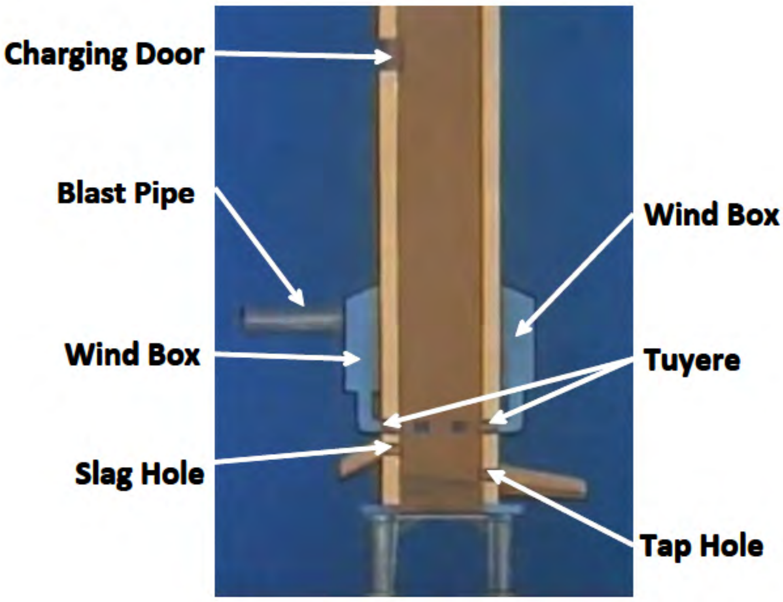
1.1 General description of Cupola

A cupola or cupola furnace is a melting device used in foundries that can be used to melt cast iron, Ni-resist iron and some bronzes. The cupola can be made almost any practical size. The size of a cupola is expressed in diameters and can range from 1.5 to 13 feet (0.5 to 4.0 m). The overall shape is cylindrical and the equipment is arranged vertically, usually supported by four legs. The overall look is similar to a large smokestack.

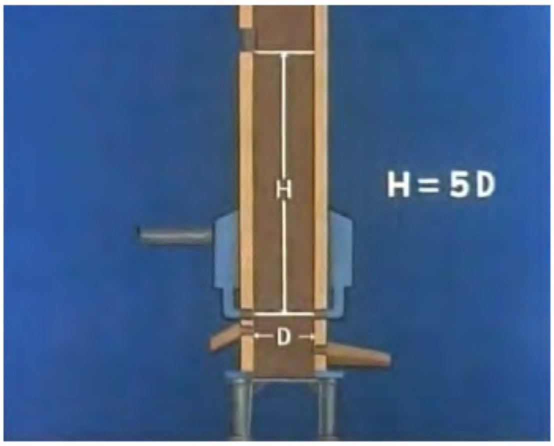
The bottom of the cylinder is fitted with doors which swing down and out to 'drop bottom'. The top where gases escape can be open or fitted with a cap to prevent rain from entering the cupola. To control emissions a cupola may be fitted with a cap that is designed to pull the gases into a device to cool the gases and remove particulate matter.

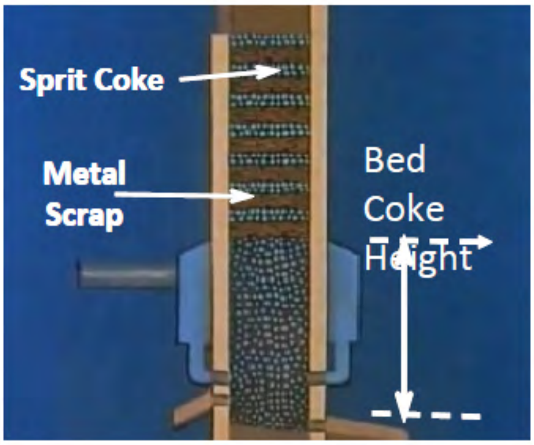
The shell of the cupola, being usually made of steel, has refractory brick and plastic refractory patching material lining it. The bottom is lined in a similar manner but often a clay and sand mixture ("bod") may be used, as this lining is temporary. Finely divided coal ("sea coal") can be mixed with the clay lining so when heated the coal decomposes and the bod becomes slightly friable, easing the opening up of the tap holes. The bottom lining is compressed or 'rammed' against the bottom doors. Some cupolas are fitted with cooling jackets to keep the sides cool and with oxygen injection to make the coke fire burn hotter.

1.2 Structure of cupola furnace



1.3 Importai



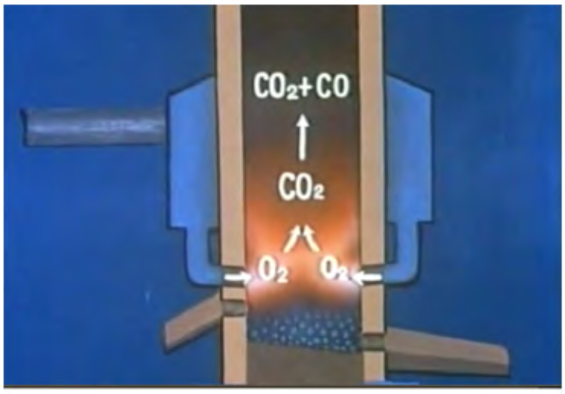


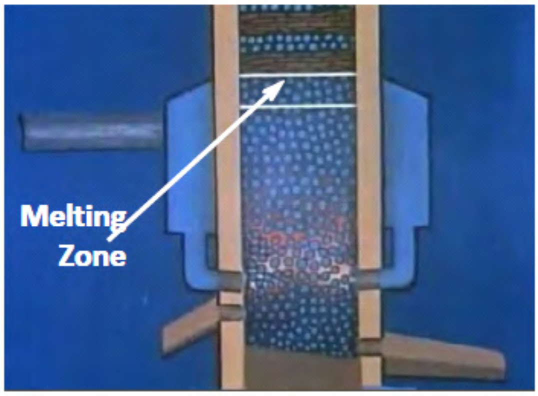
Bed Coke Height 3 t/H: 1000mm

2 t/H: 900mm

1 t/H: 800mm

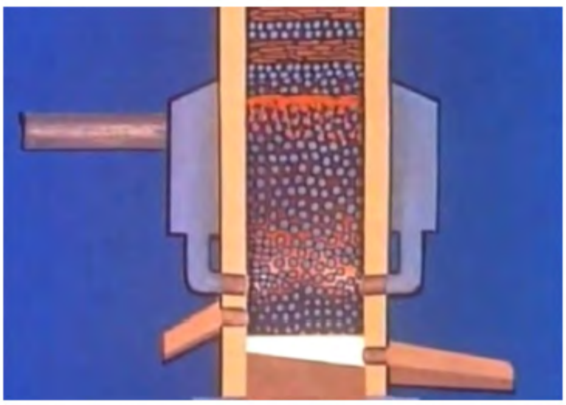
1.4 Melting zone





Reducing Atmosphere (CO_2 +CO) : Melting Zone (Molten metal is not oxidized.)

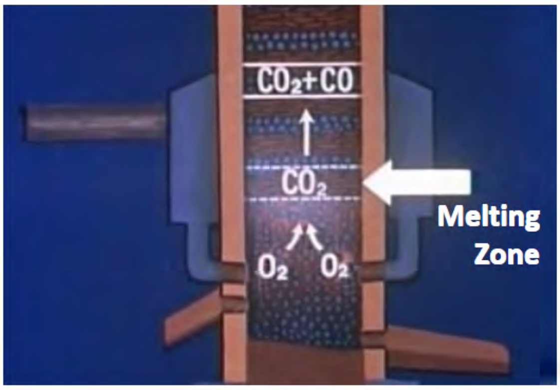
Oxidizing Atmosphere (CO_2) : Molten metal is oxidized.



Metal melts at the top area of Bed Coke.

Sprit coke layer (200mm) goes down and the bed coke height is kept.

1.5 What happens if bed coke is short?

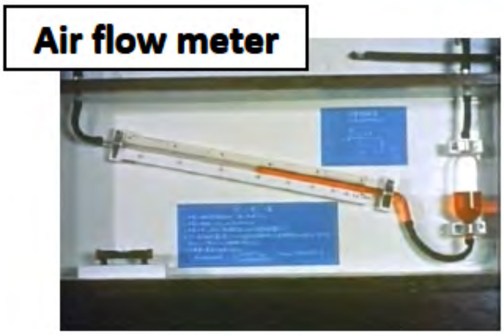


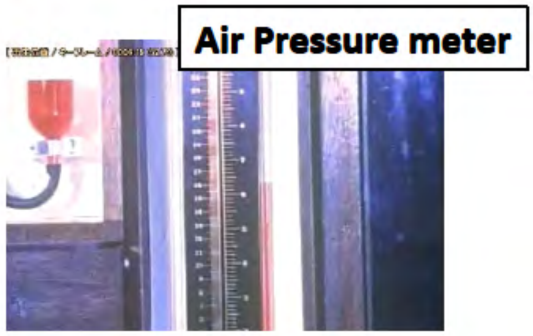
Metal melts in oxidizing atmosphere, and metal is oxidized.

1.6 How to keep the bed coke height?

To keep Air Flow and Air Pressure of blow air from Tuyeres. They are measured with an air flow meter and an air pressure meter.

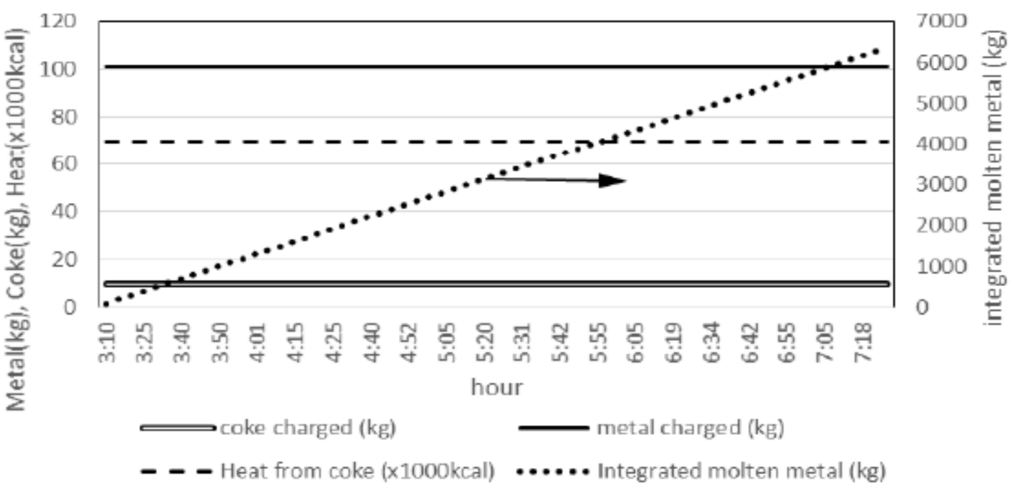
If air is too strong, coke burns rapidly and bed coke becomes short.



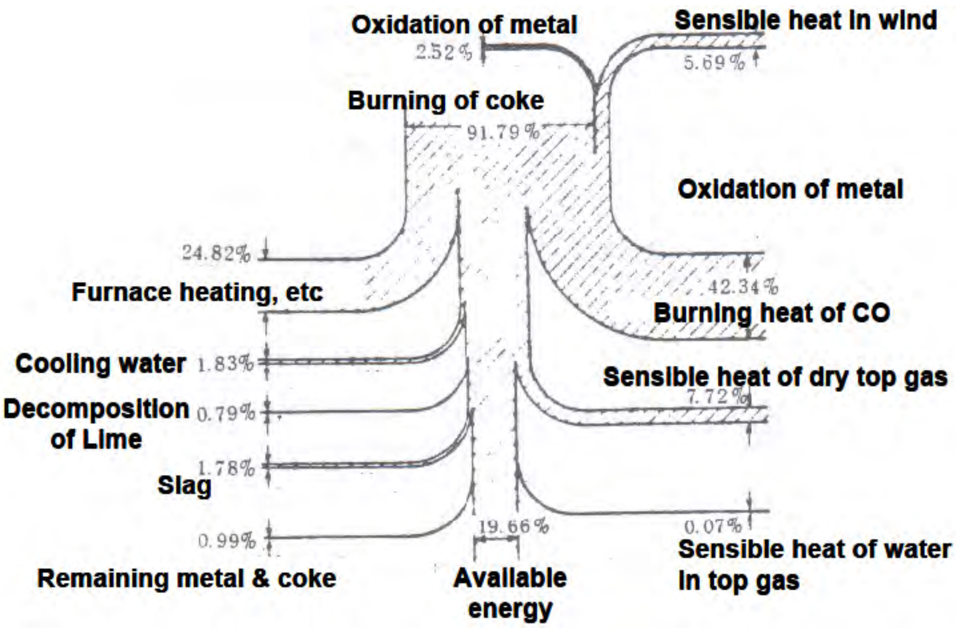


1.7 Cupola furnace operation

In stable operation cupola furnace can produce molten metal continuously for a long time. Figure below shows the time chart of stable cupola operation.



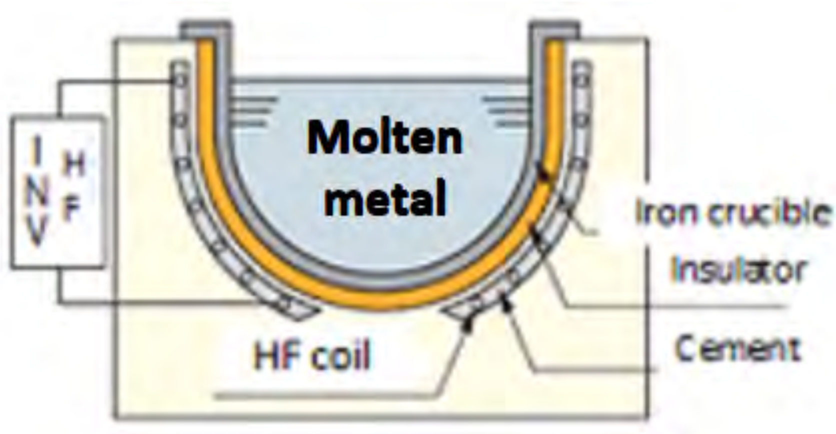
1.8 Energy consumption breakdown of Cupola



Available output energy from cupola is about 20 – 30%.

2 Induction heating furnace

2.1 Structure of induction heating furnace and its specialties



- No exhaust gas from heating mechanism.
- Metal temperature in crucible is uniform.
- Metal temperature is easy to control.

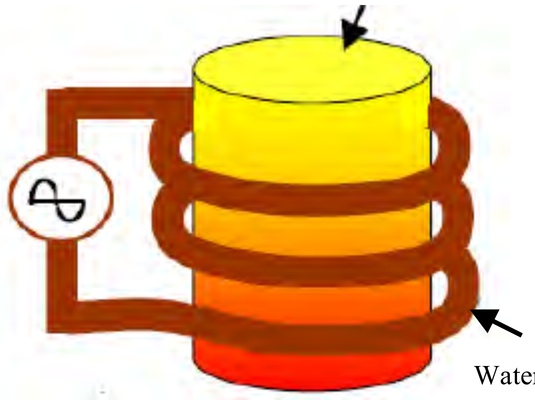
1) Unit energy consumption (Japanese experiences) Small furnace of 1-3 tons: 700kWh/ton
Medium furnace of 12-15tons: 600kwh/ton

2) Use of remaining metal in crucible

Continuous operation with remaining liquid metal can reduce unit energy consumption.

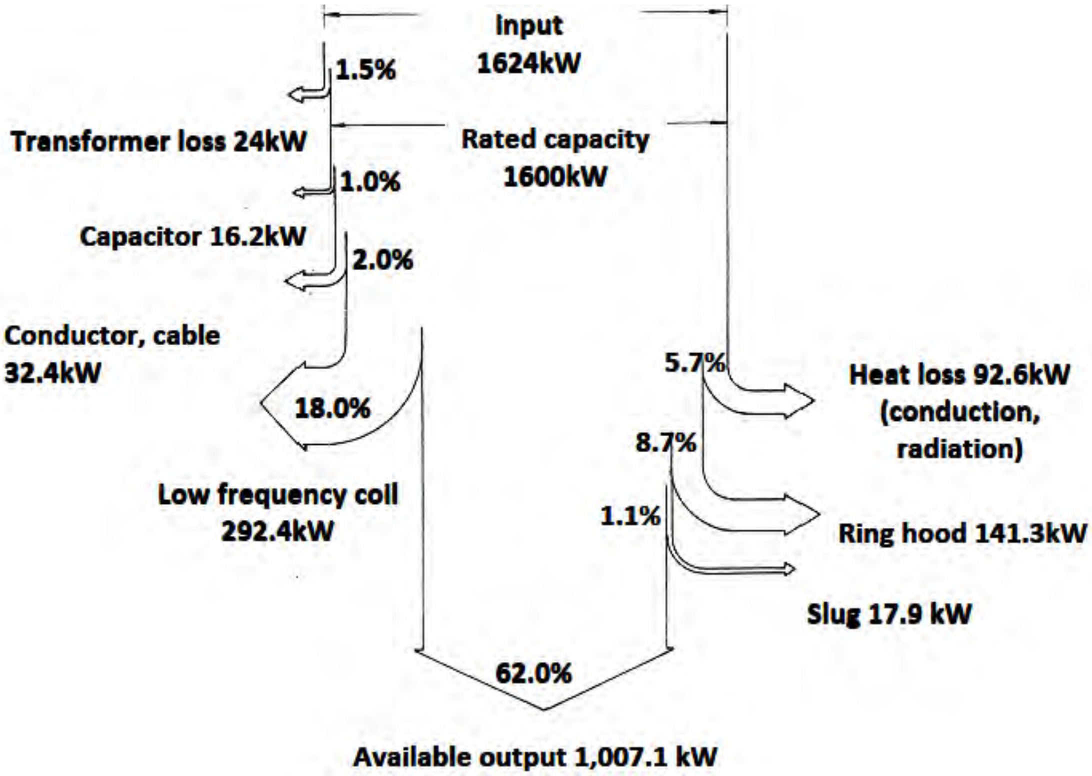
2.2 Heating principle

Iron crucible and melting metal:
Equivalent to secondary coil of the transformer

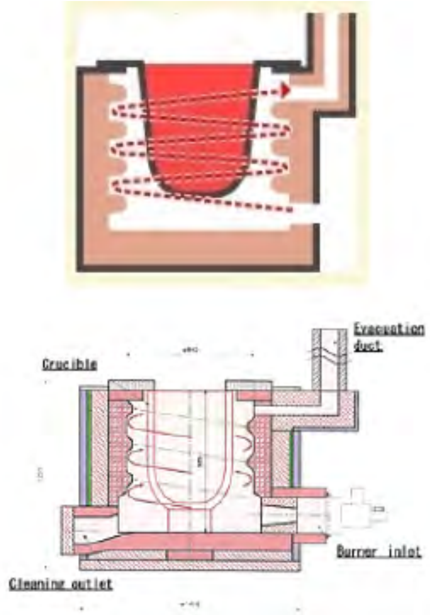


Water cooled Heating coil: Equivalent to primary coil of the transformer

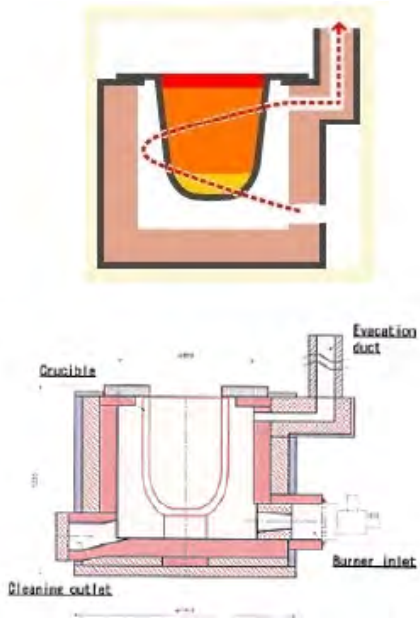
2.3 Energy consumption breakdown of low frequency induction crucible furnace



3 Flame heating crucible furnace: flame control for heating efficiency



Spiral flame flow

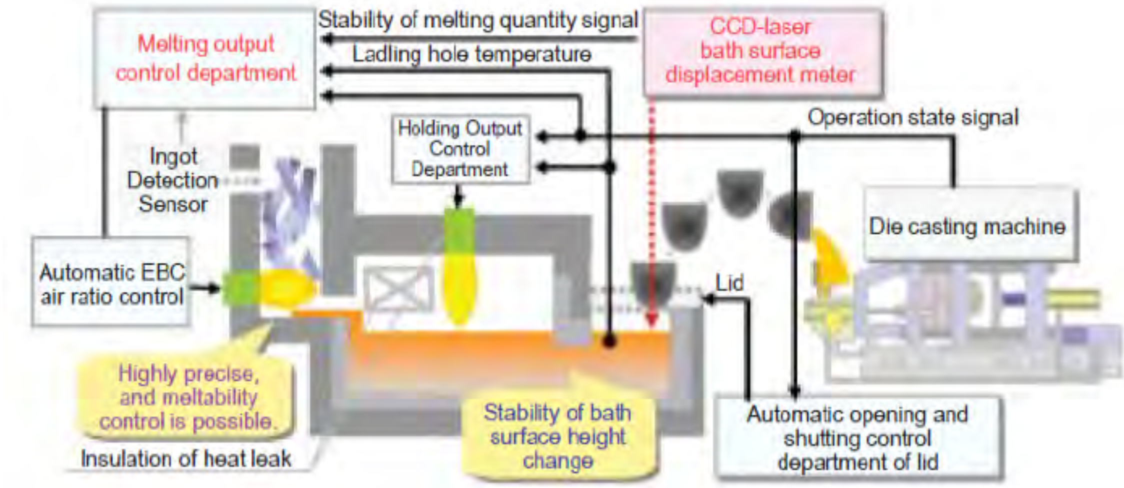


Conventional flame flow

- Spiral flame flow crucible furnaces have better heating efficiency.
- Flame guides are formed on the inside wall of furnace by castable heat insulating material.
- Spiral flame flow reduces damage of iron crucibles.

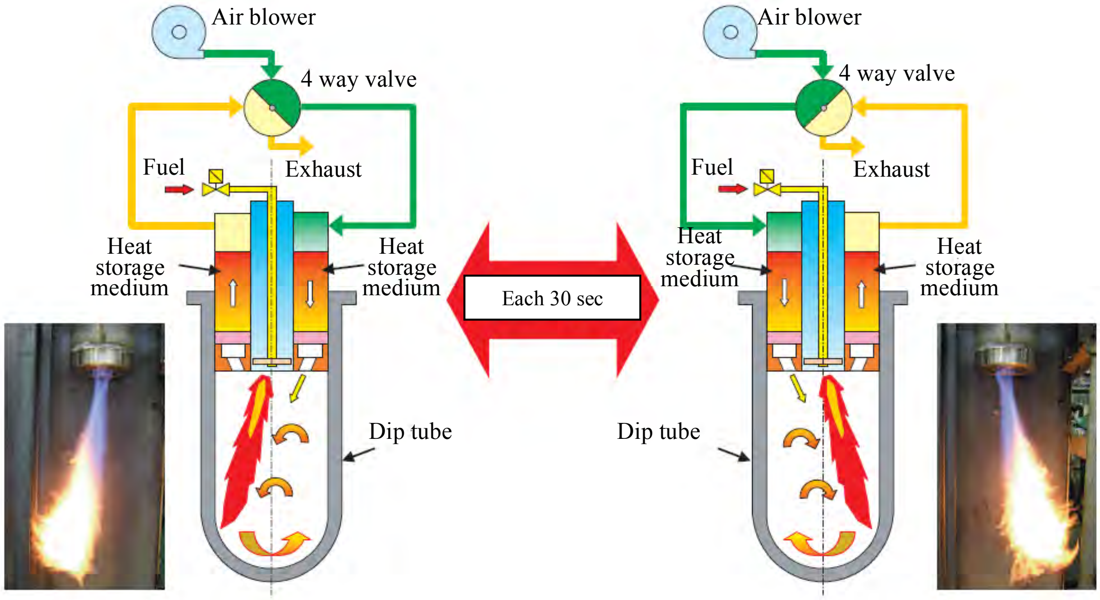
4 Advanced furnaces for Aluminium high pressure diecasting

4.1 Metal melting and retaining furnace



1) Flame control for adequate metal melting
2) Metal surface height control
3) Precise metal temperature control
4) Automatic opening and closing control of melting chamber lid

4.2 Regenerating gas burner

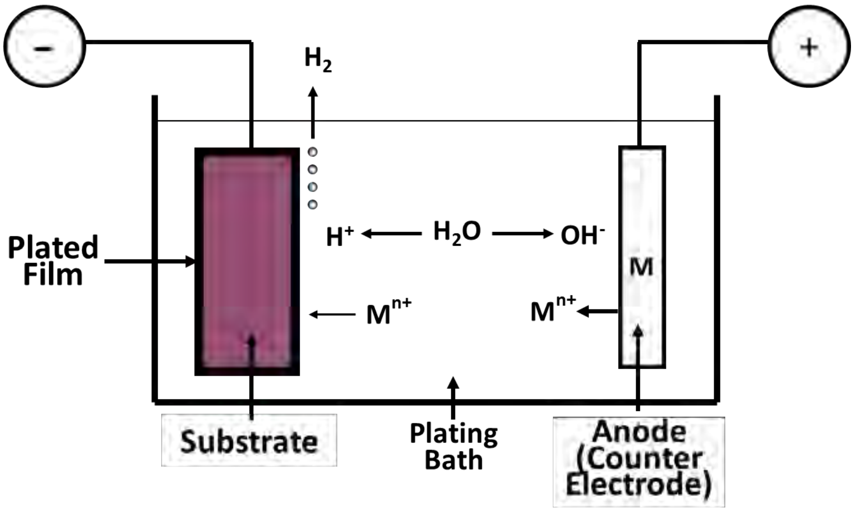


Regenerating system is a unified one of two heat storage media and a burner. Exhaust gas heats a heat storage medium and the medium heats air in the next step. High heat efficiency is expected.

Chapter 14 Electroplating and Energy Saving

1 Basic Knowledge of Electroplating

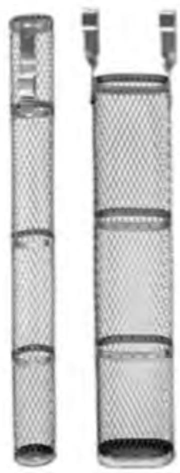
1.1 Electrochemical reaction in plating bath



Products to be plated is connected to the minus terminal of electrical power supply, and counter electrode is to the plus terminal. The counter electrode is made of plating metal such as nickel, zinc, etc.

1.2 Counter electrode

Counter electrode is made of pellet or chips of plating metal, and they are put into titanium baskets.



1.3 Plating solution

Plating solutions are composed of chemicals such as plated metal, additional chemicals, and brighteners. Usually plating baths are supplied from specialized suppliers of plating chemicals.

1.4 Plating process

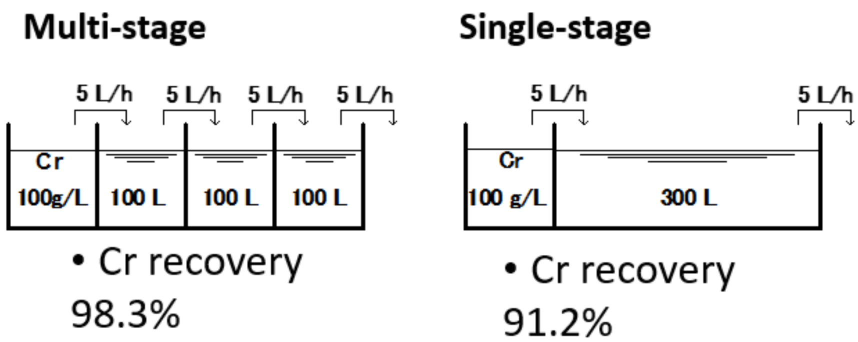
Substrates for plating are processed of deoxidation, a few steps of degreasing in acid and alkaline and metal depositing.

2 Rinsing in water

2.1 Purpose of rinsing

- To remove bath components from the surfaces of products ⇒ To keep the quality of products
- Sufficient rinsing between treatments ⇒ Good adhesion of plated films
- Sufficient final rinsing ⇒ Non-defective appearances

2.2 Comparison of Multi-stage and Single-stage Rinsing



Above figure shows the effect of multi-stage water rinsing at after rinsing in chromium plating. Multi-stage rinsing can remove chemicals sufficiently with same volume of water.

2.3 Required rinsing quality after water rinsing (Rough idea of contaminant residue on products)

Medium Rinse: 750ppm

Final Rinse (Average finish): 150～200ppm

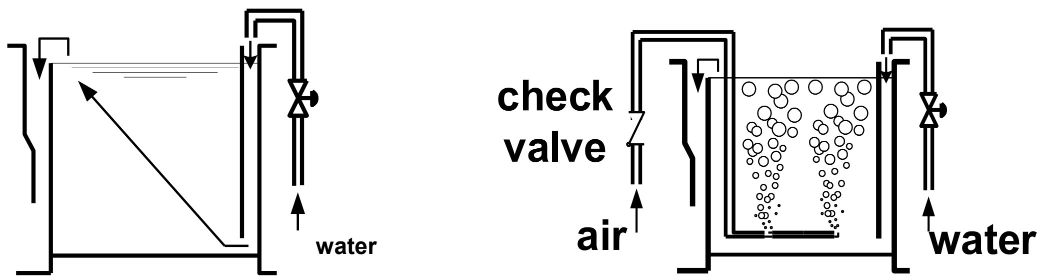
Final Rinse (Bright finish): 40ppm

2.4 Water Conservation and Improvement of Rinsing Efficiency

2.4.1 Water flow in a rinsing tank and Agitation of water with air (Aeration)

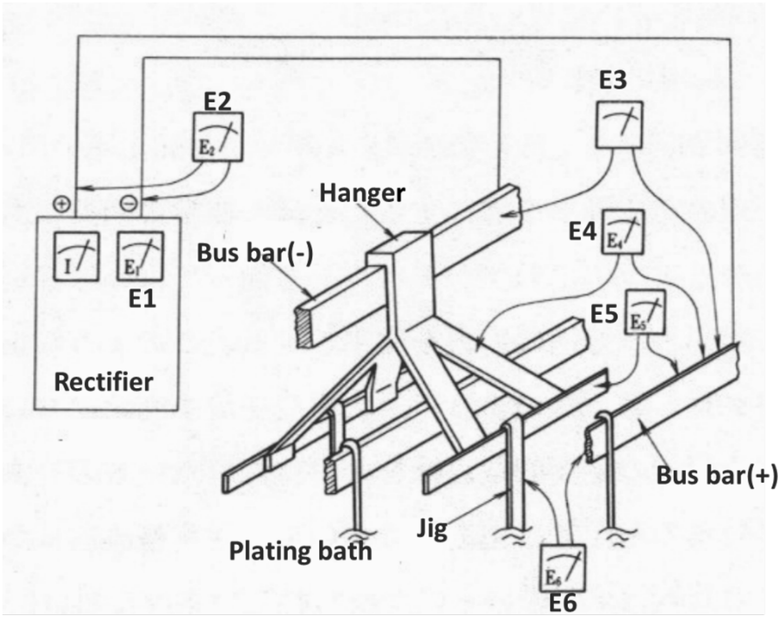
To remove treatment solution adhered on product surfaces.

To make the chemical concentration uniform in whole tank.



3 Electrical energy saving in plating

3.1 Electrical resistance in DC wiring



	E1(V)	I(A)	E2(V)	E3(V)	E4(V)	E5(V)	E6(V)	E2-E6(V)
Factory A	8.0	7980	6.8	6.8	6.6	6.5	6.4	0.4
Factory B	8.2	9900	7.8	6.2	6.2	6.2	6.1	1.7

Power loss at Factory A = $\frac{(6.8-6.4)\times 8000}{1000\times 0.8}$ = 4.0(kW)

Power loss at Factory B = $\frac{(7.8-6.1)\times 9900}{1000\times 0.8}$ = 21.0(kW)

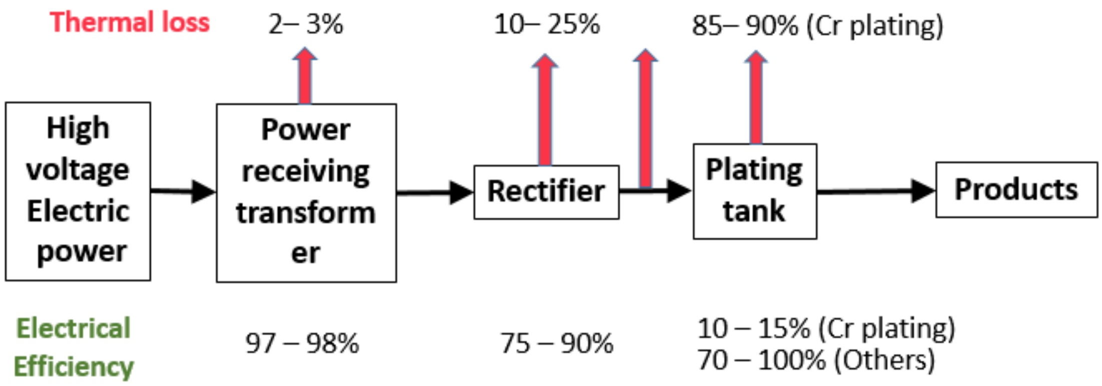
Power loss in cables and bus bars can calculate from voltage difference between rectifier terminal and bus bar at plating tank side.

3.2 Plating bath selection for reduction of plating voltage (Zn plating)

Name of zinc plating bath	**Plating voltage in production plant (V)**
Potassium Chloride Bath	2.8
Ammonium Chloride Bath	3.3
Zincate Bath	8.0
Cyanide Bath	8.0

By changing plating bath from Zincate to Potassium chloride in Factory A, Power saving at Factory A = $\frac{(8.0-2.8)\times 8000}{1000\times 0.8}$ = 52(kW)

3.3 Summary of electrical energy use in electroplating



In chromium plating, total electricity efficiency for film formation is

$0.97\times 0.95\times 0.1\times 100=7.3\%$.

In other metal plating, total electricity efficiency for film formation is 70-80%.

4 Heat energy saving in electroplating

4.1 Important terms of Heat

Term	Definition
Calorie	The amount of heat required at a pressure of one atmosphere to raise the temperature of one gram of water one degree Celsius that is equal to about 4.19 joules.
Specific heat	Specific Heat is the amount of heat required to change a unit mass of a substance by one degree in temperature.
Latent heat	All pure substances in nature are able to change their state. Solids can become liquids (ice to water) and liquids can become gases (water to vapor) but changes such as these require the addition or removal of heat. The heat that causes these changes is called latent heat.
Sensible heat	When an object is heated, its temperature rises as heat is added. The increase in heat is called sensible heat.
Boiler	A closed vessel in which fluid (usually water) is heated. The heated or vaporized fluid exits the boiler for use in various processes or heating applications, including water heating, central heating, boiler-based power generation, cooking, and sanitation.

4.2 Characteristics of steam

- Steam is a liquid at room temperature, and easily becomes a gas by heating.
- Steam has a large specific heat. Latent heat of vaporization is large.
- Steam has a large volume change after condensation (vapor to water), and heat transfer characteristics is large.

- Steam pressure increases with rise in temperature.
- Steam is chemically stable, no explosion and no flammable. In addition, it can be used repeatedly.
- Transportation, storage and control of steam is easy.

4.3 Calculation of boiler efficiency

Boiler efficiency = $\frac{G(h''-h')\times 100}{B\times H}$

where

G: actual amount of evaporation(kg/h)

h”: specific enthalpy of generated steam (kcal/kg)

h’: specific enthalpy of supplied water (kcal/kg)

(As the specific heat is 1.0 kcal/kg^{o}C, its temperature can be used as specific enthalpy)

B: consumed fuel (kg/h or Nm^{3}/h)

H: low heat value of fuel (kcal/kg or kcal/Nm^{3})

Example

the amount of used heavy oil: 980L (specific gravity 0.89)

low heating value of heavy oil: 10,000kcal/kg

generated steam: 12ton

steam pressure: 10kgf/cm2

(evaporation heat 478.1kcal/kg, dryness 98% specific enthalpy 185.6kcal/kg)

supplied water temperature: 20^{o}C

Specific enthalpy of steam

=478.1 x 0.98 + 185.6 = 654.1(kcal/kg)

Boiler efficiency = $\frac{12000\times(654.1-20)\times 100}{980\times 0.89\times 10000} \fallingdotseq 87(\%)$

4.4 Boiler capacity

Steam boilers output - the capacity of a steam boiler - can be expressed in Pounds of Steam delivered per hour, BTU or in Boiler Horsepower.

1) Lbs Steam delivered per Hour

Large boiler capacities are often given in lbs of steam evaporated per hour under specified steam conditions.

2) BTU - British Thermal Units

Since the amount of steam delivered varies with temperature and pressure, a common expression of the boiler capacity is the heat transferred over time expressed as British Thermal

Units per hour. A boilers capacity is usually expressed as kBtu/hour (1000 Btu/hour) and can be calculated as $W = (h_g - h_f)\, m$

where

W = boiler capacity (Btu/h, kW)

h_g = enthalpy steam (Btu/lb, kJ/kg)

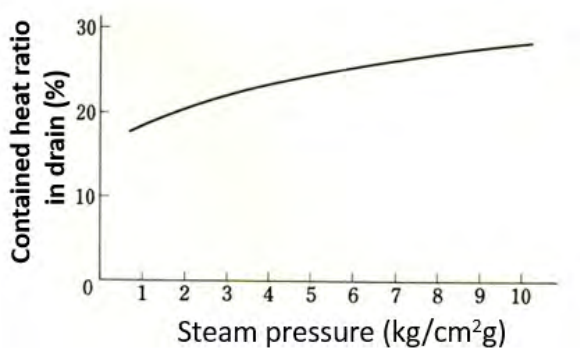
h_f = enthalpy condensate (Btu/lb, kJ/kg)

m = steam evaporated (lb/h, kg/s)

3) Boiler Horsepower – BHP

The Boiler Horsepower (BHP) is the amount of energy required to produce 34.5 pounds of steam per hour at a pressure and temperature of 0 Psig and 212 ^{o}F, with feedwater at 0 Psig and 212 ^{o}F.

4.5 Drain recovery



- Heat in saturated water contains 20 – 30 % of consumed energy in boiler.
- If all heat in drain is recovered, 20-30 % of energy is saved and boiler water and wastewater treatment can be reduced.

5 Summary of energy saving in electroplating process

- Low temperature operation
- Adequate temperature control
- Energy saving plan based on calculation
- High heat efficiency of boiler
- To use steam without leakage
- To use steam of low pressure and high dryness
- Select efficient steam trap
- Effective drain recovery
- Heat insulation on piping and tanks

6 Analysis of acidic zinc chloride electroplating bath

6.1 Zinc metal

① Measure 2 ml of plating bath precisely with a volumetric pipette, and add 50 ml of distilled water.

② Add 20 ml buffer solution of pH10 and a few drops of BT indicator.

③ Add 30% formalin solution till the color of the specimen solution changes to reddish violet.

④ Heat the solution up to about 35 oC.

⑤ Titrate the specimen solution with 0.1M EDTA standard solution till the color of the solution changes from reddish violet to blue.

⑥ Calculation: zinc metal (g/l) = ml of 0.1M EDTA x 3.27 x factor of 0.1M EDTA

6.2 Total chlorine

① Measure 1 ml of plating bath precisely with a volumetric pipette, and add 100 ml of distilled water.

② Add a few drops of 10% potassium chromate as an indicator.

③ Titrate the specimen solution with 0.1N silver nitrate standard solution till the color of the solution changes from yellow to oxblood red.

④ Calculation: total chlorine (g/l) = ml of 0.1N silver nitrate x 3.55 x factor of 0.1N silver nitrate.

Chapter15 Enforcement of Thermal Insulation

1. Procedure of energy conservation measures of enforcement of thermal insulation

Enforcement of thermal insulation is effective measures to reduce heat loss from surface of equipment and piping.

Energy conservation measures of enforcement of thermal insulation are implemented as the following procedure.

1st step: Repairing broken insulation work of equipment and piping

2nd step: Measurement of surface temperature of equipment and piping

3rd step: Calculation of heat loss from the surface of equipment and piping

4th step: Design of enforcement of thermal insulation of equipment and piping

5th step: Implementation of enforcement of thermal insulation work

6th step: Measurement of surface temperature and confirmation of effects of enforcement of thermal insulation

2. Measurement of surface temperature of equipment and piping

2.1 Measurement devices

The following measurement devices are used to measure surface temperature

(1) Surface contact type thermometer

(2) Radiation thermometer

(3) Thermal image camera

2.2 Measurement data

The following data are recorded by inspectors

(1) Ambient temperature at 1 meter from equipment

(2) Surface temperature of equipment and piping

(3) Operation condition such as load ratio and inner temperature

3. Calculation of heat loss from the surface of equipment and piping

3.1 Heat transfer method

Heat transfer methods are the following 3 methods.

(1) Conduction heat

(2) Convection heat

(3) Radiation heat

3.2 Heat dissipation loss

Heat dissipation loss (Q) is radiation heat (Qr) and convection heat (Qc) as follows:

Q = Qr + Qc

(1) Radiation heat loss

Radiation heat Qr (kcal/m^2h) through radiation from the equipment surface

$$Qr = 4.88 \times \varepsilon \times A \times \left\{ \left(\frac{t + 273}{100} \right)^4 - \left(\frac{a + 273}{100} \right)^4 \right\}$$

(Stefan-Boltzmann law)

Where

t: Furnace wall surface temp. (degC)

a: Air temperature. surrounding the furnace (degC)

ε: Equipment wall and piping surface radiation rate

A: Furnace wall surface area (m^2)

Table 1 Equipment wall and piping surface radiation rate (ε)

Material	Condition	ε
Steel plate	30 degC	0.75 - 0.85
Melting iron	1300 – 1400 degC	0.29
Aluminum plate	40 degC	0.05 - 0.07

(2) Convection heat loss

Convection heat Qc (kcal/m^2h) from the equipment surface

Qc = α x A x (t – a)

Where

t: Furnace wall surface temp. (degC)

a: Air temp. surrounding the furnace (degC)

α: Convection heat transfer rate (kcal/m^2/h/degC)

A: Equipment wall and piping surface area (m^2)

Table 2 Convection heat transfer rate (kcal/m^2/h/degC) (α) at natural convection

Condition	Value of α
Upper side of horizontal surface	$2.8 \times (t - a)^{0.25}$
Bottom side of horizontal surface	$1.5 \times (t - a)^{0.25}$
Vertical surface	$2.2 \times (t - a)^{0.25}$

Surface of horizontal pipe	$2.1 \times ((t - a) / D)^{0.25}$

Note: D = Diameter of pipe (m)

3.3 Heat conduction

(1) Conduction heat Qd (kcal/h) through equipment wall and thermal insulation material

$$Qd = \lambda / d \times A \times (t1 - t2)$$

Where

t1: Equipment wall surface temp. (degC)

t2: Equipment inside wall temperature (degC)

λ : Equipment wall and insulation material heat conductivity (kcal/m/h/degC)

d: Equipment wall thickness (m)

A: Equipment wall surface area (m^2)

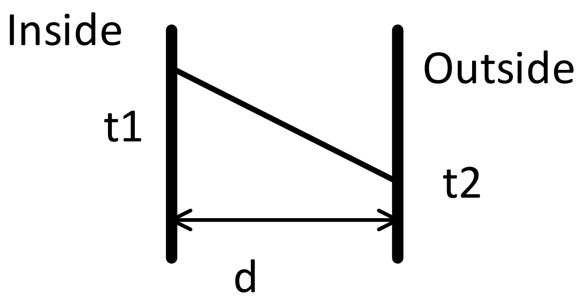


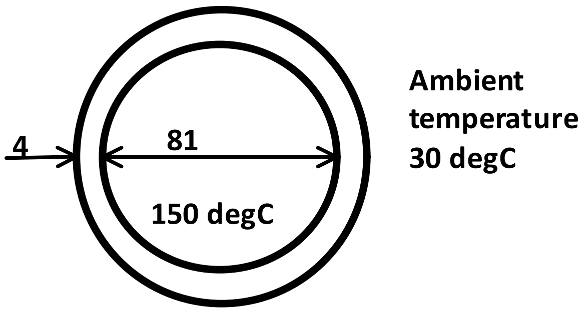
Figure 1 Heat conduction

Table 3 Equipment wall and insulation material heat conductivity (kcal/m/h/degC) (λ)

Material	Condition and shape	Density (kg/m^3)	Max. temp. (degC)	λ
Steel plate				50
Rock wool	Blanket	160	600	0.037
Glass wool	Blanket	40	400	0.037
Calcium silicide	Insulation pipe	130	1000	0.042
Ceramic fiber	Blanket	128	1400	0.07 – 0.23
Polystyrene	Form	30	70	0.031
Hard urethane	Form	35	100	0.021
Perlite	Board	250	900	0.062

4. Enforcement of thermal insulation of steam piping

4.1 Heat loss of steam pipe without insulation



α1 = 5,000 kcal/m2/h/C
α2 = 10 kcal/m2/h/C
λ1 = 50 kcal/m/h/C

Figure 2 Steam pipe

Heat loss from surface of steam pipe (kcal/m/h) (Q)

Q = (ts – ta) / R

Where

R: Total heat resistance

ts: Steam temperature (degC)

ta: ambient temperature (degC)

(1) Convection heat resistance to inner wall of steel pipe (R1)

R1 = 1 / (α1 x Inner surface area of pipe) = 1 / (5000 x 3.14 x 0.081) = 0.0008

(2) Conduction heat resistance in steel pipe (R2)

R2 = Thickness of pipe / (λ1 x Average surface area of pipe) = 0.004 / (50 x 3.14 x 0.085)
= 0.0003

(3) Convection heat resistance to air from outer surface of steel pipe (R3)

R3 = 1 / (α2 x Outer surface area of pipe) = 1 / (10 x 3.14 x 0.089) = 0. 357

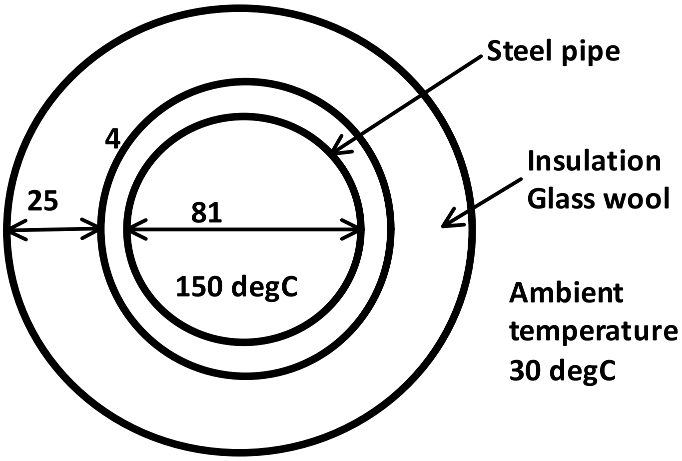
(4) Total heat resistance (R)

R = R1 + R2 + R3 = 0.0008 + 0.0003 + 0.357 = 0.358

(5) Heat loss from surface of steel pipe (Q)

Q = (150 – 30) / 0.358 = 335 kcal/m/h

4.2 Heat loss of steam pipe with insulation



$\alpha1$ = 5,000 kcal/m2/h/C
$\alpha2$ = 10 kcal/m2/h/C
$\lambda1$ = 50 kcal/m/h/C
$\lambda2$ = 0.037 kcal/m/h/C

Figure 3 Steam pipe with insulation

(1) Convection heat resistance to inner wall of steel pipe (R1)

R1 = 1 / ($\alpha1$ x Inner surface area of pipe) = 1 / (5000 x 3.14 x 0.081) = 0.0008

(2) Conduction heat resistance in steel pipe (R2)

R2 = Thickness of pipe / ($\lambda1$ x Average surface area of pipe) = 0.004 / (50 x 3.14 x 0.085) = 0.0003

(3) Conduction heat resistance in glass wool (R3)

R3 = Thickness of insulation / ($\lambda2$ x Average surface area of insulation) = 0.025 / (0.037 x 3.14 x 0.114) = 1.877

(4) Convection heat resistance to air from outer surface of insulation (R4)

R4 = 1 / ($\alpha2$ x Outer surface area of insulation) = 1 / (10 x 3.14 x 0.139) = 0. 223

(5) Total heat resistance (R)

R = R1 + R2 + R3 = 0.0008 + 0.0003 + 1.877 + 0.223 = 2.1

(6) Heat loss from surface of steel pipe (Q)

Q = (150 – 30) / 2.1 = 57 kcal/m/h

4.3 Effects of thermal insulation

Heat loss is reduced to 57 kcal/m/h from 335 kcal/m/h with insulation of glass wool.

Heat recovery ratio is 83%.

5. Enforcement of thermal insulation of furnace wall

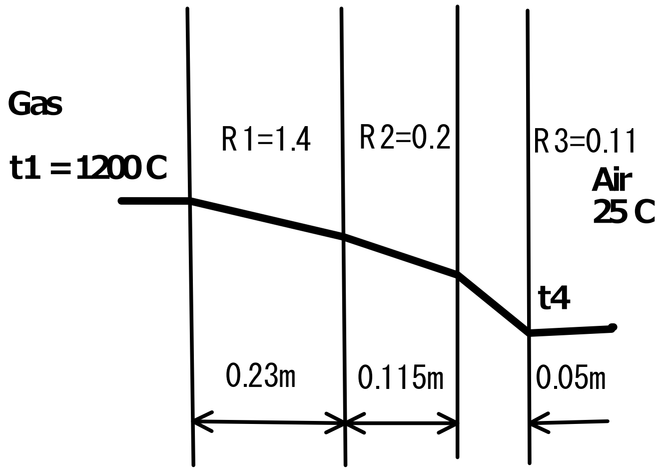


Figure 4. Furnace wall at present

5.1 Heat transfer through wall at present

(1) Case 1 (trial)

t4 is assumed as 105 C.

Heat transfer is calculated as follows:

Q1 = (t1 –t4) / (d1/R1 + d2/R2 + d3/R3)

= (1200 – 105) / (0.23/1.4 + 0.115/0.2 + 0.05/0.11) = 918 kcal/m/h

Dissipation heat from surface of furnace wall

Q2 = Radiation heat + convection heat

$= 4.88 \times 0.85 \times ((378/100)^4 - (298/100)^4) + 2.2 \times (378 - 298)^{0.25} \times (378 - 298)$

= 1046 kcal/m/h

Q2 > Q1: t4 is smaller than 105 C

(2) Case 2 (trial)

t4 is assumed as 98 C.

Heat transfer is calculated as follows:

Q1 = (t1 –t4) / (d1/R1 + d2/R2 + d3/R3)

= (1200 – 98) / (0.23/1.4 + 0.115/0.2 + 0.05/0.11) = 921 kcal/m/h

Dissipation heat from surface of furnace wall

Q2 = Radiation heat + convection heat

$= 4.88 \times 0.85 \times ((371/100)^4 - (298/100)^4) + 2.2 \times (371 - 298)^{0.25} \times (371 - 298)$

= 928 kcal/m/h

Q2 = Q1: t4 is 98 C.

5.2 Heat transfer through wall with ceramic fiber veneering

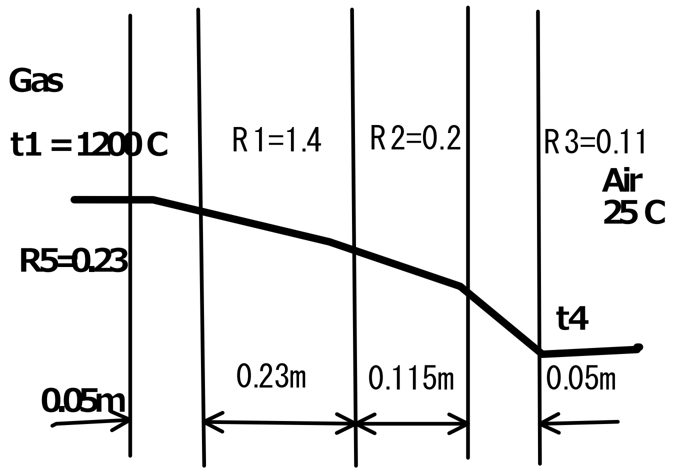


Figure 5 Furnace wall with ceramic fiber veneering

t4 is assumed as 90 C.

Heat transfer is calculated as follows:

Q1 = (t1 –t4) / (d1/R1 + d2/R2 + d3/R3)

= (1200 – 90) / (0.23/1.4 + 0.115/0.2 + 0.05/0.11 + 0.05/0.23) = 787 kcal/m/h

Dissipation heat from surface of furnace wall

Q2 = Radiation heat + convection heat

$= 4.88 \times 0.85 \times ((363/100)^4 – (298/100)^4) + 2.2 \times (363 – 298)^{0.25} \times (363 – 298)$

= 799 kcal/m/h

Q2 = Q1: t4 is 90 C.

5.3 Effects of ceramic fiber veneering

Heat loss is reduced to 790 kcal/m/h from 925 kcal/m/h with veneering of ceramic fiber.

Heat recovery ratio is 15%.