Text No.17

MEASUREMENT OF ENERGY CONSUMPTION

エネルギー使用量計測

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1. Promotion Method for Energy Conservation

Preface

This measurement training segment of the course is designed to facilitate trainee understanding of various energy conservation techniques learnt earlier on a theoretical basis and popularize them through hands-on experience in the preparation of measuring equipment, execution of measurement, and analysis of measured data. Along these lines, the following considerations have been made in preparing this textbook, to ensure that it can be readily utilized in various situations of practical energy conservation, whether they involve implementation or promotion:

(1) Energy conservation techniques have been presented along with concrete approaches to them so as to make their efficient application possible.

(2) The importance of measurement and control in energy conservation has been stressed, with an explanation given on the link that energy conservation is one of major measure of cost reduction in every manufacturing field.

(3) For promotion of energy conservation, it is necessary to introduce an energy monitoring and control system for identifying the energy consumption in an entire factory. In reference to a case of ECCJ factory, the configuration, functions, effects, and introduction cost of a system are presented.

(4) A factory energy audit manual has been prepared, which allows energy conservation effects to be identified quantitatively using relatively inexpensive measuring instruments for factory energy audit. The values referred to for quantification conform to the standard values and target values stated for evaluation of energy conservation in the Energy Conservation Law, and to Japanese Industrial Standards. These reference values and factory audit manual were designed to allow reflection in the policies of respective countries.

(5) In addition to measuring equipment handling methods, the textbook also covers the various benefits of energy conservation efforts learnt earlier on a theoretical basis in such a way that they can easily be recognized from measurement data.

(6) A conscious effort has been made to illustrate that even simple measurement data obtained in training sessions can provide useful information, as well as encouraging trainees to familiarize themselves fully with the process involved in bringing about an improvement from an analysis of measurement data.

1.1 Energy conservation promotion method

In factories, energy conservation is attained by systematic procedures shown in Fig. 1.1.

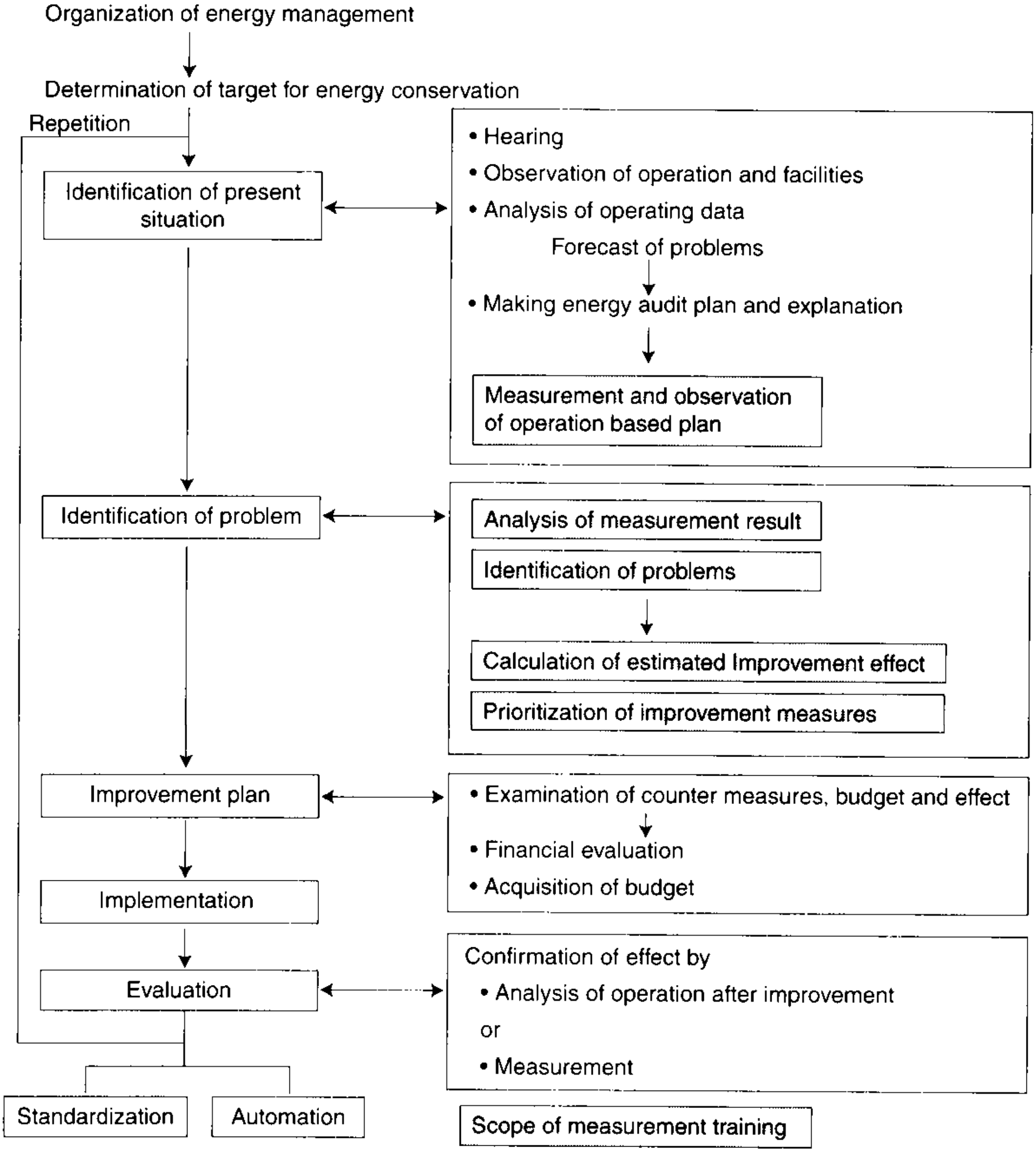


Fig. 1.1 Method for promoting energy conservation in factories

These energy conservation promotion techniques must be carried out repeatedly throughout the factory as a whole and for each one of its individual facilities and equipment. As a result of that process, energy conservation of the factory progresses by leaps.

The first step of energy conservation—an assessment of the present situation—boils down to a quantitative study of how efficiently energy is being used. The quantitative data obtained through this process is then utilized as the basic numerical data to estimate the existing state of energy consumption in making various assessments right up to the evaluation of the improvement results. As a result, the effectiveness of the implementation of energy conservation measures largely depends on the soundness of the quantitative basis of the assessment of the situation. For this reason, such an assessment must be carried out based on a carefully thought-out investigation plan prepared through adequate preparatory investigation, with the choice of an appropriate set of measuring equipment made followed by accurate measurements.

Needless to say, measurement activity using measuring equipment constitutes the means to obtain quantitative data, and therefore plays an important role in energy conservation efforts.

1.2 Importance of measurement in energy conservation

The term "measurement" means the technology that consists of studying the methods and techniques for knowing quantity with a certain objective, measuring them and utilizing the obtained results.

In factories, measurement is mainly undertaken for the purpose of reducing manufacturing costs, including energy costs, and protecting the environment. Its use takes the following three forms:

- Control
- Monitoring/management
- Investigation/analysis

In particular, measurement associated with control or monitoring/management is designed to help maintain manufacturing costs at low but sustainable levels. Along these lines, various measurement/control equipment has been introduced into manufacturing processes to ensure high efficiency stable plant operation through constant measurement, control or monitoring/management. For this reason, the use of measurement/control equipment in manufacturing processes is essential for a reduction in manufacturing costs, including energy costs, and its investment efficiency is very high.

On the other hand, measurement as part of investigation/analysis is designed to assist in the formulation of measures necessitated by a decision to further improve operational efficiency or an investigation into causes of abnormal conditions. Measurement undertaken to assess the present situation as discussed in section 1.1 is included in this utilization category.

To remind you of the importance of measurement, its contribution to cost reduction measures involving four types of manufacturing costs (labor/material costs excluded) is summarized in Table 1.1. In addition, to facilitate an understanding of the concept of broad energy conservation efforts, the way in which individual cost reduction measures affect each other is shown in Table 1.2. These tables highlight the following three points:

- The introduction of automatic control into production processes is the most effective measure to achieve a reduction in manufacturing costs. (It is not an overstatement to say that, without this, effective energy conservation would be impossible.)
- All manufacturing cost reduction measures are in essence equivalent to energy conservation measures.
- Ultimately, therefore, the most effective energy conservation efforts follow from the pursuit of the most effective manufacturing cost reduction measures as a whole, rather than a narrow focus on traditional energy conservation measures (e.g. waste heat recovery).

Table 1.1 Contribution of measurement to manufacturing cost reduction measures

Manufacturing cost reduction measure	Utilization forms of measurement		
	Automatic control	Manual control	Monitoring/ management
Stabilization of product quality	●	○	Δ
Improvement of productivity/yield	●	○	Δ
Stabilization of plant	●	○	Δ
Energy conservation	●	○	Δ

●: Large ; ○: Medium; Δ: Small

Table 1.2 Interaction between individual manufacturing cost reduction measures

Manufacturing cost reduction effect	Focuses of manufacturing cost reduction measures			
	Quality/Yield	Productivity	Plant stability	Energy consumption
Stabilization of product quality/Yield		Δ	●	Δ
Improvement of productivity	●		●	○
Stabilization of plant	Δ	○		●
Energy conservation	●	●	●	

●: Large ; ○: Medium; Δ: Small

1.3 Introduction of energy monitoring and control system

To reduce the production cost, it is also necessary to reduce the cost of energy used in a factory in addition to enhancing the efficiencies of individual production processes. The energy monitoring and control system for identifying the energy consumption in an entire factory is used for the above mentioned purposes and the achievement control of respective production processes. A case of introducing an energy monitoring and control system for the ECCJ factory in which you are being trained is described below.

(1) Utilities and measuring instruments of ECCJ factory

The utilities used include electricity, fuel oil, water, steam and compressed air. Table 1.3 shows the utilities used for respective apparatuses and the numbers of measuring instruments.

Table 1.3 Utilities used for respective apparatuses and numbers of measuring instruments

Item	Name of apparatus	Quantity	Utilities					No. of meters	
			Electricity	Fuel	Water	Steam	Compressed air	Watt-meter	Flow meter
Utility equipment	Supply meter	1	●					2	
	Transformer	2	●					4	
	Storage pump	1	●		●			1	1
	Feed water pump	1	○						
	Boiler	2	●	●	●		○		4
	Compressor	4	●				●	1	1
Production equipment	Heating furnace	1	○	●	●		○	1	2
	Dyeing machine	5	○		●	●			2
	Drying machine	2	○			●			1
	Production machine	2	●				○	2	
Environmental equipment	Dust collector	3	●					1	
Auxiliary equipment	Illumination	1	●					1	
	Air conditioning	1	●			●		1	1
Number of installed meters		●	14	3	5	3	1	14	12
Number of processes without meter		○	4	0	0	0	3	4	3

(2) System configuration, functions and effects

Figure 1.2 shows the configuration, functions and effects of the energy control system.

A. Functions of system

- Automatic collection of energy consumption data
- Display of trends in energy consumption data
- Electricity demand monitor
- Calculation of energy cost, power distribution loss, etc.
- Automatic production of daily reports and monthly reports
- Analysis of energy data

B. Effects of system

Energy conservation and energy cost reduction are achieved by

- Quick actions against abnormal conditions based on daily energy intensity control
- Reduction of contract power based on electricity demand monitor
- Reduction of basic charges based on power factor control
- Efficiency enhancement of operation based on analysis of various data
  * Smoothening of energy loads
  * Priority operation of highly efficiency apparatuses

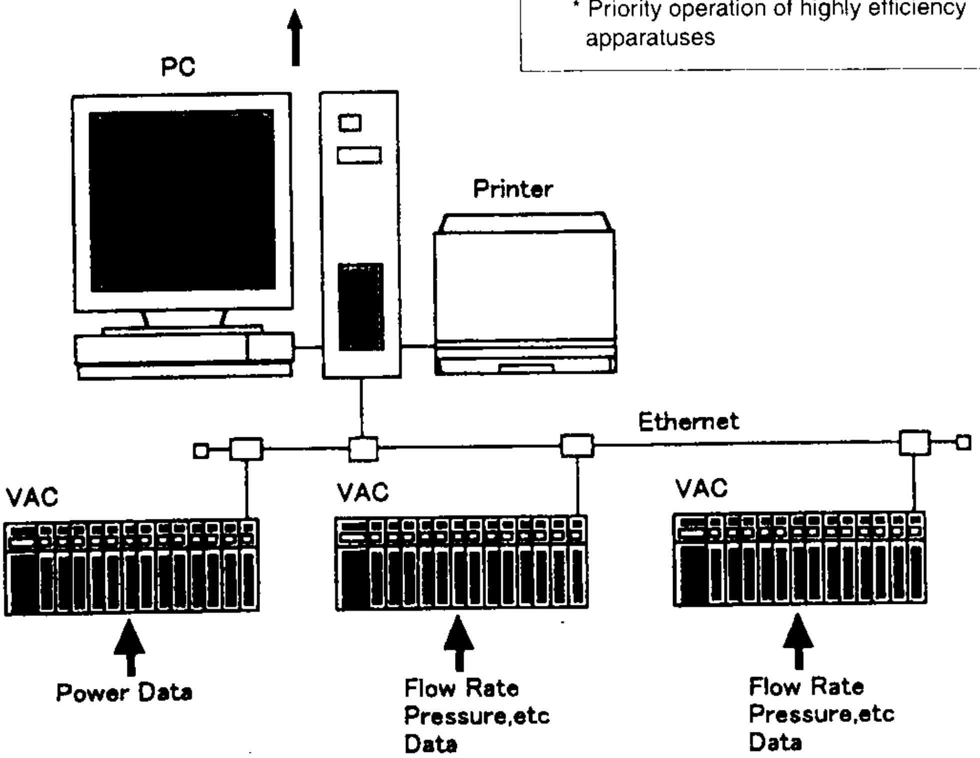


Fig. 1.2 Configuration, functions and effects of energy monitoring and control system

(3) System introduction cost

Table 1.4 shows the cost for introducing the energy control system.

Table 1.4 Cost for introducing the energy control system

	Item		Introduction cost *1 (in yen)	Reference
1	Computer system			
	1) Hardware	Operator station	574,000	574,000
		Printer	84,000	84,000
		8-port hub	30,000	30,000
		Control unit	1,061,000	1,061,000
		Total	1,749,000	1,749,000
	2) System software		600,000	600,000
	3) Development tool package		534,000	534,000
	4) Application software		2,600,000	2,600,000
	5) Project engineering		470,000	470,000
	6) Others		75,000	75,000
	Sub-total		6,028,000	6,028,000
2	Local instruments *2			
	1) Panel mounted wattmeter	(14 pcs. × 190,000 yen)		2,660,000
	2) Turbine type flowmeter	(3 pcs. × 330,000 yen)		990,000
	3) Vortex flowmeter	(9 pcs. × 600,000 yen)		5,400,000
	Sub-total			9,050,000
3	Construction work			
	1) Signal cable installation		2,000,000	2,000,000
	2) Meter installation and connecting pipe work			1,000,000
	Sub-total		2,000,000	3,000,000
4	Grand total		8,028,000	18,078,000

*1. US$1.0 = ¥120 (May 1999)
*2. If instruments are not installed, the instruments listed on the left must be purchased.

2. Measurement for Identification of the Present Situation of Energy Utilization

2.1 Measured items

Measurement items necessary for an assessment of the state of energy consumption include weight, flow rate, temperature, pressure, constitution, calorific value, electric energy, current and voltage. Suitable measurement items are selected from these on a case by case basis, depending on the objectives of the investigation plan, which must be carefully drawn up beforehand as discussed in section 1.1.

As measurement associated with an assessment of the present state of energy consumption is an activity which itself incurs costs, the investigation plan must be conducive to obtaining maximum data as investment output from a minimum measurement effort as investment input. In this regard, therefore, the following preparatory steps involving target facilities become important:

- Interviews with operation/maintenance personnel for feedback on problems
- Observation of facilities and their operational state, as well as gaining of access to construction drawings/control system flowcharts
- Gaining of access to operation records and identification of problems through their analysis
- Gaining of access to information on past examples of energy conservation measures
- Preparation of investigation plan based on above steps and explanation to operation/maintenance personnel.

In addition, the possible uses of measurement involving various measurement items and measurement targets are summarized in Table 2.1. The table can be utilized in the formulation of an investigation plan or the design of an instrumentation/control system. As discussed in section 1.2, the generic purpose of measurement is to maintain high-efficiency stable plant operation through control and monitoring based on measuring instruments mounted on the equipment.

Table 2.1 Relationship between objectives and variables of measurement

< Legend > ●: For automatic control; ❏: For operation/management; Δ: For investigation/analysis

Measured objectives		Measured variables	Weight	Flow rate	Temperature	Pressure	Constitution	Calorific value	Electric energy	Current	Voltage	Examples of measurement used in automatic control
Heated object or Cooled object	Solid		❏ Δ		● Δ							Temperature: Fuel. steam and electricity input control
	Liquid			❏ Δ	● Δ	●❏ Δ						
	Gas			❏ Δ	● Δ							Pressure: Boiler fuel input control
Heat source or Mechanical power source — Fuel	Solid		❏ Δ				Δ	❏ Δ				
	Liquid or Gas	Without preheating		❏ Δ	Δ	●❏ Δ	Δ	❏ Δ				Pressure: Fan/pump rotation speed control
		With preheating			●❏ Δ							Temperature:
Steam	Saturated			❏ Δ		❏ Δ						Liquid - viscosity adjustment
	Superheated				❏ Δ							Gas - Recuperator protection
Electricity									❏ Δ	❏ Δ	❏ Δ	
Combustion air	Without preheating			●❏ Δ	Δ	●❏ Δ						Flow: Combustion air control Pressure: Fan rotation speed control
	With preheating				●❏ Δ							Temperature: Recuperator protection
Combustion gas or Exhaust gas	Furnace interior				●❏ Δ	● Δ	● Δ					Temperature: Substitution for solid temperature measurement Pressure: Pressure control for furnace interior
	Flue			Δ	❏ Δ	Δ						Constitution: Combustion air ratio control
Cooling water				❏ Δ	❏ Δ	●❏ Δ						Pressure: Pump speed control
Furnace body radiation					Δ							

2.2 Measured points

Using a boiler, which is a typical heat source, as an example, measurement locations designed to cover all the measurement aspects of a heat balance calculation are shown in Fig. 2.1.

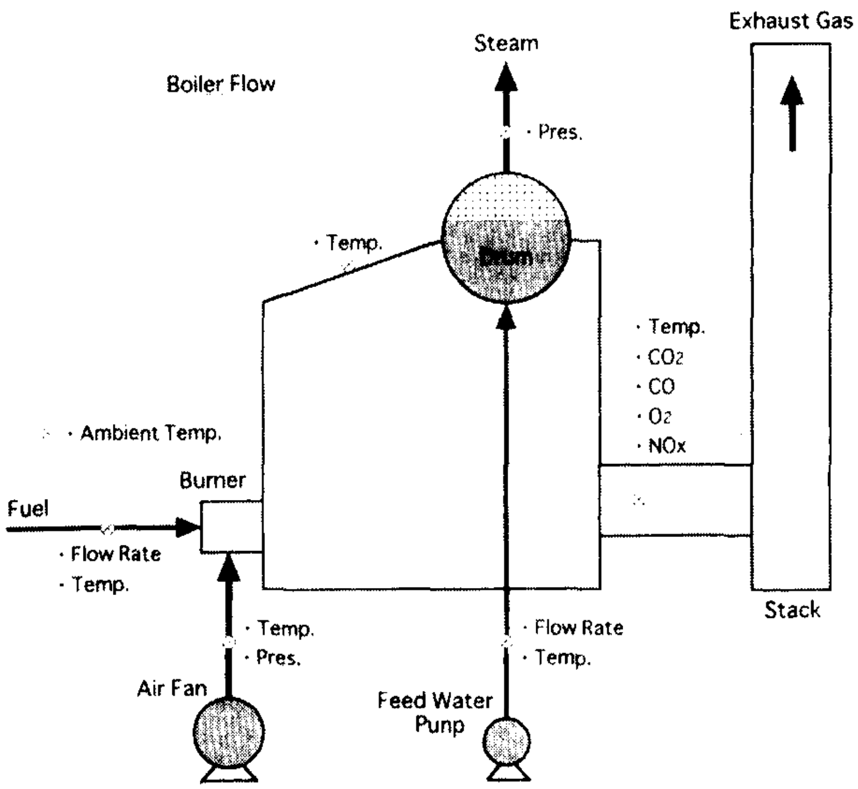


Fig. 2.1 Boiler heat balance measurement locations

2.3 Training equipment for measurement

Table 2.2 shows portable measuring instruments used for investigation and analysis.

Table 2.2 Practice measuring instruments and their uses

No	Measurement item	Function: Portable	Function: Continuous	Measuring instrument	Application	Standard/target set for evaluation under Energy Conservation Law: Air ratio	Waste gas temperature	Preheated air temperature	Waste heat recovery rate	Furnace outer wall temperature	Power factor improvement	Highly efficient motor	JIS: Feed water and boiler water	JIS: Standard illuminance	Price of measuring instrument (unit: yen) US$1.00 = ¥120
1	Temperature	○		Radiation thermometer (high temperature)	Indirect temperature measurement for high temperature objects										240,000
		○		Radiation thermometer (600°C or more)	Indirect temperature measurement for high temperature objects										211,000
		○		Radiation thermometer (−50~400°C)	Indirect temperature measurement for furnace surfaces etc.					○					58,000
		○		Thermometer	Direct temperature measurement for various objects		○	○	○	○					84,000
				(Transducer: Thermocouple)	Need for choice of thermocouple according to temperature to be measured		○	○	○	○					
		○		Surface thermometer	Direct temperature measurement for furnace surfaces etc.					○					84,000
		○	○	Infrared imager	Indirect measurement of temperature distribution for various objects					○					2,650,000
2	Gas analysis	○		O_2 analyzer	O_2 analysis of combustion gas	○			○						145,000
			○	O_2 analyzer	O_2 analysis of combustion gas	○			○						450,000
			○	CO/CO_2 analyzer	CO/CO_2 analysis of combustion gas	○			○						2,530,000
			○	Sampling unit	Suction, dusting, dehumidification and cooling of combustion exhaust gas	○			○						825,000
				Sampling tube	Collection of combustion exhaust gas in high temperature furnace	○			○						
3	Flow rate	○	○	Ultrasonic flowmeter (Ultrasonic thickness gauge)	Flow rate measurement for liquids up to 100°C in temperature Measurement of piping thicknesses										1,753,000
		○	○	Hot-wire anemometer	Measurement of flow rate of gases up to 500°C in temperature				○						531,000
4	Power	○		Clamp-type power meter	Measurement of voltage, current, real power, etc.						○	○			98,000
			○	Clamp-type power meter	Measurement of voltage, current, real power, power factor, etc.						○	○			755,000
5	Pressure	○		Digital manometer	Measurement of gas pressure										50,000
			○	Differential pressure meter	Measurement of gas pressure										270,000
6	Water quality	○		pH meter	Boiler water quality control								○		85,000
		○		Conductivity meter	Boiler water quality control								○		98,000
7	Illuminance	○		Illuminometer	Illumination measurement for indoor working surfaces									○	28,000
8	Recording		○	20-point recording meter	Recording of measurement trends										930,000
			○	Memory card reader	Reading of measurement values stored on memory cards										160,000
				(Memory card)	Storage of measurement data										

3. Energy Conservation Audit Manual

3.1 Necessity of factory energy conservation audit

A factory which does not have any organization or engineer for promoting energy conservation does not know how to promote energy conservation. The energy conservation audit is effective for promoting the prevalent use of the energy conservation technology in such factories. It is important that the factory audit presents quantitative energy conservation effects for respective problems in an entire factory. Under this condition, the usefulness of energy conservation can be understood, and the energy conservation technology can be easily promoted in prevalent use.

3.2 Energy conservation audit manual

An audit manual for achieving the purpose of 3.1 is shown in Table 3.1. The results of investigation by hearing, observation and simple measurement are stated there to calculate the effects of energy conservation measures.

- Table 3.1.1 is a sheet for identifying the control situation of an entire factory.
- Table 3.1.2 is a sheet for auditing a boiler, industrial furnace and steam system.
- Table 3.1.3 is a sheet for auditing electric power receiving and transforming equipment, electric heating equipment, motor, pump and fan.
- Table 3.1.4 is a sheet for auditing a compressor, illumination and introduction of cogeneration.
- Table 3.1.5 is a sheet for auditing air conditioning and refrigerating equipment.

3.3 Standard values, target values, etc. specified for evaluation of energy conservation in Energy Conservation Law

For evaluating, at the time of audit, whether operation is appropriate, the values to be referred to are necessary. The values specified in the Energy Conservation Law are shown in Tables 3.2 to 3.8 and Fig. 3.1.

- Table 3.2 shows the standard values and target values of air ratios and waste gas temperatures of combustion equipment.
- Table 3.3 shows the standard values and target values of waste heat recovery rates for industrial furnaces.
- Table 3.4 shows the standard values and target values of furnace wall outer surface temperatures for industrial furnaces with furnace temperatures of 500°C and higher.
- Table 3.5 shows the water quality specifications (JIS) of boiler feed water and boiler water.
- Table 3.6 shows the apparatuses to be improved in power factor.
- Table 3.7 shows the target efficiencies of highly efficient motors.
- Table 3.8 shows the relation between the capacities and optimum voltages of motors. This table shows recommended values irrespective of the law.
- Fig. 3.1 shows the standard illuminances (JIS) of offices and factories.

Table 3.1.1 Energy Conservation Auditing Manual   Category <General condition items>

Check item				Judgment standard/audit result		Evaluation and comment	Auditing instrument
Item	Sub item			Standard/result	Unit		
Outline of company/factory	Business categoryMajor products						
	Major products						
	Annual shipment				thousand yen/year		
Annual energy consumption	Fuel (by kind)		Consumption		/year		
			Unit purchase cost		yen/		
			Purchase cost		thousand yen/year		
			Consumption		/year		
			Unit purchase cost		yen/		
			Purchase cost		thousand yen/year		
			Consumption		/year		
			Unit purchase cost		yen/		
			Purchase cost		thousand yen/year		
		Total fuel cost			thousand yen/year		
		Fuel cost ratio			%		
	Electric power	Contract power			kW		
		Agreed power factor			%		
		Received voltage			V		
		Consumption			MWh/year		
		Unit purchase cost			yen/kWh		
		Purchase cost			thousand yen/year		
		Electric power cost ratio			%		
	Water (by kind)		Consumption		m^3/year		
			Unit purchase cost		yen/m^3		
			Purchase cost		thousand yen/year		
			Consumption		m^3/year		
			Unit purchase cost		yen/m^3		
			Purchase cost		thousand yen/year		
		Total water cost			thousand yen/year		
		Water cost ratio			%		
	Others		Consumption		/year		
			Unit purchase cost		yen/		
			Purchase cost		thousand yen/year		
			Consumption		/year		
			Unit purchase cost		yen/		
			Purchase cost		thousand yen/year		
	Total energy cost				thousand yen/year		
	Energy cost ratio				%		

Check item			Judgment standard/audit result		Evaluation and comment	Auditing instrument
Item	Sub item		Standard/result	Unit		
Process, energy consuming facility	Acquisition of manufacturing process					
	Name of facility	Specifications				
		Number		Units		
		Specifications				
		Number		Units		
		Specifications				
		Number		Units		
		Specifications				
		Number		Units		
		Specifications				
		Number		Units		
		Specifications				
		Number		Units		
Energy management system	Management organization	Existence of organization	Yes or no			
		Number of persons of the organization		persons		
	Holding of energy conservation committee	Frequency of committee meetings		times/year		
		Number of participants		persons		
	Education of employees	Frequency of education courses		times/year		
		Number of participants		persons		
	Energy conservation targets	Targeted or not	Yes or no			
		Ratio		%		
		Reduction in monetary term		thousand yen/year		
	Budget for energy conservation investment	Budgeted or not	Yes or no			
		Amount of budget		thousand yen/year		
	Implementation of energy conservation measures	Implemented or not	Yes or no			
		Number of measures		cases		
	Utilization of official preferential treatments	Utilized or not	Yes or no			
		Number of cases		cases		
	Observance of environmental standards	Number of subject facilities		Units		
		Frequency of measurement		times/year		
Measurement of energy	Watt-hour meter	Measured or not	Yes or no			
		Number of units		Units		
	Fuel flow meter	Measured or not	Yes or no			
		Number of units		Units		

Check item			Judgment standard/audit result		Evaluation and comment	Auditing instrument
Item	Sub item		Standard/result	Unit		
Measurement of energy	Steam flow meter	Measured or not	Yes or no			
		Number of units		Units		
	Compresses air flow meter	Measured or not	Yes or no			
		Number of units		Units		
	Cooling water flow meter	Measured or not	Yes or no			
		Number of units		Units		
	Others	Measured or not	Yes or no			
		Number of units		Units		
		Measured or not	Yes or no			
		Number of units		Units		
	Inspection of instruments	Inspected or not	Yes or no			
		Frequency of inspections		times/year		
Management of energy consumption	Record of consumption by major facilities	Form recorded or not	Yes or no			
		Number of forms		sheets		
	Control of unit consumption by major	Form recorded or not	Yes or no			
		Number of forms		sheets		
Maintenance and management of facilities	Periodic inspection of major facilities	Inspected or not	Yes or no			
		Inspection interval		months		
	Repairing of leaks (water, air, steam)	Repaired or not	Yes or no			
		Repair interval		months		
	Inspection of thermal insulation	Inspected or not	Yes or no			
		Inspection interval		months		
	Cleaning of facilities (filter, strainer)	Cleaned or not	Yes or no			
		Cleaning interval		months		
Improvement of process	Execution of operation improvement	Implemented or not	Yes or no			
		Number of cases		cases		
	Efficiency improvement of facilities	Implemented or not	Yes or no			
		Number of cases		cases		
	Continuous operation of facilities	Implemented or not	Yes or no			
		Number of cases		cases		
Measure for leveling of load	Improvement of operation mode	Implemented or not	Yes or no			
		Number of cases		cases		
	Installation of holders, heat storage facilities	Implemented or not	Yes or no			
		Number of cases		cases		

Table 3.1.2 Energy Conservation Auditing Manual — Category <Boiler, industrial furnace, steam system, *effluent hot water system, etc.*>

Item	Check item	Sub item	Judgment standard/audit result: Standard/result	Judgment standard/audit result: Unit	Reduction *effect*	Evaluation and comment	Auditing instrument
Boiler and industrial furnace	Furnace type						
	Material heated						
	Acquisition of process flow diagram and instrumentation diagram						
(Operation condition and improvement)	Fuel	Type					
		Heat of combustion		kJ/			
	Throughput			t/h			
	Fuel consumption			/h			Liquid fuel: ultrasonic flow meter
	Fuel unit consumption			MJ/t			
	Thermal efficiency			%			
	Lowering of heated temperature and pressure	Required temperature and pressure		°C, MPa	MJ/t		Optical pyrometer
		Operation temperature		°C			Radiation thermometer
		Operation pressure		MPa			
(Combustion control)	Capacity of the burner	Design load		MJ/h			
		Actual load		MJ/h			
	Visual inspection of flames	*Flame pattern*					
		Visibility in furnace					
	Optimization of air ratio	O_2 concentration		%	MJ/t		Portable oxygen meter
		Standard values (Table 3.2)					
		Air ratio					
(*Control method and* improvement)	Control of temperature or pressure	Proportional control					
		On/off control					
		Sequential startup control					
	Control of air ratio	*Flow rate control*					
		Pressure control					
		Interlock mechanism					
	Control of combustion chamber pressure	Controlled or not	Yes or no				*Portable pressure gauge*
		Operation pressure		Pa			
	Improvement of controlling facility	Item			MJ/t		
		Improvement effect		%			
(Recovery of waste heat and improvement)	Degree of waste heat recovery	Combustion air		°C			Portable thermometer
		Fuel		°C			Contact surface thermometer
		Water supply		°C			Radiation thermometer
		Material heated		°C			
	Exhaust gas recirculation	*Temperature*		°C	MJ/t		
		Heat users					
	Lowering of exhaust gas temperature	Standard values (Table 3.3)		°C	MJ/t		
		Temperature		°C			
		Heat loss		MJ/h			
(*large-scale facility* improvement)	Regenerative combustion system	Reduction of energy loss		%	MJ/t		
		Reduction effect		MJ/t			

Table 3.2 Standard values and target values of air ratios and waste gas temperatures for combustion equipment

Classification					Air ratio					Waste gas temperature				
	Item			Load factor (%)	Solid fuel		Liquid fuel	Gas fuel	Byproduced gas such as blast furnace gas	Solid fuel		Liquid fuel	Gas fuel	Byproduced gas such as blast furnace gas
					Fixed bed	Fluidized bed				Fixed bed	Fluidized bed			
Boiler	Standard	For electric utility		75~100	—	—	1.05~1.2	1.05~1.1	1.2	—	—	145	110	200
		Other (quantity of evaporation)	30 t/h or more	50~100	1.3~1.45	1.2~1.45	1.1~1.3	1.1~1.2	1.2~1.3	200	200	200	170	200
			10 to less than 30 t/h	50~100	1.3~1.45	1.2~1.45	1.15~1.3	1.15~1.3	—	200	200	200	170	—
			5 to less than 10 t/h	50~100	—	—	1.2~1.3	1.2~1.3	—	—	—	220	200	—
			Less than 5 t/h	50~100	—	—	1.2~1.3	1.2~1.3	—	—	—	250	220	—
	Target	For electric utility		75~100	—	—	1.05~1.1	1.05~1.2	1.05~1.2	—	—	135	110	190
		Other (quantity of evaporation)	30 t/h or more	50~100	1.2~1.3	1.2~1.45	1.1~1.15	1.1~1.15	1.20~1.3	180	170	160	140	190
			10 to less than 30 t/h	50~100	1.2~1.3	1.2~1.45	1.15~1.25	1.15~1.25	—	180	170	160	140	—
			5 to less than 10 t/h	50~100	—	—	1.15~1.3	1.15~1.25	—	—	300	180	160	—
			Less than 5 t/h	50~100	—	—	1.15~1.3	1.15~1.25	—	—	320	200	180	—

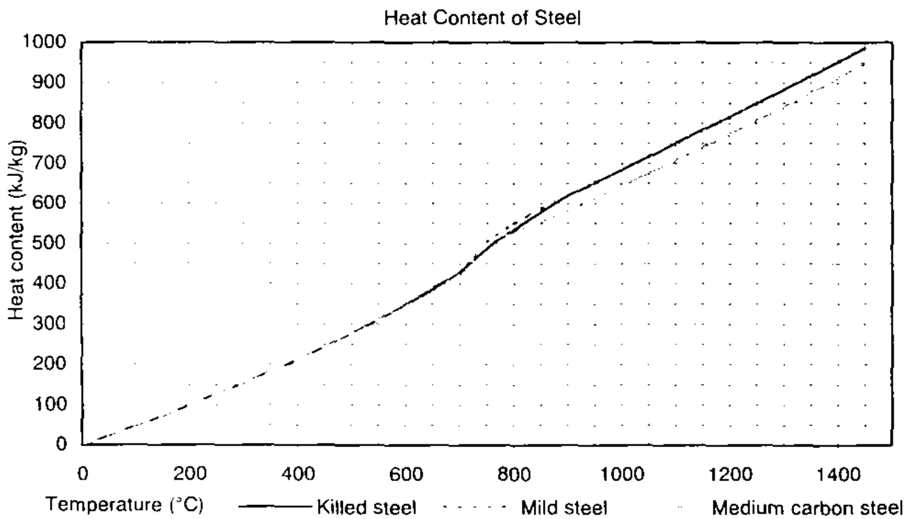
Industrial furnace		Item	Gas fuel		Liquid fuel		Remarks
			Continuous type	Intermittent type	Continuous type	Intermittent type	
	Standard	Melting furnace for metal forging	1.25	1.35	1.30	1.40	
		Steel strand heating furnace	1.20	—	1.25	—	
		Metal heating furnace other than the above	1.25	1.35	1.25	1.35	
		Metal heat treatment furnace	1.20	1.25	1.25	1.30	
		Oil heating furnace	1.20	—	1.25	—	
		Thermal decomposition furnace and reforming furnace	1.20	—	1.25	—	
		Cement kiln	1.30	—	1.30	—	Value of liquid fuel in the case of pulverized coal firing
		Coal kiln	1.30	1.35	1.30	1.35	Value of liquid fuel in the case of pulverized coal firing
		Drying furnace	1.25	1.45	1.30	1.50	Burner portion only
	Target	Melting furnace for metal forging	1.05~1.20	1.05~1.25	1.05~1.25	1.05~1.30	
		Steel strand heating furnace	1.05~1.15	—	1.05~1.20	—	
		Metal heating furnace other than the above	1.05~1.20	1.05~1.30	1.05~1.20	1.05~1.30	
		Metal heat treatment furnace	1.05~1.15	1.05~1.25	1.05~1.20	1.05~1.30	
		Oil heating furnace	1.05~1.20	—	1.05~1.25	—	
		Thermal decomposition furnace and reforming furnace	1.05~1.20	—	1.05~1.25	—	
		Cement kiln	1.05~1.25	—	1.05~1.25	—	Value of liquid fuel in the case of pulverized coal firing
		Coal kiln	1.05~1.25	1.05~1.35	1.05~1.25	1.05~1.35	Value of liquid fuel in the case of pulverized coal firing
		Drying furnace	1.05~1.25	1.05~1.45	1.05~1.30	1.05~1.50	Burner portion only

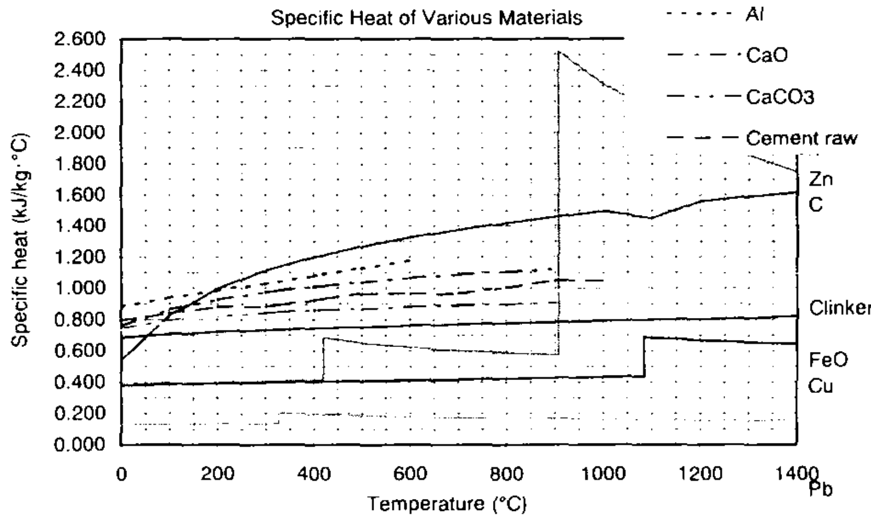
Table 3.3 Standard values and target values of waste heat recovery rates for industrial furnaces (including waste gas temperatures for reference)

Exhaust gas temperature (°C)	Capacity class	Standard waste heat recovery rate (%)	Target waste heat recovery rate (%)	Reference	
				Waste gas temperature (°C)	Preheated air (°C)
Less than 500	A · B	25	35	275	190
500~600	A · B	25	35	335	230
600~700	A	35	40	365	305
	B	30	35	400	270
	C	25	30	435	230
700~800	A	35	40	420	350
	B	30	35	460	310
	C	25	30	505	265
800~900	A	40	45	435	440
	B	30	40	480	395
	C	25	35	525	345
900~1,000	A	45	55	385	595
	B	35	45	485	490
	C	30	40	535	440
1,000 or more	A	45	55		
	B	35	45	—	—
	C	30	40		
Gas temperature at furnace outlet or recuperator inlet	A	84,000	—	20,059	—
	B	21,000	84,000	5,015	20,059
	C	840	21,000	201	5,015
Remark		MJ/h or more	Less than MJ/h	MJ/h or more	Less than MJ/h

Table 3.4 Standard values and target values of furnace wall outer surface temperatures for industrial furnaces with furnace temperatures of 500°C or more

Item	Furnace temperature (°C)	Furnace wall outer surface temperature (°C)		
		Ceiling	Lateral wall	Bottom in contact with open air
Standard	1,300 or more	140	120	180
	1,100~1,300	125	110	145
	900~1,100	110	95	120
	Less than 900	90	80	100
Target	1,300 or more	120	110	160
	1,100~1,300	110	100	135
	900~1,100	100	90	110
	Less than 900	80	70	90



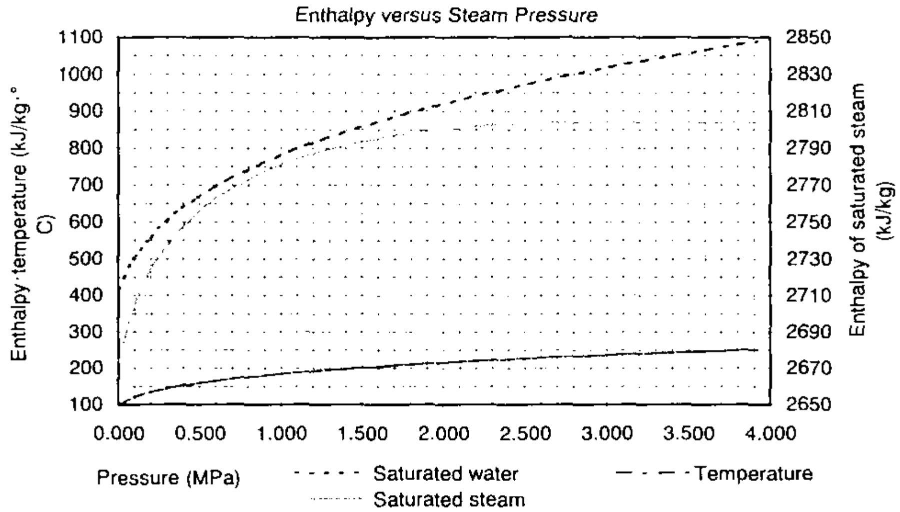


Density of Matters

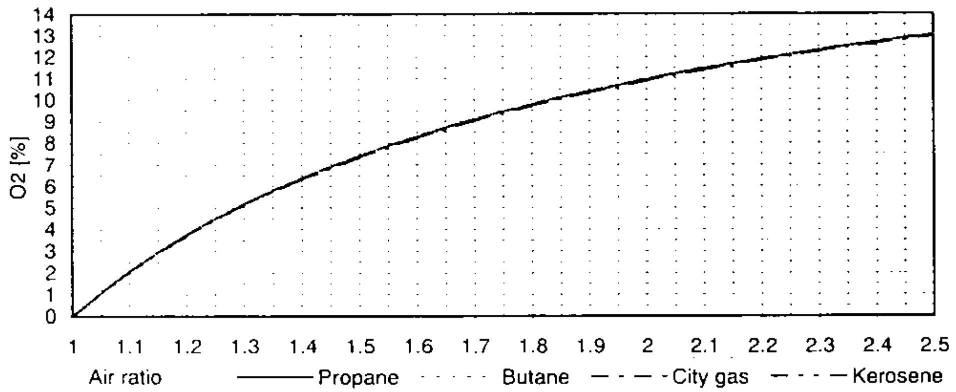
Material	Density (15°C)kg/m³	Melting point °C	Heat of fusion kJ/kg
Killed steel	7,856	1,496	247.4
Mild steel	7,859	Pure iron	Pure iron
Medium carbon steel	7,854	1,537	267.0
Pure copper	8,897	1,084	205.0
Pure lead	11,342	328	24.7
Pure zinc	7,139	420	102.0
Pure aluminum	2,689	660	395.0

Heat of Combustion of Gaseous and Liquid Fuel and other properties

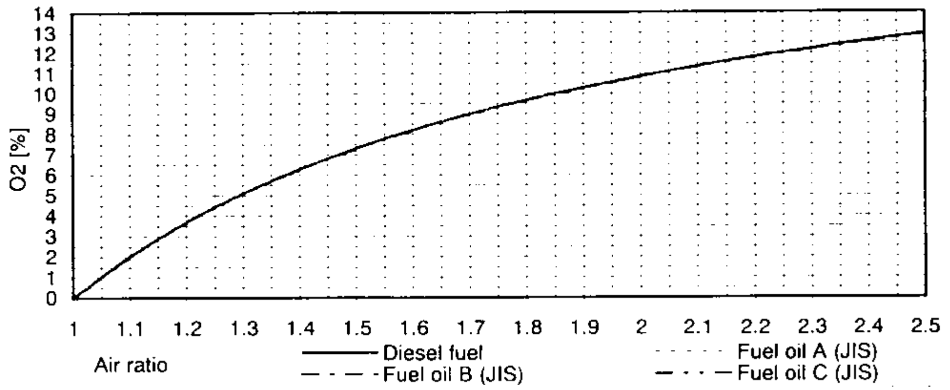
Fuel	Heat of combustion kJ/Nm³ kJ/kg	Density kg/Nm³ kg/L	Theoretical air rate Nm³/Nm³ Nm³/kg	Exhaust gas rate (dry base) Nm³/Nm³ Nm³/kg	Exhaust gas rate (wet base) Nm³/Nm³ Nm³/kg	CO_2Max %
LPG (Propane)	93,575	1.967	23.81	21.810	25.810	13.8
LPG (Butane)	123,008	*2.587*	*30.88*	*28.386*	*33.376*	14.1
Tokyo Gas (13A)	41,701	0.842	10.95	9.846	12.045	12.2
Kerosene	43,543	0.795	11.36	10.575	12.143	15.1
Diesel Fuel	43,040	0.840	11.13	10.403	11.881	15.4
Fuel oil A (LS) (JIS)	42,747	0.850	10.83	10.170	11.514	15.8
Fuel oil B (JIS)	41,282	0.915	10.53	9.920	11.185	15.9
Fuel oil C (LS) (JIS)	41,449	0.945	10.56	9.965	11.185	16.1



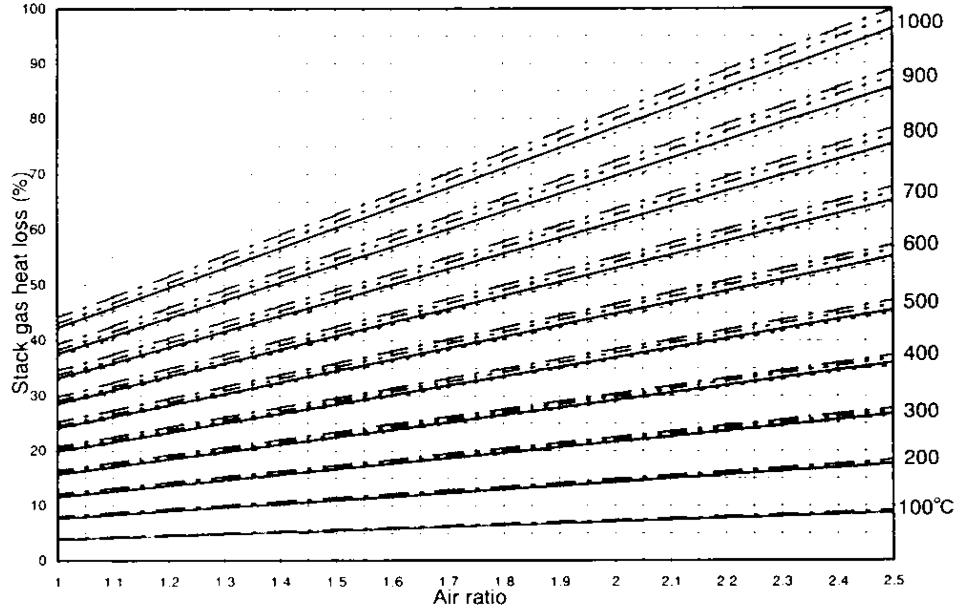
Concentration of O2 versus Air Ratio



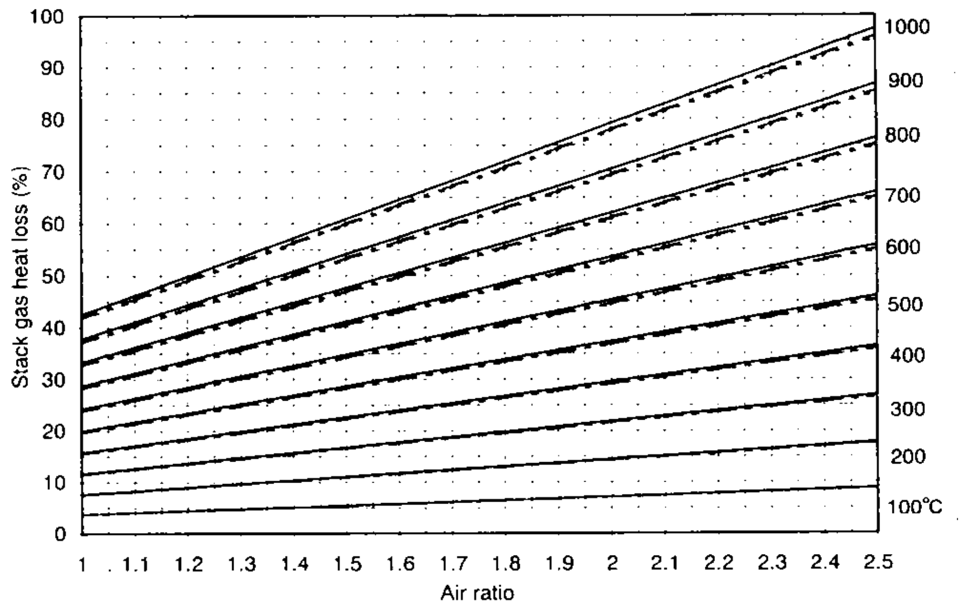
Concentration of O2 versus Air Ratio



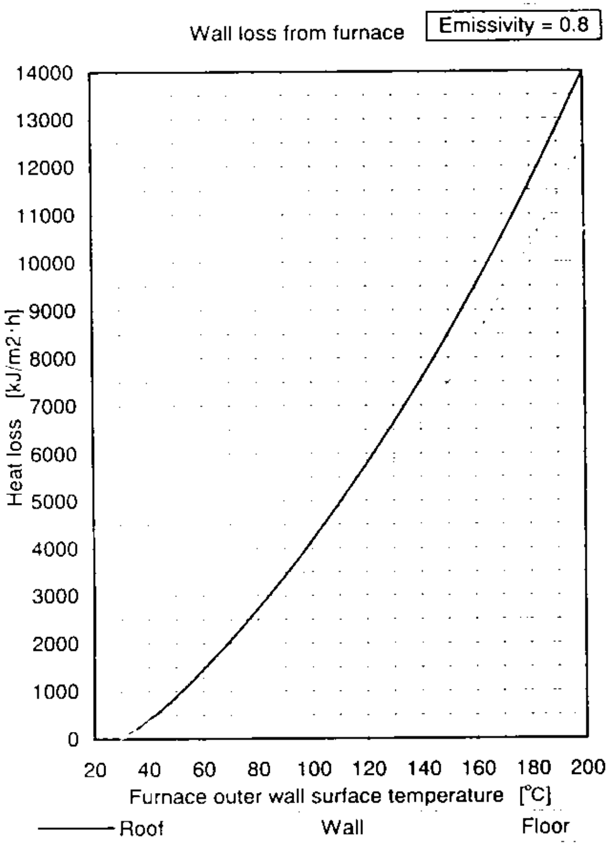
Stack Gas Heat Loss versus Air Ratio

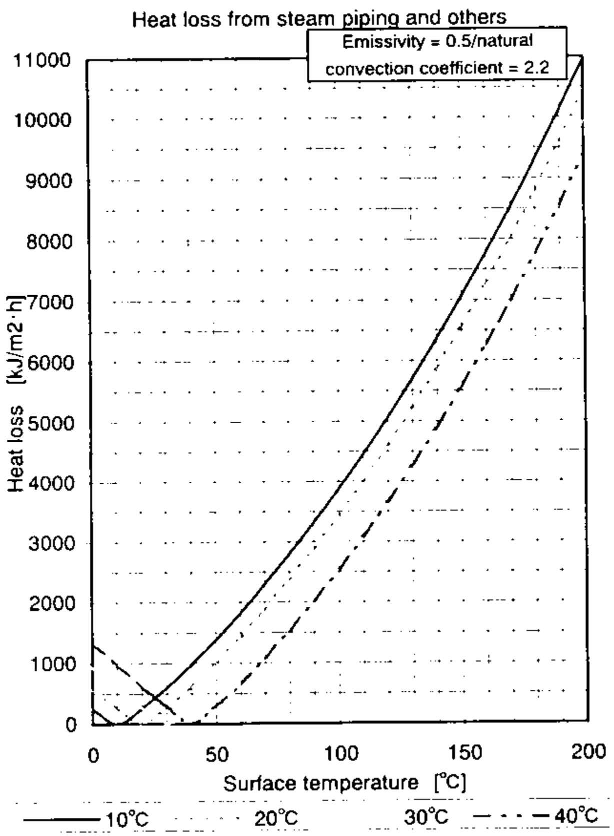


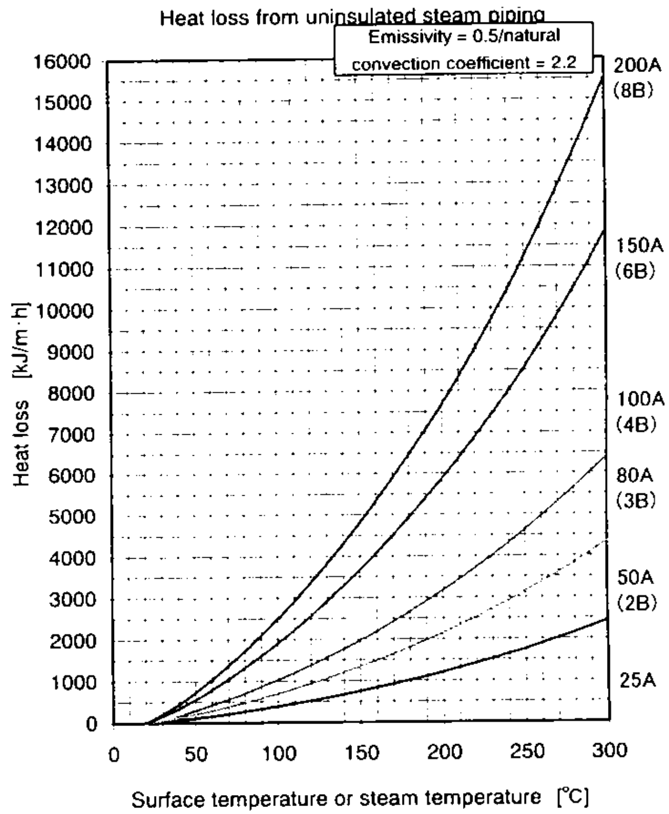
Stack Gas Heat Loss versus Air Ratio



Check item			Judgment standard/audit result		Reduction effect	Evaluation and comment	Auditing instrument
Item	Sub item		Standard/result	Unit			
Thermal insulation and improvement	Furnace wall surface temperature	Standard values (Table 3.4)		°C	MJ/t		Radiation thermometer
		Surface temperature		°C			Contact surface thermometer
		Heat loss		kJ/h			Portable thermometer
	Duct temperature	Standard values (Table 3.4)		°C	MJ/t		
		Surface temperature		°C			
		Heat loss		kJ/h			
	Reduction of heat loss through openings	Cross-sectional area		m^2	MJ/t		
		Furnace internal temperature		°C			
		Heat loss		kJ/h			
Operation control of boiler	Quality control of boiler feed water and boiler	Kind of feed water					pH meter
		Controlled or not	Yes or no				Electric conductivity meter
	Control of blow water	Blow rate (Table 3.5)		%	MJ/t		
		Heat loss		kJ/h			
(Improvement of energy-using facility)	Reduction of steam consumption	Minimum requirement		t/h	t/h		
		Consumption		t/h			
	Lowering of pressure	Minimum required pressure		MPa	MJ/t		
		Operation pressure		MPa			
	Recovery of drain	Amount of drain water		t/h	t/h		
		Users					
	Utilization of flash steam	Amount of drain water		t/h	t/h		
		Users					
	Leveling of steam consumption	Fluctuation range		t/h	t/h		
		Average flow		t/h			
Steam system : Small-scale	Acquisition of piping diagram and instrumentation diagram						
	Repairing of leaking pipes and steam traps	Leakage	Yes or no		t/h		Trap sensor
		Amount of leakage		t/h			
	Improvement of insulation	(Equal to or lower than ambient temperature plus 15°C)		°C	t/h		Radiation thermometer
		Surface temperature		°C	t/h		Contact surface thermometer
		Heat loss		kJ/h			
	Reduction of pressure drop through pipes	Reduction of pressure drop		MPa	MJ/t		
	Trimming of pipe length, piping	Reduction of pipe length		m	t/h		
		Reduction of heat loss		kJ/h*m			
: Medium-scale improvement	Recovery of drain	Amount of drain		t/h	t/h		
		Users					
	Use of ejector as vacuum pump	Steam consumption		t/h	t/h		
		Electric power consumption		kWh			
: Large-scale improvement	Installation of accumulator	Effect of installation		t/h	MJ/t		
		Fuel saving effect		C			
Reduction of hot water discharge	Recirculation of cooling water	Unit cost difference		円/t	yen/year		Ultrasonic flow meter
		Reduction		t/h			Portable thermometer
	Recovery of heat from hot water	Flow rate of hot water		t/h	t/h		
		Temperature of hot water		°C			
		Recovered heat		MJ/h			







Surface area of piping parts

			15A	20A	25A	40A	50A	65A	80A	100A	125A	150A	200A
Nominal size			15A	20A	25A	40A	50A	65A	80A	100A	125A	150A	200A
Pipe outside diameter [mm]			17.3	27.2	34.0	48.6	60.5	76.3	89.1	114.3	139.8	165.2	216.3
Pipe wall thickness [mm]			2.8	2.9	3.4	3.7	3.9	5.2	5.5	6	6.6	7.1	8.2
Surface area of insulated portion [m²]	Piping (unit length)		0.054	0.085	0.107	0.153	0.190	0.240	0.280	0.359	0.439	0.519	0.680
	0.98MPa	Flange	0.034	0.039	0.059	0.072	0.083	0.100	0.118	0.139	0.195	0.235	0.301
		Globe valve	0.078	0.090	0.131	0.170	0.211	0.294	0.349	0.455	0.616	0.776	1.137
		Gate valve	0.076	0.083	0.123	0.201	0.231	0.278	0.367	0.429	0.556	0.699	1.032
		Reducing valve	0.133	0.145	0.179	0.228	0.295	0.383	0.466	0.567	0.840	0.915	1.231
		Control valve		0.146	0.197	0.239	0.304		0.430			0.770	
	1.96MPa	Flange	0.035	0.039	0.058	0.072	0.094	0.011	0.139	0.165		0.289	0.345
		Globe valve	0.084		0.129	0.183	0.243	0.360	0.436	0.567		0.923	1.271
		Gate valve	0.088	0.096	0.141	0.188	0.290		0.456	0.537		0.996	

Pressure drop in steam

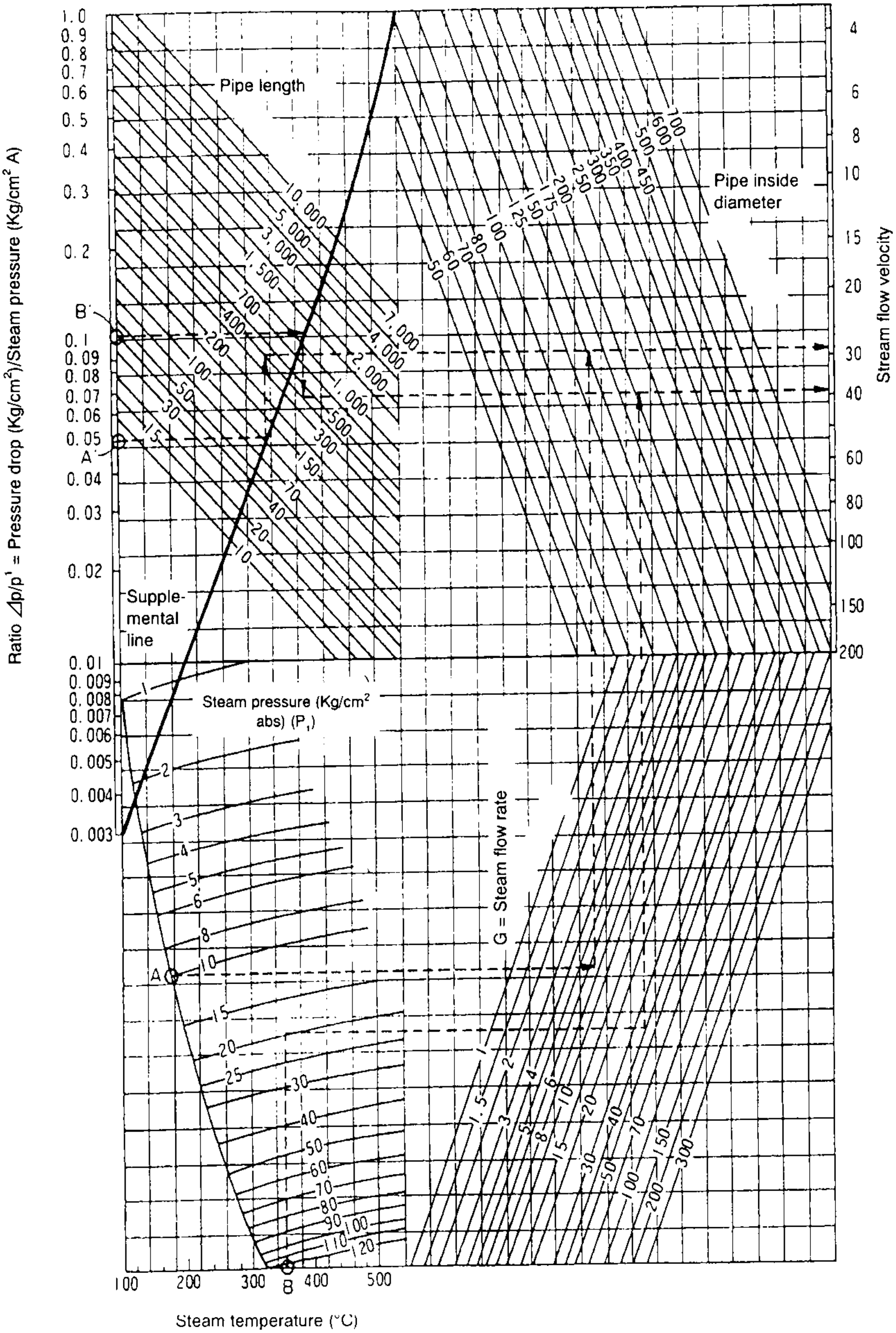


Table 3.5 Water quality specifications for boiler feed water and boiler water (JIS B 8223)

Item	Kind of boiler	Cylindrical boiler			Water tube boiler													
Item	Maximum pressure (kg/cm^2)	—			~10		10~20	20~30	30~50	50~75	75~100		100~125		125~150		150~200	
	Heating surface evaporation rate ($kg/m^2 \cdot h$)	~30	30~60	60~	~50	50~												
Feed water	pH (25°C)	7~9			7~9		7~9	7~9	8~9.5	8.5~9.5	8.5~9.5		8.5~9.5		8.5~9.5		8.5~9.5	
	Oils and fats (mg/l)	~60	~2	~1	~1		~1	0	0	0	0		0		0		0	
	Hardness ($mgCaCO_3/l$)	To be kept at 0 as far as possible			To be kept at 0 as far as possible		To be kept at 0 as far as possible		To be kept at 0 as far as possible		To be kept at 0 as far as possible		To be kept at 0 as far as possible		To be kept at 0 as far as possible		To be kept at 0 as far as possible	
	Dissolved oxygen (mgO/l)	To be kept low			To be kept low		~0.5	~0.1	~0.03	~0.007	~0.007		~0.007		~0.007		~0.007	
	Total iron (mgFe/l)	—			—		—	—	~0.1	~0.05	~0.03		~0.03		~0.02		~0.002	
	Total copper (mgCu/l)	—			—		—	—	~0.05	~0.03	~0.02		~0.01		~0.01		~0.005	
	Hydrazine (mgN_2H_4/l)	—			—		—	0.2~	0.06~	0.01~	0.01~		0.01~		0.01~		0.01~	
	Electric conductivity (25°C · μs/cm)	—			—		—	—	—	—	—		—		~0.03		~0.03	
Boiler water	Treatment method	Alkali treatment			Alkali treatment				Alkali/phosphate treatment		Phosphate	Volatile matter	Phosphate	Volatile matter	Phosphate	Volatile matter	Phosphate	Volatile matter
	pH (25°C)	11.0~11.8			11.0~11.8		10.8~11.3	10.5~11.0	9.4~11.0	9.2~10.8	8.7~9.7	8.5~9.5	8.5~9.5	8.5~9.5	8.5~9.5	8.5~9.5	8.5~9.5	8.5~9.5
	M alkalinity ($mgCaCO_3/l$)	100~800			100~800		~600	~150	—	—	—	—	—	—	—	—	—	—
	Alkalinity ($mgCaCO_3/l$)	80~600			80~600		~500	~120	—	—	—	—	—	—	—	—	—	—
	Total evaporation residue (mg/l)	~4000	~3000	~2500	~3000	~2500	~2000	~700	~500	~300	~100	~20	~30	~5	~20	~3	~10	~2
	Electric conductivity (25°C · μs/cm)	~6000	~4500	~4000	~4500	~4000	~3000	~1000	~800	~500	~150	~60	~60	~20	—	—	—	—
	Chloride ions ($mgCl^-/l$)	~600	~500	~400	~500	~400	~300	~400	~80	~50	~10	—	~3	—	—	—	—	—
	Phosphate ions ($mgPO_4^{3-}/l$)	20~40			20~40		20~40	5~15	5~15	3~10	2~6	—	1~5	—	0.5~3	—	0.5~3	—
	Sulfite ions ($mgSO_3^{2-}/l$)	10~20			10~20		10~20	5~10	5~10	—	—	—	—	—	—	—	—	—
	Hydrazine (mgN_2H_4/l)	0.1~0.5			0.1~0.5		0.1~0.5	—	—	—	—	—	—	—	—	—	—	—
	Silica ($mgSiO_2/l$)	—			—		—	~50	~20	~5	~2		~0.5		~0.3		~0.2	

Item	Kind of boiler	Once through boiler					
	Maximum pressure (kg/cm^2)	~25	75~100	100~125	125~150	150~200	200~
Feed water	pH (25°C)	10.5~11.0	8.5~9.5	8.5~9.5	8.5~9.5	8.5~9.5	9.0~9.5
	Hardness ($mgCaCO_3/l$)	~1	0	0	0	0	0
	Dissolved oxygen (mgO/l)	~0.5	~0.007	~0.007	~0.007	~0.007	~0.007
	Total iron (mgFe/l)	—	~0.03	~0.03	~0.02	~0.02	~0.01
	Total copper (mgCu/l)	—	~0.01	~0.01	~0.005	~0.003	~0.002
	Hydrazine (mgN_2H_4/l)	—	0.01~	0.01~	0.01~	0.01~	0.01~
	Silica ($mgSiO_2$) with separator	—	~0.04	~0.04	~0.03	~0.02	~0.02
	Silica ($mgSiO_2$) without separator	—	~0.02	~0.02	~0.02	~0.02	~0.02
	Total evaporation residue (mg/l)	~700	—	—	—	—	—
	Electric conductivity (25°C · μs/cm)	~1000	~0.3	~0.3	~0.3	~0.3	~0.25
	Phosphate ions ($mgPO_4^{3-}/l$)	20~40	—	—	—	—	—

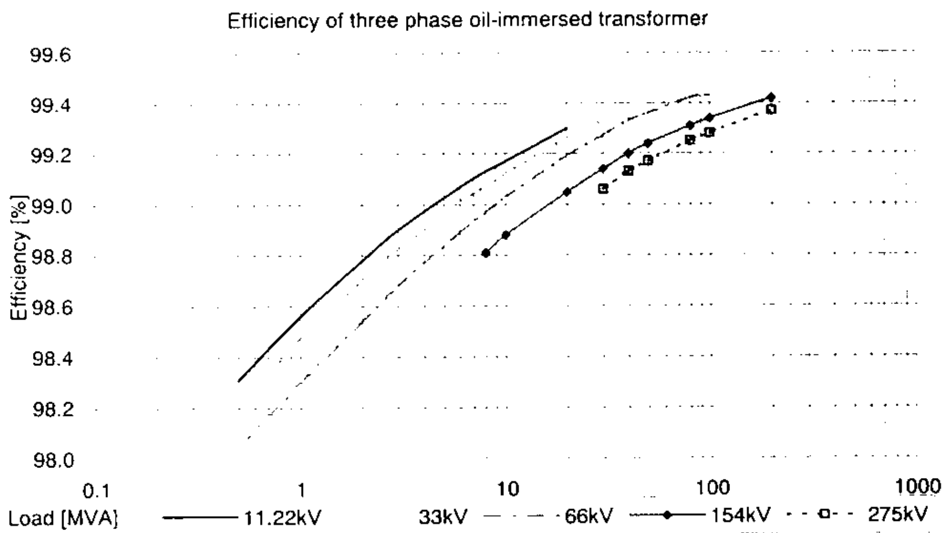
Table 3.1.3 Energy Conservation Auditing Manual

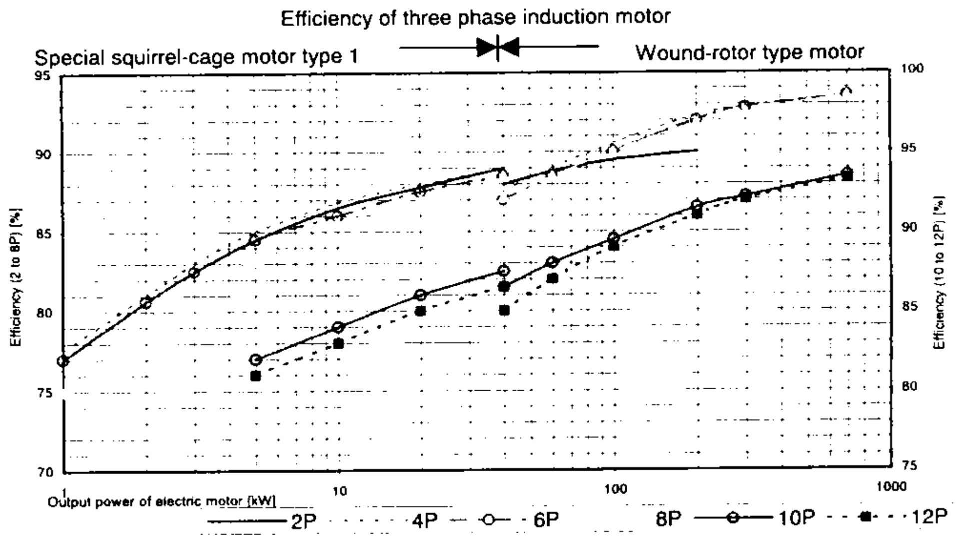
Category <Electric power receiving and transformer facility, electric heater, electric motor, pump, fan>

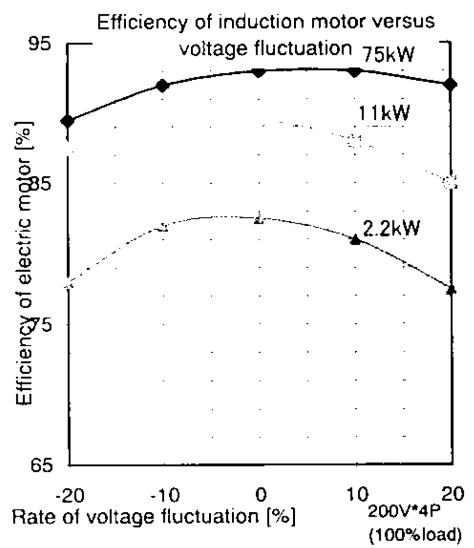
Check item			Judgment standard/audit result		Reduction effect	Evaluation and comment	Auditing instrument
Item	Sub item		Standard/result	Unit			
Operation control of electric power receiving and transformation facility	Acquisition of one-line wiring diagram						
	Contract power			kW			
	Purchased electric power			MWh/month			
	Control of transmission loss	Total consumption by energy-using facility		MWh/month			
Receiving facility		Loss factor		%			
	Control of load factor	Maximum electric power		kW			
		Average electric power		kW			
		Load factor		%			
	Improvement of power factor	Target	95	%	thousand yen/month		
		Power factor					
(Medium-scale facility improvement)	Introduction of power demand control	Reduced contract power		kW	thousand yen/month		
Transformation facility	Transformer	Capacity		kVA			
		Number		units			
	Execution of voltage regulation	Maximum voltage		V			
		Minimum voltage		V			
	Shutting off of transformer when not in	Loss factor		%	kWh/month		
		Unused time		h/month			
	Rationalization of transformer load	Recommended load factor	50~70	%	kWh/month		
		Load factor		%			
		Difference in efficiency		%			
(Improvement of energy-using facility)	Utilization of night and holiday electricity	Average electric power		MWh/day	thousand yen/month		
		Difference in unit electric power cost		yen/kWh			
		Number of days utilized		day/month			
Operation control of electric heating facility	Furnace type						
	Type of heated material						
	Power source	Capacity		kW			
		Voltage		V			
	Availability of process flow diagram and instrumentation diagram						
(Operation conditions and improvement)	Throughput			t/h			Portable wattmeter
	Electric power consumption			kWh			
	Unit consumption of electric power			kWh/t			
	Thermal efficiency			%			
	Lowering of heating temperature	*Minimum required temperature*		°C	kWh/month		Optical pyrometer
		Operation temperature		°C			Radiation thermometer
	Improvement of power factor	Target power factor	95	%	kWh/month		Portable wattmetery
		Power factor		%			
		Difference in efficienc		%			

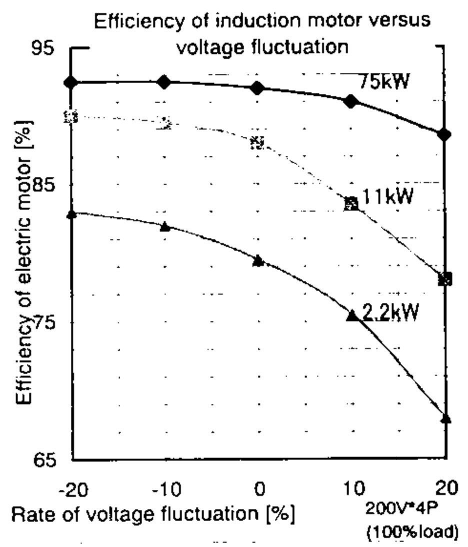
Check item			Judgment standard/audit result		Reduction effect	Evaluation and comment	Auditing instrument
Item	Sub item		Standard/result	Unit			
Control method and improvement	Temperature control	Proportional control					
		On/off control					
	Control of furnace pressure	Controlled or not	Yes or no				Portable pressure gauge
		Operation pressure		Pa			
	Improvement of controlling equipment	Item			kWh/t		
		Improvement effect		%			
(Waste heat recovery and improvement)	Waste heat recovery	Exhaust gas volume		Nm^3/h	kWh/month		Portable thermometer
		Temperature		°C			Radiation thermometer
		Material heated					Contact surface thermometer
		Throughput		t/h			
		Heating temperature		°C			
		Recovered heat		kJ/h			
(Improvement of thermal insulation)	Furnace wall surface temperature	Standard values (Table 3.4)		°C	kWh/month		Radiation thermometer
		Wall surface temperature		°C			Contact surface thermometer
		Heat loss		kJ/h			
	Duct temperature	Standard values (Table 3.4)		°C	kWh/month		Radiation thermometer
		Wall surface temperature		°C			Contact surface thermometer
		Heat loss		kJ/h			
	Reduction of heat loss through openings	Cross-sectional area		m^2	kWh/month		Portable thermometer
		Furnace inside temperature		°C			
		Heat loss		kJ/h			
: Large-scale improvement	Oxygen injection	Conversion rate to electric power	3.00	kWh/m^3	kWh/month		
		Oxygen consumption		m^3/t			
	Installation of auxiliary burner	Conversion rate to electric power	1.16	kWh/MJ	kWh/month		
		Fuel consumption		MJ/t			

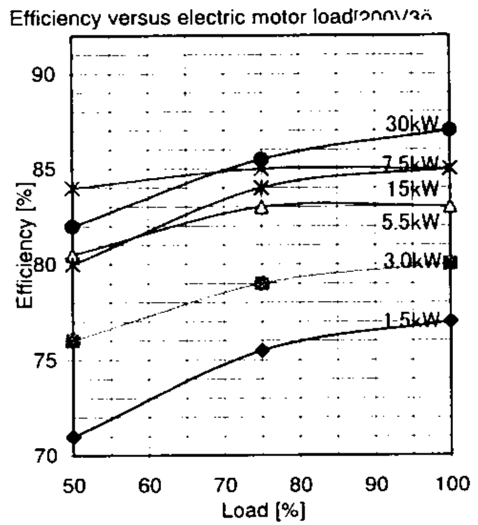
Check item			Judgment standard/audit result		Reduction effect	Evaluation and comment	Auditing instrument
Item	Sub item		Standard/result	Unit			
Operation control of electric motor	Equipment specifications	Rated capacity		kW			
		Rated voltage		V			
	Selection of optimum cap	Operating power		kWh	kWh		Portable wattmeter
		Load factor		%			
		Optimum load factor	70~100	%			
		Difference in efficiency		%			
	Optimum voltage	Optimum voltage (Table 3.8)		V	kWh		
		Optimum efficiency		%			
	Stop no-load run	No-load power		V	kWh		Portable wattmeter
		No-load time		h/day			
Operation control of pump and fan	Acquisition of process flow diagram, instrumentation diagram, characteristic curve						
	Equipment specifications	*Type*					
		Delivery flow		m^3/min			
		Delivery pressure		Pa, MPa			
	Operation data	Operating flow rate		m^3/*min*			Hot-wire anemometer *Ultrasonic flow meter*
		Operating pressure		Pa, MPa			Pressure gauge
		Unit consumption of electric power		kWh/m^3			*Power meter*
(Energy-consuming facility)	Reduction of consumption	Minimum required flow		m^3/min	kWh		Hot-wire anemometer
		Rate of reduction		%			Ultrasonic flow meter
	Lowering of pressure	Minimum required pressure		Pa, MPa	kWh		Portable pressure gauge
		Rate of reduction		%			
(Small-scale facility improvement)	Repair of leak	Leakage	yes or not		kWh		Hot-wire anemometer
		Leaking rate		m^3/min			Ultrasonic flow meter
	Reduction of pressure drop in pipe and duct	*Reduction of pressure drop*		Pa, MPa	kWh		Portable pressure gauge
(Large- and medium-scale facility improvements)	Reduction of *impeller* diameter	Rate of reduction		%	kWh		
	Adoption of number and rotation control of motors	Rate of reduction		%	kWh		
	Adoption of high-*efficiency motor* Rate of reduction	*Rate of reduction*		%	kWh		


Efficiency of three phase oil-immersed transformer
Efficiency [%]
Load [MVA]
11.22kV
33kV
66kV
154kV
275kV


Efficiency of three phase induction motor
Special squirrel-cage motor type 1
Wound-rotor type motor
Efficiency (2 to 8P) [%]
Efficiency (10 to 12P) [%]
Output power of electric motor [kW]
2P
4P
6P
8P
10P
12P


Efficiency of induction motor versus voltage fluctuation
75kW
11kW
2.2kW
Efficiency of electric motor [%]
Rate of voltage fluctuation [%]
200V*4P
(100%load)


Efficiency of induction motor versus voltage fluctuation
75kW
11kW
2.2kW
Efficiency of electric motor [%]
Rate of voltage fluctuation [%]
200V*4P
(100%load)


Efficiency versus electric motor load
30kW
7.5kW
15kW
5.5kW
3.0kW
1.5kW
Efficiency [%]
Load [%]

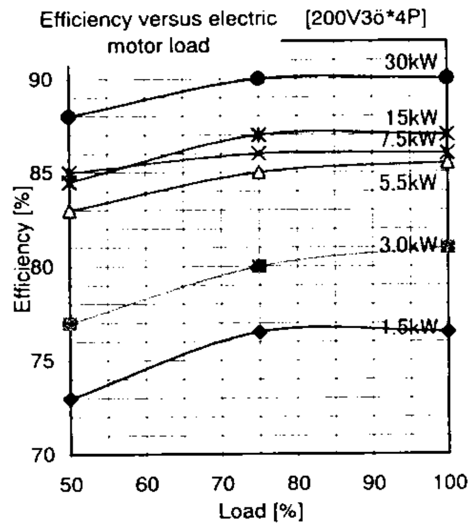

Efficiency versus electric motor load
[200V3ö*4P]
30kW
15kW
7.5kW
5.5kW
3.0kW
1.5kW
Efficiency [%]
Load [%]

Table 3.6 Apparatuses to be improved in power factor

Name of apparatus	Capacity: (kW)
Squirrel cage induction motor	75
Wound rotor induction motor	100
Induction furnace	50
Vacuum melting furnace	50
Induction heater	50
Arc furnace	—
Flash butt welding machine (excluding portable type)	100
Arc welding machine (excluding portable type)	10
Rectifier	10,000

Table 3.7 Target efficiencies of highly efficient totally enclosed motors (0.2 to 37 kW)

Output	Standard full load efficiency values					
(kW)	2-pole		4-pole		6-pole	
	50 Hz	60 Hz	50 Hz	60 Hz	50 Hz	60 Hz
0.2	73.8	75.3	72.6	75.4	—	—
0.4	78.0	79.4	77.5	80.0	74.6	78.0
0.75	81.8	82.4	81.4	83.2	80.0	82.0
1.5	84.4	84.8	84.4	85.8	83.5	85.0
2.2	86.5	86.3	86.6	87.6	85.8	86.8
3.7	88.0	87.8	88.4	89.2	87.4	88.0
5.5	89.3	89.0	89.8	90.3	88.8	89.3
7.5	90.4	90.0	90.8	91.0	89.8	90.3
11	91.2	90.8	91.6	91.8	90.8	91.2
15	91.8	91.5	92.2	92.2	91.6	91.8
18.5	92.4	92.0	92.6	92.6	92.2	92.4
22	92.9	92.3	93.0	92.8	92.7	92.8
30	93.3	92.6	93.3	93.0	93.0	93.0
34	93.5	92.8	93.5	93.2	—	—

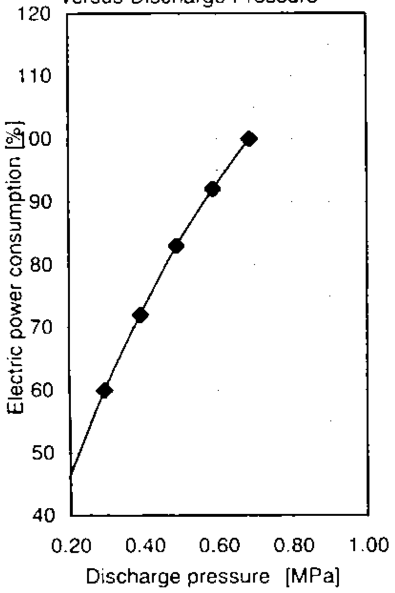
Table 3.8 Capacities and optimum voltages of motors

Capacity of motor	Optimum voltage
0.2 ~ 70 kW	200 V
3.5 ~ 300 kW	400 V
70 ~ 1000 kW	3 kV
300 ~ 1000 kW	6 kV
1000 ~ 3000 kW	11 kV

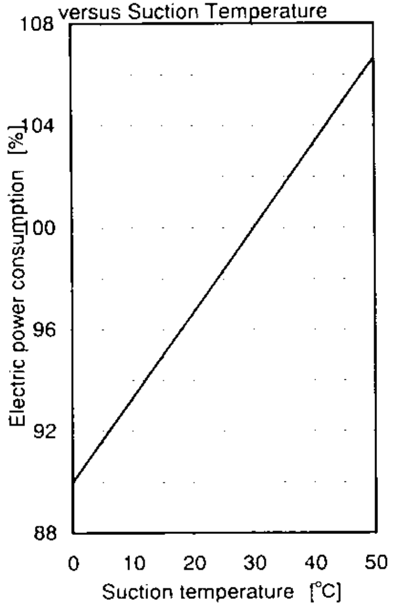
Table 3.1.4 Energy Conservation Auditing Manual   Category <Compressor, lighting, co-generation, etc.)

Check item			Judgment standard/audit result		Reduction effect	Evaluation and comment	Auditing instrument
Item	Sub item		Standard/result	Unit			
Control of pneumatic system	Acquisition of process flow diagram, instrumentation diagram, *characteristic curve*						
	Specifications of motor	Rated capacity		kW			
		Rated voltage		V			
	Selection of optimum capacity	Operating power		kWh	kWh		Portable wattmeter
		Load factor		%			
		Optimum load factor	70~100	%			
		Efficiency improvement		%			
	Optimum voltage	Optimum voltage (Table 3.8)		V	kWh		
		Efficiency improvement		%			
	Specifications of compressor	Type					
		Delivery flow		m^3/min			
		Discharge pressure		MPa			
	Operation data	Operating flow rate		m^3/min			
		Operating pressure		MPa			
		Unit consumption of electric power		kWh/m^3			
	Preferential operation of higher efficiency	Electric power load factor?		%	kWh		
		Efficiency improvement		%			
(Energy-consuming facility)	Reduction of consumption	Minimum required flow rate		m^3/min	kWh		
		Rate of reduction		%			
	Lowering of pressure	Minimum required pressure		MPa	kWh		
		Rate of reduction		%			
(Small-scale facility improvement)	Repairing of leakage	Leakage	yes or not	m^3/min	kWh		
		Leaking rate		m^3/min			
	Lowering of suction temperature	Design temperature?		°C	kWh		Portable thermometer
		Suction temperature		°C			
		Efficiency improvement		%			
	Lowering of machine and cooling water temperature	Design temperature?		°C	kWh		Portable thermometer
		Cooling water temperature		°C			
		Efficiency improvement		%			
	Reduction of pressure drop in the suction	Reduction of pressure drop		Pa	kWh		
		Efficiency improvement		%			
	Reduction of pressure drop in the distribution	Reduction of pressure drop		MPa			
		Efficiency improvement		%			
	Segregation between high-pressure system	*Segregation*	yes or not		kWh		
		Efficiency improvement		%			

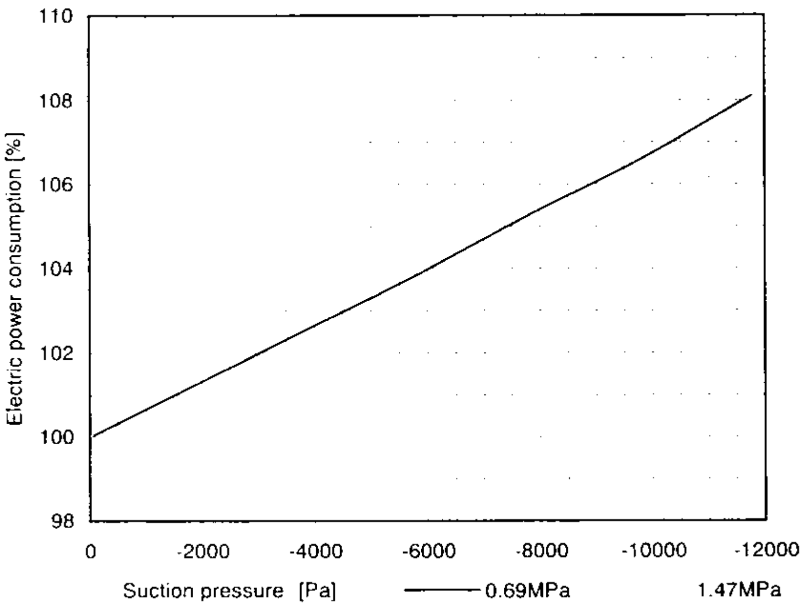
Electric Power Consumption versus Discharge Pressure



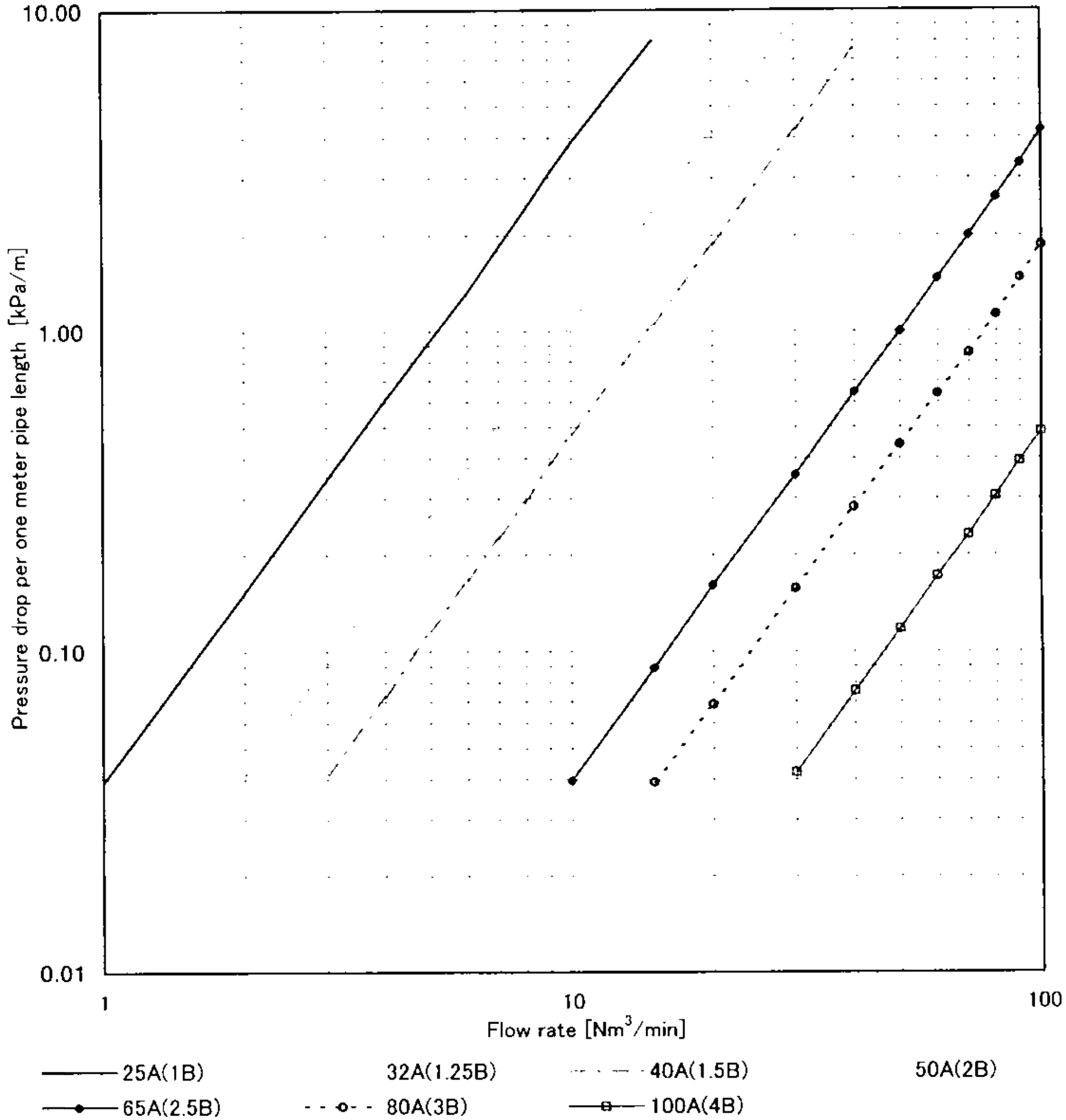
Electric Power Consumption versus Suction Temperature



Electric Power Consumption versus Suction Pressure



Pressure Drop in Pneumatic Air Pipe



- Standard conditions for pressure drop are 0.69MPa*20°C.
- For different pressure and temperature, the adjustment is done by the following equation

Check item			Judgment standard/audit result		Reduction effect	Evaluation and comment	Auditing instrument
Item	Sub item		Standard/result	Unit			
(Medium-scale facility improvement)	Adoption of sequential startup control	Efficiency improvement		%	kWh		
	Adoption of optimum capacity control	Efficiency improvement		%	kWh		
	Installation of receiver	Efficiency improvement		%	kWh		
	Waste heat recovery from effluent cooling water	Water flow rate		t/h	kJ/h		Ultrasonic flow meter
		Temperature		℃			Portable thermometer
		Facility to use the recovered heat					
(Large-scale facility improvement)	Adoption of distributed system	Efficiency improvement		%	kWh		
	Adoption of integrated system	Efficiency improvement		%	kWh		
	Selection of facility of optimum size	Efficiency improvement		%	kWh		
	Adoption of high-efficiency equipment	Efficiency improvement		%	kWh		
Management of lighting fixture	Classification of lighted place						
	Lighting fixture	Capacity		W			
		Number		Lights			
	Control of illuminance	Standards (Figure 3.1)		lx			Illuminance meter
		Illuminance		lx			
		Number increased or reduced		Lights			
	Cleaning of lighting fixture	Recommended frequency	2	times/year			
		Cleaning frequency		times/year			
	Cleaning of lighting fixture	Life of lighting element	6～12	thousand hours			
		Replacement frequency					
	Turning off of light when not needed	Number of lights turned off		Lights	kWh		
		Off time		h			
	Utilization of sunlight	Number of lights turned off		Lights			
		Off time		h			
	Adoption of automatic on-off device	Number of lights turned off		Lights			
		Off time		h			
	Adoption of high-efficiency light and	Reduction of electric power		W	kWh		
	Adoption of spotlight	Reduction of electric power		W	kWh		
	Adoption of separated circuits	Number of lights turned off		Lights			
		Off time		h			

Illuminance lx	Office: Place			Office: Work	Factory: Place	Factory: Work	Illuminance lx
3000 2000				Design, drafting, typewriting, calculation, key punching	Instrument board and control board of control room, etc.	Production of precision machines and electronic parts, very fine visual work in printing factory (assembling, inspection, testing, sorting, design, drafting)	3000 2000
1500 1000	Office room, sales room, design roof, drafting room, vestibule hall (daytime)				Design room, drafting room	Sorting and inspection in textile factory, typesetting and proof-reading in printing factory, fine visual work such as analysis in chemical factory (assembling, inspection, testing, sorting)	1500 1000
750 500	Meeting room, drawing room, dining hall, amusement hall, guard room, kitchen, vestibule hall (night), elevator hall	Director's room, meeting room, printing room, computer room, control room, dispensary room, distribution board and instrument board of electric room, etc.			Control room Control room	Ordinary visual work in general production process, etc. (assembling, inspection, testing, sorting, packaging, office work in warehouse)	750 500
300 200		Library, auditorium, electric room, machine room, elevator	Hot water service room, corridor, stairway, bath room, toilet, washroom		Electric room, air conditioned machine room	Rough visual work (limited work, packing, packaging)	300 200
150 100	Coffee room, night keeper's room, dressing room, warehouse				Outlet, inlet, corridor, passage, stairway, washroom, toilet, warehouse in which workers work	Very rough visual work (limited work, packing, packaging)	150 100
75 50	Indoor emergency stairway				Indoor emergency stairway, warehouse, outdoor power equipment	Cargo handling such as loading and unloading	75 50
30 20					Outdoors (passage, yard place to be guarded)		30 20
10							10

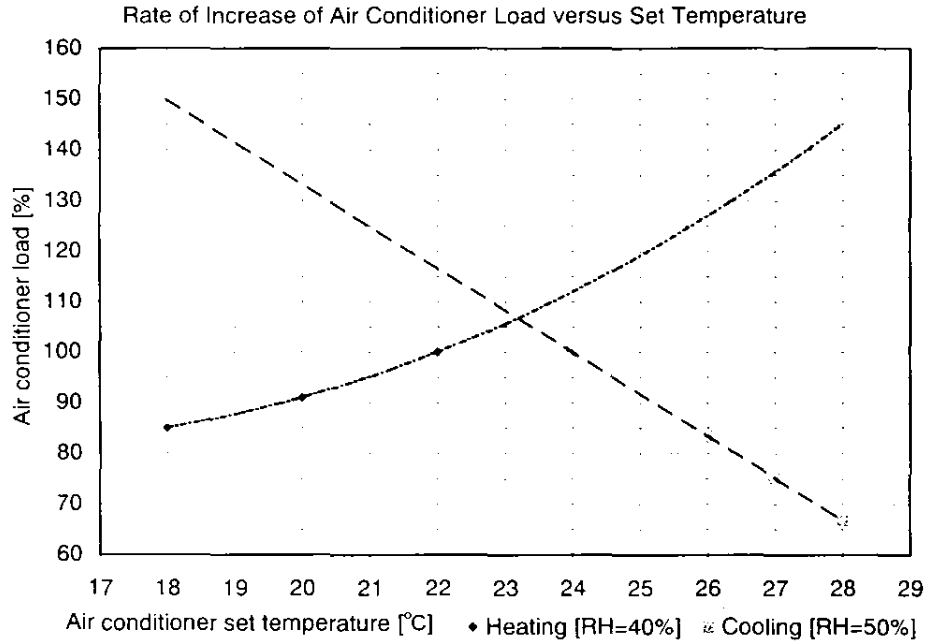
Fig. 3.1 Standard illuminances of offices and factories (JIS Z 9110)

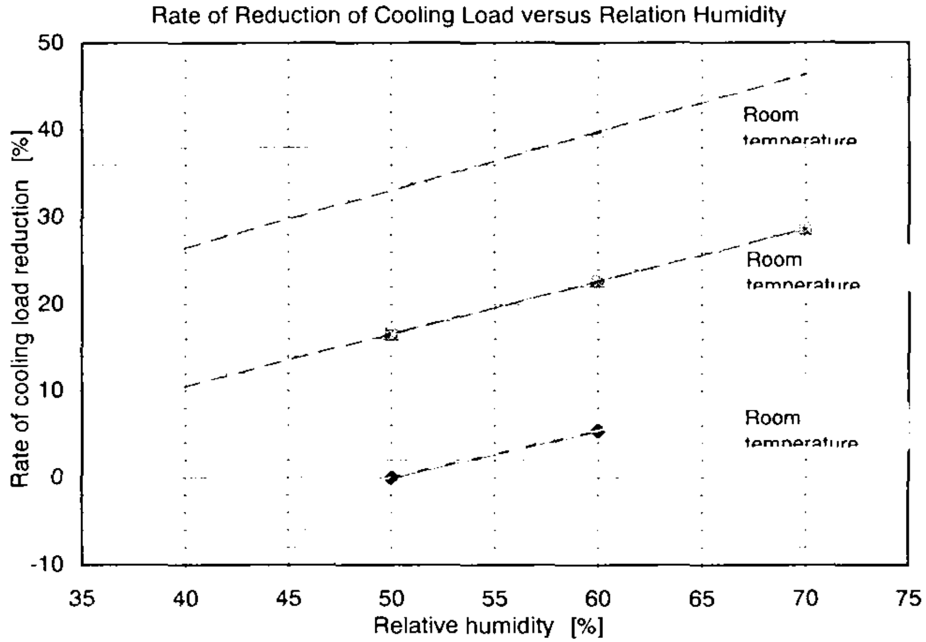
Check item				Judgment standard/audit result		Reduction effect	Evaluation and comment	Auditing instrument
Item	Sub item			Standard/result	Unit			
Adoption of co-generation	Study on the use of utility	Electric power	Consumption		kWh			
			Voltage		V			
		Fuel	Consumption		L or Nm^3/h			
			Pressure		Pa, MPa			
		Steam	Consumption		t/h			
			Pressure		Mpa			
		Hot water	Consumption		t/h			Portable thermometer
			Temperature		°C			Ultrasonic flow meter
	Annual energy cost	Electric power			yen/year			
		Fuel			yen/year			
		Total			yen/year			
	Selection of specifications of the facility	Electric power generation			kWh			
		Steam generation			t/h			
		Hot water production			MJ/h			
		Fuel consumption			L or Nm3/h			
	Construction cost	Equipment cost			thousand yen			
		Construction cost			thousand yen			
		Total			thousand yen			
	Operation cost	Fuel cost			thousand yen/year			
		Maintenance cost			thousand yen/year			
	Effect of co-generation	Reduction of cost			thousand yen/year			
		Payout year			year			

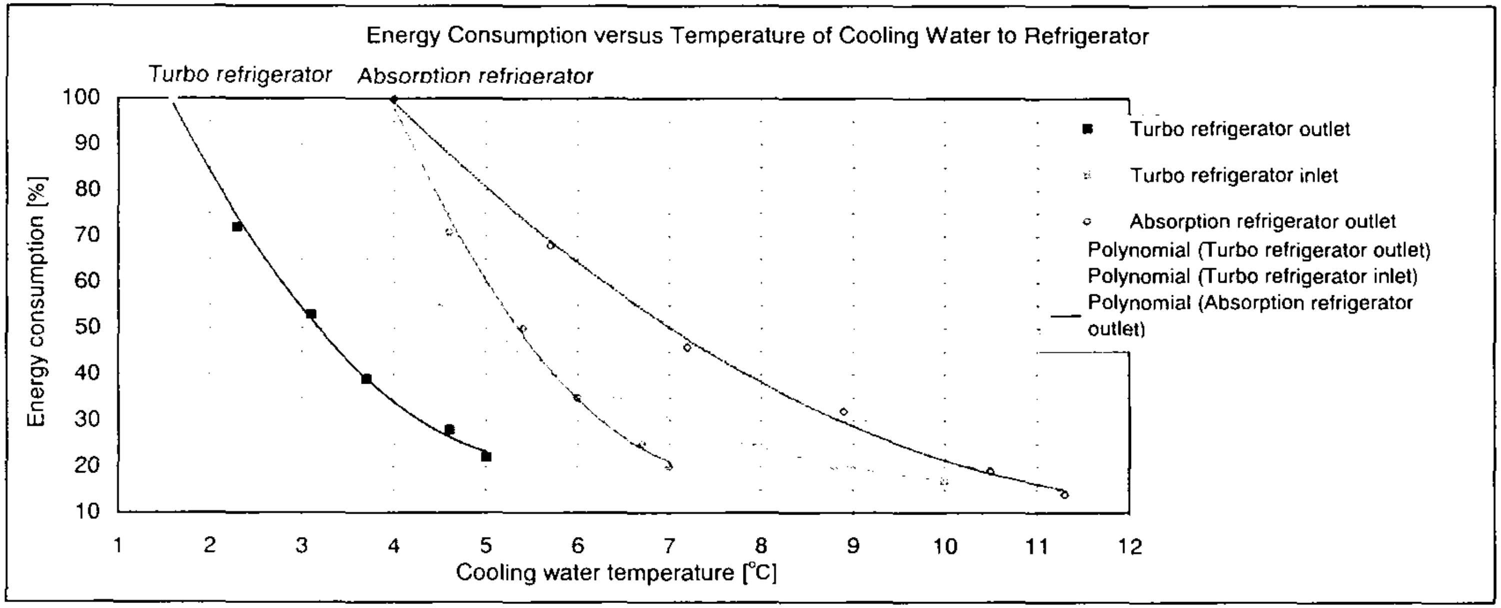
Table 3.1.5 Energy Conservation Auditing Manual

Category <Air conditioner and refrigerator>

Check item			Judgment standard/audit result		Reduction effect	Evaluation and comment	Auditing instrument
Item	Sub item		Standard/result	Unit			
Operation conditions of air conditioner	Air conditioning requirement	Floor area		m^2			
		Number of persons		Person			
	Specifications of air conditioner	Type					
		Capacity		kW			
		Air flow rate		m^3/h			
		Unit consumption of electric power		kWh/m^3			
		Thermal efficiency		%			
	Measured air flow	Air flow velocity		m/s			Hot-wire anemometer
		Volumetric air flow rate		m3/h			
	Electric power requirement for operation	Blower		kWh			Portable wattmeter
		Heating equipment		kWh			
		Cooling tower		kWh			
		Pump		kWh			
		Total power requirement		kWh			
		Unit consumption of electric power		kWh/m^3			
	Acquisition of process flow diagram and instrumentation diagram						
Energy conservation measures of air conditioner	Set temperature for heating	Recommended set temperature	20	°C	kWh		
		Set temperature or room temperature		°C			
		Rate of lowering		%			
	Set temperature for cooling	Recommended set temperature	28	°C	kWh		
		Set temperature or room temperature		°C			
		Rate of raising		%			
	Relative humidity (Guidelines on environmental sanitation	Standard value	40~70	%	kWh		
		Set value or actual humidity		%			Hygrometer
		Rate of relaxing		%			
	Maintenance of proper ventilation (Guidelines on environmental sanitation in buildings)	Standard for air flow velocity	0.5>	m/s	kWh		
		Measured air flow velocity		m/s			Hot-wire anemometer
		Standard for CO2 concentration	1000>	ppm	kWh		
		Measured CO2 concentration		ppm			CO_2 detection tube
	Reduction of fresh air intake (Building Standard Law)	Standard air flow rate	20	m^3/h*head	kWh		
		Air flow velocity		m/s			Hot-wire anemometer
		Outside air temperature		°C			Portable thermometer
		Reduction of heat input with outside air		kJ/h			
		Equivalent electric power		kWh			


Rate of Increase of Air Conditioner Load versus Set Temperature
Air conditioner load [%]
160
150
140
130
120
110
100
90
80
70
60
17
18
19
20
21
22
23
24
25
26
27
28
29
Air conditioner set temperature [°C]
Heating [RH=40%]
Cooling [RH=50%]


Rate of Reduction of Cooling Load versus Relation Humidity
Rate of cooling load reduction [%]
50
40
30
20
10
0
-10
35
40
45
50
55
60
65
70
75
Relative humidity [%]
Room
Room
Room


Energy Consumption versus Temperature of Cooling Water to Refrigerator
Turbo refrigerator
Energy consumption [%]
100
90
80
70
60
50
40
30
20
10
1
2
3
4
5
6
7
8
9
10
11
12
Cooling water temperature [°C]
Turbo refrigerator outlet
Turbo refrigerator inlet
Absorption refrigerator outlet
Polynomial (Turbo refrigerator outlet)
Polynomial (Turbo refrigerator inlet)
Polynomial (Absorption refrigerator outlet)

Check item			Judgment standard/audit result		Reduction effect	Evaluation and comment	Auditing instrument
Item	Sub item		Standard/result	Unit			
(Small-scale facility improvement)	Shielding of sunlight/curtain, blind, multi-grazing window	Irradiation temperature		kJ/h	kWh		Radiation thermometer
		Incident heat		℃			Portable thermometer
		Equivalent electric power		kWh			
	Cutting off of outside air	Air velocity		m/sec	kWh		Hot-wire anemometer
		Outside air temperature		℃			Portable thermometer
		Heat of entering air		kJ/h			
		Equivalent electric power		kWh			
	Shielding of radiation from hot object	Surface temperature		℃	kWh		Radiation thermometer
		Radiation heat		kJ/h			Portable thermometer
		Equivalent electric power		kWh			
(Medium-scale facility improvement)	Optimizing position of ventilation air inlet	Optimum position	?	m	kWh		
		Height of ventilation		m			
		Wind velocity		m/sec			Hot-wire anemometer
		Temperature difference		℃			Portable thermometer
		Heat replaced by ventilation		kJ/h			
		Equivalent electric power		kWh			
	Adoption of localized exhaust	Wind velocity		m/s	kWh		Hot-wire anemometer
		Exhaust air temperature		kJ/h			Portable thermometer
		Heat exhausted		kWh			
		Equivalent electric power					
	Adoption of localized cooling	Cooling electric power		kWh	kWh		
		Reduction of electric power		kWh			
	Reduction of conditioned air volume	Reduction of air volume		m2	kWh		
		Reduction of heat input		kJ/h			
		Equivalent electric power		kWh			
	Intensification of insulation of building (insulation thickness)	Surface temperature		℃·kW	kWh		Radiation thermometer
		Reduction of heat input		kJ/h			Contact surface
		Equivalent electric power		kWh			Portable thermometer
(Large-scale facility improvement)	Adoption of stratified air conditioning	Rate of reduction		%			
Operation control of cooling facility	Optimization of cooling water outlet set temperature	Recommended set temperature		℃			
		Set temperature		℃			
		Rate of reduction		%			
	Outlet pressure of refrigerant	Recommended pressure		MPa	kWh		
		Operation pressure		MPa			
		Rate of reduction		%			
	Inlet pressure of refrigerant	Recommended pressure		MPa	kWh		
		Operation pressure		MPa			
		Rate of reduction		%			
	Outlet temperature of cooling water	Recommended temperature		℃	kWh		
		Operation temperature		℃			Portable thermometer
		Rate of reduction		%			

Check item			Judgment standard/audit result		Reduction effect	Evaluation and comment	Auditing instrument
Item	Sub item		Standard/result	Unit			
	Outlet pressure of cooling water	Recommended pressure		MPa	kWh		
		Operation pressure		MPa			
		Rate of reduction		%			
	Inlet temperature of cooling water	Recommended temperature		°C	kWh		
		Operation temperature		°C			Portable thermometer
		Rate of reduction		%			
	Inlet pressure of cooling water	Recommended pressure		MPa	kWh		
		Operation pressure		MPa			
		Rate of reduction		%			
	Water quality control of cooling tower	Recommended electric conductivity		μS/cm	kWh		
		Electric conductivity		μS/cm			Electric conductivity meter
		Rate of reduction		%			
(Medium-scale facility improvement)	Speed control of pneumatic conveyer air	Rate of reduction		%	kWh		Hot-wire anemometer
	Sequential startup control of heaters	Rate of reduction		%	kWh		
	Scheduled operation	Rate of reduction		%	kWh		
	Utilization of outside air	Rate of reduction			kWh		
(Large-scale facility improvement)	Recovery of waste heat	Flow rate		m/sec·m^3/h	kWh		Hot-wire anemometer
		Temperature		°C			Ultrasonic flow meter
		Recovered heat		kJ/h			Portable thermometer
		Equivalent electric power		kWh			
	Adoption of heat pump	Difference in efficiency		%	kWh		
	Ice thermal storage system (night electricity)	Difference in unit cost		yen/kWh	thousand yen/year		
Instalation and refrigerator	Intensification of thermal insulation	(Equal to or lower than ambient temperature minus 5°C)		°C	kWh		Radiation thermometer
		Surface temperature		°C			Contact surface thermometer
		Reduction of heat requirement		kJ/h			
		Equivalent electric power		kWh			
	Prevention of air inflow with persons entering and leaving	Air flow velocity		m/sec	kWh		Hot-wire anemometer
		Outside air temperature		°C			Portable thermomete
		Entering heat quantity		kJ/h			
		Equivalent electric power		kWh			
	Adoption of high-efficiency facility	Difference in efficiency		%			

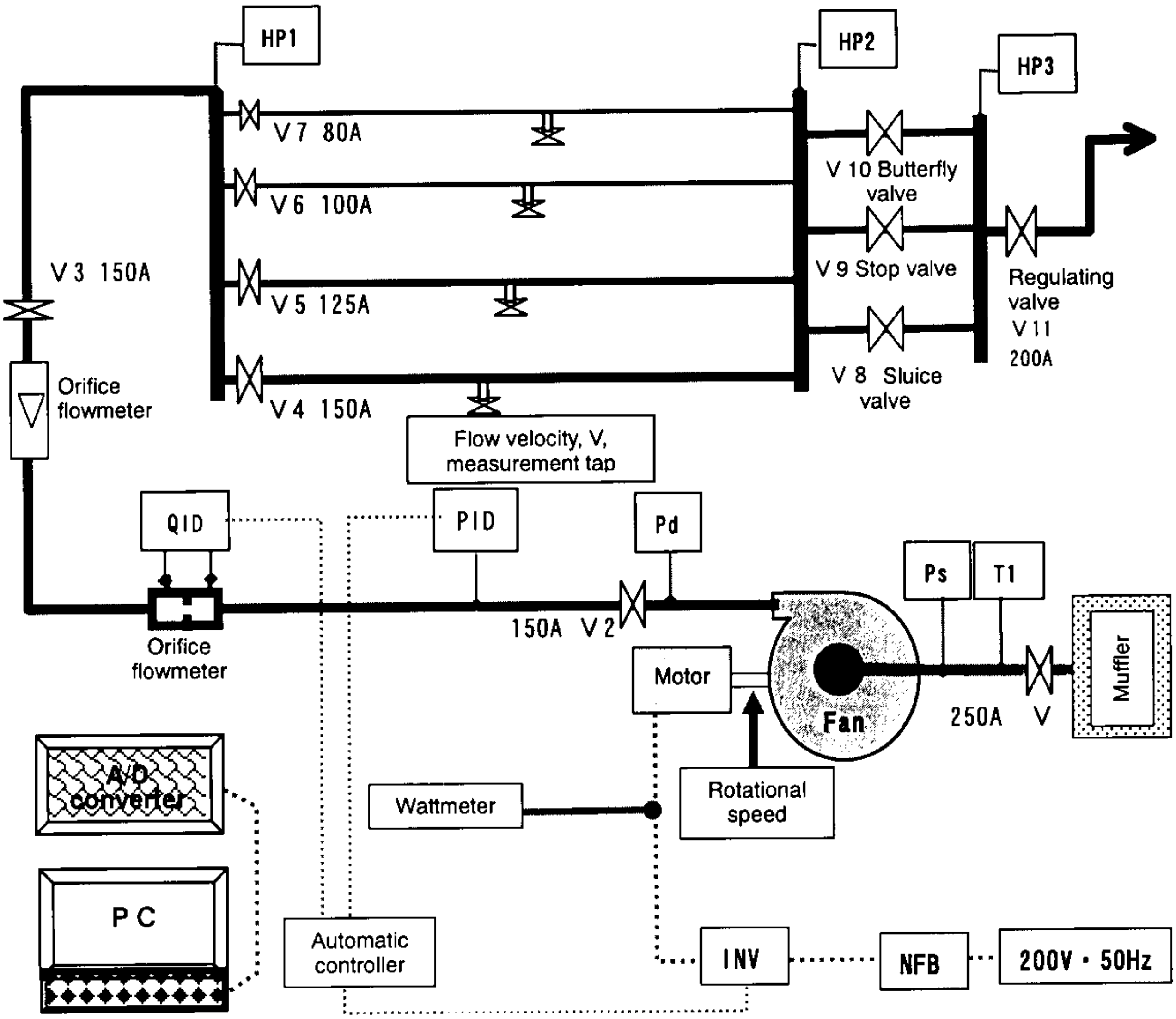
4. Training on Measurement

4.1 Gas Measurement Training

I. Measurement Exercises for Fan Equipment

1. Electric power, voltage and current measurement using wattmeter (digital power meter)
2. Pressure measurement using pressure gauge
3. Flow measurement using flow velocity meter
4. Connection between data logging system and various measuring instruments and setting
5. Comparison of electric output vs. flow rate characteristics (damper control and motor speed control)
6. Preparation of performance curves
7. Analog-to-digital conversion of data and data manipulation

II. Training Facility and Measurement Equipment Arrangement Diagram



III. Measuring Equipment

1. Measurement of electric power

(1) Configuration of measurement system

Wattmeter (digital power meter) + clamp-on sensor

(2) Wattmeter

① Measuring instrument : HIOKI 3165 Clamp-on Power Hitester

② Applicable circuit configurations : 1 ϕ 2w, 1 ϕ 3w, 3 ϕ 3w, 3 ϕ 4w

③ Measurement items : voltage, current, real power, reactive power, apparent power, power factor, watt-hour and frequency (10 Hz～)

④ Measuring range : Voltage100V, 200V, 400V(Max600V)

With a high tension circuit, measurement is undertaken on the secondary side of a PT.

Be careful not to cause a short circuit or touch a live part.

Electric power range (auto-range) set according to the combination of voltage and current range settings

⑤ Analog output : Analog output DC 2V/f.s kW, V1, V2, V3, A1, A2, A3

D/A output DC 2V/f.s kW, V1, V2, V3, A1, A2, A3, pf, Hz (chose one from list)

⑥ Power source : AC85V～250V(45Hz～66Hz)

(3) Clamp on sensor

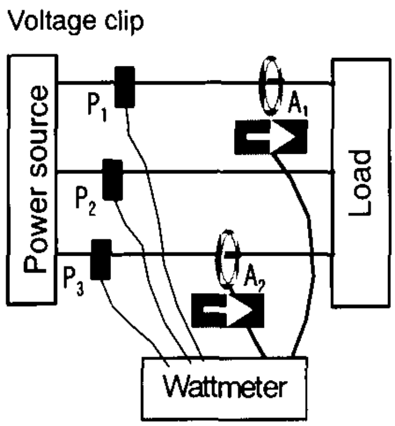
① Measuring instrument : 9272 20／200A

Measuring range : Current 2A, 5A, 10A, 20A, 50A, 100A, 200A

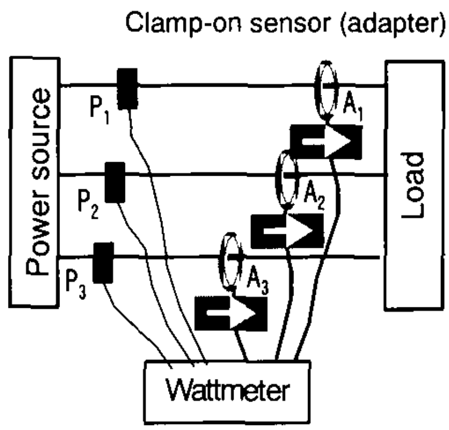
② High-current clamp-on adapter : 9290 1000A CT ratio10:1

Electric currents are measured on the secondary side of a CT in the case of a high-tension high-current circuit and via a clamp-on adapter in the case of a low-tension high-current circuit. Such indirect measurement expands the measuring range and protects the clamp-on adapter from damage.

(4) Connection examples



Three-phase Two-current and Two-voltage Method



Three-phase Three-current and Three-voltage Method

2. Pressure measurement

(1) Digital low differential pressure gauge

① Measuring instrument : GC62 (Nagano Keiki)
② Measuring range : 0～1, 0～5, −10～10, 0～10, 0～20kPa
③ Analog output : 1～5VDC, 4～20mADC
④ Power source : 24VDC

① Measuring instrument : DPG502N (Okano Works)
② Measuring range : 0～5, 0～20kPa
③ Analog output : 4～20mADC
④ Power source : 100VAC

(2) Differential pressure transmitter

① Measuring instrument : EJA110 (Yokogawa Electric)
② Measuring range : 0～2kPa
③ Analog output : 4～20mADC
④ Power source : 24VDC

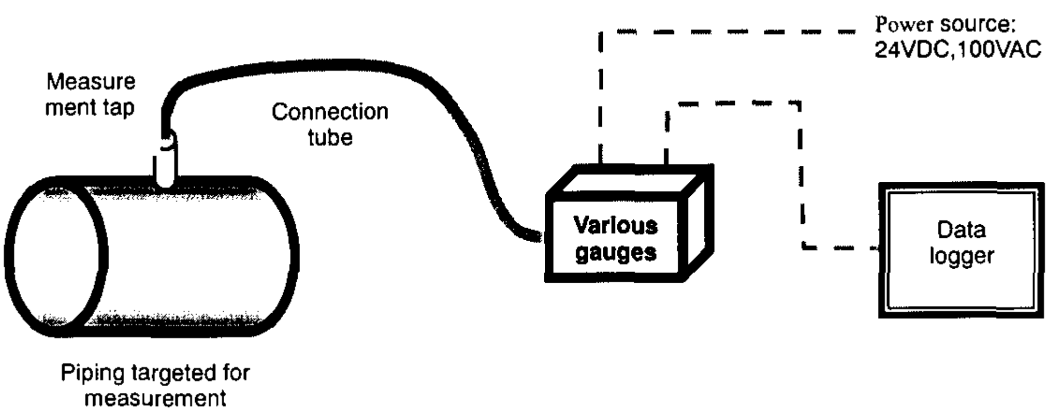
(3) Bourdon-tube pressure gauge

① Measuring instrument : GL20−2GI (Nagano Keiki)
② Measuring range : 0～10 kPa, 0～20kPa

(4) Analog low differential pressure gauge

① Measuring instrument : Manostar gauge (Yamamoto Electric Industrial)
② Measuring range : 0～50, 0～100, 0～200, 0～500Pa,
0～2, 0～5, 0～10, 0～20kPa

(5) Connection example



3. Flow measurement

(1) Orifice flowmeter

① Measuring instrument : corner tap type (Yokogawa Electric)

② Measuring range : 0～2000 m^3_N/h

③ Analog output : 1～5 VDC

Differential pressure transmitter : EJA110 (Yokogawa Electric)

Measuring range : 0～3.5 kPa

④ Power source : 24VDC

⑤ Measurement point : Permanently mounted between discharge valve and header 1

(2) Differential pressure type flow meter

① Measuring instrument : Oriflo (Tokyo Keiso)

② Measuring range : 0～2000 m^3_N/h

③ Measurement point : Permanently mounted between discharge valve and header 1

(3) Pitot tube

① Measuring instrument : Two-hole pitot tube (Okano Works)

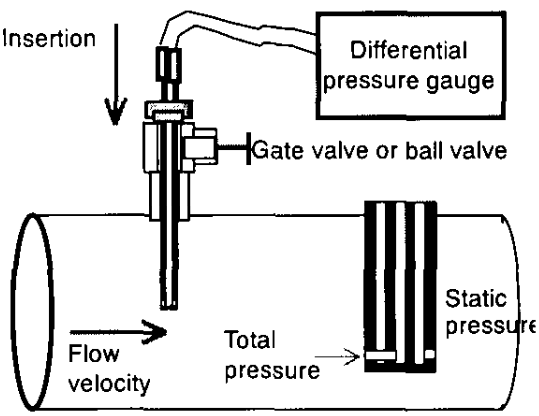
② Measurement point : Distance from the center of piping, rn (m)

Inserted at 0.707r (1m±2r)

③ Pitot coefficient : C:0.754

Differential pressure⊿P≒Dynamic pressure Pv

Dynamic pressure = Total pressure − Static pressure



Instrument Mounting Method

(4) Hot-wire anemometer

① Measuring instrument : Flow Sensor SKA Ltd. (SCHMIDT)

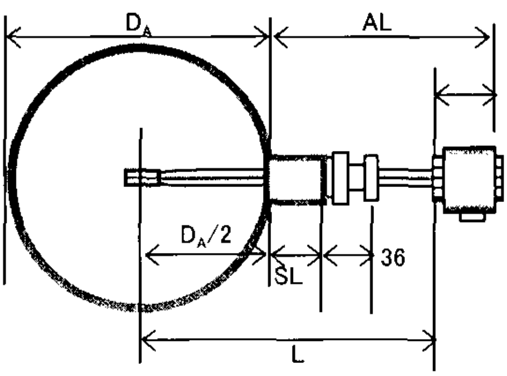
② Measuring range : 0～40 m/sec

③ Analog output : 4～20 mADC→(250 Ω) 1～5 VDC

④ Power source : 24 VDC

⑤ Measurement point : Inserted into center of piping

$AL = D_A/2+57$ $L > D_A/2+SL+36$ L=180mm

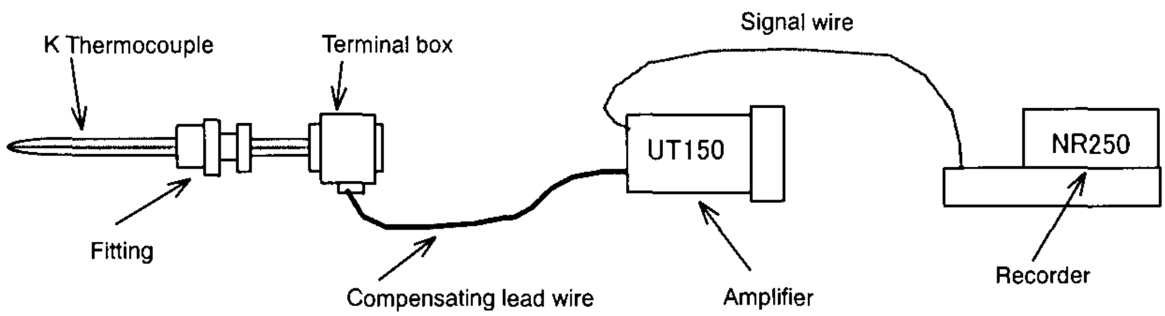


Nominal diameter		Carbon steel pipes for piping SGP	
(A)	(B)	Outside diameter (mm)	Inside diameter (mm)
80	3	89.1	80.7
100	4	114.3	105.3
125	5	139.8	130.8
150	6	165.2	155.2

*1. Temperature measurement

(1) Configuration of measurement system

Metal sheath



(2) K Thermocouple (Kawaso Electric)

① Materials : + side wire Alloy of mainly nickel and chromium

− side wire Alloy of mainly nickel

② Measuring range : −100～1370℃

(3) Compensating lead wire (Kawaso Electric) (KX-2-G-0.5mm²)

① Compensation junction temperature : −25～+200℃

② Materials : + side wire Chromel (alloy of nickel and chromium)

− side wire Alumel (alloy of nickel)

③ Electric resistance : 1.5Ω／m

(4) Amplifier

① UT150 Temperature controller : Yokogawa Electric

② Measuring range : 0～400℃

③ Analog output : 4～20 mADC→(250Ω) 1～5 VDC

④ Power source : 100 VAC

*2. Measurement of rotational speed

① Measuring instrument : Portable tachometer 3632, noncontact type (Yokogawa Electric)

② Measuring range : L range 60～1999.9 rpm (min^{-1})

: H range 60～19999 rpm (min^{-1})

③ Output range : 1000 rpm／0.1V～20000 rpm／2V

④ Power source : 9V dry battery 1P

4. Recorder

(1) Configuration of data logging system

Personal computer + Keyence NR-250

(2) Laptop computer

IBM ThinkPad 130

(3) Keyence NR-250

Used in conjunction with a PC, it collects and stores data via software installed on the PC, with system setting and data processing also undertaken on the PC.

① Function : Analog voltage → Digital conversion of data → Storage on PC

② Number of input channels : 16ch

③ Analog voltage input : Range ±10, ±5, ±2.5, ±1, ±0.5, ±0.25VDC

Thermocouple input : Thermocouple K, J, E, T

Max. input voltage : ±30VDC

④ Sampling cycle : 0.1s~24Hr

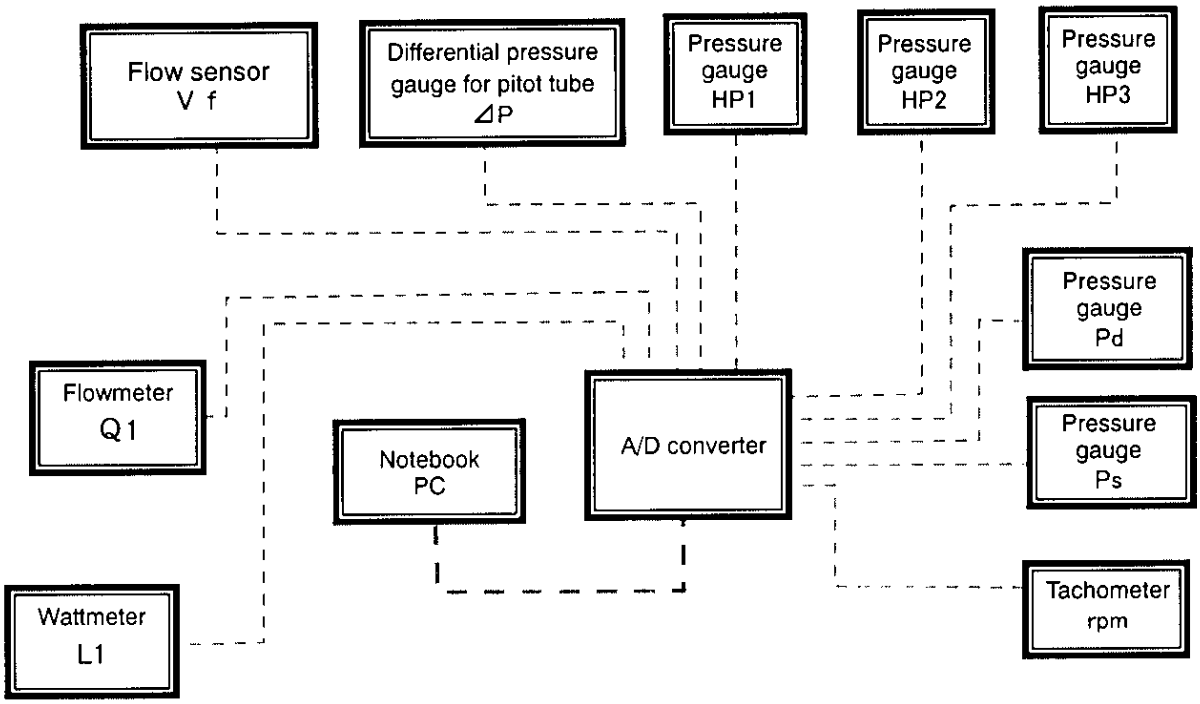
⑤ Measurement accuracy : Analog input ±0.1% of FS (±0.2% of FS for ±0.25VDC)

(4) Signal connection box

Facilitates the connection of analog voltage signal cables from various measuring instruments.

① Number of terminals: 32 (16 reds and 16 blacks)

(5) Connection example



(6) Software setting

Keyence NR-250 (For details, refer to the instruction manual.)

CH	Quantity	Abbre-viation	Unit	Measuring instrument	Measuring range	Output voltage V	Remarks
1	Motor input power	L1	kW	3165	0～20	0～2	§1
2	Motor input frequency	Hz	Hz	3165	0～100	0～2	
3	Flow rate	Q1	m^3_N/h	Corner tap orifice flowmeter	0～2000	1～5	
4	Suction temperature	T1	℃	K+UT150	0～400	1～5	
5	Suction pressure	Ps	kPa	GC62	−10～10	1～5	
6	Discharge pressure	Pd	kPa	GC62	0～10	1～5	
7	Header 1 pressure	HP1	kPa	GC62	0～10	1～5	
8	Header 2 pressure	HP2	kPa	GC62	0～10	1～5	
9	Header 3 pressure	HP3	kPa	GC62	0～10	1～5	
10	Motor rotational speed	rpm	min^{-1}	3632	0～20000	0～2	§2
11	Flow velocity	Vf	m/sec	Flow sensor	0～40	1～5	
12	Pitot tube differential pressure	Pv	Pa	DPG502N	0～500	1～5	

§1 Wattmeter 3165 measuring range table

Voltage V	Phase/line configuration	Current A 2	5	10	20	50	100	200
100	(Abbreviation)							
200	1P2W	400W	1.0kW	2.0kW	4.0kW	8.0kW	20kW	40kW
	1P3W	800W	2.0kW	4.0kW	8.0kW	20kW	40kW	80kW
	3P3W-2	800W	2.0kW	4.0kW	8.0kW	20kW	40kW	80kW
	3P3W-3	800W	2.0kW	4.0kW	8.0kW	20kW	40kW	80kW
	3P4W	1.2kW	3.0kW	6.0kW	12kW	30kW	60kW	120kW
400	(Abbreviation)							

§2 Pocket tachometer 3632 ▼

Reflective tape	One sheet	Two sheet	Four sheet	Six sheet	Eight sheet
Number of revolutions min^{-1}	0～20000	0～10000	0～5000	0～3333	0～2500
Output V	0～2	0～2	0～2	0～2	0～2

Ⅳ. Hands-on Measurement Exercise

1. Measurement data sheet

Date of measurement

Name of measurer

Suction air

Temperature T1 ℃

Humidity ϕ_1 %

		Orifice flowmeter flow rate	Electric power	Suction pressure	Discharge pressure	Pitot tube differential pressure
	Opening % Rotational speed rpm	Q1	L1	Ps	Pd	⊿P
		m^3_N /h	kW	kPa·G	kPa·G	Pa
Damper control						
Speed control						

2. Calculation sheet

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Differential static pressure	Pitot tube flow velocity	Pitot tube flow rate	Equivalent suction flow rate	Theoretical mechanical power	Overall efficiency	Electric energy intensity
	H	VP	QP	Qs	Lt	η T	L1／Q1
	kPa	m/sec	m^3/min	m^3/min	kW	%	Wh/m^3_N
Damper control							
Speed control							

3. Supplementary information

(1) Differential static pressure

ex. $Pd=7$ [kPa] $Ps=-1$ [kPa]

$H=Pd-Ps$ [kPa] $=7-(-1)=8$ [kPa]

(2) Pitot tube flow velocity

ex. $C=0.754$ $\varDelta =100$ [Pa]

$VP=C\times\sqrt{(2\times\varDelta P\ [Pa])}=0.754\times\sqrt{(2\times300\ [Pa])}\fallingdotseq 18.5$ [m/sec]

(3) Pitot tube flow rate

ex. $d=155.2$ [mm]

$QP=V\times\pi/4\times(d\ [m])^2=18.5\ [m/sec]\times\pi/4\times(0.155\ [m])^2\times60\fallingdotseq20.9\ [m^3/min]$

(4) Equivalent suction flow rate

ex. Temperature $T1=30$[℃] (vapor saturation pressure $Ps=4.243$[kPa])

Humidity $\phi_1=70$[%]

$Qs=QP\times(101.3)/(101.3+Ps-\phi_1\times Ps)\times(273+T1)/(273)$ [m^3/min]

$=20.9\times(101.3)/(101.3+(-1)-0.7\times4.243)\times(273+30)/(273)=24.1$ [m^3/min]

(5) Theoretical mechanical power

$Lt=Qs/60\times H$ [kW] $=24.1/60\times8=3.2$ [kW]

(6) Overall efficiency

ex. $L1=6.5$ [kW]

$\eta T=Lt/L\times100$ [%] $=3.2/6.5\times100$ [%] $=49.2$ [%]

(7) Electric energy intensity

It is advisable to proceed with energy conservation through energy intensity management as it is both effective and easy to measure in monetary terms. The energy intensity of a fan can be expressed as electricity consumption [kWh] per unit flow [m^3_N] or unit available flow [m^3_N]

① Electric energy intensity [kWh/m^3_N] = Electricity consumption [kWh] / Unit flow [m^3_N]

② Electric energy intensity [kWh/m^3_N] = Electricity consumption [kWh] / Unit available flow [m^3_N]

ex. $L1=6.5$ [kW] $Q1=1500$ [m^3_N/h]

$L1/Q1$ [W/m^3_N] $=(6.5\ [kW]\times1000)$ [W] $/1500$ [m^3_N/h] $=4.333$ [W/m^3_N]

V. Preparation of Performance Curves

1. Specification of hands-on exercise fan

Fan: air flow rate 1800 m^3/h, wind pressure 600 mmAq, efficiency and rotational speed 2940 min^{-1}

Motor: power output 7.5 kW, voltage 200 V, current 26.8 A,

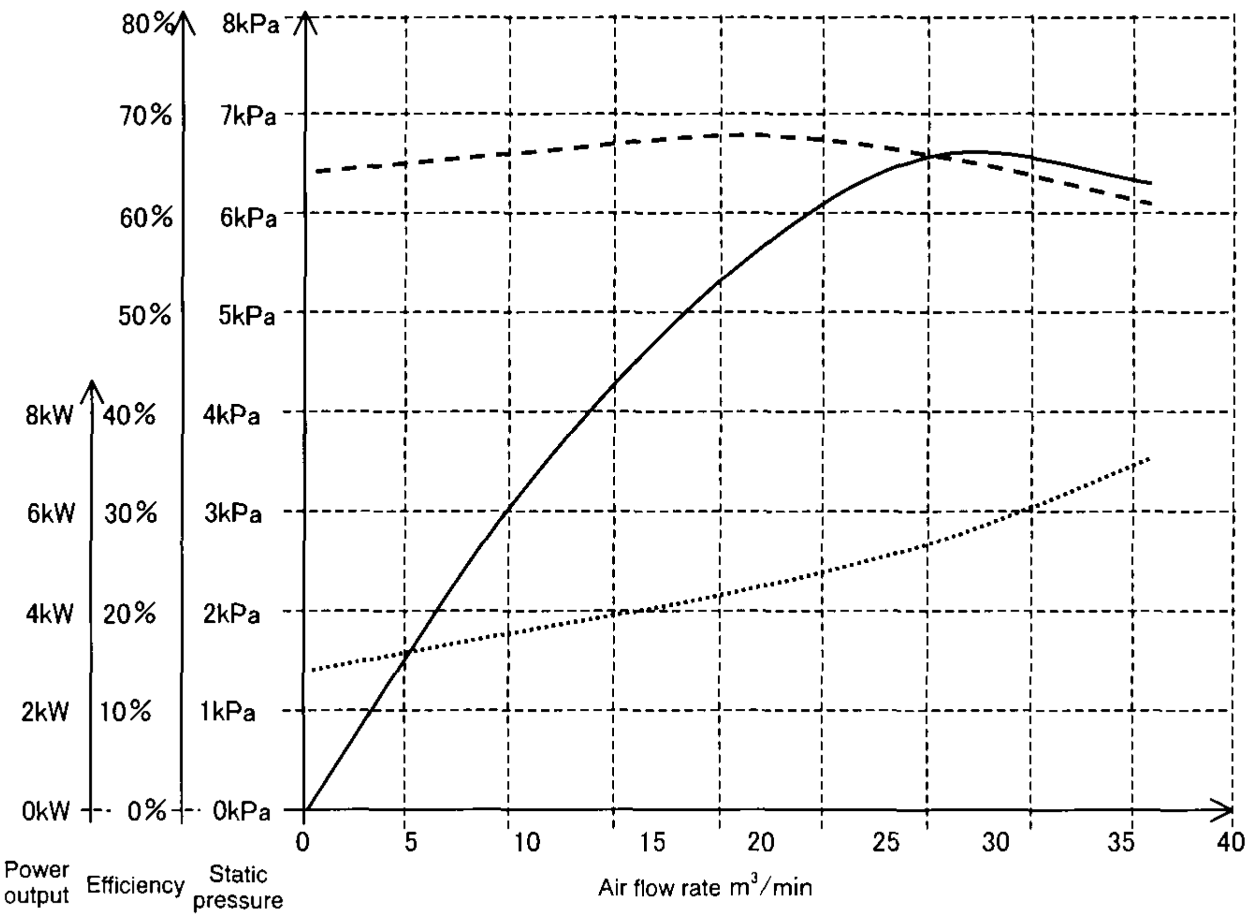
efficiency and rotational speed 2890 min^{-1}

Extraction of manufacturer's test results

Air flow rate		Differential static pressure		Theoretical mechanical power	Fan efficiency	Rotational speed	Motor power output	Motor efficiency	Motor power input
Q		H		L1	ηF	SP	L2	ηM	L3
m^3/h	m^3/min	mmAq	kPa	kW	%	min^{-1}	kW	%	kW
0	0.0	664	6.507	0.0	0.0	2982	2.59	92.5	2.80
606	10.1	677	6.634	1.1	31.1	2972	3.26	92.4	3.53
1260	21.0	694	6.801	2.3	53.2	2966	4.07	92.3	4.41
1872	31.2	679	6.654	3.4	66.3	2959	4.78	92.5	5.17
2460	41.0	639	6.262	4.3	62.9	2951	6.29	92.4	6.81

2. Performance curves

* Plot the data recorded in the calculation sheet explained in section 2 of "IV. Hands-on Measurement Exercise" to obtain performance curves.



Ⅵ. Data Processing and Manipulation Methods

1. Turning on PC and starting Keyence WAVE THERMO software
   ① Retrieve the saved file (WAVE THERMO proprietary format).
   ② Specify the portion of the data required.
2. Saving data in CSV format
   ① Set the resampling cycle.
   ② Give the data an appropriate filename and save it.
3. Converting file format from CSV to Excel
   ① Start Excel.
   ② Retrieve the CSV file saved.
   ③ Insert about ten lines.
   ④ Enter the required labels, including channel numbers, quantities measured, measuring instruments, ranges and outputs, in the cells.

	CH1	CH2	CH3	CH4	CH5	CH6	CH11	CH12
Measuring instrument	3165		Orifice flowmeter	UT	GC62	GC62	Flow sensor	DPG
Quantity	Electric power	Fre-quency	Flow rate	Tem-perature	Suction pressure	Discharge pressure	Flow velocity	Differential pressure
Unit	kw	Hz	m^3_N/h	℃	kPa	kPa	m/sec	Pa
Range L	0	0	0	0	-10	0	0	0
Range H	40	100	2000	400	10	10	40	500
Output LV	0	0	1	1	1	1	1	0
Output H V	2	2	5	5	5	5	5	2
Coefficient	1	1	1	1	1	1	1	1/2
Calculation result ⑤								

In the case of two pieces of reflective tape being provided

	CH1	CH2	CH3	CH4	CH5	CH6	CH11	CH12
	Data	***	***	***	***	***	***	***

   ⑤ Enter conversion formula.
   =((RangeH−RangeL)×(* CH data *−outputL)／(outputH−outputL)−RangeL)
   ×(coefficient)
   Copy this onto all cells to the right as it is a common formula.
   ⑥ Save in Excel format.

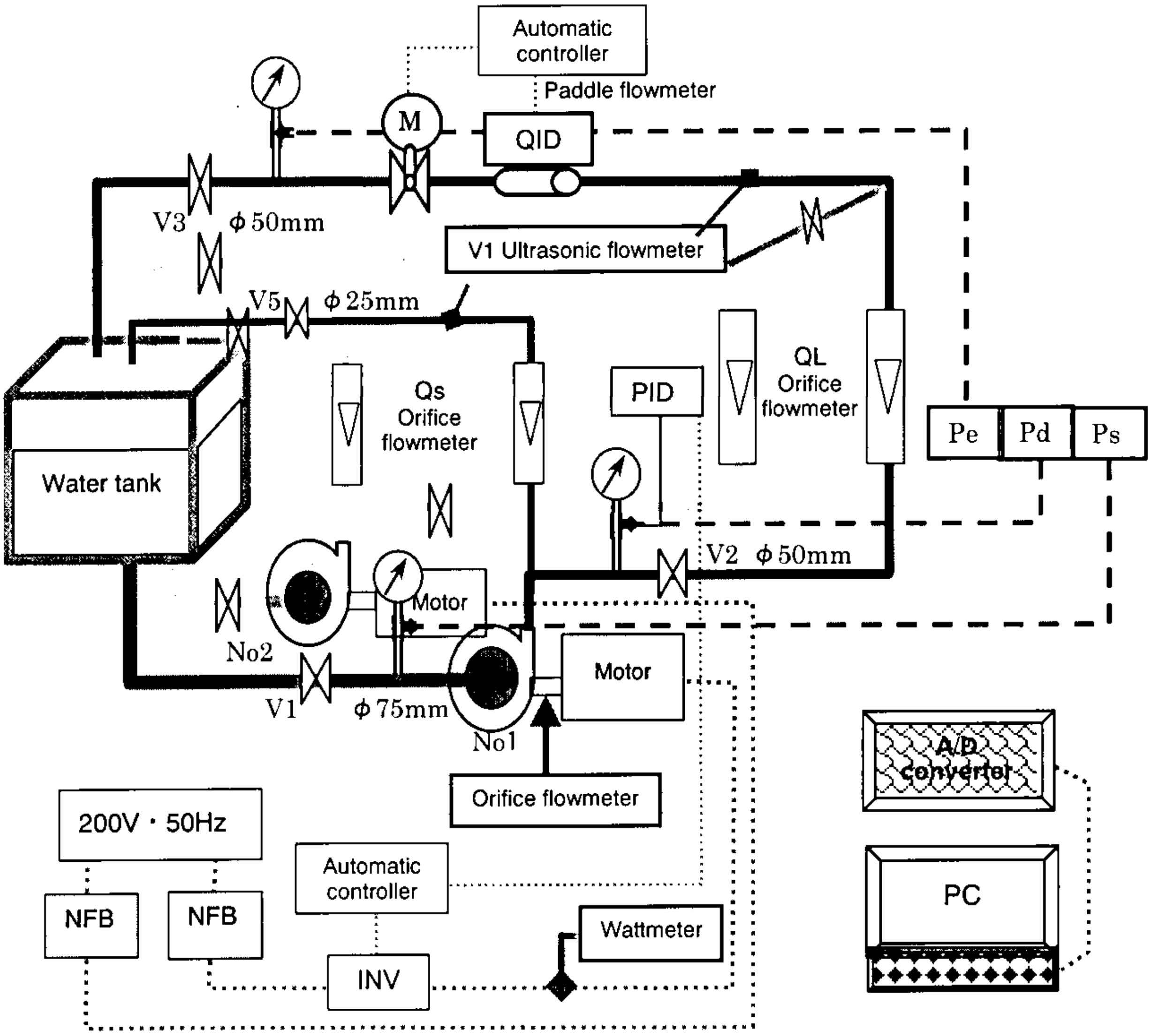
4. Numerical processing
   ① Process and analyze the data using a spreadsheet program to qualitatively establish energy conservation.
   ② Draw graphs of air flow rate and electric power .

4.2 Liquid Measurement Training

I. Measurement Exercises for Pump Equipment

1. Electric power, voltage and current measurement using wattmeter (digital power meter)
2. Pressure measurement using pressure gauge
3. Flow measurement using flow velocity meter
4. Connection between data logging system and various measuring instruments and setting
5. Comparison of electric output vs. flow rate characteristics (damper control and motor speed control)
6. Preparation of performance curves
7. Analog-to-digital conversion of data and data manipulation

II. Training Facility and Measurement Equipment Arrangement Diagram



Ⅲ. Measuring Equipment

1. Measurement of electric power

(1) Configuration of measurement system

Wattmeter (digital power meter) + clamp-on sensor

(2) Wattmeter

① Measuring instrument : HIOKI 3165 Clamp-on Power Hitester

② Applicable circuit configurations : 1 ϕ2w, 1 ϕ3w, 3 ϕ3w, 3 ϕ4w

③ Measurement items : voltage, current, real power, reactive power, apparent power, power factor, watt-hour and frequency (10 Hz～)

④ Measuring range : Voltage100V, 200V, 400V (Max600V)

With a high tension circuit, measurement is undertaken on the secondary side of a PT.

Be careful not to cause a short circuit or touch a live part.

Electric power range (auto-range) set according to the combination of voltage and current range settings

⑤ Analog output : Analog output DC 2V/f.s kW, V1, V2, V3, A1, A2, A3
D/A output DC 2V/f.s kW, V1, V2, V3, A1, A2, A3, pf, Hz (chose one from list)

⑥ Power source : AC85V～250V(45Hz～66Hz)

(3) Clamp on sensor

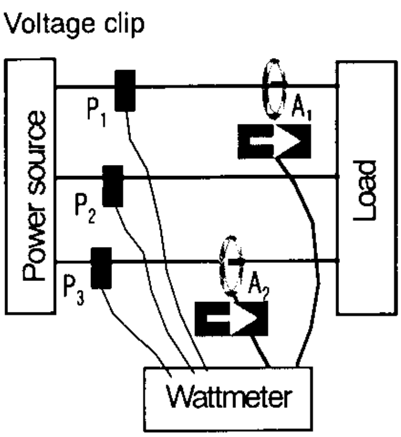
① Measuring instrument : 9272 20／200A

Measuring range : Current 2A, 5A, 10A, 20A, 50A, 100A, 200A

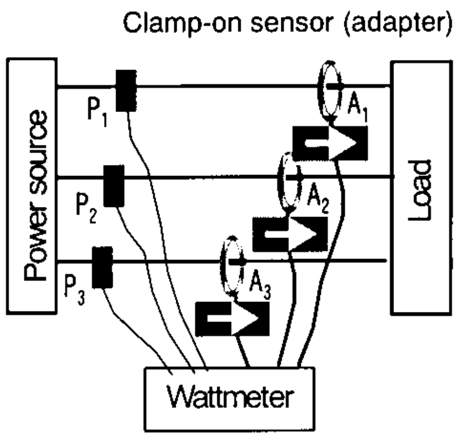
② High-current clamp-on adapter : 9290 1000A CT ratio 10:1

Electric currents are measured on the secondary side of a CT in the case of a high-tension high-current circuit and via a clamp-on adapter in the case of a low-tension high-current circuit. Such indirect measurement expands the measuring range and protects the clamp-on adapter from damage.

(4) Connection examples



Three-phase Two-current and Two-voltage Method



Three-phase Three-current and Three-voltage Method

2. Pressure measurement

(1) Digital low differential pressure gauge

① Measuring instrument : GC61 (Nagano Keiki)

② Measuring range : −0.1〜0.5, 0〜0.5, 0〜1MPa

③ Analog output : −0.1〜0.5, 0〜0.5, 0〜1MPa

④ Power source : 24V DC

(2) Differential pressure transmitter

① Measuring instrument : EJA110 (Yokogawa Electric)

② Measuring range : 0〜2MPa

③ Analog output : 4〜20mA DC

④ Power source : 24V DC

(3) Bourdon-tube pressure gauge

① Measuring instrument : GL20−2GI (Nagano Keiki)

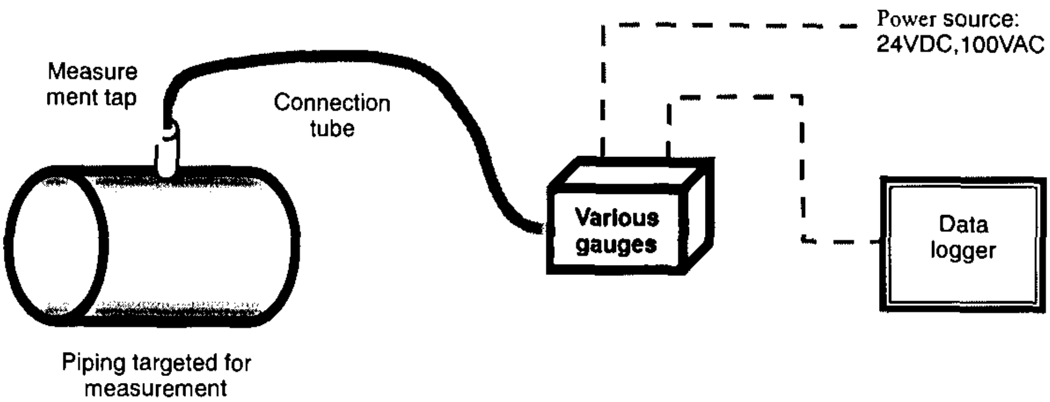
② Measuring range : −0.1〜0.5, 0〜0.5, 0〜1MPa

(4) Analog low differential pressure gauge

① Measuring instrument : Manostar gauge (Yamamoto Electric Industrial)

② Measuring range : 0〜50, 0〜100, 0〜200, 0〜500Pa,
0〜2, 0〜5, 0〜10, 0〜20kPa

(5) Connection example



※ Measurement of number of revolutions

① Measuring instrument : Portable tachometer 3632 Noncontact type (Yokogawa Electric)

② Measuring range : L range 60〜1999.9 rpm (min^{-1})
: H range 60〜19999 rpm (min^{-1})

③ Output range : 1000 rpm／0.1V〜20000 rpm／2V

④ Power source : 9V Dry battery 1P

3. Flow measurement

(1) Paddle flowmeter

① Measuring instrument : MK515-P0 (Ryutai Kogyo)

② Measuring range : 0～40 m^3/h 0.5 MPa

③ Analog output : 4～20 mADC→(250 Ω) 1～5 VDC

Digital indicator/integrator : RDM-100-A1-N2

④ Power source : 24VDC

⑤ Measurement point : Permanently mounted on discharge line

(2) Differential pressure type flow meter

① Measuring instrument : Oriflo (Tokyo Keiso)

② Measuring range QL : 0～30 m^3/h

③ Measurement point : Permanently mounted on main discharge line

(3) Differential pressure type flowmeter

① Measuring instrument : Oriflo (Tokyo Keiso)

② Measuring range Qs : 0～20 m^3/h

③ Measurement point : Permanently mounted on discharge blow line

(4) Portable ultrasonic flowmeter

① Measuring instrument : Portaflow X (Fuji Electric)

② Measuring range : −32～0～32 m/sec

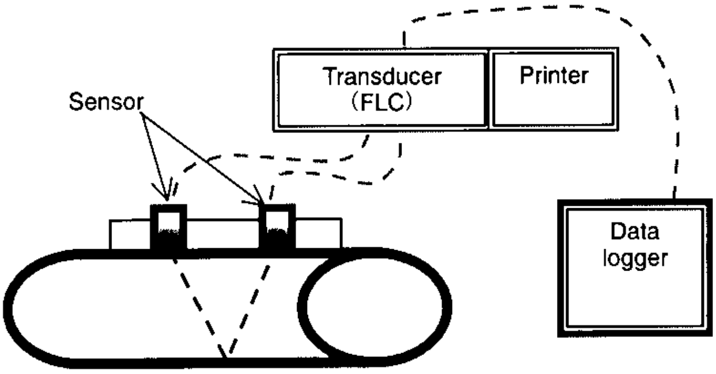
Sensor type	Model	Applicable diameter range	Temperature range
Small diameter	FLD22	13～100mm	−40～100℃
Standard	FLD12	50～400mm	−40～100℃

③ Analog output : 4～20 mADC→(250 Ω) 1～5 VDC

④ Power source : AC/DC adapter AC90～264V

⑤ Measurement point : Sensor mounted on external wall of liquid piping

(5) Connection example



Nominal diameter	Rigid PVC pipes	
(A)	Outside diameter mm	Inside diameter mm
25	32	25.0
50	60	51.0
75	89	77.2
100	114	99.8

4. Recorder

(1) Configuration of data logging system

Personal computer + Keyence NR-250

(2) Laptop computer

IBM ThinkPad 130

(3) Keyence NR-250

Used in conjunction with a PC, it collects and stores data via software installed on the PC, with system setting and data processing also undertaken on the PC.

① Function : Analog voltage → Digital conversion of data → Storage on PC

② Number of input channels : 16ch

③ Analog voltage input : Range ±10, ±5, ±2.5, ±1, ±0.5, ±0.25VDC

Thermocouple input : Thermocouple K, J, E, T

Max. input voltage : ±30VDC

④ Sampling rate : 0.1s~24Hr

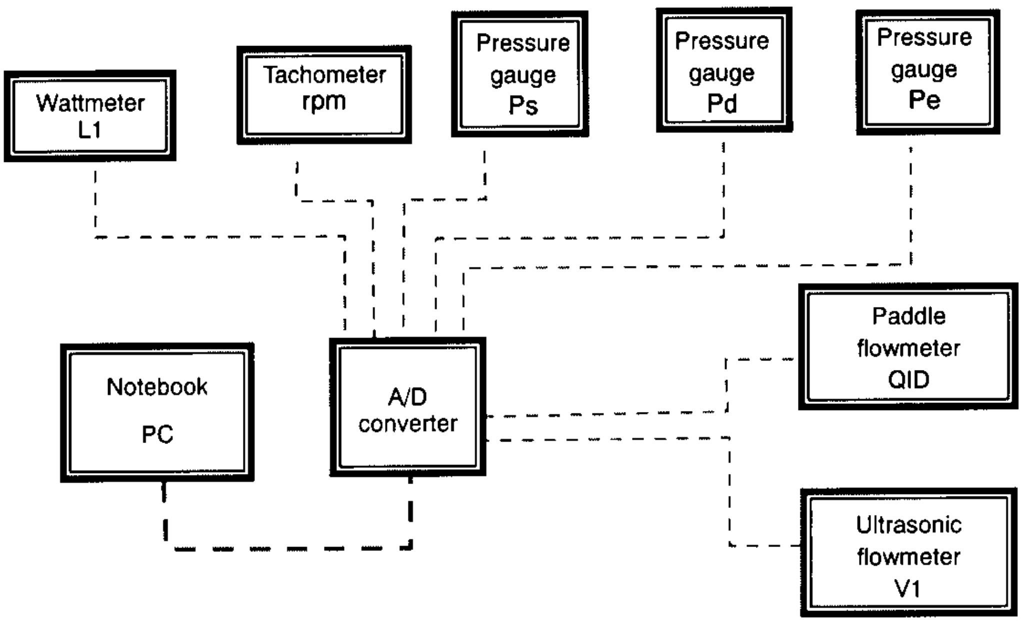
⑤ Measurement accuracy : Analog input ±0.1% of FS (±0.2% of FS for ±0.25 VDC)

(4) Signal connection box

Facilitates the connection of analog voltage signal cables from various measuring instruments.

① Number of terminals : 32 (16 reds and 16 blacks)

(5) Connection example



(6) Software setting

Keyence NR-250

CH	Quantity	Abbre-viation	Unit	Measuring instrument	Measuring range	Output voltage V	Remarks
1	Motor input power	L1	kW	3165	0~20	0~2	§1
2	Motor input frequency	Hz	Hz	3165	0~100	0~2	
3	Flow rate	QID	m^3/h	Paddle flowmeter	0~40	1~5	
4	Suction pressure	Ps	MPa	GC61	−0.1~0.5	1~5	
5	Discharge pressure	Pd	MPa	GC61	0~1.0	1~5	
6	End pressure	Pe	MPa	GC61	0~0.5	1~5	
7	Motor rotational speed	rpm	min^{-1}	3632	0~20000	0~2	§2
8	Flow velocity	V1	m/sec	Portaflow X	0~10	1~5	§3

§ 1 Wattmeter 3165 measuring range table

		Current A						
Voltage V	Phase/line configuration	2	5	10	20	50	100	200
100	(Abbreviation)							
200	1P2W	400W	1.0kW	2.0kW	4.0kW	8.0kW	20kW	40kW
	1P3W	800W	2.0kW	4.0kW	8.0kW	20kW	40kW	80kW
	3P3W-2	800W	2.0kW	4.0kW	8.0kW	20kW	40kW	80kW
	3P3W-3	800W	2.0kW	4.0kW	8.0kW	20kW	40kW	80kW
	3P4W	1.2kW	3.0kW	6.0kW	12kW	30kW	60kW	120kW
400	(Abbreviation)							

§ 2 Pocket tachometer 3632 ▼

Reflective tape	One sheet	Two sheet	Four sheet	Six sheet	Eight sheet
Number of revolutions min^{-1}	0~20000	0~10000	0~5000	0~3333	0~2500
Output V	0~2	0~2	0~2	0~2	0~2

§ 3 Portaflow X measures flow velocity, but is also capable of calculating/indicating flow rate if piping type and size are entered.

For exercise purposes, it is set to flow velocity measurement here, with flow rate obtained by calculation.

IV. Hands-on Measurement Exercise

1. Measurement data sheet

Date of measurement

Name of measurer

		Paddle flowmeter flow rate	Electric power	Suction pressure	Discharge pressure	End pressure	Portaflow X flow velocity
	Opening % Rotational speed rpm	QID	L1	Ps	Pd	Pd	V1
		m^3 /h	kW	kPa·G	kPa·G	kPa·G	m/sec
Damper control							
Speed control							

2. Calculation sheet

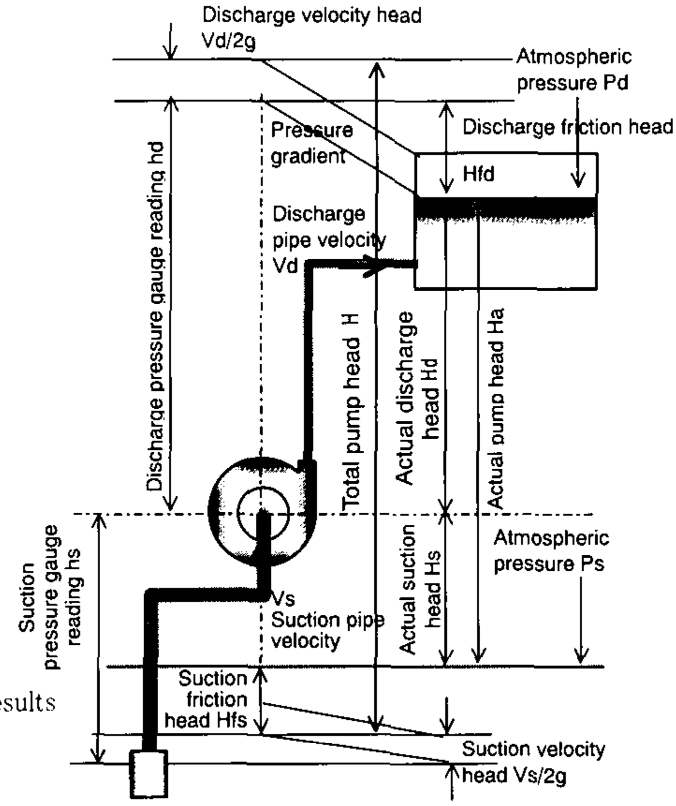
	(1)	(2)	(3)	(4)	(5)
	Pump head	Portaflow X flow rate	Theoretical mechanical power	Overall efficiency	Electric energy intensity
	H	Q1	Lw	ηT	L1／Q1
	m	m^3/min	kW	%	Wh/m^3
Damper control					
Speed control					

3. Supplementary information

(1) Pump head

ex. Pd:300 [kPa] +0.5 [m]   Ps: −1 [kPa]   +0.5 [m]

H=hd− hs [m]=(300 [kPa]−(−1 [kPa])/9.8) +0.5−(−0.5)=30.7 [m]



*Detailed calculation procedure.

① Total pump head

$$H = Ha + Hl + \frac{Vd^2}{2g} + \frac{(Pd - Ps)}{\rho} \ [m]$$

Ha : Actual pump head [m]

Ha=Hs+Hd

Hl : Head loss [m]

Hl=Hfs+Hfd

Vd : Discharge pipe velocity [m/sec]

Vd/2g : Discharge velocity head [m]

Vs : Suction pipe velocity [m/sec]

Vs/2g : Suction velocity head [m]

ρ : Density of water 998 [kg/m^3]

② Calculation of total head from measurement results

$$H = hd - hs + \frac{Vd^2}{2g} - \frac{Vs^2}{2g} + hm$$

hd : Discharge pressure gauge [m]

hs : Suction pressure gauge [m]

Vd : Velocity at discharge pressure measurement point [m/sec]

Vs : Velocity at suction pressure measurement point [m/sec]

Hm : Pressure gauge installation height at suction and discharge pressure measuring points

g : Acceleration of gravity 9.8 [m/sec^2]

③ Conversion of measured pressures and heads

10 [m]=1 [kg/cm^2]=0.098 [MPa]=98 [kPa]

0.1 [MPa]c100 [kPa]=100/9.8=10.2 [m]

ex. Pd :300 [kPa] +0.5 [m]   Ps: −1 [kPa] + 0.5 [m]

Q1= 20 [m^3 /h] Suction d=77.2 [mm] Discharge d=51.0 [mm]

hd [m]=Pd[kPa] /9.8=(300 [kPa] /9.8)=30.6 [m]

hs [m] =Ps[kPa] /9.8=(−1 [kPa] /9.8)=−0.1 [m]

Vs =Q1×4/(π×d^2) =20 [m^3 /h]/60^2×4/(π×0.0772^2)=1.19 [m/sec]

Vd =Q1×4/(π×d^2) =20 [m^3 /h]/60^2×4/(π×0.051^2)=2.72 [m/sec]

H =hd− hs [m] +Vd^2/2g−Vs^2/2g+hm

=30.6−(−0.1)+(2.72^2−1.19^2)/19.6+0.5−0.5=31.0 [m]

(2) Portaflow X flow rate

ex. $V1 = 2.72$ [m/sec] $d = 51.0$ [mm]

$Q1 = V \times \pi / 4 \times (d\ [m])^2 = 2.72\ [m/sec] \times \pi / 4 \times (0.051\ [m])^2 \times 60 \fallingdotseq 0.33\ [m^3/min]$

(3) Theoretical mechanical power

$Lw = (Q1 \times H[m] \times \rho \times g) / (60 \times 10^3)\ [kW]$

$= (0.33 \times 30.7 \times 998 \times 9.8) / (60 \times 10^3) = 1.65\ [kW]$

$Lw = Q1 \times H[kPa] / 60\ [kW] = 0.33 \times 301[kPa] / 60 = 1.65\ [kW]$

(4) Overall efficiency

ex. $L1 = 3.5$ [kW]

$\eta T = Lw / L1 \times 100\ [\%] = 1.65 / 3.5 \times 100\ [\%] = 47.1\ [\%]$

(5) Electric energy intensity

It is advisable to proceed with energy conservation through energy intensity management as it is both effective and easy to measure in monetary terms. The energy intensity of a pump can be expressed as electricity consumption [kWh] per unit flow [m^3] or unit available flow [m^3]

① Electric energy intensity [kWh/m^3]

= Electricity consumption [kWh] / Unit flow [m^3]

② Electric energy intensity [kWh/m^3]

= Electricity consumption [kWh] / Unit available flow [m^3]

ex. $L1 = 6.5$ [kW] $Q1 = 25$ [m^3/min] s

$L1 / Q1\ [W/m^3] = (3.5\ [kW] \times 1000)\ [W] / 20\ [m^3/h] = 175\ [W/m^3]$

V. Preparation of Performance Curves

1. Specification of hands-on exercise pump

Pump No. 1: discharge rate 24 m^3/h, total head 33 m, rotational speed 3000 min^{-1} and vane diameter 187mm

Pump No. 2: discharge rate 24 m^3/h, total head 33 m, rotational speed 3000 min^{-1} and vane diameter 180mm

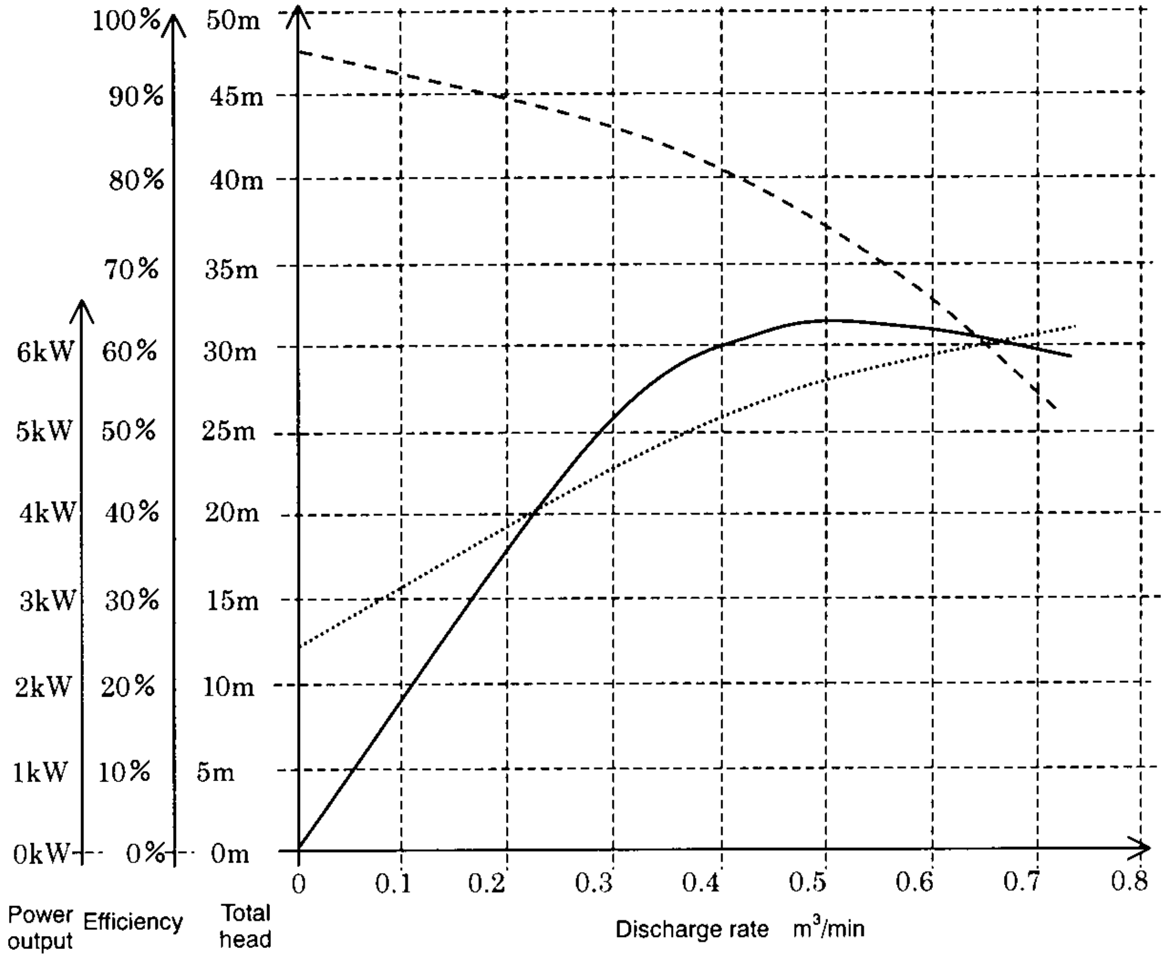
Motor : power output 5.5 kW, voltage 200 V, current 20.8 A and rotational speed 2870 min^{-1}

Extraction of manufacturer's test results (pump No. 1)

Discharge rate		Total head		Theoretical mechanical power	Pump efficiency	Rotational speed	Motor power output	Motor efficiency	Motor power input
Q		H		Lw	η_P	SP	L2	η_M	L3
m^3/h	m^3/min	m	kPa	kW	%	min^{-1}	kW	%	kW
0	0.0	46.9	459	0.0	0.0	2955	2.048	81.9	2.500
17.6	0.294	43.1	422	2.065	53.1	2910	3.888	86.0	4.521
26.46	0.441	39.1	383	2.811	61.5	2889	4.570	85.7	5.333
35.28	0.588	33.0	323	3.163	62.6	2874	5.052	85.3	5.923
44.10	0.735	26.8	263	3.211	59.7	2868	5.383	85.2	6.318

2. Performance curves

* Plot the data recorded in the calculation sheet explained in section 2 of "IV. Hands-on Measurement Exercise" to obtain performance curves.



VI. Data Processing and Manipulation Methods

1. Turning on PC and starting Keyence WAVE THERMO software
   ① Retrieve the saved file (WAVE THERMO proprietary format).
   ② Specify the portion of the data required.
2. Saving data in CSV format
   ① Set the resampling cycle.
   ② Give the data an appropriate filename and save it.
3. Converting file format from CSV to Excel
   ① Start Excel.
   ② Retrieve the CSV file saved.
   ③ Insert about ten lines.
   ④ Enter the required labels, including channel numbers, quantities measured, measuring instruments, ranges and outputs, in the cells.

No.1 Pump

	CH1	CH2	CH3	CH4	CH5	CH6	CH7	CH8
Measuring instrument	3165		Paddle flowmeter	GC61	GC61	GC61	3632	Portaflow X
Quantity	Electric power	Fre-quency	Flow rate	Suction pressure	Discharge pressure	End pressure	Rotational speed	Flow velocity
Unit	kw	Hz	m^3/h	kPa	kPa	kPa	rpm	m/sec
Range L	0	0	0	-0.1	0	0	0	0
Range H	40	100	40	0.5	100	50	20000	10
Output LV	0	0	1	1	1	1	1	1
Output H V	2	2	5	5	5	5	5	5
Coefficient	1	1	1	1	1	1	1/2	1
	⑤							

In the case of two pieces of reflective tape being provided

	CH1	CH2	CH3	CH4	CH5	CH6	CH7	CH8
	Data	***	***	***	***	***	***	***

⑤ Enter conversion formula
= ((RangeH − RangeL) × (* CH data * − outputL) ∕ (outputH − outputL) − RangeL) × (coefficient)
Copy this onto all cells to the right as it is a common formula.
⑥ Save in Excel format.

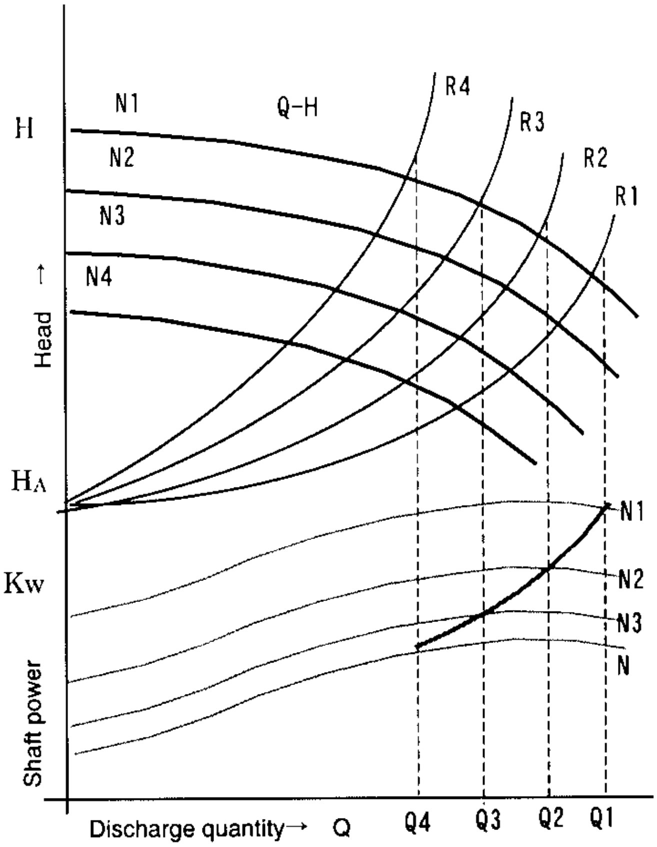
4. Numerical processing
   ① Process and analyze the data using a spreadsheet program to quantitatively establish energy conservation.
   ② Draw graphs of water flow rate and electric energy.

* Supplementary information

Effects of controlling number of revolutions

Discharge quantity

This is to realize energy conservation by changing the number of revolutions of pump and by meeting required water quantity and pressure, according to change in use



① Discharge quantity $Q_2 = \left[\frac{N_2}{N_1}\right] \times Q_1$

② Head $H_2 = \left[\frac{N_2}{N_1}\right]^2 \times H_1$

③ Shaft power $L_2 = \left[\frac{N_2}{N_1}\right]^3 \times L_1$

N_1: Number of revolutions before change

N_2: Number of revolutions after change

Q_1: Flow rate before change Q_2: Flow rate after change

H_1: Pump head before change H_2: Pump head after change

L_1: Shaft power before change L_2: Shaft power after change

④ Shaft power of flow rate control $L_2 = \left[\frac{Q_2}{Q_1}\right]^3 \times L_1$

The shaft power is proportional to the cube of change in the number of revolutions and will decrease greatly, while the pump head will also decrease in proportion to square of it, so detailed study will be required when introducing

⑤ Shaft power of pressure control $L_2 = \left[\frac{P_2}{P_1}\right]^{3/2} \times L_1$

Generally pressure control is widely used, and the following two kinds are considered

(A) Constant control of discharge pressure

(B) Constant control of end pressure

4.3 Temperature Measurement Training

I. Hands-on Exercises

1. Temperature measurement using thermocouple thermometer
   (1) Thermocouple thermometer connection and data collection methods
   (2) Advantages of thermocouple thermometer and measurement considerations

2. Temperature measurement using contact (noncontact) surface thermometer
   (1) Contact thermometer handling and data collection methods
   (2) Radiation thermometer handling and data collection methods (emissivity measurement method)

3. Heat balance exercise
   (1) Data collection, reduction and calculation methods

II. Locations of Temperature Measurement Positions

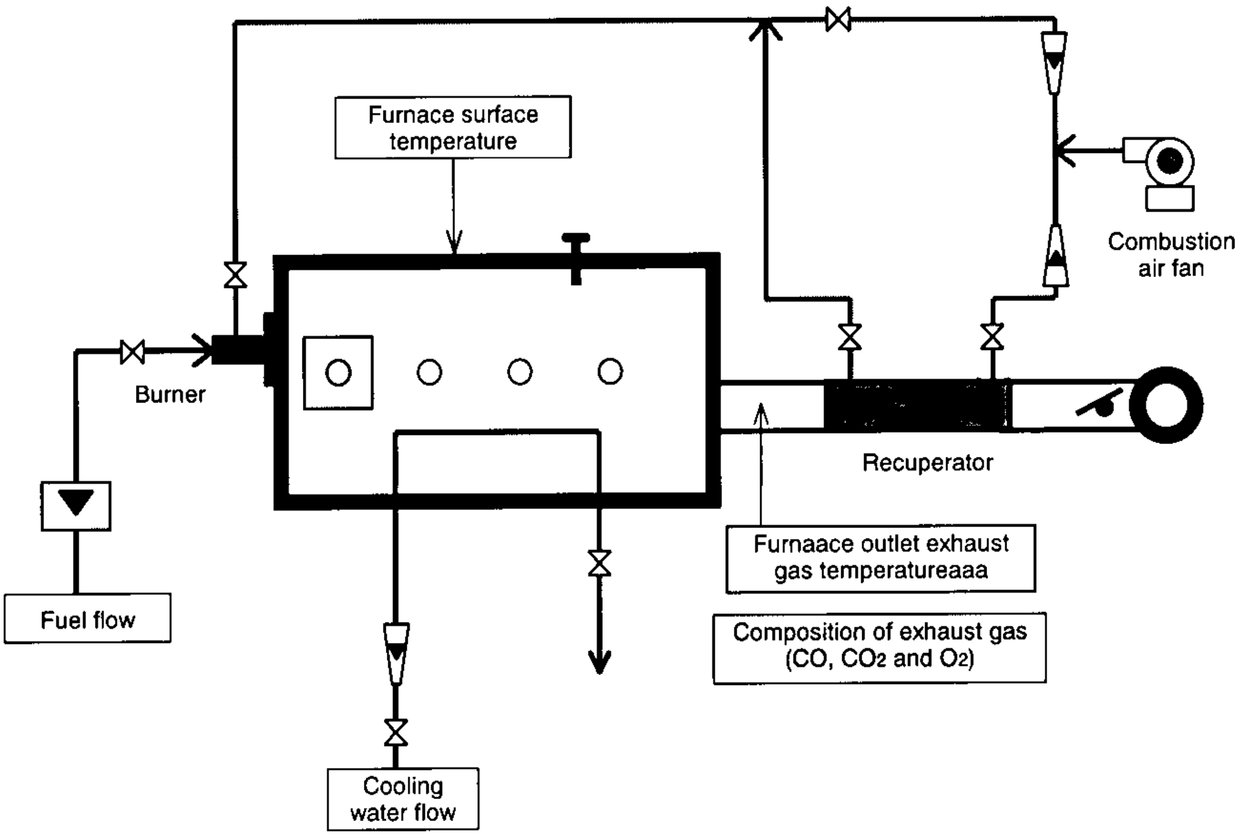


Figure 3-1 Training Facility and Measurement Equipment Arrangement Diagram

III. Temperature Measurement

1. Operation temperature ranges of major types of thermometers

Temperature measurement methods are classified into two categories, the contact type and the noncontact type. In the contact type, the thermometer sensor comes into direct contact with the temperature measurement site, while in the noncontact type, the thermometer sensor stays away from the temperature measurement site.

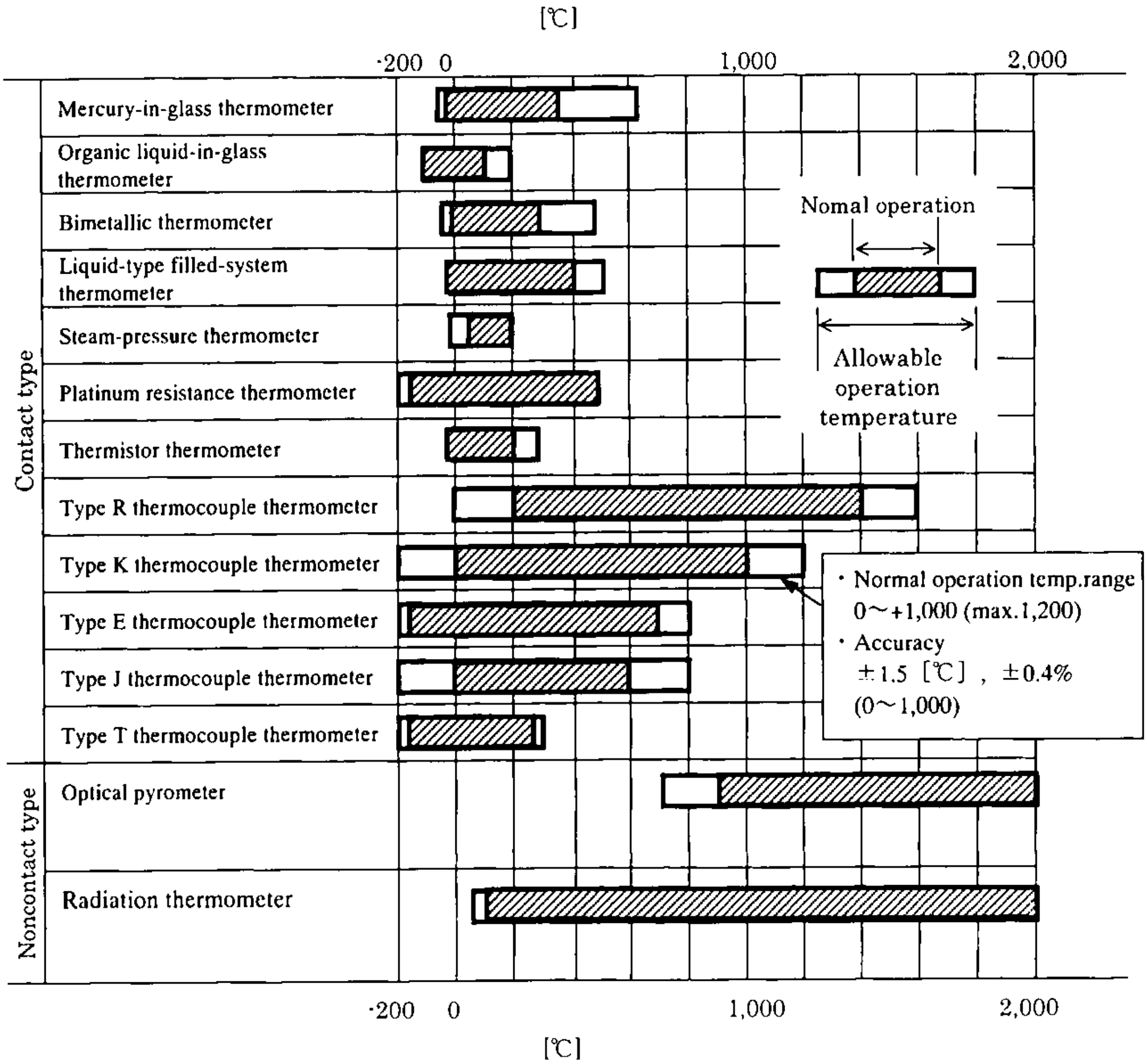


Figure 3-2 Operation Temperature Ranges of Major Types of Thermometers

2. Temperature measurement using thermocouple thermometer

(1) Thermocouple thermometer connection and data collection methods

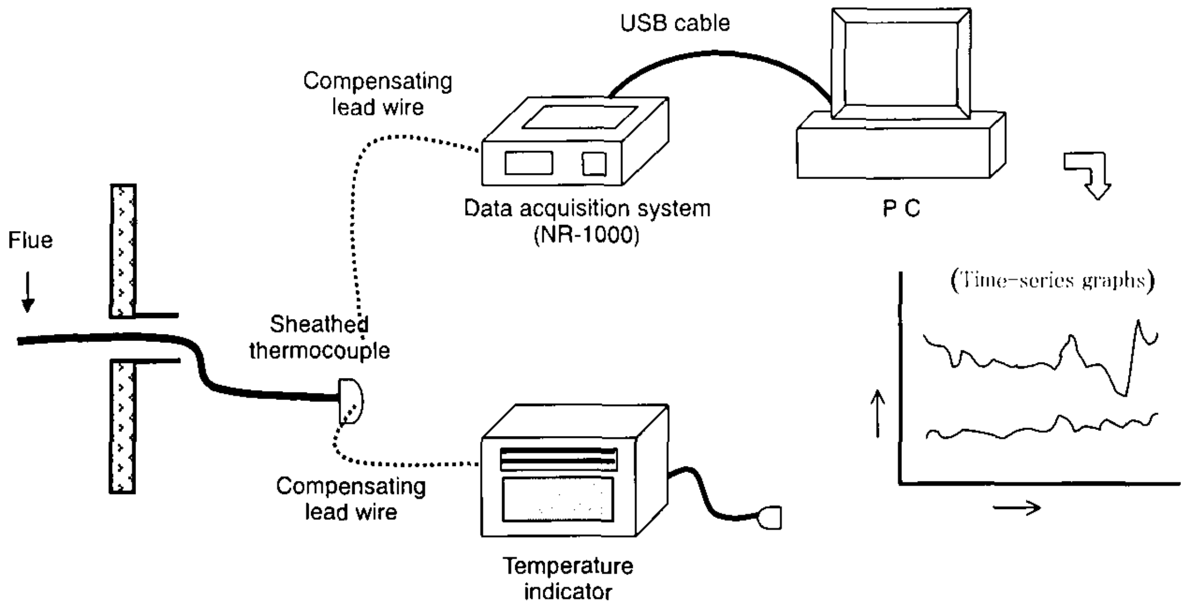


Figure 3-3 Thermocouple Thermometer Connection Diagram

(2) Advantages of thermocouple thermometer and measurement considerations

① Advantages

A Large thermal electromotive force

B Stable thermal electromotive force even under high-temperature or low-temperature conditions, as well as long service life

C High durability and undiminished mechanical strength even at high temperatures

D High corrosion resistance, making it safe to use with virtually all gases and other substances

② Measurement considerations (contributing factors to measurement errors)

A Effect of insertion depth (heat transfer error attributable to the thermal effect of the environment on the temperature sensor)

- Ensure adequate insertion depth. Generally speaking, the insertion depth must be 15-20 times the diameter or more in the case of a mental protective tube being used.

B Effect of time delay

- Take a reading after waiting for it to stabilize according to the construction of the temperature sensor, measurement conditions, etc.

C Effect of radiation heat (measurement error due to a gain or loss of heat energy through radiation)

- Provide a shield for the temperature sensor against a high-temperature object (solid wall).

D Effect of increased thermal resistance (measurement error due to the deposition of soot, dust, etc on the surface of the protective tube)

- Inspect and clean the instrument regularly or as necessary.

3. Temperature measurement using contact (noncontact) surface thermometer

(1) Contact thermometer handling and data collection methods

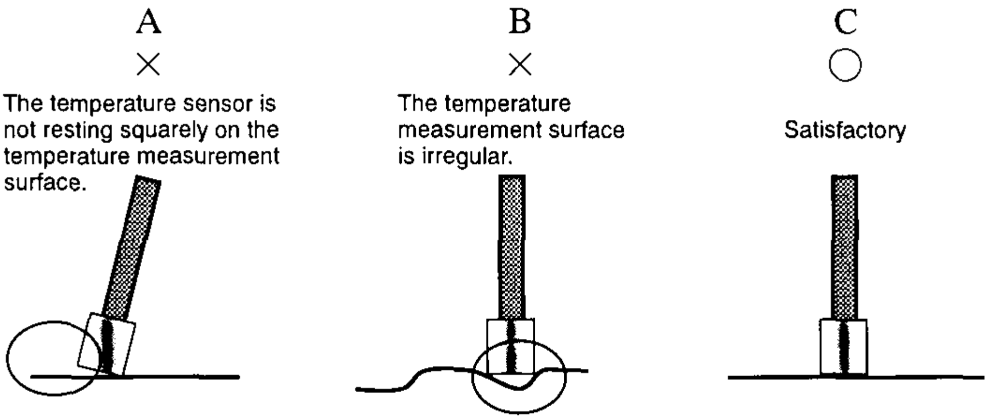


Figure 3-4 Temperature Measurement Surface and Temperature Sensor

(2) Advantages of contact surface thermometer and measurement considerations

① Advantages

A Thermal equilibrium is easy to obtain because of direct contact with the measurement object.

B Fabrication is relatively easy, so that a range of shape and construction options can be explored to suit various measurement objects.

② Measurement considerations

A As the protective guard, etc. of the temperature sensor is highly liable to take heat from the measurement object, special care must be taken when the contact surface of the measurement object is small.

B If air flows onto the temperature measurement site, complete thermal equilibrium cannot be obtained, so that care should be taken to avoid exposure to air flows.

C Even a small amount of dust or any other foreign matter that is present between the temperature measurement surface and temperature sensor surface gives rise to a measurement error due to the formation of an air layer.

(3) Advantages of radiation (noncontact) thermometer and measurement considerations

① Advantages

A Generally speaking, radiation thermometers have quicker response speeds than contact thermometers, as well as being capable of temperature measurement even if the measurement object is at a distance.

B Objects for which radiation thermometers are used include hot objects, revolving/moving objects and objects with a small thermal capacity that would lose heat if they came into contact with a temperature sensor.

② Measurement considerations

A The fundamental condition for accurate temperature measurement using a radiation thermometer is the correct establishment of the emissivity of the measurement object.

B The measurement environment in which the measurement object and thermometer are placed, in terms of the distance between them, ambient temperature and humidity, gases present in the optical path, and like, must be clearly ascertained.

IV. Heat Balance Exercise

1. Purpose of heat balance

The heat balance is calculated to quantitatively establish heat input and output and investigate rectification measures for any heat loss with a view to improving the thermal efficiency through a reduction in fuel consumption.

2. Heat balance conditions

(1) Fuel type Propane gas

(2) Table 3-1 Heat Balance Conditions

	Furnace interior temperature [℃]	Air ratio [m]	Air preheating Yes/No	Cooling water flow [m³/h]	Time taken [h]
Condition-1	850	1.05	Yes	2.8	1.0
Condition-2		1.50	Yes		

3. Measurement position locations

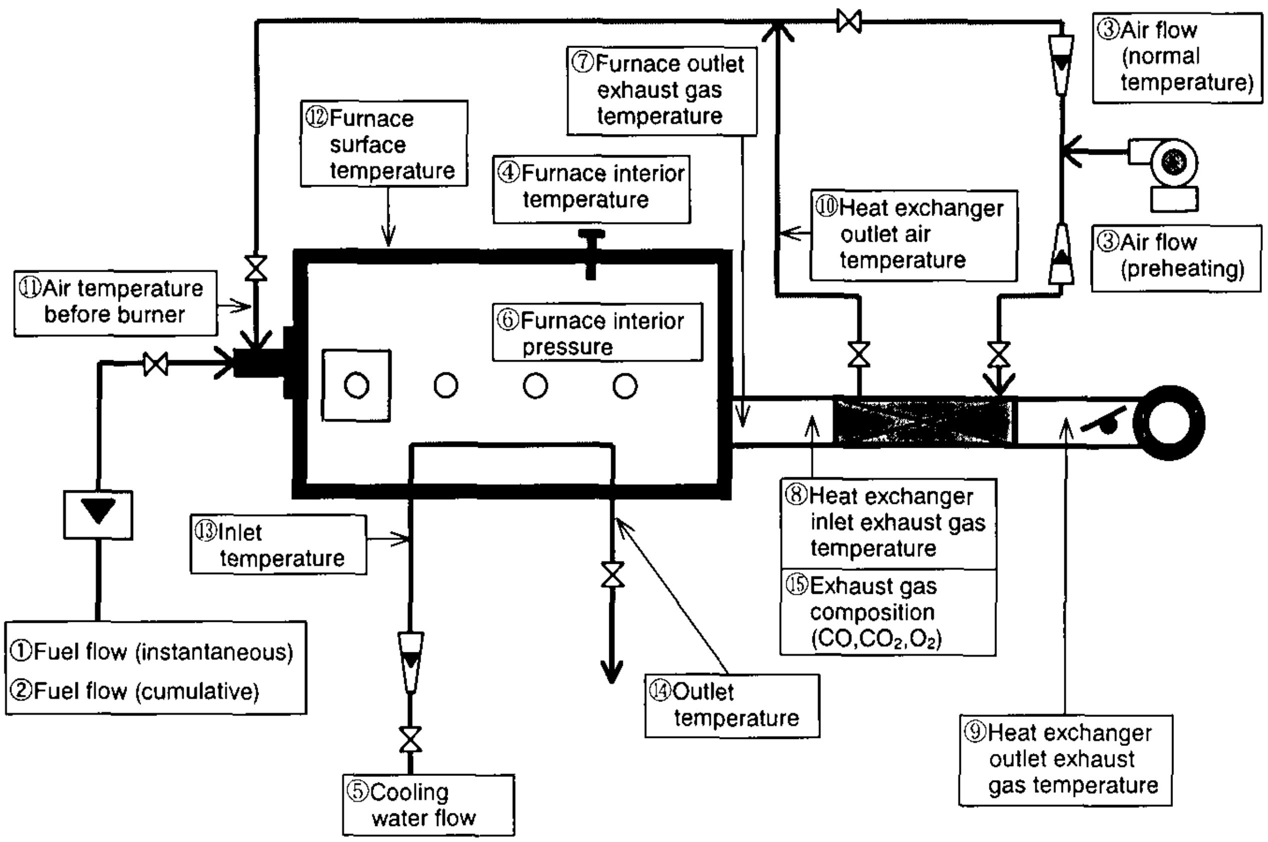
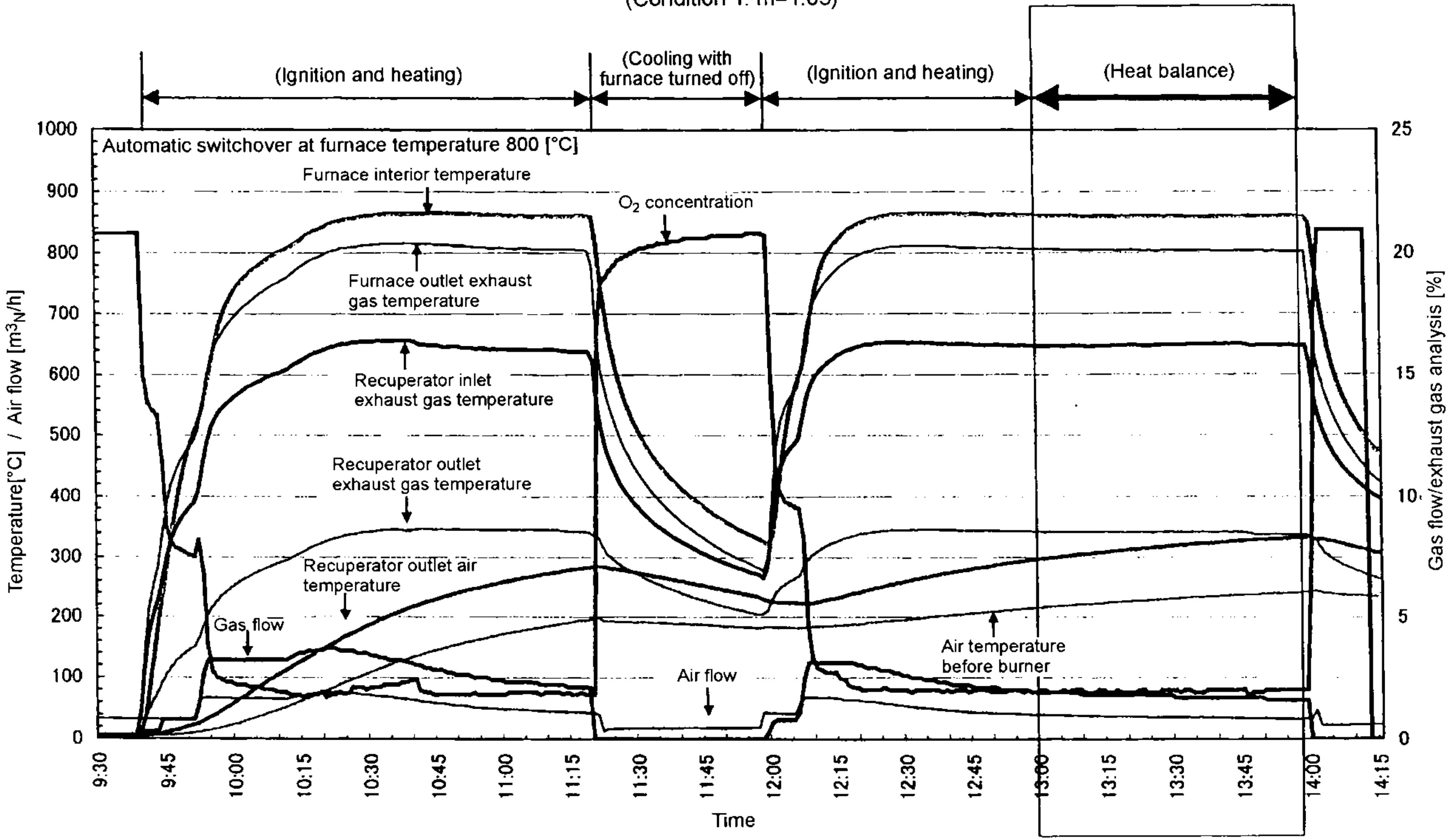


Figure 3-5 Measurement Position Location Diagram

Furnace temperature fluctuation pattern
(Condition 1: m=1.05)



4. Heat balance measurement items

Table 3-2 shows heat balance measurement and recording items. Measurement should be undertaken at regular intervals, with the length of interval determined according to the fluctuation of readings. Generally speaking, a 30-minute interval would be sufficient where fluctuations are small, while a 10-minute interval would be necessary where fluctuations are large.

Table 3-2 Measurement Items and Recording Frequency

Item	Frequency	Item	Frequency	Item	Frequency
①Fuel flow (instantaneous)	15 min.	⑦Furnace outlet exhaust gas temperature	15 min.	⑬Cooling water inlet temperature	15 min.
②Fuel flow (cumulative)	30 min.	⑧Heat exchanger inlet exhaust gas temperature	15 min.	⑭Cooling water outlet temperature	15 min.
③Air flow	15 min.	⑨Heat exchanger outlet exhaust gas temperature	15 min.	⑮Exhaust gas composition	15 min.
④Furnace interior temperature	15 min.	⑩Heat exchanger outlet air temperature	15 min.	⑯Dry bulb temperature	15 min.
⑤Cooling water flow	15 min.	⑪Air temperature before burner	15 min.		
⑥Furnace interior pressure	15 min.	⑫Furnace surface temperature	1 time		

5. Hands-on exercise procedure

(1) Data collection (error checking) ⇨ (2) Data reduction (averaging) ⇨ (3) Data verification (final checking) ⇨ (4) Heat balance calculation

(5) Preparation of heat balance table ⇨ (6) Analysis of results (investigation into improvement measures)

6. Heat balance calculation results

(1) Date and time Y M D H M ~ H M

(2) Conditions Condition 1: m = 1.05, air preheating

Condition 2: m = 1.50, air preheating

(3) Heat balance calculation results

Table 3-3 Measurement Results

Item / Condition	Fuel consumption [m^3_N/h]	Furnace interior temperature [℃]	Furnace interior pressure [mmAq]	Exhaust gas composition [%]			Cooling water		
				CO	CO_2	O_2	Flow rate [m^3/h]	Inlet temperature [℃]	Outlet temperature [℃]
Condition-1									
Condition-2									

Heat exchanger [℃]					Furnace body temperature [℃]		Room temperature [℃]	Relative humidity [%]
Exhaust gas temperature			Air temperature					
Furnace outlet	Heat exchanger inlet	Heat exchanger outlet	Heat exchanger outlet	Before burner	Side walls	Ceiling		

Table 3-4 Heat Balance Table [MJ/t-cooling water]

Item	Heat input				Item	Heat output			
	m=1.05		M=1.50			m=1.05		m=1.50	
	Absolute	Share	Absolute	Share		Absolute	Share	Absolute	Share
Combustion heat of fuel					Heat taken away by cooling water				
Sensible heat of fuel					Sensible heat of exhaust gas				
(Sensible heat of air)					Heat dissipated from furnace				
					Other				
Total					Total				

Heat balance calculation rules
- Any waste heat recovery equipment attached to the furnace is included. The item shown with brackets in the table is regarded as circulating heat, and is therefore not included in the total heat input.
- The heat balance is calculated on the basis of outside air temperature.

Table 3-5 Thermal Efficiency [%]

Condition	Thermal efficiency	Waste heat recovery efficiency

(4) Analysis of calculation results

7. Heat balance calculation method

SI unit : 1 kcal = 4.1868 kJ
1 mmAq = 9.8067 Pa

(1) Assumptions

Table 3-6 Propane gas composition[%]

c_2h_4	c_3h_8	$i\text{-}c_4h_{10}$		Lower heating value Hl
1.0	97.4	1.6		93,683 [kJ/m^3_N]

1) Stoichiometric amount of air (A_0)

$$A_0[m^3_N/m^3_N] = \frac{1}{0.21}(3\cdot c_2h_4 + 5\cdot c_3h_8 + 6.5\cdot c_4h_{10})$$

$$= \frac{1}{0.21}\times(3\times 0.01 + 5\times 0.974 + 6.5\times 0.016) = 23.83$$

2) Stoichiometric amount of wet exhaust gas (G_0)

$$G_0[m^3_N/m^3_N] = 1 + A_0 - 0.5(-2\cdot c_3h_8 - 3\cdot c_4h_{10})$$

$$= 1 + 23.83 - 0.5(-2\times 0.974 - 3\times 0.016) = 25.82$$

3) Combustion water generation by fuel (Gwf)

$$Gwf[m^3_N/m^3_N] = 2\cdot c_2h_4 + 4\cdot c_3h_8 + 5\cdot c_4h_{10} = 2\times 0.01 + 4\times 0.974 + 3\times 0.016 = 3.96$$

4) Stoichiometric amount of dry exhaust gas (G_0')

$$G_0'[m^3_N/m^3_N] = G_0 - Gwf = 25.82 - 3.96 = 21.86$$

5) Air ratio (m)

$$m = \frac{1}{1 - 3.76\cdot\dfrac{O_2 - O_0}{N_2}}$$

m: Air ratio

h_2, co, c_xh_y, n_2, o_2: Volume share of hydrogen, carbon monoxide, hydrocarbons, oxygen and nitrogen contained in 1 m^3 of fuel (m^3_N/m^3_N-fuel)

[H_2], [CO], [CO_2], [Cx'Hy'], [O_2], [N_2]: Volume share of hydrogen, carbon monoxide, carbon dioxide, hydrocarbons, oxygen and nitrogen contained in 1 m^3 of dry exhaust gas (m^3_N/m^3_N-dry exhaust gas)

[O_0]: Stoichiometric amount of oxygen needed to have the unburnt fuel contained in 1 m^3 of dry exhaust gas undergo complete combustion (m^3_N/m^3_N-dry exhaust gas)

[O_0] = 0.5 [H_2] + 0.5 [CO]

6) Fuel consumption per ton of cooling water

$$Fv[m^3_N/t] = \frac{Fh[m^3_N]}{Wg[t]}$$

(2) Heat balance calculation (based on room temperature, unit: MJ/t-cooling water)

[Calculation of heat input]

1) Combustion heat of fuel **(Q1)**

$$Ql[kJ/t] = Fv[m^3{}_N/t] \times Hl[kJ/m^3{}_N]$$

....

2) Sensible heat of fuel **(Q2)**

A Sensible heat of dry fuel **(QFd)**

$$QFd[kJ/t] = Fv[m^3{}_N/t] \times \left(cpf[kJ/m^3K] \times Tf[K] - cpf_0 \times Ta_0[K]\right)$$

....

B Sensible heat of water vapor contained in fuel **(QFw)**

$$QFw[kJ/t] = Fw[m^3{}_N/t] \times \left(cpw[kJ/m^3K] \times Tf[K] - cpw_0[kJ/m^3K] \times Ta_0[K]\right)$$

....

C Amount of water vapor contained in fuel **(Fw)**

$$Fw[m^3{}_N/t] = Fv[m^3{}_N/t] \times Fuel\,1[m^3] \times \frac{\phi f \cdot Psf}{Pf \times 100 - \phi f \cdot Psf}[m^3/m^3.fuel]$$

....

$$Q2 = QFd + QFw$$

....

Φf	: Relative humidity of fuel	[%]
Assumed to be 100 [%] in the case of a recovered combustible gas fuel		
Psf	: Saturated vapor pressure at fuel temperature before preheating	[Pa]
Pf	: Fuel pressure before preheating	[Pa]
Fv	: Fuel consumption per ton of cooling water	$[m^3{}_N/t]$
Hl	: Lower heating value of fuel	$[kJ/m^3{}_N]$
cpf	: Average constant-pressure specific heat of fuel for fuel temperature before burner	$[kJ/m^3,K]$
cpw	: Average constant-pressure specific heat of water vapor contained in fuel for fuel temperature before burner	$[kJ/m^3,K]$
Cpf_0	: Average constant-pressure specific heat of fuel for standard temperature	$[kJ/m^3,K]$
Cpw_0	: Average constant-pressure specific heat of water vapor contained in fuel for standard temperature	$[kJ/m^3,K]$
Tf	: Fuel temperature before burner	[K]
Ta_0	: Standard temperature	[K]

3) Sensible heat of combustion air **(Q3)**

A Sensible heat of dry combustion air **(Qad)**

$$Av[m^3{}_N/t] = Fv[m^3{}_N/t] \times m \times A_0[m^3{}_N/m^3{}_N]$$

$$Qad[kJ/t] = Av[m^3{}_N/t] \times \left(cpa_2[kJ/m^3K] \times Ta_2[K] - cpa_0[kJ/m^3K] \times Ta_0[K]\right)$$

B Sensible heat of water vapor contained in combustion air **(Qaw)**

$$Qaw = Aw[m^3{}_N/t] \times \left(cpw[kJ/m^3K] \times Ta_2[K] - cpw_0[kJ/m^3K] \times Ta_0[K]\right)$$

C Amount of water vapor contained in combustion air **(Aw)**

$$Aw[m^3{}_N/t] = Av[m^3{}_N/t] \times \frac{\phi \cdot Ps}{Pm \times 100 - \phi \cdot Ps}$$

Sensible heat of combustion air **Q3 = Qad + Qaw**

<u>Total heat input = **Q1 + Q2**</u>

ϕ	: Relative humidity	[%]
Ps	: Saturated vapor pressure at atmospheric air temperature	[Pa]
Pm	: Atmospheric air pressure	[1.013×10^5Pa]
Av	: Amount of combustion air per ton of cooling water	[$m^3{}_N$/t]
Aw	: Amount of water vapor contained in combustion air per ton of cooling water	[$m^3{}_N$/t]
cpa_2	: Average constant-pressure specific heat of air before burner	[kJ/m^3,K]
cpa_0	: Average constant-pressure specific heat of air for standard temperature	[kJ/m^3,K]
Ta_2	: Temperature of air before burner	[K]
Ta_0	: Standard temperature	[K]

[Calculation of heat output]

4) Heat taken away by cooling water (Q4)

$$Q4[kJ/t] = Wt[1{,}000kg/t] \times \left(Tw_2[K] - Tw_1[K]\right) \times 4.186[kJ/kgK]$$

5) Sensible heat of exhaust gas (Q5)

$$G'[m^3{}_N/m^3{}_N] = G_0' + A_0(m-1)$$

A Sensible heat of dry exhaust gas (Qd)

$$Qd = Fv[m^3{}_N/t] \times G'[m^3{}_N/m^3{}_N] \times \{(cpg_2[kJ/m^3K] \times Tg_2[K] - cpg_0[kJ/m^3K] \times Ta_0[K])\}$$

B Sensible heat of water vapor (Qw)

$$Qw = Fv[m^3{}_N/t] \times (Gwf + Gwa) \times \{(cpw[kJ/m^3K] \times Tg_2[K] - cpw_0[kJ/m^3K] \times Ta_0[K])\}$$

$$Gwa[m^3{}_N/m^3{}_N] = 1.61 \times Z[kg/kg.dry] \times m \times A_0$$

Gwf = Combustion water generation by fuel 3.96[$m^3{}_N/m^3{}_N$]

Gwa = Amount of water vapor contained in combustion air [$m^3{}_N/m^3{}_N$]

$$Z[kg/kg.dry] = 0.622 \times \frac{\phi \cdot Ps}{Pm \times 100 - \phi \cdot Ps}$$

Sensible heat of exhaust gas **Q5 = Qd + Qw**

Pm	: Atmospheric air pressure [1.013×10^5Pa]	cpg_0	: Average constant-pressure specific heat of exhaust gas for standard temperature [kJ/m^3, K]
ϕ	: Relative humidity [%]	cpw	: Average constant-pressure specific heat of water vapor for recuperator outlet temperature [kJ/m^3, K]
Ps	: Saturated vapor pressure at dry bulb temperature [Pa]	cpw_0	: Average constant-pressure specific heat of water vapor for standard temperature [kJ/m^3,K]
Z	: Absolute humidity [kg/kg.dry]	Tao	: Standard temperature [K]
Wt	: One ton of cooling water as expressed in kg [kg/t]	Tg_2	: Combustion water generation by fuel [K]
Tw_2	: Cooling water outlet temperature [K]	Gwf	: Amount of water vapor contained in combustion air 3.96 [$m^3{}_N/m^3{}_N$]
Tw_1	: Cooling water inlet temperature [K]	Gwa	: Average constant-pressure specific heat of exhaust gas for standard temperature [$m^3{}_N/m^3{}_N$]

G´ : Actual dry exhaust gas generation by fuel [$m^3{}_N/m^3{}_N$]

cpg_2 : Average constant-pressure specific heat of exhaust gas for recuperator outlet temperature [kJ/m^3,K]

6) Heat dissipation from furnace body (Q6)

$$Q6[kJ/t] = \frac{H[h] \times As[m^2] \times (Qr[kJ/m^2h] + Qc[kJ/m^2h])}{Wh[t]}$$

A Radiation heat flux (Qr)

$$Qr[kJ/m^2h] = \varepsilon \times 20.428 \times \left\{ \left(\frac{Tw[K]}{100} \right)^4 - \left(\frac{Tao[K]}{100} \right)^4 \right\}$$

B Natural convection heat flux (Qc)

Horizontal wall surface facing upwards $Qc[kJ/m^2h] = 11.721 \times \Delta T^{1.25}[K]$

Vertical wall surface $Qc[kJ/m^2h] = 9.209 \times \Delta T^{1.25}[K]$

Horizontal wall facing downwards $Qc[kJ/m^2h] = 6.279 \times \Delta T^{1.25}[K]$

Flue $Qc[kJ/m^2h] = 8.791 \times \left(\frac{\Delta T}{D} \right)^{1.25}$

G. Other heat loss (Q7)

Other heat loss Q7 = Total heat input Q1 − (Q4 + Q5 + Q6)

Total heat output = Q4 + Q5 + Q6 + Q7

③ Efficiency

A. $\eta h[\%] = \frac{Q4}{Q1} \times 100$

B. $\eta c[\%] = \frac{Q3}{Qgin} \times 100$

Q4	:Amount of heat taken away by cooling water	[kJ/t]
Q1	:Combustion heat of fuel	[kJ/t]
Q3	:Sensible heat of air before burner	[kJ/t]
Qgin	:Sensible heat of exhaust gas at recuperator inlet	[kJ/t]
ε	:Emissivity of furnace body surface	(0.4)
Tw	:Temperature of exterior wall	[K]
Ta_0	:Standard temperature	[K]

ΔT : Tw - Ta [K]

D	Diameter of flue pipe	: 0.45 [m]
Surface area of side walls		: 12.74 [m^2]
Surface area of ceiling		: 3.47 [m^2]
Surface area of flue (including heat exchanger)		: 10.2 [m^2]

As	:Surface area of side walls	[m^2]
H	:Duration of heat balance measurement	[h]
Wh	:Amount of cooling water	[t]
ηh	:Thermal efficiency	[%]
ηe	:Waste heat recovery efficiency	[%]

4.4 Exhaust Gas Measurement and Analysis Training

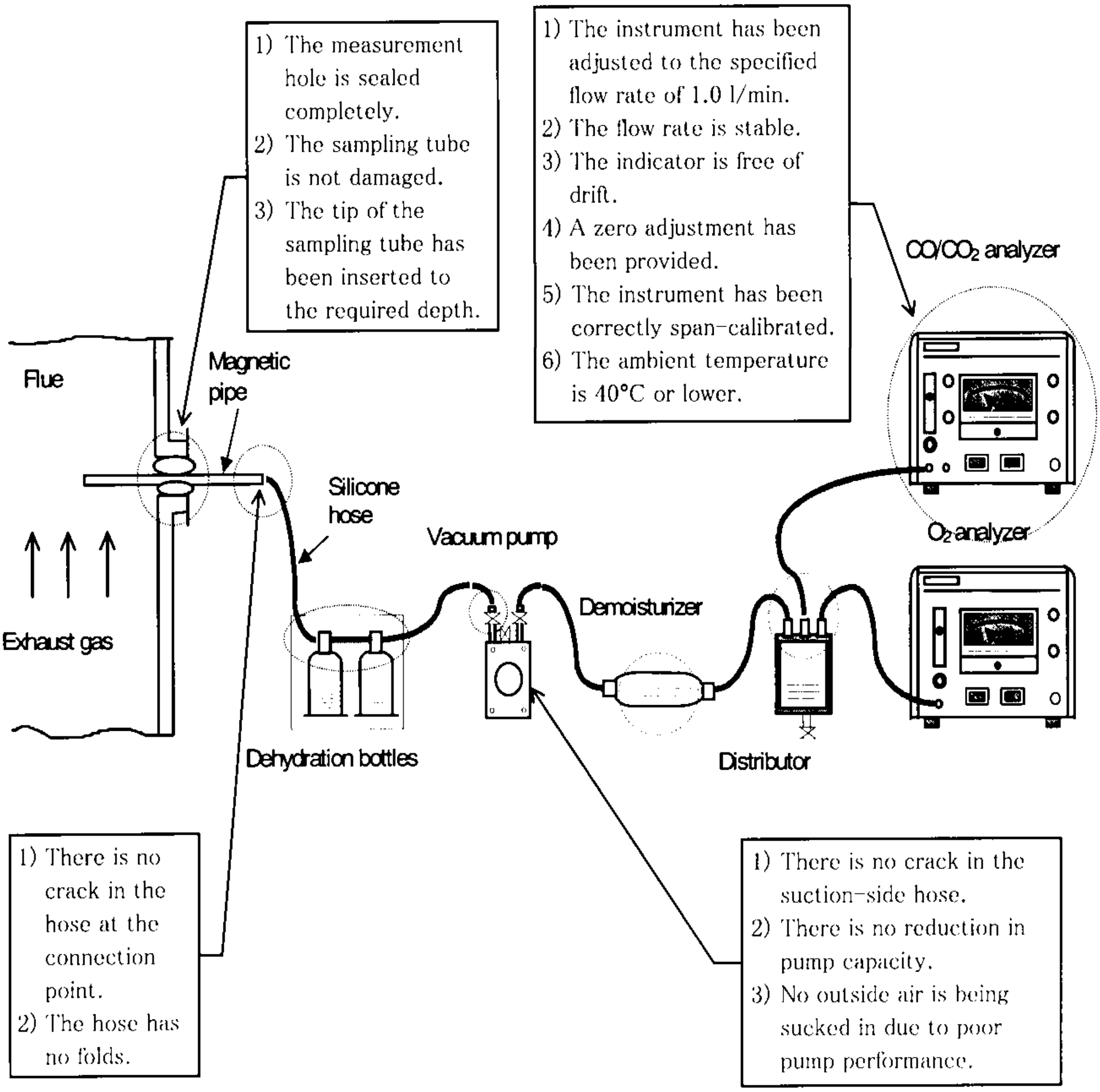
I. Hands-on Exercises

1. Combustion gas measurement using exhaust gas analyzers
   (1) Connection of CO/CO_2 and O_2 analyzers and handling method
   (2) Data collection method and measurement considerations

2. Calibration of exhaust gas analyzers
   (1) Zero adjustment of analyzers and calibration using standard gases ($CO/CO_2/O_2$)

II. Exhaust Gas Analysis

1. Connection of analyzers and considerations



2. Analyzer calibration method

(1) CO/CO_2 analyzer

Span calibration record

Standard gas	Standard gas concentration [%],[ppm]	Residual pressure of cylinder [MPa]	Zero point prior to calibration [%],[ppm]	Span calibration result		
				①Before [%],[ppm]	②After [%],[ppm]	Difference ①-②
CO[1]						
CO[2]						
CO_2[1]						
CO_2[2]						

(2) O_2 analyzer

Span calibration record

Standard gas	Standard gas concentration [%], [ppm]	Residual pressure of cylinder [MPa]	Zero point prior to calibration [%], [ppm]	Span calibration result		
				①Before [%], [ppm]	②After [%], [ppm]	Difference ①-②
O_2[1]						
O_2[2]						

Heat balance exercise data sheet [1]

Condition 1: m = 1.05 (air preheated)

Time	Fuel flow [m^3_N/h]		Air flow [m^3_N/h]		Furnace interior temperature [°C]	Furnace interior pressure [mmAq]	Cooling water flow [m^3/h]	Cooling water temperature [°C]		Exhaust gas composition			Air temperature before burner [°C]
	Instantaneous	Integrated	Normal temperature section	Preheated section				Inlet	Outlet	CO	CO_2	O_2	
13:00	2.92	0	–	73	851	0.8	2.8	10	23	0	11.7	0.8	247
13:15	2.89		–	72	849	1.0	2.8	10	24	0	11.7	0.8	249
13:30	2.86		–	71	849	0.8	2.8	10	23	0	11.6	1.0	253
13:45	3.20		–	79	858	0.8	2.8	11	23	0	11.2	1.1	254
14:00	2.86	2930	–	72	853	1.0	2.8	10	23	0	11.7	0.8	259
Average	2.95	2.93	–	73	852	0.9	2.8	10	23	0	11.6	0.9	252

Time	Heat exchanger [°C]				Furnace body temperature [°C]			Room temperature [°C]	Relative humidity [%]		Remarks
	Exhaust gas temperature at inlet	Exhaust gas temperature at outlet	Air temperature at inlet	Air temperature at outlet	Side walls	Ceiling	Flue				
13:00	659	338	20	339				20	18		
13:15	661	338	21	343				21	22		
13:30	662	338	21	347				21	19		
13:45	671	343	22	349				22	18		
14:00	668	340	22	354				22	17		
Average	664	339	22	346	48	39	65	21	19		

Heat balance exercise data sheet [2]

Condition 2: m = 1.50 (air preheated)

Time	Fuel flow [m^3_N/h]		Air flow [m^3_N/h]		Furnace interior temperature [°C]	Furnace interior pressure [mmAq]	Cooling water flow [m^3/h]	Cooling water temperature [°C]		Exhaust gas composition			Air temperature before burner [°C]
	Instan-taneous	Integrated	Normal tem-perature section	Preheated section				Inlet	Outlet	CO	CO_2	O_2	
15:00	3.83	6320	–	136	852	0.5	2.8	11	27	0	9.6	6.5	292
15:15	3.72		–	133	851	0.6	2.8	12	27	0	9.6	6.6	294
15:30	3.72		–	132	851	0.8	2.8	11	27	0	9.6	6.5	295
15:45	3.66		–	131	850	0.5	2.8	12	27	0	9.7	6.6	296
16:00	3.66	9980	–	130	851	0.5	2.8	12	27	0	9.8	6.5	296
Average	3.72	3.75	–	132	851	0.6	2.8	12	27	0	9.7	6.5	295

Time	Heat exchanger [°C]				Furnace body temperature [°C]			Room tempera ture [°C]	Relative humid-ity [%]		Remarks
	Exhaust gas temperature at inlet	Exhaust gas temperature at outlet	Air temperature at inlet	Air temperature at outlet	Side walls	Ceiling	Flue				
15:00	741	432	21	352				21	15		
15:15	740	438	20	354				20	17		
15:30	742	440	18	356				18	17		
15:45	742	441	16	357				16	18		
16:00	742	441	17	358				17	18		
Average	741	438	18	355	58	51	66	18	17		

Average Constant-Pressure Specific Heat Values of Various Gases (kJ/m³·K)

Temperature °C	H_2	N_2	N_2 in air	O_2	CO	H_2O	H_2S	CO_2	SO_2	Air	CH_4	C_2H_2	C_2H_4	C_2H_6	C_3H_6	C_3H_8	C_4H_8 1-Butene	C_4H_8 2-Butene	C_4H_{10} n-Butane	C_4H_{10} i-Butane
0	1.277	1.302	1.298	1.306	1.302	1.427	1.532	1.620	1.776	1.298	1.549	1.884	1.913	1.804	2.662	3.059	3.700	3.718	4.123	3.998
100	1.285	1.302	1.298	1.319	1.306	1.440	1.561	1.726	1.863	1.302	1.670	2.122	2.076	2.022	3.052	3.587	4.270	4.240	4.759	4.663
200	1.293	1.306	1.302	1.340	1.310	1.457	1.595	1.808	1.942	1.306	1.771	2.344	2.206	2.189	3.395	3.978	4.751	4.701	5.208	5.207
300	1.293	1.310	1.306	1.360	1.319	1.473	1.628	1.884	2.013	1.319	1.896	2.549	2.315	2.240	3.721	4.367	5.208	5.186	5.790	5.777
400	1.298	1.323	1.319	1.381	1.331	1.494	1.666	1.951	2.068	1.331	2.022	2.742	2.399	2.332	4.019	4.768	5.618	5.538	6.275	6.276
500	1.302	1.335	1.327	1.398	1.344	1.520	1.700	2.009	2.122	1.344	2.147	2.918	2.474	2.411	4.295	5.116	5.994	5.911	6.714	6.727
600	1.306	1.344	1.340	1.419	1.360	1.545	1.741	2.064	2.168	1.366	2.269	3.073	2.545	2.495	4.579	5.479	6.304	6.287	7.156	7.106
700	1.310	1.360	1.356	1.436	1.377	1.570	1.779	2.110	2.206	1.378	2.386	3.215	2.608	2.545	4.785	5.785	6.647	6.569	7.498	7.518
800	1.314	1.377	1.369	1.453	1.390	1.595	1.817	2.156	2.240	1.386	2.495	3.370	2.667	2.604	4.998	6.007	6.932	6.848	7.856	7.801
900	1.323	1.386	1.381	1.469	1.402	1.620	1.850	2.189	2.269	1.398	2.595	3.474	2.721	2.654	5.195	6.254	7.187	7.108	8.154	8.179
1 000	1.327	1.398	1.394	1.482	1.415	1.645	1.884	2.227	2.294	1.415	2.696	3.592	2.771	2.700	5.379	6.484	7.614	7.351	8.447	8.468
1 100	1.335	1.415	1.406	1.490	1.427	1.674	1.913	2.260	2.319	1.420	2.788			2.746	5.546	6.698	7.702	7.572	8.715	8.732
1 200	1.344	1.420	1.415	1.503	1.440	1.700	1.942	2.290	2.340	1.436	2.872			2.792	5.706	6.894	8.904	7.778	8.962	8.979
1 300	1.352	1.432	1.427	1.515	1.448	1.720	1.972	2.315	2.357	1.444										
1 400	1.360	1.444	1.440	1.524	1.457	1.750	1.993	2.340	2.373	1.457										
1 500	1.365	1.453	1.448	1.532	1.469	1.771	2.018	2.365	2.386	1.465										
1 600	1.373	1.465	1.457	1.540	1.478	1.792	2.043	2.386	2.399	1.478										
1 700	1.381	1.469	1.465	1.549	1.486	1.813	2.064	2.407	2.415	1.482										
1 800	1.390	1.478	1.473	1.557	1.494	1.838	2.085	2.424	2.424	1.490										
1 900	1.398	1.482	1.482	1.566	1.499	1.854	2.101	2.440	2.432	1.499										
2 000	1.407	1.490	1.486	1.574	1.507	1.875	2.110	2.457	2.440	1.503										

Remarks: The above table lists the average constant-pressure specific heat values of various gases for the temperature interval between 0°C and each temperature shown. The values for H_2 through to C_2H_2 were taken from the data contained in E. Schmidt's 1958 publication entitled "Einfuhrung in der Technische Thermodynamik" with a measurement unit conversion from kcal/kmol·deg to kJ/m³·K, while those for C_2H_2 through to C_4H_{10} (i-butane) were taken from average constant-pressure specific heat entries in the Steelmaking Heat Calculation Data (1996), compiled by the Japan Society for the Promotion of Science and the Iron and Steel Institute of Japan, with a measurement unit conversion from kcal/m³·deg to kJ/m³·K. Molar volume values (m_n^3/kmol), on the other hand, were taken from the Science Handbook (1952).

Saturated Water and Saturated Steam Table (Parameter: Temperature)

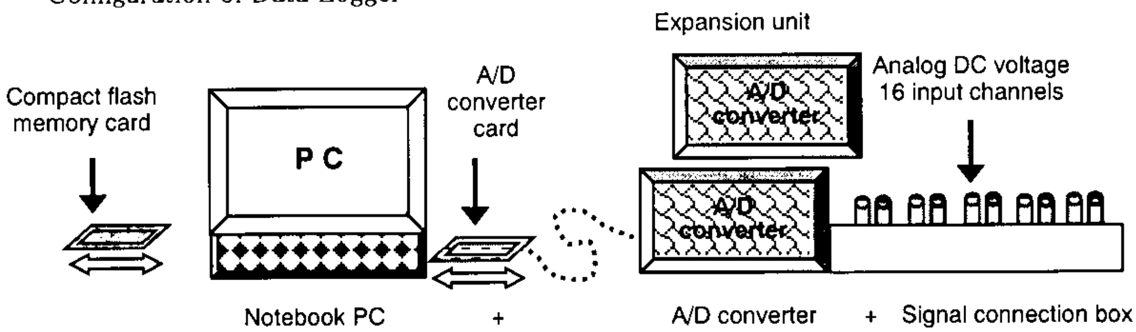
Temperature		Saturation pressure	Specific volume [m³/kg]		Specific enthalpy [kJ/kg]			Specific entropy [(kJ/(kg·K)]	
t [°C]	T [K]	Ps [MPa]	v′	v″	h′	h″	r=h″−h′	s′	s″
0.00	273.15	0.000 610 8	0.001 000 2	206.3	−0.04	2 501.6	2 501.6	−0.000 2	9.157 7
0.01	273.16	0.000 611 2	0.001 000 2	206.2	0.00	2 501.6	2 501.6	0.000 0	9.157 5
2	275.15	0.000 705 5	0.001 000 1	179.9	8.39	2 505.2	2 496.8	0.030 6	9.104 7
4	277.15	0.000 812 9	0.001 000 0	157.3	16.80	2 508.9	2 492.1	0.061 1	9.052 6
6	279.15	0.000 934 5	0.001 000 0	137.8	25.21	2 512.6	2 487.4	0.091 3	9.001 5
8	281.15	0.001 072 0	0.001 000 1	121.0	33.60	2 516.2	2 482.6	0.121 3	8.951 3
10	283.15	0.001 227 0	0.001 000 3	106.4	41.99	2 519.9	2 477.9	0.151 0	8.902 0
12	285.15	0.001 401 4	0.001 000 4	93.84	50.38	2 523.6	2 473.2	0.180 5	8.853 6
14	287.15	0.001 597 3	0.001 000 7	82.90	58.75	2 527.2	2 468.5	0.209 8	8.806 0
16	289.15	0.001 816 8	0.001 001 0	73.38	67.13	2 530.9	2 463.8	0.238 8	8.759 3
18	291.15	0.002 062	0.001 001 3	65.09	75.50	2 534.5	2 459.0	0.267 7	8.713 5
20	293.15	0.002 337	0.001 001 7	57.84	83.86	2 538.2	2 454.3	0.296 3	8.668 4
22	295.15	0.002 642	0.001 002 2	51.49	92.23	2 541.8	2 449.6	0.324 7	8.624 1
24	297.15	0.002 982	0.001 002 6	45.93	100.59	2 545.5	2 444.9	0.353 0	8.580 6
26	299.15	0.003 360	0.001 003 2	41.03	108.95	2 549.1	2 440.2	0.381 0	8.537 9
28	301.15	0.003 778	0.001 003 7	36.73	117.31	2 552.7	2 435.4	0.408 8	8.495 9
30	303.15	0.004 241	0.001 004 3	32.93	125.66	2 556.4	2 430.7	0.436 5	8.454 6
32	305.15	0.004 753	0.001 004 9	29.57	134.02	2 560.0	2 425.9	0.464 0	8.414 0
34	307.15	0.005 318	0.001 005 6	26.60	142.38	2 563.6	2 421.2	0.491 3	8.374 0
36	309.15	0.005 940	0.001 006 3	23.97	150.74	2 567.2	2 416.4	0.518 4	8.334 8
38	311.15	0.006 624	0.001 007 0	21.63	159.09	2 570.8	2 411.7	0.545 3	8.296 2
40	313.15	0.007 375	0.001 007 8	19.55	167.45	2 574.4	2 406.9	0.572 1	8.258 3
42	315.15	0.008 198	0.001 008 6	17.69	175.81	2 577.9	2 402.1	0.598 7	8.220 9
44	317.15	0.009 100	0.001 009 4	16.04	184.17	2 581.5	2 397.3	0.625 2	8.184 2
46	319.15	0.010 086	0.001 010 3	14.56	192.53	2 585.1	2 392.5	0.651 4	8.148 1
48	321.15	0.011 162	0.001 011 2	13.23	200.89	2 588.6	2 387.7	0.677 6	8.112 5
50	323.15	0.012 335	0.001 012 1	12.05	209.26	2 592.2	2 382.9	0.703 5	8.077 6
55	328.15	0.015 741	0.001 014 5	9.579	230.17	2 601.0	2 370.8	0.767 7	7.992 6
60	333.15	0.019 920	0.001 017 1	7.679	251.09	2 609.7	2 358.6	0.831 0	7.910 8
65	338.15	0.025 01	0.001 019 9	6.202	272.02	2 618.4	2 346.3	0.893 3	7.832 2
70	343.15	0.031 16	0.001 022 8	5.046	292.97	2 626.9	2 334.0	0.954 8	7.756 5
75	348.15	0.038 55	0.001 025 9	4.134	313.94	2 635.4	2 321.5	1.015 4	7.683 5
80	353.15	0.047 36	0.001 029 2	3.409	334.92	2 643.8	2 308.8	1.075 3	7.613 2
85	358.15	0.057 80	0.001 032 6	2.829	355.92	2 652.0	2 296.5	1.134 3	7.545 4
90	363.15	0.070 11	0.001 036 1	2.361	376.94	2 660.1	2 283.2	1.192 5	7.479 9
95	368.15	0.084 53	0.001 039 9	1.982	397.99	2 668.1	2 270.2	1.250 1	7.416 6
100	373.15	0.101 33	0.001 043 7	1.673	419.06	2 676.0	2 256.9	1.306 9	7.355 4
110	383.15	0.143 27	0.001 051 9	1.210	461.32	2 691.3	2 230.0	1.418 5	7.238 8
120	393.15	0.198 54	0.001 060 6	0.891 5	503.72	2 706.0	2 202.2	1.527 6	7.129 3
130	403.15	0.270 13	0.001 070 0	0.668 1	546.31	2 719.9	2 173.6	1.634 4	7.025 1
140	413.15	0.361 4	0.001 080 1	0.508 5	589.10	2 733.1	2 144.0	1.739 0	6.928 4
150	423.15	0.476 0	0.001 090 8	0.392 4	632.15	2 745.4	2 113.2	1.841 6	6.835 8
160	433.15	0.618 1	0.001 102 2	0.306 8	675.47	2 756.7	2 081.3	1.942 5	6.747 5
170	443.15	0.792 0	0.001 114 5	0.242 6	719.12	2 767.1	2 047.9	2.041 6	6.663 0
180	453.15	1.002 7	0.001 127 5	0.193 8	763.12	2 776.3	2 013.1	2.139 3	6.581 9
190	463.15	1.255 1	0.001 141 5	0.156 3	807.52	2 784.3	1 976.7	2.235 6	6.503 6
200	473.15	1.554 9	0.001 156 5	0.127 2	852.37	2 790.9	1 938.6	2.330 7	6.427 8
210	483.15	1.907 7	0.001 172 6	0.104 2	897.74	2 796.2	1 898.5	2.424 7	6.353 9
220	493.15	2.319 8	0.001 190 0	0.086 04	943.67	2 799.9	1 856.2	2.517 8	6.281 7
230	503.15	2.797 6	0.001 208 7	0.071 45	990.26	2 802.0	1 811.7	2.610 2	6.210 7
240	513.15	3.347 8	0.001 229 1	0.059 65	1 037.6	2 802.2	1 764.6	2.702 0	6.140 6
250	523.15	3.977 6	0.001 251 3	0.050 04	1 085.8	2 800.4	1 714.6	2.793 5	6.070 8
260	533.15	4.694 3	0.001 275 6	0.042 13	1 134.9	2 796.4	1 661.5	2.884 8	6.001 0
270	543.15	5.505 8	0.001 302 5	0.035 59	1 185.2	2 789.9	1 604.6	2.976 3	5.930 4
280	553.15	6.420 2	0.001 332 4	0.030 13	1 236.8	2 780.4	1 543.6	3.068 3	5.858 6
290	563.15	7.446 1	0.001 365 9	0.025 54	1 290.0	2 767.6	1 477.6	3.161 1	5.784 8
300	573.15	8.592 7	0.001 404 1	0.021 65	1 345.0	2 751.0	1 406.0	3.255 2	5.708 1
310	583.15	9.870 0	0.001 448 0	0.018 33	1 402.4	2 730.0	1 327.6	3.351 2	5.627 8
320	593.15	11.289	0.001 499 5	0.015 48	1 462.6	2 703.7	1 241.1	3.450 0	5.542 3
330	603.15	12.863	0.001 561 5	0.012 99	1 526.5	2 670.2	1 143.6	3.552 8	5.449 0
340	613.15	14.605	0.001 638 7	0.010 78	1 595.5	2 626.2	1 030.7	3.661 6	5.342 7
350	623.15	16.535	0.001 741 1	0.008 799	1 671.9	2 567.7	895.7	3.780 0	5.217 7
360	633.15	18.675	0.001 895 9	0.006 940	1 764.2	2 485.4	721.3	3.921 0	5.060 0
370	643.15	21.054	0.002 213 6	0.004 973	1 890.2	2 342.8	452.5	4.110 8	4.814 4
374.15	647.30	22.120	0.00317		2 107.4		0.0	4.429	

4.5 Data Processing and Manipulation

I. Data Processing and Manipulation Exercises

1. Connection between data logger and various measuring instruments
2. Data collection setting, collection and saving
3. Digitization of data and graphic representation

II. Configuration of Data Logger



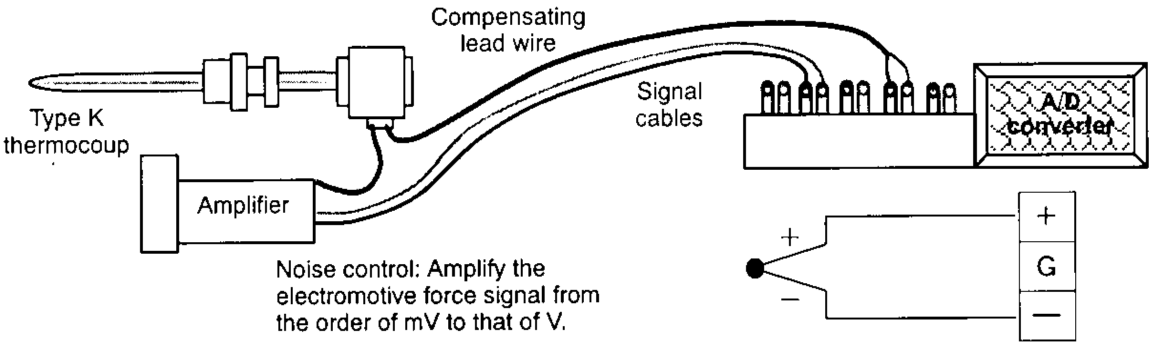
III. Connection and Setting of Various Measuring Instruments

1. Specification of data collection system

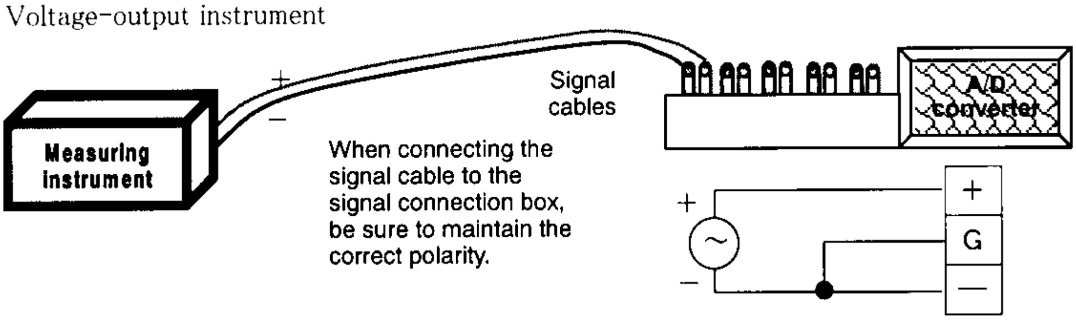
Model			NR-250		NR-255 (Expansion unit)	
Function			Analog voltage → Digital voltage			
A/D conversion method			Successive approximation			
Interface standard			PCMCIA2.1／JEIDA4.2 TYPE－II			
Signal input	Number of input channels		16CH		16CH (Up to three expansion units accepted)	
	Analog input voltage		Range: ±10V, ±5V, ±2.5V, ±1V, ±0.5V, ±0.25V			
	Thermo-couple input	Type	K	J	E	T
		Measuring range	-200～1200℃	-200～800℃	-200～600℃	-200～400℃
	Maximum input voltage		±30V			
Measure-ment accuracy	Analog input		±0.1% of F.S. (±0.2% of FS for ±0.25 V range			
	Thermocouple input		±0.1% of rdg±1℃(Reference junction compensation ±0.5℃) ※			
A/D conversion	Resolution		14Bit			
	Conversion accuracy		±1LSB			
	Sampling rate		0.1 sec (sampling cycle)			
Triggering mode			Software or external			

2. Connection of measuring instruments

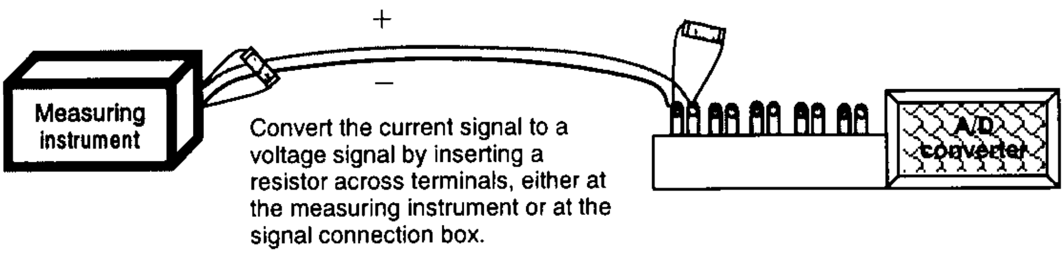
(1) Thermocouple (electromotive force signal)



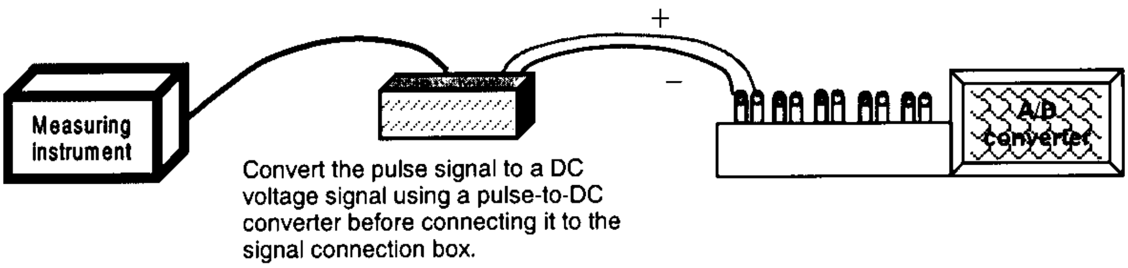
(2) Voltage-output instrument



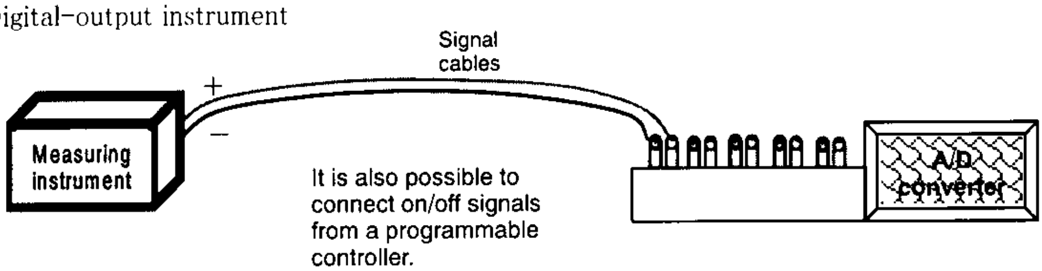
(3) Current-output instrument



(4) Pulse-output instrument



(5) Digital-output instrument



* Refer to III. 4. (data logger) of 4.1 "Gas Measurement Training" and 4.2 "Liquid Measurement Training".

IV. Data Collection Setting, Collection and Saving

1. Data collection setting

* Refer to item (6) of III. 4. (data logger) of 4.1 "Gas Measurement Training" and 4.2 "Liquid Measurement Training".

(1) Setting input ranges

Input ranges: Select input ranges from the following list:

① Analog voltage input range → ±10V, ±5V, ±2.5, ±1V, ±0.5, ±0.25V

② Thermocouple input range → Type K, J, E and T thermocouples

③ Digital voltage input range → ±10V

○ Setting (S) → Input range (R) → (○ Press key F1)

When observing a digital voltage signal, use ±10 V range. Any input outside this range will be truncated to around 10 V.

The following input ranges are available for thermocouples:

Type K thermocouple → −200～1200℃ Type E thermocouple → −200～600℃

Type J thermocouple → −200～800℃ Type T thermocouple → −200～400℃

(2) Setting sampling rate

Choose a sampling cycle using the following as a guide:

←FAST SLOW→

100ms→200ms→500ms→1s→5s→10s→20s→50s→1min→2min→5min→10 min→20min→1h→2 h→5 h→10h→20h

* In this regard, ms, s, min and h denote milliseconds, seconds, minutes and hours, respectively.

* When collecting data over a long period, a slow sampling rate (long sampling cycle) may be chosen to save storage space.

○ Click on the sampling cycle setting box. (○ Setting (S) → Input range (R))

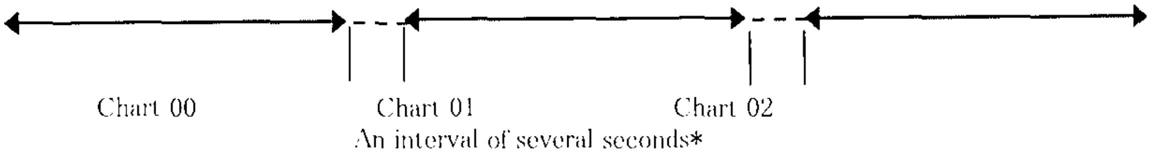
(3) Setting start and finish triggers

If necessary, set measurement start and finish triggers.

○ Setting (S) → Start/finish trigger (T) (○ Press key F2)

(4) Auto-save function

This is a function which enables continuous measurement regardless of the memory capacity of NR-250 by automatically saving data in a file each time the measurement duration reaches the limit (see below).



* Varies with the processing speed of the PC being used.

Each set of data saved via the auto-save function is assigned a file name whose last two characters are digits that serve as a counter.

The measurement duration after which auto-save is evoked is determined in the following manner:

- Where the number of channels in use is less than 16:

  Measurement duration = Sampling cycle × 262144 / (Number of channels in use + 1)

- Where the number of channels in use is 16 or more:

  Measurement duration = Sampling cycle × 262144 / 17

Example: In the case of a sampling cycle of 1 sec:

Only one channel in use → Approx. 36.4 hours

16 or more channels in use → Approx. 4.3 hours

2. Data collection

(1) Starting and finishing measurement

① Start measurement using the settings specified via the above procedure.

○ Click on the measurement start/finish button. (○ File (F) → Start measurement (B))

② Finish measurement.

○ Click on the measurement start/finish button. (○ File (F) →Finish measurement (E))

③ New (producing a new chart)

○ Click on "New". (○ File (F) → New (N))

(2) Observation of signal trace

① Changing chart speed reference

Change the time length assigned to one division (div) of the scale (mesh).

○ Click on the chart speed reference setting button. (○ File (F) → Speed reference (S))

Chart time scale: Choose an appropriate time scale from the following list:

- s/div → 1 div = 1 sec
- min/div → 1 div = 1 min
- h/div → 1 div = 1 hour
- day/div → 1 div = 1 day

(2) Changing analog display settings

Change the display settings for each channel.

○ Setting (S) → Analog display (A)

Change over between the basic and miscellaneous setting dialog boxes using selection tabs.

〈 Basic setting dialog box 〉

- Range: Set the input range.
  The setting cannot be changed during or after measurement.
- Graphic display/color: Enable/disable graphic display and choose color.
- CH/Tag: Set the details of a tag caption to be displayed underneath the trace.
  - CH/Tag → In CH mode, the channel name is displayed.
    In Tag mode, characters specified as a Tag name are displayed.
  - Tag name → Up to ten half-size characters can be entered for display in Tag mode.
  - Width → The width of the display is set in terms of the number of divs.
- Recording range: Specify a recording range within the input range.
  A narrow recording range allows the trace to be enlarged.
- Display location: Specify a display location within the signal display area.
- Number of zones: This function offers a simple way of displaying more than one channel in tiers by vertically dividing the display area. Specify the number of zones and click on desired display locations.

〈 Miscellaneous setting dialog box 〉

- Scale labeling: Change the scale labeling setting for each channel.
  Labeling → Choose an option from the following list:
  - No labeling
  - 0%, 100 %
  - 0%, 50%, 100%
  - 0%, 25%, 50%, 75%, 100%,
  - 0%, 20%, 40%, 60%, 80%, 100%
- Scaling: Scale the input voltage/temperature signals.
  Scale → Tick it to carry out scaling.
  Unit → Enter the desired unit of measurement to be displayed.

  Note that changing the scale setting will change the vertical cursor size and the values displayed in the digital display window. This is a convenient function for displaying a sensor output or similar voltage signal in actual magnitude.
- Interpolation: Connects sampled data points together by straight line.
- Moving average: Evens out the trace to reduce the effects of noise, etc.
  Use moving average → Tick it to use the moving average method.
  Number of samples → Enter a number between 1 and 99.

③ Changing magnification factor

Choose a magnification factor from the following list:

Smaller ← → Larger

100%→150%→200%→300%→500%→1000%

To keep the size of characters constant regardless of the magnification factor, choose "Always the same" during font setting.

④ Horizontal cursors

Read values off a chart using a horizontal cursor. The use of two cursors, A and B, enables the measurement of the difference between two values (A-B).

· Click on the color of the channel whose values are desired. (The line around the box for the selected channel color becomes thicker.)

○ Click on horizontal cursor A or B, and then click on the desired point in the signal display area.

· Use selection tabs (H) to change over.

⑤ Vertical cursors

Read values off a chart using a vertical cursor. The use of two cursors, A and B, enables the display of the times and values of the signal chosen at the cursor locations and the time difference between the cursors, as well as the signal fluctuation frequency, maximum, minimum and average in that time span.

· Click on the color of the channel whose values are desired. (The line around the box for the selected channel color becomes thicker.)

○ Click on a vertical cursor, A or B, and then click on the desired point in the signal display area.

· Use selection tabs (V) to change over.

⑥ Rectangular cursor

Select the desired portion (rectangular shaped) of the signal display area to print or copy-and-past it onto another application.

○ Click on the rectangular cursor.

· Click on the desired location on the signal display area and with the left button pressed down drag the mouse diagonally to mark off a rectangular area.

⑦ Split-window display

Splits a chart window into two. This is a convenient feature when comparing two sections of a trace.

·To split a window, drag the split box provided at its bottom-right corner.

It is not possible to assign separate magnification factors to the two halves of a split window.

⑧ Storing display setting combinations

Complete combinations of display settings, including the magnification factor and analog display settings, can be stored via buttons. Up to four buttons, A to D, are available. You can switch from one display setting combination to another by simply clicking on the desired button.

Storing a display setting combination will erase the previously-stored combination under the same button.

⑨ Viewing display setting combinations

Display setting combinations stored under the previous section can be viewed.

⑩ Newly creating mark

A mark can be placed at any point on a trace on the chart.

· Click on the color of the channel whose values are desired. (The line around the box for the selected channel color becomes thicker.)

○ Mark (M) → New (A) → Click on the mark setting button.

· A cross cursor will appear. Drag it to the point where you want a mark.

Up to 20 half-size characters can be entered to provide an explanatory text.

The text will appear on the currently selected channel. To place a mark on a different channel, click on the appropriate box in the channel color/legend display section, and repeat the above process.

⑪ Modifying/deleting mark

You can delete a mark or modify its explanatory text.

○ Mark (M) → Modify/delete (D)

· Modifying text: Select the appropriate mark on the screen, and click on the modify button.

· Deleting mark: Select the appropriate mark on the screen, and click on the delete button.

⑫ Jumping to marked point

You can jump to a point where a mark has been placed.

○ Mark (M) → Jump (J)

· Select the mark to which you want to jump on the screen, and click on the jump button.

· When split window display is used, jumping occurs in the left-hand side window.

⑬ Search

You can jump to a point by specifying conditions. As you jump, the vertical cursor A will move to the point.

○ Edit (E) → Find (F)

< Setting details >

· Search conditions: Choose appropriate search conditions from the following list:

Date and time → Jump to the specified date and time.

Leading edge → Jump to a point where the trace crosses over the specified threshold value from below.

Trailing edge → Jump to a point where the trace crosses over the specified threshold value from above.

Maximum → Jump to the global maximum point of the specified trace.

Minimum → Jump to the global minimum point of the specified trace.

Local maximum → Jump to the next local maximum point of the specified trace.

Local minimum → Jump to the next local minimum point of the specified trace.

· Search direction: Select search direction.

Forward search → Search in the forward direction from the current display position.

Backward search → Search in the backward direction from the current display position.

· Designation of channel: Specify the channel for which search is required.

(3) Finishing data collection and saving

① Click on the measurement start/finish bottom

This terminates data collection.

② Saving chart

Save the recorded chart.

○ File (F) → Save as (A)

< Setting details >

· Filename: Specify a filename under which the collected data is to be saved. The last two characters of the filename must be digits.

· File format: Select the desired file format from the following list:

CHART → Proprietary format used by WAVE THERMO software

CSV → A file format that can be read by spreadsheet and other software. Voltage signals (in mV or V) from various measuring instruments are converted to a series of numerical values and saved. It is possible to save a chart with a reduced number of sampling points as specified through a signal trace simplification ratio.

· Saving portion: Specify the portion of the chart you want to save.

Entire chart → Save the chart from the beginning to the end.

Portion specified with vertical cursors

→ Save only the portion specified with vertical cursors. This saves storage space.

③ Retrieving chart

You can retrieve a previously-saved chart file.

○ File (F) → Open (O)

④ Saving setting information

You can save the entire current setting information in a file.

○ File (F) → Save setting information (W)

⑤ Retrieving setting information

You can retrieve previously-saved setting information

○ File (F) → Read in setting information (R)

V. Digitization of Data and Graphical Representation

1. Turn on the PC and start WAVE THERMO software.

2. Retrieve a file that has been saved in CHART format.

3. Convert data from analog to digital.

(1) Converting entire data contained in saved file

① Choose CSV file format.

② Set a signal trace simplification ratio. (If necessary)

This saves storage space.

Set a resampling cycle that is the same as or longer than the original sampling cycle.

Sampling cycle: 1 sec → Signal trace simplification ratio 1/1 → Digital data at 1 sec/div

1 sec → Signal trace simplification ratio 1/60 → Digital data at 1 min/div

③ Saving data in CSV format under new filename

CSV format → Can be read by spreadsheet and other software

Converts voltage signals (in mV or V) from various measuring instruments to a series of numerical values and saves them.

(2) Converting selected portion of data contained in saved file

① Specify the desired portion of the data under CHART format.

· By setting vertical cursors A and B, a portion of the data can be selected in terms of a time span. (This is a convenient feature in synchronizing time with charts from other data loggers.)

· This saves storage space.

② Select CSV format.

③ Set a signal trace simplification ratio. (If necessary)

④ Save data in CSV format under a new filename.

4. Manipulating numerical data

(1) Start spreadsheet software (Excel).

(2) Open a previously-saved CSV file.

(3) Input necessary conditions.

① Insert about ten lines.

② Enter the required labels, including channel numbers, quantities measured, measuring instruments, ranges and outputs, in the cells.

* Refer to III. 4. (data logger) of 4.1 "Gas Measurement Training" and 4.2 "Liquid Measurement Training".

* Refer to IV. 1. (data collection setting) of 4.5 "Data Processing and Manipulation".

③ Convert the numbers entered in cells on row A to time.

(4) Manipulate numerical data (voltage signals in mV or V)

① Copy the necessary conditions listed on a separate sheet.

② Enter a conversion formula.

= ((RangeH − RangeL) × (* CH data * − outputL) / (outputH − outputL) − Range L) × (coefficient)

③ Copy this onto all cells to the right and below as it is a common formula.

④ Provide further numerical processing, if necessary.

Maximum, minimum, average, etc.

⑤ Draw a graph

Trend (broken line graph), distribution (scatter plot), etc.

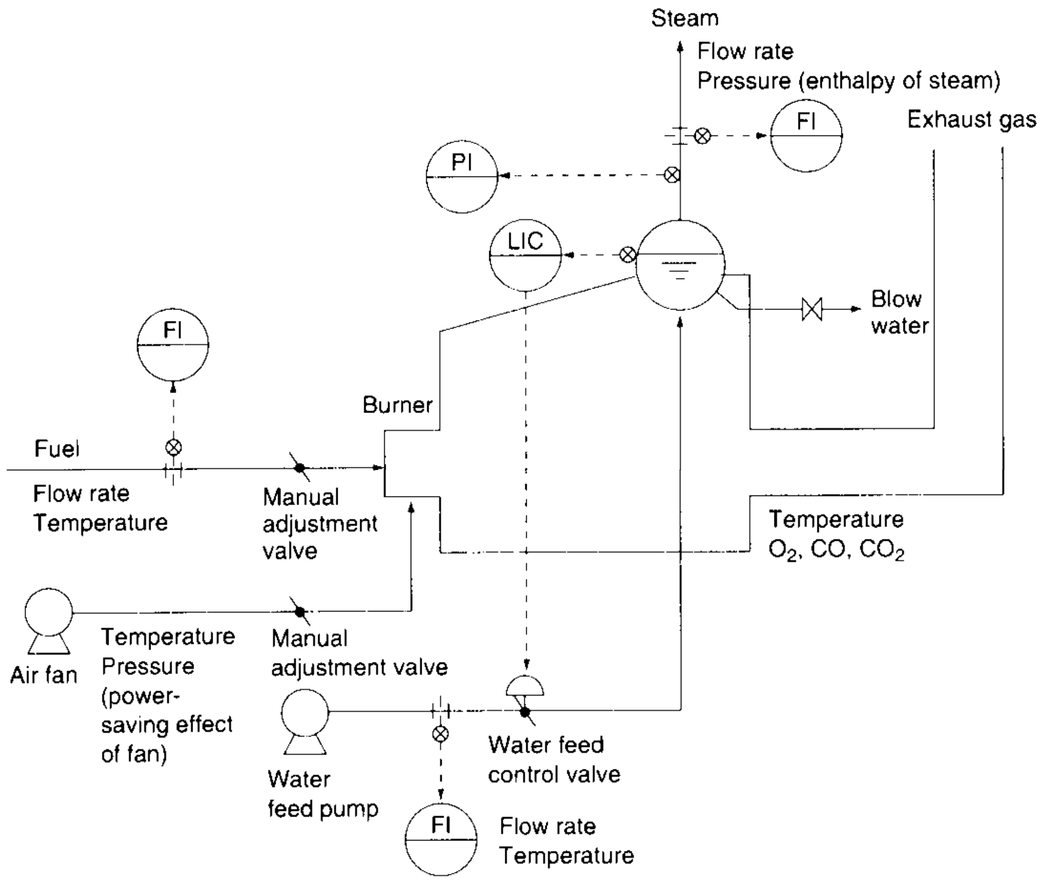
(5) Save the file in Excel format under a new filename.

5. Turn off the PC.

5. Identification of the Problems and Analysis of the Improvement Effects (Example of boiler)

5.1 Purpose

In the boiler shown in the process flow schematics of the figure below, the combustion control is carried out manual operation. The required pressure of steam being used in the factory is 8 kg/cm^2, but the boiler is being operated at pressures above 8 kg/cm^2. Energy conservation of this boiler is at issue, and it was decided to study the energy conservation measures and the improvement effects.

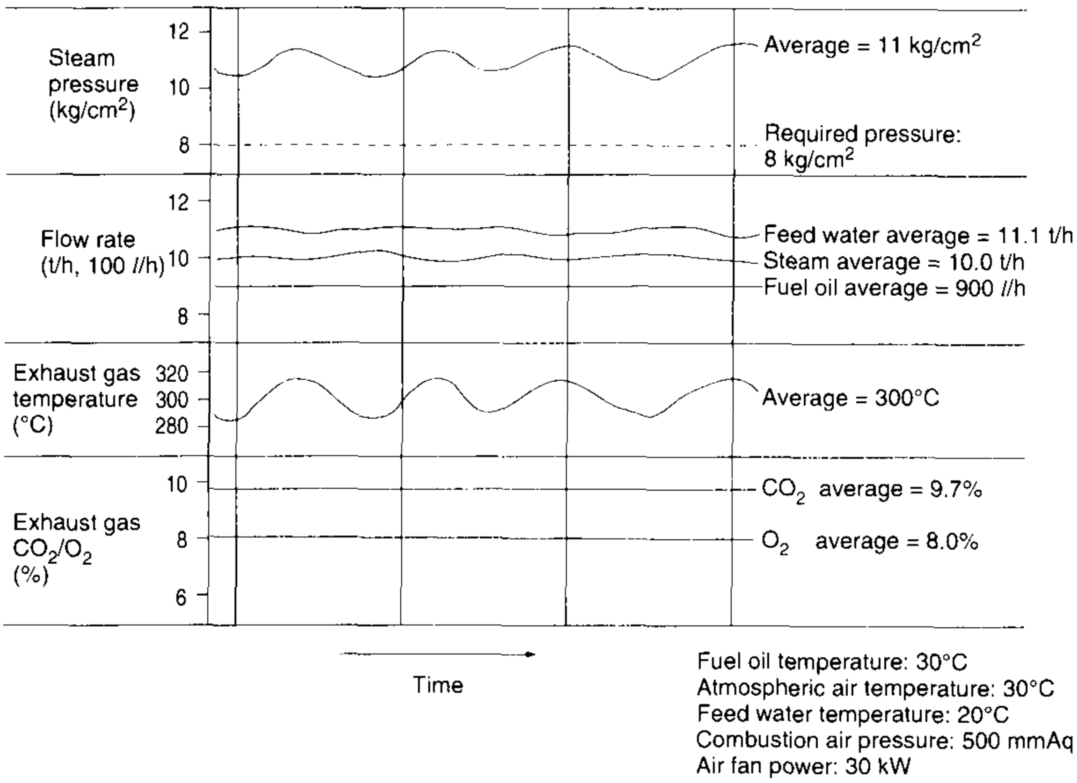


5.2 Study of the present situation of energy consumption

(1) Measurement items

- Fuel: Flow rate/temperature/calorific value/composition
- Combustion air: Temperature/pressure
- Feed water: Flow rate/temperature
- Steam: Flow rate/pressure
- Exhaust gas: Temperature/composition
- Air fan: Power

(2) Measurement results



(3) Problems related to the operation

- Since the boiler is operated under condition of constant fuel consumption rate, the average steam pressure 11 kg/cm^2, which is higher than the 8 kg/cm^2 required at the consumption side.
- O_2 concentration in the exhaust gas is as high as 8%, and that means much energy losses in the exhaust gas.

- The average exhaust gas temperature is as high as 300°C, it is possible to recover waste heat by 120°C, which is the sulfuric acid dew point.

(4) Current heat balance

- Fuel

  Combustion heat = 900 l/h × 0.870 kg/L × 10,210 kcal/kg = 7,994 Mcal/h

  Sensible heat = 900 l/h × 0.870 kg/h × 0.446 kcal/kg·°C × 30°C = 10 Mcal/h

- Feed water

  Sensible heat = 11.1 t/h × 20.0 kcal/kg = 222 Mcal/h

- Steam

  Sensible heat = 10.0 t/h × 664.8 kcal/kg = 6,648 Mcal/h

- Blowed off water

  Sensible heat = 1.1 t/h × 189.7 kcal/kg = 209 Mcal/h

- Exhaust gas

  Air ratio: $m = 1 + \dfrac{G\ CO_2\ (O_2 - 0.5\ CO)}{0.21 \times Ao \times (CO_2 + CO)} = 1.576$

  Wet base exhaust gas flow rate

  $= 900\ l/h \times 0.870\ kg/l \{11.55 + (1.576 - 1) \times 10.9\} Nm^3/kg = 13{,}960\ Nm^3/h$

  Sensible heat of exhaust gas

  $= 13{,}960\ Nm^3/h \times 0.330\ kcal/Nm^3 \cdot °C \times 300°C = 1{,}382\ Mcal/h$

- Combustion air

  Air volume = 900 h/h × 0.870 kg/l × 10.9 Nm^3/sec × 1.576 = 134,51 Nm^3/h

  Sensible heat of air = 13.451 Nm^3/h × 0.310 kcal/Nm^3 × 30°C = 125 Mcal/h

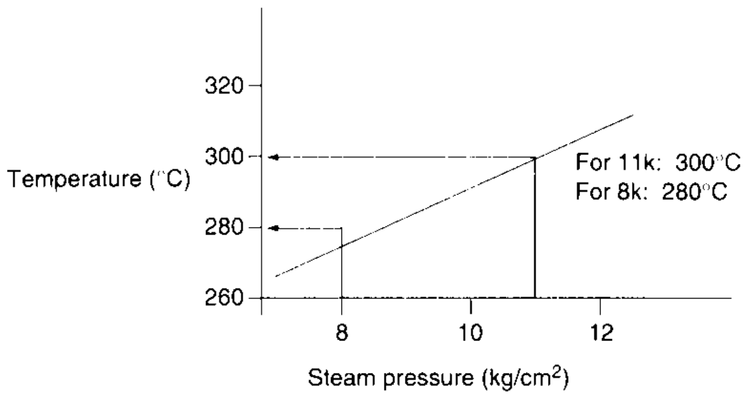
Table 5.1 Heat Balance Table

	Item	Measurement data	Mcal/t	%
Input heat	Combustion heat of fuel	900 l/h	799.4	95.7
	Sensible heat of fuel	900 l/h × 30°C	1.0	0.1
	Sensible heat of air	13,451 Nm^3/h × 30°C	12.5	1.5
	Sensible heat of feed water	11.1 t/h × 20°C	22.2	2.7
	Total		835.1	100.0
Output heat	Sensible heat of steam	10.0 t/h	664.8	79.6
	Sensible heat of blowed off water	1.1 t/h × 190°C	20.9	2.5
	Sensible heat of exhaust gas	13,960 Nm^3/h × 300°C	138.2	16.5
	Heat loss, etc.	Balance	11.2	1.4
	Total		835.1	100.0
Thermal efficiency = (664.8 – 22.2)/799.4				80.9

5.3 Analysis of the improvement effects

(1) Improvement effect attained when the steam pressure is controlled at 8 kg/cm^2

- Sensible heat of steam = 10.0 t/h × 662.2 kcal/kg / 10.0 t/h = 662.2 Mcal/t
- Sensible heat of blowed off water = 1.1 t/h × 174.5 kcal/kg / 10.0 t/h = 19.2 Mcal/t
- Sensible heat of fuel = X kg/t × 0.446 kcal/kg· °C × 30°C = 0.013X Mcal/t
- Exhaust gas temperature estimation



Sensible heat = X kg/t × 17.83 Nm^3/kg × 0.330 $kcal/Nm^3 \cdot °C$ × 280°C = 1.647 X Mcal/t

- Air

Sensible heat = X kg/t× 17.18 Nm^3/kg × 0.310 $Kcal/Nm^3 \cdot °C$ × 30°C = 0.160X Mcal/t

- Fuel

$10.210X + 0.013X + 0.160X + 19.2 = 662.2 + 20.9 + 1.647X + 11.2$

Consumption rate $X = \frac{(662.2 + 19.2 + 11.2) - 22.2}{(10.210 + 0.013 + 0.160) - 1.647} = 76.74$ kg/t

Combustion heat = 76.74 kg/t × 10.210 kcal/kg = 783.5 kcal/t

- Thermal efficiency = (662.2 – 20.0)/783.5 = 82.0%

(2) Improvement effect attained when the O_2 concentration in the exhaust gas is kept at 3% by adjusting the air ratio

- Calculation of the excess air volume:

$A \times 21 \{(G_0 - G\ H_2O) + A\} \times 3$

$A = \frac{(Go - G\ H_2O) \times 3}{(21 - 3)} = \frac{(11.55 - 1.34) \times 3}{21 - 3} = 1.70\ Nm^3/kg$

Note: m = 1 + 1.70/10.9 = 1.160

- Sensible heat of air:

X kg/t × (10.90 + 1.70) Nm^3/kg × 0.310 Kcal/Nm^3 × 30°C= 0.117 X Mcal/t

- Sensible heat of exhaust gas:

X kg/t × (11.55 + 1.70) Nm^3/kg × 0.330 Kcal/Nm^3 × 280°C= 1.224 X Mcal/t

- Fuel:

Consumption rate $X = \frac{(662.2 + 19.2 + 11.2) - 22.2}{(10.210 + 0.013 + 0.117) - 1.224} = 73.54$ kg/t

Combustion heat = 73.54 kg/t × 10.210 kcal/kg = 750.8 Mcal/t

- Thermal efficiency: (662.2 – 20.0)/750.8 = 85.5%

(3) Improvement effect attained when air heater and economizer are installed

- Exhaust gas:

Temperature: The recovery of waste heat of temperatures above the sulfuric acid dew point and down to 120°C is strengthened.

Sensible heat = X kg/t × (11.55 + 1.70) Nm^3/kg × 0.330 Kcal/Nm^3 × 120°C
= 0.525 X Mcal/t

- Fuel:

  Consumption rate $X = \dfrac{(662.2 + 19.2 + 11.2) - 22.2}{(10.210 + 0.013 + 0.117) - 0.525} = 68.30$ kg/t

  Combustion heat = 68.30 kg/t × 10.210 kcal/kg = 697.4 Mcal/t

- Thermal efficiency = (662.2 – 20.0) × 697.4 = 92.1%

(4) Power saving in the air fan

- Fan motor efficiency as things now stand:

  - Measured values:

    Power requirement: 30 kW

    Delivery pressure: 500 mm Aq

    Suction volume: $\dfrac{13.451\ \text{Nm}^3/\text{h}}{60\ \text{min}} \times \dfrac{303}{273} = 249\ \text{m}^3/\text{min}$

    (from the combustion calculation)

  - Efficiency:

$$\eta = \frac{Q \times H}{6120 \times L} \times 100 \quad \frac{249 \times 500}{6120 \times 30} \times 100 = 67.8\%$$

- kWh after combustion adjustment

  - Measured values:

    Suction volume: $\dfrac{(73.48 \times 10.9 \times 1.16)\ \text{Nm}^3/\text{h}}{60\ \text{min}} \times \dfrac{303°\text{C}}{273°\text{C}} = 172\ \text{m}^3/\text{m}$

    It is assumed that the discharge pressure A and the fan motor efficiency remain unchanged.

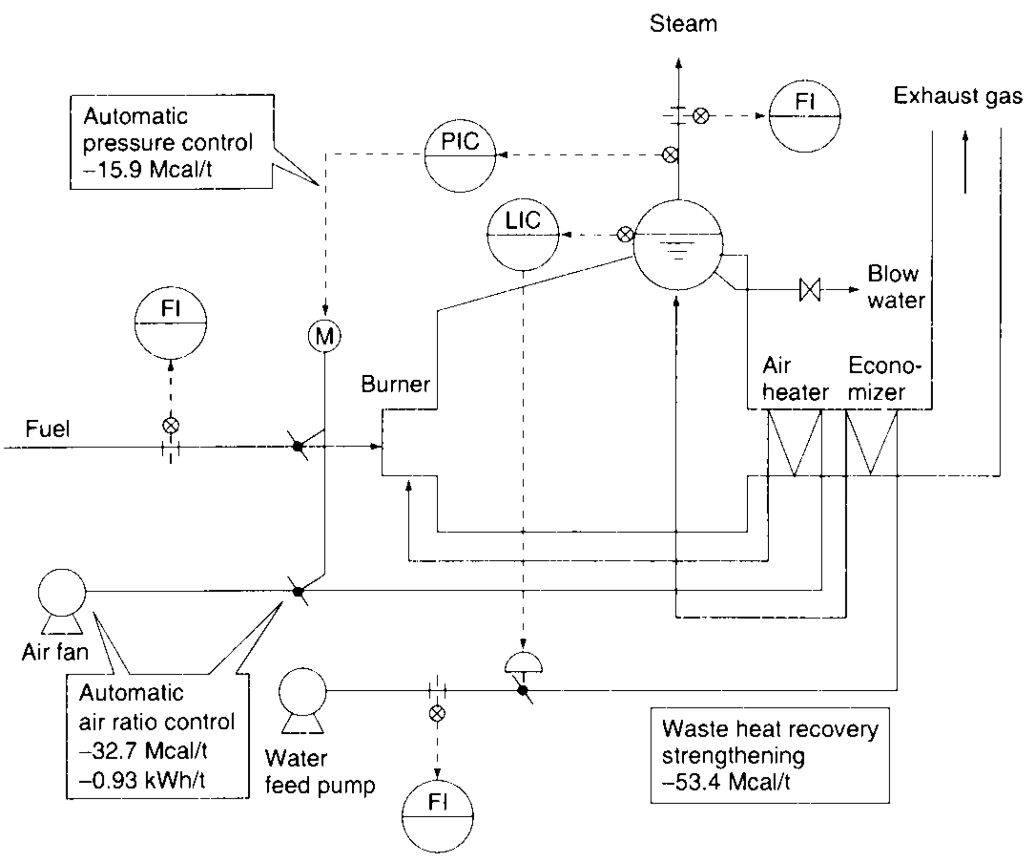
  - Power requirement: $H = \dfrac{172 \times 500}{6120 \times 0.678} = 20.7$ kW

- Power saving: 9.3 kWh

(5) Heat balance comparison

Item		Status quo Mcal/t	Status quo %	Steam pressure reduction Mcal/t	Steam pressure reduction %	Air ratio adjustment Mcal/t	Air ratio adjustment %	Waste heat recovery Mcal/t	Waste heat recovery %
Input heat	Combustion heat of fuel	799.4	95.7	783.5	95.7	750.8	95.9	697.4	95.7
	Sensible heat of fuel	1.0	0.1	1.0	0.1	1.0	0.1	0.9	0.1
	Sensible heat of air	12.5	1.5	12.3	1.5	8.6	1.1	8.0	1.1
	Sensible heat of feed water	22.2	2.7	22.2	2.7	22.2	2.8	22.2	3.7
	Total	835.1	100.0	819.0	100.0	782.6	100.0	728.5	100.0
Output heat	Sensible heat of steam	664.8	79.6	662.2	80.8	662.2	84.6	662.2	90.0
	Sensible heat of blowed off water	20.9	2.5	19.2	2.3	19.2	2.5	19.2	2.7
	Sensible heat of exhaust gas	138.2	16.5	126.4	15.5	90.0	11.5	35.9	4.9
	Dissipation heat, etc.	11.2	1.4	11.2	1.4	11.2	1.4	11.2	1.5
	Total	835.1	100.0	819.0	100.0	782.6	100.0	728.5	100.0
Thermal efficiency		80.7		82.0		85.5		92.1	

(6) Process flow chart after improvement



<Reference> Basic numerical values for analysis

(1) Characteristics of A Fuel Oil

Specific gravity:	0.870 kg/l
Lower calorific value:	Hl = 10,210 kcal/kg
Theoretical air volume:	Ao = 10.90 Nm^3/kg
Theoretical exhaust gas volume (Wet):	Go = 11.55 Nm^3/kg
Theoretical CO_2 volume:	GCO_2 = 1.60 Nm^3/kg
Theoretical H_2O volume:	GH_2O = 1.34 Nm^3/kg
Average specific heat:	0.446 kcal/kg·°C at 30°C

(2) Specific heat of gas

Air:	0.310 kcal/Nm^3·°C
Exhaust gas:	0.330 kcalNm^3·°C

(3) Steam

Steam pressure	11 kg/cm^2	8 kg/cm^2
Saturated steam enthalpy	664.8 kcal/kg	662.2 kcal/kg
Saturated water enthalpy	189.7 kcal/kg	176.5 kcal/kg
Temperature	187.1°C	174.5°C
Dryness	100 %	100 %

(4) Water feed

Enthalpy	20.0 kcal/kg at 20°C

6. Measurement in General

6.1 Analyzing method for combustion exhaust gases

Combustion exhaust gases, which are mainly composed of N_2, O_2, CO_2, and H_2O, may contain also trace constituents such as CO, SO_2, NO, NO_2, HCl and unburnt hydrogen carbonate depending on the fuel and combustion conditions. These gases may also contain particulate substances such as soot. Analyzing these components in a combustion exhaust gas is important for grasping an amount of combustion gas based on the assumed air ratio, calculating the heat loss by exhaust gas in heat balance, improving the combustion state, and so forth. Analyzers of these gases can be basically classified into chemical analyzers and physical analyzers, and classified as shown in Table 1.

A chemical CO_2 meter uses the property of CO_2 that it is very soluble in a strong alkali. Flue gas is introduced into an absorbing tank containing a strong alkali solution for absorbing CO_2, to obtain CO_2 concentration in % from a decrease in gas volume. Recently it is not commonly used in plants.

Physical analyzers utilize the differences of respective gases in density, viscosity, thermal conductivity, magnetism, reactivity, infrared absorbability, etc. Kinds of gas analyzers used for combustion control are listed in Table 1.

Table 1 Classification of gas analyzers

	Method of measurement	Name of analyzer	Measured ingredients
Chemical gas analyzer	Absorption by solution	Hempel gas analyzer Orsat gas analyzer	CO_2, O_2, CO, N_2 CO_2, O_2, CO, N_2
Physical gas analyzer	Thermal conductivity method	Electric CO_2 meter Unburnt gas meter	CO_2 $CO + H_2$
	Specific gravity method	Specific gravity type CO_2 meter	CO_2
	Absorption of ultraviolet rays	Infrared gas analyzer	CO_2, CO, CH_4, SO_2
	Electric conductivity	SO_2 automatic recorder	SO_2
	Electrochemical method	Zirconia type O_2 meter Galvanic cell type O_2 meter	O_2 O_2
	Magnetic method	Magnetic O_2 meter	O_2
	Gas chromatography	Gas chromatography	CO_2, N_2, H_2, O_2, CO, CH_4, SO_2, NO_2

6.1.1 Sampling methods for exhaust gas

When gas for analyzing gas components is sampled out of flue, the matters specific to a component to be measured should be taken into consideration with JIS K0095 "Method for Sampling of Stack Gas" as the reference.

(1) Selection of gas sampling points

Measuring ports in the flue should be provided at the positions which conform to the specification in JIS Z8808 "Method of Measuring Dust Concentration in Flue Gas" avoiding places where air leaks into the flue, where dust is deposited in the flue, or places which are subject to frequent fall of dust. Several measuring ports should be set, depending on the size and form of the flue. However, if the analytical results are little different among respective measuring points, and gas concentrations are considered to be almost the same at the cross sections of respective sampling positions as in the flue for a boiler, then any one point can be selected for sampling.

(2) Structure of a gas sampler

A sampler is generally composed of a sampling tube, conduit, cooling dehumidifier, gas-liquid separating tube, condensed water trap, dust filter, etc. The material of the sampling tube and conduit must not affect the analytical result of exhaust gas due to the chemical reaction or adsorption, etc. and must be resistant against corrosion. In case the water or gas component with high dew point in the exhaust gas should be condensed to clog the conduit, the sampling tube and conduit should be thermally insulated or heated as required.

To prevent the ingress of dust, etc. into the sample gas, the sampling tube should contain a filter as required, and furthermore, a fine filter medium should be used downstream of the gas-liquid separating tube. To avoid indication errors due to the disturbance by the deposition of condensed water or water content in the tube inside the analyzer, a cooling dehumidifier for cooling and condensing water, gas-liquid separating tube, condensed water trap, desiccant, adsorbent, etc. should be used as required.

6.1.2 Analysis of carbon dioxide

(1) Thermal conductivity method

A meter using this method is also called electric CO_2 meter and this method is widely used. It applies that the thermal conductivity of CO_2 is very small compared with that of air.

As for the mechanism, as shown in Figure 1, current is fed through the thin platinum wires stretched in the gas chamber ① and air chamber ③, to heat them about 100°C. Since the thermal conductivity of the flue gas, high in CO_2 content, which is fed into the gas chamber, is smaller than that of air, the heat loss from the heated platinum wire is smaller in the gas chamber. Therefore, the temperature of the platinum wire in the sample gas chamber is higher than that in the reference gas chamber, to increase the electric resistance, and it is measured by a Wheatstone bridge and indicated by meter ⑥ or recorded by recorder ⑦.

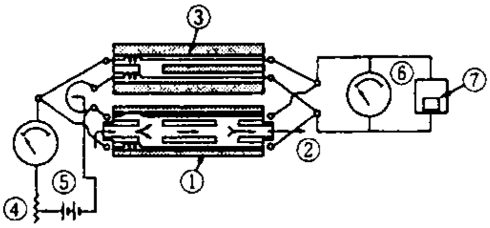


Figure 1 CO_2 meter using thermal conductivity

(2) Specific gravity method

This is intended to measure the CO_2 content based on the fact that the specific gravity of CO_2 is larger than that of air.

As shown in Figure 2, two impellers of the same form and speed are used. One impeller is revolved in an air chamber and the other one is revolved in a chamber fed with the flue gas mutually in reverse directions. The wind pressures generated by them are received by passive impellers of the same form respectively facing the above mentioned impellers. If air current of the same condition is blown to both the impellers, to actuate both, the force for turning the air arm downward and the force for turning the gas arm upward are the same, and the connecting rod connecting both the arms does not move.

However, if flue gas is fed into the gas chamber, the revolving torque of the gas arm becomes larger than that of the air arm due to the difference of both in specific gravity, which raises the connecting rod by the gas arm. The movement of the air and gas arms and the connecting rod due to the torque difference is indicated by a needle or recording pen attached at the passive impeller shaft for air.

At the bottom of the meter, a water tank is provided to always give the same humidity to gas and air.

In using this type of CO_2 meter for flue gas, if the composition of components other than CO_2 is different, it affects the specific gravity of the entire gas, which causes some error.

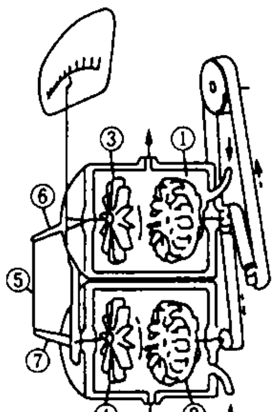


Figure 2 Specific gravity type CO_2 meter

(3) Infrared gas analysis method

Most gases such as CO_2, CO and CH_4 except gases in which diatomic molecules, such as H_2, N_2 and O_2, have respectively specific absorption wavelength bands of infrared rays. This property is used in the method. An industrial infrared gas analyzer is either of a positive filter type or of a negative filter type. As shown in Figure 3, a positive filter type analyzer usually uses a heated nichrome wire as the heat source and the heat is divided into two rays by a reflector. One ray goes through a sample tank into detector **1**, and the other goes through a comparator chamber (usually containing N_2) into detector **2**. A reference gas for a component to be analyzed, for example, a reference CO_2 gas in case when the concentration of CO_2 content is to be measured, is sealed in the both detector chambers **1** and **2**. (In recent years, also available is a simplified infrared gas analyzer which uses a semiconductor and solid filter instead of detector chambers.) The energy absorbed by detector chamber **2** remains the same, but the energy absorbed by detector chamber **1** depends on the concentration of the gas to be analyzed in the sample chamber. The difference of both the detector chambers **1** and **2** in the absorbed energy is taken out, for example, as the change in the capacity of the capacitor held between them, for indicating the concentration of the gas component analyzed. A negative filter type analyzer uses non-selective detectors. The filter chamber contains 100% test gas, and the compensator chamber contains N_2, or the gas obtained by excluding the gas components to be analyzed from the gas of the sample chamber. The difference between the outputs of both the detectors such as bolometers is measured to know the concentration of the test gas. (See JIS K0151 "Non-dispersive Infrared Gas Analyzer.")

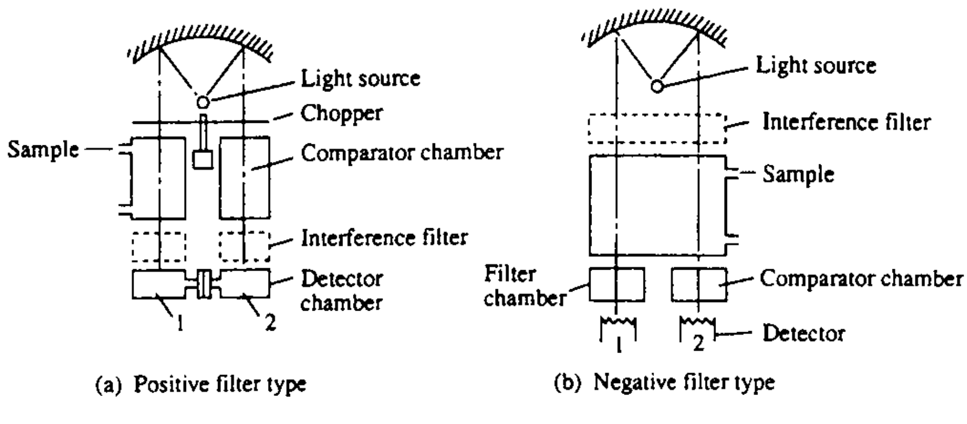


Figure 3 Infrared gas analyzer

6.1.3 Analysis of oxygen

For automatic meters for continuously measuring the oxygen concentration in exhaust gas, it is preferable to use those specified in JIS B7983 "Continuous Analyzers for Oxygen in Flue Gas."

(1) Magnetic O_2 meter

The magnetic method continuously obtains oxygen concentration by using the attractive force generated when oxygen molecules, which are a paramagnetic material, are magnetized in a magnetic field, and includes a magnetic wind type and magnetic force type. The magnetic method can be used when the influence of the gas with high bulk susceptibility (nitrogen monoxide) is negligible.

a. Magnetic wind detecting type O_2 meter

In this type, the intensity of the magnetic wind generated when the oxygen molecules attracted in the magnetic field are partially heated to lose magnetism, is detected by a hot wire element.

b. Magnetic force detecting type O_2 meter

Dumbbell type: The displacement caused when a nonmagnetic dumbbell is extruded outside the magnetic field by magnetized oxygen molecules is detected.

Pressure detector type: In a periodically intermittent magnetic field, the intermittent attractive force acting on oxygen molecules is detected as the back pressure variation of auxiliary gas flowing into the magnetic field at a constant rate.

(2) Electrochemical O_2 meter

The electrochemical method uses the electrochemical oxidation reduction reaction of oxygen, for continuously obtaining oxygen concentration and includes zirconia type and electrode type.

Zirconia type: In this type, electrodes are provided at both ends of a zirconia element heated to a high temperature, and the sample gas is fed to one of them while air is fed to the other, in order to give an oxygen concentration difference, and for detecting the electromotive force generated between both the electrodes. Figure 4 shows the structure of a zirconia type analyzer.

Electrode type: This type detects the electrolytic current generated when the oxygen diffused and absorbed in an electrolyzer cell through a gas permeable diaphragm is reduced on the surface of a solid electrode. This type can be further classified into a contact potential electrolysis type for giving reduction potential from outside, polarograph type, and galvanic cell type for forming galvanic cells.

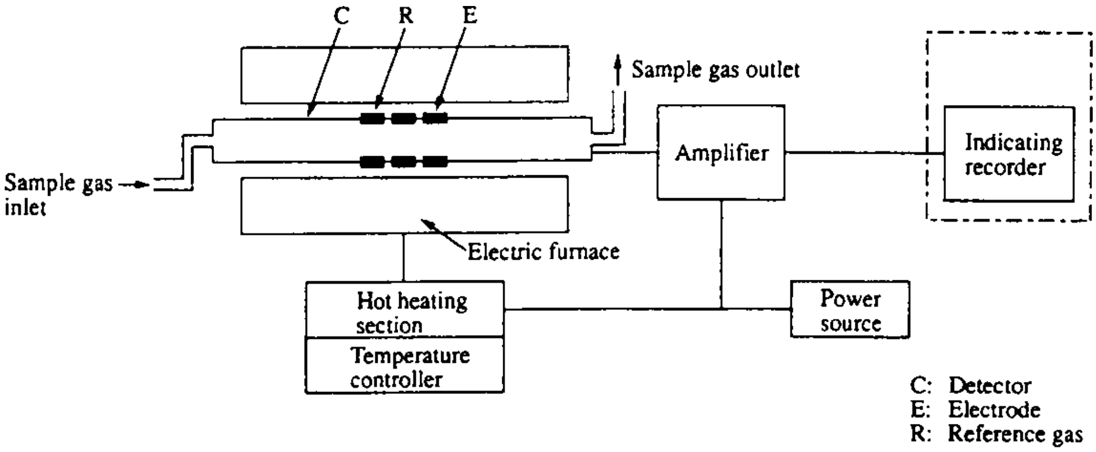


Figure 4 Structure of a zirconia analyzer

6.1.4 Analysis of carbon monoxide

Carbon monoxide in exhaust gas can be analyzed by the following methods according to JIS K0098 "Method for Determination of Carbon Monoxide in Flue Gas."

(1) Oxidation condensation method

Sample gas is cooled by liquid air to remove the condensable components in the gas, and the remaining gas is fed through a gas oxidizing agent based on copper oxide, to oxidize carbon monoxide into carbon dioxide which is simultaneously condensed by liquefied air. In this case, the difference between gas pressures before and after oxidation condensation is measured (differential pressure method), or it is gasified once into a certain volume, and the pressure is measured (gasification pressure measurement method), for the determination of carbon monoxide.

(2) Gas chromatography

A certain amount of sample gas is taken and introduced into a gas chromatograph with a thermal conductivity type detector, and carbon monoxide concentration is obtained from the height of the peak shown in the chromatogram.

(3) Infrared gas analysis method (non-dispersion method)

The ray absorption of carbon monoxide in the infrared region is used, and the carbon monoxide concentration of the sample gas is measured using a non-dispersion type infrared gas analyzer.

(4) Detector tube method

Sample gas is fed through a carbon monoxide detector tube which is a thin glass tube packed with a certain amount of a detecting agent, and the coloring achieved is used to determine carbon monoxide. This is a simple method for knowing the approximate carbon monoxide concentration of exhaust gas.

6.1.5 Other analysis methods

(1) Orsat method

Carbon dioxide, oxygen, and carbon monoxide in exhaust gas are analyzed by the absorption method using an Orsat gas analyzer. As absorbants, potassium hydroxide solution (CO_2), alkaline pyrogallol solution (O_2) and ammoniacal copper chloride solution (CO) are used. The instrument is small in size and light in weight, being convenient to carry and is simple in operation. However, skill is required.

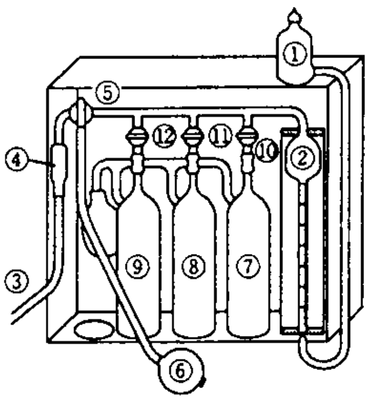


Figure 5 Orsat gas analyzer

(2) Gas chromatography

Combustion gas can be analyzed also by using a gas chromatograph. Compared with the infrared gas analyzer, etc., this method is slow in the response speed and does not allow continuous analysis. However, if an automatic gas sampler is attached, automatic analysis can be made. Gas chromatography is suitable for analyzing a sample consisting of many components, and especially allows trace element analysis. Main components of combustion gas such as CO_2, O_2, CO, N_2, CH_4, SO_2, and NO_2 can be analyzed.

The gas chromatograph used has a thermal conductivity type detector, and a gas sample introducer or automatic gas sampler. The carrier gas used is either helium or nitrogen. Since the above components cannot be isolated and extracted by single packing column, it is convenient to use two columns different in isolation capability, and to isolate and determine by the intermediate cell method in which one column is installed upstream of a detector and the other column downstream of the detector in a thermoregulator as shown in Figure 6. It is recommended to pack C_1, column with silica gel or Porapak Q and C_2 column with Molecular Sieve 13X or 5A. In this case, the polarity of a sensor signal after passing through C_1, column is reversed to that after passing through C_2 column; therefore, the polarity of the recorder should be changed halfway. (Refer to JIS K0 114 "General Rules for Gas Chromatograph Analysis" and JIS K2301 "Fuel Gas and Natural Gas — Methods for Chemical Analysis and Testing.")

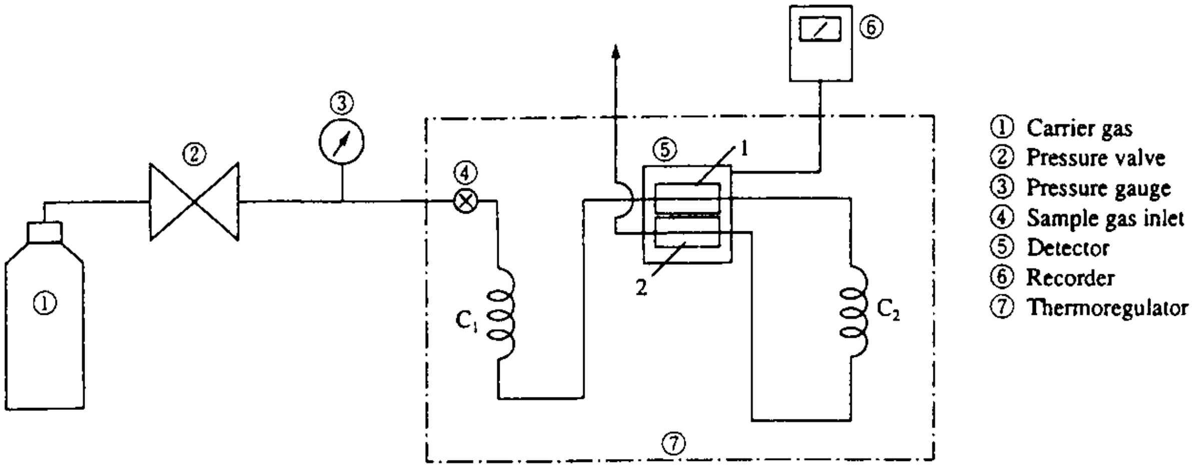


Figure 6 Intermediate cell type gas chromatograph

6.2 Methods of temperature measurement

6.2.1 Kinds and selection of thermometers

There are two methods to measure temperature. One is contact type, and the other is non-contact type. The former is based on the heat transfer by conduction or convection between the measured objective and temperature sensing element in thermally tight contact. The latter is based on the heat transfer by radiation without contact between the measured objective and temperature sensing element. The features and requirements of thermometers for respective methods are shown in Table 2. The following items should be examined, to select a thermometer suitable for the purpose of measurement.

(1) The range of temperatures to be measured (working temperatures in principle).
(2) Accuracy and error possibly occurring in measurement.
(3) Material, form, size, etc. of the sensing section.
(4) Response time.
(5) Easiness to read the indication.
(6) Function: Necessity of telemetering, recording, alarm or automatic control.
(7) Durability, corrosion resistance and reliability.
(8) Easiness to handle.
(9) Interchangeability.

Kinds and working ranges of various thermometers are shown in Figure 7.

Table 2 Contact method and non-contact method

	Contact type method	Non-contact type method
Requirements	(1) The object to be measured should be kept in close contact with the sensing element. (2) The temperature of the object to be measured should not be substantially changed even by the contact with the sensing element.	The radiation from the object to be measured should sufficiently reach the sensing element.
Features	(1) If the sensing element is brought into contact, the temperature to be measured tends to be changed. Therefore, it is difficult to measure the temperature of a small object. (2) The temperature of a moving object is difficult to measure. (3) The temperature at an optional point can be measured.	(1) Since the sensing element is not brought into contact, the temperature to be measured is not changed. (2) The temperature of a moving object can also be measured. (3) In general, surface temperature is measured.
Temperature range	Temperatures lower than 1000°C can be easily measured.	Suitable for measuring high temperatures.
Accuracy	In general, about 1% of full scale.	In general about 10 degrees.
Delay	Generally large	Generally small

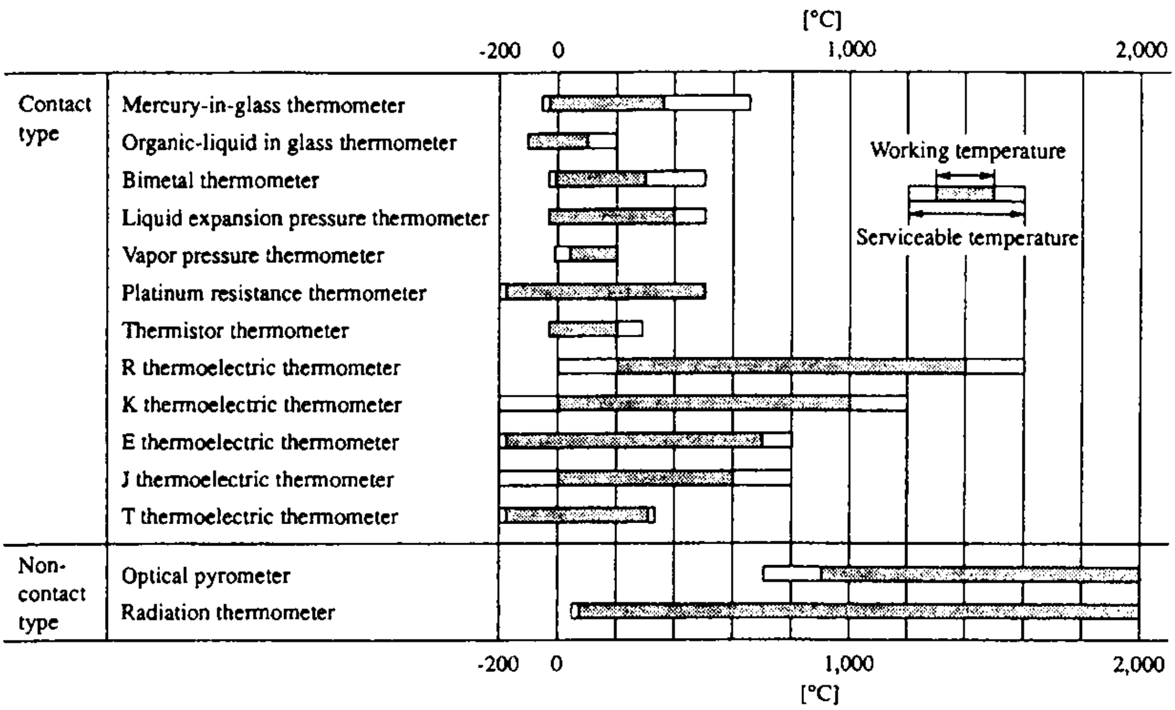


Figure 7 Kinds and working ranges of thermometers (J1S Z 8710)

6.2.2 Liquid-in-glass thermometer

Among various thermometers, this thermometer is the simplest to handle and the least expensive. Generally used liquid-in-glass thermometers are either enclosed scale type thermometers or bar thermometers. An enclosed scale type thermometer has a capillary tube and a scale plate of milky white glass behind it enclosed in one glass tube, and mostly has fine graduations, to allow accurate reading for the indication. Therefore, it is generally used for precise measurements. A bar thermometer has graduations directly stamped on a thick-wall capillary tube, and is generally higher in mechanical strength than an enclosed scale type thermometer.

JIS Z8705 specifies the temperature measurement methods using liquid-in-glass thermometers. A liquid-in-glass thermometer needs to be handled with care, because a glass tube is easy to be broken.

6.2.3 Pressure thermometer

If mercury or any other liquid or gas enclosed in a sealed tube is heated, the pressure in the tube increases. The pressure is used to determine the temperature. As shown in Figure 8, the main components are a heat sensor to be inserted into the temperature measuring point, a Bourdon tube in the meter, and a capillary tube connecting them.

Though not high in accuracy, it is structurally strong and allows easier reading compared with the liquid-in-glass thermometer. Since it is suitable for telemetry, it allows measurements at a place apart from a dangerous place. It can also be used for automatic control.

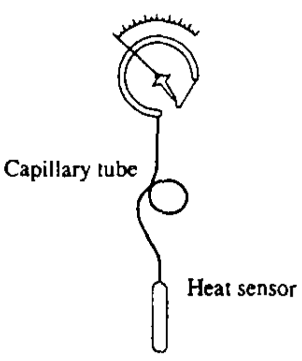


Figure 8 Pressure thermometer

Table 3 shows the kinds and performance of pressure thermometers.

Table 3 Kinds and performance of pressure thermometers

Kind	Liquid expansion type	Vapor pressure type
Enclosed material	Mercury	Volatile liquid
Scale range (°C)	–30 to 500	–20 to 200
Maximum length of capillary tube (m)	8 to 20	50
Sensibility	Good	Rather poor
Influence of capillary tube on temperature	A little	Nil
Influence of atmospheric pressure	Extremely little	A little at low pressure
Influence by the locations of heat sensor and meter	A little	Considerable at low pressure

6.2.4 Resistance thermometer

(1) Resistance bulb

According to the change of temperature, a metal wire certainly changes in electric resistance. Therefore, if a metal wire is brought into contact with an object to be measured, and if it becomes equal to the object in temperature, the electric resistance of the metal wire can measure the temperature of the object.

The change of electric resistance of resistance bulb according to temperature, should be as large, regular and stable as possible. To satisfy these requirements, a platinum wire is the most excellent for accurate measurement and has been used for a long time as a resistance bulb, but it has a disadvantage to be expensive.

Figure 9 shows the most general platinum resistance element for accurate measurement. A platinum wire of about 0.01 to O_2 mm in diameter is folded at the center into two parallel lines, and wound around a crossed frame of mica plate or ceramic plate, and usually three or four lead wires are attached to remove the error otherwise caused by lead wire resistance.

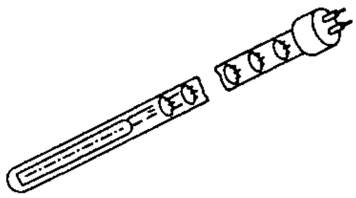


Figure 9 Platinum resistance element

The resistance wire may be used as it is, but generally it is used in a protective tube made of glass, quartz, porcelain or metal, etc., depending on the temperatures to be measured or the measuring condition.

Since nickel resistance element is inexpensive, stable at room temperature and large in temperature coefficient, it is often used next to platinum. However, it cannot be used at temperatures of 200°C or higher.

A thermistor is a semiconductor prepared by mixing and sintering a metal oxide of nickel, manganese or cobalt, etc. The temperature coefficient of the thermistor changes, depending on the temperature. Therefore, it cannot be considered that the temperature coefficient is constant in a wide temperature range. However, the temperature coefficient of a thermistor at 25°C is as large as about –2 to 6%/°C, being about 10 times that of a platinum wire. For a measurement temperature range from about –50° to 350°C, a small temperature sensing element can be made, and therefore the time delay is also small.

(2) Measuring instrument

a. Method by use of Wheatstone bridge: As shown in Figure 10, the four sides of Wheatstone bridge are resistances P and Q, variable resistance R and platinum wire resistance X, and if R is adjusted to let ammeter G indicate zero,

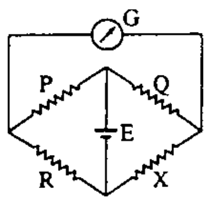


Figure 10 Wheatstone bridge

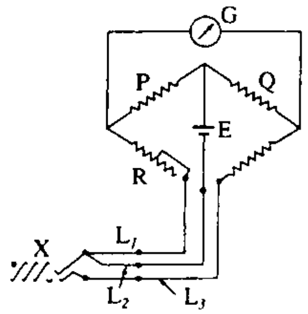


Figure 11 Three lead wires

$$X = R\frac{Q}{P}$$

usually P = Q, hence X = R.

For precise resistance measurement, the resistance of lead wires connecting the resistance bulb with the measuring instrument cannot be neglected. To eliminate the influence, lead wires are variously contrived. Figure 11 shows a case of three-wire connection. That is, if two lead wires L_1 and L_2 are taken from one end of the platinum wire coil and a lead wire L, from the other end (total 3 lead wires), and the respective resistances are L_1 , L_2 and L_3, then

$$X + L_3 = R + L_1$$

If $L_1 = L_3$, then we have X = R, and the value of R gives the resistance X of the coil.

b. Method by electronic automatic null balancing instrument: An electronic automatic null balancing mechanism is combined with a bridge circuit, to indicate or record the temperature by the zero method. The method includes an AC bridge type and a DC bridge type, depending on the measurement principle used. The AC bridge type is prone to cause an error due to the AC noise voltage induced in the resistance element or lead wires, and DC bridge type is more practically used.

c. Method by moving coil type ratio meter: Figure 12 shows a connection diagram for measuring the platinum wire resistance X, using a moving coil type ratio meter. Moving coils A and B are located between both the poles N and S of a permanent magnet, and the coil B contains resistance X of platinum wire.

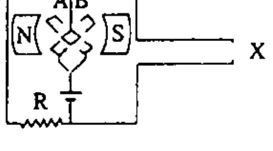


Figure 12 Moving coil type ratio meter

If X is changed by a temperature change, the needle is deflected till the resultant magnetic field of both coils A and B and the magnetic field of the permanent magnet reach a new equilibrium. This is widely used industrially.

d. Method by potentiometer: Resistance, i.e., temperature can be measured very accurately. This method is mainly used for precise measurement and calibration.

(3) Error by self-heating

In a resistance thermometer, since current flows in a resistance element, Joule heat is generated to raise the temperature. The magnitude is usually less than 0.2°C, though depending on the resistance wire, and is mostly negligible.

6.2.5 Thermoelectric thermometer

(1) Thermocouple

If two different kinds of metal wires are bonded at both ends as shown in Figure 13 and both junctions are kept in different temperatures, a thermoelectromotive force is generated by Seebeck Effect. The electromotive force is measured using a DC millivolt meter or potentiometer, to know the temperature. Such a combination of metals is called a thermocouple. The cold junction is kept at 0°C in ice bath for base point, but in case of general plants, it is put in water, underground or atmosphere, to be kept at a constant temperature, and the other end (hot junction) is inserted into the measuring point.

Figure 14 shows the structure of a thermocouple.

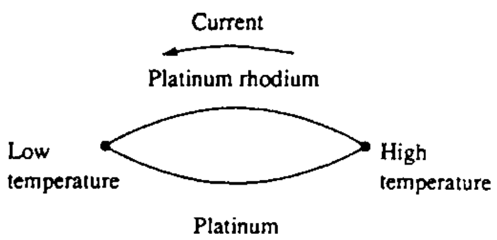


Figure 13 Principle of thermocouple

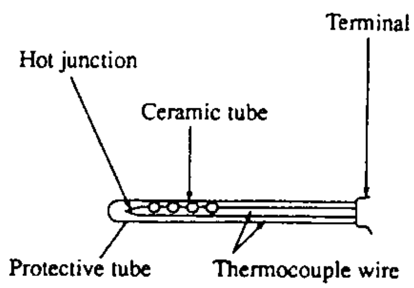


Figure 14 Thermocouple

(2) Requirements for thermocouple material

a. To be large in thermoelectromotive force which should rise continuously according to the rise of temperature.

b. To be stable in thermoelectromotive force, withstand long-term use and be free from hysteresis.

c. To be resistant against heat, mechanically strong even at high temperature, and resistant against corrosion in high temperature air and gas.

d. To be high in reproducibility, easily manufactured with constant characteristics and processed.

e. To be as small as possible in electric resistance and temperature coefficient, and also to be small in thermal conductivity.

f. To be smoothly available at low cost.

As materials satisfying these requirements, platinum-platinum-rhodium (JIS symbol: R.S.), chromel-constantan (E), chromel-alumel (K), iron-constantan (J), copper-constantan (T), etc. are used.

Figure 15 shows a thermoelectromotive force diagram of thermocouples specified in JIS.

Thermocouples for high temperature measurement include Ir-Ir·Rh (40%) 2000°C, W-Ir 2100°C, W-W·Re (26%) 2980°C, etc.

Platinum-platinum-rhodium thermocouple is smaller than chromel-alumel thermocouple (K) in the thermoelectromotive force, but high in heat resistance and good in accuracy. It is resistant in oxidizing atmosphere but weak in the reducing atmosphere and metal vapor.

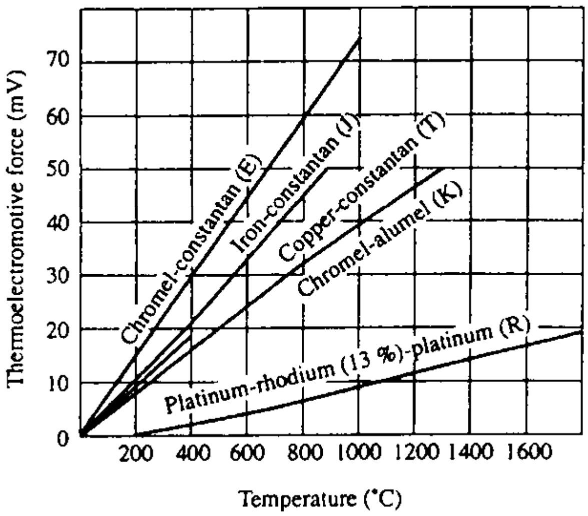


Figure 15 Thermoelectromotive forces of thermocouples specified in JIS

(3) Compensating lead wire

As thermocouples are generally expensive, the part from the terminal of protective tube to the cold junction is substituted by a compensating lead wire.

A compensating lead wire is an electric wire which has the same characteristic as the electromotive force characteristic of the thermocouple at about the terminal temperature, and is mainly a combination of copper wire and copper nickel alloy wire. The electromotive characteristic is properly determined by nickel content.

(4) Correction for cold junction temperature

The cold junction should be kept at 0°C in principle, but when it is difficult to keep it at 0°C, the temperature of the hot junction is corrected as follows. That is, if an electromotive force of E (mV) is generated between the cold junction t_c kept at any other temperature than 0°C and the hot junction t_H, the thermoelectromotive force e between 0°C and t_c is obtained from the temperature vs. thermoelectromotive force curve of the thermocouple used, and the temperature corresponding to E + e is obtained from the diagram or electromotive force table.

The thermocouple, compensating lead wire, copper lead wire and indicator can be connected by various methods as shown in Figure 16. The temperature at the cold junction in respective connection methods is the correction temperature for the cold junction temperature.

There is also a meter which allows the cold junction temperature correction to be automatically carried out using a resistance wire or bimetal, etc. large in temperature coefficient.

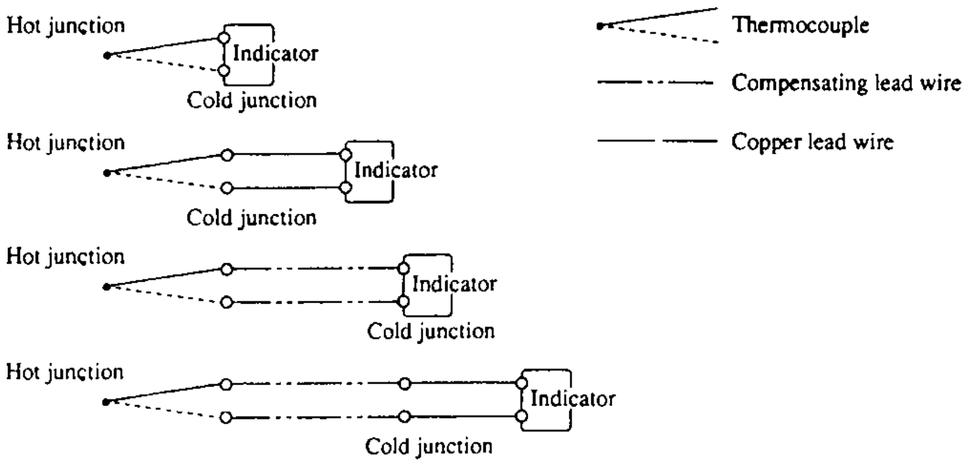


Figure 16 Various connection methods and cold junction

(5) Measuring instrument

When the thermoelectromotive force is measured by an ordinary potentiometer, as shown in Figure 17, the electromotive force generated in the thermocouple M is compared with a known constant current supplied from the dry battery B, and the position of the contact F on the slide rheostat C-D is adjusted to let the indicating needle of the galvanometer G show zero. The position at that time indicates the temperature corresponding to the electromotive force of the thermocouple. The potentiometer uses a mechanical method for balancing the specified current and the thermoelectromotive force, and requires a relatively delicate galvanometer for detecting the unbalance. The detection is intermittent.

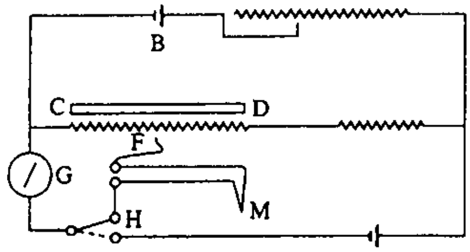


Figure 17 Potentiometer

Electronic type uses an electronic continuous balancer instead of the galvanometer, and the related mechanism is the same as the electronic balancer used for the resistance wire.

The electronic type is large in the torque for moving the needle, to allow expression on a large scale, thus allowing observation from a remote place, and the indication is reliable and highly accurate. Automatic recording is also easy, and a meter with a scale narrow in temperature range can also be manufactured. However, the structure is complicated.

(6) Error of thermoelectric thermometer

The electric error includes the error caused by the combination of a thermocouple and a meter, and the general error of an electric meter affected by temperature, magnetic field, etc. It also includes the secular change of the meter, and the error caused by the deterioration of the thermocouple.

What must be noted during use is thermal error. If a thermocouple is brought into contact with an object to be measured, the thermocouple may take away heat from the object, to lower the temperature of the measured object. In another case, when a thermocouple is inserted into the measuring point, heat is transmitted through the thermocouple and the protective tube. Figure 18 shows a case of such error.

Furthermore, since a thermocouple which senses the temperature of the measuring point may be subject to the radiant heat from a nearby object with a higher temperature or may give heat to an object with a lower temperature by radiation, an error is caused especially in the temperature measurement of gas.

Figure 19 shows a suction-pyrometer for preventing the radiation error. In the suction-pyrometer, the thermocouple is provided as a double tube to prevent the influence of thermal radiation, and gas is sucked at a high velocity toward the circumference of the thermocouple, for a better heat transfer to the thermocouple, and to know the temperature of the gas itself.

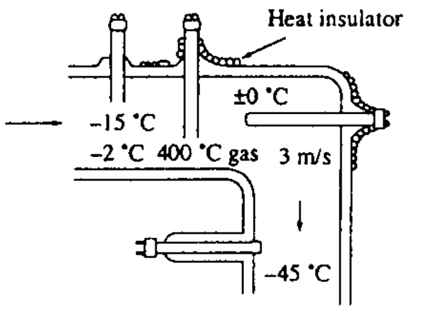


Figure 18 Caution on installation of thermometer

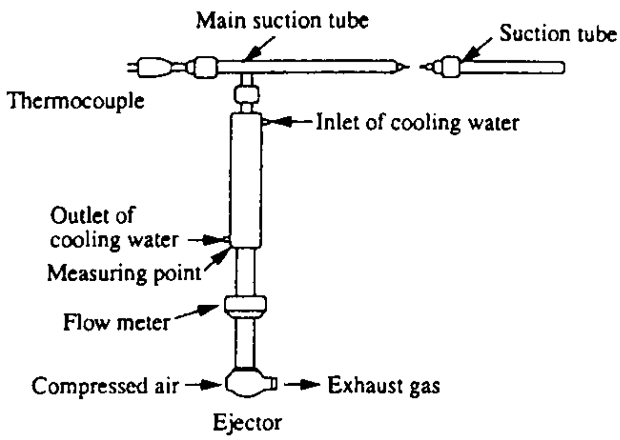


Figure 19 Suction pyrometer

(7) Sheathed thermocouple

In a sheathed thermocouple, as shown in Figure 20, magnesia (MgO) or alumina (Al_2O_3) is kept and solidified in the protective tube of the thermocouple. And sheathed thermocouple is made very thin in order to be flexible. Sheathed thermocouples of about 0.25 to 12 mm in diameter are also manufactured, and the radius of bending is greater than 5 times the diameter. Since they are thin, they are suitable for local temperature measurement and quick response. Furthermore, they do not disturb the temperature of the measured object.

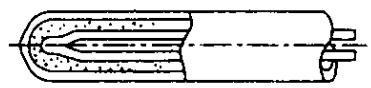


Figure 20 Sheathed thermocouple

(8) Surface thermometer

As shown in Figure 21, the cold junction of the thermocouple is grasped by hand and the hot junction is brought into contact with the surface of an object, for surface measurement.

There is another surface thermometer which is heated internally to prevent the temperature drop of the measured object otherwise caused by contact with the thermometer.

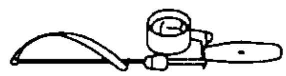


Figure 21 Surface thermometer

6.2.6 Radiation thermometer

An object higher in temperature radiates stronger heat. The radiant heat Q emitted from a unit area of an object with emissivity ε and absolute temperature T (K) into a space during a unit time is expressed by

$$Q = 5.67 \times \varepsilon \times \left(\frac{T}{100}\right)^4 \left[W/m^2\right]$$

The radiant energy is measured, to know the temperature.

Since the meter indicates the emissivity (blackness) of the black body as $\varepsilon = 1$, the real temperature of the measured object which is not a black body can be obtained by knowing ε of the measured object and dividing by $\sqrt[4]{\varepsilon}$.

Table 4 shows emissivities of some materials, which vary to some extent, depending on the temperature, state, etc. of each material.

Table 4 Surface emissivities ε of some materials

Surface	Temperature range (°C)	Emissivity ε
Iron oxide	500 to 1200	0.87 to 0.89
Silica brick	1000	0.80
Rough aluminium surface	25	0.055
Rolled steel sheet	21	0.675
Limestone	63 to 193	0.36 to 0.40

A radiation thermometer collects radiant energy by a lens or reflector, as shown in Figure 22. The former type is mainly used.

A lens radiation thermometer uses a lens transparent for the visible and infrared range of radiation. For the measurement of radiant energy, a thermocouple, a thermopile with many thermocouples assembled or bimetal, optoelectronic semiconductor, etc. is used. In this arrangement, consumable parts such as battery are not required, and a considerably large output is available. Therefore, the output voltage allows direct recording and can also be used for temperature control.

Notes for use:

(1) If smoke, water vapor or carbon dioxide, etc. exists between the thermometer and the measured object, an error is caused due to the emitted energy by radiation from the media.

(2) If the temperature of the thermometer rises, an error is caused. Therefore, any proper air- or water-cooling device should be used or the temperature needs to be automatically compensated.

(3) It must be noted that each meter has its distance coefficient. As shown in Figure 23, if the distance from the measured object to the lens of the transmitter is L, the effective diameter

of the measured object is D, the distance from the lens to the thermal sensitive material is *l*, and the size of the thermal sensitive material is d, then l/d is called the distance coefficient. It is usually 10 to 30. In this case, L and D must be selected to satisfy the relation of L/D < *l*/d.

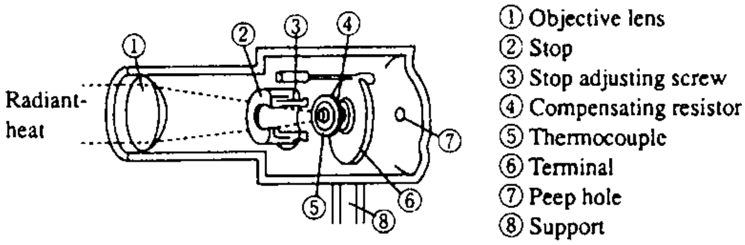


Figure 22 Radiation thermometer

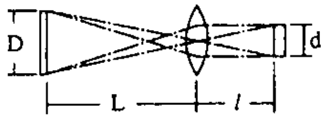


Figure 23 Distance coefficient

6.2.7 Optical pyrometer

An optical pyrometer is a kind of radiation thermometer. The radiant energy of 0.65 μm wavelength in the radiation from a hot object is compared in luminance with that of a hot material (lamp filament) as reference temperature in the pyrometer, to know the temperature.

Figure 24 shows the internal structure of a filament dissipation type optical pyrometer most widely used.

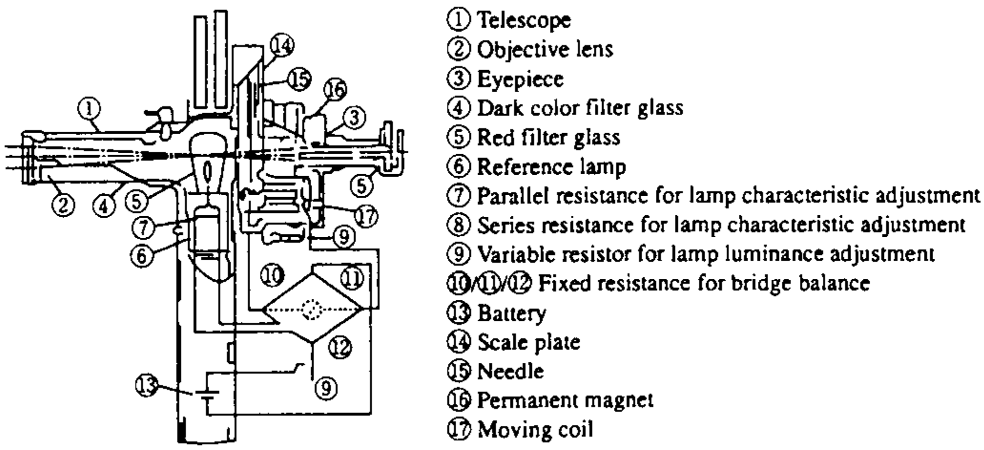


Figure 24 Structure of Optical Pyrometer

It is mainly composed of one telescope and a reference lamp for comparison which is located at the center. The telescope is pointed toward the hot object to be measured, and the lens barrel is visually adjusted to superimpose the image of the object on the plane of the filament. Visually comparing the luminance of the object image with that of the filament through the red filter glass plate, and the filament current is adjusted by the resistance to make both the luminances equal. Since the relation between the filament temperature and filament current of the reference lamp is known beforehand, the temperature corresponding to the filament current can be obtained by reading the current flowing in the filament of the lamp using an ammeter. The temperature is indicated on the scale.

There is also another measuring method, in which with the luminance of the reference light source kept always constant by a constant current, the light from the hot object to be measured is made to pass obscure glass with a certain thickness or a polariscope, to weaken the luminance, for the adjustment to be equal to the luminance of the reference light source.

When the temperature of an object other than a black body is measured by an optical pyrometer, correction must be made to know the real temperature, by knowing the emissivity ε_λ, of the object to 0.65 μm of wavelength (red). Figure 25 is a correction value for the optical pyrometer.

An optical pyrometer using a photoelectric cell or photoelectric tube to substitute human eyes is called a photocell pyrometer or phototube pyrometer.

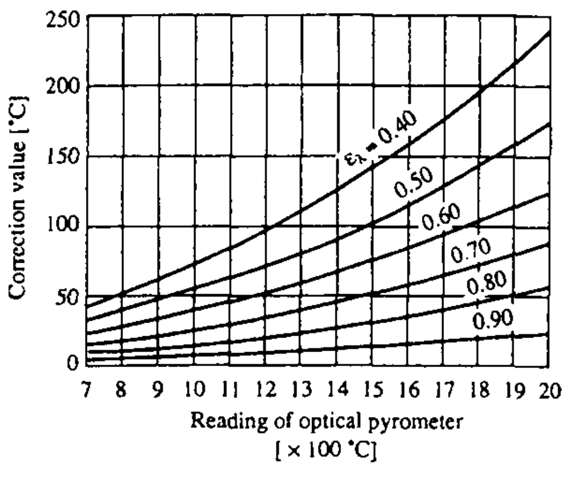


Figure 25 Correction by emissivity

6.2.8 Color thermometer

In general, a material begins to emit light at a temperature higher than 700°C, and changes color from red to reddish yellow and further to bluish according to the rise in temperature. The reason is that according to the rise in temperature, the short wavelength (blue) component contained in ray increases, while on the contrary, the long wavelength (red) component decreases. To use a color temperature while a hot object is observed through a color filter, the filter is adjusted to weaken one of the radiant energies of two wavelengths until it is visually confirmed that the color of the hot object becomes the same color as the reference. This is in order to obtain the temperature of the hot object from the weakened degree of the radiant energy of one wavelength.

This principle is used by the color filter thermometer and bioptics thermometer. There is also a two-color thermometer which measures the ratio of radiant energies of two wavelengths using photoelectric tubes, etc. and automatically indicates and records the temperature. A color thermometer is little affected by emissivity and the measured value is close to the real temperature.

6.2.9 Other temperature measuring methods

(1) Seger cone

This is a triangular pyramid prepared by mixing clay, various silicates, and metal oxides. If it is heated, each specific ingredient is softened and deformed at a specific temperature. It is used, for example, to know the internal temperature of a furnace. It is affected by the heating rate, gas atmosphere in the furnace, gas flow velocity, temperatures of surrounding furnace walls, etc. It can be more convenient than ordinary thermometers, depending on the place of use. It is used in the ceramic industry, etc.

(2) Thermal paint

A thermal paint is applied to the portion to be measured, to know the temperature by using the property of the paint color that it changes at a predetermined temperature. Both reversible and irreversible paints are available.

(3) Bimetal thermometer

Two kinds of metals which are different in the thermal expansion coefficient are stuck together, and their bending caused by temperature change is transmitted to an indicating needle. It can also be used for temperature control.

6.3 Flow rate measurement

6.3.1 Kinds and features of flow meters

Major methods for measuring the flow rate of a liquid or gas include volume method for measuring a volume or mass, differential pressure method using an orifice plate or nozzle throttle mechanism, area method for knowing the flow rate by changing the throttle area with the differential pressure kept constant, flow velocity method for knowing the flow rate from the revolution of a propeller, etc. in a liquid, method using a Pitot tube, method using vortexes of a fluid, hot wire method for measuring the absorbed heat of a fluid, etc. Kinds, features and accuracies of main flow meters used for heat control are listed in Table 5.

Table 5 Kinds, features and accuracies of flow meters

Measuring method	Flow meter	Features	Accuracy
Volume method	Wet gas meter	• Gas only can be measured. • Measuring range: 1 m/min to large flow rates	±0.5%
	Dry gas meter	• There is no fear of freezing since water is not used. • Handling is simpler than with wet type.	±0.5%
	Rotary piston type	• Measuring accuracy depends on the flow rate range and the nature of fluid. • Pressure loss is small.	Approximately ±0.5%
	Oval flow meter Roots flow meter	• Volume flow rate can be measured irrespective of kind, viscosity and density of liquid. • Mainly for liquid.	±0.1 to 2%
Flow velocity method (impeller method)	Axial flow type (Waltman type)	• In general, used for measuring the flow rate of city water.	Approximately ±4%
	Venturi tube diversion	• Can measure large flow rates of water. • Apparatus is simple.	
	Turbine meter	• Small and can measure large flow rates.	0.2 to 1%
Area method	Rotameter	• Effective measuring range is wide. • Flow rate at low Reynolds number can be measured. • Scale keeps almost linearity.	Approximately ±2%
	Piston type flow meter	• Used for measuring fuel oil with high viscosity. • Allows telemetry.	
Measurement of velocity head	Pitot tube	• Simple and inexpensive.	
Throttle method (differential pressure method)	Orifice Flow nozzle	• Mechanism is simple. • Liquid, gas, vapor, etc. can be measured.	Approximately ±1%
	Venturi tube	• Pressure loss is small.	
Vortex	Swirl meter	• For gas	
	Delta flow meter	• Measuring range is wide.	
Hot wire method	Thomas gas meter	• For gas	
Electromagnetic method	Electromagnetic flow meter	• No pressure loss. • Quick response.	Approximately ±2%
Ultrasonic method	Ultrasonic flow meter	• No pressure loss.	

In the selection of a flow meter, the following should be considered.

(1) Temperature, pressure and density of fluid
(2) Average and variation range of flow rate
(3) Solid content and pressure loss
(4) Corrosivity, harmfulness and flammability
(5) Accumulated value or momentary value
(6) Recorded value or indicated value
(7) Direct reading measurement or telemetry

6.3.2 Volume method

A fluid is introduced into a container with a certain volume, to obtain the flow rate. Figure 26 shows a wet gas meter used to measure the flow rate of gas. This flowmeter has a rotary drum with four chambers A, B, C, and D installed in a horizontal cylinder filled with water up to a half. The gas entering from inlet G into the respective chambers sequentially replaces the water in the chamber. The buoyant force produced at this time rotates the drum to cause the gas in the drum to be replaced by water again and discharged from outlet F. This allows the number of rotations proportional to the flow rate to be obtained. Here, however, it should be noted that the water level should be constant; otherwise, the volume of the measuring chamber would change, thus causing an error in measurement. The measurement tends to be affected by vapor pressure, and therefore the water temperature should be accurately measured and compensated.

A dry gas meter usually has two drums made of synthetic rubber, and if one drum is filled with a gas, valve action occurs, to change the gas passage in the other way. The expansion and contraction of the synthetic rubber drums moves a metering mechanism. The dry type has advantages over the wet type so that freezing does not occur and that moisture does not go into the gas.

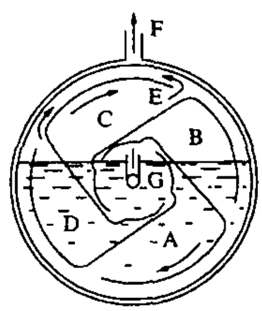


Figure 26 Wet gas meter

Figure 27 shows a rotary piston type flow meter. In the radial direction of a cylinder, one partition wall is provided, and the cutout of a rotary piston slides on it for eccentric motion with one point on the circumference of the piston kept always in contact with inner wall of the cylinder. The action is caused by the fluid pressure applied to the inside and outside of the piston, and the fluid is measured by the volumes inside and outside the piston.

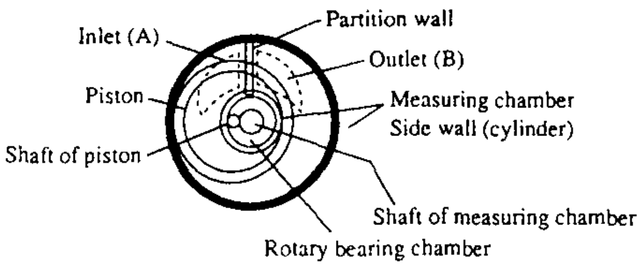


Figure 27 Rotary piston type flow meter

Figure 28 shows an oval f low meter. Two oval gear rotors are rotated by the difference between inlet and outlet pressures of a fluid, and from the number of revolutions, the flow rate is obtained. Various types and various flow rates transfer and indication methods are available.

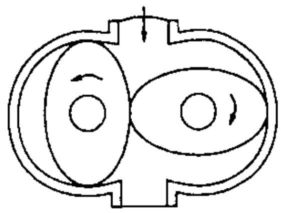


Figure 28 Oval flow meter

6.3.3 Flow velocity method

In this method, from a propeller, etc. rotated in a fluid by flow velocity, the flow rate is obtained. Figure 29 shows an impeller type flow meter, and it is available as a single box type or double box type. Waltman type flow meters are used for measuring large flow rates of city water, etc. For industrial use, turbine flow meters are generally used which belong to Waltman type.

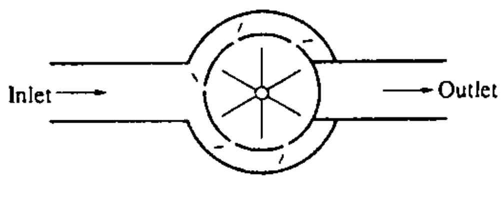


Figure 29 Impeller type flow meter

6.3.4 Area method

In this method, with differential pressure kept constant, the throttle area is changed to know the flow rate. Figure 30 shows a rotameter. When a fluid to be measured flows through a vertical tapered tube with a bottom bore slightly smaller than the top bore, the buoy in the tube pushed the float up to a height corresponding to the flow rate of the fluid and comes to a standstill. Graduations are given to indicate the momentary flow rate from the stationary position. When this flow meter is used, it must be noted that the measured value depends on the density, pressure, viscosity, etc. of the fluid. Various kinds are available for various conditions. If properly used, it is simple and convenient, and widely used in many fields.

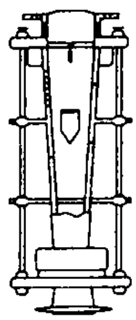


Figure 30 Rotameter

6.3.5 Method for measuring velocity pressure

Figure 31 shows a Pitot tube. Pitot tube is based on the dynamic pressure of flow. The dynamic pressure h is proportional to the squared flowing speed v;

$$h \propto \frac{\rho}{2g} v^2$$

h: Dynamic pressure [mm Aq]

ρ: Specific weight of fluid [kg/m^3]

g: 9.8 [m/s^2]

v: Flowing speed [m/s]

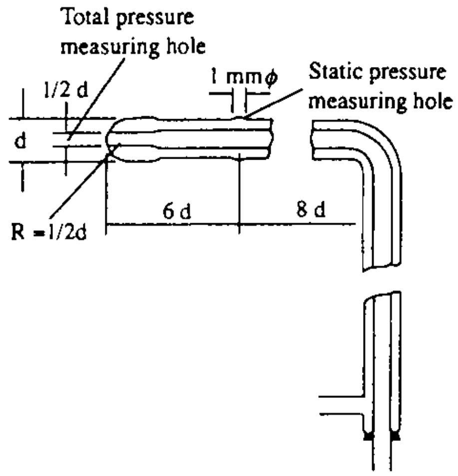


Figure 31 Pilot tube

Flow rate Q can be obtained by the following equation;

$$Q = A \cdot C \cdot v$$

$$= A \cdot C \cdot \sqrt{\frac{2gh}{\rho}} \ [\mathrm{m^3/s}]$$

Q: Flow rate [m^3/s]

A: Cross sectional area of duct [m^2]

C: Flowing coefficient

There are two types of Pitot tube. One is L type, and the other is Weston type. The former looks like a capital letter L, as shown in Figures 31. It has two holes. One is located in front of tip, which is for the total pressure of the total pressure and the static pressure. The other hole is located on the side wall, which is for only static pressure. The difference between the two pressures shows the dynamic pressure. Because the dynamic pressure works in the same direction as the flow, on the other hand, the static pressure works istropically.

The latter looks like a capital letter Y. It has a hole at the and of each branch of Y, and the holes face opposite to each other. One hole needs to be faced against the flowing direction, the other hole needs to be faced to follow the flowing direction. Difference between pressures of front hole and the rear hole gives the dynamic pressure. Weston type Pitot tube is for the exhaust gas with much concentration of dust. Weston type is more sensitive to flow coefficient which is calibrated to each tube.

Though the measurement by Pitot tube is simple, if it is wrongly used, large amount of error may happen. Especially the Pitot tube must be rightly directed to the flow. The sectional area of the Pitot tube must be smaller than 1% of the sectional area of the duct. Upstream of the Pitot tube, straight portion longer than 20 times of the duct is necessary to obtain uniform profile of flow rate.

6.3.6 Throttle mechanism method

An orifice is a flow rate sensing element generally used for this method.

A throttling plate is inserted in a pipe line, and the pressure difference generated is measured, to obtain the flow rate according to Bernoulli's theorem. That is, as shown in Figure 32, in a straight tube, a throttling plate (orifice plate or nozzle plate) with a hole smaller than the sectional area of the tube is inserted, to restrict the flow, and from the difference pressures between upstream and downstream of the plate, the flow rate is measured. It can be used for either a gas or liquid. If F is the sectional area of the hole of the throttle plate (m^2), $P_1 - P_2$ is the pressure difference between upstream and downstream of the throttle plate (Pa), ρ is the specific gravity of the fluid (kg/m^3), c is the flow coefficient, and ε is the expansion coefficient, then the mass M and the volume W of the fluid passing through the pipeline per unit time can be obtained by the following:

$$M = c \cdot \varepsilon \cdot F\sqrt{\rho\,(P_1 - P_2)}\ [kg/s]$$

$$M = c \cdot \varepsilon \cdot F\sqrt{(P_1 - P_2)/\rho}\ [m^3/s]$$

That is, they are proportional to the square root of the differential pressure.

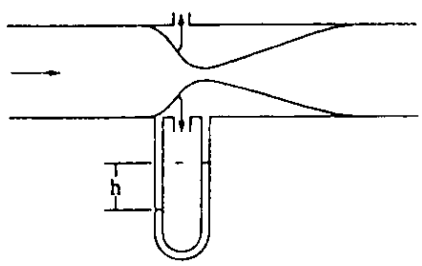


Figure 32 Throttle plate flow meter

6.3.7 Hot wire method

In the hot wire method, a wire of metal such as tungsten or thin film is placed in the fluid flow, heated by application of an electric current, and thus the amount of heat taken away through convection is measured to obtain the flow rate. Generally, the flow rate is obtained from the heating value with the hot wire controlled and kept at a constant temperature. A hot wire flowmeter, which has a small sensing element with quick response up to several kHz, is suitable for measuring the fluctuations in the flow rate, but it is susceptible to temperature, humidity and specific weight of the fluid. A mass flowmeter, which has been popular in recent years, is mainly used for measuring the flow rate of gas. In this method, a fluid resistance such as capillary is inserted in the main flow passage and a bypass tube is provided with a heater, upstream and downstream of which a detecting resistance wire is wound. When the heater is heated, a temperature rise on the upstream side differs from that on the downstream side due to the factors including fluid density, specific heat and flow rate. This difference in the temperature is detected to obtain the flow rate. This flow rate is a mass-based flow rate and therefore temperature and pressure exert no influence on the measured value.

This method, which offers quick response and the output by electric signals, is, in many cases, used together with automatic valves as a flow controller. Additionally, since the sensing element does not come into direct contact with the fluid, this method can be used also for a corrosive fluid.

6.3.8 Electromagnetic method

If a magnetic field is adopted across the flow direction of a conductive fluid flowing in a tube as shown in Figure 33, an electromotive force E is generated in the direction perpendicular to both of the flow and the magnetic field.

If a conductive fluid flows in a tube of D in diameter at an average velocity v, and the intensity of the magnetic field is B, then the volumetric flow rate Q can be expressed by

$$Q = \frac{AE}{DB}$$

$$A = \frac{\pi D^2}{4}$$

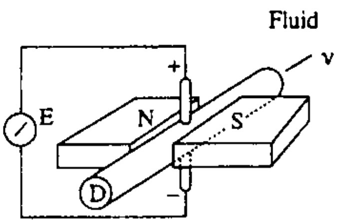


Figure 33 Electromagnetic flow meter

If the intensity of the magnetic field and the tube diameter are constant, the electromotive force is proportional to the volume flow rate.

The flow meter is characterized by a perfect freedom from pressure loss and a very quick response and from wear by some solid grains in the fluid.

6.3.9 Method by fluid vortexes

The method was developed with attention paid to the phenomenon that the frequency of vortexes generated in a fluid is proportional to the flow velocity. Figure 34 shows a delta flow meter using the principle. Two thermal sensors are set in a triangular prism-like vortex generator, and the alternating change of von Karman's vortex street is taken as the change in the electric resistances of the sensors, for expressing as the flow rate.

Figure 35 shows another type of vortex flow meter which uses the same principle as the delta flow meter. It uses a cylindrical sensor and one very thin platinum wire as the sensing element (the delta flow meter uses thermistors), and therefore, is different in electric circuit configuration. Both are small in pressure loss due to their structures, and can be easily installed and removed. A purge type vortex flow meter is available for use for a fluid containing dust or corrosive fluid in a flue etc., because the sensing elements in the body are purged by clean air to prevent entrance of dirty fluid out of body.

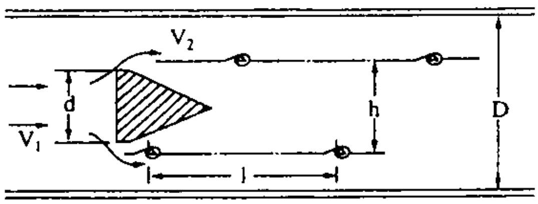


Figure 34 Delta flow meter

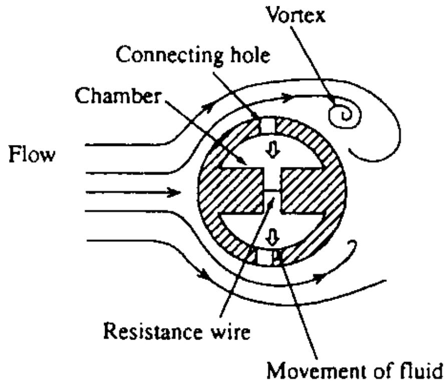


Figure 35 Vortex flow meter

Figure 36 shows a swirl meter which is composed of a meter proper, swirler, de-swirler, sensor and sensing amplifier. The meter proper has internally Venturi tube structure. It was developed for gas. Each vortex generated by the swirler has a velocity distribution protruding at the axial portion and symmetrical around the axial center, and causes a braying motion at the neck portion of the Venturi tube. Since the number of revolutions at the velocity center (vortex center) is proportional to the actual volume of the gas, it is sensed by a thermistor, in order to indicate as the flow rate.

The de-swirler is provided to remove the influence on the downstream side, and restores the original condition free from vortexes.

All the flow meters are wide in measuring a range as a common advantage, and their respective features are used to widen their applications.

6.3.10 Other flow rate measuring methods

The following two types of flow meter are based on Doppler Phenomenon of ultrasonic sound of laser.

If an acoustic wave is generated in flow, the sound is propagated at a velocity equal to synthesize the vector of the sound velocity and the flow velocity. An ultrasonic flow meter is based on this principle, to measure the propagation velocity, for measuring the flow velocity and rate. As for a laser flow meter, since a laser beam is composed of only one wavelength, and is monodirectional with uniform wave front, the reflected in a fluid is used to measure the flow velocity. It has such features as non-contact measurement and a good response.

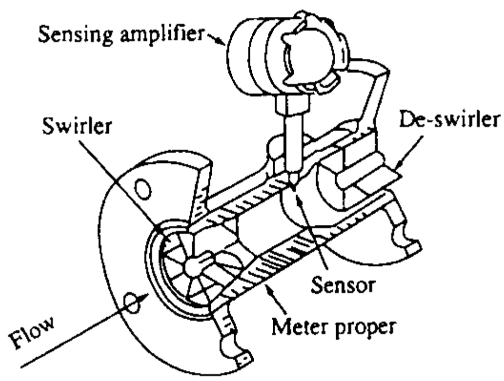


Figure 36 Swirl meter

6.4 Measurement of pressure

6.4.1 Kinds and features of pressure gauges

Pressures gauges include liquid column type, elastic type, inverted bell jar type, ring type, electric type, etc., and their features and accuracies are listed in Table 6.

Table 6 Kinds, features and accuracies of pressure gauges

Measuring method	Pressure gauge	Features	Accuracy
Liquid column type	Mono-tube type	• Only once reading is required. • Significantly influenced by temperature.	0.1 mmH_2O (Users' tolerance)
	U-tube type	• Higher in accuracy than mono-tube type. • Tube diameter and temperature affect error.	0.1 mmH_2O (Users' tolerance)
	Mono-tube inclined type	• Straightness and inclination angle of tube exert a large influence.	Approximately 0.01 mmH_2O
Elastic type	Bourdon tube	• Structure and operation is so simple that it is a generally called pressure gauge. • Easy in handling and maintenance. • Telemetry and automatic recording are easy. • Allows measurement even in relatively severe conditions such as solid-containing fluid, corrosive fluid, etc. • Suitable for high pressure measurement and wide in measuring range. • Unsuitable for measuring slight pressure. • Since only elasticity is used, it is difficult to change the measuring pressure range. • Errors due to creep, hysteresis or time dependent change are liable to be caused.	Approximately ±0.5 to 2.5% of FS (Full Scale)
	Diaphragm type	• Pressure receiving face is large. • Corrosion preventive measure can be easily taken. • Response is quick. • Maximum pressure is 2 kg/cm^2.	Approximately ±0.5 to 2.0% of FS
	Bellows type	• Measuring range can be changed. • Displacement is large. • Pressure tightness and temperature compensation can be easily done.	Approximately ±0.5 to 2.0% of FS
	Capsular type	• Very sensitive to a slight pressure change. • Unsuitable for high pressure nor quick response.	Approximately ±0.5 to 2.0% of FS
Inverted bell jar type	Single bell type	• Mechanical friction is small. • Impact vibration can be measured.	Approximately ±1% of FS
	Double bell type	• Higher in sensitivity and accuracy than single bell type.	Approximately ±0.5% of FS
Ring type		• Turning torque is large. • Measuring range can be adjusted. • At end connection, elastic resistance is liable to occur.	±1% to 2% of FS
Electric type	Strain gauge type	• Sudden change can be followed. • Suitable for telemetry and multi-point measurement.	Approximately ±1.5% of FS
Piston type		• Measuring range can be adjusted.	Approximately ±1% of FS
Weight type		• Measuring range is wide. • Accuracy is high.	1/200 of indication (Users' tolerance)

In the selection of a pressure gauge, the following should be considered;

(1) Measuring range: In the case of Bourdon gauge, etc., the measuring range should be 2/3 or less of the maximum graduation.
(2) Direct reading measurement or telemetry.
(3) Place of installation.
(4) To have a safety device, in case of high pressure.
(5) Inspection should be carried out constantly to confirm that the indication is correct.

6.4.2 Liquid manometer

(1) U-tube manometer

As shown in Figure 37, a glass tube is bent in U shape, and one end connects to a measuring point, while the other end connects to another pressure measuring port or is usually open to the atmosphere, regarded as a 1-atmosphere constant pressure chamber.

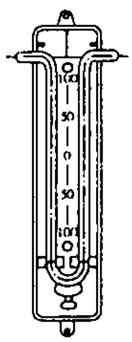


Figure 37 U-tube manometer

The measuring liquid used is usually water. However, for large pressure difference, mercury is used, and for small pressure difference, any liquid lighter than water is used. However, in this case, calculation of multiplying the differential pressure by the specific weight of the fluid used is required. The liquid used for the pressure measurement is required to have such properties as (1) small viscosity, (2) small thermal expansion coefficient, (3) small capillarity, (4) certain chemical ingredients, etc.

Therefore, if a precise measurement is required, correction of temperature, gravity and capillarity is required.

(2) Mono-tube inclined manometer

As shown in Figure 38, this is a modification of U-tube manometer. The sectional area of P_1 side is very large compared with that of P_2 side, and the change of the liquid level in the container large in sectional area can be neglected compared with the change of the liquid level in the thin tube. Therefore the difference x in the height of the liquid in the mono-tube shows the pressure, enlarged by $1/\sin\theta$.

Since x corresponds to $h/\sin\theta$ where θ is the indicated angle, pressure P_1 can be obtained by the following equation:

$P_1 = P_2 + \rho x \sin\theta$

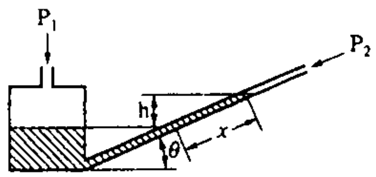


Figure 38 Mono-tube inclination manometer

where ρ is the specific weight of the liquid. Both types constant and adjustable in the angle θ of the inclined tube are available.

(3) U-tube manometer using two liquids

As shown in Figure 39, two liquids are used, to enlarge the differential pressure. The pressure difference can be calculated by:

$$\Delta P = P_1 - P_2 = \frac{A}{a}\ x\ \left\{(\rho_2+\rho_1)\frac{a}{A}+(\rho_2-\rho_1)\right\}$$

where A: Sectional area of pressure receiving chamber

a : Sectional area of measuring tube

ρ_1: Specific weight of light liquid

ρ_2: Specific weight of heavy liquid

If a/A and $\rho_2 - \rho_1$ are smaller, even a slight pressure difference can be enlarged more. For example, if A/a = 1000, specific weight of alcohol ρ_1 = 800 kg/m^3, and specific weight of petroleum ρ_2 = 810 kg/m^3, then the enlarging factor becomes about 81 times.

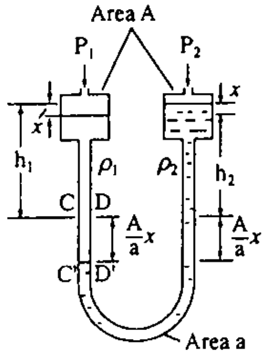


Figure 39 Two-liquid manometer

6.4.3 Elastic pressure gauge

(1) Bourdon gauge

As shown in Figure 40, a metallic pipe bent like a circular arc (or spiral, helix, any other form, etc.), and one end is fixed, while the other end is kept free. If an internal pressure is applied, the free end moves. The movement is enlarged by a lever or gear, to move the indicating needle. Bourdon gauges are available in a wide accuracy range from superhigh accuracy to low accuracy. For various applications, various forms and sizes are available. Bourdon gauges are generally used in large quantities for industrial use.

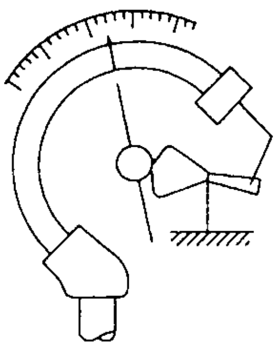


Figure 40 Bourdon gauge

(2) Pressure gauges

Pressure gauges for instrumentation are offered for measurement and control in many plants and industrial processes, and are applied for measuring static pressure, differential pressure and absolute pressure. Measurement is transmitted by either electric current (4 to 20 mADC) or pneumatic pressure (20 to 100 kPa). The gauges are standardized for indication, recording and arithmetic input respectively.

The pressure receiving element is a diaphragm made of a special metal, and a liquid media is contained between the diaphragm and the sensing element, to transfer pressure. The diaphragm is available in various forms, sizes and materials, for various working conditions and pressure ranges. The measuring range available is generally from about 20 mm water column to hundreds of atmospheric pressure. Zero adjustment, span adjustment and damping adjustment can be made.

6.4.4 Other methods of pressure measurement

(1) Inverted bell jar type manometer

As shown in Figure 41, this combines a beam with a bell. For industrial application, it is little used.

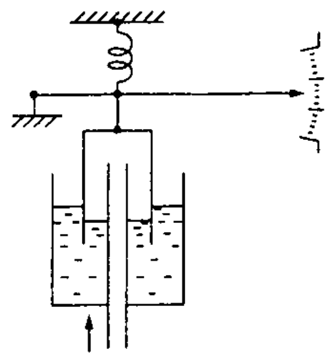


Figure 41 Inverted bell jar type manometer

(2) Strain gauge type pressure gauge

In general, a strain gauge is used as the sensing element. Strain gauge type pressure gauges are used mostly for industrial applications. The sensing element is small in size and quick in response. They are available from superhigh pressure to slight pressure. There are some using a semiconductor strain gauge or magneto-strain effect.

6.5 Measurement of humidity

6.5.1 Kinds and features of hygrometers

The humidity of a gas can be measured by using a hygrometer, dew point meter, electric hygrometer, hair hygrometer, etc. Kinds and features of hygrometers are shown in Table 7.

Table 7 Kinds and features of hygrometers

Kinds	Advantages	Disadvantages
Simple hygrometers	Simple in structure	1. Does not directly indicate relative humidity. 2. Poor in accuracy. 3. Requires water.
Sling-type hygrometers	Convenient to carry.	1. Does not directly indicate relative humidity. 2. Requires much skill. 3. Requires water.
Asmann ventilated hygrometers	1. Allows a, relatively high accuracy to be obtained at room temperature. 2. Convenient to carry.	1. Does not directly indicate relative humidity. . 2. May sometimes be low in ventilation. 3. Requires some skill. 4. Requires water.
Meteorological Agency type ventilated hygrometers	Allows a high accuracy to be obtained at room temperature.	1. Does not directly indicate relative humidity. 2. Requires water.
Resistance thermometer type hygrometers	1. Indicates relative humidity directly. 2. Allows continuous recording and telemetering. 3 Can be used for automatic control. 4. Allows measurement at several positions by one indicator.	1. A simple calculation formula is used for direct indication of relative humidity, thus causing a large error in measurement of a wide range of operating temperatures and humidity. 2. Requires water.

6.5.2 Hygrometer

This meter is usually used. Two ordinary mercury-in-glass thermometers are placed in the air to be measured, and the bulb of either of them is wrapped with cloth wetted by water.

From the dry bulb temperature and wet bulb temperature, the humidity is obtained in reference to the hygrometer diagram.

The wet bulb indication of a stationary hygrometer is generally too high, affected by radiant heat, and does not coincide with the real wet bulb temperature. Therefore, there is also a device contrived to increase the velocity of the air around the wet bulb.

A sling hygrometer has the hygrometer mounted on one frame, and swung around the frame, to reach an equilibrium temperature.

An Asmann ventilated hygrometer has a small spring revolved like the works of a watch at the top of the hygrometer, and it is revolved to cause an air current of about 2.5 m/s in flow velocity on the surfaces of the dry and wet bulbs.

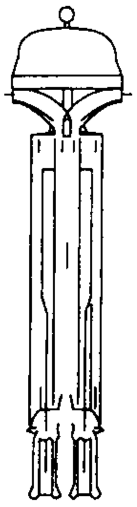


Figure 42 Asmann ventilated hygrometer

6.5.3 Resistance thermometer type hygrometer

As shown in Figure 43, the principle is the same as that of a hygrometer. Instead of mercury thermometers, resistance thermometers are used. The cold junction is wrapped with wet cloth, and the hot junction is exposed to air, to generate an electromotive force corresponding to the difference between dry and wet bulb temperatures. Remote indication and recording can also be realized.

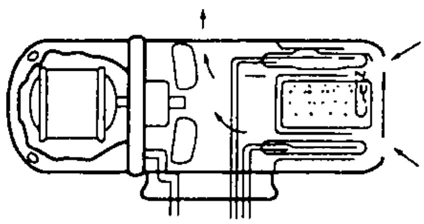


Figure 43 Resistance thermometer type hygrometer

6.5.4 Dew point meter

A cooling dew point meter has a smoothly polished metallic face placed in the air to be measured, and the metallic face is gradually cooled by feeding water inside or using the evaporation heat of ether, etc. At a certain temperature, the glossy face becomes cloudy with a thin film of dew. On the contrary, if the temperature of the metallic face which is cloudy with dew is gradually raised, the cloud disappears at almost the same temperature as before. The mean temperature of both is called a dew point. If the dew point of the fluid is known, the humidity can be obtained from the water vapor table or humidity diagram.

The cloud by dew can be judged visually, or using a photoelectric tube or electric resistance.

A phototube dew point meter measures the cloud on the metallic specular face using a phototube circuit, and allows recording.

6.5.5 Electric hygrometer

If a hygroscopic conductive thin film (e.g., containing lithium chloride) is spread between two electrodes insulated from each other, the moisture around it is absorbed according to the increase of the humidity of the air around it, and it causes decrease in electric resistance. This principle is used in this hygrometer.