APPLICATION OF POOR QUALITY COAL FOR CLOSED CYCLE GAS TURBINE

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I. PREFACE

In these several years, utilization of poor quality coal in a mine is being a remarkable problem in view of a tendency of rationalization of coal enterprises and some thermal power plants aiming to use poor quality coal exclusively can be actually found out. What is called poor quality coal? Clear definition of this word is very difficult, but considering that it can not be handled as general selected coal, there are many kinds of coals, i.e., high ash content coal (about 3,000 kcal/kg) which is produced in large quantity in mines, and low-calorific coal such as low carbonized peat with much moisture and low calorific turf.

In the case of utilizing coals for a closed cycle gas turbine, the burned gas of coal cannot enter the working gas driving the turbine as the cycle is closed, i.e., external combustion system, therefore the air heater can be considered to be just the same as the steam boiler. Thus, in Europe, many coal fired gas turbine plants have already started in operation, and various kinds of coals are applied, such as bituminous coal, brown coal, peat and coal slurry etc. and their calorific values range from about 7,000 kcal/kg to 2,500 kcal/kg. *Table 1* shows an example of coal fired closed cycle gas turbines. European poor quality coals which are shown in the Table differ from Japanese ones at some points, for instance, the former has lower ash content, higher volatility and higher moisture than the latter. Therefore, in spite of low calorific value, many of them can be burnt easily as long as they are dried. On the contrary, many Japanese coals are difficult to be burnt because of higher ash content, and lower volatility. As described above, intrinsic differences are seen between Japanese and European coals, and it is extremely questionable if European design of air heater can be applied to the Japanese coals or not. Therefore, in 1955, we built the same dry bottom model air heater for testing as the actual one in our factory and have been studied the combustion test for each kind of coal. The coals which have been used for the test are

***Table 1* Example of coal fired closed cycle gas turbine**

No.	Plant name	Rated output (kW)	Fuel	Completion (year)	Manufacturer
1	Test Plant, Clydebank (I) (Scotland)	400	Peat	—	John Brown
2	Test Plant, Clydebank (II) (Scotland)	1,000	Coal	1951	John Brown
3	Ravensburg Power Plant (Germany)	2,000	〃	1956	GHH Escher Wyss
4	Altnabreac Power Plant (Scotland)	2,000	Peat	1959	John Brown
5	Rothes Power Plant (Scotland)	2,000	Coal slurry	Under construction	John Brown
6	Moscow Power Plant (Russia)	12,000	Brown coal	1960	Escher Wyss
7	Coburg Power Plant (Germany)	6,600	Coal	1959	GHH
8	Oberhausen Power Plant (Germany)	13,750	Coal	1960	GHH
9	Haus Aden Power Plant (Germany)	6,300	Coal	Under construction	GHH

picked up from whole Japan. Their calorific values range from about 2,500 kcal/kg to 3,000 kcal/kg, and they are high ash content coals and part of them contains coal slurry. For each coal, the establishment of combustion condition, the ash trouble and its features, the distribution of radiant heat intensity and the construction of burners have been researched, and many useful results have been obtained. In order to research the combustion mechanism quantitatively we constructed a small furnace and are now researching the ignition mechanism, burning-out-characteristics, corrosion and erosion. From these researches it has been cleared up that such poor quality coals are available for closed cycle gas turbine fuel. In the following section the results from the test of the poor quality coal which has been conducted with this model testing furnace are outlined.

II. AIR HEATER AND COMBUSION OF POOR QUALITY COAL

Fig. 1 and *Fig. 2* show examples of coal fired air heater. The former is installed in Ravensburg of South Germany and the latter in Moscow, and their capacities are 2/2.3 MW and 10/12 MW, respectively. *Fig. 3* shows the diagram of Ravensburg's air heater.

The cycle air enters at first the pipe bundles which are forming a convective heating surface (*Fig. 1–c*) and is heated with rising burned gas, which goes down to the lower pipe collector, and then through the connecting pipe to the upper pipe collector

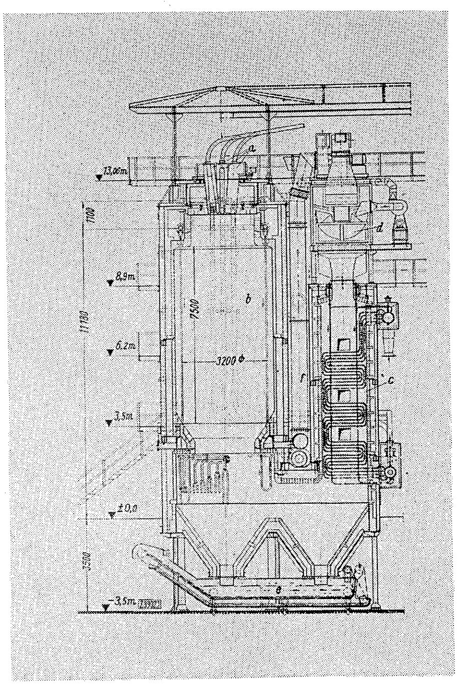


Fig. 1 Air heater (Ravensburg P.S.)

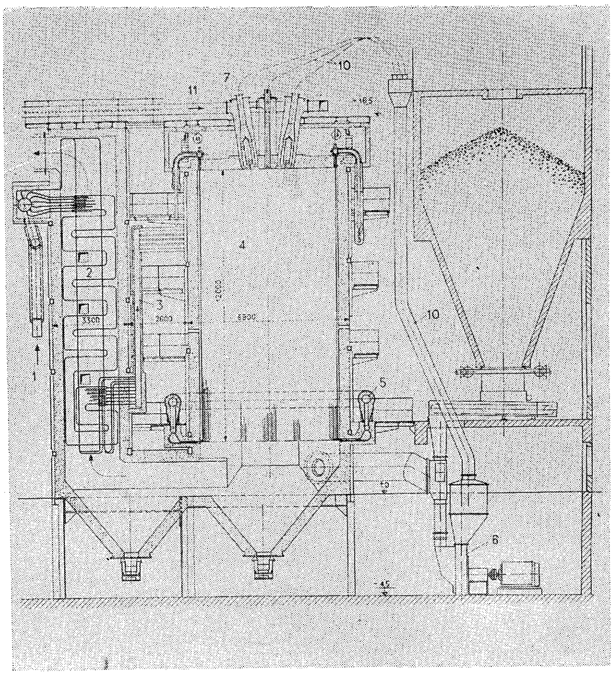
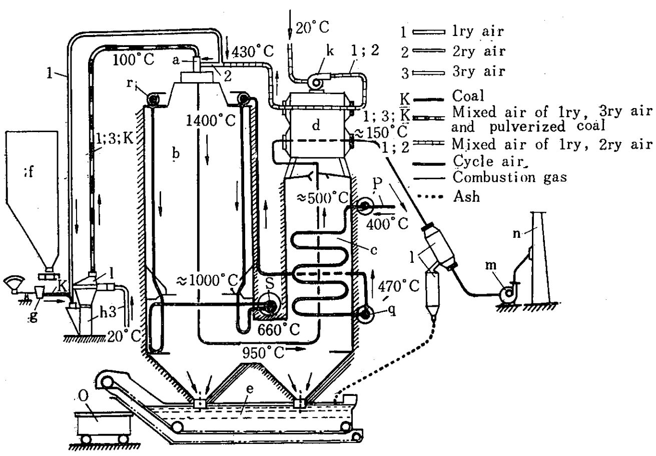


Fig. 2 Air heater (Moscow P.S.)



a: Burner b: Radiation heating part c: Convection heating part d: Air preheater e: Water sealed ash hopper f: Bunker g: Feeder h: Pulverizer i: Separator k: Forced fan l: Dust collector m: Induced fan n: Chimney o: Ash car p: Cycle air inlet q: Outlet of convection part r: Inlet collector of radiation part s: Outlet collector of radiation part

Fig. 3 Diagram of Ravensburg's air heater

of the combustion chamber (b). Then the air is heated as final heating almost by radiation of the firing gas of coal fuel thrown into the combustion chamber from several burners (a) settled on the upper deck of furnace, going down through many pipes arranged in front of the inner wall of the combustion chamber. Before entering the prescribed convection part, the burned gas lets fall part of their ash into the water sealed hopper (e). Furthermore, the burned gas runs through the convection part to the air preheater (d) (Ljungström type) in which the combustion air is preheated and the gas flows through dust collector and is exhausted to the chimney by the fan. In the combustion chamber the cycle air flows in the same direction of the flow of the burned gas and special regard is paid, so that the temperature of the pipe wall may not rise partially by the distribution of radiant heat intensity from the flame and the temperature-rise of the cycle air. As the pipes must be heated uninformly, the air heater is made to have a circular or regular polygon section. The higher the turbine inlet temperature, as is known well, the higher the efficiency of the gas turbine, but now simple air as a working gas, the heat transfer coefficient of which is lower than that of steam, is applied for closed cycle, and so the pipe wall temperature in the furnace is higher than that of the pipes of the boilers. Therefore, partial higher temperature of pipes must be avoided to the atmost. However, the air heater is still now not so large as the modern boiler of large capacity and the pipes must be arranged long in the direction of fire flame, so the radiant heat intensity for the pipes in the furnace will partially vary remarkably and the evaluation of the partial pipe wall temperature also will be altered.

Fig. 4 (a) & (b) show examples of the distribution of thermal intensity of radiant heating surface and the pipe wall temperature under designed and measured values, respectively. This distribution of thermal intensity will be changed due to the kinds of coal fuel, combustion system and conditions of combustion etc.

For the stable combustion of poor quality coal, it is necessary that the preheating temperature of combustion air and the wall temperature in the furnace are high. As prescribed, the wall temperature of air heater is high, and the temperature of cycle air entering the air heater is about 400°C, as shown in *Fig. 3*, and consequently, as also the combustion gas leaves the furnace with higher temperature than the inlet cycle air, so its thermal energy is available for the preheating of combustion air until over 400°C, which is profitable for the combustion of poor quality coal.

On the other hand, in order to avoid overheating of the pipe wall, ash trouble, corrosion and erosion, the furnace must be designed under consideration of combustion characteristics and thermal intensity distribution of the poor quality pulverized coal flame. By our experiment with our test apparatus the combustion characteristics, the distribution of thermal intensity of heating surface and pipe wall temperature and the ash trouble of Japanese poor quality coal have been researched, and these test results may be utilized for the quantitative guess for the actual air heater.

III. TEST APPARATUS

1. Scope of apparatus

Fig. 5 shows the test apparatus, and the diagram of test apparatus is shown in *Fig. 6*. The dimensions of the main parts are listed up in the *Table 2*.

The drying apparatus is to be used for the coal slurry (C & D coal). The furnace is about 1.4 m in diameter and 4.8 m in height from the floor, and the concentric swirling burners are equipped on the top. In the combustion chamber, about 60 pipes are arranged as heat transfer surface to be cooled by the air. The ratio of the heat quantity to be carried out by the cooling air against the heat quantity generated in the combustion chamber (cooling ratio φ) can be raised to about 70%. After exhausting much ash continuously under the furnace with multi-cyclon, the burned gas preheats combustion air through the heat exchanger (Secondary air preheater) and is conducted to the electrostatic precipitator, further the gas is exhausted to the chimney by the fan. A flash dryer is adopted for drying of slurry and exhausted gas is used. Furthermore, an

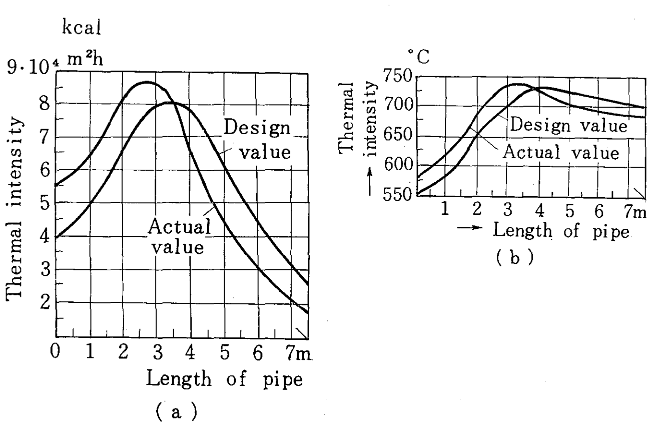


Fig. 4 Distribution of thermal intensity of heating surface and pipe wall temperature

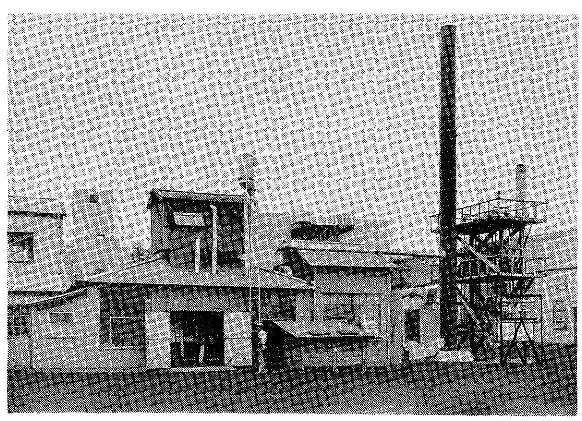
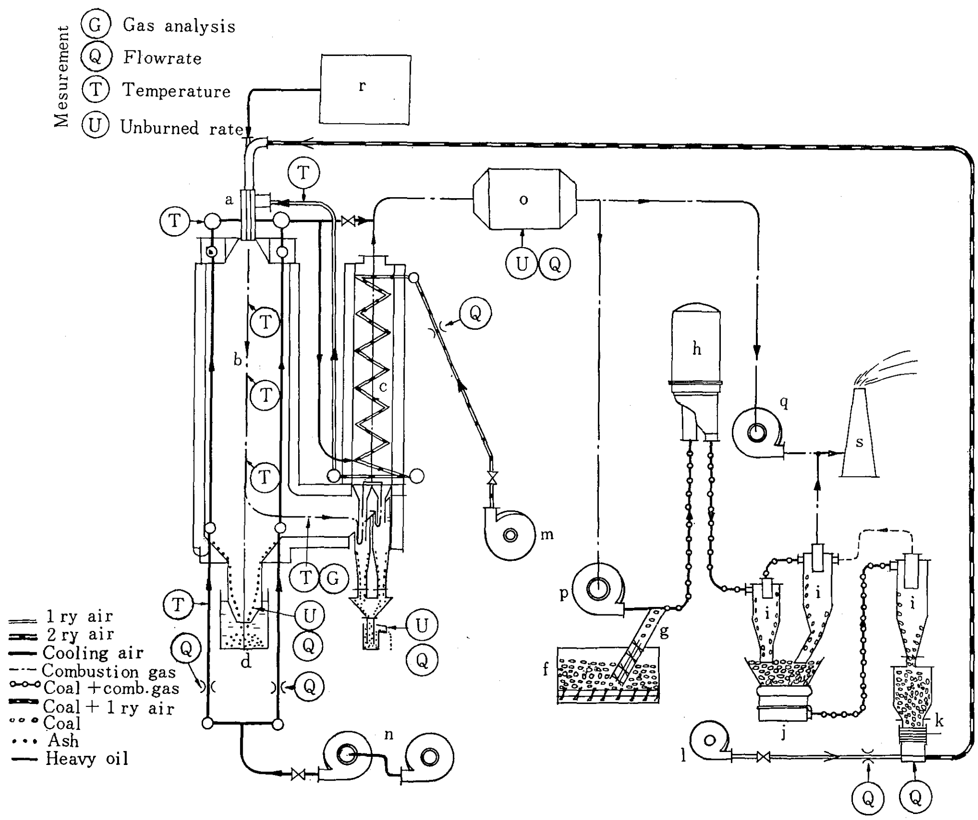


Fig. 5 Whole view of test apparatus



a: Burner
b: Combustion chamber
c: 2ry air preheator
d: Water sealed pit
e: Vibrated overflow system ash exhauster
f: Coal burner
g: Lift
h: Dryer
i: Cyclone separater
j: Pulverizer
k: Rotary valve
l: 1ry air blower
m: 2ry air blower
n: Cooling air blower
o: Electro-static precipitator
p: Blower for dryer
q: Induced fan
r: Heavy oil service apparatus
s: Chimney

Fig. 6 **Diagram of test apparatus**

Table 2 **Dimension of test apparatus**

No.	Name	Type and dimension	
1	Burner	Concentric swirling burner	
		Pulverized coal outlet diameter	68 mm
		2ry air outlet diameter	125 mm
2	Combustion chamber	Diameter × Height	1,000 × 3,000 mm
		Capacity	2.4 m^3
		No. of radiant heat pipes	25 ϕ × 60
		Heating area	14 m^2
3	Coal pulverizer	Centrifugal impact type	
		Fineness mesh 200 pass	70%
		Maximum capacity	250 kg/h
4	Coal dryer	Flash dry type	
		Maximum floating diameter	25 mm
		Maximum drying capacity	200 kg/h
		Inlet/outlet moisture	20/2%

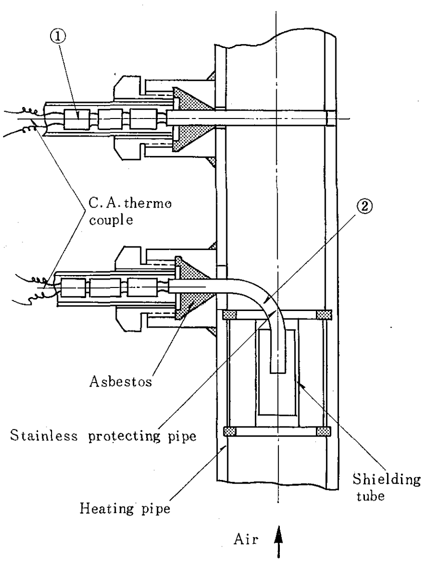
auxiliary heavy oil combustion apparatus is provided. After the tested coals are pulverized by the impact type pulverizer, they are stocked and supplied by the rotary valve to the burner with primary air. Furthermore, an auxiliary heavy oil combustion apparatus is provided.

2. Measuring apparatus

Coal feeding quantity is controlled by the coal feeding apparatus mounted on the pulverizer and revolution of rotary valve, and the quantity is decided from the correction curves which are previously calibrated for every coal. Grade of drying and fineness of pulverized coal are sampled and measured at the inlet of rotary valve. Quantity and temperature of primary air, secondary air and cooling air are measured by the orifice and the C–A thermo-couple, respectively. Furnace interior temperature is measured by PR suction pyrometer. *Fig. 7* shows the apparatus which is used for temperature measuring of cooling pipe air and pipe wall.

In every measurement, C–A thermo-couple is adopted and, especially for measurement of flowing air temperature, the ceramic-covered pipe is set up to reduce errors caused by radiation. For gas analysis, Orsat apparatus, magnetic oxygen meter and electric CO_2 meter are adopted.

Unburned loss is measured from the ash which gathers on the bottom of the furnace, the multi-cyclon and the electrostatic precipitator.



① Temperature of heating pipe wall
② Temperature of flowing air in the pipes

Fig. 7 **Measurement of temperature**

IV. QUALITY OF COAL

Coals used for the tests until now are listed in the *Table 3*. These 6 kinds of coals are different in the producing district and the process of coal selection, but their ratio of fixed carbon to volatile matter is 0.5—0.9 and high heat value ranges 3,000—3,800 kcal/kg, which belong to the so-called poor quality coal.

V. TEST RESULT

1. Unburned loss

Fig. 8 shows an example of the result of unburned loss test. This example shows only the case of

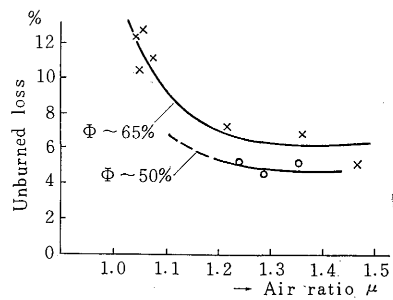


Fig. 8 **Relation between unburned loss and air ratio**

Table 3 **Nature of tested coal**

		coal A	coal B	coal C	coal D	coal E	coal F
		Washed fine coal	Washed fine coal	Slurry	Slurry	Fine coal	Fine coal
Industrial analysis	Ash %	48.99	54.68	45.88	52.69	47.6	52.6
	Moisture %	6.35	1.48	8.32	1.77	1.1	2.2
	Volatility %	29.05	27.99	26.83	27.26	26.9	24.7
	Fixed carbon %	15.61	15.85	18.96	18.28	23.4	20.5
	Total sulpher %	2.79	0.3	1.25	—	—	—
Highest calorific value kcal/kg		3,166	3,134	3,116	3,530	3,809	3,580
Ash refractories	Softening point ℃	—	1,300	1,150	1,210	>1,400	1,175
	Melting point ℃	1,330	1,450	1,211	1,250	—	1,250

testing coal F, but there is little difference from one another. The more cooling ratio increases, the more unburned loss increases. In case of an actual air heater, under considering of staying time of the coal grain in the furnace, pulverized coal size and conditions of the cooling surface, the unburned loss will be reduced to below 1% to be available for actual use.

2. Distribution of thermal intensity

Fig. 9 and *10* show examples of the distribution

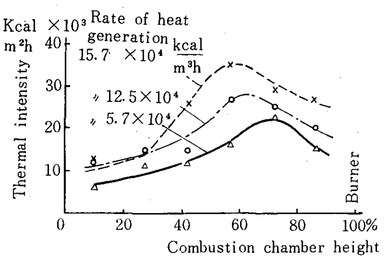


Fig. 9 Distribution of thermal intensity of heating surface

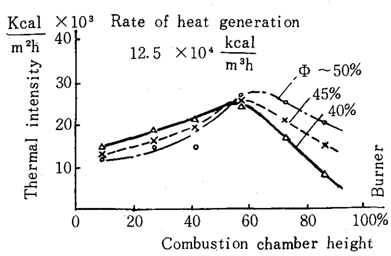


Fig. 10 Distribution of thermal intensity of heating surface

of thermal intensities calculated from the measurement of air and pipe wall temperatures of every position of pipe in the furnace.

The examples show the measurement on the tested coal C and a case of constant cooling ratio and a case of constant rate of heat generation. In the case of *Fig. 9*, the maximum intensity point is shifting downwards as the rate of heat generation increases. On the other hand, *Fig. 10* shows that the distribution curves are crossing each other as the cooling ratio increases and maximum points are gathered approximately at the same point. And the distribution shows a little elongation of flame.

3. Ash deposit

Fig. 11 shows the view of situation of the burner after high heat generation of coal D.

The melting points of both coal C and D are low and at the time of high heat generation clinkers were found out on the burner cone. In the case of other coals, the melting points are comparatively high and the birdnest was found out on the same

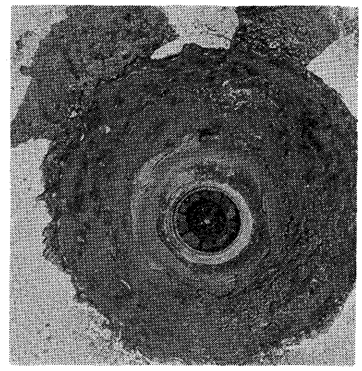


Fig. 11 View of burner tile clinker

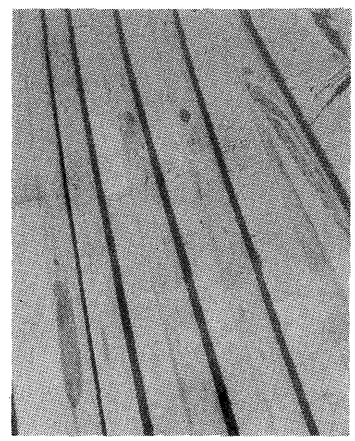


Fig. 12 View of pipe deposit

place. If these clinkers once appear, it is very difficult to take them off. By changing the form of cone and the wall temperature, appearance of these clinkers can be avoided. On the other hand, the deposits on the cooling pipes of furnace were thin powdery ash and were taken off easily by a sootblower. *Fig. 12* shows view of pipe deposit.

Melting temperature of these deposits at high temperature is rather lower than that of fuel ash. The compositions of them are very much different from each other and concentration of some materials can be found out (*Table 4*). As shown in the evaporation characteristic tests* of coal C, D, E (*Fig. 13*) alkali oxide evaporates in the high temperature fire flame and precipitates on the low temperature pipes and forms a basis layer, then on this layer flyash is gathered.

However, sulpher trioxide was not found out in the high temperature deposit, and by the evaporation characteristic test it was considered to be unevaporative within measuring error range. As to the ash deposit, it would be avoidable with a more suitable design of furnace, for example, temperature control of re-circulation of flue gas. In the extreme case, the ash trouble can be reduced by some additive.

Table 4 **Chemical composion of coal ash and pipe deposit**

	coal D		coal E	
	Coal ash	Pipe deposit	Coal ash	Pipe deposit
SiO_2	56.38	60.3	57.94	61.20
Al_2O_3	15.31	18.25	28.35	28.36
Fe_2O_3	5.40	3.20	3.54	2.40
CaO	17.45	12.37	9.00	4.22
Cl	0.01	0.01	0.01	Tr
SO_3	0.73	Tr	0.54	Tr
Na_2O	0.37	0.47	0.38	0.39
K_2O	0.53	1.71	0.49	1.08
Softening point °C	1,210	1,110	>1,400	1,170
Melting point °C	1,250	1,190	—	1,225

As to the effect of additive, the measurement results of compressive strength of flyash of coals C, D, E by the method which is introducedin the References (3), (4) are shown in *Fig. 14.*

At a certain temperature, the stronger compressive strength, the more pipe trouble occuvs by adherent. All three kinds of coals are effected remarkably with MgO as an additive. And it is understood that CaO makes the adherent strength greater at higher temperature.

* Loss on 2 hrs redhot of ash made at 500°C in 0.6 cm/S air-flowing
a: total loss *b:* Na_2O loss *c:* K_2O loss

VI. CONCLUSION

In the above section, we described outline of the results from the test of poor quality coal which has been performed with the testing furnace until now. From results of these tests, even if considering of reported errors, References (5), it is confirmed that the poor quality coal is available for actual air heater, and further we have obtained useful data.

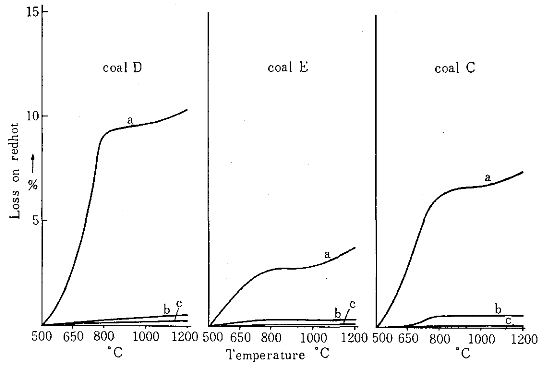


Fig. 13 **Evaporation characteristics of coal**

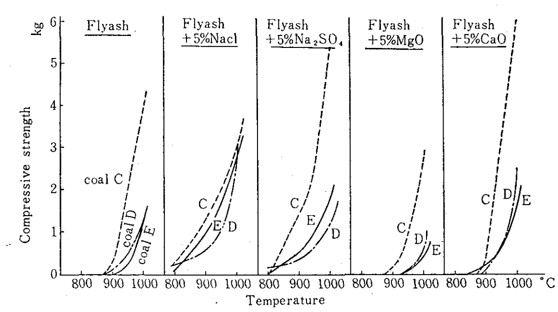


Fig. 14 **Compressive strength of flyash**

We hope to develope the application in this field under our experience with the operation of Toyotomi Power Station and the construction of the large capacity gas turbine delivered to Nippon Kokan K.K.

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Introduction of Products

FUJI MAXIMUM CURRENT INDICATING METER, TYPE AH 6 T

I. INTRODUCTION

In order to know whether or not the electric current meets the demanded capacity of distributors or distributing equipment, it is necessary to grasp the current and its variation conducted in the distribution line. For measuring these values maximum current indicating meter with split iron cores, type AH 6 T is newly manufactured by our Company.

This meter is used for measuring not only the current of a distribution line but also the maximum current at optional period.

As the meter is equiped with a split iron core type current transformer, when measuring, it can be inserted into or removed from the line very easily without breaking line or opening circuit.

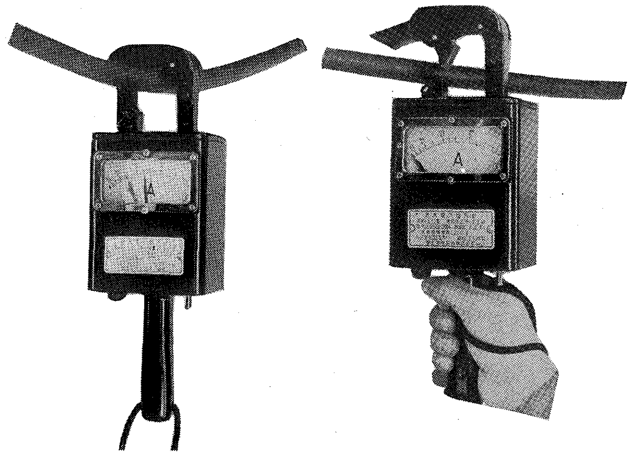

Fig. 1 Outer view of type AH6T

II. STRUCTURE AND PERFORMANCE

This meter consists of the converting part and the drive-indicating part and they are constructed to be a single unit.

The converting part is through type current transformer which converts the current into the operating current for the driving part, and by making and breaking its magnetic circuit, the meter is made to be inserted into the line easily and suspended without breaking the line. Making and breaking of the magnetic circuit is done by making use of the dead point of the spring, so even in case of measurment at high place, operation can be done easily and surely by one hand. The gap surface of magnet is covered with anti-corrosive metal cap and the iron core is coated with synthetic resin, so the meter is suitable for outdoor use.

The drive indicating part is a thermal type ammeter used bimetal and has two indicators, one is for showing the instant current value such as a general indicating instrument and other is for showing the maximum current during the measuring period. The drive indicating part consists of a driving bimetal having the superior deflection and the high specific resistance, and of a temperature compensating bimetal. Those bimetals are fitted with a same axis in order that those thermal displacement work negatively. When the meter is suspended in the line, the current proportional to the line current is conducted to the driving bimetal and generates heat in the bimetal itself, takes place a displacement and indicates the line current. The indication of the line current follows exponentially with regards to time, and the time required for indicating 90% of the line current, i. e. response time, is approx. 6.5 minutes. The maximum indicator is grease damped structure, sealed with special silicone grease, so it is stable against the exterior vibration and shock.

1. Rating

Working circuit :	220 V or less
Rated current :	100—200 A, 200—400 A
Frequency :	50/60 c/s

2. Characteristics

1) Current characteristics :

The error will be below ±2.5%, at 25~100% of rated current and ambient temperature 20°C.

2) Temperature charateristics :

Variation of error due to 10°C change of ambient temperature (between 0°C and 40°C) will be under 1.5%.

3) Sustained over current

This meter is capable of continuous use at less than 200% of rated current.

4) Other characteristics are in accordance with the JIS C 1102 "Indicating electric instrument".

3. Constants

1) Scale angle: 76°
2) Scale length: 75 mm
3) Full-load torque: 550 g-mm
4) Outer diameter of the measurable electric wire: 25 mm
5) Net weight: 1.8 kg

(*By* K. Shimoda, Matsumoto Factory)

FUJI MAXIMUM AND MINIMUM VOLTAGE INDICATING METER, TYPE VH 1 PR

I. INTRODUCTION

In order to supervise and stabilize the quality of distribution power, it is necessary to grasp the voltage regulation of the distribution line. For the measurement of this voltage regulation we have accomplished a maximum and minimum voltage indicating meter, type VH 1 PR.

This meter is used for measuring the maximum and minimum voltage at optional period and suitable for the patrol measurement of the distribution line. This meter is portable, outdoor use type, and provided with the clamp mechanism of minimum indicator to prevent the indicator from going back to zero point under no potential state.

II. STRUCTURE AND PERFORMANCE

This meter is a thermal type voltmeter used a bimetal, and is equipped with three indicators, which consist of a driving indicator showing the present voltage such as a conventional voltmeter, a maximum indicator showing the maximum voltage and a minimum indicator showing the minimum voltage during the measuring period. Especially the minimum indicator has a clamp mechanism so as the minimum indicator to remain at the same position even when the meter is free from the measuring circuit and the driving indicator is returned to zero point. The driving indicator consists of a driving bimetal having the superior deflection characteristic and the high specific resistance, and of a temperature compensating bimetal. Those bimetals are fitted with a same axis in order that those thermal displacement work negatively. The electric current proportional to the line voltage is conducted to the driving bimetal through the transformer contained in the meter, and it generates heat in the bimetal itself, takes place a displacement, and indicates the line

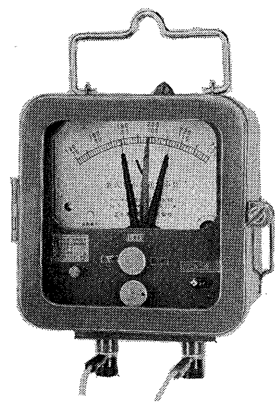

Fig. 1 Outer view of type VH1PR

voltage. According to the variation of the line voltage, the driving indicator drives the maximum and the minimum pointer and indicates the maximum and minimum voltage of the line. The minimum scale is 80/160 V at the meter of rated voltage 130/260 V, 70/140 V at the meter of the rated voltage 120/240 V, and the indication below this value is locked mechanically, so the measuring scale is enlarged substantially. The indication of line voltage follows exponentially with regards to time, and the time required to reach 90% of the line voltage, i.e. response time, is approx. 3.5 minutes. The maximum and minimum indicators are grease damped structure, sealed with special silicone grease, so are stable against the exterior vibration and shock.

1. Rating

Working circuit: 110 V, 220 V (applicable to the both voltage)
Rated voltage: (1) 130/260 V (double ratio)
(2) 120/240 V (double ratio)
Frequency: 50/60 c/s.

2. Characteristics

1) Voltage characteristics:

Error will be under ±1.5% at the ambient