during the initial stage of the governing valve movement. However, the larger pressure drop is observed after a certain position of the valve opening.

This is due to the reduction in steam inflow at the same governing valve opening caused by the change of the main steam characteristics by the other reason.

d. Drum level & feedwater flow

In normal reduction of load, drum level will be lower corresponding to the temporary drum pressure up due to the negative response and will rise afterwards. But, sharp increase of the drum level with the load variation shown on the actually recorded chart means the amplified negative response in feedwater flow before the feedwater compensation signal generated by the level controller corresponding to the drum level change. After that drum level lowering signal is added by the detection of drum level high onto the aforementioned phenomenon, which changes feedwater flow with the over gradient for balancing governing valve, main steam flow and feedwater flow.

Fig. 4-5 ABC System Disturbance due to Over-responce of Feedwater Control System under Constant Plant Load

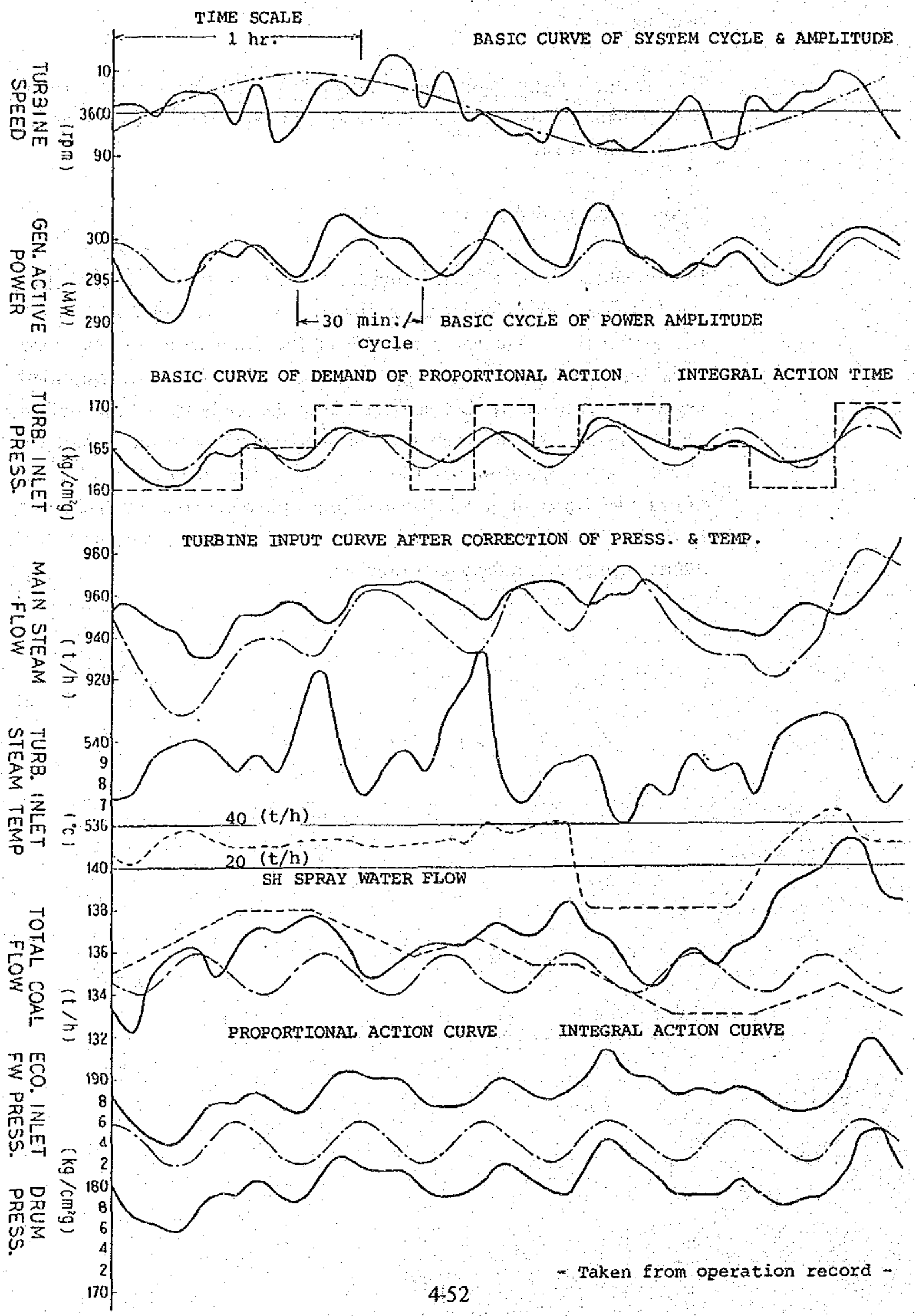
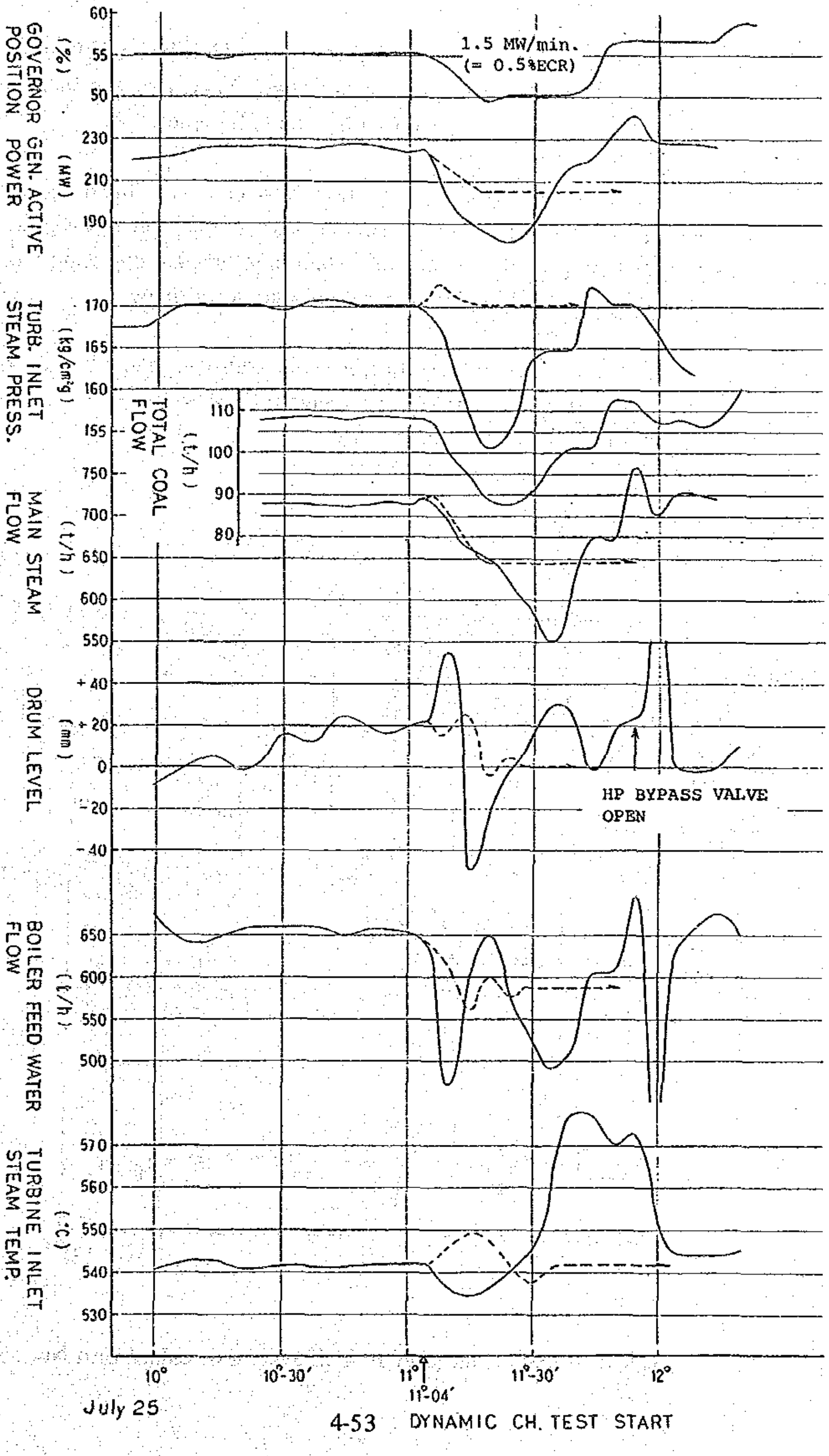


Fig. 4-6 ABC System Disturbance due to Over-reduction in Feedwater Flow caused by Change in Load Corresponding to Governing Valve Actauation



(5) The Present Condition of ABC System of Calaca Unit No. 1

The design specifications of ABC for Calaca Unit No. 1 is basically a conventional system on the basis of such design concept of the plant as base load coal-fired thermal power plant with drum type boiler.

The point on which special attention must be paid is the about 30 seconds of additional time lag of the boiler peculiar to the coal firing power plant and the management of the control system must involve due consideration on the time delay between boiler input and output accordingly.

At the same time proper coordination is also needed for individual control systems of feedwater and steam through the boiler drum.

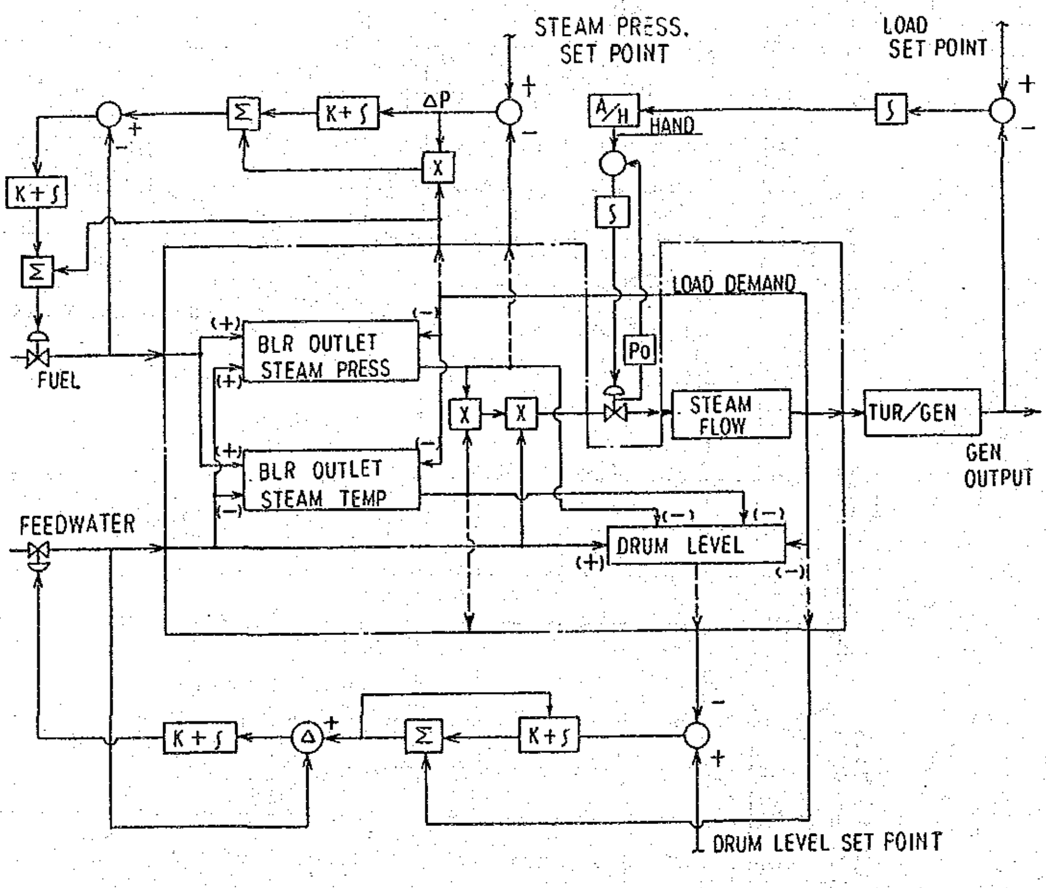


Fig. 4-7 Present Condition of ABC System of Calaca Unit No. 1

The problems identified in the ABC system through the investigation on the actual ABC performance and actual results of the survey of this time are described in the following.

a. The design concept to adopt the first stage pressure of the turbine as the load demand signal is not suited for the plant process which has fluctuating tendency.

   First stage pressure of the turbine needs constant steam condition at the governing valve inlet to act as the basic demand signal for controlling of the boiler input to correspond to the target generator output, and the existing control system can not perform the required function should there be any hunting factors in the control system.

b. The stability of this control system is greatly dependent upon the proper selection of pressure/load ratio in the fuel demand.

   Usual figures of that ratio in this kind of process lies at 0.2/0.8, however, it is supposed that the present ratio is much larger than these figures or proper consideration during initial adjustment is insufficient.

c. The cascaded system of feedwater control and drum level control involves inherent difficulty in adjustment for the coordinated control system of both controls because of the limited frequency band in the frequency response.

   Current control system adopts summarizing system of error signals of feedwater control and drum level control to make the combined signal input of the controller.

d. The most serious problem of the control system revealed by the survey of this time is the insufficient tuning of the control system, most probably, due to the insufficient time for adjustment during the trial operation.

   The normal means of tuning is as follows;

   a) On the basis of the static characteristics data of the boiler having plant load as parameter, balance diagram of plant variables shall be prepared. (Heat balance diagram prepared at design stage will be sufficient.)

b) Process performance characteristics corresponding to the full range of the drive units (for valves, dampers, etc.) shall be determined by the actual measurements and/or assumptions. This is one of the most important work for the adjustment of ABC system.

For example, the attached characteristics curve of the feedwater control shows extraordinary curve of the feedwater flow versus input demand. Refer to Fig. 4-8.

c) In the next place, simulation shall be made in writing by varying the generator output, in such a way as to obtain linear response of all drive units and controlled processes by distributing the feed-foward signal to them.

The factors to be considered at this stage are to make a study on the necessity of inserting function generators in the transfer system or actual feedback system.

As far as the present observation concerned, some function generators seem to be lacking.

d) Final adjustment shall be made through tuning by cut and try method of the integral function of the minor loops to be added to the basic control function.

e. The improvement in the stability of the existing ABC system, which can be expected by readjustment, will be expressed as follows on the basis of the plant load change by 3% ECR/min.

Main steam pressure:	± 2 $kg/cm^2 g$
Main steam temperature:	± 5 °C
Drum level:	±10 mm
Generator output:	± 2 MW

The above improvement will be possible provided that the plant will be operated under load limit mode.

f. Stable plant operation under the coordinated control mode between LMC and ABC needs some more additional functions in the control system even after the readjustment of ABC.

The improvement plan for the above coordinated control is presented in the Chapter 8.

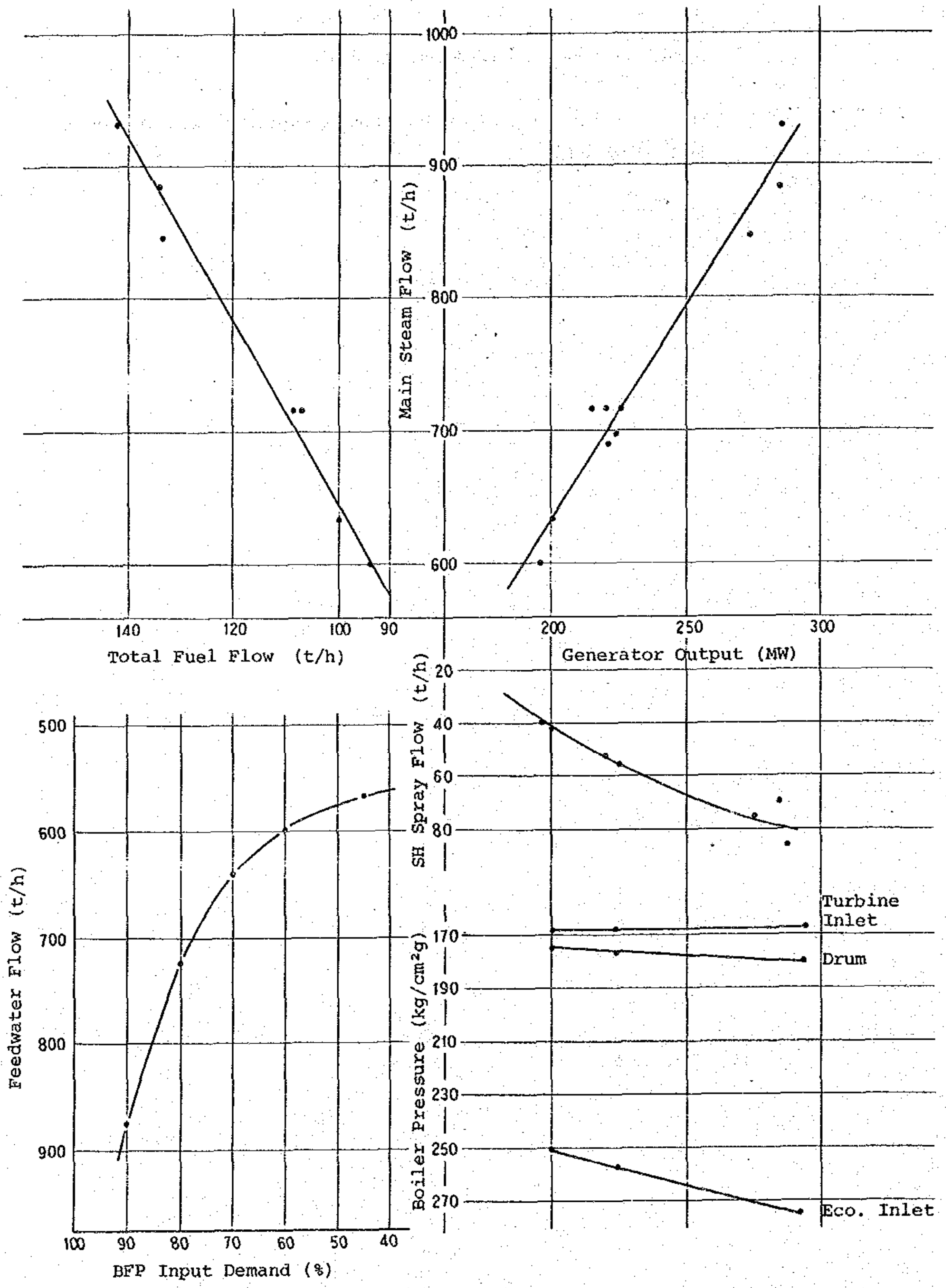


Fig. 4-8 Characteristics Curves of Main Operational Factors

5. Boiler Combustion Test

5. Boiler Combustion Test

5-1 Purpose of Combustion Test

The prupose of the combustion test is to seek for the maximum blend ratio possible of Semirara coal and Australian coal aiming at 100% use of Semirara coal as the ultimate target by conducting the combustion test with Calaca No. 1 boiler with coals of various blend ratios, and to establish a stable combustion system after confirming the combustion test results.

5-2 Results of Combustion Test and Evaluation

Combustion tests were conducted with three (3) stages of burners, A, B and C burners corresponding to A, B and C mills, because the D mill for the lowest stage burners was out of order.

Even though there were some limiting factors such as restriction in the steam temperature control, flue gas temperature high, etc. in the process of the combustion test, the possibility of continuous operation of the plant with the coal of 60/40 blend ratio of Semirara and Australian coals was confirmed by the test.

It is regretted, however, that because of the severe power demand/supply situation caused by the unusual drought and the trouble of D mill, some of the tests, like some load variation tests, combustion test with all (four) mills, etc. could not be carried out.

5-2-1 Result of Combustion Test

As the result of the combustion test, the optimum O_2 value in flue gas for stable combustion has been obtained and the proper air port damper positions for flame stability were established. Before the combustion test by JICA, Calaca Unit No. 1 was operated with low oxygen content in the flue gas (about 2.5% at 300 MW load) and 50% opening of the lower air port damper (wind box draft of 50 mmAq at 300 MW load and zero or negative draft at 225 MW load) to avoid slagging and fouling of the boiler furnace.

At the first glance, the combustion condition of the boiler under normal plant operation looked to be fair, but careful observation of the burner flame at 225 MW load revealed that there was no whirl or agitation of flame by the secondary air. And the stability of combustion was doubtful and the combustion adjustment was necessary.

5-2-2 Reduction of Unburnt Carbon in Ash

As mentioned above, by the increase of the excess air and the adjustment of lower air port damper, sufficient reduction of unburnt carbon in EP ash was attained.

1) Though there were only a few past data available of unburnt carbon in EP and economizer ash during the plant operation at 300 MW load with S/A:50/50 blended coal from August 1986 to February 1987, the unburnt carbon in the EP and economizer ash were as follows:

EP :	9.57–13.04%
Economizer:	3.64–14.27%

2) From February 1987 to July 1987 (Plant operation with S/A:50/50 and 55/45 blended coal before the combustion test: According to the explanation by the first JICA survey team of the necessity of regular unburnt carbon measurement of EP ash and the suggestion as to the means for reduction of unburnt carbon content, Calaca Power Plant had tried combustion adjustment by themselves.)

EP :	2.31–7.68%
Economizer:	4.02–13.42%

3) Results of Combustion Adjustment (Blend Ratio S/A:60/40)

EP :	2.03–3.30%
Economizer:	2.24–7.32%

As for the transition of unburnt carbon, etc. by combustion adjustment, refer to Figs. 5-1 and 5-2 attached.

5-2-3 Test for Increase of Local Coal in Blending

1) Operation with S/A:70/30 Blend Ratio

The combustion test results with S/A:70/30 blended coal and A, B, C mills operation are as shown in the following. (Further combustion test by NAPOCOR is requested with the coal of same blend ratio and B, C, D mills operation after the overhaul scheduled in October 1987.)

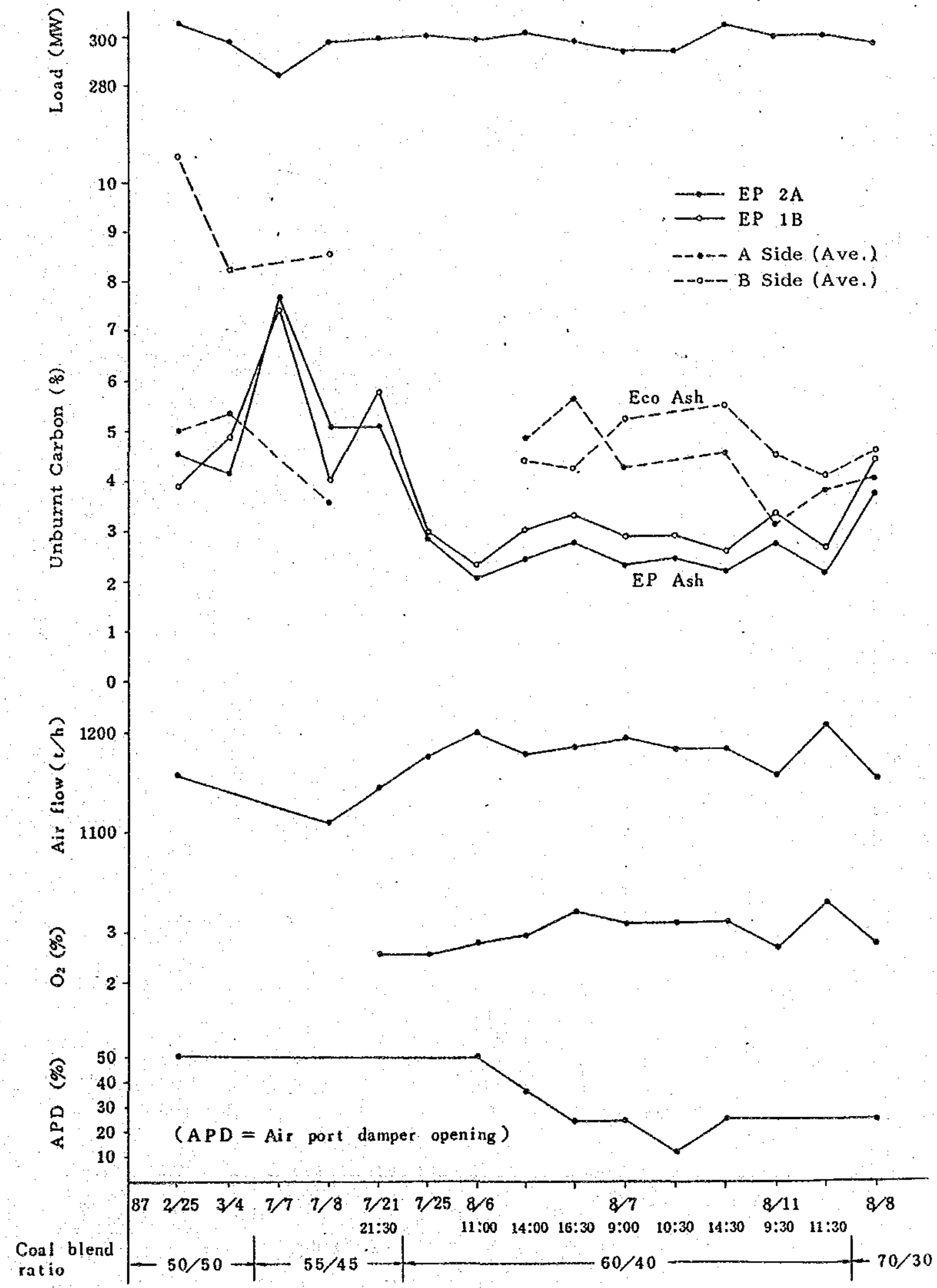


Fig. 5-1 Unburnt Carbon of Ash at 300 MW (A, B, C mill)

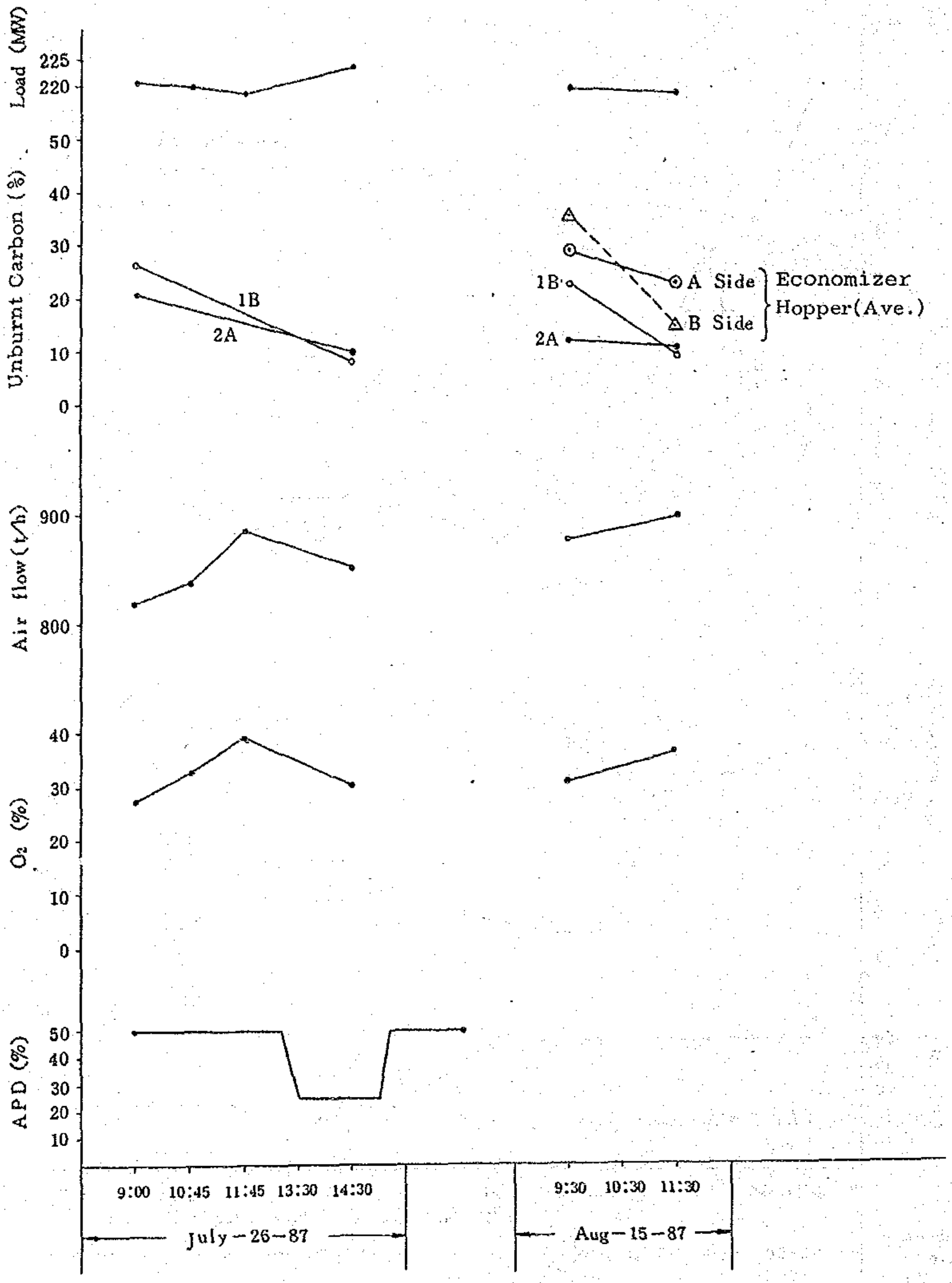


Fig. 5-2 Combustion Test (SSC 100% with A, B, C mill)

Data of static characteristics test of the boiler with 200 MW, 225 MW and 300 MW load each could be obtained.

Rated output, 300 MW, could actually be attained with 70/30 blended coal, but the following problems were encountered.

a. Ash clogging took place at economizer hoppers on the B side (No. 3 and 4 hoppers) just before the load reached 300 MW. (The clogged ash was rather fragile and easy to crush.) Inspection of the economizer hopper inside revealed that there were many sparks (burning ash) falling onto the hopper bottom.

b. Once an increase of O_2 was considered, but as the superheater spray control valve was already fully open, further combustion adjustment was given up with this coal blend ratio because the steam temperature control with the operation of A, B, C mills located on the upper part was judged difficult.

2) 300 MW Operation with S/A:60/40 Blend Ratio

Optimum O_2 value	:	3 to 3.5% (Nearly 3%)
Lower air port damper opening:		25%

The performance of the plant with 60/40 coal blend ratio was fair, and stabler operation can be expected by the use of B, C, D mills in lieu of A, B, C mills. However, it is necessary to take the quality of coal ash characteristics into consideration.

3) SSC 100% Combustion at 225 MW Load

When 100% SSC (Selected Semirara Coal) firing was tested, primary hot air damper was fully open due to high moisture content of the coal. The total moisture of the test coal was 26.8%, which is much higher than the design value of 19%.

Combustion adjustment under this condition by closing of lower air port damper, however, had an adverse effect on the combustion, i.e. longer black skirt of the flame.

On the other hand, increase of O_2 value (excess air) from 3% to 3.5% resulted in better and stabler combustion and reduction of unburnt carbon in the EP ash.

The following values are recommended when 100% SSC is burned.

Optimum O_2 Value	:	3.5%
Lower air port damper opening:		50% (Same as at present)

5-2-4 Dynamic Characteristics Test of Boiler

Load increase and decrease test of a total of 15 MW at the load variation rate of 2 MW/minute was conducted with boiler master "Auto" as the dynamic characteristics test of boiler.

In the process of load decrease, the fuel demand signal was too quick and over-reduced the coal feed, resulting in an over dip of the main steam pressure. After the load decrease was finished, the coal feed delayed in recovery and entailed long pressure recovery time to the rated pressure, showing poor pressure response of the boiler control to load variation.

And also, the drum water level fluctuated widely especially at the moment when the high pressure turbine by-pass valve was opened by the excessive rise of the main steam pressure, and it took quite a long time before the drum level was stabilized.

Superheater and reheater steam temperature control was generally acceptable since sootblowing was carried out effectively to bring down excessive rise of the steam temperatures, even though there happened sometimes full opening of the superheater spray control valve owing to excessive steam temperature rise.

Judging from the results of the dynamic characteristics test, the adjustment of both control systems for main steam pressure and feedwater flow seems to be insufficient and needs urgent readjustment.

The Automatic Boiler Control (ABC) system of Calaca Unit No. 1 is a similar type to those used in Japan and can be readjusted without difficulty. Therefore, the functioning of those control systems can be made normal to assure stable plant operation by calibrating the operational units and sensors during the overhaul of the plant and by securing some period of time for readjustment and testing of ABC and other controls after the overhaul.

5-2-5 Static Characteristics Test of Boiler

1) Fineness Test (Refer to Fig. 5-3.)

The 100-mesh-residue regarding the pulverized coal fineness which affects the unburnt carbon content in the ash was about 5%, however, the target of the 100-mesh-residue should be less than 4% at least. And in the case of the exclusive firing of Semirara coal, the 200-mesh-residue will increase in comparison with the case of the blended coal firing.

Therefore, the pulverizing capabilities of the mills should be examined and the method to maintain the pulverizing capabilities should be established.

2) Static Characteristics Test (Refer to Fig. 5-4.)

Judging from the mass balance of boiler input and output with the parameter of loads during the static characteristcs test with the coal blending ratio S/A: 60/40 as shown in Fig. 5-4, the steam flow and the feedwater flow were nearly as design value, but the fuel was supplied more than the design value for each load.

The causes of excessive fuel supply are judged due to the high moisture content of the fuel coal and the decrease of efficiencies of the combustion and the heat transfer.

However, in the combustion adjustment during the period of the test, the total fuel flow at 4/4 load was decreased to the design value, and the improvement of the combustion efficiency produced a good effect. Namely the plant efficiency was also improved by the decrease of the total fuel flow.

Though the air flow was balanced at lower value than the design value, it was confirmed by the data of the combustion adjustment that the excess air for the combustion was not enough. Flue gas O_2 should be kept at 3% to 4% during high load.

3) Black Skirt of Burner Flame (Refer to Fig. 5-5.)

The black skirt length judged by visual observation is a very important factor for evaluation of the combustion. From the relation between the black skirt length and the load before the combustion adjustment as shown in Fig. 5-5, it was observed that the black skirt length is within 50 cm under the good combustion.

The black skirt length at 200 MW load was in proportion to the thermal load of the furnace from the lower stage to the upper stage, and the length at 225 MW to 280 MW was in proportion to the fuel flow. It was remarkable that the black skirt length of the B-stage burners became shorter at the load over 220 MW.

As the above reason, the surrounding temperature of the B-stage burners became high because the burners were sandwiched by A and C-stage burners, and the ignition of the B-stage burners was stabilized.

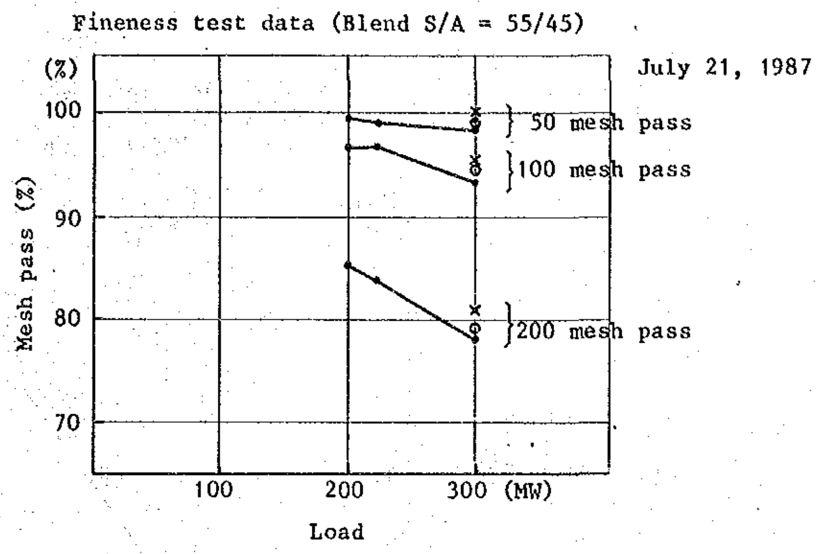
Since the temperature of the furnace became high around the full load, the ignition of the all stage burners was stabilized.

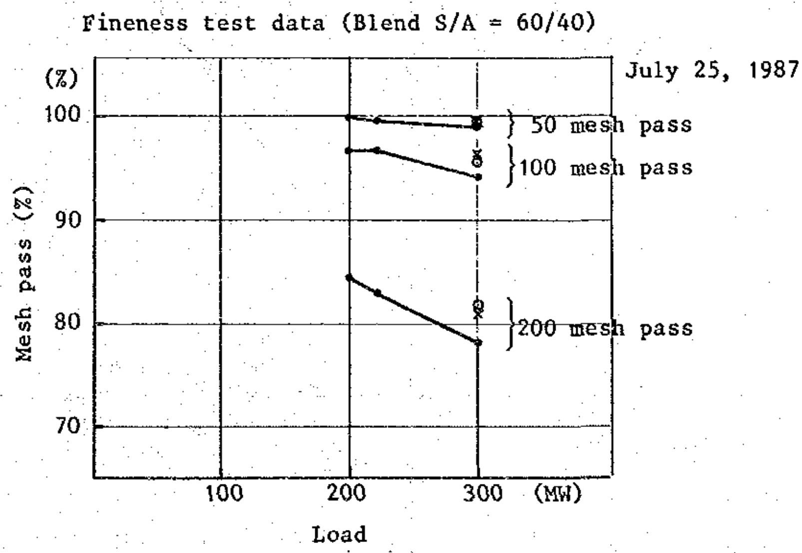
As the characteristics of the combustion at the B-side furnace, the black skirt length of A and B-stage burners were nearly same, and that of the C-stage burners was longer than those of the other stage burners due to improper distribution of the air to the B-side. Same black skirt length of both sides can be obtained by the optimum distribution of the air.

In the next combustion adjustment, the pressure of the burner wind box was raised by closing the lower air port damper to increase the secondary air flow through air register and necessary data was obtained as shown in Fig. 5-5.

As the results of the combustion adjustment for all stage burners of the A-side furnace the black skirt lengths were kept within 50 cm and that of C-stage burners of the B-side furnace became nearly the same as those of the A and B-stage burners.

For further improvement of the combustion, the combustion zone can be lowered and the dead space of the combustion at lower part of the furnace can be decreased by operation of the lowest stage burners (D mill operation), and the temperature around the lowest stage burners will be kept high, and the stable combustion of the lower stage burners will be expected and the stable combustion of all stage burners will be attained.





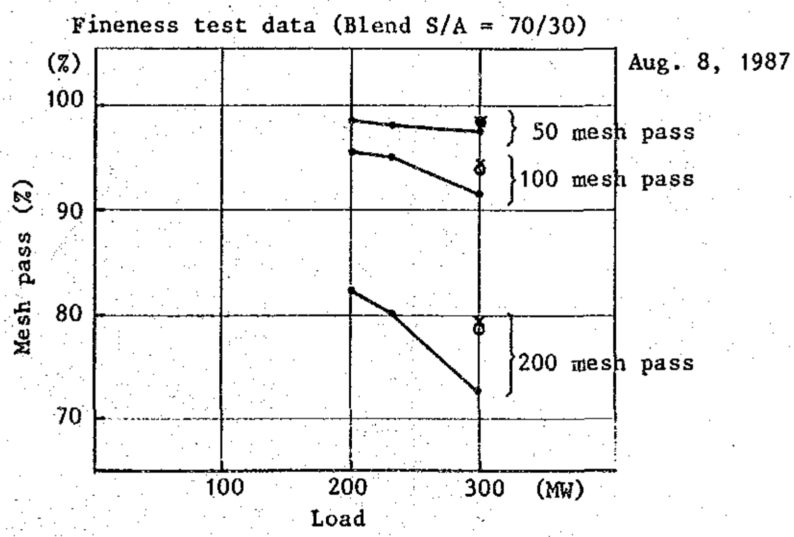


Fig. 5-3 Fineness Test

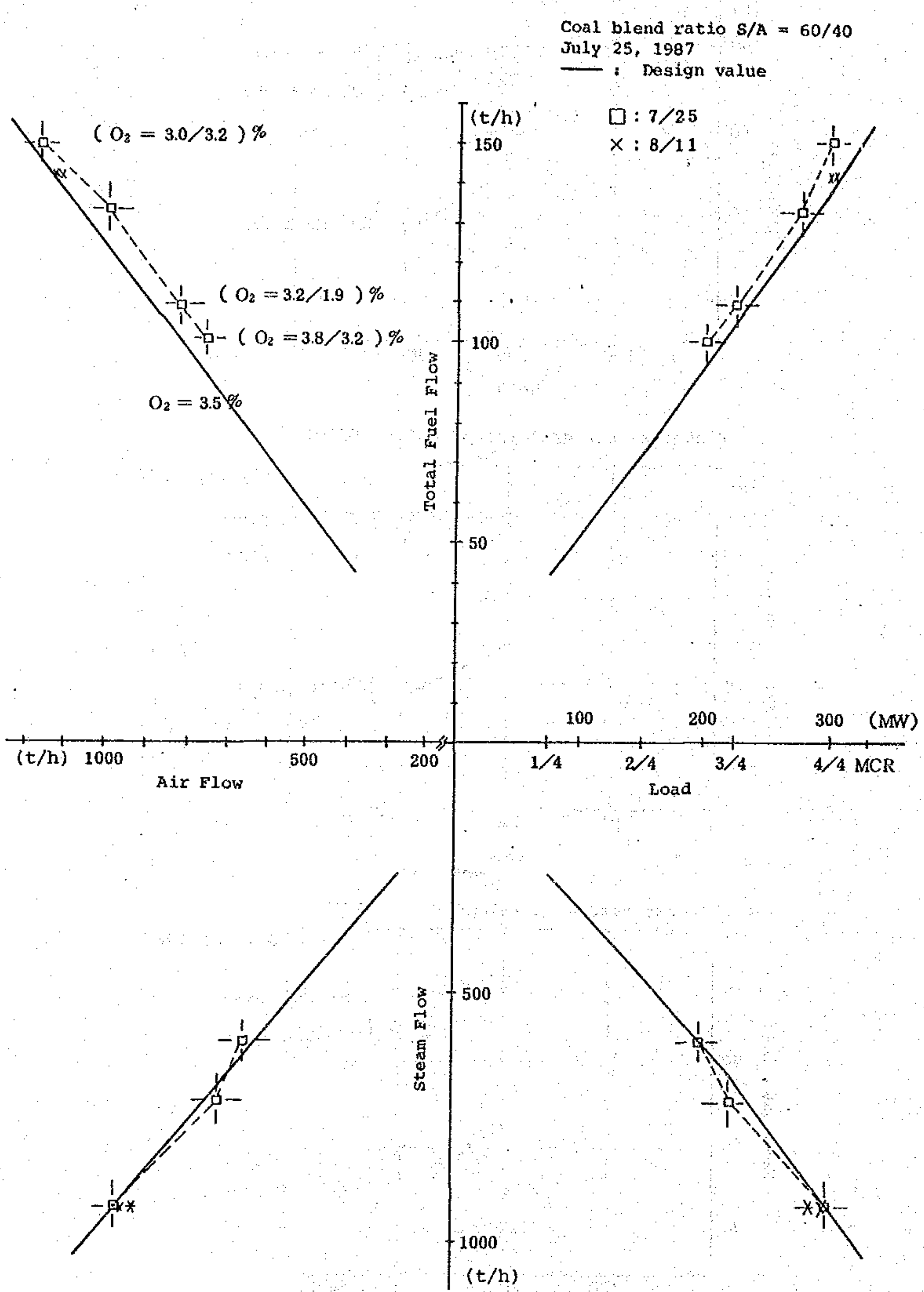


Fig. 5-4 Mass Balance of Boiler Input and Output

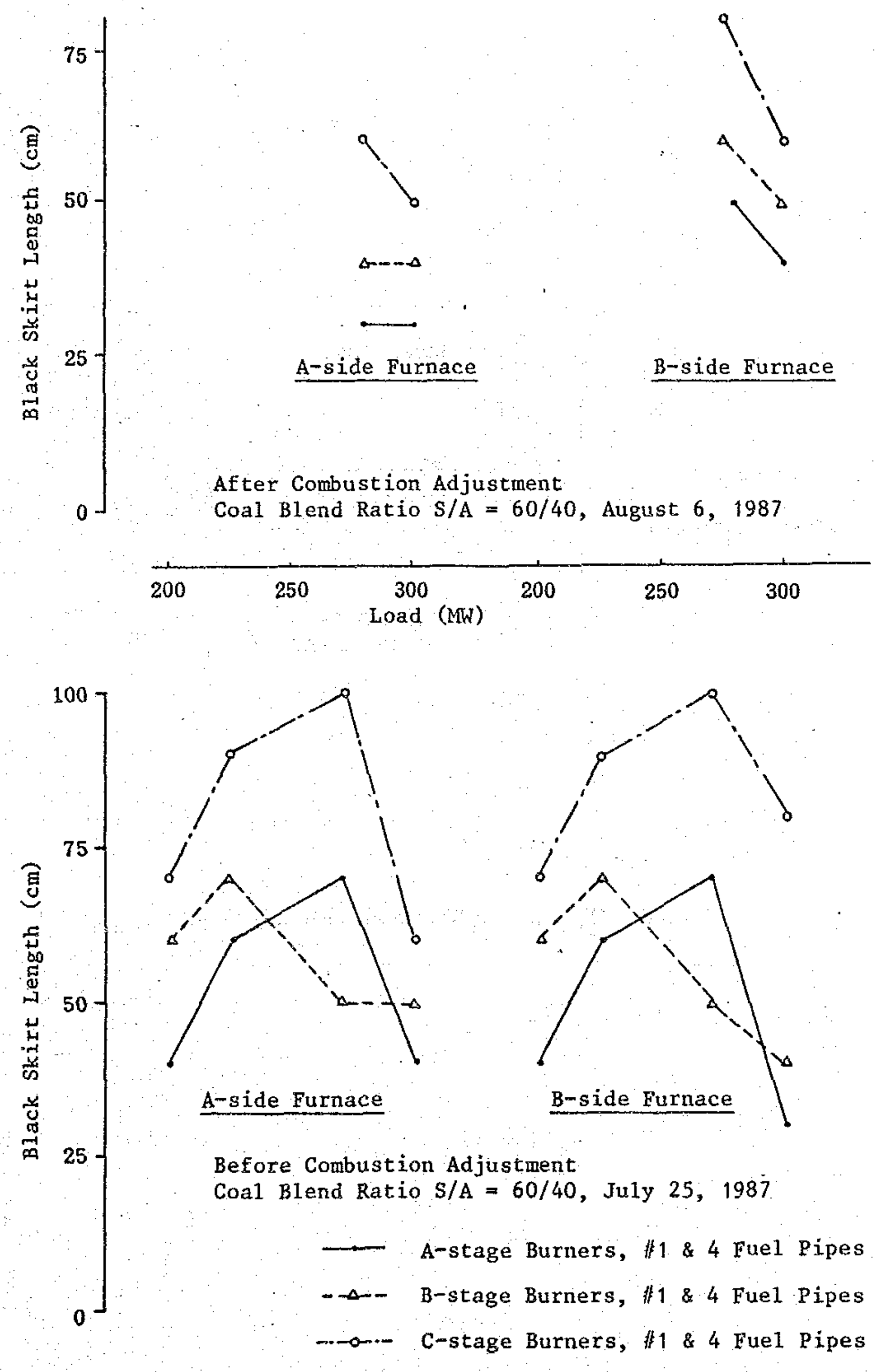


Fig. 5-5 Black Skirt Length Characteristics

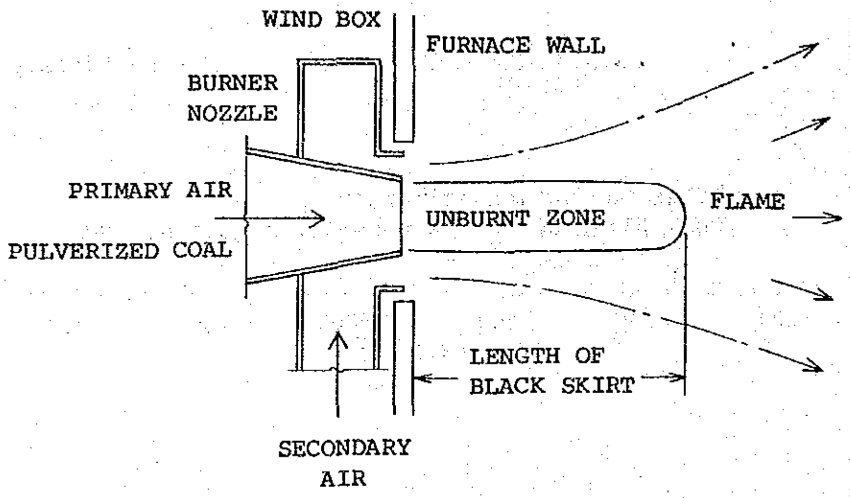


Fig. 5-6 Definition of Black Skirt of Burner Flame

5-3 Combustion Test Items and Schedule

5-3-1 Combustion Test Items

Summary of the combustion test items for each test coal is as shown in Table 5-1.

Table 5-1 Combustion Test Items

Kind of Test	Kind of Test Coal Blend Ratio: Semirara Coal/Australian Coal (S/A)			
	S/A:55/45	SA/:60/40	S/A:70/30	Semirara Coal 100%
1. Mill Performance Test (Fineness test)	o	o	o	o
2. Static Characteristics Test	o	o	o	o (For 225 MW)
3. Dynamic Characteristics Test	o	o	o	—
4. Combustion Adjustment Test				
(1) Excess air (O_2) variation test	o	o	o	o
(2) Wind box draft variation test	o	o	o	o
(3) Mill outlet temp. variation test	—	o	—	o
5. Maximum Output Confirmation Test	o	o	o	o

5-3-2 Purpose of Individual Tests and Implementation

1) Mill Performance Confirmation Test (Fineness Test)

Fineness of coal is one of the deciding factors for good combustion. Normally 200 mesh fine coal should account for 80% or more of the total pulverized coal for optimum combustion at the maximum output of the power plant.

This coal condition, however, can be attained on the basis of good coal grindability, appropriate gap between mill rollers and crushing table, primary air flow and normal classifier vane condition which controls fine coal circulation in the mill. Therefore, mill inspection and adjustment was expected before the combustion test, but because of the very strict power supply/demand condition of the Luzon grid and time constraint, the overhaul of only two (2) mills (A and D mills) could be finished.

Further, D mill could not be used during the combustion test because of the leak of D-3 burner barrel by erosion.

Since the drive units of the classifier vanes of all coal mills were out of order, check of the combustion condition by variation of coal fineness could not be carried out. Therefore, the mill performance test to observe the change in coal fineness was conducted with fixed classifier vane position, only by changing the power plant load. The results of the test are as shown below.

Table 5-2 Fineness of Pulverized Coal

#200 mesh pass (%)

Blend Ratio (S/A)	55/45			60/40			70/30			100% SSC
Load (MW) / Coal Mill	200	225	300	200	225	300	200	225	300	225
A	–	–	79.38	–	–	81.79	–	–	78.72	77.54
B	–	–	81.00	–	–	81.07	–	–	79.05	73.43
C	85.13	84.36	78.44	83.10	83.72	78.80	82.40	80.58	72.98	70.26

2) Static Characteristics Test of Boiler

In order to judge the optimum blend ratio, the static load characteristics of boiler corresponding to the parameters of coal blend ratio, and the steady state data of boiler output versus coal supply were investigated for each test coal.

The samples of the above coals were collected at the coal feeder and the transfer tower during the combustion test.

3) Dynamic Boiler Characteristics Test (Load Change Test)

For the stable operation of the boiler firing the coal of low calorific value, proper back up of ABC system matching to the dynamic characteristics of the boiler is necessary.

Therefore, by applying several magnitudes and rates of load variation under automatic operation mode, the transient response of the boiler was analyzed to attain the optimum adjustment of combustion of the boiler.

But, insufficient adjustment of ABC system was revealed, as mentioned in Items 4-1 and 5-2 of this report, by unstable performance of boiler system, and especially by quite slow response of fuel control system to the change in the turbine throttle pressure.

4) Maximum Load Test by Increase of Local Coal Blend Ratio

The boiler load was gradually increased from 3/4 to 4/4 with specific blend ratios of fuel to find the maximum limit of output.

The maximum limit of the output was judged on the basis of forecasted point by the data of static characteristic test and estimated boiler process performance versus time duration by the data of dynamic characteristics test.

The limiting factors of output which come from the coal blend ratio were those like excessive steam temperature rise and moisture content of the coal, due to the operation of three mills from the top (A, B, C mills) caused by the unavailability of D mill and capacity of hot primary air.

5) Excess Air Test (O_2 Test)

In the boiler furnace combustion process, excess air controls the distance of ignition point from the burner mouth and residence time.

For instance, if the combustion time is made longer by low O_2 operation, generated NOx will be less, but the longer flame length will cause partial overheating of the furnace wall facing the burner. The urburnt carbon in the ash will increase due to imperfect combustion and cause heating surface clogging. The above phenomenon means the apparent reduction in boiler furnace volume and eventual limit of the boiler output.

Therefore, the behavior of coal ash was monitored by operating the boiler with the excess air of more or less 3 to 3.5% of O_2.

Before the combustion test, as Calaca Unit No. 1 was being operated under low O_2 condition and high unburnt carbon in ash was resulting, combustion adjustment was conducted this time to obtain the optimum O_2 value.

6) Wind Box Draft Test

This test was carried out for the purpose of investigating the flame stability and determining the optimum wind box draft by controlling the draft in the wind box which affects the flame propagation velocity.

Past operational data of the wind box draft show 115 mmAq at 300 MW at the time of commissioning, but the current operational data show a low value of 50 mmAq.

The adjustment of wind box draft during the combustion test was carried out by controlling the secondary air port damper installed on the lower portion of the boiler as a deslagging countermeasure.

7) Coal Mill Outlet Temperature Test

In coal-fired thermal power plants in Japan, the coal mill outlet temperature is maintained at approximately 80°C, irrespective of dry coal or wet coal. On the other hand the coal mill outlet temperature at Calaca Power Plant is low at 66°C.

This low temperature seems to be adopted because of the lignite characteristics of SSC, high volatile content, and resulting easy ignitability.

In the combustion test, raising the outlet temperature to 80°C was tried to confirm the improvement of combustion.

5-3-3 Combustion Test Schedule

The actual combustion test schedule is as shown in Table 5-3 "Combustion Test Schedule (Actual)".

5-4 Analysis of Test Coal and Ash

5-4-1 Preliminary Analysis of Test Coal

The samples of the coals used for the combustion test were sent from NAPOCOR to Japan for analysis in the end of June 1987.

The analysis of the above coals are as follows;

1) Samples

Selected Semirara Coal (SSC):		5 samples, taken from delivery No. 199 to 203 (5 shipments)
Australian Coal (AC)	:	2 samples

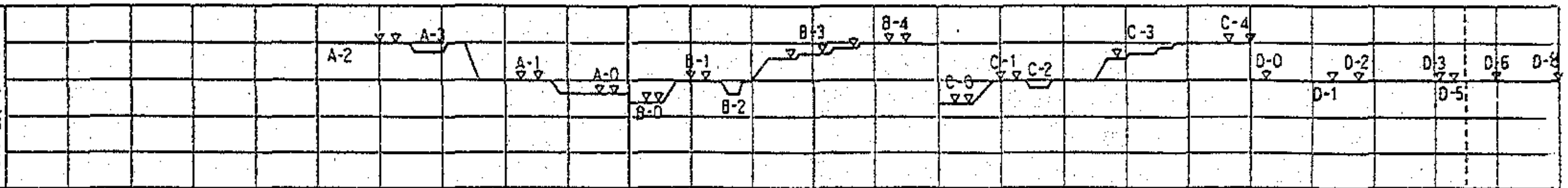
2) Items of Preliminary Analysis

a. Proximate analysis and calorific value
b. Ultimate analysis
c. Ash analysis (9 items)
d. Ash fusion temperature
e. Coal grindability

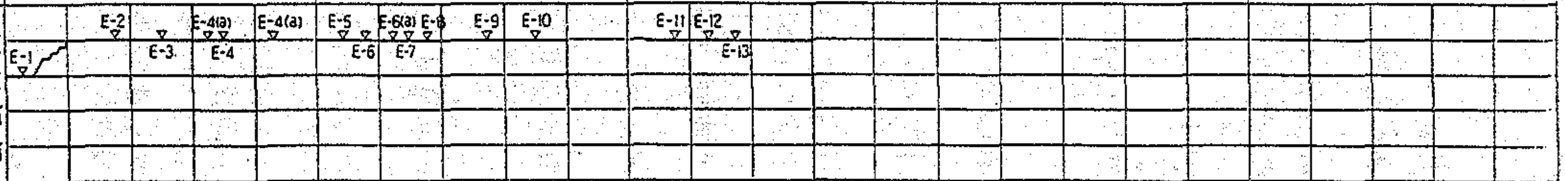
3) Results of Analysis

Results of analysis of Selected Semirara Coal used for the combustion test is shown in Table 6-1.

Table 5-3 Combustion Test Schedule (Actual)



Load Change Pattern	(chart above)				
		21 23 1 3 July 21 / July 22	10 12 14 16	10 12 14 16	10 12 14 / 10 July 26 / Aug. 15
Coal blend ratio (Semirara coal/ Australian coal)	Meeting on testing	55/45	60/40	70/30	SSC 100%
Test Item	Preparation for test and rehearsal	Static and dynamic characteristics test	Static and dynamic characteristic test, and load increase test	Static and dynamic characteristic test, and load increase test	Combustion adjustment test and static characteristic test
Purpose of Test	—	To obtain basis of blend ratio and characteristic of boiler response, and unburnt carbon measurement	Monitoring of boiler performance (Furnace monitoring and unburnt carbon measurement) Comparison of data, check of test continuity	Monitoring of boiler performance (Furnace monitoring and unburnt carbon measurement) Confirmation of maximum available output.	Combustion adjustment
Date of Test		July 21 and 22, 1987	July 25, 1987	August 8, 1987	July 26 and August 15, 1987



Load Change Pattern	(chart above)				
	10 12 14 16	10 12 14 16	10 12 14		
Coal Blend Ratio (Semirara coal/ Australian coal)	60/40	60/40	60/40		
Test Item	Combustion adjustment test	Combustion adjustment test	Combustion adjustment test		
Purpose of Test	Combustion adjustment	Combustion adjustment	Combustion adjustment		
Date of Test	August 6, 1987	August 7, 1987	August 15, 1987		

Analysis of the test coal of SSC shows less alkali content (Na_2O, K_2O), which causes slagging and fouling of the boiler, than the Semirara coal usually used before. However, due consideration must be given to the combustion condition because of high slagging index.

5-4-2 Coal Analysis during the Combustion Test

1) Sampling of Coal

Coal sampling was carried out at coal feeders during the combustion test, and at transfer tower No. 6 during the coal discharging into the coal silo, in compliance with Japanese Industrial Standard (JIS-M-8811).

2) Coal Sample Analysis

Proximate analysis of test coals sampled during the test period as mentioned above were made at Calaca Power Plant. Analyzed data of coal samples of blended coal and single brand coal are shown in Table 5-4.

Table 5-4 Proximate Analysis of Combustion Test Coal

	Samples / Items	Unit	Coal Feeder Coal 7/21-7/22 S/A=55/45	7/25 S/A=60/40	8/8 S/A=70=30	8/11 S/A=60/40	7/26 SSC 100%	Transfer Tower #6 7/21-7/22 S/A=55/45	7/25 S/A=60/40	Analysis condition
JICA Analysis	Moisture	%	6.92	7.70	9.37	8.79	11.68	6.46	7.29	
	Ash	%	16.90	15.10	14.20	14.70	15.10	16.00	16.10	D.B
	Volatile matter	%	37.10	37.70	39.30	39.30	42.80	36.00	37.00	D.B
	Fixed carbon	%	46.00	47.20	46.50	46.00	42.10	48.00	46.90	D.B
	Calorific value	Cal/g	5,810	5,840	5,650	5,640	5,150	5,950	5,830	A.D
NAPOCOR Analysis	Total moisture	%	19.39		22.02	20.32	26.86	18.09		A.R
	ADL	%	9.13		7.85	6.42	9.19	8.28		
	Inherent moisture	%	11.29		15.38	14.85	19.46	10.70		A.D
	Volatile matter	%	31.75		32.75	31.98	34.63	31.30		A.D
	Ash	%	14.45		12.56	13.46	11.24	14.54		A.D
	Fixed carbon	%	42.51		39.31	39.71	34.68	43.46		A.D
	Sulfur	%	0.67		0.72	0.63	0.78	0.65		A.D
	Calorific value	Btu/lb	10,042		9,339	9,475	8,540	10,296		A.D
AR Conversion (JICA/ NAPOCOR)	Inherent moisture	%	6.0/10.26		8.1/14.17	7.7/13.90	9.7/17.67	5.7/ 9.81		A.R
	Volatile matter	%	29.9/28.85		30.6/30.18	36.7/29.93	31.3/31.45	29.5/28.71		A.R
	Ash	%	13.6/13.13		11.1/11.57	11.7/12.60	11.0/10.21	13.1/13.34		A.R
	Fixed carbon	%	37.1/38.63		36.3/36.23	31.3/37.16	30.8/31.49	33.3/39.86		A.R
	Sulfur	%	- / 0.61		- / 0.66	- / 0.59	- / 0.71	- / 0.60		A.R
	Calorific value	Cal/g	5124/5069		4960/4781	5008/4925	4396/4309	5294/5247		A.R

D.B: Dry Base, A.R: As Received, A.D: Air Dried

6. Analysis of Coal and Evaluation

6-1 Previous Coal Analysis Data

- 6-1-1 Variation of Alkali Content ($Na_2O + K_2O$)
- 6-1-2 Dolomite ($CaO + MgO$) and Iron Oxide (Fe_2O_3) Content
- 6-1-3 Ash Fusion Temperature

6-2 Study of Slagging and Fouling Potential of Coal for Combustion Test

- 6-2-1 Study of Coal Classification
- 6-2-2 Evaluation as Lignite Coal
- 6-2-3 Evaluation as Bituminous Coal (For Reference)

6. Analysis of Coal and Evaluation

The coal composition will have important effects upon the boiler capacity, the boiler efficiency and the operating conditions of the auxiliaries such as coal mills, draft fans, etc. The coal moisture effects various problems in the boiler performance such as combustion gas volume, gas speed, heat transfer, low temperature corrosion, coal mill capacity, decline of boiler efficiency, increase of auxiliary power, etc.

The ash generated by coal combustion causes slagging in the boiler furnace, etc., erosion of the boiler tube outer surface, and the environmental problems by ash dispersion from the stack.

The ash deposits not only lower the boiler efficiency due to the decrease of heat absorption of the boiler and the imbalance of the steam temperature, but also limit the output in some cases, and further, force the unit to shutdown.

And, it is often experienced that the slagging formed at the upper furnace falls and damages the lower furnace tubes and aggravates ash accumulation.

Though this modification can effect to lower the slagging and fouling phenomena are described in the following, which need countermeasures, specially this time.

Slagging appears mainly on the radiant surface wall: Unburnt carbon melted during the coal combustion is carried by the gas flow and cooled down by contacting with lower temperature heating surface than the flow temperature, and adheres to the surface in solid form. Especially, some of slag formed at high-temperature part of the furnace is, at first, in the form of fluid like molten glass and becomes plastic-like, and grows up to big deposit.

Fouling appears mainly on convection heating pass: Volatile matter in the gas is condensed at the low gas temperature part of the boiler and the condensed matter adheres to the heating surface with fly ash. The volatile matter in the gas reacts with the fly ash, the adherent ash on the heating tube and the combustion gas, and forms strongly bonded deposit.

Slagging and fouling potential can be presumed from the composition of the coal ash and the ash fusion temperature. Therefore, it is required to analyze and evaluate them, and take necessary measures to meet the slagging and fouling potential.

6-1 Previous Coal Analysis Data

With respect to the design limiting values of coal ash content, the data analyzed by Semirara Coal Corporation on the coal delivered to Calaca Power Plant by the 64th to 153rd shipment were plotted as shown on Figs. 6-1 to 6-4. These figures show that Na_2O + K_2O values of alkali content are not stable. That calls for careful study on slagging and fouling potential of the coal which hinders the stable combustion in the boiler. The limiting values of coal property in the boiler design submitted by the boiler manufacturer, FWEC, are as follows.

Content	Limiting Value
$Na_2O + K_2O$	Max. 4.0% (wt.)
$CaO + MgO$	Max. 20.0% (wt.)
Fe_2O_3	Max. 14.6% (wt.)
Ash fusion temperature (Initial deformation temperature)	Min. 1,120°C

6-1-1 Variation of Alkali Content ($Na_2O + K_2O$)

Against the limiting value of $Na_2O + K_2O$ of 4.0%, K_2O content is almost stable at less than 2.0% but Na_2O content varies in a wide range and $Na_2O + K_2O$ value varies from 2.09 to 9.23%. Concerning the coal delivered by the 95th to 102nd and the 130th to 140th shipments, which showed the extremely high Na_2O content as shown in Figs. 6-1 and 6-2, the Semirara Coal Mine side might have already recognized the mining pit (or seam) of the coal.

For the stable operation of power plant, close contact between the power plant and the coal mine, and adjustment of the coal blend ratio are necessary.

6-1-2 Dolomite ($CaO + MgO$) and Iron Oxide (Fe_2O_3) Content

The dolomite ($CaO + MgO$) and the iron oxide (Fe_2O_3) contents in the coal ash make the coal classification indices, and the analysis shows a general tendency that the dolomite content exceeds the iron oxide content, so the coal is classified as "Lignite coal". As shown on Figs. 6-3 and 6-4, the maximum value of dolomite content is 19%, which clears the boiler design limiting value of maximum 20%. Also, the maximum value of iron oxide of 8.61% is less than the limiting value of maximum 14.6%.

6-1-3 Ash Fusion Temperature

The initial deformation temperature (IDT) of 1,120°C (minimum value) is set as the limiting ash fusion temperature for the boiler design. Nine (9) measurements of IDT are included in the ash analysis this time and they range from 1,190°C to 1,200°C. However, since IDT of 1,050°C is found as the lowest value in the 3rd Interim Report prepared by Kennedy & Donkin International (KDI), a careful attention should be paid to the slagging and fouling due to the low ash fusion temperature.

(Analysis by SCC)

64 --- Received on 25 Aug. 1985

#120 --- Received on 25 July 1985

Max. value of $Na_2O + K_2O$ on 8 Apr. 1986

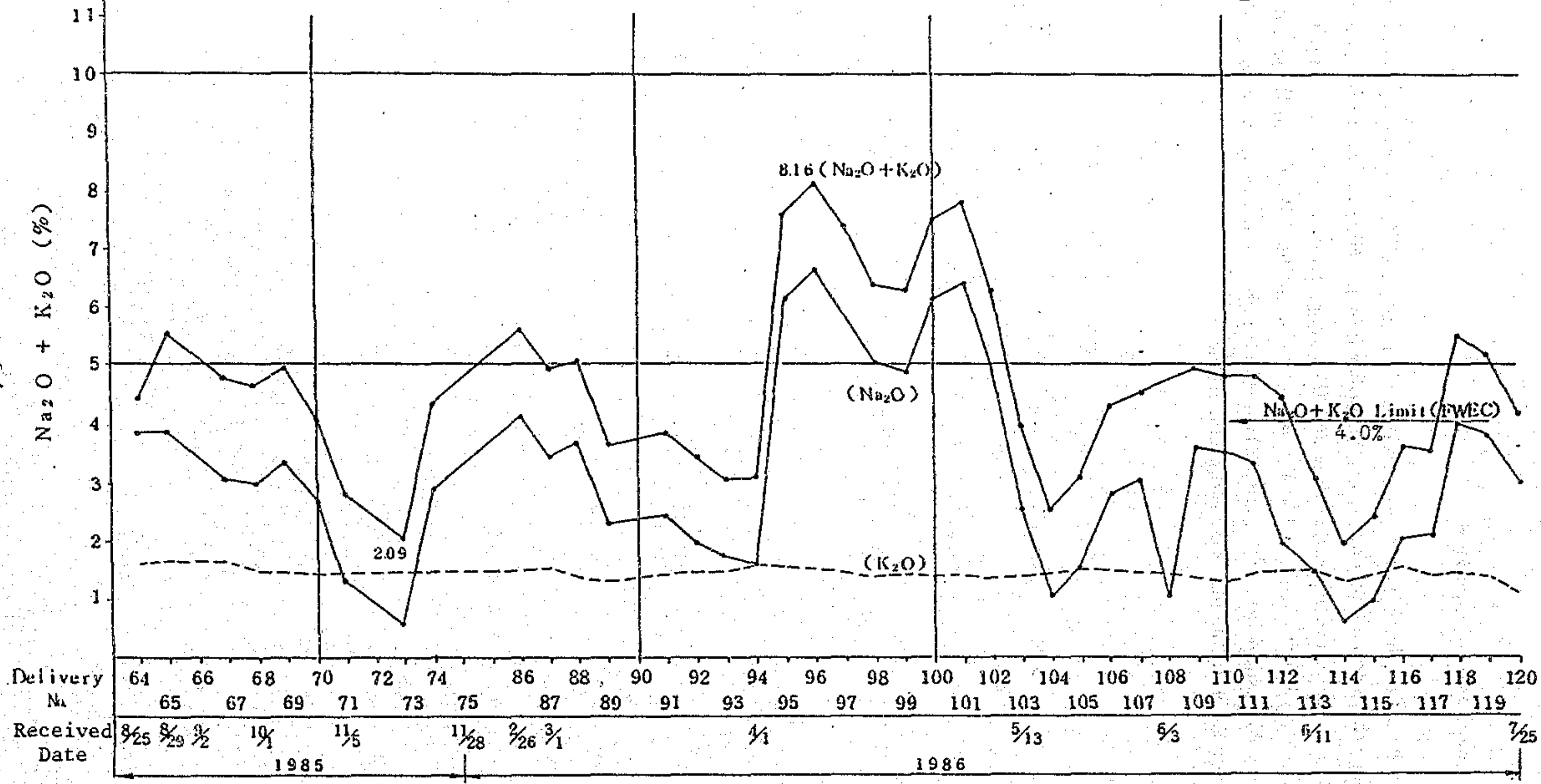


Fig. 6-1 Selected Semirara Coal, Variation of $Na_2O + K_2O$ in Coal Ash (1/2)

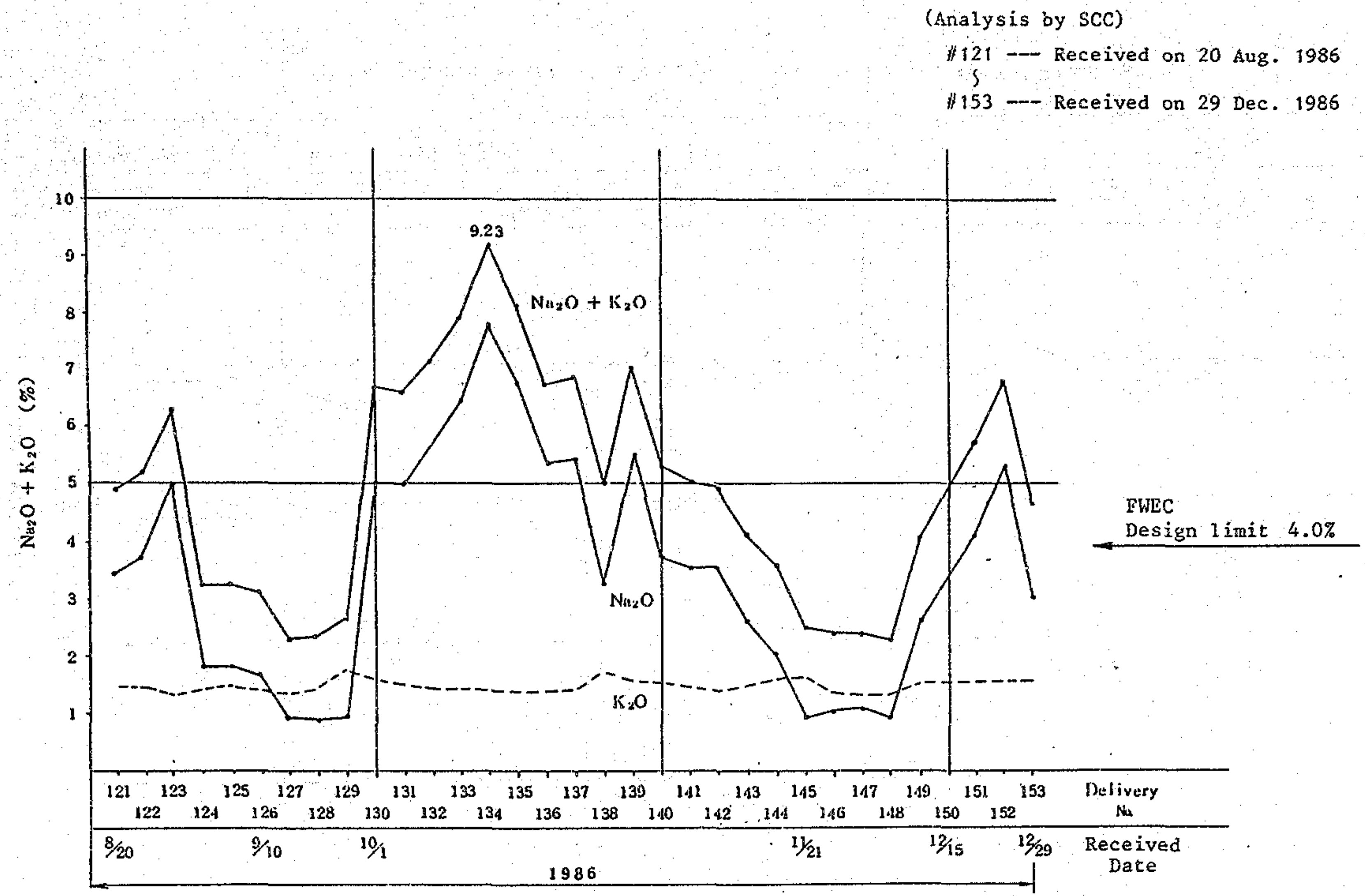


Fig. 6-2 Selected Semirara Coal, Variation of $Na_2O + K_2O$ in Coal Ash (2/2)

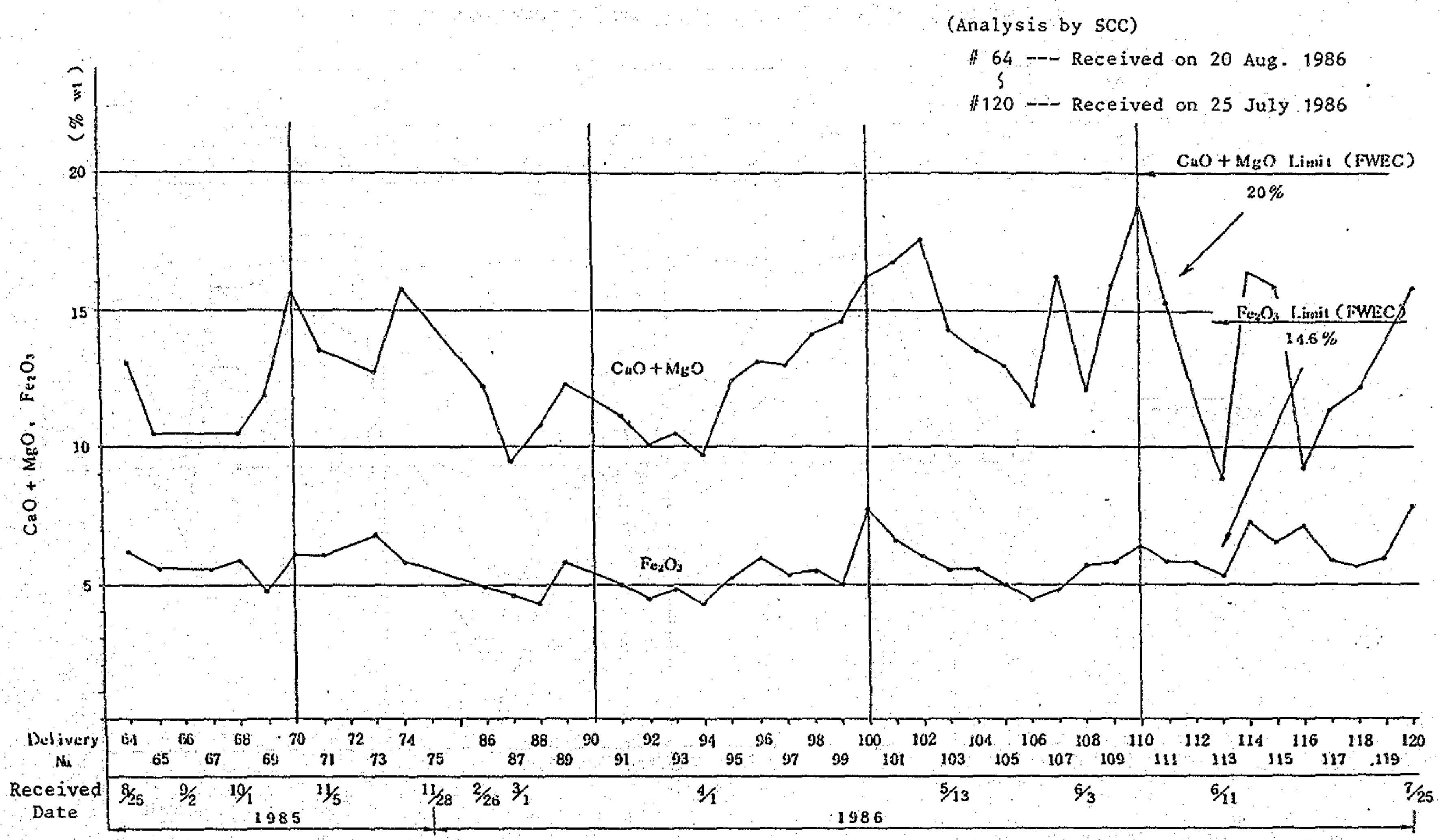


Fig. 6-3 Selected Semirara Coal, Variation of CaO + MgO and Fe_2O_3 in Coal Ash (1/2)

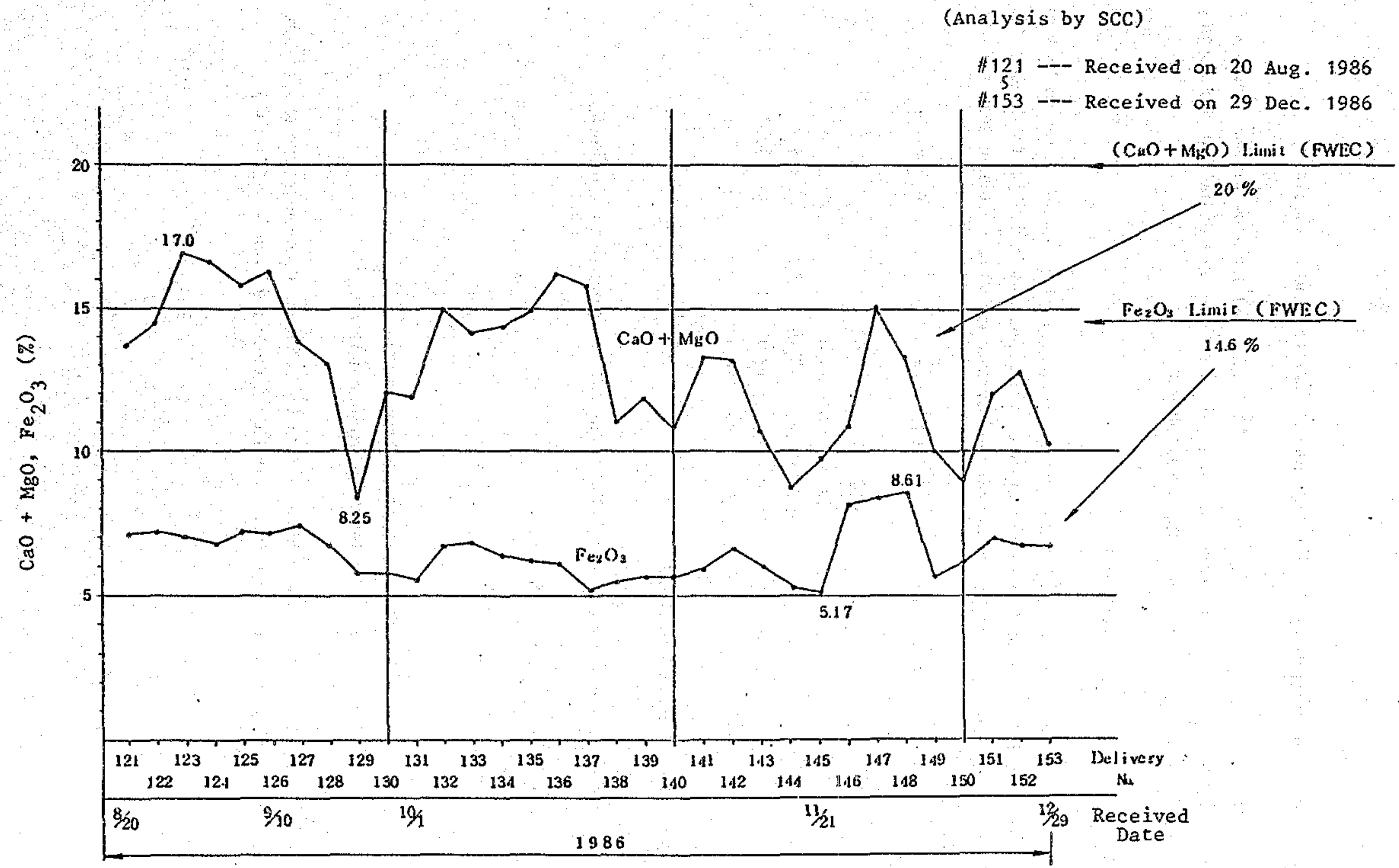


Fig. 6-4 Selected Semirara Coal Variation of CaO + MgO and Fe_2O_3 in Coal Ash (2/2)

6-2 Study of Slagging and Fouling Potential of Coal for Combustion Test

Prior to the boiler combustion test, JICA analyzed the coal for the combustion test, and the results are tabulated on Table 6-1. With reference to the data, the slagging and fouling potential of the coal is studied as follows.

6-2-1 Study of Coal Classification

The dolomite (CaO + MgO) and the iron oxide (Fe_2O_3) contents in the coal ash of five (5) Semirara coal samples were compared in the following, and all the results show the characteristics of lignite coal because all the dolomite contents are higher than the iron oxide contents.

Sample No.	CaO + MgO	≷ Fe_2O_3
1	6.12 + 5.7 = 11.82	> 5.82
2	1.95 + 5.66 = 11.61	> 5.32
3	2.75 + 3.11 = 5.86	> 5.2
4	7.24 + 6.75 = 13.99	> 7.24
5	5.58 + 4.84 = 10.42	> 4.76

6-2-2 Evaluation as Lignite Coal

The slagging and fouling potential of lignite coal is evaluated in the following.

(1) Slagging Index (Rs)

$$Rs = \frac{HT + 4 \times IT}{5}$$

Where, HT: Hemispherical temperature (°C)
IT: Initial deformation temperature (°C)

(Because IT is the temperature in the reducing atmosphere, the temperature measured in the oxidizing atmosphere is corrected by deducting 60°C.)

Slagging potential	Slagging index
Medium	More than 1,230
High	1,230 – 1,150
Severe	Less than 1,150

Sample No.	(HT + 4 x IT)/5	= Rs
1	$Rs = \frac{1,280 + 4 \times 1,160}{5} = 1,184$	High
2	$Rs = \frac{1,280 + 4 \times 1,170}{5} = 1,192$	High
3	$Rs = \frac{1,280 + 4 \times 1,120}{5} = 1,152$	High
4	$Rs = \frac{1,260 + 4 \times 1,140}{5} = 1,164$	High
5	$Rs = \frac{1,280 + 4 \times 1,140}{5} = 1,168$	High

(2) Fouling Index (Rf) = Na_2O

Fouling Potential	Fouling index (Na_2O)	
	Case 1	Case 2
Medium	Less than 1.2	Less than 3
High	1.2 – 3.0	3 – 6
Severe	More than 3.0	More than 6

Case 1: $CaO + MgO + Fe_2O_3 > 20\%$
Case 2: $CaO + MgO + Fe_2O_3 < 20\%$

Sample No.	$CaO + MgO + Fe_2O_3$	Na_2O	Rf
1	$6.12 + 5.7 + 5.82 = 17.64 < 20$	1.78	Medium
2	$5.95 + 5.66 + 5.32 = 16.93 < 20$	1.51	Medium
3	$2.75 + 3.11 + 3.2 = 9.06 < 20$	1.41	Medium
4	$7.24 + 6.75 + 4.85 = 18.84 < 20$	1.82	Medium
5	$5.58 + 4.84 + 4.76 = 15.18 < 20$	1.26	Medium

Note: The fouling index (Rf) of case 2 is used since the values of $CaO + MgO + Fe_2O_3$ of all samples are less than 20.

(3) Evaluation

As a result of evaluation of slagging and fouling potential of the Semirara coal used for the combustion test, the slagging potential is high and the fouling potential is medium.

6-2-3 Evaluation as Bituminous Coal (For Reference)

For evaluation of slagging and fouling potential of bituminous coal ($Fe_2O_3 > CaO + MgO$), the base/acid ratio is used as an approximate index. Though the coal used for the combustion test is lignite coal, the following evaluation is made for reference.

(1) Slagging Potential

a. Slagging index

$$Rs = \frac{\text{Base}}{\text{Acid}} \times S = \frac{Fe_2O_3 + CaO + MgO + Na_2O + K_2O}{SiO_2 + Al_2O_3 + TiO} \times S$$

Note: S: Sulfur content (wt%, Dry basis)

b. Slagging potential

Slagging Potential	Slagging index
Low	Less than 0.6
Medium	0.6 – 2.0
High	2.0 – 2.6
Severe	More than 2.6

Sample No.	$\frac{Fe_2O_3 + CaO + MgO + Na_2O + K_2O}{SiO_2 + Al_2O_3 + TiO}$ x S	= Rs
1	$\frac{5.82 + 6.12 + 5.70 + 1.78 + 0.97}{43.9 + 23.6 + 1.09}$ x 0.84 = 0.252	Low
2	$\frac{5.32 + 5.95 + 5.66 + 1.51 + 1.04}{46.9 + 23.9 + 1.11}$ x 0.85 = 0.230	Low
3	$\frac{3.2 + 2.75 + 3.11 + 1.41 + 0.56}{61.5 + 17.2 + 0.83}$ x 0.80 = 0.112	Low
4	$\frac{4.85 + 7.24 + 6.75 + 1.82 + 1.0}{43.9 + 23.6 + 1.09}$ x 0.82 = 0.260	Low
5	$\frac{4.76 + 5.58 + 4.84 + 1.26 + 1.1}{48.5 + 26.0 + 1.01}$ x 1.01 = 0.234	Low

(2) Fouling Potential

a. Fouling index

$$Rf = \frac{\text{Base}}{\text{Acid}} \times Na_2O$$

b. Fouling potential

Fouling potential	Fouling index
Low	Less than 0.2
Medium	0.2 – 0.5
High	0.5 – 1.0
Severe	More than 1.0

Sample No.	$\frac{Base}{Acid} \times Na_2O$	= Rf
1	0.297 x 1.78 = 0.529	High
2	0.271 x 1.51 = 0.409	Medium
3	0.139 x 1.41 = 0.196	Low
4	0.318 x 1.82 = 0.579	High
5	0.232 x 1.26 = 0.293	Medium

(3) Evaluation

The slagging potential as bituminous coal is low and may cause no trouble in combustion but some of the fouling potential are evaluated to be high.

Table 6-1 Coal Analysis Data (JICA)

Item	Selected Semirara Coal							Blend Coal	Australian Coal (June 30, '87)			
	JICA Nov. 86	JICA Mar. 87	#1	#2	#3	#4	#5	Mar. 87	JICA Nov. 86	JICA Mar. 87	M/V MAGRITE	M/V GENCRUZ
Proximate Analysis												
Inherent moisture(*1) %	(15.4)	(15.2)	(14.7)	(16.5)	(11.3)	(15.4)	(15.6)	(10.0)	(3.1)	(3.2)	(2.8)	(2.8)
Volatile matter(*2) %	47.7	43.7	45.2	45.6	39.5	45.7	45.4	36.6	29.9	30.2	31.6	31.3
Fixed carbon(*2) %	40.7	45.7	42.4	41.0	48.2	42.9	39.9	47.9	51.5	51.8	50.6	51.1
Ash(*2) %	11.6	10.6	12.4	13.4	12.3	11.4	14.7	15.5	15.5	18.0	17.8	17.6
Calorific value(*1) kcal/kg	5140	5283	5250	5030	5800	5230	5040	5760	6660	6386	6570	6590
Calorific value(*1) BTU/lb	9252	9509	9450	9054	10440	9414	9072	10368	11988	11494	11826	11862
Sulfer(*1) %	0.79	0.3	0.72	0.71	0.71	0.69	0.86	0.4	0.67	0.5	0.39	0.54
Ultimate Analysis												
Carbon(*2) %	-	65.6	63.71	63.47	67.59	66.06	61.14	62.9	-	69.1	68.58	69.75
Hydrogen(*2) %	-	4.7	4.09	3.91	4.14	4.32	3.89	4.8	-	4.4	4.21	3.43
Oxygen(*2) %	-	17.4	17.84	17.3	13.84	16.26	18.18	15.16	-	6.38	7.38	7.06
Nitrogen(*2) %	-	1.1	1.12	1.07	1.33	1.14	1.08	1.2	-	1.6	1.63	1.60
Sulfer(*2) %	-	0.6	0.84	0.85	0.8	0.82	1.01	0.44	-	0.52	0.4	0.56
Ash(*2) %	-	10.6	12.4	13.4	12.3	11.4	14.7	15.5	-	18.0	17.8	17.6
Ash Analysis												
SiO_2 %	43.6	44.5	43.9	46.9	61.5	43.7	48.5	68.2	75.8	83.8	79.5	78.1
Al_2O_3 %	23.2	23.83	23.6	23.9	17.2	23.4	26.0	16.76	13.9	12.36	11.9	13.4
TiO_2 %	1.0	1.14	1.09	1.11	0.83	1.05	1.01	0.76	0.7	0.68	0.61	0.60
Fe_2O_3 %	4.8	4.28	5.82	5.32	3.20	4.85	4.76	3.16	8.3	1.82	2.54	2.07
CaO %	6.2	7.41	6.12	5.95	2.75	7.24	5.58	2.74	0.0	0.0	<0.1	<0.1
MgO %	4.8	5.64	5.70	5.66	3.11	6.75	4.84	2.17	0.1	0.28	0.16	0.12
Na_2O %	1.3	3.44	1.78	1.51	1.41	1.82	1.26	1.83	0.1	0.11	0.07	0.06
K_2O %	1.5	1.49	0.97	1.04	0.56	1.0	1.10	0.76	0.6	0.43	0.25	0.25
Slagging, Fouling Potential Check												
(Bituminous coal)												
Base/acid ratio	0.274 18.6/67.8	0.320 22.26/69.47	0.297 20.39/68.59	0.271 19.48/71.91	0.139 11.03/79.53	0.318 21.66/68.15	0.232 17.54/75.51	0.124 10.66/85.72	0.101 9.1/ 90.4	0.027 2.64/ 96.84	0.031 2.86/ 92.01	0.028 2.6/ 92.1
$Na_2O + K_2O$	2.8	4.93	2.75	2.55	1.97	2.82	2.36	2.59	0.7	0.54	0.32	0.31
Slagging index (B/A x S)	0.216 L	0.192 L	0.249 L	0.230 L	0.111 L	0.261 L	0.234 L	0.050 L	0.068 L	0.014 L	0.012 L	0.015 L
Fouling index (B/A x Na_2O)	0.767 H	1.1 S	0.529 H	0.409 M	0.196 L	0.579 H	0.292 M	0.332 M	0.010 L	0.002 L	0.002 L	0.007 L
Coal Class												
CaO + MgO ≷ Fe_2O_3	11 > 4.8	13.05 > 4.28	11.82 > 5.82	11.61 > 5.32	5.86 > 3.2	13.99 > 4.85	10.42 > 4.76	4.91 > 3.16	0.1 < 8.3	0.28 < 1.82	0.26 < 2.54	0.22 < 2.07
Ash Fusion Temp.												
Initial deformation temp. °C	1190	1160	1220	1230	1180	1200	1200	1150	1380	1320	1450	1430
Hemispherical temp. °C	1280	1270	1280	1280	1280	1260	1280	1340	1490	>1450	>1500	>1500
Flow temp. °C	1320	>1450	1300	1300	1330	1280	1300	1450	1500	>1450	>1500	>1500
H.G.I	-	-	45	44	44	40	50	-	-	-	45	45
Lignite Coal												
Slagging index	H	S	H	H	H	H	H	S	-	-	-	-
Fouling index	M	H	M	M	M	M	M	M	-	-	-	-

Note: 1) Combustion Test Coal : Selected Semirara Coal #1 - #5
Australian coal M/V MAGRITE, M/V GENCRUZ
2) Slagging, Fouling Index: L = Low, M = Medium, H = High, S = Severe
3) (*1): Air Dried Basis
4) (*2): Anhydrous Basis

7. Calculation of Optimum Coal Blend Ratio (Study on the Increase of Blend Ratio of Semirara Coal)

7-1 Limitation by the Alkali Content of Ash

7-1-1 Fouling Limit
7-1-2 Calculation of Coal Blend Ratio
7-1-3 Adjustment of Coal Blend Ratio

7-2 Limitation by Total Moisture Content

7-3 Limitation by Calorific Value

7-4 Operational Problems

7-4-1 Economizer Hopper Clogging
7-4-2 Difficulty of Main Steam Temperature Control
7-4-3 Selection of Operating Mill

7. Calculation of Optimum Coal Blend Ratio (Study on the Increase of Blend Ratio of Semirara Coal)

The optimum boiler combustion adjustment has been achieved by the JICA team for the increase of blend ratio of Semirara coal. And it is recommendable to increase the blend ratio considering the accuracy of blending, based upon the stable combustion of the boiler and taking fully the following limitations into account:

- Limitation by ash characteristics, especially by the alkali content (Na_2O, K_2O, etc.) influencing the slagging and fouling potential,

- Limitation by the total moisture content (Boiler design total moisture: 19%), and

- Limitation by rather low calorific value of coal (Boiler design calorific value as received basis: 8,500 Btu/lb).

And the operational problems should be taken into account such as the economizer hopper clogging with ash, the main steam temperature control, the operating mill selection, etc.

Considering the above limitations, studies in the following were carried out on the basis of coal analysis data and the results of boiler combustion test.

7-1 Limitation by the Alkali Content of Ash

7-1-1 Fouling Limit

The alkali content in the ash of the coal (SSC) for the combustion test was as low as 1.97–2.82%, and the maximum alkali content including the blended Australian coal was 2.07%, those were quite lower than the limit value of 4% designated by the boiler manufacturer, FWEC. Therefore, the actual fouling limitation could not be confirmed this time, which is 4% or not.

However, the forced outage due to the fouling was not reported in 1986 even the operation with coal blend ratio (S/A) of 50/50 and the blending with the reclaimers in the latter half year.

The highest alkali content in the SSC in 1986 is 9.28% (Na_2O: 7.82%, K_2O: 1.41%) and the firing with the blended coal consisting of 50% SSC and 50% Australian coal with

0.5% of alkali (Na_2O: 0.4%, K_2O: 0.1%) did not cause any troubles, which means that the firing with 4.8% alkali coal as received base did not cause any trouble.

Therefore, if the alkali content is kept less than 4% as recommended by the FWEC, no trouble will be caused.

7-1-2 Calculation of Coal Blend Ratio

Rough estimation of the coal blend ratio can be made by Fig. 7-1 with adequate margin of safety, which satisfies the boiler design value of $Na_2O + K_2O < 4\%$. Actually, it will be more reasonable to adopt the blend ratio on ash basis (dry coal basis). However, the coal blending on wet coal basis will be more practical in consideration of wide variation of total moisture of Semirara coal and longer time required for ash analysis.

Calculation Formula:

	Semirara Coal	Australian Coal
Design coal blend ratio (%) (Wet coal)	A	B
Dry coal	$A \times (1-a) = X_1$	$B \times (1-b) = Y_1$
Dry coal ratio (%)	$\frac{X_1}{X_1+Y_1} \times 100 = X_2$	$\frac{Y_1}{Y_1+X_1} \times 100 = Y_2$
Ash content in dry coal	$X_2 \times c = X_3$	$Y_2 \times d = Y_3$
Ash in blended coal (%)	$\frac{X_3}{X_3+Y_3} \times 100 = X$	$\frac{Y_3}{Y_3+X_3} \times 100 = Y$

where,

a, b: Total moisture (%) of respective coals (as received)

c, d: Ash content (%) of respective coals (dry basis)

The above equations show that the ash blend ratio X/Y will be derived from the planned coal blend ratio A/B, total moisture and ash content of respective coals. A trial calculation of ash blend ratio is shown below.

Trial Calculation of Ash Ratio for Coal Blend Ratio S/A:70/30

	Semirara Coal	Asutralian Coal
Inherent moisture (%)	14.7	2.8
Total moisture (%)	28.43	10.0
Ash (dry basis) (%)	13.0	17.6
Coal blend ratio (wet coal) (%)	70	30
Dry coal (%)	70x(1–0.2843) = 50.099	30x(1–0.1) = 27.0
Dry coal ratio (%)	$\frac{50.099}{50.099+27} \times 100 = 64.98$	$\frac{27.0}{50.099+27} \times 100 = 35.02$
Ash content (%)	64.98 x 0.13 = 8.45	35.02 x 0.176 = 6.16
Ash blend ratio (%)	$\frac{8.45}{8.45+6.16} \times 100 = 57.8$	$\frac{6.16}{8.45+6.16} \times 100 = 42.2$

In Fig. 7-1, it is assumed that the alkali content (Na_2O+K_2O) of Australian coal is 1% and the coal blend ratio S/A is 70/30. Straight line A can be drawn from the point of 1% on the left side Y-axis passing the point of intersection (point a) of limit value of alkali concent of 4% and coal blend ratio (S/A) of 70/30 up to the right side Y-axis. In this case, the alkali content of Semirara coal should be less than 5.3% to limit the total alkali content below 4.0%.

On the other hand, the intersection (point a') of ash blend ratio (S/A) 57.8/42.2 and line A represents the alkali content of 3.5% in the blended coal. Namely, it is possible to increase the coal blend ratio (S/A) of 70/30 by considering the alkali content derived from the ash blend ratio.

In view of the alkali content in ash, it is theoretically correct to adopt the ash blend ratio, but practically, it is recommendable to decide the coal blend ratio using Fig. 7-1 by wet coal blend ratio basis for adequate safety margin as previously mentioned.

Further, the line B in Fig. 7-1 shows that the allowable alkali content of Semirara coal is 7% under the condition that the coal blend ratio (S/A) is 50/50 and alkali content of Australian coal is 1%. And, the line C shows that the allowable coal blend ratio (S/A) is 37/63 if the alkali content of Semirara coal is 9.23% (maximum value in the past).

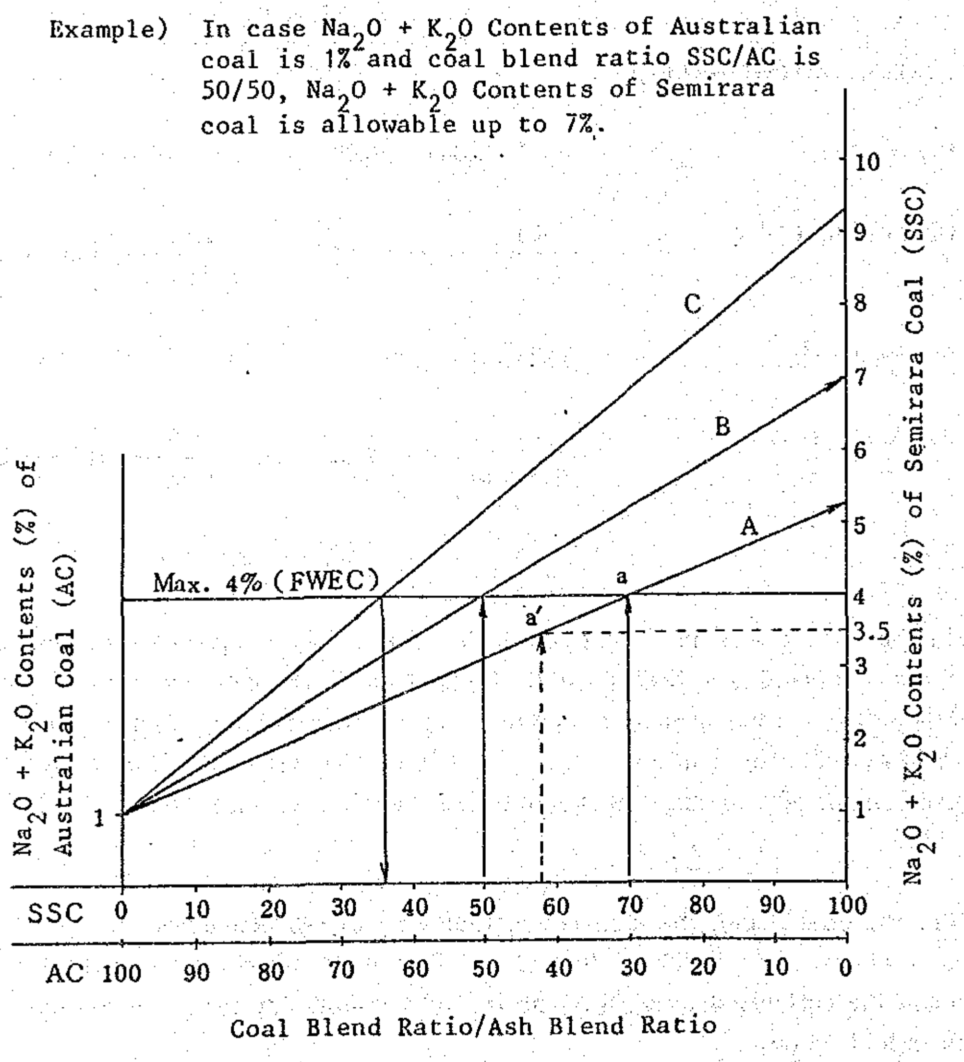


Fig. 7-1 Content of Na_2O+K_2O in Ash and Limit of Coal Blend Ratio

7-1-3 Adjustment of Coal Blend Ratio

The ashes of the SSC delivered in 1986 were analyzed by SCC and the results revealed that the delivered SSC with the alkali content in ash of 4% or more account for more than 60% of the total 67 shipments as shown in Table 7-1.

Table 7-1 Alkali Content in Ash of SSC in 1986

$Na_2O + K_2O$	No. of Shipments	(%)	
Less than 3%	12	17.9	38.8
3–4%	14	20.9	
4–5%	12	17.9	61.2
5–6%	10	14.9	
6–7%	9	13.4	
7–8%	7	10.5	
More than 8%	3	4.5	
Total	67	100.0	

And the shipments of the high alkali SSC were continued for a certain period, around 5 to 10 shipments, as shown on Fig. 7-2. Thus, the concentration of high alkali coal in a certain coal seam is revealed, so the advanced information for the delivery of high alkali coal to NAPOCOR by SCC is desirable.

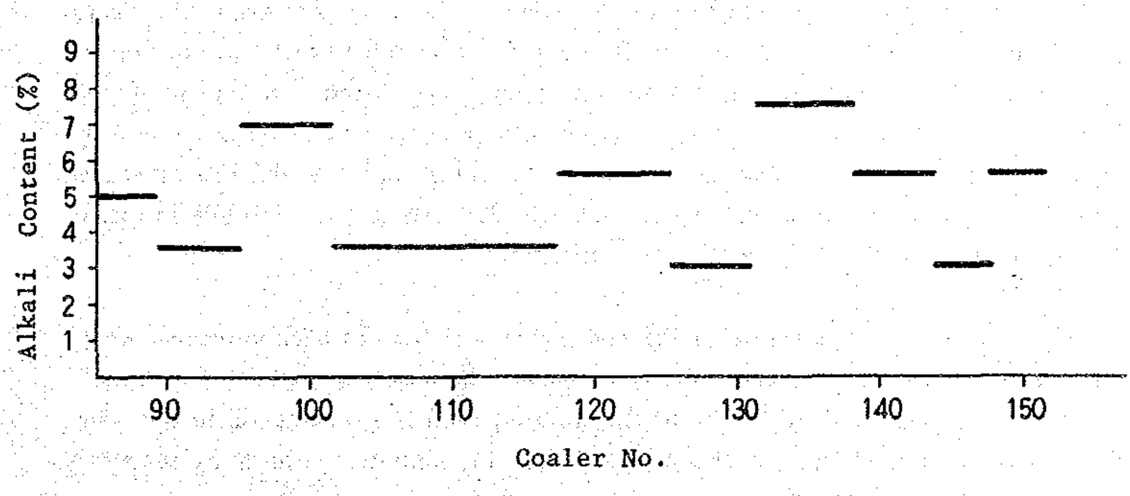


Fig. 7-2 Variation of Alkali Content by Coaler

Considering the fact above mentioned, the adjustment of the coal blend ratio corresponding to the alkali content as shown below is one countermeasures against faouling, and the output may also be derated, if possible, because the load decrease is effective for the prevention of fouling.

Alkali content in coal ash	Countermeasure by coal blend ratio of SSC	Countermeasure by output reduction
Less than 6%	60% (at 100% output)	100% (SSC 60% blended)
6–7%	50% (at 100% output)	90% (SSC 60% blended)
More than 7%	40% (at 100% output)	75% (Exclusive SSC firing possible)

7-2 Limitation by Total Moisture Content

If the total moisture content of both Semirara coal and Australian coal are known, the coal blend ratio corresponding to 19% moisture of design base can be obtained from Fig. 7-3.

The relation between total moisture and coal blend ratio is shown in Fig. 7-3, assuming that the total moisture of Australian coal is 10% and that of Semirara coal are 24%, 28% and 32.8% for evaluation. The points of intersections of the lines A', B' and C', and the line of the design total moisture (19%) show the upper limits of the coal blend ratios, namely 70/30, 50/50 and 40/60. In the case of the exclusive Semirara coal firing, the figures expressed in terms of the blend ratio of Semirara coal shows the rough ratio of possible output to the rated output. In Fig. 7-3, the line connecting 0% and 26.86% of total moistures of Australian coal and Semirara coal respectively intersect the design total moisture 19%, and the point of intersection (x) presents the possible output of the 70% rated load (= coal blend ratio value of Semirara coal), namely 300 MW x 0.7 = 210 MW in case of the exclusive Semirara coal firing with 26.86% moisture.

Up to present, the moisture of the consuming coal has not been measured though the moisture of coal has been measured at shipping. The moisture of the test coal (SSC) in the survey had increased by 4% during the storage period from the arrival to the firing, and increased remarkably in rainy season. Therefore, the limitation is made by the actual moisture content is severer rather than that of as received.

During the combustion test, the air temperature at the air preheater outlet for the coal drying was approximately 340°C under the condition of the coal blend ratio (S/A) of 70/30, the total moisture of 22.0% and the 300 MW load. And the air temperature was approximately 310°C with full open of the hot primary air dampers under the condition of the exclusive SSC firing, the total coal moisture of 26.9% and the 225 MW load, which means no operational margin. From the test results, the allowable figure of total moisture content is presumed at 23–24% for the rated output operation.

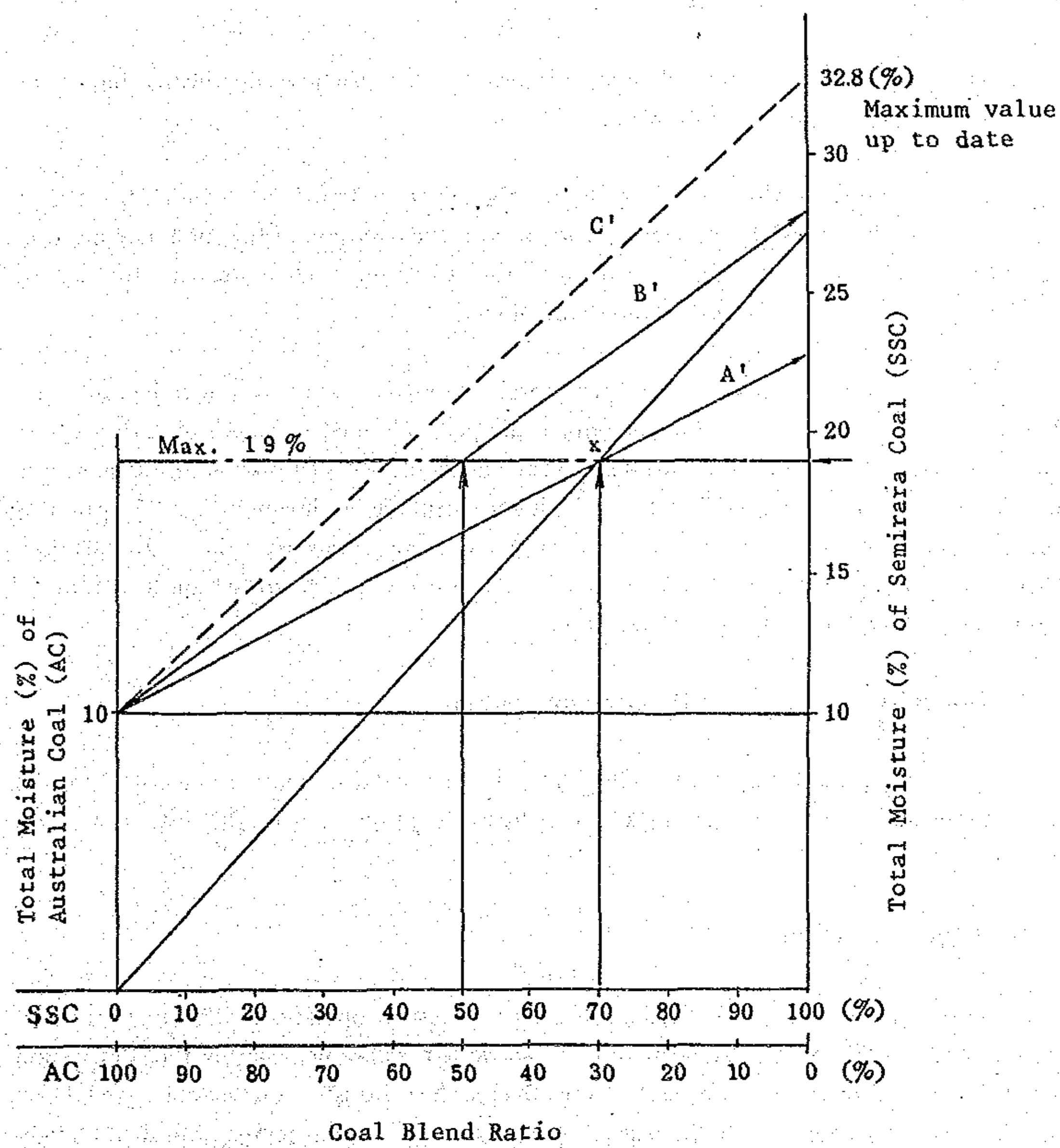


Fig. 7-3 Total Moisutre and Limit of Coal Blend Ratio

7-3 Limitation by Calorific Value

The design calorific value of coal is 8,500 Btu/lb (4,722 kcal/kg) on the as received basis, and limitation of the coal blend ratio of Semirara coal and Australian coal is around 80/20 as derived from Fig. 7-4.

7-4 Operational Problems

7-4-1 Economizer Hopper Clogging

The analysis data of the ash lump sampled on the primary superheater and in the clogged economizer hopper are shown in Table 7-2.

The ash lump is produced even though the alkali content is not so high because of the melting of the ash with low fusion temperature, the adhesion of the sublimate matters, the sintering of the fly ash, etc. And the unburnt carbon increases and reaches the convection heating pass in case of insufficient combustion air.

The slag on the primary superheater contained much alkali and seems to be caused by the fouling. The ash lump in the economizer hopper contained increased unburnt carbon, which indicated the reducing atmosphere in the boiler furnace. The ash fusion temperature decrease is around 50 to 150°C in the reducing atmosphere as shown in Fig. 7-5. And it is also said that the solid clinker is produced when silica rebounds after the decomposition. Therefore, there is a possibility of the clinker clinging onto the convection heat transfer surface even though the alkali content is low.

7-4-2 Difficulty of Main Steam Temperature Control

The main steam temperature might increase beyond the control range because the coal supply and combustion gas flow will increase in proportion to the SSC increase in the blend ratio.

7-4-3 Selection of Operating Mill

With a relation to the foregoing subsection, in case of operation with the upper mills, the tendency of the phenomenon mentioned above is remarkable. During the combustion test, the carrying of the unburnt carbon into the rear heat transfer zone was observed, however, the air flow could not be increased because the main steam temperature had already risen beyond the control range.

By the lower mills operation, the main steam temperature will be controlled within the range and the boiler firing with the coal blend ratio (S/A) of more than 60/40 can be expected.

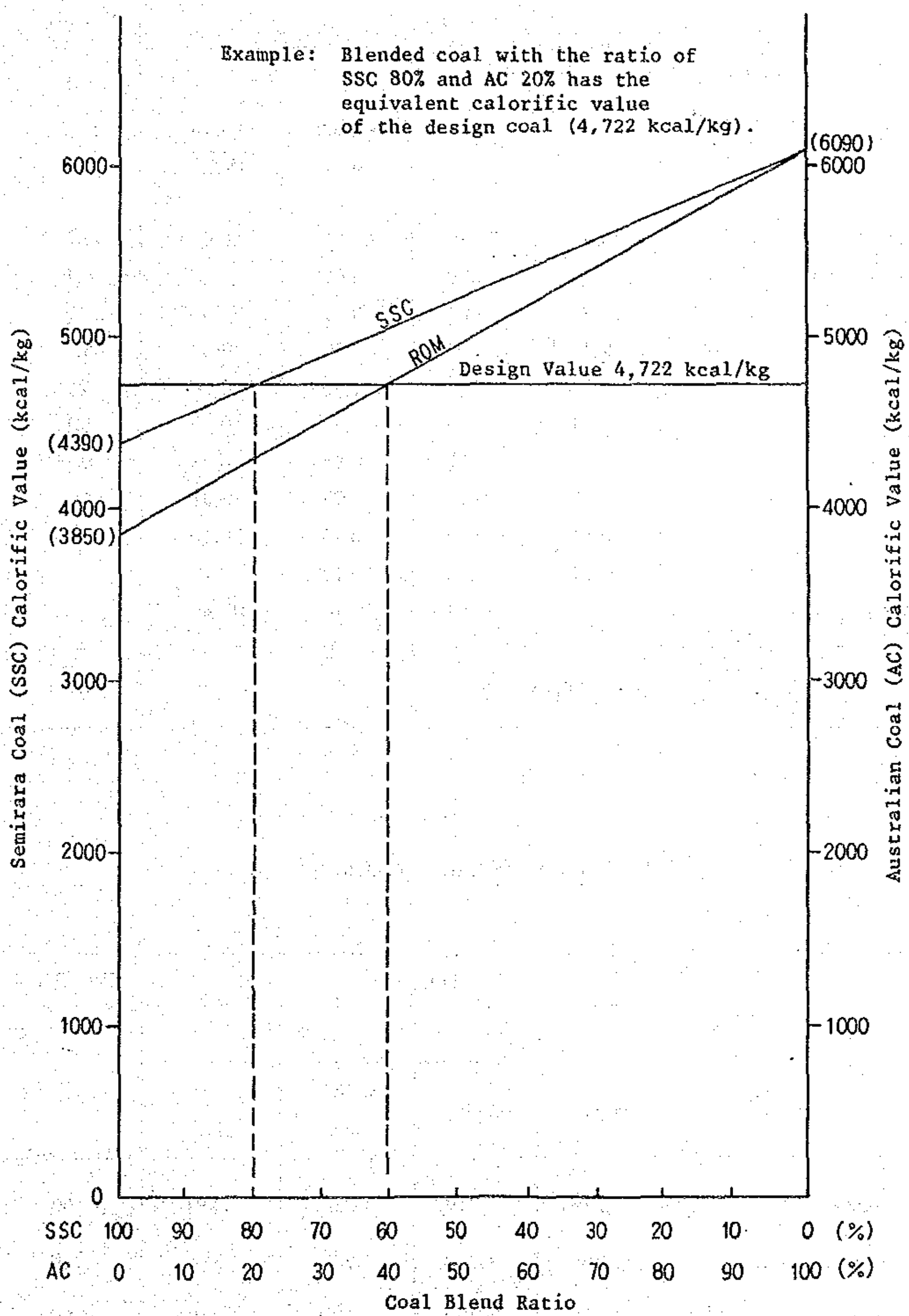


Fig. 7-4 Calorific Value and Coal Blend Ratio

Table 7-2 Analysis Data of Ash Sampled in Furnace

Item \ Samples		Eco. Hopper				Pry. SH
		Particle		Slag		
		Powder	Pebble	Melting Side	Opposite Side	Slag
SiO_2	%	70.30	71.80	68.8	68.0	44.7
Fe_2O_3	%	3.26	2.76	4.06	4.00	4.1
Al_2O_3	%	17.03	18.01	19.09	20.60	24.8
CaO	%	2.34	2.20	2.29	2.42	5.9
MgO	%	1.82	1.92	1.99	2.06	4.9
TiO_2	%	0.83	0.79	0.90	0.89	1.1
Na_2O	%	0.98	1.12	0.96	0.98	6.1
K_2O	%	0.75	0.72	0.93	0.91	1.7
SO_3	%	0.14	0.10	0.16	< 0.10	
P_2O_5	%	0.14	0.10	0.13	0.13	
Unburnt Carbon	%	2.72	0.54	+0.16	+0.09	
Sampling date		August 1987				1987

Ash Fusion Test (Oxidizing Atmosphere)

Item \ Samples		Eco. Hopper				Pry. SH
		Particle		Slag		
		Powder	Pebble	Melting Side	Opposite Side	Slag
Softening temp.	°C	1,240	1,210	1,210	1,230	1,160
Hemispherical temp.	°C	1,360	1,370	1,360	1,370	1,240
Flow temp.	°C	1,430	1,440	1,440	1,450	1,260

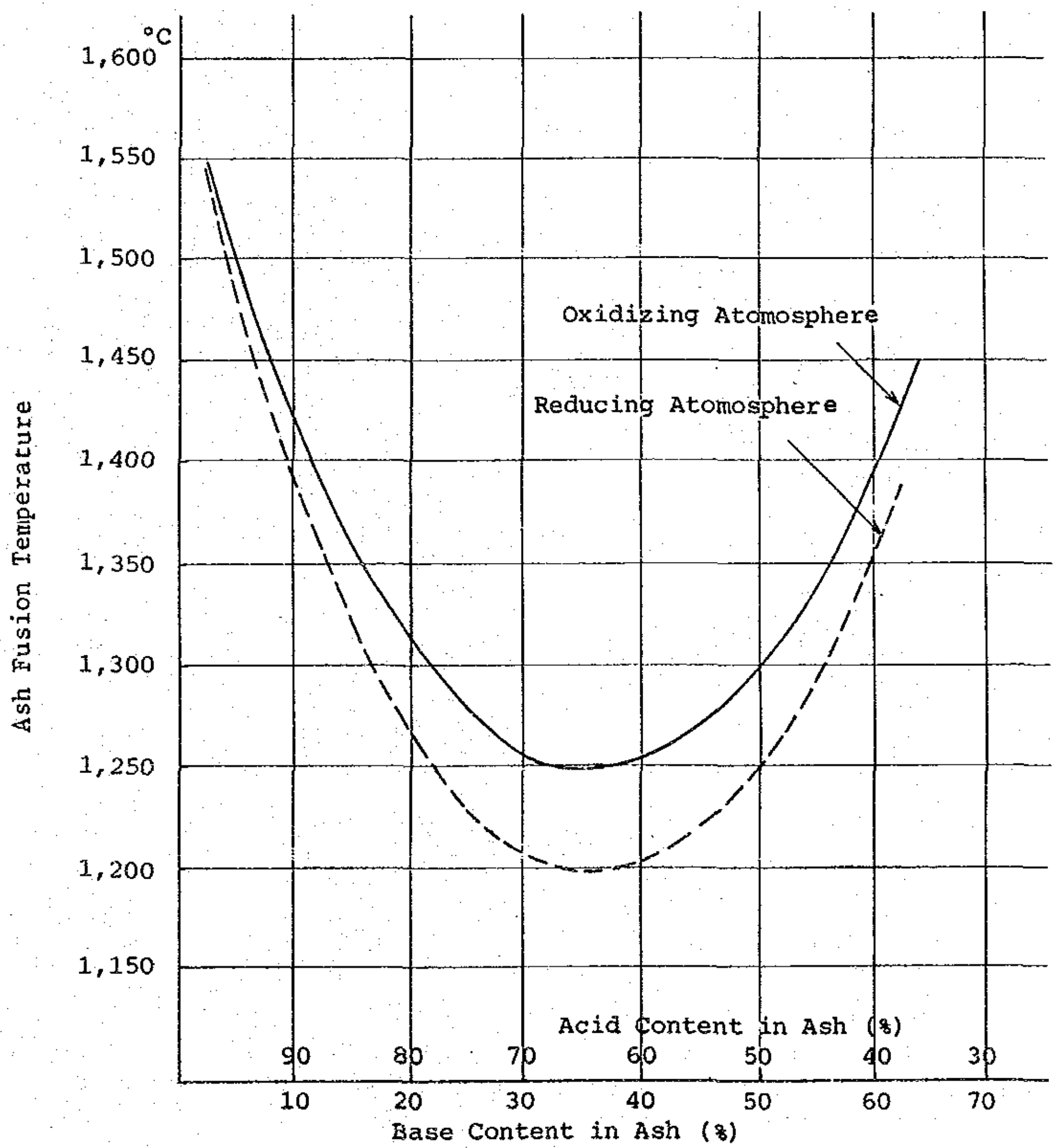


Fig. 7-5 Ash Composition and Fusion Temperature

8. Proposal of Improvement Program

8. Proposal of Improvement Program

8-1 Boiler Proper and Auxiliaries

If an existing boiler is to be fired with coal of widely different kinds from the design coal, it is necessary to clarify the properties of the coal to be used and to examine the suitability of the furnace, boiler parts, and auxiliaries from the view point of design, and take appropriate measures to match the coal.

For example, if the volatile matter, moisture, alkali content in ash, etc., are extremely different from the design, it would be necessary even to modify the furnace wall area, furnace volume, the height of the furnace, etc., and to take preventive measures against ash erosion due to increased gas velocity. Thus, adequate countermeasures should be taken to match the specific kind of coal to be fired.

The countermeasures and improvements necessary for Calaca Unit No. 1 are described hereinafter for firing of the future anticipated coal under the following conditions.

1. Exclusive ROM coal firing
2. Exclusive SSC firing
3. Blended coal firing with higher SSC ratio by modifying the boiler
4. Blended coal firing with higher SSC ratio at derated output
5. Continuation of present operating condition aiming at increase of SSC consumption as much as possible.

8-1-1 Exclusive ROM Coal Firing

(1) Problems associated with ROM Coal Firing

Judging from the operating conditons when ROM coal was fired exclusively at the initial stage of the plant operation and from the analysis of ROM coal, the Semirara ROM coal is considered to be of a very problematic coal quality. Although there are few descriptions of the property of clay included in ROM coal, it seems to be very sticky in view of the nature of the troubles in the record and the information from the people who experienced the handling of said coal.

The total moisture of the ROM coal including this sticky clay is as high as 21 to 31%, and this adds to the adhesive property. Further, once dry, this clay turns very hard and is hard to break away.

The troubles caused in the past by such properties of clay are as follows.

a. Troubles with coal handling facilities

a) Sticking of coal on side walls of coalers
b) Clogging of unloader hopper chutes
c) Clogging of belt conveyor transfer hopper chutes
d) Sticking of coal on belt conveyors
e) Sticking on and clogging of reclaimer wheel buckets
f) Sticking on and clogging of crushers and screens
g) Clogging of coal bunker chutes

b. Troubles with boiler combustion

a) Combustion instability due to frequent tripping of coal feeders and mills caused by clogging of coal bunker chutes

The operating conditions during the period when ROM coal was used are tabulated in the following Table 8-1. The continuous operation of the unit was 188.91 hours at the maximum, and the main cause of unit trips was the failures of coal feeders and mills due to the coal clogging.

Table 8-1 Operation Data with ROM Coal Firing (1985)

Period	Jan. 20–23	Jan. 24–30	Feb. 6–8	Mar. 26–Apr. 3	Mar. 11–18
Fuel	ROM (100%)	ROM/AC Mixed firing (Approx. 70/30)	ROM/AC Mixed firing (50/50)	ROM/AC Mixed firing (40/60)	Semirara Selected Coal SSC (100%)
Output range (MW)	164–207	191–315	293–302	268–305	179–303
Continuous operating hours of boiler (h)	69.93	130.69	46.17	188.91	132.03
Coal feeder trips	144	240	127	117	11
Mill trips	10	20	13	14	13

Note: Mixed firing means firing of ROM coal at upper level burners and firing of Australian Coal (AC) at lower level burners. Namely, individual mills are fed with a single kinds of coal, either ROM or AC. Occasional oil firing was also adopted to stabilize the combustion as needed.

b) Increase in frequency of sootblowing

In the case of exclusive ROM coal firing, the frequency of sootblowing increases for prevention of ash deposit. However, excessive increase in sootblowing frequency is not advisable in view of erosion due to the blowing steam and thermal impact on boiler tubes.

c) Shorts of primary air

The design temperature of air/coal at the mill outlet is 65.5°C, and if the temperature is lower than this, the combustion in the boiler is liable to get unstable due to poor ignition, and use of heavy oil or light oil is necessary for stabilizing the combustion.

Originally the moisutre of coal for the basis of design of the boiler and ancillary facilities is 19% in total moisture and 11.5% in surface moisture.

The ROM coal delivered has very high total moisture of 21.7 to 30.8%, which requires higher air temperature and larger air flow on the part of the mills, this results in the shortage of heating surface of the air heater. The situation is the same with SSC.

d) Support firing with heavy oil and light oil

During the period of trial operation using ROM coal, the support firing with heavy oil and light oil was necessary for prevention of furnace fire failure and securing stable combustion.

As there are many problems and difficulties involved in firing of ROM coal, drastic improvement of facilities and countermeasures would be necessary if ROM coal is to be used.

The countermeasures and improvements of individual equipment are described in the following.

(2) Boiler Proper

The slagging and fouling potential of ROM coal is slightly lower than that of

SSC, but the range of fluctuation of coal property of ROM coal is very wide. Therefore, the boiler for exclusive firing of ROM coal must be designed to cover the fluctuation of coal quality including SSC.

The following Table 8-2 shows the analyses of coal and coal ash of various kinds of coal, and it is seen that the quality of ROM coal and SSC is much poorer than the design coal in the proximate analysis and composition of ash.

Table 8-2 Coal and Coal Ash Analyses

		Design coal	ROM coal	SSC	Australian coal
Total Moisutre	(%)	19	25.87	27.92	8.58
Calorific Value	(kcal/kg)	4,722	3,850	4,390	6,090
	(Btu/lb)	8,500	6,930	7,900	10,960
Proximate Analysis					
Moisture	(%)	7.5			
Ash	(%)	6.72	17.63	8.10	16.67
Volatile matter	(%)	14.48	29.6	32.31	29.22
Fixed carbon	(%)	59.80	26.81	31.67	45.52
Sulphur	(%)	0.64	0.59	0.50	0.50
Hardgrove Index	(H.G.I.)	39–40	40–50	40–50	50
Ash Fusion Temperature					
Softening temp.	(°C)	1,120	1,220	1,170	1,500
Hemispherical temp.	(°C)	1,310	1,370	1,270	1,600
Flow temp.	(°C)	1,380	1,450	1,370	1,600
Composition of Ash	(%)				
SiO_2		44.2–63.4	50.45	38.30	74.00
Al_2O_3		22.0–30.6	24.68	19.52	17.80
Fe_2O_3		0.85–1.10	4.62	4.25	4.40
CaO		3.80–14.6	3.78	8.46	0.80
MgO		0.65–4.90	3.79	8.00	0.20
K_2O		1.23–3.70	2.37	1.87	0.40
Na_2O		0.22–1.13	2.15	6.27	0.10
P_2O_5				0.47	0.01
TiO_2		0.72–1.45	0.79	1.50	0.80
SO_3		1.58		8.75	1.30

The fuel ratio (ratio of fixed carbon to volatile matter) of the Semirara coal is much lower than that of the design coal and it follows that Lignite is fired actually instead of Bituminous coal of the design. Consequently, the increased moisture and ash and decreased calorific value result in the increase of coal consumption, combustion air flow, flue gas flow and ash, necessitating respective countermeasures.

Also because of the higher slagging and foulding potential of the ash, the preventive measures against slagging and fouling are very important. Actually frequent troubles from slagging and fouling have been experienced. It is necessary also to take countermeasures against ash erosion to cope with the increased ash volume.

The countermeasures are described individually in the following.

a. Countermeasures against slagging and fouling

The following countermeasures are necessary for prevention of slagging and fouling.

a) Prevention of slagging

i. To prevent hot spots on heating surfaces of the furnace, by selecting adequate thermal load, by adopting adequate spacing between burners and between burner and furnace wall, and by limiting the area covered with castable to a minimum.

ii. To keep the oxidizing atmosphere in furnace.

b) Prevention of fouling

i. To prevent molten ash from entering the rear pass, by selecting adequate furnace outlet gas temperature.

ii. To design the bank so that ash may not deposit easily, by selecting adequate tube spacing.

b. Countermeasures against ash erosion

Erosion of heat transfer tubes leads to bursting of tubes and is a large factor of lowering the reliability of coal-fired boilers.

The ash erosion by coal ash depends largely on the gas velocity and the ash content in the coal. Generally, the speed of erosion by ash is proportional to the product of 3rd to 3.5th power of the gas velocity and the quantity of ash in the coal.

Calaca No. 1 boiler was designed for 6.72% of ash content in coal and 19.18 m/s of gas velocity in the convection heating section. Therefore, with the actual coal of ash content of 17.7% on an average and as high as 26.8% at the maximum, not only the reduction of gas velocity, but special countermeasures against ash erosion should be taken. Otherwise, boiler tube failure would occur frequently. It is necessary to prevent deflections of flow of flue gas, namely to prevent local increase of gas velocity as well as to install tube protectors.

The fundamental policy for the countermeasures is to complete the combustion of fuel in the furnace and to keep the ash particles in the combustion gas, namely to lower the temperature of the gas as much as possible before it comes in contact with the convection heating surfaces. Then, the deposition and growing of molten slag on boiler tubes would be minimized.

For this, the following design parameters should be given thorough consideration.

Heat Liberation Rate/	($Btu/ft^3 h$ or $kcal/m^3 h$)
Heat Release Rate/Plan Area	($Btu/ft^2 h$ or $kcal/m^2 h$)
Heat Liberation Rate/Burner Zone Volume	($Btu/ft^3 h$ or $kcal/m^3 h$)
Furnace exit gas temperature	(°F or °C)
Combustion gas velocity	(ft/s or m/s)

Especially, the heat liberation rate/furnace volume is the fundamental condition. The heat liberation rate/furnace volume of the existing boiler is designed at 15.02×10^3 $Btu/ft^3 h$ (135×10^3 $kcal/m^3 h$) at MCR, while the recommended value for firing low-grade coal or Lignite is smaller than 11×10^3 $Btu/ft^3 h$ (100×10^3 $kcal/m^3 h$). The design heat release rate/plan area of the existing boiler is 1.8×10^6 $Btu/ft^2 h$ (4.9×10^6 $kcal/m^2 h$), and values smaller than 1.4 x 10^6 Btu/ft^2h (3.8 x 10^6 kcal/m^2h) are commonly adopted with Lignite, for higher boiler reliability.

The tendency is shown in the following Fig. 8-1.

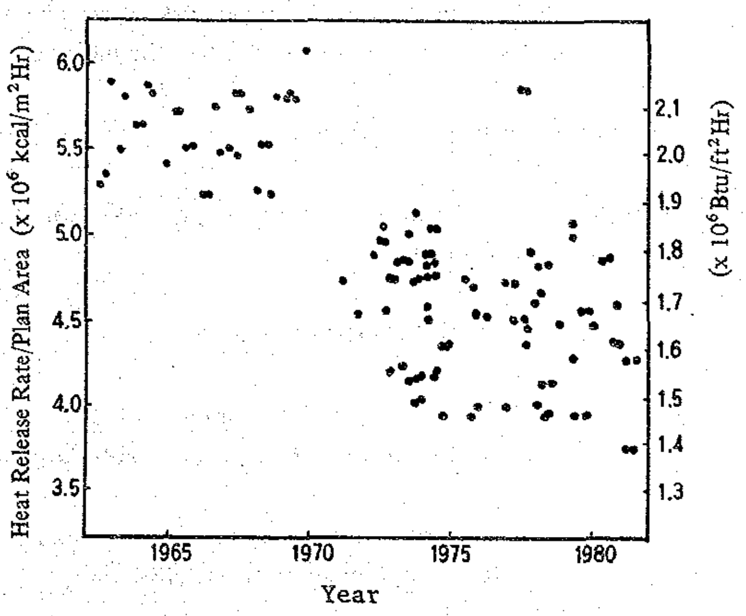


Fig. 8-1 Trend of Boiler Heat Liberation Rate/Furnace Volume

Thus, it is extremely difficult to fire ROM coal or SSC exclusively, which have quite different coal quality from that of the design coal in the existing boiler, and it would be necessary to build a new boiler of new design.

Basically, it would be necessary to increase the cross-sectional area by 25% and the furnace volume by 60 to 70% of the existing boiler's ones respectively.

(3) Combustion Facilities

The coal consumption with the design coal is 140 t/h, but with the ROM coal of 3,837 kcal/kg (as received) of average calorific value, the coal consumption becomes 177 t/h.

Judging from the design moisture for the mills (total moisture 19% and surface moisture 11.5%), 4 mills are short in capacity and one mill must be added. And one unit each of the coal silo and coal feeder, and 4 burners and the air duct must be added.

(4) Draft Equipment

To meet the increased coal consumption and moisture content of the coal, it is necessary to increase the capacity of the air preheaters, primary air fans, forced draft fans and the induced draft fans. Especially, the capacities of the primary air fans and the air heaters must be studied fully, because the mill outlet temperature tends to decrease when the moisture content is high.

(5) Prevention of Clogging of Coal Silo

The following study was made on the prevention of clogging of ROM coal at coal silo of Calaca Unit No. 1.

a. Problems with the existing coal silo

a) The coal silo outlet diameter of 0.51 m is extremely small as compared to that of the other coal-fired power plants.

b) The distance from the coal silo outlet to the coal feeder entrance gate is as extremely long as 2,438.4 mm.

c) The design of coal silo is liable to occur clogging as the coal silo is of symmetrical and cylindrical shape with conical shape at the bottom.

d) The coal of high moisture and clay content is liable to cause clogging due to compaction in the coal silo.

b. Countermeasures

a) Expansion of coal silo outlet sectional area

When the outlet sectional area of the coal silo is studied, about 1.0 m^2 is usually adopted by experience taking the surface moisture content of coal into consideration. However, the coal silo outlet section of Calaca Unit No. 1 is of a round shape and the area is as extremely small as 0.2 m^2 (or 0.51 m in diameter). As the moisture content of coal generally used in Japan ranges from 7 to 10% or so, the enough sectional area is taken and the a-symmetrical shape is generally applied.

Some examples of coal silo in Japan are shown in the following Table 8-3.

Table 8-3 Examples of Silo Outlet Design

Power Plant	Mill Capacity (t/h/unit)	Silo Outlet Dimension		Coal Flow Rate per Unit Area	Remarks
		L x B (mm)	Area (m^2)		
A	18.6	1,371 x 610	0.836	22.3	Clad Steel
B	16.6	1,200 x 600	0.72	23.1	Clad Steel
C	23.0	1,200 x 1,000	1.2	19.2	Clad Steel
D	58.0	914 ϕ	0.66	87.9	Square hopper, round outlet, Hi-Moler* lining at the slope part
CALACA	57.5	520 ϕ	0.2	287.5	Stainless steel lining at the slope part

* Ultra-high molecular weight polyethylene.

b) Slope of coal silo

It is generally said that the most effective measure to prevent the coal clogging is to make the coal silo shape asymmetrical. And there are many cases of the slope degree at 65° to 77° for the coal silo handling low quality coal with high ash and moisture content while some coal silos for general quality coal are designed with a 60° slope. The slope degree of the coal silo's conical part of Calaca power plant is as sufficient as 76.4°, but the shape is symmetrical. Recently, an asymmetrical silo shape with a slope degree of 73.5° to 78.2° is planned for imported coal in Japan.

c) Partition plate inside coal silo

The fitting of a partition plate inside the coal silo is effective to negate symmetry at the slope part. But, if the fitting of a partition plate extends to the coal silo outlet, the section area of coal flow becomes narrow and that may result in coal bridging in the coal silo. So, fitting of the partition plate extended up to the middle stage of the conical hopper is advisable. As the slope of Calaca coal silo is steep enough, however it may be possible to prevent clogging only by enlargement of outlet area.

d) Distance from coal silo outlet to coal feeder entrance gate

The distance from coal silo outlet to coal feeder entrance gate stands 2,438.4 mm. The straight part should be as short as possible to prevent clogging due to compaction of coal.

e) Lining materials of coal silo inside

In Calaca Unit No. 1, the stainless steel with 3 mm thickness is used for lining of the coal silo's inner surface. In Japan, the lining materials were developed in the order of gunite, glass, concrete mortar, artificial stone and clad steel. And recently, the lining by Hi-Moler (Ultra-high molecular weight polyethylene) is generally used for the new plants.

f) Vibrators and tamping holes

As an ancillary measure, installation of vibrators and tamping holes is conceivable.

(6) Coal Feeder

At the lower part of coal silo will be modified, the length of coal feeder should also be changed. The existing feeder should be replaced with a feeder of a new type.

As aforementioned, the study of the boiler proper and auxiliaries for exclusive firing of ROM coal is made. And it is concluded that new construction of a boiler is necessary as well as reinforcement of the related auxiliaries. The planning specifications of the major equipment to be constructed newly are tabulated as follows:

Specifications of Boiler for Exclusive Semiarara ROM Coal Firing

a. Boiler proper

Type	:	Natural circulation, balance draft, outdoor type, pulverized coal-fired
Evaluation	:	1,033.2 t/h at MCR
Drum pressure	:	191.5 kg/cm² g
SH outlet	:	
Pressure	;	178.5 kg/cm² g
Temperature	;	541°C
RH outlet	:	
Pressure	;	33.7 kg/cm² g
Temperature	;	541°C
Eco. inlet	:	
Temperature	;	282°C
Furnace	:	
Width	;	17,000 mm (Present boiler 13,500)
Depth	;	11,000 mm (Present boiler 11,049)
Volume	;	9,500 m³ (Present boiler 5,446)
Structure height (Up to lower edge of top girder)	:	75 m (Present boiler 61.0)
Sootblower	:	
Long retractable	;	40 sets (Present boiler 34)
Short retractable	;	16 sets (Present boiler 12)
Wall blower	;	74 sets (Present boiler 52)

b. Draft facilities

Air preheater	:	Ljungstrom tri-sector type	2 sets
Primary fan	:	Bigger capacity than the existing one	2 sets
Forced draft fan	:	Bigger capacity than the existing one	2 sets
Induced draft fan	:	Bigger capacity than the existing one	2 sets

c. Combustion facilities

Coal silo	:		5 sets (Present 4 sets)
Coal feeder	:	Gravimetric type	5 sets (Present 4 sets)
Coal mill	:	Ring roller MBF 23.5	5 sets (Present 4 sets)
Burner	:		20 sets (Present 16 sets)

8-1-2 Exclusive SSC Firing

Because the volatile and Na_2O+K_2O content of the SSC are higher than those of the ROM coal, it is necessary to pay more attention to the slagging and fouling problems. The measures for individual equipment are summarized in the following.

(1) Boiler Proper

A new boiler of the same specifications as the exclusive ROM coal firing should be needed.

(2) Combustion Equipment

The existing 4 units of mill (without standby) may be able to cope with the SSC, because the calorific value is higher than that of ROM coal. But the same equipment planned for the case of the exclusive ROM coal firing will be applied taking wide fluctuation of the coal quality into condieration.

(3) Draft Equipment

The new equipment as same as the one for the exclusive ROM coal firing should be needed.

(4) Preventive Measures for Clogging at Coal Silo

As compared to the case of exclusive ROM coal firing, the clogging problems of coal silo may decrease in the case of exclusive SSC firing. But the clogging troubles seemed to have happened occasionally with exclusive SSC firing, and the coal quality varied in a wide range. Thus, the modification of the coal silo in the same extent of the case of the exclusive ROM coal firing will be needed.

8-1-3 Blended Coal Firing with Higher SSC Ratio by Modifying Boiler

So far, the blending ratio of SSC and Australian coal has been set at 60 : 40 as an upper limit. If further increase of the SSC blending ratio is intended, a part of the equipment shoud be modified, but the modification works themselves are limited by the space, technical restrictions, etc.

(1) Boiler Proper

An essential factor for the increase of SSC blending ratio is to prevent slagging and fouling problems.

a. Modification of furnace

In order to decrease the gas temperature at the furnace outlet, the furnace height should be extended downward about 2.6 m equivalent to a length of one stage of burner. And then, the uppermost burner should be relocated to downward. The furnace space of the boiler should be enlarged by about 7%.

b. Relocation and addition of sootblowers

A set of long retractable sootblower should be added to each side of the lower part of the plate type superheater where slagging and fouling are liable to occur. The existing right and left side sootblowers should be relocated to the upper part of primary superheater respectively, and the same type of sootblowers should be added to both the right and left sides to increase the sootblowing effect.

Further, the installation of the observation holes and/or the monitoring TV is recommendable for better observation of the fouling of coal ash on the primary superheater.

(2) Modification of Auxiliaries and Pertinent Equipment

The following partinent equipment should be modified to match the enlargement of the boiler furnace.

a. Relocation and modification of bottom ash handling equipment

b. Re-arrangement of fuel supply pipes to connect with the relocated burners

c. Modification of air ducts and burner wind boxes

d. Modification of down comers and distribution pipes

By the measures described in items (1) and (2), the furnace space increases by 7% approximately and the gas temperature at furnace outlet is expected to decreases by about 20 to 30 °C. Since the cross section area of the furnace will hardly be modified and left unchanged the increase of the domestic coal blending ratio will not be expected much, namely around 5% or so.

(3) Change of Loading Conditions on Boiler Structures

The modification of the furnace is estimated to increase the load on the structures by about 60 tons. Although the increase of the load would not affect much on the foundation, the boiler supporting structure should be given some reinforcements or modifications.

(4) Modification of Coal Silo

The lower part shape of the existing coal silo should be modified to an asymmetrical slope. And the existing round outlet should also be modified to rectangular one with enlarged section area.

(5) Replacement of Coal Feeder

The existing coal feeder should be replaced with new one suitable for the modified lower part shape of the coal silo.

(6) Coal Blending Facilities

Coal blending facilities should be installed in the coal handling system. As an alternative, coal scale will be mounted on the reclaimers for the accurate blending of coals.

(7) Confirmation of Accurate Blending by Combustion Tests

The combustion tests should be carried out with the coals accurately blended by weight. Especially, using the lower most stage of mill, the combustion test, in which the domestic coal's blending ratio will be increased gradually, should be carried out. And, it is necessary to grasp the coal characteristics, especially alkali content as accurately as possible.

(8) Modification of ABC System

A part of ABC system should be modified for the stable boiler operation.

8-1-4 Exclusive SSC Firing or Increase in SSC Blending Ratio by Derated Output

The exclusive SSC firing with the rated output can only be attained by new construction of a boiler and reinforcement of the auxiliaries which requires a large amount of investment and a long construction period. For the exclusive SSC firing or increase in SSC blending ratio with the existing boiler and auxiliaries without extensive modifications, the output should be reduced as shown on the following:

Alkali Content (%)	less than 6	6~7	more than 7
Output (%)	100	90	75
Blending Ratio (S/A)	60/40	75/25	100/0

Some facilities, however, need modifications as itemized below:

(1) Modificationof Coal Silo

The shape of the lower part of coal silo should be modified and the coal feeder should be replaced to prevent clogging in the coal silo.

(2) Coal Scale

Coal scale should be mounted on the reclaimer to increase the accuracy of the coal blending ratio.

(3) Modfication of ABC System

A part of ABC system should be modified and readjusted for the stable boiler operation.

8-1-5 Increase in SSC Blending Ratio without Extensive Modifications

This subchapter discusses about a method to increase the SSC blending ratio as much as possible without extensive modifications.

(1) Coal Sampling and Analysis

The sampling and analysis of the as fired coal should be done properly so that the coal quality delivered to the power plant can be grasped accurately.

(2) Coal Scale

The reclaimer should be provided with coal scale. With the scale, the blending conditions should be grasped as early as possible and the blending accuracy should be improved so that the plant operating conditions may be supervised properly.

(3) Discharge Coal Scale

The discharge coal scale should be repaired. Accurate measurement of the coal consumption is essential for plant performance control and coal storage management.

(4) Combustion Control Instrument and ABC System

The combustion control instruments and the ABC system should always be maintained and adjusted in their normal conditions for the plant's proper and stabilized operation.

(5) Modification of ABC System

ABC system should partially be modified and adjusted, and its proper conditions should always be maintained for the stable operation of power plant.

(6) Modification of Coal Silo

As same as the description in the previous subsection, the lower part of the coal silo should be modified to an asymmetrical shape and the present round shape outlet should be modified to the rectangular shape to increase its section area. These modifications are necessary to decrease the minimum output with two-unit mill operation.

(7) Replacement of Coal Feeder

To match with the modification of the lower part of the coal silo, the existing coal feeder should be replaced with the longer type than the original.

(8) Improvement of Air Heater (AH) Operation

The operation of the air heater should be improved. The air heater elements will be added to the spare section to increase the primary air temperature and to improve the plant efficiency.

Table 8-4 is a summary of the problems, corresponding countermeasures and improvement items in each case of the study.

Table 8-4 Summary of Improvement Program on Boiler Proper

Case	1	2	3	4	5
		Increase in Coal Blend Ratio of SSC			
	Present Operating Condition	Operation with Derated Output	Improvement of Facilities	Exclusive SSC Firing	Exclusive ROM Coal Firing
Problems	1. SSC has high slagging and fouling potential. 2. SSC contains high moisture. 3. Clogging is liable to occur. 4. Accurate coal blend ratio cannot be known. 5. Coal blend ratio limit of SSC is approx. 60/40.	Same as left	Same as left	1. SSC has high slagging and fouling potential, and cannot be used for the exclusive firing for the time being 2. SSC contains high moisture. 3. The exclusive firing of SSC is impossible due to low calorific value. 4. Clogging is liable to occur.	1. ROM contains much sticky clay and shows high adhesiveness. 2. ROM contains high moisture. 3. Clogging is liable to occur and stable operation is impossible. 4. Slagging and fouling potential is high. 5. Ash erosion is liable to occur.
Countermeasures	Continue the present operation (blend ratio 50/50) and increase the blend ratio as much as possible by confirming the operating condition.	If the coal contain high alkali content, derate the output and increase the consumption of SSC. (Example) Alkali content (%): Less than 6 / 6 – 7 / More than 7 Output (%): 100 / 90 / 75 Blend ratio S/A: 60/40 / 75/25 / 100/0	Improvement of the boiler	– Installation of the new boiler – Improvement of the coal handling system	
Improvement Items	Improve the following items as occasion arises: 1) Modification of the lower part shape of coal silo 2) Replacement of the coal feeder 3) Installation of the additional sootblowers 4)* Improvement of air heater 5)* Installation of the new coal dryer (*Note: In case the moisture of coal is at issue.)	Improve the following items. 1) Modification of the lower part shape of coal silo 2) Replacement of the coal feeder	1. Modification of the boiler: 1) Extension of the furnace: downward 2) Increase of the furnace volume: approx. 7% 3) Replacement of the burners: 1 stage downward 4) Installation of the additional sootblowers 2. Modification of the lower part shape of coal silo 3. Replacement of the coal feeder	1. Installation of the new boiler: 1) Furance volume will be approx. 70% more than the present boiler. 2) Furnace section area will be approx. 30% more than the present boiler. 3) Number of sootblowers will be increased. 4) Measures for ash erosion will be taken. 2. Number of coal mill will be five (5). 3. Increase of the capacity of FDF, IDF, Pry A-FAN and AH 4. Improvement of ash handling facilities 5. Number of coal silo will be five (5), and modify the lower part shape of the coal silo. 6. Replacement of the coal feeder 7. Improvement of the coal handling facilities	
	Improvement of operation: 1) Installation of coal blending facility 2) Repair of coal scale for consumed coal 3) Modification and adjustment of ABC 4) Replacement and repair of combustion supervisory instruments 5) Sufficient maintenance works of coal mills				
Cost Thousand Dollar (Million Yen)	Coal blending facility: 5,140 (720) Coal silo, coal feeder: 4,500 (630) Sootblower: 500 (70) Improvement of ABC: 500 (70) Air heater: 1,210 (170) Coal dryer: 6,790 (950)		Coal blending facility: 5,140 (720) Improvement of boiler: 11,290 (1,580) Sootblower: 500 (70) Improvement of ABC: 500 (70)	Installation of the new boiler (Replacement): 110,570 (15,480) [including improvement of coal handling system: 113,930 (15,950)]	
Required Period	12 – 18 months		18 months	40 months	

8-1-6 Conclusion on Improvement Program of Boiler

(1) For Exclusive ROM Coal or SSC Firing

According to the analysis data of SSC and ROM coal, the compositions of coal and combustion ash are quite different from those of the design, and widely fluctuate as shown on Table 8-5 below.

Table 8-5 Analysis Data of ROM Coal SSC and Design Value

	Unit	ROM Coal	SSC	Design Value
Calorific value	kcal/kg	3,400–4,400	4,125–4,720	4,722
Total moisture	%	21.70–30.87	20.15–30.87	19
$Na_2O + K_2O$	%	–	1.97– 9.23	less than 4
Ash	%	7.76–26.80	6.08–16.66	6.72–19
Ash softening temp.	°C	–	1,160–1,240	1,120

The existing boiler and its auxiliaries are hardly expected to cope with the exclusive firing of the coals, compositions of which largely deviates from the design value. So, if the exclusive firing of either coal is intended, the existing boiler facilities should be replaced with new one. The new construction or replacement of the boiler including improvement works of the coal handling facilities needs an investment of about US$114 million (¥16 billion) and a construction period of 4 years. Furthermore, it is extremely hard and uneconomical to design a boiler capable of firing every kind of coal with a wide range of quality fluctuations.

As an improvement plan of the existing facilities, the installation of a new boiler is not practicable and not effective in term of economy. Thus, the installation of a new boiler is not advisable.

(2) Increase in SSC Blending Ratio by Modification of Boiler

The modification of th existing boiler needs an investment of about US$11 million (¥1,600 million) and 18 months of construction period. The modification plan, however, is formulated with respect to the very limited space taking the existing facilities into account.

Though the plan incorporates the maximum extent of modification items possibly carried out in the limited space, it does not satisfy all the essential conditions. The SSC blending ratio will be increased only by 5% without any further allowance. As a conclusion, this modification plan is not recommendable either, because of little economic merit.

(3) Derated Output for Exclusive SSC Firing or Increase in SSC Blending Ratio

If exclusive firing of the local coal is intended to avoid the use of imported coal, the existing facilities can only be operated at the derated output by all means. As compared with the current operation with the SSC blending ratio of 60 : 40, the exclusive SSC firing at 225 MW output would increase the domestic coal consumption by about 300,000 tons per year.

In consideration of the power demand and supply conditions in Luzon, the plan may hardly be acceptable to NAPOCOR. But, this kind of operation is actually undertaken on weekeneds, Saturdays and Sundays when system demand is low. And if the ample water is available for hydro power plants in the Grid during the rainy season, the plan will be practical and acceptable.

In addition, when the coal delivered to the plant has a high alkali content, and if system load condition allows, this derated operation may be accepted for higher domestic coal consumption.

In either case, the modifications of coal silo and coal feeder are desirable.

(4) Increase in SSC Blending Ratio Without Extensive Modification

The most advisable upgrading plan for the moment is to provide the existing equipment and facilities with the necessary modifications to enable smooth operation under the present coal blending ratio, and to increase the coal blending ratio of SSC gradually by confirming the boiler performance for each SSC blending ratio through combustion test step by step.

To attain the objective, the following measures should be taken.

a. The combustion test with an accurate blending ratio should be carried out.

   Especially, it is most important and urgent to conduct combustion test using the lowest mill (D mill) to maximize the use of the boiler furnace volume and observe and monitor precisely the combustion condition of the boiler.

b. The combustion control instruments and ABC system should be adjusted and maintained in proper conditions to establish the continuous and stable plant operation.

c. So far, the blending ratio between SSC and Australian coal has been manually controlled by visual reading of coal flow, with which accurate measurement of the blending ratio is difficult. To improve this unstable conditions, it is necessary to install a blending facility or a coal scale on the reclaimer for accurate control of the blending ratio.

d. The effective daily inspection and maintenance of the line up of all equipment and facilities topped by coal mill should be implemented to keep the proper operating conditions.

e. Accurate coal quality should be obtained and recorded by maximizing the use of coal analysis instruments donated by JICA this time.

f. As for the accidents and troubles encountered, reliable record for the conditions, causes, countermeasures, pending items, etc. should be kept for effective use of them afterwards.

g. The modification of coal silo and feeder for the troubles liable to happen during the rainy seasons, and the additional installation of sootblowers as the preventive measures against slagging and fouling problems are desirable.

8-1-7 Other Improvement Plans

(1) Additional Installation of Coal Dryer

In the case that only high moisture content of the coal is the bottle neck for the increase of plant output, plant capability will be increased by coal dryer.

Supposing that total moisture content is reduced from 30% to 19% and coal consumption is 140 t/h, the following dryer will be necessary. Refer to Fig. 8-2.

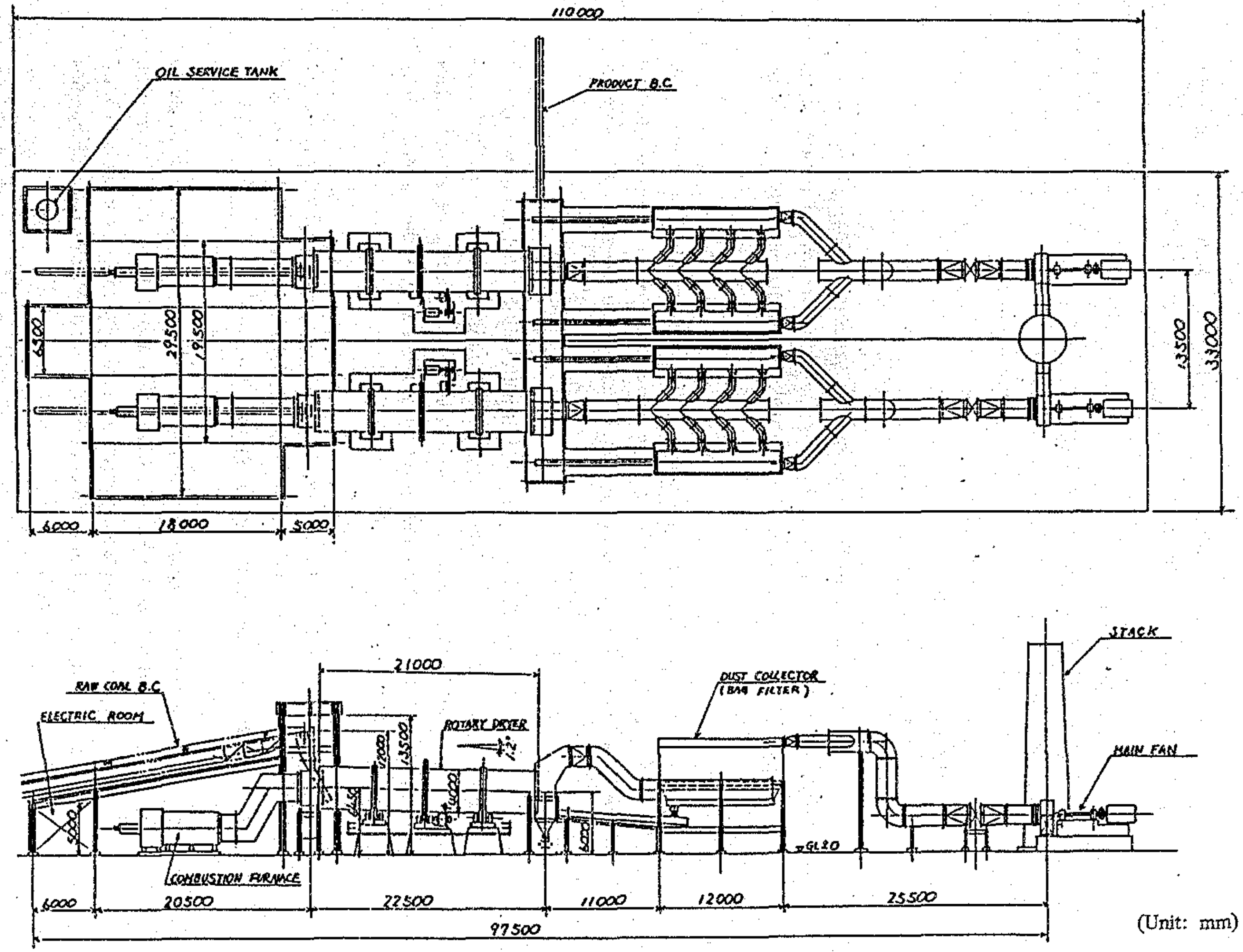
Type:	Parallel flow, direct heating, rotary type
Number of set:	2 sets
Dimension:	4 m diameter, 20 m long
Heat source:	C heavy oil (2,500 kg/h)
Required land space:	100 m x 40 m
Cost estimate:	US$6,800 thousand (¥950 million)

Problems with coal handling due to high moisture content will be solved by coal dryer; however, the coal dryer will not be effective for reduction of imported coal blending in case of high alkali content in SSC. For application of the coal dryer, it is necessary to forecast clearly the alkali content of SSC delivered in the future.

(2) Increase of Air Heater Element

When moisture conent of coal is comparatively high, hot primary air to coal mill will be running short. During the combustion test, it was experienced that supply of hot primary air reached to the maximum capacity at 225 MW under the exclusive SSC firing. High moisture content of the coal may only be the bottleneck for further increase of the plant output.

The existing air heater consists of 4 layers, namely high, high-medium, low-medium and low temperature layers and the low-medium layer is provided as a space for future installation. If one layer is additionally installed in this layer, primary air temperature may be increased by only 5°C. Though this modification can effect to lower the exhaust gas temperature, the temperature rise of primary air will not be expected so much.



(Unit: mm)

Fig. 8-2 Additional Installation of Coal Dryer

(3) Use of Coal Additives

Recently, as the countermeasures against the following problems in coal firing, additives have come to be used.

Reduction of dust
Prevention of slagging and fouling
Prevention of high and low temperature corrosion
Increase of efficiency of electrostatic precipitator
Reduction of unburnt carbon
Reduction of NOx
Reduction of SO_3 gas

It is said that coal additives consisting of magnesium oxide, calcium oxide, ferrous oxide, etc. as major components prevent occurrence or growth of slagging and fouling and made clinker fragile to the degree easily removed by sootblowing.

But high running cost and a long-term analysis for justification of the effect are problems to the fuel additive application. The running cost of the fuel additives stands at 5% or so of the annual coal cost if the additives are always used in Calaca Power Plant.

For the use of high alkali coal in the existing facilities, coal additives is one of the countermeasures to prevent slagging and fouling problem. The fuel additives have not been proven to be effective actually for such problems of Calaca Power Plant. For selection and adoption of the additives, the following study are required.

a. In the case of Calaca Power Plant, since slagging and fouling will be problem, reaction mechanism of the additives against fouling and slagging must be confirmed to the manufacturer.

b. In the study of experiences in the fuel additive application, it should be confirmed if the applied coal was similar in quality to the Semirara coal. In addition to the plant operating records, the data of clinker adherence in the furnace, coal and ash composition, and other practical parameters should be collected.

c. Test procedure of coal additives

a) Study of coal composition

Proximate analysis, calorific value, ultimate analysis, sulfur, ash fusion temperature, composition of ash (slagging and fouling index).

Test shall be done using the coal with higher slagging and fouling potential.

b) Test timing

It is desirable to implement the injection test after boiler cleaning.

c) Injection point

Injection point shall be chosen so that quantity of additives is adjustable.

d) Test record

During the test, combustion condition, adherence of ash in boiler furnace and operating parameter shall be recorded and ash sample shall be taken from dust collector, eonomizer and bottom ash hopper.

e) Analysis of samples

Analysis of above ash samples and microscopic picture

d. Injection of additives

Justification of effectiveness of coal additives is difficult in a short time. Effectiveness of the additives shall be confirmed step by step, while adjusting injection quantities.

In long term, injection quantity shall be determined in accordance with the alkali content and blending ratio of coal. It is desirable that additives shall be injected only when higher alkali coal is fired.

e. Utilization of coal dryer with coal additives

If any coal additives effective for slagging and fouling will be discovered, high moisture and low calorific value will follow as barriers of exclusive SSC firing. Moisture can be eliminated by the coal dryer and four-mill-operation can cope with low calorific value, which shall preliminarily be confirmed the possibility of good combustion. Four-mill-operation means that load-down or heavy oil firing is necessary in case of mill maintenance.

8-2 Combustion Control System

8-2-1 Outline of Improvement Plan of Calaca Unit No. 1 ABC System

After several investigations and careful studies, it was concluded to recommend that re-inspection and adjustment of ABC and LMC systems of Calaca Unit No. 1 are necessary in view of the regular performance standard. Results of the study on three alternative plans are described in the following.

(1) Basic Concept of Improvement

a. Plan 1

It is necessary to make a detailed study on the possibility of performance improvement within the present ABC system specifications but with additional re-adjustment, after conducting the detailed investigation on the existing automatic plant control (LMC & ABC) system.

The study by JICA Team up to present indicates the possibility of stable operation by re-adjustment of ABC system with load change rate of 1%/min. under load limiter operation.

b. Plan 2

Since there is some lack of basic control function in the existing feed-water control system including drum level control, modifications and re-adjustment of ABC system will be made on the assumption that the existing system is technically compatible with. Stable plant operation can be expected under the load change rate of 3%/min.

c. Plan 3

This plan conceives total re-adjustment of APC system and needs the modification of the existing control into coordinated control system of boiler and turbine.

Therefore, addition of coordinated control function to the existing LMC and ABC systems as above will require detailed preliminary survey to decide the design of new control circuit as well as the time necessary for additional work and adjustment.

The Plan 3 naturally includes Plan 2, and the improved performance can ensure the satisfactory on governor (governor free) operation.

(2) The Cost and Work Period of Improvement Work

Table 8-6 Cost and Schedule of ABC Improvement

Improvement Plan	Cost Thousand Dollar (Million Yen)	Work Period (Month)
Plan 1	210 (30)	3
Plan 2	390 (55)	12
Plan 3	500 (70)	14

The cost and work period mentioned above are still tentative since they will be influenced by the finding of detailed site survey of control systems needed prior to the preparation of the technical specifications.