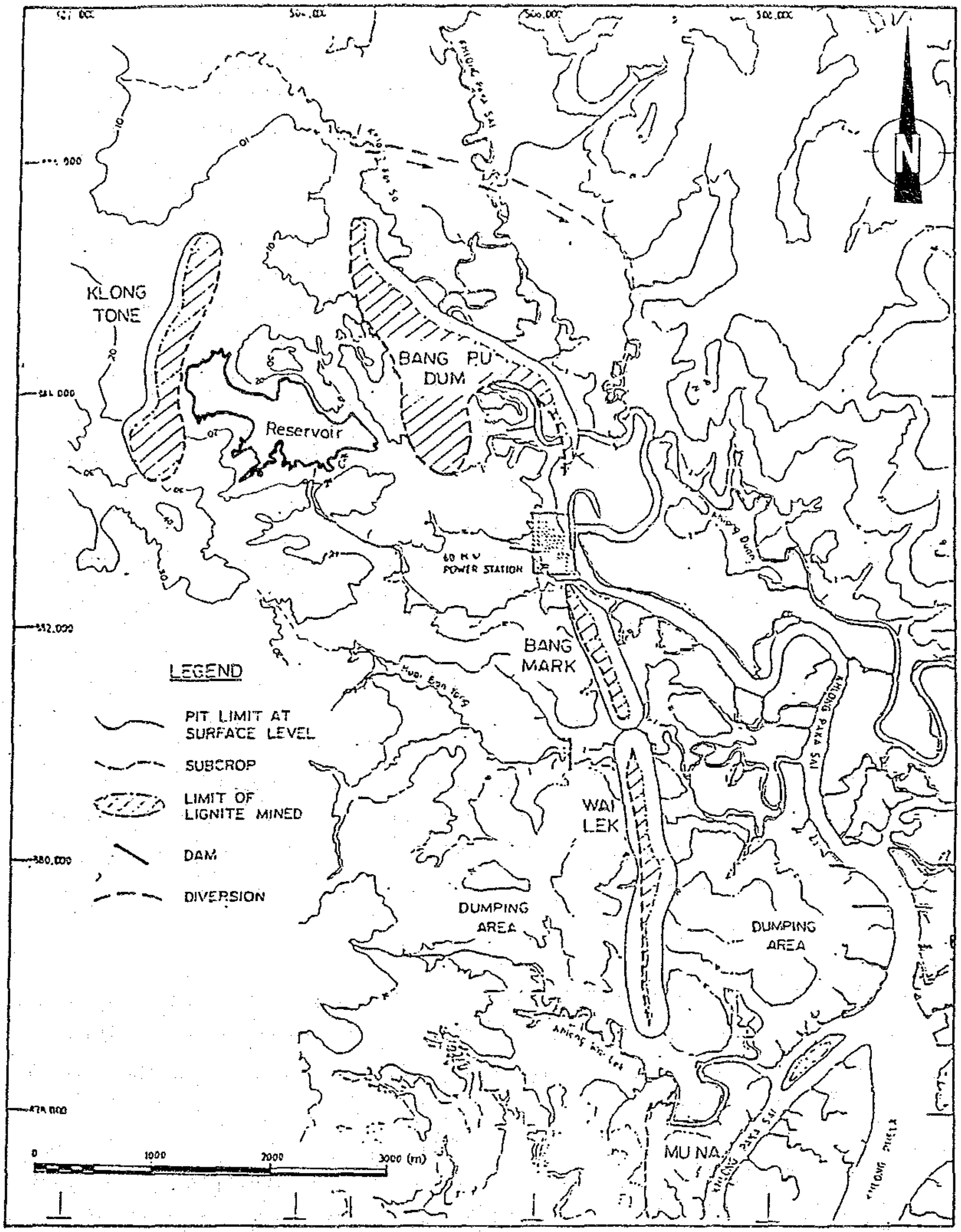


modified from Krabi Coal Deposit Geological Report, July 1986

Fig. 6-10 Krabi Coal Deposits

using Krabi coal as supporting fuel for generating electricity. In 1965, Krabi open pit mine was enlarged to supply its lignite to the power plants.

Since then geological investigation works were intermittently carried out. In 1985 a drilling program including geological, geotechnical and quality assessment fields was conducted in order to get the most likely economic areas for mining in the Krabi basin.

Krabi mine, reserves 120 million tons, produces about 250 thousand tons of lignite per annum by the truck and shovel mining method and provides all of them to the Krabi power plant (3 x 20 MW), generating about 34 MW from October 1989 to September 1990.

The Feasibility Study on Krabi Mine Expansion Project for Power Plant, February 1988 revealed that the Krabi mine is able to provide total 5 million tons per 25 years to the power plant.

The supply of 200 thousand tons per annum to the Sin Pun A-FBC power plant is adequately possible.

6.3.2 Geography

The Krabi Basin lies on the western Thailand coast and a majority of the southern portion of the basin is covered with essentially estuarine, mangrove, mudflat and some flood plain deposits, while the northern portion is covered with unconsolidated sediment, clay, silt and sand with some gravel in old channel.

The Paka Sai River flows from north to south along the eastern side of the Bang Pu Dum, Bang Mark, Wai Lek and Mu Na deposits and down to the Phela River which flows into the Malacca Strait. The small tributaries join the Paka Sai River from both sides.

The landform of the Krabi Basin is characterized by flood plain of the Paka Sai river with average height about 20 meters(MSL). A good deal of tributaries cover throughout the basin. The area is moderately rolling landform, height about 40 meters (MSL).

The climate around the Krabi Basin is divided into two season; a dry season and a wet season. The dry season from January to May is characterized by sunny and hot with little rain or breeze. The tropical weather causes a long rainy season from May to December. The meteorological data at the Krabi mine recorded by EGAT during 1988 - 1989 is summarized in the following table.

Table 6-5 Meteorological Data at Krabi Area

		Temperature				Rainfall		
		Max.		Min.				
		Ext. (°C)	Ave. (°C)	Ext. (°C)	Ave. (°C)	Monthly Rainfall (mm)	No. of Rain Day (day)	Greatest in 24hr. (mm)
	Jan.	36.5	35.3	19.5	21.3	14.50	4	10.00
	Feb.	37.8	36.9	20.2	21.8	2.00	1	2.00
1	Mar.	38.9	37.3	20.7	22.2	128.20	5	70.50
	Apr.	38.3	36.2	21.0	22.9	103.50	6	30.60
9	May	37.7	35.7	22.7	23.5	422.20	20	75.80
	Jun.	36.2	34.5	22.5	24.0	65.00	6	40.90
9	Jul.	35.5	33.5	21.5	22.9	261.30	17	53.60
	Aug.	34.6	32.8	21.3	23.2	352.40	19	69.20
1	Sep.	33.8	32.7	21.5	22.8	193.10	19	38.20
	Oct.	35.1	33.7	21.0	21.8	139.30	18	50.00
	Nov.	34.9	33.0	20.3	21.3	53.40	11	22.00
	Dec.	34.0	32.9	20.1	20.9	49.10	9	13.50

6.3.3 Geology

6.3.3.1 Regional Stratigraphy

The Krabi Tertiary coal Basin is one of isolated intermontane basins in Peninsula of Thailand. The previous geological study reveals that it is formed on the southern end of narrow graven-like terrain near Pnang-nga Bay with the depositional environment under shallow marine and lacustrine.

Krabi area is underlain by Paleozoic to Quaternary rocks (Fig. 6-12). The basement rocks is composed of late Paleozoic to Mesozoic sedimentary rocks. The Tertiary sequence (Krabi Group) consists of six formations: the Bang Pu Dum, Pakasai, Khlong Siat, Khuan Muang, Tha Nun and Huai Khram Formations in ascending order (Fig. 6-11). The Bang Pu Dum Formation is a main coal bearing

Age	Group	Formation	Description
QUATERNARY			Clay, silt and sand with gravel
			UNCONFORMITY
TERTIARY	KRABI GROUP	HUAI KHRAM Fm.	Brown to gray clay and claystone with some sand and gravel in some parts; thickness varies from a few meters to 150 meters.
TERTIARY	KRABI GROUP	THA NUN Fm.	Gray to brownish gray claystone, sandstone, siltstone with thin layer of lignite on the northern part and gray to reddish brown claystone with fine to coarse grained sandstone on the southern part; thickness is about 100-150 meters.
TERTIARY	KRABI GROUP	KHUAN MUANG Fm.	Gray to brownish gray claystone, fossiliferous with slightly silty claystone and sandstone in part; thickness is about 100 meters.
TERTIARY	KRABI GROUP	KHLONG SIAT Fm.	Gray claystone, fine grained sand-stone and fosiliferous limestone; thickness is about 100 meters.
TERTIARY	KRABI GROUP	PAKASAI Fm.	Gray to greenish gray claystone and laminated shale, calcareous and fossiliferous in some parts, inter-bedded with sandstone and siltstone in western part of the basin; thick-ness varies from 50- 450 meters.
TERTIARY	KRABI GROUP	BANG PU DUM Fm.	Greenish gray to gray claystone, sandstone, limestone, carbonaceous claystone several thin lignite seams, gradually change to reddish brown and gray claystone, siltstone and sandstone in the lower portion; thickness is at least 150 meters.
			UNCONFORMITY
TRIASSIC-CRETACEOUS PERMIAN CARBONIFEROUS-PERMIAN			Basement of Mesozoic, Permian and Carboniferous - Permian Rock

After Krabi Coal Deposit Geological Report, June 1986

Fig. 6-11 Lithostratigraphy of Krabi Basin

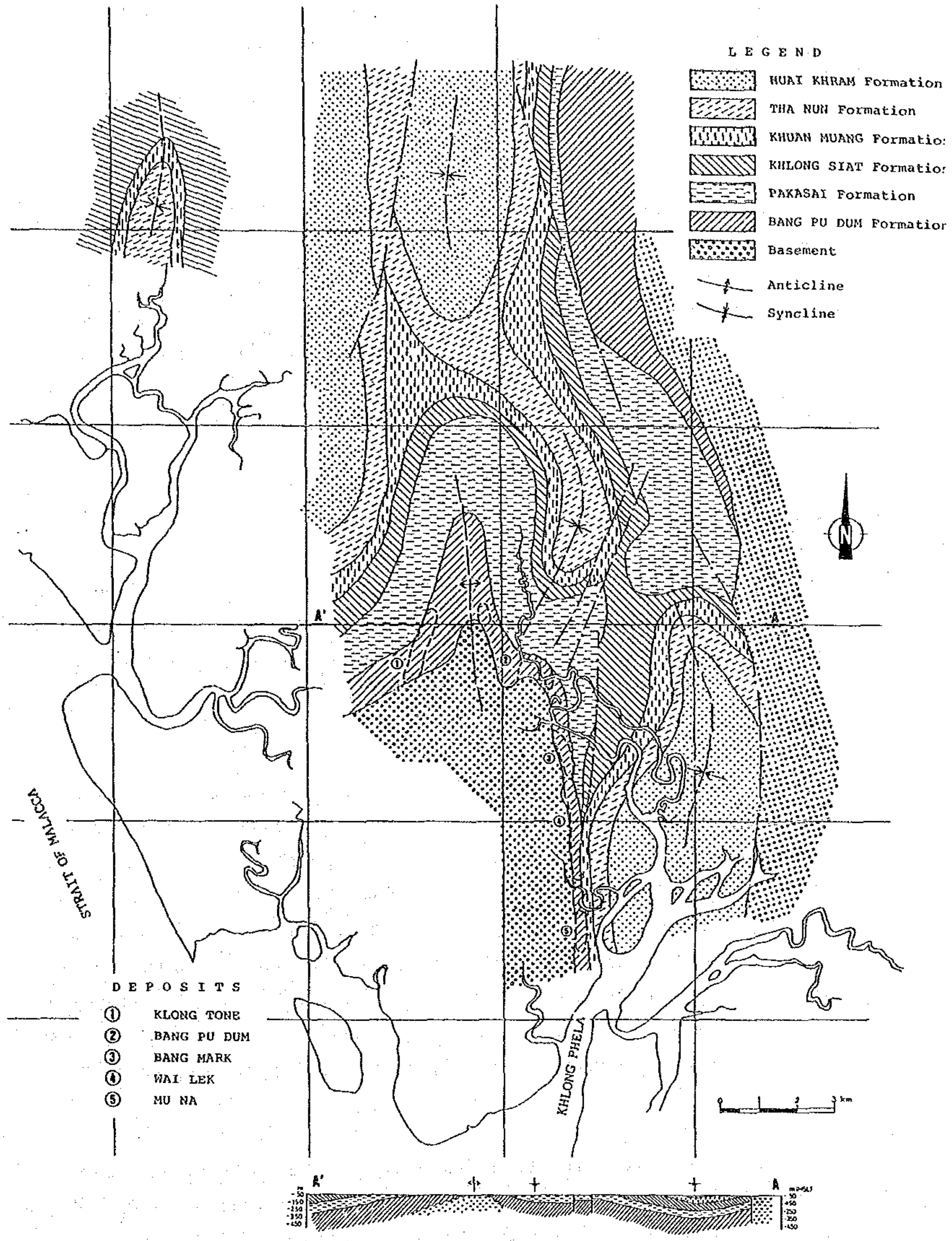


Fig. 6-12 Geologic Sketch Map at Elev. -50 m (MSL)

formation while the Tha Nun Formation includes thin uneconomic lignite layers. The Krabi Basin is covered throughout with Quaternary sediments. Detailed description of each rock is as follows:

(1) Pre-Tertiary Rocks

Permian limestone range, which is characterized by light to dark gray massive and bedded limestone interbedded with sandstone and shale, bounds on the western side of the Tertiary basin. The basin is presumably bounded on the south by Carboniferous to Permian rocks which are made up of sandstone, shale, conglomerate and chert. The range and some hills of Mesozoic red bed form the northern and eastern boundary of the basin. This red bed is marked by sandstone, shale and conglomerate of fluviatile deposits.

(2) Tertiary Rocks

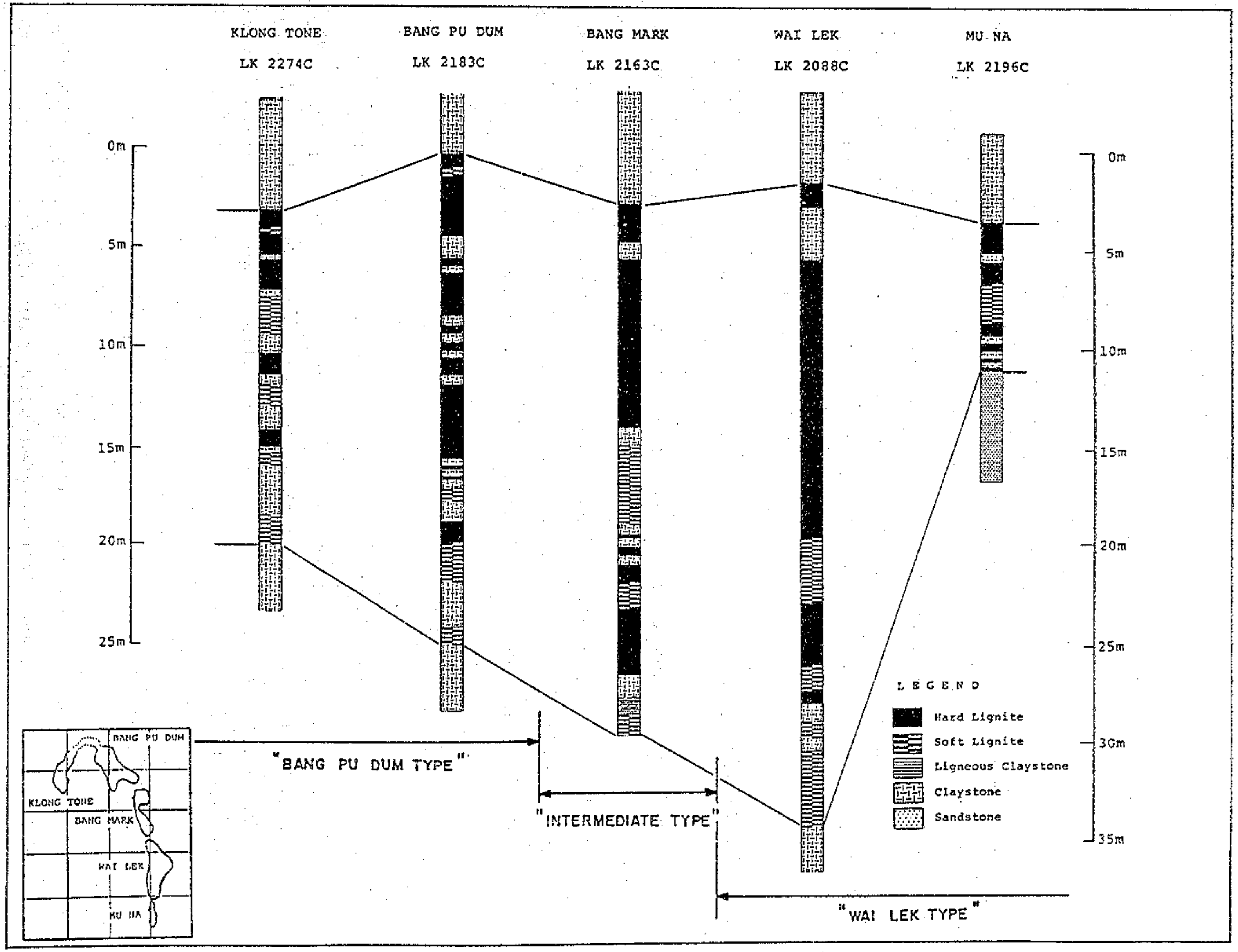
The Tertiary sediments called Krabi Group(EGAT 1986) is divided into six formations: the Bang Pu Dum, Pakasai, Khlong Siat, Khuan Muang, Tha Nun and Huai Khram Formations in ascending order (Fig. 6-11).

<u>Bang Pu Dum Formation</u>

This is the lowest unit of the Krabi Group and unconformably overlies the pre-tertiary basement rocks. This formation consists of reddish brown and gray claystone, siltstone and sandstone in the lower portion while the upper portion is made up of greenish gray to gray claystone, sandstone, limestone, carbonaceous claystone and several lignite seams. The thickness is at least 150 meters. The lignite seams thicken towards the central part of the basin. Although the stratigraphy of the coal zone varies markedly, the two different types of coal zone can be summarized by Longworth-CMPS engineers in 1981 as follows (Fig. 6-13):

<u>Wai Lek Type</u> is fairly uniform seam of good quality lignite with thickness about 15-20 meters. It has steeply dipping (30-45 degrees) in the west and extend downdip with less steep. The associated sediment are gray calcareous claystones.

Fig. 6-13 Typical Geological Logging of Five Coal Deposits of Krabi Basin



Simplified from Krabi Coal Deposit Geological Report, June 1986

Bang Pu Dum Type is a more shallow, gentle dipping, splitting seam and lower quality with thickness about 10 meters. The associated sediments are generally more sandy and contain varicolored clay.

Pakasai Formation

This formation consists of claystone and laminated shale, gray to greenish gray, calcareous and fossiliferous in some parts. Coarse grained sediments, sandstone and siltstone occur as interbeds at the west to the mine, meaning the change in environment of deposition in these parts. This formation is 10 to 50 meters thick at the northern and northwestern parts and thickens toward south, increasing to more than 200 meters at the north of Krabi Mine and rapidly up to 450 meters around the mine.

Khlong Siat Formation

This formation consists of well compacted gray claystone, fine grained sandstone and fossiliferous limestone around the northern edge of the main basin and gradually change to poor compacted claystone and shale toward south. The central and eastern parts have more silty and sandy rock facies in part. This formation is about 100 meters thick.

Khuan Muang Formation

This formation is made up of gray to greenish gray claystone, fossilifereous with silty claystone and sandstone in some part. This formation has a thickness of about 100 meters uniformly throughout the basin and is a good key marker for stratigraphic correlation of Tertiary beds.

Tha Num Formation

This formation is composed of gray to brownish gray claystone, sandstone, siltstone, intercalated with thin lignite layers at the northern part of the basin and gray to reddish brown claystone, intercalated with fine to coarse grained sandstone at the southern part of basin. This variation of lithology represented the lateral change of depositional condition during the sediment of this formation. This formation is about 100 meters thick.

Huai Khram Formation

This formation is made up of brown to gray clay and claystone with some sand and gravel in some part. The thickness of this uppermost formation varies greatly from a few meters in the southern part up to 100 to 150 in the northern part.

(1) Quaternary Rocks

Quaternary deposit covers all over the Krabi Basin. In the north, it is composed of unconsolidated sediment: clay, silt and sand with some gravel in old channels, whereas, in the south, it consists essentially of estuarine, mangrove, mudflat and flood plain deposits. The northern part has a thickness of less than 10 meters, which the thickness in the southern part of the basin varies approximately from 20 to 50 meters.

6.3.3.2 Coal Deposits

The Krabi basin has five main coal deposits in the Bang Pu Dum Formation at the central area: Klong Tone, Bang Pu Dum, Bang Mark, Wai Lek and Mu Na deposits(Fig. 6-10).

Electricity Generating Authority of Thailand(EGAT) is running the open-pit mining at the Bang Mark and Wai Lek deposits for providing lignite to their mine-mouth power plants(75MWx2). The Bang Pu dum pit has been mined out recently. The Klong Tone deposit is planned to be developed for supply lignite to the JICA A-FBC coal-fired power plant. Detailed description of each formation will be discussed in following passage:

Klong Tone deposit (Fig. 6-14 and 6-16)

EGAT plans to provide 20 thousand tons per annum of Klong Tone coal for the A-FBC power plant. This deposit is located in the west limb of a fold. Its

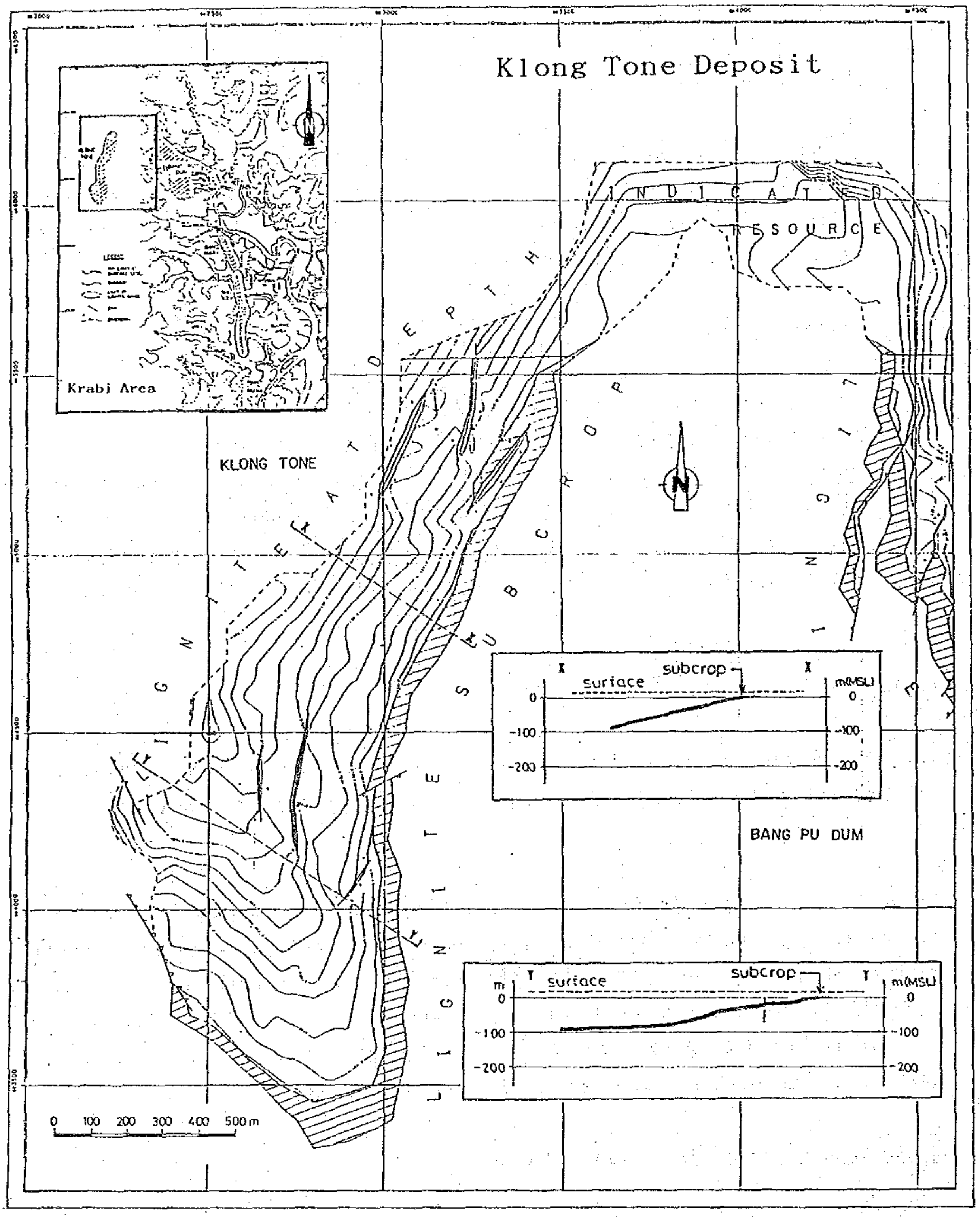


Fig. 6-14 Klong Tone Deposit

areal extension is more than 1.3 square kilometers. The total thickness of coal layers in coal zone varies from 10-25 meters near subcrop to 5 meters in deeper part with average about 8.0 meters. The central part has a general tendency to yield many partings in the coal zone, where total thickness of these partings is 20 meters. In southern and northern partings, the parting total thickness is about 5-10 and 5-15 meters respectively. The ratio of coal and parting is about 1.34:1. The coal zone is classified as "Bang Pu Dum Type." Subcrop of coal zone crops out along the eastern limitation of the deposit with its width 75-100 meters and its total length about 3.0 kilometers.

The coal zone strikes NNW and its dip varies from about 10°-20°. Around the southern boundary, the bedding trends NW and dips NE, while northern area are connected to the Bang Pu Dum deposit with changing strike as EW and dipping to north. Only few antithetic faults are observed near subcrop area.

Bang Pu Dum deposit

This deposit is located in the east limb of a fold and consists of EGAT's existing Bang Pu Dum pit and the surrounding area. The deposit, however, has almost finished mining. Its areal extension is about 2 square kilometers. The total thickness of coal layers in coal zone varies from less than 5 meters to more than 25 meters with average about 12 meters. The thickness varies NNW-ward. The parting total thickness varies from less than 5 meters to more than 20 meters. The coal zone is classified as "Bang Pu Dum Type." The ratio of coal and parting is about 3.19 : 1. Subcrop of coal zone crops out along the western limitation of the deposit with its width from 50 meters to 100 meters and its total length about 3.0 kilometers.

The coal zone strikes NNW and its dips to NEE with dip angle about 10°-20°. In the northern part, the bedding shift its strike as EW and connects to the Klong Tone deposit. There are observed two antithetic faulting systems with trending direction as NE and NW at the western portion near subcrop area and southern portion. Subcrop of coal zone is exposed along the western limitation of the deposit with its width from 50 to 100 meters and total length about 3.0 kilometers. The outcrop of coal zone is repeated by faulting.

Bang Mark deposit

This deposit is about 0.5 kilometers southeast to the Bang Pu Dum deposit and its aerial extension is more than 1.5 square kilometers. The total thickness of coal layers in coal zone varies from less than 5 meters in the southern part to more than 30 meters in the central part with average about 17 meters. The coal zone is classified as "Intermediate type" between "Bang Pu Dum Type" and "Wai Lek Type." The southern part has a general tendency to yield many partings in the coal zone. The total parting thickness varies from less than 5 meters in the northern part to more than 35 meters in the southern part. Coal and parting is in the ratio of about 2.89 : 1. Subcrop of coal zone crops out along the western limitation of the deposit with its width about 50 meters and length about 2.5 kilometers.

The coal zone strikes NNW and dips about 30 degrees NEE. The northern and southern boundaries are vague. Two small faults are known in the central part, whereas three larger faults are observed in the northern part.

Wai Lek deposit

This deposit is to the south of the Bang Mark deposit. EGAT's existing open pit is going in the deposit. Its areal extension is more than 2 square kilometers. The total thickness of coal layers in coal zone varies from 20-25 meters near subcrop to about 5-10 meters in deeper part with average about 15 meters. The total coal portion thins at the northern and southern parts. The coal zone is classified as "Wai Lek Type." The deeper part has a general tendency to yield many partings in the coal zone. The total parting thickness varies from less than 5 meters near subcrop to more than 20 meters in the southern part. The ratio of coal and parting is about 3.9 : 1. Subcrop of coal zone crops out along the western limitation of the deposit with its width from 50 meters on the north to less than 30 meters on the south and its total length about 2.0 kilometers.

The coal zone strikes NS and its dip varies from about 30 degrees E near subcrop to 15-20 degrees E in the deeper area. There are observed eight faults in the central part of the deposit.

Mu Na deposit

This deposit is to the south of the Wai Lek deposit. Its areal extension is more than 0.4 square kilometers. The total thickness of coal layers in coal zone varies from more than 10 meters in the northern and southern parts to about 5-10 meters in the central part with average about 8 meters. The total coal portion thins at the northern and southern parts. The coal zone is classified as "Wai Lek Type." The splitting in coal zone occurs in the deeper area. The average total parting thickness is about 2.15 meters. The ratio of coal and parting is about 3.92 : 1. Subcrop of coal zone is traced along the western limitation of the deposit with its width less than 25 meters its length about 1.0 kilometer.

The coal zone strikes NNW and its dip varies from about 30 degrees NNE near subcrop to 20 degrees NNE in the deeper area. The northern and southern boundaries are vague. There are observed eight faults in the central part of the deposit.

6.3.3.3 Structure

Krabi basin is characterized by folding system(Fig. 6-12); anticlines run north-south direction at the center of the east and west blocks and plunge toward north; synclines having curved axes occur at the east part of the east block. The marginal fault runs along the east margin of the basin and dips to the west. Tertiary rocks are in fault contact with pre-Tertiary basement rocks along this fault. There are some NE-SW faults between the Bang Pu Dum deposit and the Bang Mark deposit. In each coal deposit, several faults are observed but seem not to be obstacles to the mining for the present.

6.3.4 Coal Reserves

Feasibility Study on Krabi Mine Expansion Project for Power Plant Unit 4, February 1988, shows the geological and economical minable reserves of Krabi Coal Deposit respectively as follows:

* Geological reserves with 70% ash cut-off.

  Measured ..... 83 million tons

  Indicated .... 37 million tons

  Total .... 120 million tons

* Economical minable reserves

  20 million tons

Geological reserves are calculated on the basis of total 1,437 boreholes by using the computerized evaluation system of EGAT coal exploration. Geological reserves of each deposit are summarized in the following table.

Table 6-6 Geological Reserves of Krabi Coal Deposit

Deposit	Reserves Measured (1,000t)	Indicated (1,000t)	Total (1,000t)	Ave. Specific Energy (kcal/kg)
Klong Tone	13,504	11,317*	24,821	1,611
Bang Pu Dum	27,056	-	27,056	2,001
Bang Mark	14,928	7,652	22,580	2,041
Wai Lek	24,624	18,208	42,832	2,237
Mu Na	3,500	-	3,500	1,924
Total	83,612	37,177	120,789	1,815

* : Indicated Reserves of Klong Tone and Bang Pu Dum could not be separated due to their continuously geological structure

The economic minable reserves of 13.28 million tons shown in Table 6-7 are more conservative than above-mentioned 20 million tons. It was also calculated by EGAT for studying the potential of the supply of Krabi lignite to a new coal fired power plant.

The Klong Tone deposit are sufficient for the supply to provide 200 thousand tons per annum to the new FBC power plant.

Table 6-7 Economic Minable Lignite Reserves

Deposit	Reserves Proven (1,000t)	Ave. Specific Energy (kcal/kg)
Klong Tone	5,000	2,240
Bang Pu Dum	5,000	2,450
Bang Mark	2,300	2,700
Wai Lek	980	2,700
Mu Na	-	-
Total	13,280	2,430

6.3.5 Coal Quality

Generally, quality of Krabi coal varies greatly area by area, the Wai Lek deposit shows relatively the highest quality (average Net Calorific Value 2,236 kcal/kg) and the Klong Tone deposit presents relatively the lowest quality (average Net Calorific Value 1,610 kcal/kg) among five deposits in Krabi area. Table 6-8 and 6-9 summarize quality of Krabi coal. Quality of coal in the Klong Tone deposit, which is planned to supply the total 5 million tones to the A-FBC power plant for 25 years, is summarized as follows:

Net specific energy: Ave. 1,610 Max. 2,404 Min. 924 (Kcal/kg)

Net specific energy around the subcrop area(eastern part) and the southern area is relatively higher than one of the western and northern parts of the area.

Ash content: Ave. 42.75% Max. 54.46% Min. 25.64%

The subcrop and southern sides show relatively lower ash contents than the western and northern sides. Generally, ash content of Klong Tone lignite is relatively the highest among five deposits in Krabi Basin.

Moisture content: Ave. 24.22% Max. 27.51% Min. 21.47%

The northern side exhibits relatively lower moisture contents than the southern side. Generally, moisture content of Klong Tone lignite is relatively the lowest among five deposits in Krabi Basin.

Table 6-8 Coal Quality Distribution in Krabi Basin

Parameters (as received)	Klong Tone			Bang Pu Dum			Bang Mark		
	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min
Net Specific Energy (kcal/kg)	2,404	1,610	924	2,978	2,000	1,162	3,114	2,047	1,412
Ash Content (%)	54.46	42.75	25.64	49.73	36.32	19.69	41.42	33.76	17.23
Moisture Content (%)	27.51	24.22	21.47	30.16	25.91	22.61	30.85	26.84	24.63
Sulphur Content (%) - dry basis	2.50	1.94	1.44	5.14	2.11	0.80	—	—	—
Relative Density (g/cc)	1.75	1.61	1.46	1.90	1.55	1.33	1.59	1.49	1.30

Parameters (as received)	Wai Lek			Mu Na			Total		
	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min
Net Specific Energy (kcal/kg)	3,273	2,236	1,614	2,449	1,924	1,555	3,273	1,976	924
Ash Content (%)	42.59	30.59	14.46	41.36	36.39	29.27	54.46	36.45	14.46
Moisture Content (%)	31.61	27.65	24.41	27.74	26.66	25.79	31.67	26.14	21.50
Sulphur Content * (%) - dry basis	—	—	—	—	—	—	5.14	1.95	0.80
Relative Density (g/cc)	1.59	1.45	1.26	1.60	1.54	1.43	1.75	1.53	1.26

* : Sulfur content of Bang Mark, Wai Lek and Mu Na were not modelled due to low density of data.

after Feasibility Study on Krabi Mine Expansion Project for Power Plant Unit 4, Feb.1988

Table 6-9 Coal Quality of Each Deposit in Krabi Basin

Parameters (as anal.)	Klong Tone	Bang Pu Dun	Bang Mark
Proximate Analysis(%)			
Moisture	10.00	10.20	10.20
Ash	46.30	43.80	43.03
V.M.	25.00	24.67	24.77
F.C.	18.70	21.33	21.00
Net Calorific Vale (kcal/kg)	2,670	3,004	2,925
Relative density	1.83	1.8	1.78
Ultimate Analysis (daf %)			
Carbon	28.00	30.40	30.50
Hydrogen	2.37	2.53	2.53
Nitrogen	0.75	0.86	0.77
Sulphur	3.76	3.20	3.03
Chlorine	0.01	0.01	0.03
Carbonate	0.19	0.19	0.29
Sulphur (adb %)	3.76	3.20	3.03
Ash Analysis (%)			
SiO3	55.70	55.75	56.55
Al2O3	23.20	24.10	23.60
Fe2O3	9.28	9.22	7.67
CaO	3.39	2.51	3.50
MgO	2.16	2.42	2.34
TiO2	0.79	0.83	0.81
Na2O	0.10	0.23	0.26
K2O	2.34	2.48	2.35
P2O5	0.12	0.15	0.11
Mn3O4	0.06	0.05	0.07
SO3	2.32	1.66	2.18
Ash Fusion Temp. (° C)			
Deformation	1,207	1,190	1,250
Sphere	1,327	1,380	1,325
Hemisdhere	1,360	1,395	1,330
Flow	1,403	1,445	1,400
Trace Element Analysis			
U (ppm)	54.4	39.8	35.3
F	332.0	407.0	349.0
B	64.0	71.5	83.0
As	69.0	73.0	69.5
Hardgrove Grindability Index (HGI)	81(35)	79(39)	69(41)

Remarks: This analytical data were analysed in Australia by ACIRL.
Three samples from each deposit were collected .

after Feasibility Study on Krabi Mine Expansion Project for Power

Sulphur content: Ave. 1.94% Max. 2.50% Min. 1.44%

The eastern side around subcrop shows relatively higher sulphur contents than the western side. Generally, sulphur content of Klong Tone lignite is relatively lower than one of Bang Pu Dum lignite.

6.3.6 JICA Works in Krabi Mine

JICA Sin Pun A-FBC Coal-Fired Thermal Development Project carried out five large-diameter cored drillings in order to collect bulk samples of Krabi coal for combustion test in Japan. Three of five holes were conducted at Klong Tone deposit and two holes at Bang Mark deposit (Fig.6-15). Total five ton coal samples were shipped to Japan from Bangkok in March 1992.

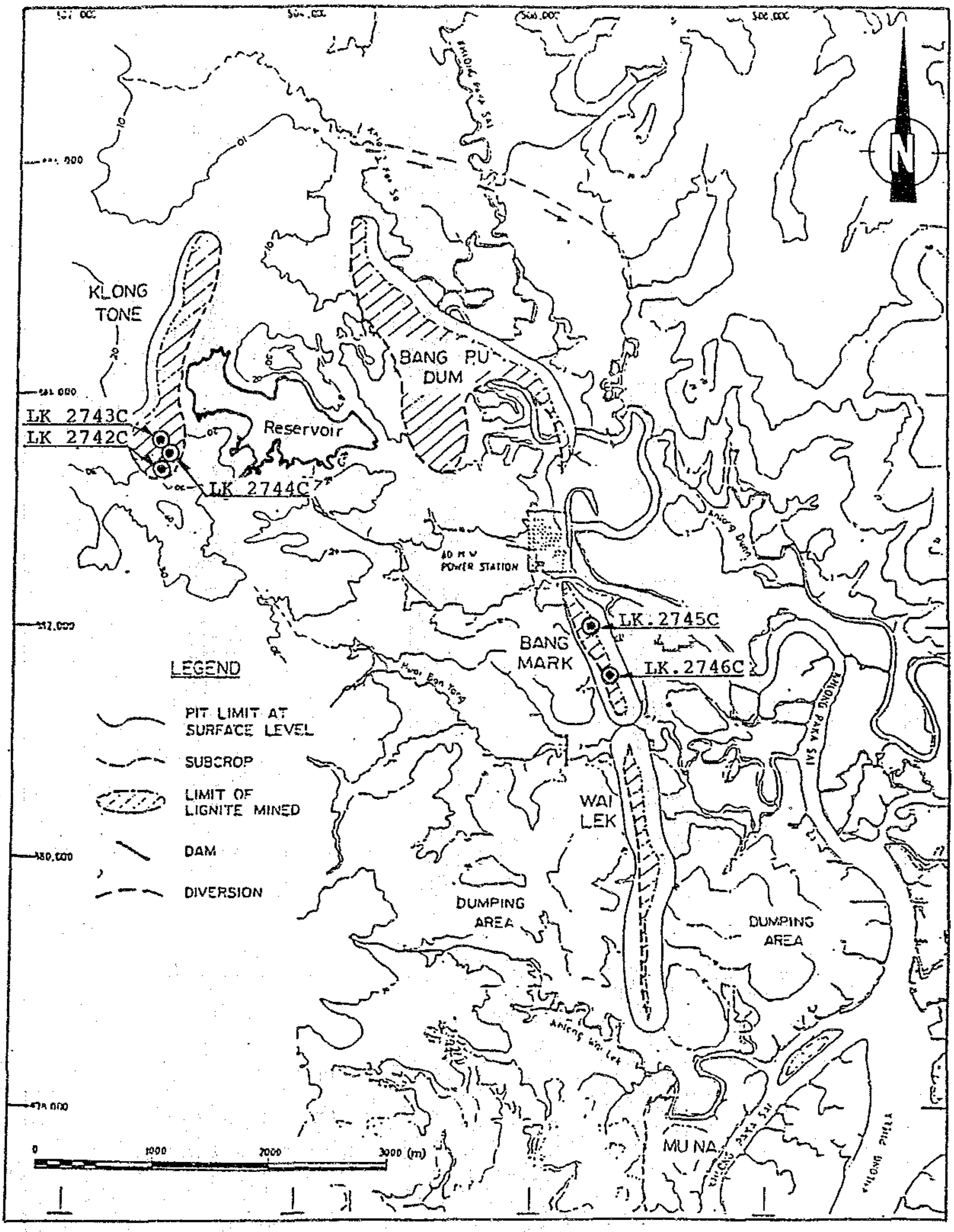


Fig. 6-15 JICA Sampling Drills in Krabi Area

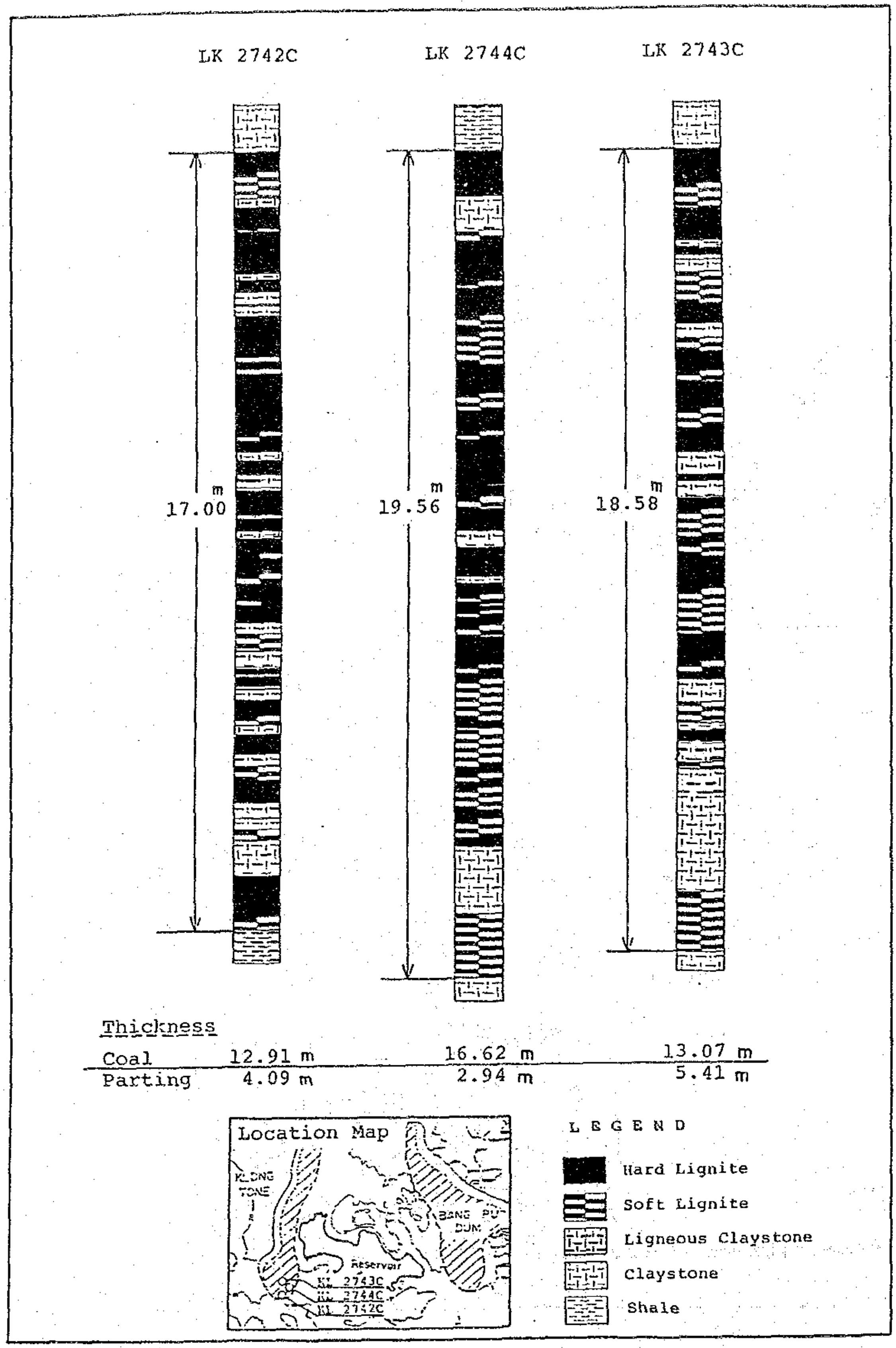


Fig. 6-16 Coal Sections of JICA Sampling Drills in Klong Tone

6.4 Mining Plan

6.4.1 Power Station Coal Requirement

The energy requirement of a 150 MW FBC-fired Power station using Sin Pun coal and Krabi coal are estimated as follows.

Capacity of plant		150 MW
Schedule Annual Hours		365 x 24 = 8,760 hours
Annual plant factor		80%
Annual average heat rate		36.4%
Operation period		25 years
Coal quality	Sin Pun coal	2,787 kcal/kg
		(Blending case 2,795 kcal/kg)
	Krabi coal	1,600 kcal/kg
	Average	2,556 kcal/kg
Coal consumption rate		
	Sin Pun coal	80%
	Krabi coal	20%

Coal consumption per hour

(860 x 150 x 1,000) ÷ 0.364 = 354,395,604 kcal/hour

354,395,604 ÷ 2,556 = 138.7 ton/hour

Coal consumption per year

138.7 x 24 x 365 x 0.8 = 972,010 ton/year

Sin Pun coal	972,010 x 0.8	= 777,608 ton/year
		≡ 800,000 ton/year
Krabi coal	972,010 x 0.2	= 194,402 ton/year
		≡ 200,000 ton/year

The energy demand for 25 years will require the mining of 20 million tons of coal from Sin Pun and 5 million tons from Krabi.

The coal for the 150MW power station is planned to be supplied from three coal deposits: two in Sin Pun Field and another in Krabi area. It is necessary to blend those coal in order to provide the stable coal as possible and then to build the mixing equipment in the power station site.

6.4.2 Mine Design Criteria and Scheduling Parameters

Design Criteria used in the estimation of mining quantities and equipment productivities are listed below:

Coal Density	1.4 ton/m^3
Waste Density	2.25 ton/m^3
Overall Lowwall Angle	10°
Overall Highway Angle	15°
Overall Endwall Angle	12°
Bench Height	5 meter
Haulage Ramp Grade	10%
Rolling Resistance - near face	6%
- main haul roads	3%
Haul Track Speed Limit	40 km/h
Swell factor of all material into equipment	1.43
Swell factor for waste dumps - long term	1.20
Overall dump slope angle	1:6.25

The mine design criteria used for the proposed "truck & shovel mining system" was reflect practices in operation at EGAT's Mae Moh and Krabi mines. So these criteria are based on the long experience of EGAT and reliable figures for mining plan.

Scheduling Parameters on coal mining and waste removal are as follows:

Scheduled hours per day	20
Shifts per day	2
Hours per shift	10
Effective hours per shift	8.75
Scheduled days per year	365

6.4.3 Selection of Mining Method

A standard strip mining technique has been planned. Mining will commence in each pit with a boxcut excavation along the coal subcrop. Overburden removal will proceed in successive horizontal benches of 5 meter height to depth of about 70 meters.

The waste will be hauled up face ramps on the highwall or endwall to surface dumps located off coal but as close to the pit limits as possible. This Mining Method has got in each coal mine such as Mae Moh and Krabi.

Provision has been made for all of the material to be drilled and partially blasted to allow high loading productivity, if necessary. But there is a possibility to increase the dilution into the Lignite by these blasting.

The potential to incorporate some input dumping must be considered in the detailed mining study.

Serious consideration is necessary for back filling, because sometimes the back filling will be the reason of the sliding at the waste disposal area especially in rainy season. It is reported that the relatively high average rainfall of 2,064 mm/year.

6.4.4 Economic Minable Resources and Mining Area

The EGAT study on 100MW power station shows that 17.1 million tons of coal are required and can be supplied entirely from Sin Pun Area. Coal resources with measured in rank and proposed production of each deposit are shown in Table 6-10.

Table 6-10 Coal Resources and Planned Production in Sin Pun Area

Deposit	Measured (MT)	Production (MT)	Waste (Mm^3)	Strip Ratio
Bang Sai	10.03	6.60	25.59	3.88
North Kuan Klang	17.21	7.23	35.49	4.91
South Kuan Klang	5.34	3.27	13.68	4.18
Total	32.58	17.10	74.76	4.37

In case of 150 MW power station, Economic Ratio Analysis indicates that the break even point is $10/Gcal and 25 million tons of coal are required during 25 years. The Economic Minable Resources within $10/Gcal is shown in Table 6-11 as 25.2 million tons: 20.1 MT from Sin Pun (Fig. 6-18) and 5.1 MT from Krabi. This means that Sin Pun and Krabi areas have still much economic coal resources enough to supply 25 million tons to the 150MW power station. Details of the resource for each deposit are shown as follows:

Table 6-11 Resources of EMR $10/Gcal or Less

Deposit	Measured	E M R ($10/Gcal)	%
Bang Sai	10.03	8.5	84.7
North Kuan Klang	17.21	7.1	41.3
South Kuan Klang	5.34	4.5	84.3
Subtotal(Sin Pun)	32.58	20.1	61.7
Klong Tone (Krabi)	14.93	5.1	34.2
Total	47.51	25.2	53.0

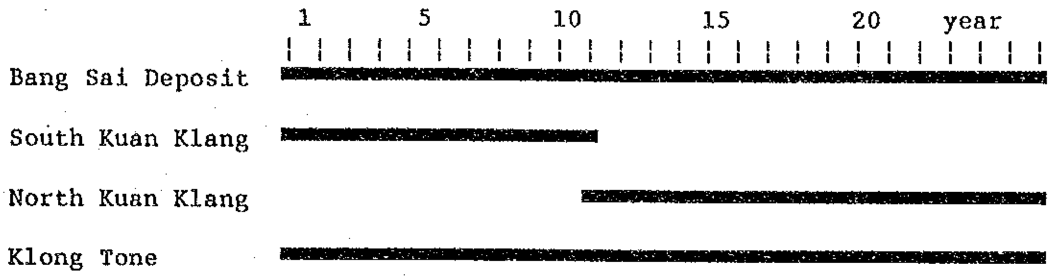
It is better to say that 3 million tons of the difference of about 8 million tons between 150 MW (25 MT) and 100 MW (17.1 MT) power stations should be mined from the Bang Sai and South Kuan Klang deposits in Sin Pun Basin and 5 million tons from Klong Tone deposit of Krabi Mine.

It is assumed that the strip ratio in both areas of Bang Sai, North Kuan Klang and South Kuan Klang could be less than 5 to 1, even if more than 20 MT of coal is mined from these three areas in Sin Pun Area. The strip ratio of almost all economic minable reserves at the Klong Tone deposit of Krabi Area is also less than 5 to 1.

From the results of ER analysis of Sin Pun deposit, it is estimated that 20 MT of coal will be supplied to the 150 MW power station with less than $10/Gcal of break even point. (Fig. 6-18)

It is considered that mining sequence should be proceeded as following basis for a better combination. First Bang Sai and South Kuan Klang areas in Sin Pun field and Klong Tone deposit in Krabi will be mined at the same time, then North Kuan Klang will take a place after South Kuan Klang is mined out.

Fig.6-17 Mining Order



The mining sequence is as follows:

Bang Sai	25 years x 340,000 T/y
South Kuan Klang	10 years x 460,000 T/y
North Kuan Klang	15 years x 460,000 T/y
Klong Tone (Krabi)	25 years x 200,000 T/y

Reasons for the above scheme are based on,

- Coal quality is almost the same in individual areas of Sin Pun field.
- Land purchase should be minimized.
- Bang Sai area is the most economic to mine and is mined through a mine life.

6.4.5 Mining Development Schedule

The operation of the new power plant is expected to start in the later part of 1996. Prior to the start, the test burning and tuning of FBC boiler are required. Consequently the supply of lignite is essential at the time of this test burning. The overburden removal should begin three months prior to coal getting (including test mining) and also the well construction for drainage should start the further prior year.

As some mining equipment (Heavy Equipment) take longer delivery time, it is necessary to consider the order time very carefully. The construction of mine road and surface facilities shall start after the agreement of Local residents is obtained. It will be the most difficult matter to get a mining permission and to successfully negotiate with the local residents after F/S is completed. The schedule of mining development is indicated in the following Figure (Fig. 6-19).

Fig. 6-18 Incremental ER vs Cumulative Tonnage in Sin Pun Area (150 MW Case)

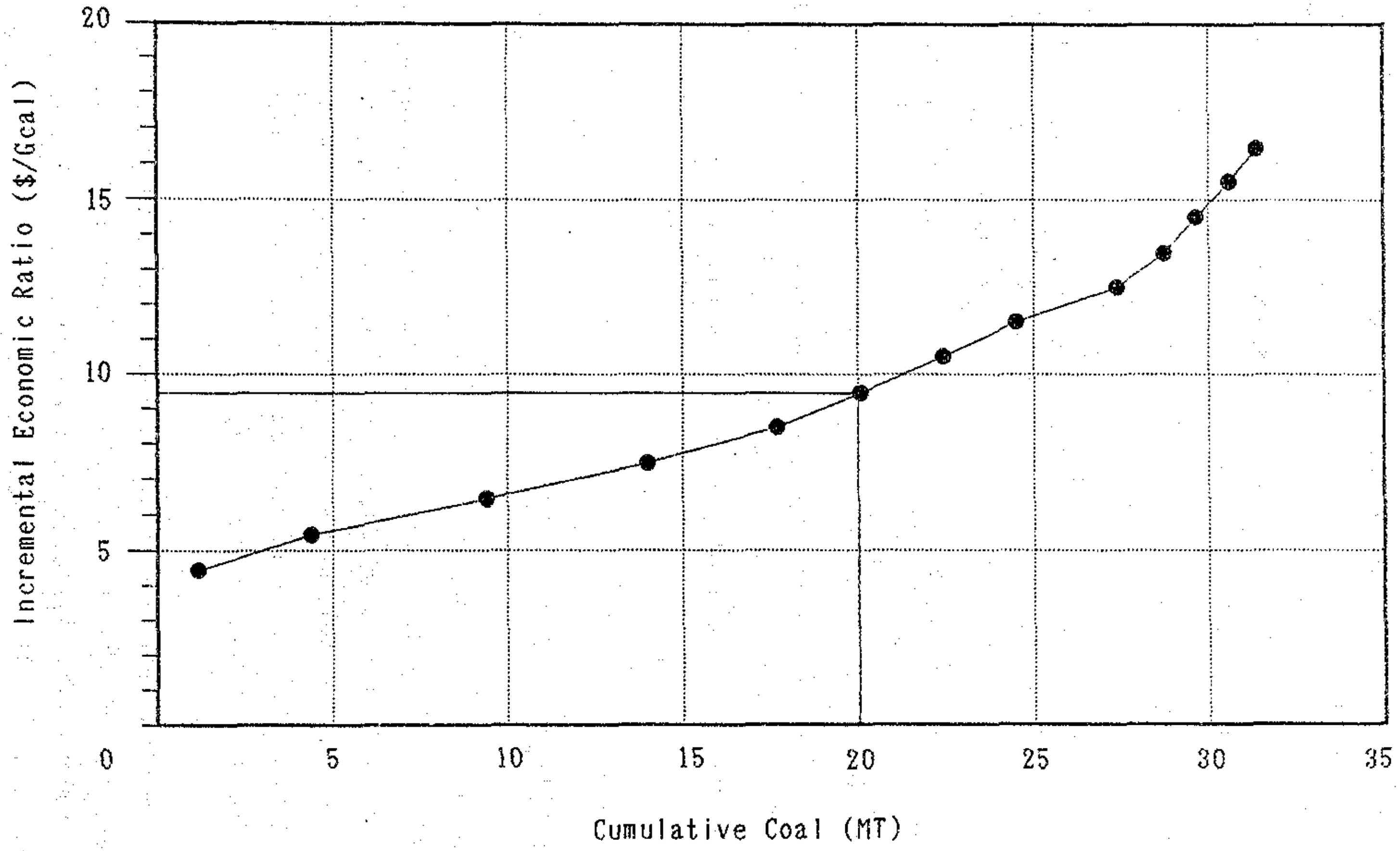
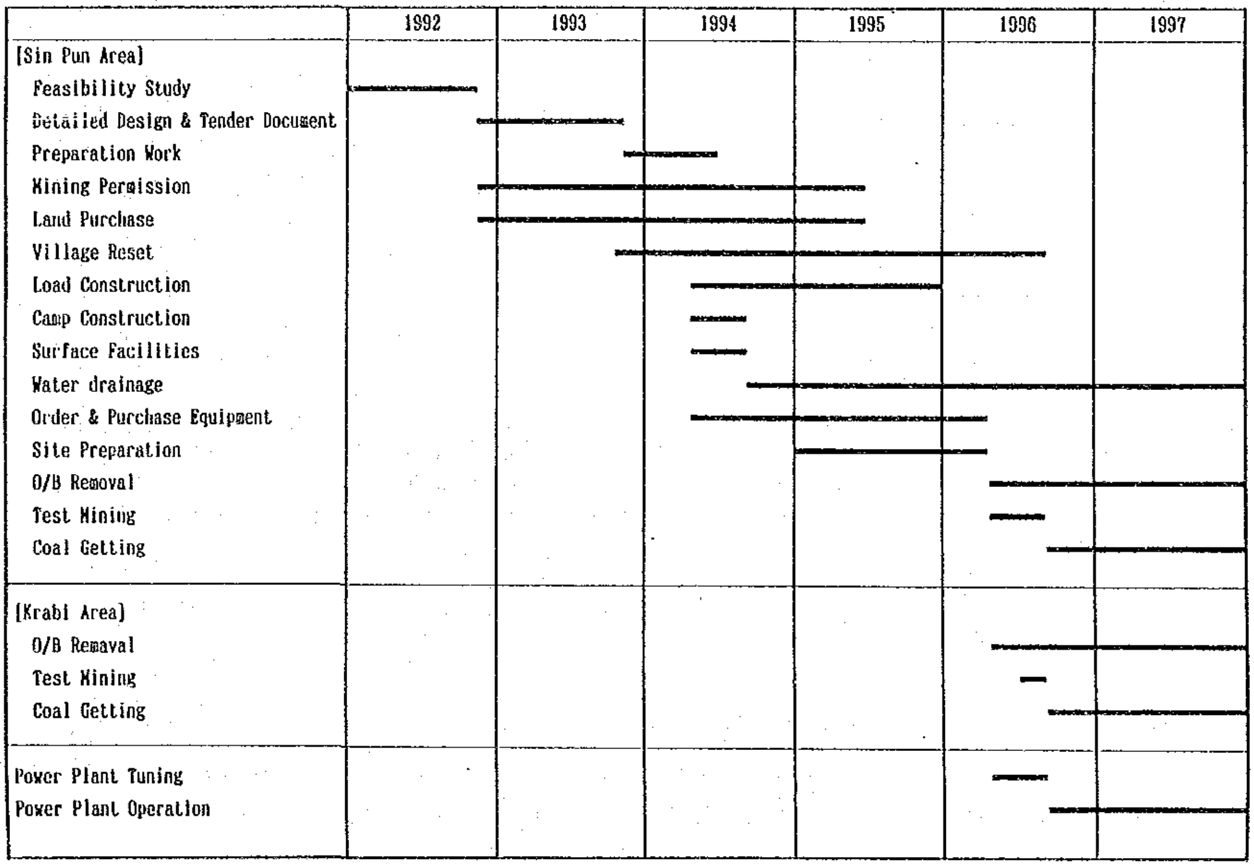


Fig. 6-19 Development Schedule of Mining



6.5 Economic Evaluation

6.5.1 Real Average Cost of Production

Real average cost (including contingency) of US$ 22.63/t or US$ 8.04/Gcal was calculated for the supply of 17 MT of coal to a 100 MW power station at Sin Pun by EGAT as follows;

	($/t of coal)
Land Purchase & Village Resettlement	4.20
Power Supply & Roads	0.19
Grand-water Control	1.58*
Administration	1.39
Mine Operation	14.51
Reclamation	1.19
Royalty Payment	0.57
Total cost of coal Supply	22.63

22.63 $/t = 8.04 $/Gcal

* : Now existing Krabi mine is operated only by direct drainage method of using pumps, so the probability of well drilling for pumping out may be estimated a little and then the cost of production will be lower than the above-mentioned cost.

6.5.2 Calculation of Levelized Cost

JICA team has calculated a Levelized Unit Cost for two cases of 100 MW and 150 MW based on the Total cash outflow for the case of 100 MW calculated by EGAT. The magnification of each item was assumed as follows:

Development	1.1
Waste removal	1.8
Coal Mining & Parting	1.5
Maintenance Service	1.5
Reclamation	1.3
Royalty Payment	1.5
Another	1.0
Contingency	15% & 20%
Discount Rate	10%

The calculation has resulted in here under:

Table 6-12 Levelized Cost

Contingency	20%	20%	15%
The power station capacity	100 MW	150 MW	150 MW
Production (x 1,000 ton/year)	667	1,000	1,000
Total Production (25 years x 1,000 ton/year)	16,675	25,000	25,000
Total cost (25 years x 1,000$)	301,647	472,785	453,086
Average Cost ($/ton)	18.09	18.91	18.12
Levelized Cost ($/ton)	21.37	21.23	20.35

The above study has concluded as described below:

(1) The fuel cost does not differ magnificently in the long-term view regards of the capacity of the power plant.

(2) The site cost comes to US$ 20.35 (US$ 7.98/Gcal) in case of the whole fuel be furnished by Sin Pun coal while it turns to a little higher cost (about US$ 8.8/Gcal) in case that 20% of Krabi coal is blended. The fuel cost is estimated at below US$ 10/Gcal in any case.

(3) The average cost climbs in line with the increase in the fuel consumption while the proportion is not big. The levelized cost is converged to about US$ 20 in the long term period of 25 years. Table 6-13a, 6-13b, 6-13c and Fig. 6-20.

Mining cost varies in some countries as figures. (Fig. 6-21)

According to EGAT's calculation, Land Purchase and Village Resettlement cost at US$ 4.20/t (19% of the cost) and Average Cost of US$ 18 does not belong to the higher tier.

Table 6-13a
TOTAL CASH OUTFLOW
POWER PLANT 100MW
CONTINGENCY 20%
DISCOUNT RATE 10%

(DISCOUNT 10%)		-3	-2	-1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	TOTAL
A. DEVELOPMENT		6,709	5,311	5,311	8,036	3	627	3	3	627	3	627	3	3	627	3	1,130	3	3	818	3	439	3	3	439	3	3	3	3	28,749
B. ADMINISTRATION		0	200	463	555	690	690	690	690	690	690	690	776	776	776	776	776	776	776	768	760	760	760	760	760	760	760	760	760	19,088
C. WASTE REMOVAL		0	0	6,740	1,485	1,485	1,485	1,485	1,485	1,485	2,615	1,782	13,934	3,514	3,514	3,514	3,514	3,514	4,928	5,505	3,810	8,058	6,638	3,514	4,000	4,000	5,000	4,000	4,000	105,004
D. COAL MINING & PARTING		0	0	0	4,937	1,313	1,313	1,313	1,649	1,819	1,313	1,313	2,905	2,885	1,380	1,885	1,716	1,380	1,380	1,380	2,815	1,948	1,380	2,885	2,000	1,500	2,000	2,000	1,500	47,909
E. PIT SERVICE		445	89	3,106	530	854	530	530	1,216	530	854	891	1,305	1,362	1,246	1,335	1,245	1,362	1,239	884	1,794	1,292	1,093	1,484	1,000	2,000	1,000	1,100	1,000	31,316
F. SURFACE FACILITIES		57	871	871	133	133	133	133	133	133	133	133	133	133	200	200	200	200	200	200	200	200	200	200	200	200	200	300	300	6,329
G. MAINTENANCE SERVICE		0	0	1,941	372	372	372	372	372	372	477	372	1,030	773	604	649	1,040	662	553	1,033	622	658	604	662	700	700	1,200	600	500	17,612
H. RECLAMATION		0	0	0	114	114	114	114	114	114	114	114	114	114	114	114	114	114	114	108	108	108	108	108	108	108	108	108	108	2,790
I. ROYALTY PAYMENT		0	0	0	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	390	380	380	380	380	380	380	380	380	380	9,810
SUBTOTAL		7,211	6,471	18,432	14,562	5,364	5,664	5,040	6,062	6,170	6,599	6,322	20,600	9,960	8,861	8,876	10,135	8,411	9,593	11,086	10,492	13,843	11,166	9,996	9,587	9,651	10,651	9,251	8,551	268,607
TOTAL CONTINGENCY		1,082	971	2,231	1,851	667	728	634	736	778	790	794	2,292	1,228	1,153	1,151	1,305	1,076	1,195	1,385	1,297	1,645	1,355	1,238	1,130	1,148	1,241	994	946	33,040
GLAND TOTAL		8,293	7,442	20,663	16,413	6,031	6,392	5,674	6,798	6,948	7,389	7,116	22,892	11,188	10,014	10,027	11,440	9,487	10,788	12,471	11,789	15,488	12,521	11,234	10,717	10,799	11,892	10,245	9,497	301,647
																												AVERAGE COST		18.09 US$/TON
PRODUCTION (x 1,000 ton)					667	667	667	667	667	667	667	667	667	667	667	667	667	667	667	667	667	667	667	667	667	667	667	667	667	16,675
COAL PRICE	21.37 US$				21.37	21.37	21.37	21.37	21.37	21.37	21.37	21.37	21.37	21.37	21.37	21.37	21.37	21.37	21.37	21.37	21.37	21.37	21.37	21.37	21.37	21.37	21.37	21.37	21.37	
REVENUE					14,254	14,254	14,254	14,254	14,254	14,254	14,254	14,254	14,254	14,254	14,254	14,254	14,254	14,254	14,254	14,254	14,254	14,254	14,254	14,254	14,254	14,254	14,254	14,254	14,254	
CASH FLOW		-8,293	-7,442	-20,663	-2,159	8,223	7,862	8,580	7,456	7,306	6,865	7,138	-8,638	3,066	4,240	4,227	2,814	4,767	3,466	1,783	2,465	-1,234	1,733	3,020	3,537	3,455	2,362	4,009	4,757	
	10 %																													
DCF	1.100	1	0.909	0.826	0.751	0.683	0.621	0.564	0.513	0.467	0.424	0.386	0.350	0.319	0.290	0.263	0.239	0.218	0.198	0.180	0.164	0.149	0.135	0.123	0.112	0.102	0.092	0.084	0.076	
NPV(i= 10%)		-8,293	-6,765	-17,077	-1,622	5,616	4,882	4,843	3,826	3,408	2,911	2,752	-3,028	977	1,228	1,113	674	1,037	686	321	403	-183	234	371	395	351	218	336	363	-23

CALCULATION OF LEVELIZED UNIT COST (8)

		-3	-2	-1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	TOTAL
TOTAL COST		8,293	7,442	20,663	16,413	6,031	6,392	5,674	6,798	6,948	7,389	7,116	22,892	11,188	10,014	10,027	11,440	9,487	10,788	12,471	11,789	15,488	12,521	11,234	10,717	10,799	11,892	10,245	9,497	301,647
NPV		8,293	6,765	17,077	12,331	4,119	3,969	3,203	3,488	3,241	3,134	2,744	8,024	3,565	2,901	2,640	2,739	2,065	2,134	2,243	1,928	2,302	1,892	1,380	1,197	1,096	1,098	860	724	106,951
PRODUCTION (x 1,000 ton)					667	667	667	667	667	667	667	667	667	667	667	667	667	667	667	667	667	667	667	667	667	667	667	667	667	
LEVELIZED UNIT COST	21.37 US$/TON				21.37	21.37	21.37	21.37	21.37	21.37	21.37	21.37	21.37	21.37	21.37	21.37	21.37	21.37	21.37	21.37	21.37	21.37	21.37	21.37	21.37	21.37	21.37	21.37	21.37	
NPV					10,709	9,736	8,850	8,046	7,314	6,649	6,045	5,495	4,996	4,542	4,129	3,753	3,412	3,102	2,820	2,564	2,331	2,119	1,926	1,751	1,592	1,447	1,316	1,196	1,087	106,927
PROD (10% DISC.)(x 1,000TON)					501	456	414	377	342	311	283	257	234	213	193	176	160	145	132	120	109	99	90	82	74	68	62	56	51	
ACCUM. COST NPV		8,293	15,058	32,135	44,466	48,585	52,554	55,757	59,245	62,487	65,620	68,364	76,387	79,952	82,853	85,493	88,232	90,297	92,431	94,674	96,602	98,904	100,598	101,978	103,173	104,269	105,367	106,226	106,951	
ACCUM. PROD.(10% DISC)(x 1,000TON)					501	957	1,371	1,747	2,090	2,401	2,684	2,941	3,175	3,387	3,580	3,756	3,916	4,061	4,193	4,313	4,422	4,521	4,611	4,693	4,768	4,835	4,897	4,953	5,004	
LEVELIZED COST (US$/TON)					88.73	50.78	38.34	31.91	28.35	26.03	24.45	23.25	24.06	23.60	23.14	22.76	22.53	22.24	22.05	21.95	21.85	21.88	21.82	21.73	21.64	21.56	21.52	21.45	21.37	

(thousand of dollers)

Table 6-13b
TOTAL CASH OUTFLOW
POWER PLANT 150MW
CONTINGENCY 20%
DISCOUNT RATE 10%

150MW/100MW	-3	-2	-1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	TOTAL
1.1 A. DEVELOPMENT	7,380	5,842	5,842	6,640	3	690	3	3	690	3	690	3	3	690	3	1,243	3	3	900	3	483	3	3	483	3	3	3	3	31,624
1.0 B. ADMINISTRATION	0	200	463	555	690	690	690	690	690	690	690	776	776	776	776	776	776	776	768	760	760	760	760	760	760	760	760	760	19,088
1.8 C. WASTE REMOVAL	0	0	12,132	2,673	2,673	2,673	2,673	2,673	2,673	4,707	3,208	25,081	6,325	6,325	6,325	6,325	6,325	8,870	9,909	6,858	14,504	11,948	6,325	7,200	7,200	9,000	7,200	7,200	189,007
1.5 D. COAL MINING & PARTING	0	0	0	7,406	1,970	1,970	1,970	2,474	2,729	1,970	1,970	4,358	4,328	2,070	2,828	2,574	2,070	2,070	2,070	4,223	2,922	2,070	4,328	3,000	2,250	3,000	3,000	2,250	71,864
1.0 E. PIT SERVICE	445	89	3,106	530	854	530	530	1,216	530	854	891	1,305	1,362	1,246	1,335	1,245	1,362	1,239	884	1,794	1,292	1,093	1,484	1,000	2,000	1,000	1,100	1,000	31,316
1.0 F. SURFACE FACILITIES	57	871	871	133	133	133	133	133	133	133	133	133	133	200	200	200	200	200	200	200	200	200	200	200	200	200	300	300	6,329
1.5 G. MAINTENANCE SERVICE	0	0	2,912	558	558	558	558	558	558	716	558	1,545	1,160	906	974	1,560	993	830	1,550	933	987	906	993	1,050	1,050	1,800	900	750	26,418
1.3 H. RECLAMATION	0	0	0	148	148	148	148	148	148	148	148	148	148	148	148	148	148	148	140	140	140	140	140	140	140	140	140	140	3,627
1.5 I. ROYALTY PAYMENT	0	0	0	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	585	570	570	570	570	570	570	570	570	570	14,715
SUBTOTAL	7,882	7,002	25,326	19,242	7,629	7,991	7,305	8,495	8,750	9,821	8,887	33,949	14,835	12,961	13,189	14,671	12,478	14,736	17,006	15,481	21,859	17,691	14,803	14,403	14,174	16,474	13,974	12,974	393,988
TOTAL CONTINGENCY (20%)	1,576	1,400	5,065	3,848	1,526	1,598	1,461	1,699	1,750	1,964	1,777	6,790	2,967	2,592	2,638	2,934	2,496	2,947	3,401	3,096	4,372	3,538	2,961	2,881	2,835	3,295	2,795	2,595	78,798
GLAND TOTAL	9,458	8,403	30,391	23,091	9,155	9,590	8,766	10,194	10,500	11,785	10,664	40,739	17,802	15,553	15,826	17,606	14,973	17,684	20,407	18,577	26,230	21,229	17,764	17,284	17,008	19,768	16,768	15,568	472,785
																												AVERAGE COST	18.91 US$/TON
PRODUCTION (x 1,000 ton)				1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	25,000
COAL PRICE 21.23 US$				21.23	21.23	21.23	21.23	21.23	21.23	21.23	21.23	21.23	21.23	21.23	21.23	21.23	21.23	21.23	21.23	21.23	21.23	21.23	21.23	21.23	21.23	21.23	21.23	21.23	
REVENUE				21,230	21,230	21,230	21,230	21,230	21,230	21,230	21,230	21,230	21,230	21,230	21,230	21,230	21,230	21,230	21,230	21,230	21,230	21,230	21,230	21,230	21,230	21,230	21,230	21,230	
CASH FLOW	-9,458	-8,403	-30,391	-1,861	12,075	11,640	12,464	11,036	10,730	9,445	10,566	-19,509	3,428	5,677	5,404	3,624	6,257	3,546	823	2,653	-5,000	1	3,466	3,946	4,222	1,462	4,462	5,662	
10 %																													
DCF 1.100	1	0.909	0.826	0.751	0.683	0.621	0.564	0.513	0.467	0.424	0.386	0.350	0.319	0.290	0.263	0.239	0.218	0.198	0.180	0.164	0.149	0.135	0.123	0.112	0.102	0.092	0.084	0.076	
NPV(I= 10%)	-9,458	-7,639	-25,116	-1,398	8,248	7,228	7,036	5,863	5,005	4,006	4,073	-6,838	1,092	1,844	1,423	868	1,362	702	148	434	-743	0	426	441	429	135	374	432	-25

CALCULATION OF LEVELIZED UNIT COST (B)

	-3	-2	-1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	TOTAL
TOTAL COST	9,458	8,403	30,391	23,091	9,155	9,590	8,766	10,194	10,500	11,785	10,664	40,739	17,802	15,553	15,826	17,606	14,973	17,684	20,407	18,577	26,230	21,229	17,764	17,284	17,008	19,768	16,768	15,568	472,785
NPV	9,458	7,639	25,116	17,348	6,253	5,954	4,948	5,231	4,899	4,998	4,112	14,279	5,672	4,505	4,168	4,215	3,259	3,499	3,670	3,038	3,899	2,869	2,182	1,930	1,727	1,825	1,407	1,188	159,286
PRODUCTION (x 1,000 ton)				1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	
LEVELIZED UNIT COST 21.23 US$				21.23	21.23	21.23	21.23	21.23	21.23	21.23.	21.23	21.23	21.23	21.23	21.23	21.23	21.23	21.23	21.23	21.23	21.23	21.23	21.23	21.23	21.23	21.23	21.23	21.23	
NPV				15,950	14,500	13,182	11,984	10,894	9,904	9,004	8,185	7,441	6,765	6,150	5,591	5,082	4,620	4,200	3,818	3,471	3,156	2,869	2,608	2,371	2,155	1,959	1,781	1,619	159,261
PROD (10% DISC.)(x 1,000TON)				751	683	621	564	513	467	424	386	350	319	290	263	239	218	198	180	164	149	135	123	112	102	92	84	76	
ACCUM. COST NPV	9,458	17,097	42,213	59,562	65,815	71,769	76,717	81,948	86,847	91,845	95,956	110,235	115,907	120,412	124,580	128,795	132,053	135,552	139,222	142,260	146,159	149,028	151,210	153,140	154,867	156,691	158,098	159,286	
ACCUM. PROD.(10% DISC)(x 1,000TON)				751	1,434	2,055	2,620	3,133	3,599	4,023	4,409	4,760	5,078	5,368	5,631	5,871	6,088	6,286	6,466	6,629	6,778	6,913	7,036	7,148	7,249	7,342	7,425	7,502	
LEVELIZED COST (US$/TON)				79.28	45.89	34.92	29.28	26.16	24.13	22.83	21.78	23.16	22.82	22.43	22.12	21.94	21.69	21.56	21.53	21.46	21.56	21.56	21.49	21.43	21.36	21.34	21.29	21.23	

(thousand of dollers)

Table 6-13c
TOTAL CASH OUTFLOW
POWER PLANT 150MW
CONTINGENCY 15%
DISCOUNT RATE 10%

		-3	-2	-1	1	2	3	4	5	6	7	8	9	10	11	12
150MW/100MW																
1.1 A. DEVELOPMENT		7,380	5,842	5,842	6,640	3	690	3	3	690	3	690	3	3	690	3
1.0 B. ADMINISTRATION		0	200	463	555	690	690	690	690	690	690	690	776	776	776	776
1.8 C. WASTE REMOVAL		0	0	12,132	2,673	2,673	2,673	2,673	2,673	2,673	4,707	3,208	25,081	6,325	6,325	6,325
1.5 D. COAL MINING & PARTING		0	0	0	7,406	1,970	1,970	1,970	2,474	2,729	1,970	1,970	4,358	4,328	2,070	2,828
1.0 E. PIT SERVICE		445	89	3,106	530	854	530	530	1,216	530	854	891	1,305	1,362	1,246	1,335
1.0 F. SURFACE FACILITIES		57	871	871	133	133	133	133	133	133	133	133	133	133	200	200
1.5 G. MAINTENANCE SERVICE		0	0	2,912	558	558	558	558	558	558	716	558	1,545	1,160	906	974
1.3 H. RECLAMATION		0	0	0	148	148	148	148	148	148	148	148	148	148	148	148
1.5 I. ROYALTY PAYMENT		0	0	0	600	600	600	600	600	600	600	600	600	600	600	600
SUBTOTAL		7,882	7,002	25,326	19,242	7,629	7,991	7,305	8,495	8,750	9,821	8,887	33,949	14,835	12,961	13,189
TOTAL CONTINGENCY (15%)		1,182	1,050	3,799	2,886	1,144	1,199	1,096	1,274	1,313	1,473	1,333	5,092	2,225	1,944	1,978
GLAND TOTAL		9,064	8,052	29,124	22,129	8,773	9,190	8,401	9,769	10,063	11,294	10,220	39,042	17,060	14,905	15,167
PRODUCTION (x 1,000 ton)					1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
COAL PRICE	20.35 US$				20.35	20.35	20.35	20.35	20.35	20.35	20.35	20.35	20.35	20.35	20.35	20.35
REVENUE					20,350	20,350	20,350	20,350	20,350	20,350	20,350	20,350	20,350	20,350	20,350	20,350
CASH FLOW		-9,064	-8,052	-29,124	-1,779	11,577	11,160	11,949	10,581	10,287	9,056	10,130	-18,692	3,290	5,445	5,183
	10 %															
DCF	1.100	1	0.909	0.826	0.751	0.683	0.621	0.564	0.513	0.467	0.424	0.386	0.350	0.319	0.290	0.263
NPV(I= 10%)		-9,064	-7,320	-24,070	-1,336	7,907	6,929	6,745	5,430	4,799	3,841	3,906	-6,551	1,048	1,577	1,365

	13	14	15	16	17	18	19	20	21	22	23	24	25	TOTAL
150MW/100MW														
1.1 A. DEVELOPMENT	1,243	3	3	900	3	483	3	3	483	3	3	3	3	31.624
1.0 B. ADMINISTRATION	776	776	776	768	760	760	760	760	760	760	760	760	760	19,088
1.8 C. WASTE REMOVAL	6,325	6,325	8,870	9,909	6,858	14,504	11,948	6,325	7,200	7,200	9,000	7,200	7,200	189,007
1.5 D. COAL MINING & PARTING	2,574	2,070	2,070	2,070	4,223	2,922	2,070	4,328	3,000	2,250	3,000	3,000	2,250	71,864
1.0 E. PIT SERVICE	1,245	1,362	1,239	884	1,794	1,292	1,093	1,484	1,000	2,000	1,000	1,100	1,000	31.316
1.0 F. SURFACE FACILITIES	200	200	200	200	200	200	200	200	200	200	200	300	300	6.329
1.5 G. MAINTENANCE SERVICE	1,560	993	830	1,550	933	987	906	993	1,050	1,050	1,800	900	750	26,418
1.3 H. RECLAMATION	148	148	148	140	140	140	140	140	140	140	140	140	140	3.627
1.5 I. ROYALTY PAYMENT	600	600	600	585	570	570	570	570	570	570	570	570	570	14.715
SUBTOTAL	14,671	12,478	14,736	17,006	15,481	21,859	17,691.	14,803	14,403	14,174	16,174	13,974	12,974	393,988
TOTAL CONTINGENCY (15%)	2,201	1,872	2,210	2,551	2,322	3,279	2,654	2,221	2,160	2,126	2,471	2,096	1,946	59.098
GLAND TOTAL	16,872	14,349	16,947	19,557	17,803	25,138	20,345	17,024	16,564	16,300	18,945	16,070	14,920	453,086
													AVERAGE COST	18.12 US$/TON
PRODUCTION (x 1,000 ton)	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	25,000
COAL PRICE	20.35	20.35	20.35	20.35	20.35	20.35	20.35	20.35	20.35	20.35	20.35	20.35	20.35	
REVENUE	20,350	20,350	20,350	20,350	20,350	20,350	20,350	20,350	20,350	20,350	20,350	20,350	20,350	
CASH FLOW	3,478	8,001	3,403	793	2,547	-4,788	5	3,326	3,780	4,050	1,405	4,280	5,430	
DCF	0.239	0.218	0.198	0.180	0.164	0.149	0.135	0.123	0.112	0.102	0.092	0.084	0.076	
NPV(I= 10%)	833	1,306	673	143	416	-712	1	409	423	411	130	359	414	10

CALCULATION OF LEVELIZED UNIT COST (8)

		-3	-2	-1	1	2	3	4	5	6	7	8	9	10	11	12
TOTAL COST		9,064	8,052	29,124	22,129	8,773	9,190	8,401	9,769	10,063	11,294	10,220	39,042	17,060	14,905	15,167
NPV		9,064	7,320	24,070	16,626	5,992	5,706	4,742	5,013	4,694	4,790	3,940	13,684	5,436	4,318	3,994
PRODUCTION (x 1,000 ton)					1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
LEVELIZED UNIT COST	20.35 US$				20.35	20.35	20.35	20.35	20.35	20.35	20.35	20.35	20.35	20.35	20.35	20.35
NPV					15,289	13,899	12,636	11,487	10,443	9,493	8,630	7,846	7,133	6,484	5,895	5,359
PROD (10% DISC.)(x 1,000TON)					751	683	621	564	513	467	424	386	350	319	290	263
ACCUM. COST NPV		9,064	16,385	40,454	57,080	63,072	68,779	73,521	78,535	83,228	88,018	91,958	105,642	111,078	115,395	119,389
ACCUM. PROD.(10% DISC)(x 1,000TON)					751	1,434	2,055	2,620	3,133	3,599	4,023	4,409	4,760	5,078	5,368	5,631
LEVELIZED COST (US$/TON)					75.97	43.97	33.46	28.06	25.07	23.12	21.88	20.86	22.20	21.87	21.50	21.20

	13	14	15	16	17	18	19	20	21	22	23	24	25	TOTAL
TOTAL COST	16,872	14,349	16,947	19,557	17,803	25,138	20,345	17,024	16,564	16,300	18,945	16,070	14,920	453,086
NPV	4,039	3,123	3,353	3,517	2,911	3,737	2,749	2,091	1,850	1,655	1,749	1,348	1,138	152,649
PRODUCTION (x 1,000 ton)	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	
LEVELIZED UNIT COST	20.35	20.35	20.35	20.35	20.35	20.35	20.35	20.35	20.35	20.35	20.35	20.35	20.35	
NPV	4,872	4,429	4,026	3,660	3,327	3,025	2,750	2,500	2,273	2,066	1,878	1,707	1,552	152,659
PROD (10% DISC.)(x 1,000TON)	239	218	198	180	164	149	135	123	112	102	92	84	76	
ACCUM. COST NPV	123,428	126,551	129,904	133,421	136,332	140,069	142,818	144,909	146,759	148,414	150,163	151,511	152,649	
ACCUM. PROD.(10% DISC)(x 1,000TON)	5,871	6,088	6,286	6,466	6,629	6,778	6,913	7,036	7,148	7,249	7,342	7,425	7,502	
LEVELIZED COST (US$/TON)	21.03	20.79	20.87	20.63	20.56	20.67	20.66	20.60	20.53	20.47	20.45	20.40	20.35	

(thousand of dollers)

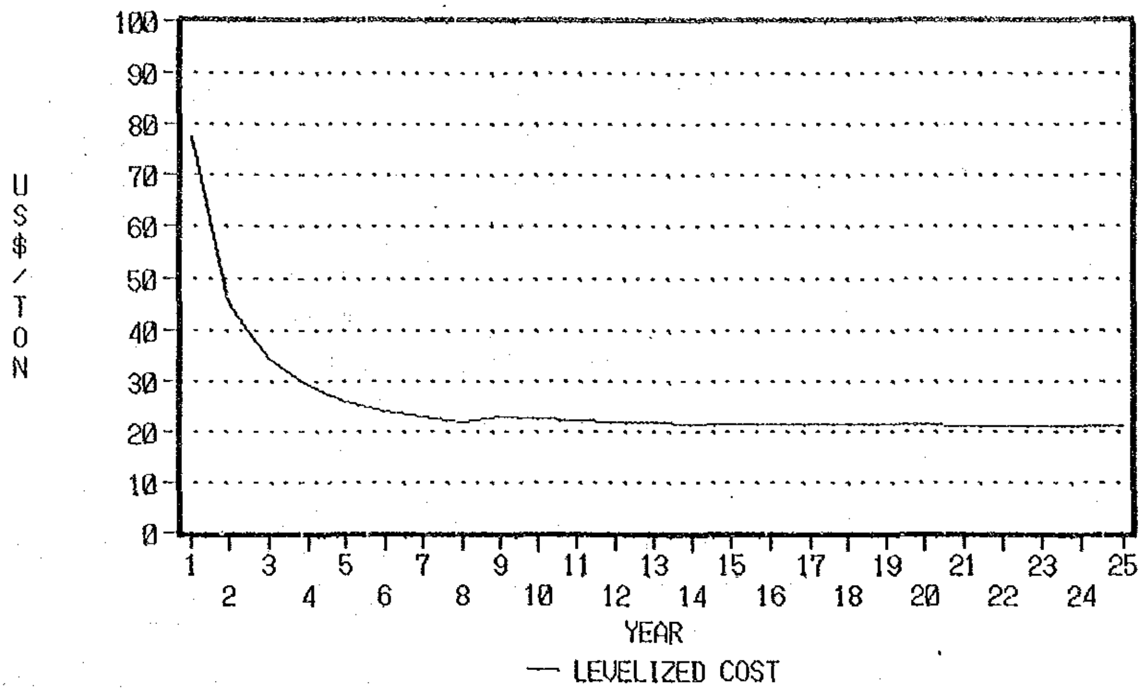
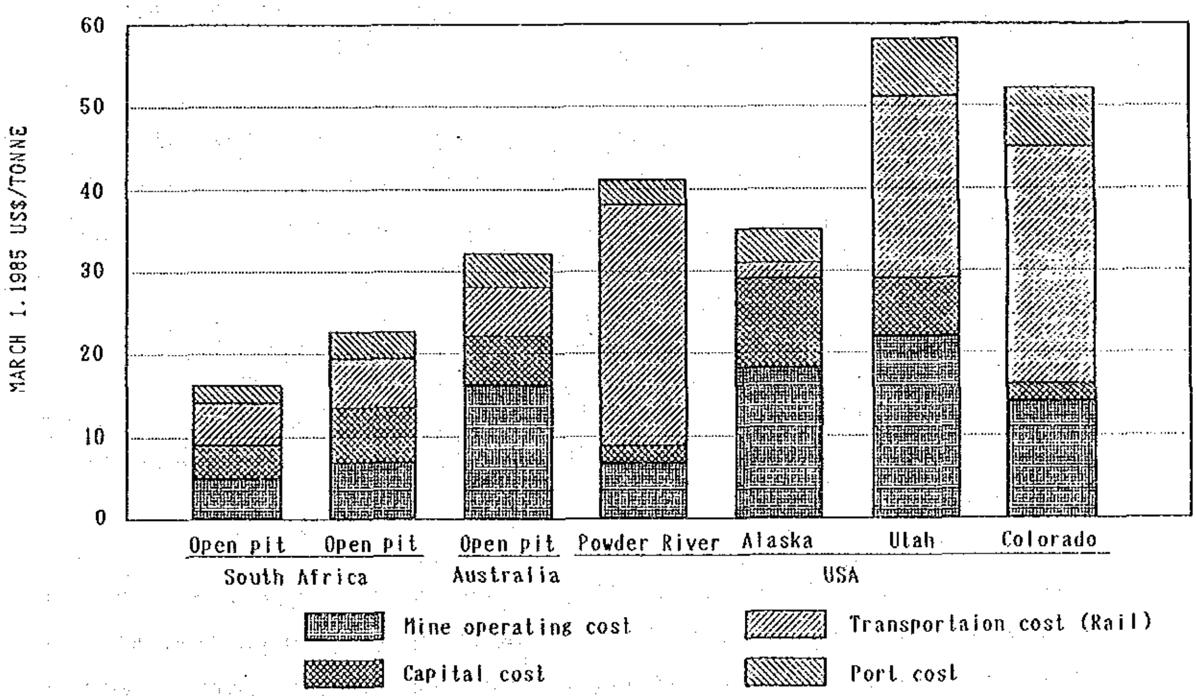


Fig. 6-20 Levelized Cost of Coal 150 MW Case (Cont. 15%)



Source : Barnett, D.W. "Export Coal Costs in Ausralia, Canada, South Afrca and the USA" (Materials and Society Vol.9, No.4)

Fig. 6-21 Comparison of Coal Supplying Costs from South Africa, Australia, USA

6.6 Conclusion

JICA team studied three documents prepared by EGAT: Sin Pun Coal Deposits Geological Report (1987), Feasibility Study on Krabi Mine Expansion Project Power Plant Unit 4 (1988) and Sin Pun Conceptual Mining Study (1991). Based on those EGAT studies, JICA team has set up and evaluated the mine development plan. The conception of the plan is interpreted by the fact that 800 thousand tons of lignite from Sin Pun area and 200 thousand tons of the same from Krabi area are supplied yearly to the A-FBC 150MW power plant.

The conclusion is as follows:

(1) The basins of Sin Pun and Krabi have enough reserves of lignite to supply to the A-FBC 150MW power plant for 25 years.

(2) The quality of the lignite is not so stable. Considering the characteristics of the FBC boiler, the quality variation in the run-of-mine product will be acceptable. However a blending system is recommended for minimizing the quality variation because the lignite is usually supplied from three deposits: two pits in Sin Pun and one in Krabi.

(3) EGAT used computers for the purpose of analyzing the geological data in detail to study economic and technical matters and selected three economic deposits (Bang Sai, North Khuan Klang and South Klang Kuan) among the five deposits in the Sin Pun Basin. JICA team reviewed the study of EGAT and confirmed its suitability.

(4) JICA team recommended the most rational and economic mining sequence for supplying lignite to the 150 MW power plant. This recommendation has been accepted by EGAT.

(5) Considering the geological condition, special mining methods or huge mining equipment are not necessary. A truck and shovel operation is the recommendable mining method in most of Sin Pun Area. From a viewpoint of the hydrogeological study, it is important to make a effective water drainage planning as the mining is progressed.

(6) Criteria used for the mining plan are based on the experience of EGAT and regarded as realistic.

(7) In this Economic evaluation based on the 15% of contingency and 10% of discount rate, Levelized Unit Cost is estimated about US$20 per ton while Average Cost is about US$18 per ton. As Operation Cost is calculated for the lengthy period of 25 years, Levelized Unit Cost will be astringent to the certain figure (US$20). Economic Ratio is lower than US$10 per Gcal. These evaluations are carried out with estimated parameters for 150 MW on the basis of the 100 MW case.

7. LIMESTONE PROCUREMENT

CHAPTER 7. LIMESTONE PROCUREMENT

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7. Limestone Procurement

7.1 Thai Limestone Mine Status

Thailand is everywhere affluent in limestone. Especially around the planned plant site are many limestone quarry candidates. Fig. 7-1 shows the distribution of limestone in Thailand.

The Thai economy has been growing rapidly since the latter half of the 1980s. Commercial demand for cement has also been significantly increasing as a result of active investment in new constructions in the Bangkok area, among other reasons. This trend has been the cause of an increase in the production of limestone.

In 1990, the total annual production of limestone in Thailand was about 19 million tons. Cement plants concentrate in the central area of Thailand because of the large demand for cement there, and 1.6 million tons of cement, slightly more than 8% of total production, is produced in the southern area. The annual demand in Thailand for limestone purposes other than cement production is only 0.18 million tons. Table 7-1 shows past limestone production records.

7.2 Present Status of the Thai Cement Producing Industry

Accompanying a strong growth in the economy has been an increase in the demand for cement. As a result, the supply of cement has been running short in the 1990s, resulting in the actual price of cement being about 1.5 times the official government price.

To overcome this situation, the amount of cement imports has been increased, and domestic production will have been significantly reinforced within the next three years through a reinforcement of facilities -- that is, new plants will be established by the existing cement producing companies. Nevertheless, the demand and supply balance should be carefully watched for the time being.

In the southern area, the Thung Song plant (40 km east of the Sin Pun plant site), owned by the SIAM Co., will be reinforced by 1.2 million tons/year.

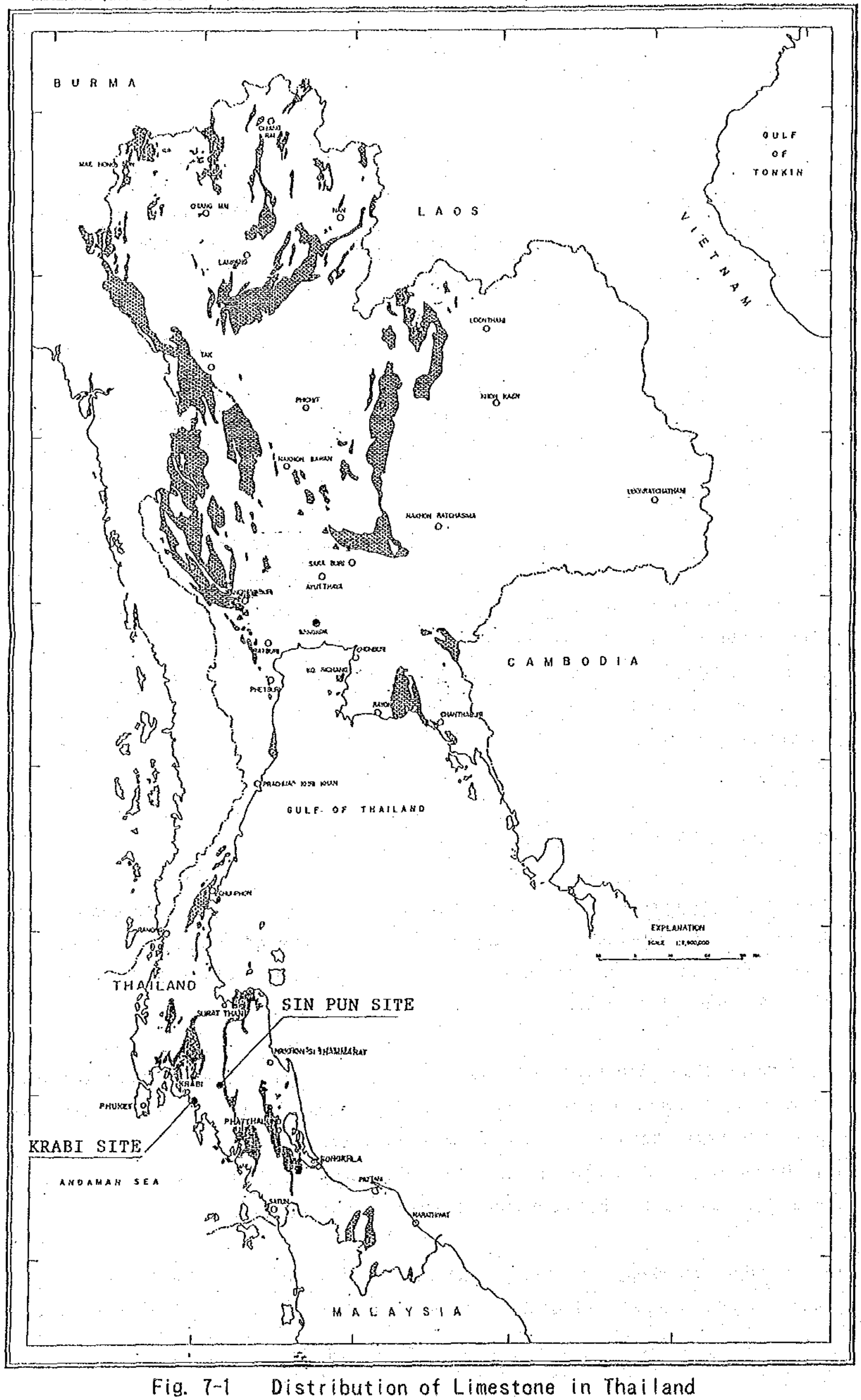


Fig. 7-1 Distribution of Limestone in Thailand

Table 7-1 Production of Limestone in Thailand

(Unit : Thousand ton)

	1986	1987	1988	1989	1990
1. Cement Industry					
Northern Region					
Nakhon Sawan	428	499	625	736	768
Central Region					
Phetchaburi	446	579	648	680	884
Sara Buri	7,770	9,448	11,844	13,362	16,319
Southern Region					
Nakhon Si Thammarat	961	865	984	1,188	1,600
Total Production	9,605	11,391	14,101	15,966	19,571
Value (M.Baht)	818.5	968.2	1,198.5	1,357.1	1,659.3
2. Other Industries					
Northern Region					
Kamphaeng Phet				3.5	8.4
Lampary			2.6	1.0	
Sukhothai			42.5	47.0	30.0
Tak		1.8	12.0	9.5	19.0
Uttaradit	under0.1	0.1	0.2	4.0	
Northeastern Region					
Nakhon Ratchasima	24.0	44.7	29.1	46.8	50.5
Central Region					
Chai Nat			2.2	1.1	0.4
Kanchanaburi				0.3	0.2
Lop Buri	0.9	1.1	9.7	16.6	12.0
Prachuap Khiri Khan	under0.1				
Ratchaburi		8.1	66.1	50.2	55.3
Southern Region					
Yala	0.3				
Total Production	25.2	55.8	164.4	180.0	175.8
Value (M.Baht)	0.6	3.9	14.0	15.3	15.0

Source ; MINERAL STATISTCS OF THAILAND
DEPARTMENT OF MINERAL RESOURCES

This plant's capacity will reach 2.1 million tons/year once the new facilities are completed this year.

Table 7-2 shows the existing cement producing facilities and reinforcement projects.

7.3 Power Plant Limestone Procurement

Thai limestone has proved to be a desulfurizer for FBC boilers. This resulted from chemical component analyses and differential thermal analyses conducted by the Japan side of limestone produced around the potential site of the power plant. A bench-scale combustion test was also of factor.

The projected 150 MW class FBC boiler will consume limestone at the rate of 0.4 million tons/year, but as noted above, annual production of limestone in the southern area is only about 1.6 million tons. If some limestone originally intended for use in the cement industry is procured by the power industry, the limestone market will go through some problem times and users will suffer from price appreciation and the imposition of severer purchase terms. We therefore propose that new limestone mines exclusively intended for producing desulfurizer be developed near the planned plant site, a move that would also contribute to reducing transportation costs.

From the pilot combustion test, it is confirmed that the particle size of limestone below 3 mm is preferable for the desulfurizer. From the crushing machine characteristics, the hammer crusher type is recommended to adopted. Fig. 7-2 shows the outline of the crushing machine and capacity.

Table 7-3 shows the estimated price of limestone to be 160 Baht/t with particle diameters of 3 mm or less.

Table 7-2 Cement Production Facilities in Thailand (Present & Future)

(Unit : Thousand ton)

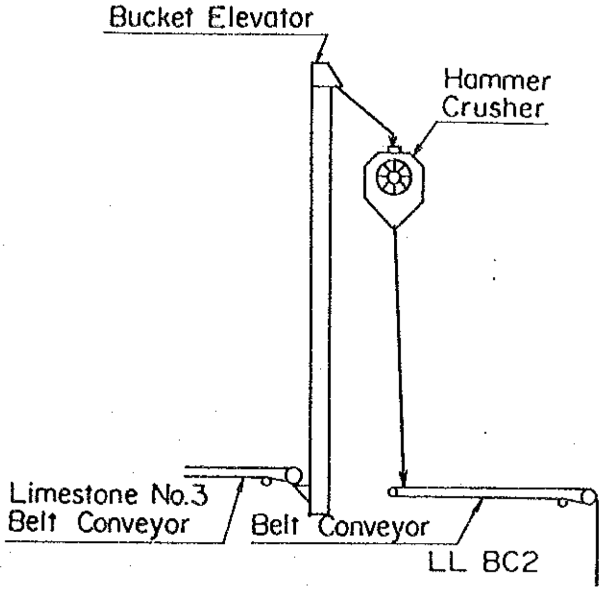
Company	Factory	1989	1990	1991	1992	1993
SIAM	KAENG KHOI	4,900	4,900	4,900	(2,200) 7,100	7,100
	TA LUANG	3,200	3,200	3,200	3,200	3,200
	THUNG SONG	900	900	(1,200) 2,100	2,100	2,100
	KOA WONG (*)	0	0	0	0	(3,600) 3,600
	Total	9,000	9,000	(1,200) 10,200	(2,200) 12,400	(3,600) 16,000
SIAM CITY	TABKWANG	4,550	4,550	(1,750) 6,300	(3,000) 9,300	9,300
JALAPRATHAN	TAKLI	400	400	400	400	400
	CHA-AM	1,200	1,200	(300) 1,500	1,500	1,500
	Total	1,600	1,600	(300) 1,900	1,900	1,900
THAIPETROCHE-MICAL INDUSTRY	SARABURI (*)	0	0	0	(2,000) 2,000	2,000
Total		15,150	15,150	(3,250) 18,400	(7,200) 25,600	(3,600) 29,200

1 ( ) ; Expansion of Existing Factory
2 (*) ; New Factory

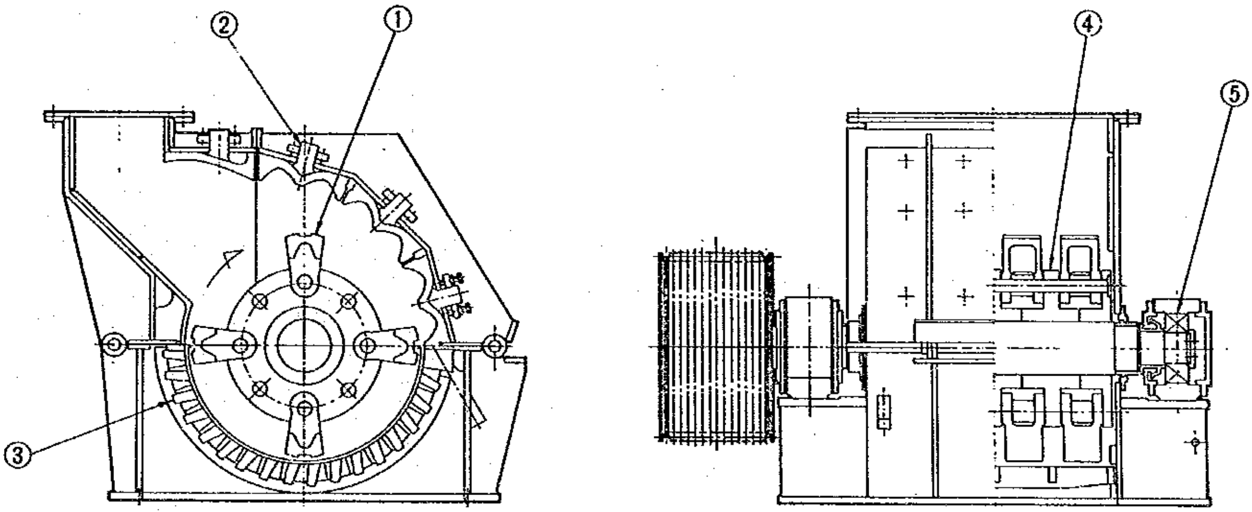
Source; Japan Cement Association, Aug. 1990.
Cement Industry in Asian 7 countries

Table 7-3 Limestone Price at Krabi Site (without Escalation)

	Baht/t	Remark
Raw Material	123	Yod Po Sila Quarry Price 1 - 2 inch 250 Baht/m^3 3/4 inch 260 Baht/m^3 1.8 - 2 ton/m^3 Assumption 220 Baht/m^3 ------> 123 Baht/ton (450 mm x 250 mm) (1.8 t/m^3)
Transportation Cost	22	2 Baht/t·km x 11 km
Crushing Cost	15	10% Discount Rate Crusher 60 Million Yen Electricity 800 kW/150 t Maintenance Cost 1.8 Million Yen/y Operation Cost 2818 kB/y (Two shift three group)
Total	160	



Limestone Crushing System



1 Hammer 2 Breaker Plate 3 Grate Bar 4 Rotor 5 Axis

Performance of Crusher

	Inlet	Outlet
Size of Limestone	250 x 450 mm max.	3 mm under (1.5 mm under 85%)
Capacity	80 t/h	
Electricity Consumption	400 kW	

Fig. 7-2 Outline of Hammer Crusher and Capacity

8. BENCH SCALE COMBUSTION TEST

CHAPTER 8 BENCH SCALE COMBUSTION TEST

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8. Bench Scale Combustion Test

8.1 General

Sin Pun lignite has several different features compared with the coal applied in the 50 MW demonstration plant in Japan, as follows;

i. Low heat value not more than 3,000 kcal/kg as received low heat value base.

ii. High sulfur content with the value from 3-9% and the mean value of the sulfur content among the recoverable reserves is 7%.

iii. High moisture content more than 30% as received base, and inherent moisture content is 10-15%.

iv. High ash content more than 20%.

Due to the high sulfur content Sin Pun lignite under the low heat value, the sulfur oxidize (herein after SOx) would be emitted in the flue gas with the density of 10,000 ppm by the pulverized coal fired power plant and this high density of SOx gas requests the special treatment in the boiler.

However, A-FBC, which was demonstrated with capacity of 50 MW in Japan, can combust the Sin Pun lignite because of the low combustion temperature as of 850°C and in-furnace desulfurizing reaction in the fluidized combustion bed by the lime content. Therefore, A-FBC boiler can combust the Sin Pun lignite without taking the special treatment in the boiler and within the regulated emission value of the Thailand.

In this feasibility study, two scales of combustion test are carried out pursuing for the economical point of the utility cost and the economical design of A-FBC suit for Sin Pun lignite.

i. Bench Scale Combustion Test
ii. Pilot Scale Combustion Test

From the result of the bench scale combustion test, it was confirmed that the Sin Pun lignite and Krabi lignite could be available for the fuel of A-FBC since SOx emission is controled under the regulated value of 700 ppm in Thailand and especially the Sin Pun lignite shows the high DeSOx performance in A-FBC boiler with the Ca/S molar ratio 2 in spite of high sulfur content.

It was also confirmed by the bench scale combustion test that Nitrogen Oxidize (herein after NOx) is emitted within the regulated value and the combustion efficiency is very high.

Furthermore, by the pilot scale combustion test, the suitability of A-FBC for the Sin Pun lignite would be confirmed and based on the data got from the pilot scale combustion test, the economical conceptional design of FBC boiler would be carried out in the second stage.

8.2 Test Items and Schedule

The test schedule of the bench scale combustion test is shown in the table below.

The sample lignite and limestone were received in August '91 and the preparation work was carried out followingly. The combustion test using the 100ϕ bench scale furnace was carried out from the beginning of September to the end of November 1991 respectively.

In the first 3 weeks, the bed temperature and Ca/S molar ratio were varied to find the suitable operating condition with the under coal feed system. The test of limestone among the Khao Tham Hora and Thung Song limestone also carried out for the selection of the limestone. Those test were carried out with under coal feed system to compare with the experienced record of the coal applied for the 50 MW demonstration plant.

After the above test, the suitable operating conditions by the over coal feed system was confirmed previous to the characteristic test for the Sin Pun lignite and Krabi lignite which was carried out two weeks for the respective lignite.

Table Bench scale test schedule

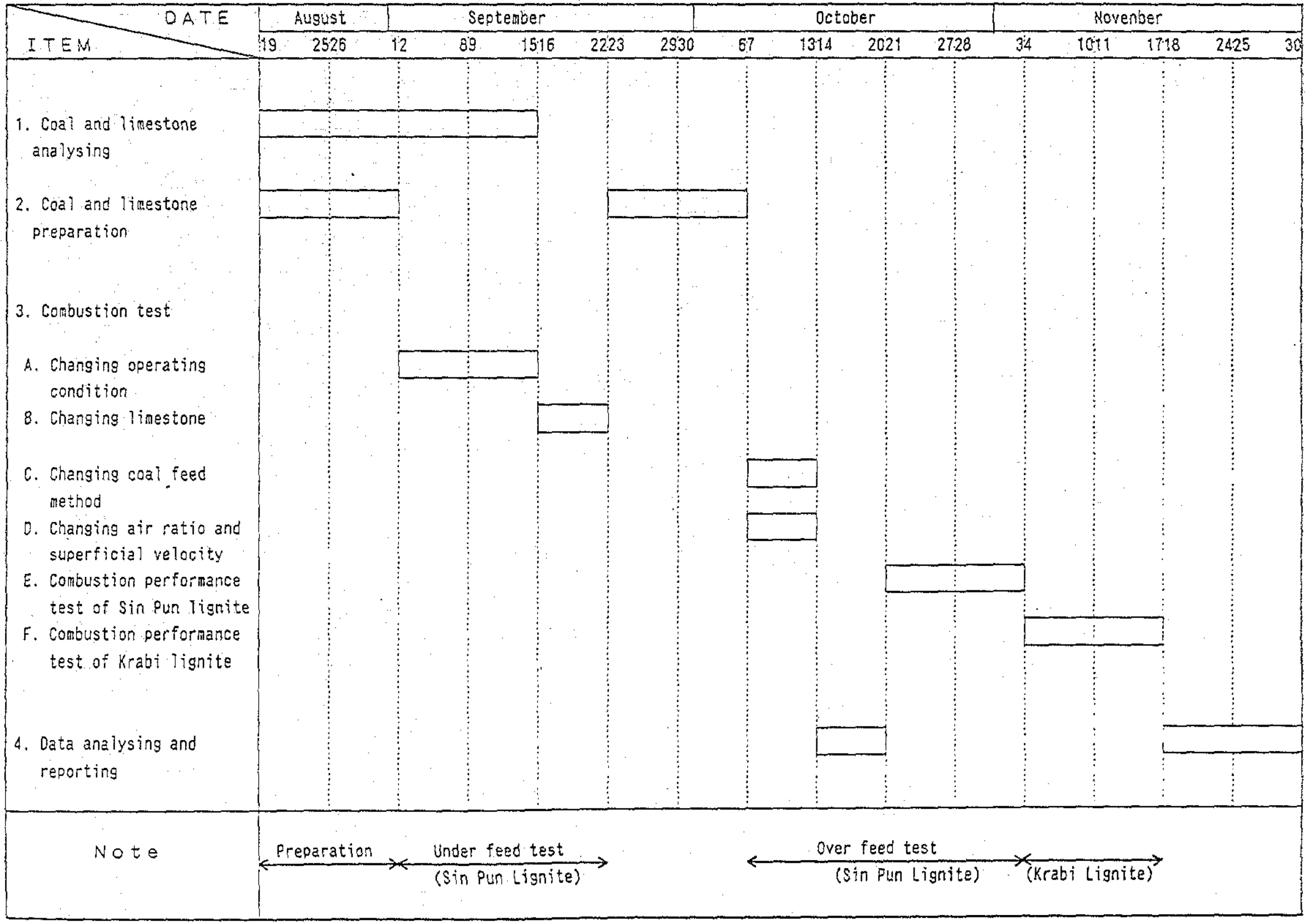


Table 8-1 Time Table for Beuch Scale Combustion Test

Date	Day	Time	RUN No	Lignite	Limestone	Coal feeding	Coal size (mm)	Limestone size(mm)	Initial BM size(mm)	Ca/S (-)	Bed Temp. (°C)	In-bed air ratio(-)	Superficial velocity(m/s)
Sep. 2	Mon	17:00-18:00	A-1-1	Sin Pun	Funao&Sekinoyama	Under feed	0.0-2.0	0.0-2.0	0.0-2.0	3.0	850	1.2	1.5
Sep. 3	Tue	15:00-16:00	A-2-1							2.0	810		
		17:00-18:00	A-2-2							2.0	850		
Sep. 4	Wed	13:40-14:40	A-3-1							3.0	810		
		14:40-15:50	A-3-2							3.0	850		
Sep. 5	Thu	14:30-15:30	A-4-1							1.0	810		
		16:00-16:30	A-4-2								850		
		17:00-18:00	A-4-3							1.0	890		
Sep. 6	Fri	13:30-14:30	A-5-1							2.0	810		
		15:00-15:30	A-5-2								850		
		16:00-16:30	A-5-3		Funao&Sekinoyama					2.0	890		
Sep. 17	Tue	14:00-15:00	B-1-1		Khao Tham Hora					2.0	810		
		15:30-16:30	B-1-2								850		
		17:00-17:30	B-1-3								890		
		18:00-18:30	B-1-4		Khao Tham Hora					2.0	780		
Sep. 18	Wed	12:30-13:30	B-2-1		Thung Song					2.0	810		
Sep. 19	Thu	15:30-16:30	B-3-1		Thung Song					2.0	850		
		17:00-18:00	B-3-2		Thung Song					2.0	890	1.2	
Sep. 20	Fri	12:30-13:30	B-4-1		Khao Tham Hora					3.0	850	1.2	
		14:00-15:00	B-4-2							2.0	850	1.4	
		15:30-16:00	B-4-3							2.0	880		
		17:00-17:30	B-4-4	Sin Pun	Khao Tham Hora	Under feed	0.0-2.0	0.0-2.0	0.0-2.0	4.0	920	1.4	1.5
Oct. 7	Mon	13:00-14:00	C-1-1	Sin Pun	Khao Tham Hora	Over feed	0.0-2.0	0.0-2.0	0.0-2.0	3.0	850	1.2	1.5
		14:30-15:30	C-1-2								850	1.4	
		16:00-17:00	C-1-3				0.0-2.0	0.0-2.0	0.0-2.0	3.0	880	1.2	
Oct. 8	Tue	13:00-14:00	D-1-1				0.5-2.0	0.5-2.0	0.0-2.0	3.0	850	1.2	
		14:30-15:30	D-1-2				0.5-2.0	0.5-2.0	0.0-2.0	3.0	850	1.4	1.5
Oct. 9	Wed	13:00-14:00	D-2-1				0.5-2.0	0.0-2.0	0.0-2.0	3.0	850	1.2	1.2
		14:30-15:30	D-2-2								850	1.4	1.2
		16:00-17:00	D-2-3				0.5-2.0	0.0-2.0	0.0-2.0	3.0	850	1.2	1.5
Oct. 16	Wed	13:00-14:00	D-3-1				0.0-2.0	0.0-1.4	0.0-1.4	2.0	850	1.2	1.1
		14:30-15:30	D-3-2								850	1.2	1.3
		16:00-16:30	D-3-3								850	1.2	1.5
		17:00-17:20	D-3-4	Sin Pun	Khao Tham Hora	Over feed	0.0-2.0	0.0-1.4	0.0-1.4	2.0	850	1.2	1.8
Oct. 21	Mon	14:00-15:00	E-1-1	Sin Pun	Khao Tham Hora	Over feed	0.0-2.0	0.0-1.4	0.0-1.4	2.0	800	1.2	1.2
		15:30-16:30	E-1-2							2.0	800	1.2	1.1
Oct. 22	Tue	14:00-15:00	E-2-1							2.0	850	1.2	1.2
		15:30-16:30	E-2-2							2.0	850	1.2	1.1
Oct. 24	Thu	14:00-15:00	E-3-1							2.0	900	1.2	1.2
		15:30-16:30	E-3-2							2.0	900	1.2	1.1
Oct. 28	Mon	15:00-16:00	E-4-1							3.0	800	1.2	1.2
		16:30-17:30	E-4-2							3.0	800	1.2	1.1
Oct. 29	Tue	14:00-15:00	E-5-1							3.0	850	1.2	1.2
		15:30-16:30	E-5-2							3.0	850	1.2	1.1
Oct. 30	Wed	14:00-15:00	E-6-1							3.0	900	1.2	1.2
		15:30-16:30	E-6-2							3.0	900	1.2	1.1
Nov. 5	Tue	14:00-15:00	E-7-1							4.0	800	1.2	1.2
		15:30-16:30	E-7-2							4.0	800	1.2	1.1
Nov. 6	Wed	14:00-15:00	E-8-1							4.0	850	1.2	1.2
		15:30-16:30	E-8-2							4.0	850	1.2	1.1
Nov. 7	Thu	14:00-15:00	E-9-1							4.0	900	1.2	1.2
		15:30-16:30	E-9-2	Sin Pun	Khao Tham Hora	Oved feed	0.0-2.0	0.0-1.4	0.0-1.4	4.0	900	1.2	1.1
Nov. 11	Mon	14:00-15:00	F-1-1	Krabi	Yod Posile Thong	Over feed	0.0-2.0	0.0-1.4	0.0-1.4	3.0	850	1.2	1.2
		15:30-16:00	F-1-2							3.0	850	1.2	1.4
		16:30-17:00	F-1-3							3.0	850	1.5	1.4
Nov. 12	Tue	13:30-14:30	F-2-1							3.0	800	1.2	1.2
		15:00-16:00	F-2-2							3.0	800	1.2	1.1
Nov. 13	Wed	13:00-14:00	F-3-1							3.0	900	1.2	1.2
		14:30-15:30	F-3-2							3.0	900	1.2	1.1
Nov. 15	Fri	14:00-15:00	F-4-1							2.0	850	1.2	1.2
		15:30-16:30	F-4-2							2.0	850	1.2	1.1
Nov. 19	Tue	14:00-15:00	F-5-1							4.0	850	1.2	1.2
		16:00-17:00	F-5-2	Krabi	Yod Posile Thong	Over feed	0.0-2.0	0.0-1.4	0.0-1.4	4.0	850	1.2	1.1

The details of each test are tabled in Table 8-1.

8.3 Lignite and Limestone Analysis

8.3.1 Features of the Test Lignite

Table 8-2 shows the analysis result of the sample lignites, and Table 8-3 shows the moisture content of the sample lignite after dry up.

For the calculation of the combustion efficiency and DeSOx efficiency, the value shown in Table 8-3 was applied.

From the analysis result of the sampled lignite, the features are described as follows;

i. The total sulfur content of the Sin Pun lignite is about 9% with dry basis and the combustible sulfur content is about 5% and occupy 60% of the total sulfur.

   Krabi lignite is about 3.6% for the total sulfur and 80% of the total sulfur is combustible sulfur.

   Since the uncombustible sulfur is not burn under the temperature 815°C, 40% of the total sulfur i.e. the uncombustible sulfur is captured by the ash for the Sin Pun lignite and 20% of the total sulfur is captured in the ash for the Krabi lignite in combusting the lignite in FBC boiler with the low temperature combustion.

ii. The fuel nitrogen content, which mainly generate NOx emission in combusting the lignite in FBC boiler, is 0.49% for Sin Pun lignite and 0.71% for Krabi lignite respectively and these values are moderate with the coal combusted in 50 MW demonstration plant in Japan.

   From the experience of the demonstration plant in Japan, NOx emission would not exceed the restriction value in Thailand.

Table 8-2 Raw Coal Analysis

Item	Base	Dimension	Sin Pun	Krabi	Note (JIS No.)
High Calorific Heating Value	A.D.	kcal/kg	3830	2940	JIS-M-8814
Total Moisture	A.R.	%	31.32	28.82	JIS-M-8801
Surface Moisture	A.R.	%	15.61	14.90	〃
<<Proximate Analysis>>					
Inferent Moisture	A.D.	%	18.62	16.36	JIS-M-8812
Volatile Matter	A.D.	%	42.35	32.80	〃
Fixed Carbon	A.D.	%	14.80	14.07	〃
Ash	A.D.	%	24.23	36.77	〃
<<Ultimate Analysis>>					
C	D.B.	%	47.04	37.72	JIS-M-8813
H	D.B.	%	3.27	1.67	〃
O	D.B.	%	13.99	13.51	〃
N	D.B.	%	0.49	0.71	〃
Total S	D.B.	%	9.08	3.64	〃
Combustible S	D.B.	%	5.44	2.83	〃
Uncombustible S	D.B.	%	3.64	0.81	〃
Cl	D.B.	%	0.006	0.010	〃
F	D.B.	%	0.03	0.03	〃
<<Ash Analysis>>					
SiO2	Ash	%	21.90	53.10	JIS-M-8815
Al2O3	Ash	%	7.47	22.50	〃
Fe2O3	Ash	%	9.44	9.36	〃
CaO	Ash	%	26.10	4.71	〃
MgO	Ash	%	2.31	1.97	〃
Na2O	Ash	%	0.13	0.14	〃
K2O	Ash	%	0.97	2.25	〃
SO3	Ash	%	30.5	4.6	〃
P2O5	Ash	%	0.17	0.15	〃
TiO2	Ash	%	0.28	0.73	〃
MnO	Ash	%	0.08	0.02	〃
V2O5	Ash	%	0.021	0.037	〃
H. G. I.	A.D.	-	70	58	JIS-M-8801
Button Index	A.D.	CSN	0	0	JIS-M-8801
<<Ash Melting Characteristic>>					
<Oxidatio>					
Initial Deformation Point	Ash	℃	1200	1250	JIS-M-8801
Spherical Point	Ash	℃	1220	1290	JIS-M-8801
Hemispherical Point	Ash	℃	1230	1320	JIS-M-8801
Fluid Point	Ash	℃	1240	1350	JIS-M-8801
<Reduction>					
Initial Deformation Point	Ash	℃	1220	1210	JIS-M-8801
Spherical Point	Ash	℃	1250	1260	JIS-M-8801
Hemispherical Point	Ash	℃	1260	1280	JIS-M-8801
Fluid Point	Ash	℃	1270	1460	JIS-M-8801

Table 8-3 Dryving Coal Analysis

Item	BASE	Dimension	Sin Pun	Krabi	Note
Total Moisture	A.R.	%	17.46	22.36	

iii. NaO content in the ash is 0.13% for Sin Pun lignite and a 0.14% for Krabi lignite respectively and these values are low to cause the aggromalation problem in FBC boiler.

iv. Fe_3O_3 content in the ash is very high with 9.44% and 9.36% for Sin Pun lignite and the Krabi lignite respectively, and may cause the settlement of the ash lump in the FBC bed. However, from the experience of the demonstration plant of Japan, 18.8% of Fe_3O_3 content in the ash has been treated by the drain pipe of the bed material (hereinafter B.M.), and the value of the Fe_3O_3 content may not cause the serious problem for A-FBC.

Besides the ultimate and proximate analysis of the lignites, the following tests are carried out for finding the further characteristics of the lignites.

i. Ash fusion test
ii. Burning profile
iii. Particle size distribution of the lignite sample as received base.

iv. Particle size distribution of the testing lignite after grinding under 2 mm.

v. Incineration test as received base.

Photo 8-1 and 8-2 shows the result of ash fusion Test under the oxidization and reduction atmosphere. The result shows that the Sin Pun lignite start to melt relatively lower temperature than the Krabi lignite, especially under the oxidization atmosphere.

It is presumed by the demonstration plant in Japan that the surface temperature of the coal is about 50 ~ 100°C higher than that of the bed temperature. Therefore the surface temperature of the coal is nearly 1,000°C in case of the bed temperature 900°C.

Both ash fusion temperatures of the Sin Pun lignite and Krabi lignite are above 1,200°C and there is not occur the ash fusion trouble in the FBC boiler.

(JIS Base;Leitz High Temperature Microscope)

Sin Pun Lignite   Krabi Lignite

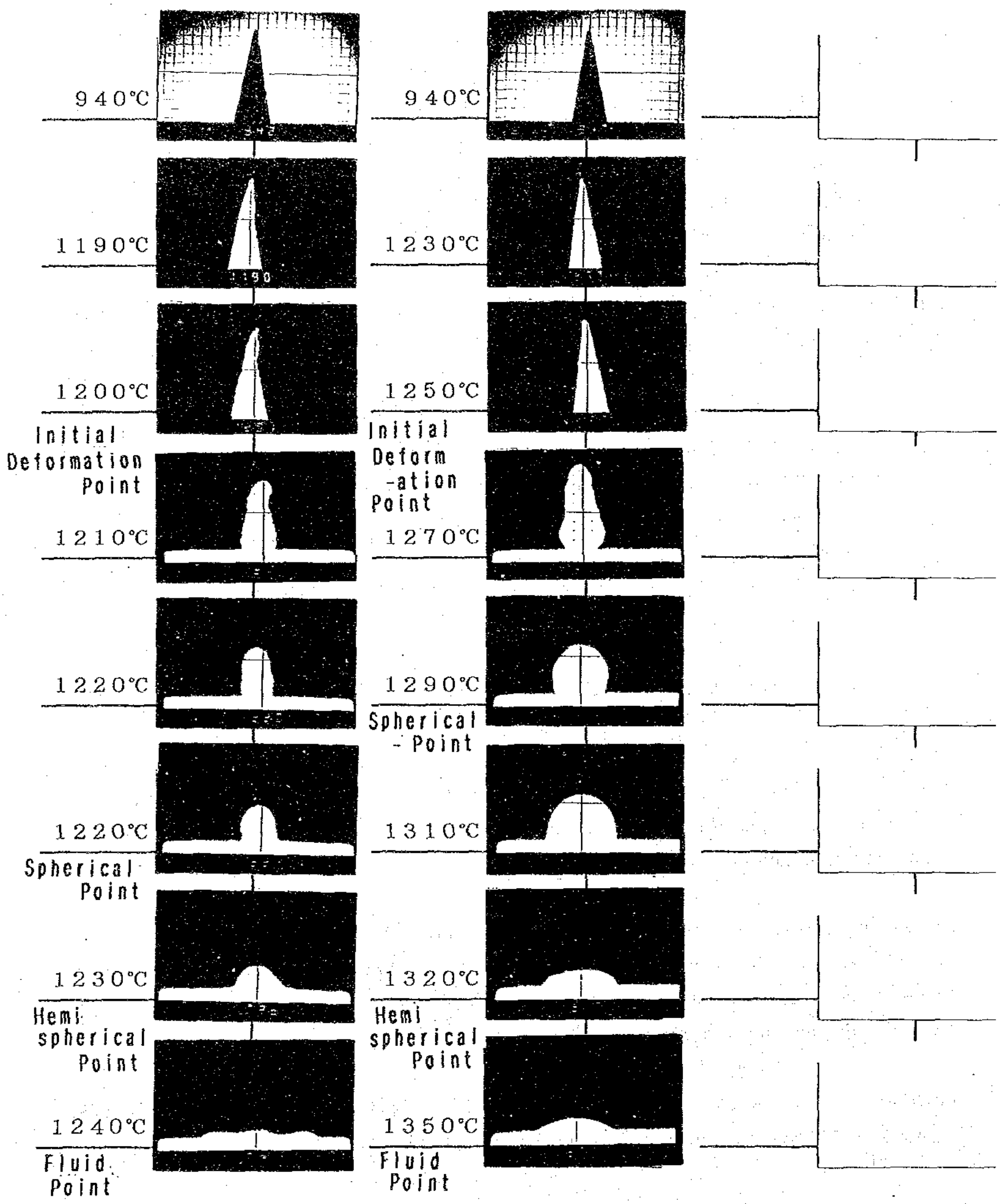


Photo 8-1 Melting characterisic of coal ash
(Oxidization)

(JIS Base;Leitz High Temperature Microscope)

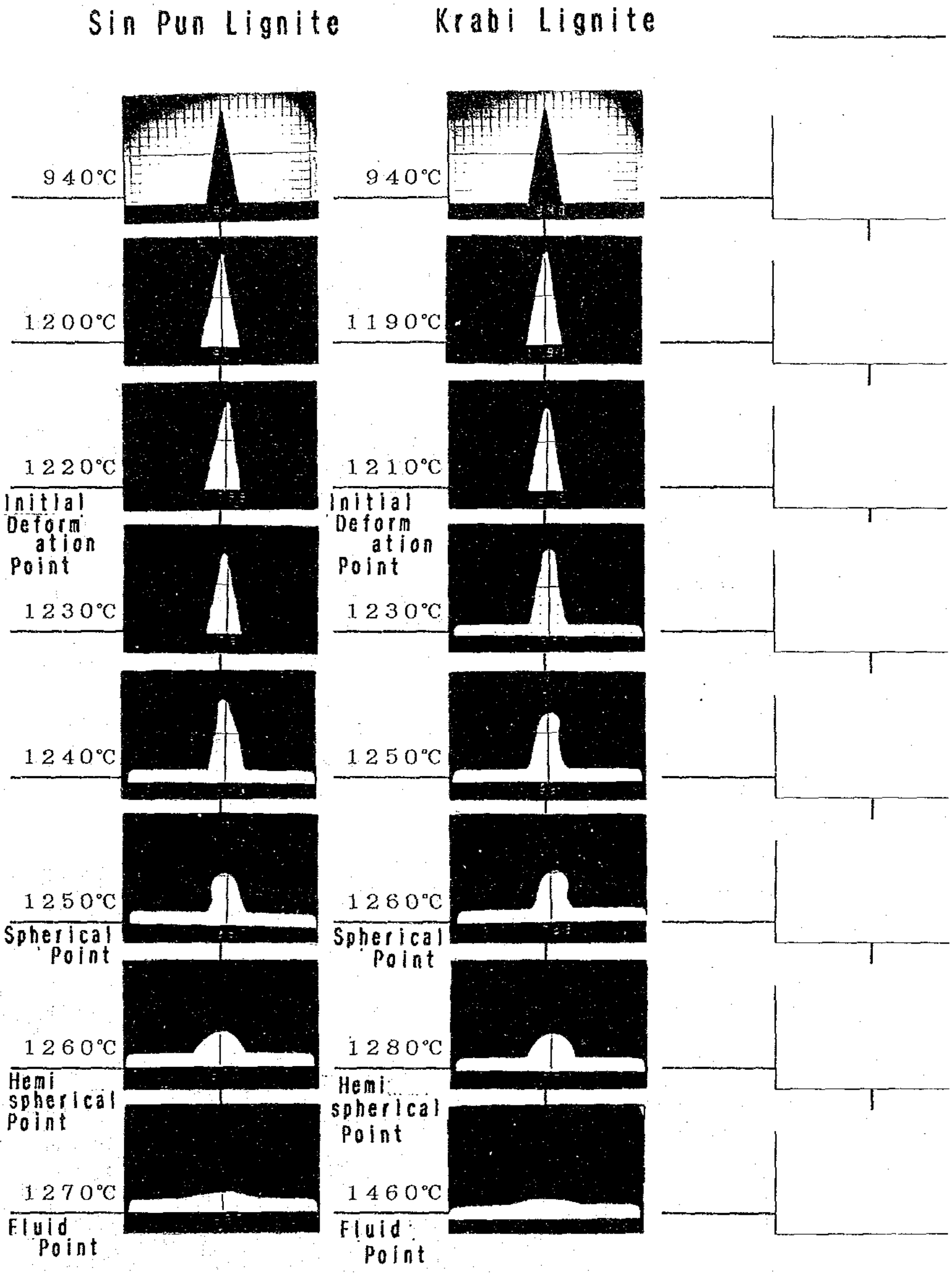


Photo 8-2 Melting characteristic of coal ash (Reduction)

During the bench scale combustion test, any trouble have not been found also due to ash fusion on the fly ash nor B.M.

Fig. 8-1 shows the burning profile of Sin Pun lignite and Krabi lignite respectively.

This shows that either Sin Pun or Krabi lignite burn up under the temperature 800°C.

It is also mentioned that the peak combustion temperature is under 550°C on the both lignites, and there remains little urburn carbon under the FBC fly ash.

Photo 8-3 show the outlook of the lignite as received, and Krabi lignite has coarse and well cut shape compared with Sin Pun lignite. It is also noted that Sin Pun lignite contain the white lump in the received coal which is composed mainly of CaO.

Fig. 8-2 shows the particle of the receiving lignite and Fig. 8-3 shows the particle size distribution of the testing lignite. Under the pre-combustion test, the relationship was checked between the particle size and DeSOx efficiency also.

Under the combustion test, the coal size of 2 mm under was applied on both Sin Pun lignite and Krabi lignite with under and over coal feed system.

Under the over coal feed system, the coarse particle may settle on the bottom of the bed because the over coal feed system apply the large size of lignite for the easiness of the handling and may cause the trouble of fludized action.

Therefore the comparison check of particle size before and after the burning was carried out.

Photo 8-4 and 8-5 shows the outlook of the particle of the lignite before and after burning and it is clear that the Krabi lignite keeps to remain the coarse particle.

Sample : Sin Pun Coal

Sampleing Time : 1.0 sec
Sample Weight : 10.532 mg
Heating Rate : 20.0 deg/min
Thermo Couple : PR

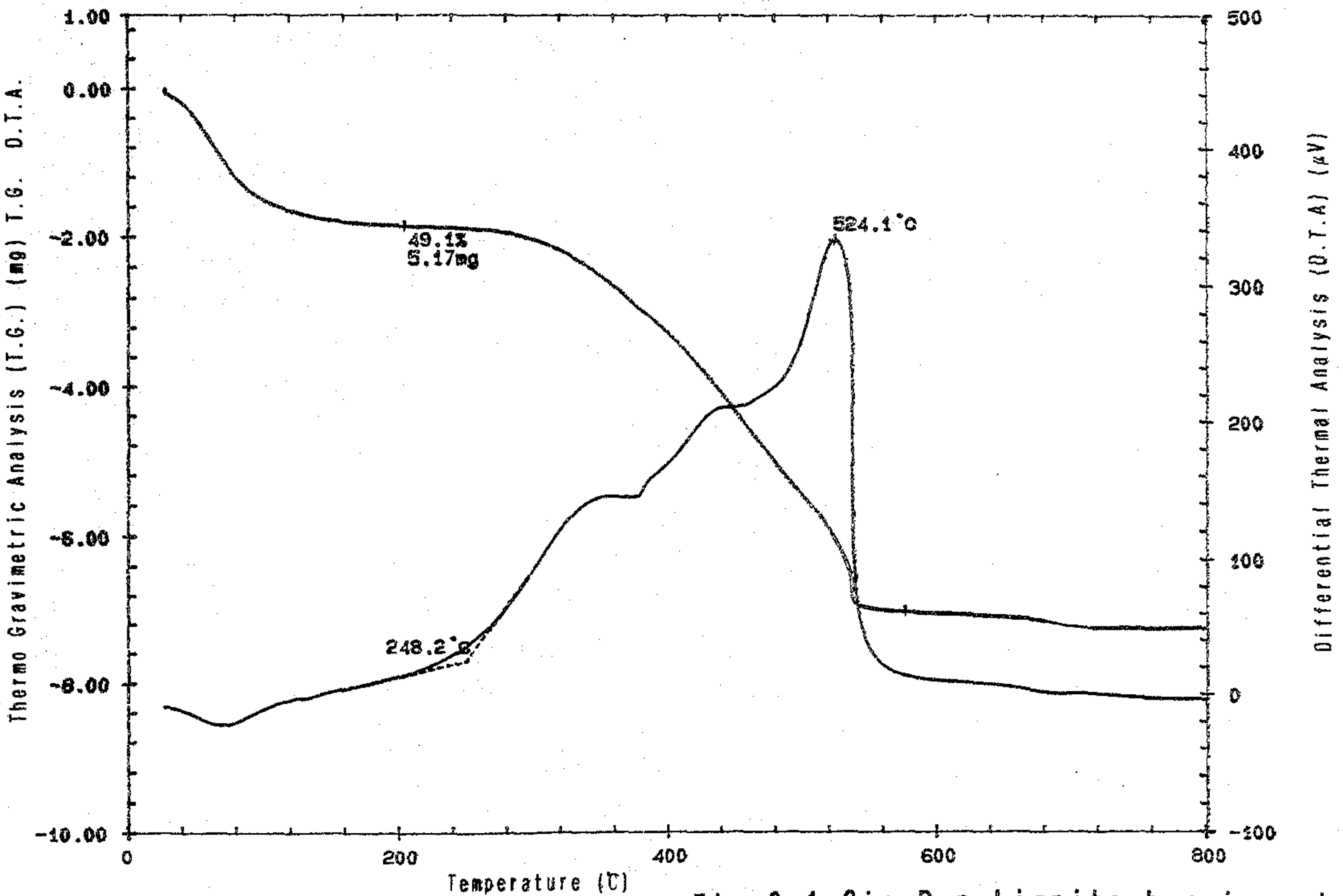


Fig.8-1 Sin Pun Lignite burning plofile

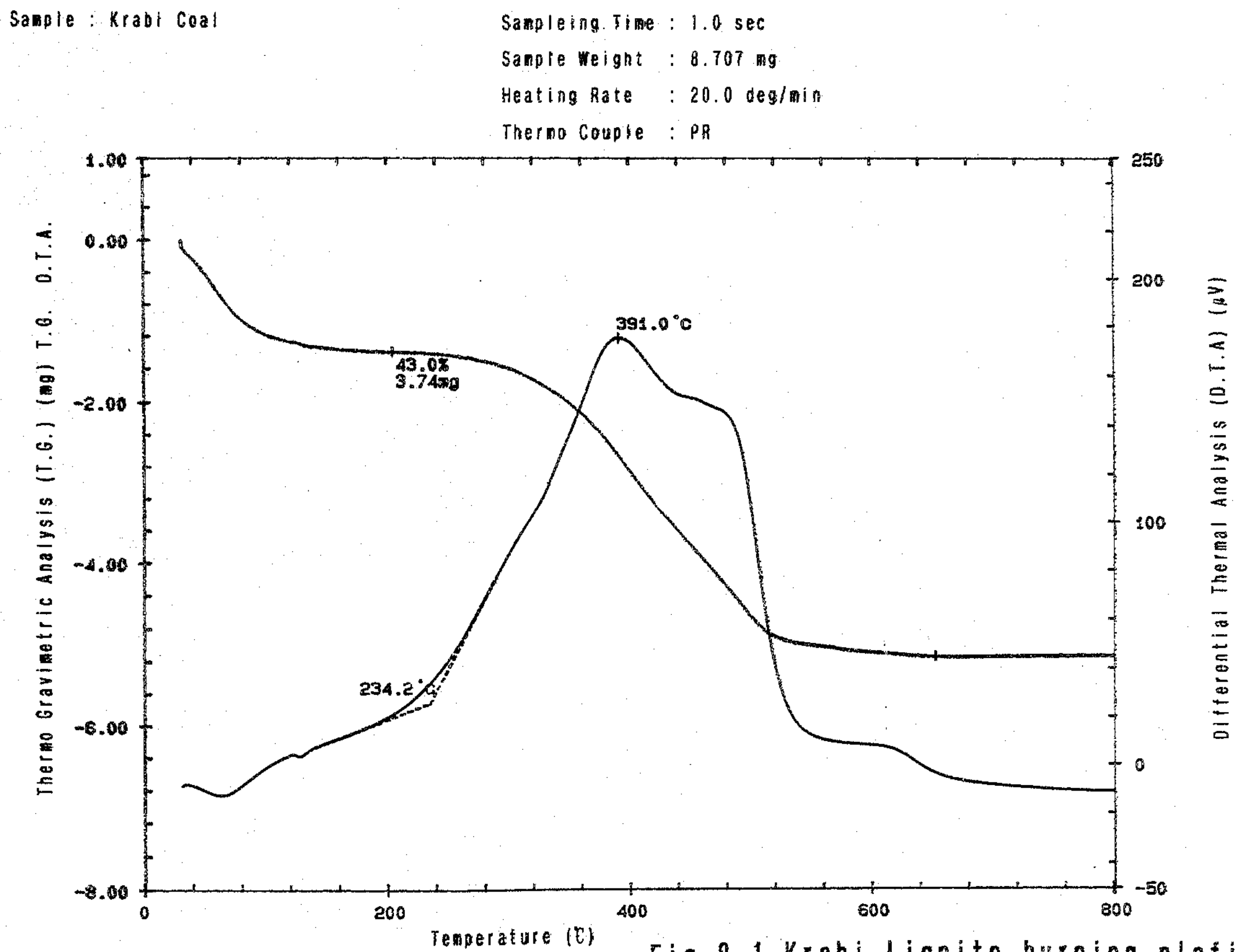


Fig.8-1 Krabi Lignite burning plofile

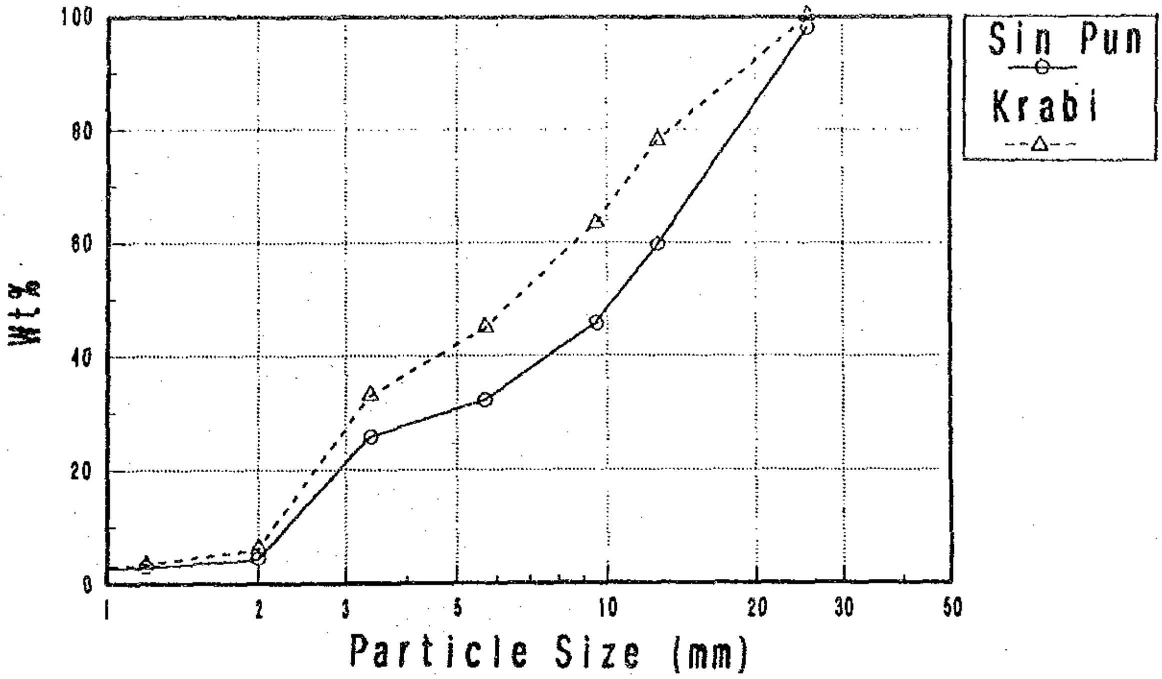


Fig.8-2 Particle size distribution of Thailand Lignite

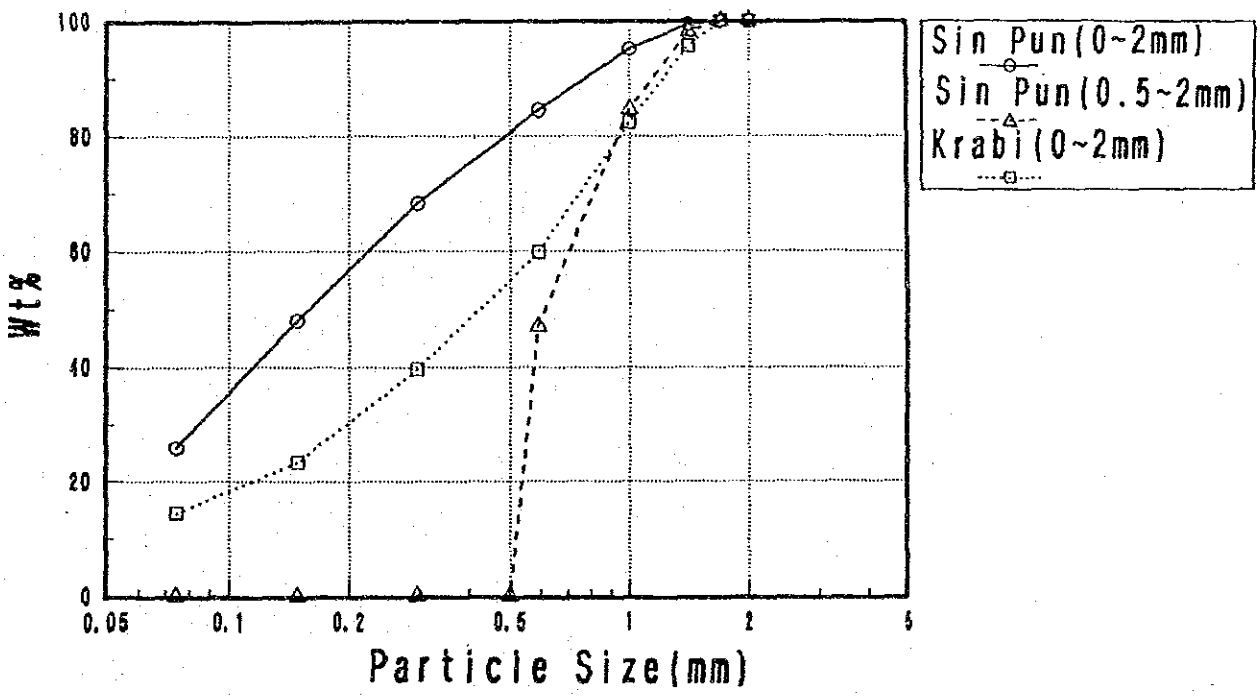
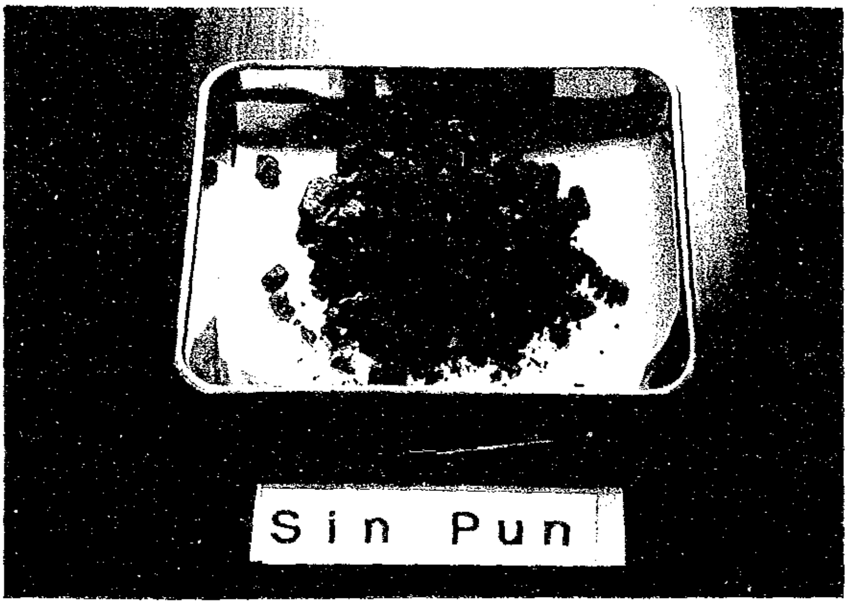


Fig.8-3 Particle size distribution of crushed coal for combustion Test



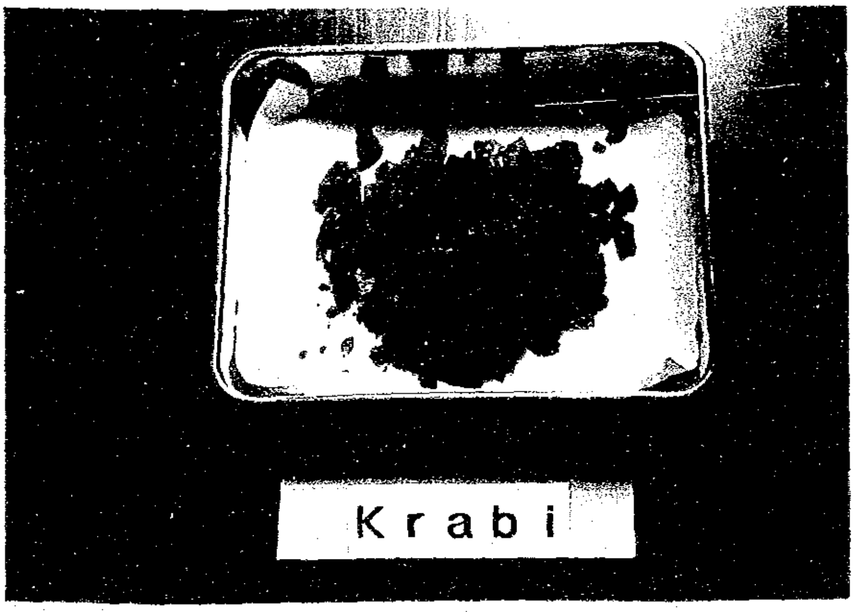
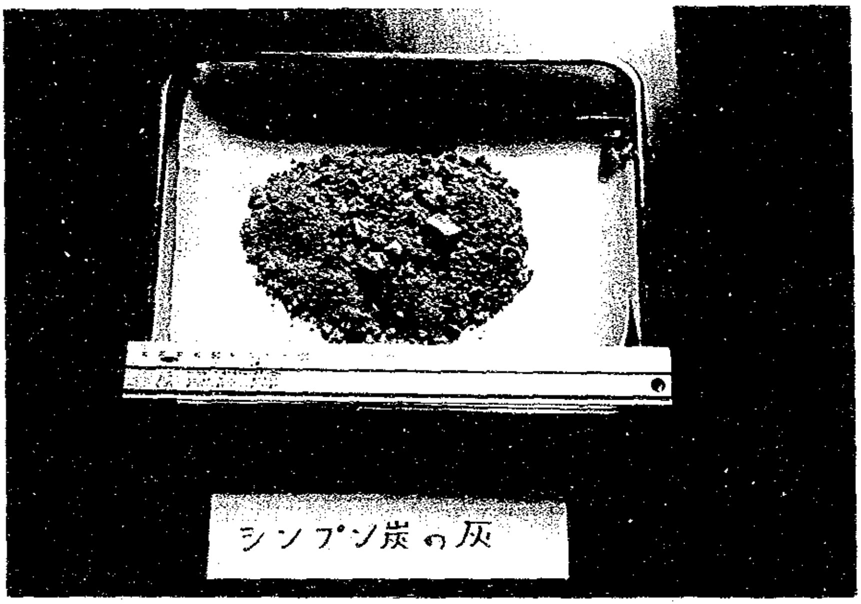


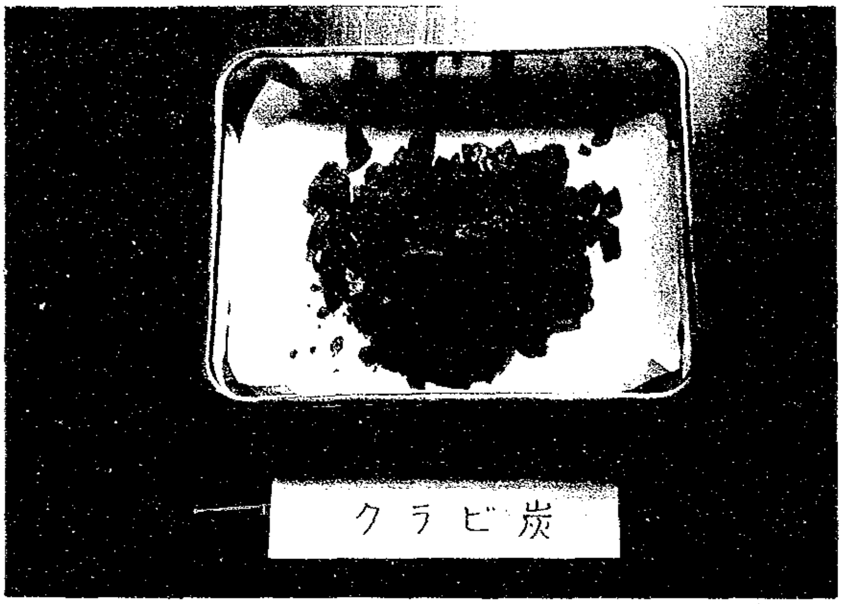
Photo 8-3 Appearance of Thailand Lignite

Before Ashing



After Ashing

Photo 8-4 Appearance of Sin Pun Lignite before and after ashing



Before Ashing

After Ashing

Photo 8-5 Appearance of Krabi Lignite before and after ashing

Fig. 8-4 shows the diversion of the particle size and that the ash after burning the Krabi lignite keeps almost same particle size of the lignite.

On the above view, Sin Pun lignite is better than Krabi lignite for A-FBC.

Table 8-4 shows the analysis result of the ash component and both lignite has ash content of SiO_2, Al_2O_3, Fe_3O_3.

Table 8-4 Proximate Analysis of Test Lignite Ash

Brand of Lignite	Sin Pun	Krabi
SiO_2	76.7 %	61.2 %
Al_2O_3	13.8 %	25.4 %
Fe_2O_3	1.79 %	3.95 %
CaO	0.45 %	0.71 %
$CaSO_4$	0.20 %	0.90 %
$CaSO_3$	0.22 %	< 0.1 %

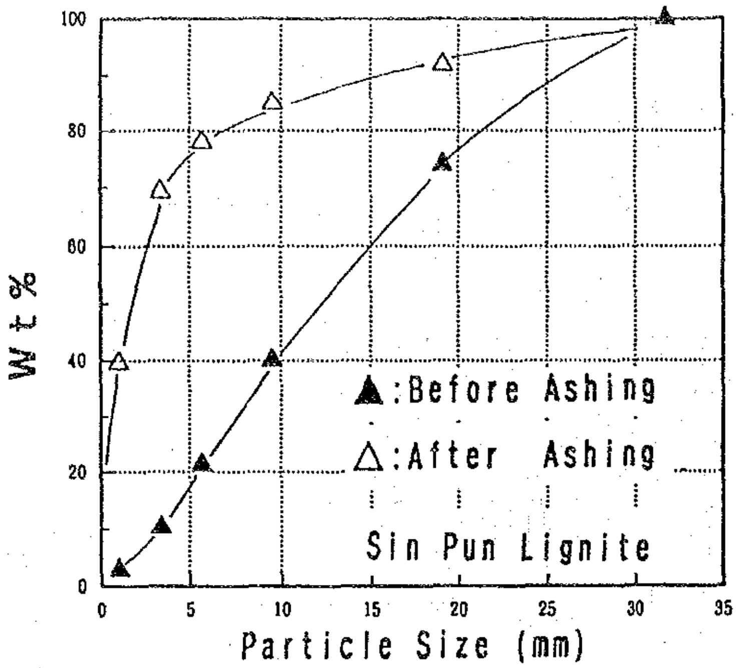
8.3.2 Features of Sample Limestone

The combustion test has applied two brands of limestone (Khao Tham Hora, Thung Song) from Sin Pun area, one brand of limestone from Krabi area and one brand of limestone from Funao-Sekinoyama in Japan, which has ample experience in 50 MW demonstration plant, and uses for the comparison data.

Table 8-5 shows the analysis result of the above limestones carried out April '91 for the site selection study.

Table 8-6 shows the purity check of $CaCO_3$ in the sample limestone for this combustion test.

From the analysis result, the purity of $CaCO_3$ for Thailand limestone is lower than that of Japan and especially the limestone of Yod Po Sila Thung has $CaCO_3$ content up to 80% only. For the calculation of the Ca/S molar ratio in the combustion test, the net $CaCO_3$ weight has applied.



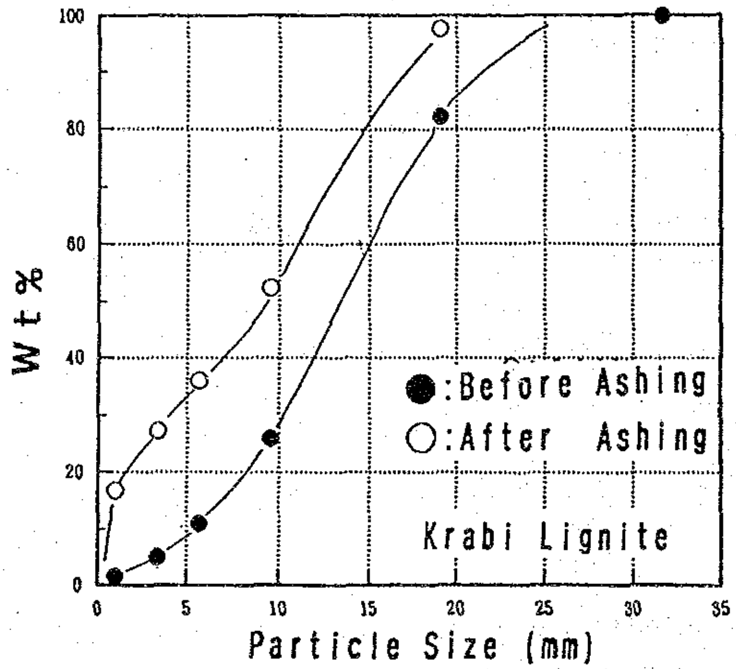


Fig 8-4 Particle size distribution before and after ashing

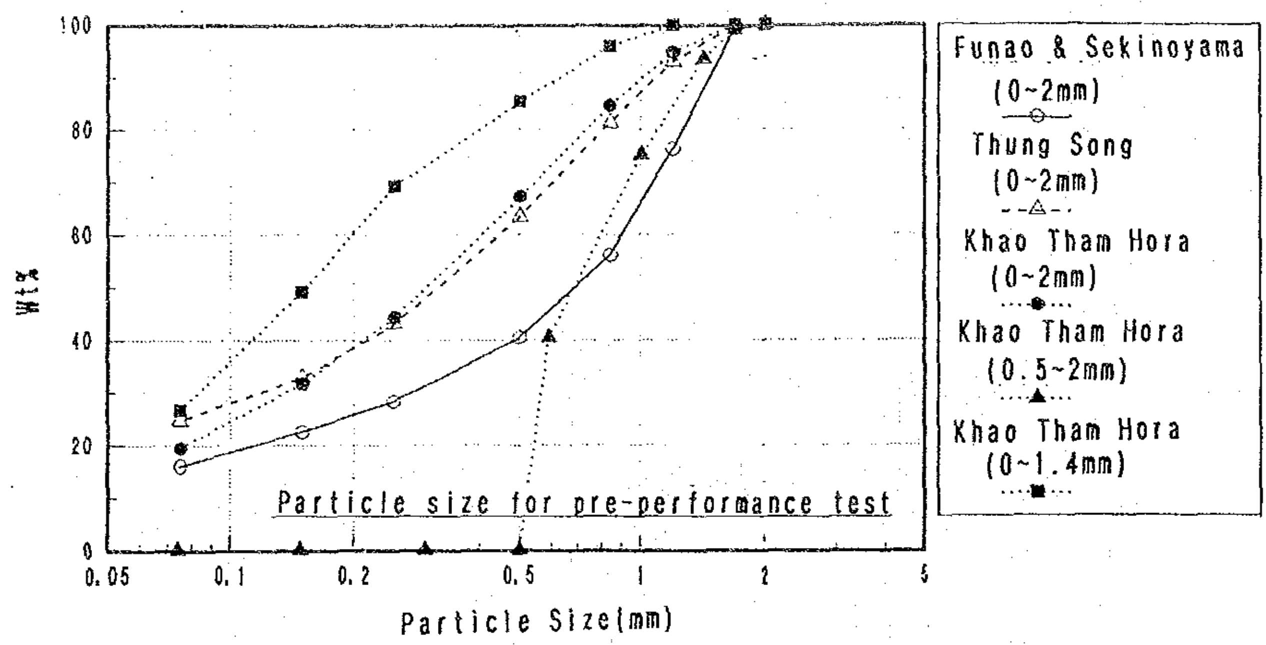
(Electric Heater;800℃×4Hr)

Table 8-5 Limestone Analysis (Analyzed on April,1991)

Item		Wat Khao Din	Khao Tham Hora #1	Khao Tham Hora #2	Khao Tham Padam	Thung song	Ban Rai Yai #2	Yod Po Sile Thong	Funao	Sekino-yama
		Thailand	Thailand	Thailand	Thailand	Thailand	Thailand	Thailand	Japan	Japan
CaSO4	wt%	-	-	-	-	-	-	-	≦0.1	≦0.1
CaCO3	wt%	61.5	88.1	98.7	66.9	89.2	94.5	90.6	99.26	98.89
CaO	wt%	1.36	0.76	0.6	1.74	0.42	1.98	3.04	≦0.1	≦0.1
SiO2	wt%	24.8	9.52	0.001	0.12	3.01	0.41	0.97	0.05	0.03
Al2O3	wt%	4.18	0.32	0.001	0.03	0.83	0.02	0.11	-	-
Fe2O3	wt%	1.75	0.05	0.002	≦0.01	0.31	0.024	0.053	-	-
MgCO3	wt%	2.82	0.72	0.39	28	5.71	3.01	4.72	-	-
MgO	wt%	0.05	0.005	0.002	0.62	0.02	0.05	0.14	-	-
Na2O	wt%	0.006	0.002	≦0.001	0.0016	0.001	0.007	0.003	-	-
Ignition Loss	wt%	30.53	38.77	43.82	44.01	42.18	43.1	42.3	43.1	43
Calcination Temp.	°C	738.1	747.7	-	740.02	750.3	735.6	725.2	782.5	785.9
Parvalized Ratio	wt%	2.9	2.3	-	0.8	0.9	3.7	3.2	5.9	0.6

Table 8-6 Limestone Purisity
(Analyzed on September,1991)

	CaCO3
Funao & Sekinoyama	98.6 %
Khao Tham Hora	94.8 %
Thung Song	86.5 %
Yod Po Sile Thong	79.4 %



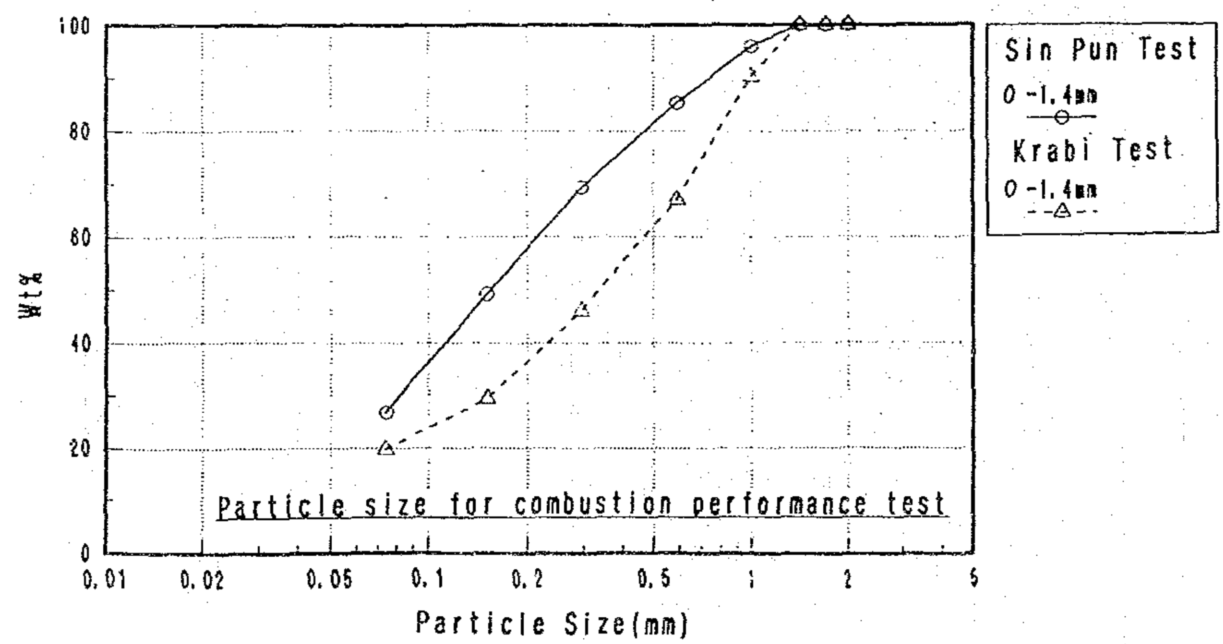


Fig.8-5 Limestone particle size distribution

Fig. 8-5 shows the particle size distribution of each limestone. For Khao Tham Hora limestone, the DeSOx characteristic has checked with the various grain size as shown in respective figure.

For the combustion test, Sin Pun lignite and Krabi lignite apply also particle size under 2 mm.

8.4 Combustion Test Facility

Fig. 8-6 shows the outline of the 100ϕ bench scale combustion facility. Under coal feeding system was applied during pre-combustion test stage and after that, the over coal feeding system was applied with the coal transportation air (15% of total combustion air) system.

This test equipment apply the following flue gas monitoring system.

- O_2 Gas (0 - 25%)
- NOx Gas (0 - 1,000 ppm)
- SOx Gas (0 - 1,000 ppm)
- SOx Gas (0 - 5,000 ppm) --- Temporary equipment for high sulfur lignite.

Fig. 8-7 shows the furnace construction which has the under coal feeding point above 50 mm from the distribution plate and the over coal feeding point above 450 mm from the distribution plate.

Photo 8-6 to 8-9 show the outlook of the facilities.

8.5 Test Result

8.5.1 Pre-Combustion Test

The pre-combustion test purposes to search the suitable operating condition for the combination of the Thailand lignite and limestone, which minimize the limestone consumption with keeping the SOx emission value under the Thailand

仕　様

1) 型　　式：流 動 層
2) 寸　　法：100 φ x2,500mmH
3) 燃 焼 量：~3 kg／h (石炭)
4) 空塔速度：~3 m／s
5) 層 温 度：~1,000 ℃

Specification

1) Type : Fluidized Bed
2) Size : 100 φ x2,500mmH
3) Capacity : ~3kg／h(Coal)
4) Superficial velocity:~3m／s
5) Bed temperature: ~1,000 ℃

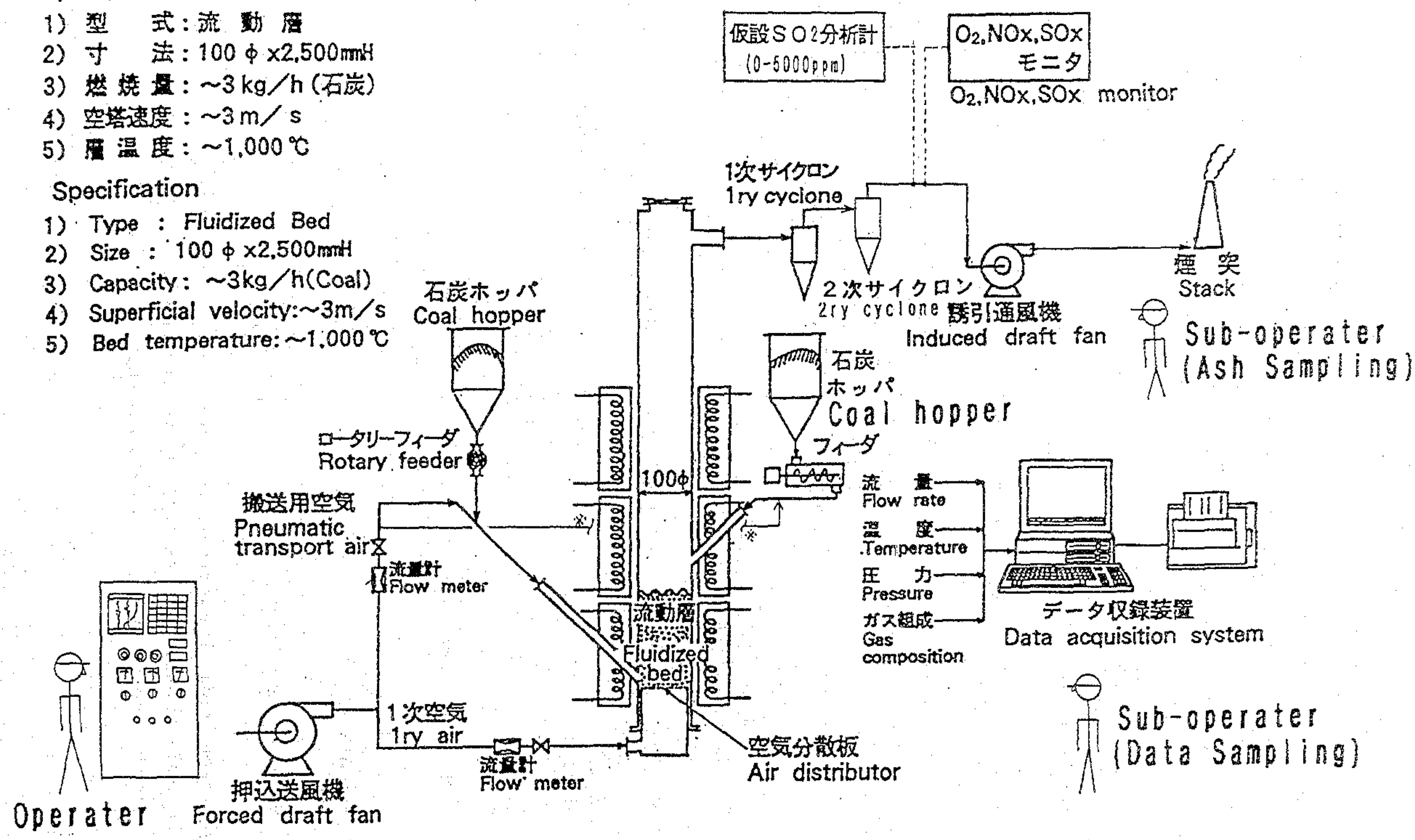


Fig.8-6 φ100 combustion test facility Flow diagram

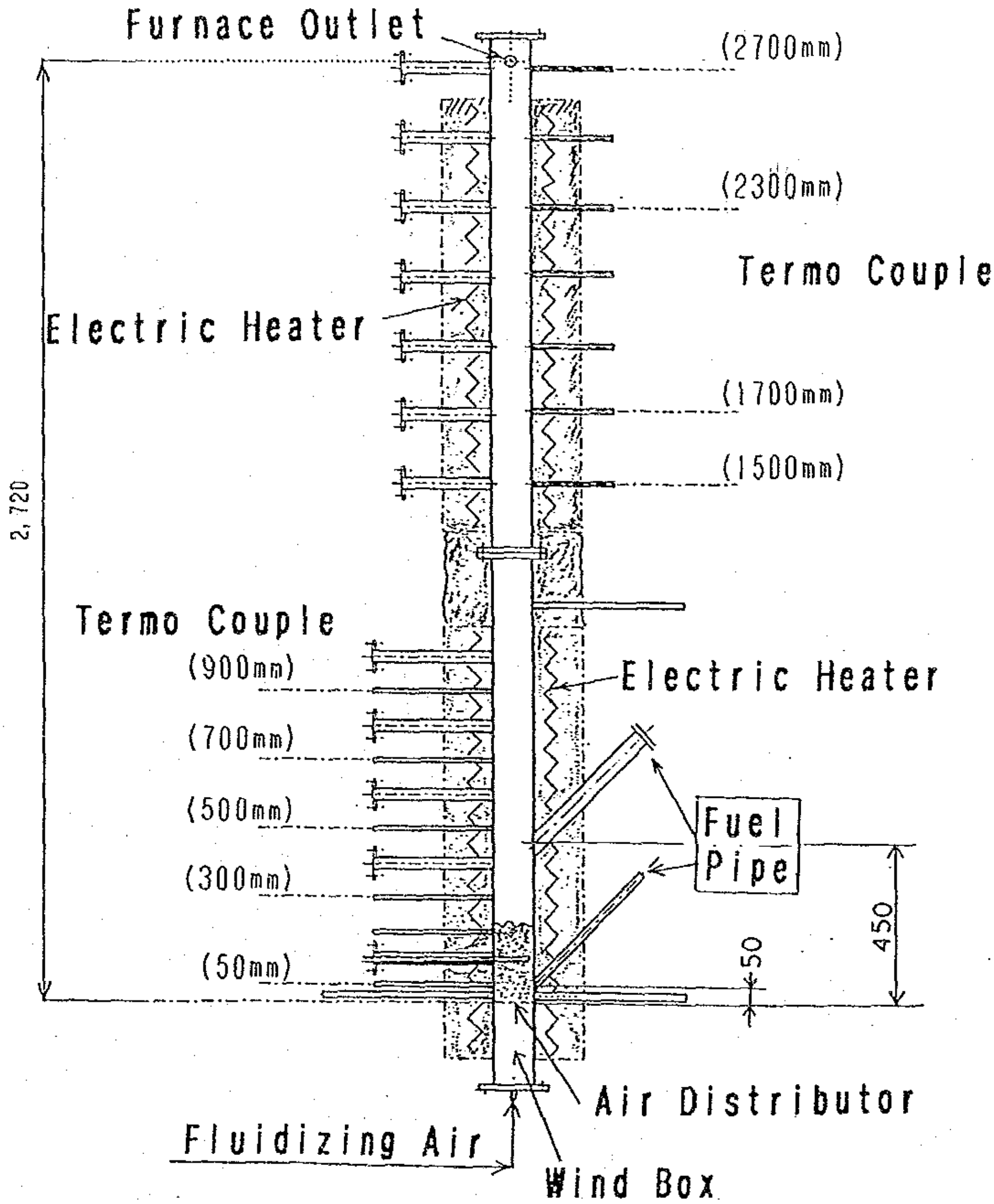


Fig.8-7 Furnace and fuel feeding points

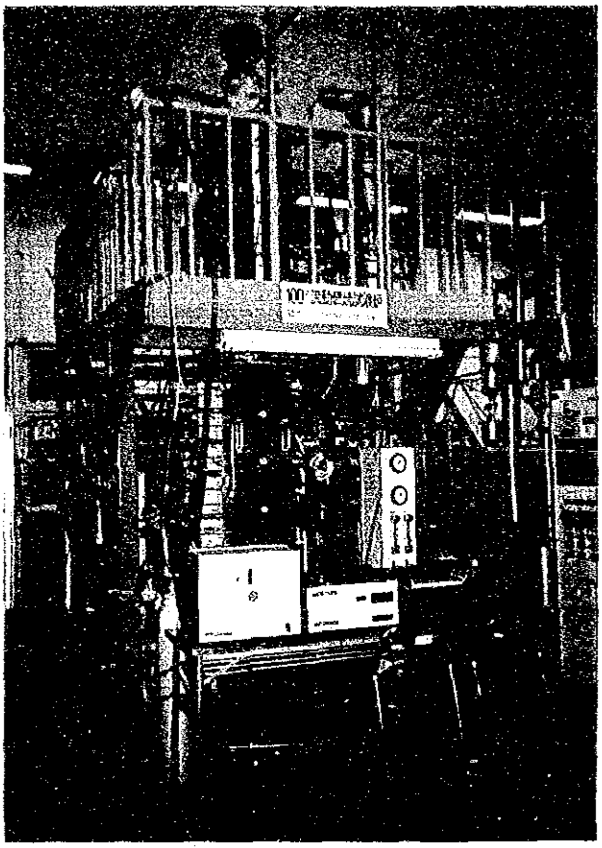


Photo 8-6 Combustion test facility

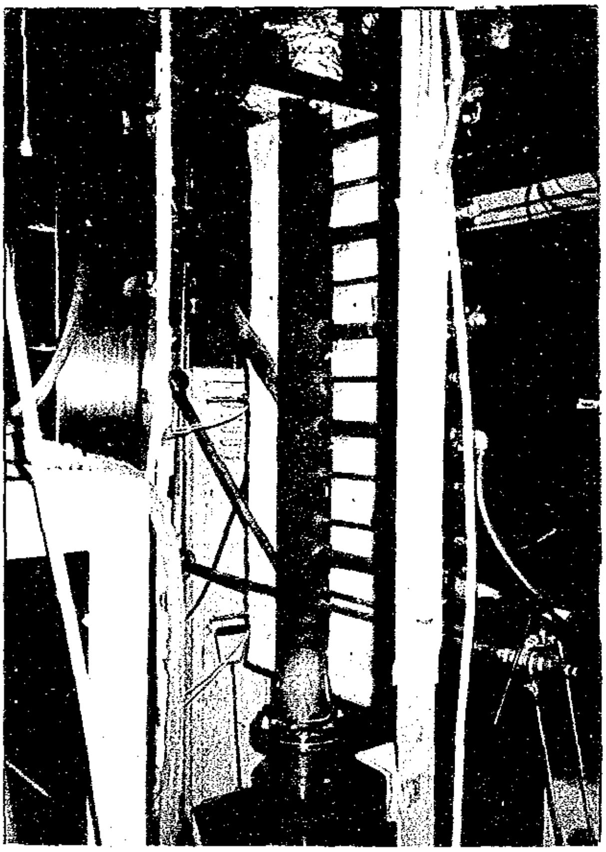


Photo 8-7 Furnace and fuel feed pipe

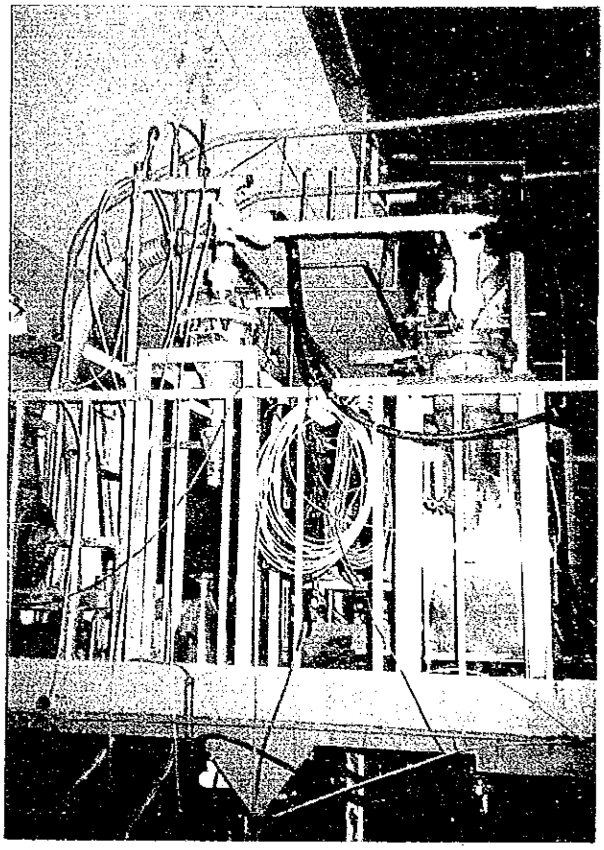


Photo 8-8 Cyclone and gas sampling system

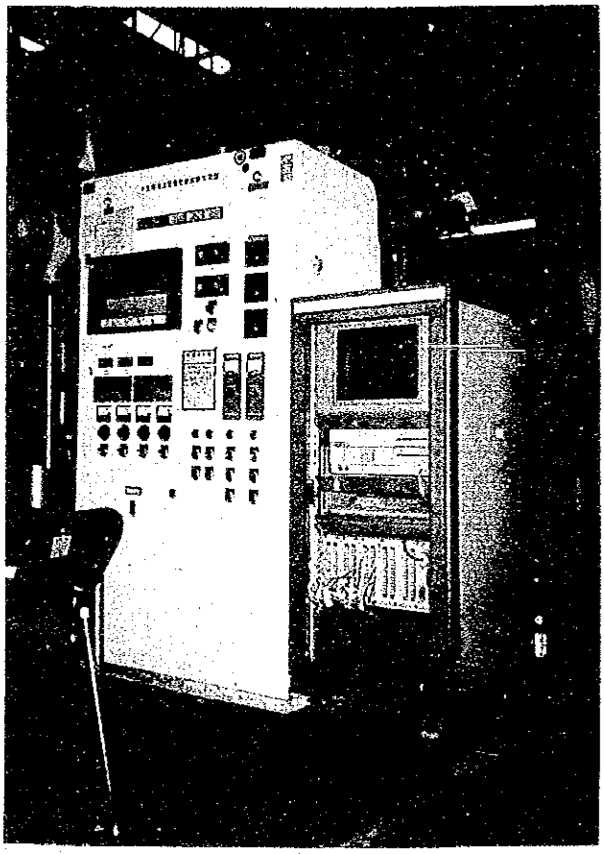


Photo 8-9 Operation and control
board and data Logger

regulation by means of varying the operation value of the bed temperature the Ca/S molar ratio, the space velocity and the blend of the limestone.

Table 8-7 shows the result of the pre-combustion test.

(1) DeSOx Performance

From the data of the lignite ultimate analysis, the SOx emission density in the flue gas due to the combustible sulfur is calculated with the dry gas bases, as follows;

Sin Pun Lignite

Theoretical amount of air, Ao

$$Ao = 8.89\ C + 26.7\ (h - \frac{0}{8}) + 3.33S$$
$$= 4.769\ Nm^3/kg\ fuel\ (D.B.)$$

c.h.o.s.n means the content ratio of the carbon, hydrogen, oxygen, sulfur and nitrogen in the dry base lignite.

Theoretical amount of gas Vo

$$Vo = 8.89C + 21.1\ (h - \frac{0}{8}) + 3.33\ S + 0.8n$$
$$= 4.688\ Nm^3/kg\ fuel\ (D.B.)$$

Amount of flue gas under for the excess air ratio 1.2

$$Vd = Vo + 0.2\ Ao$$
$$= 5.642\ Nm^3/kg\ fuel\ (D.B.)$$

Amount of combustible sulfur gas (5.44%) in the flue gas

$$\frac{5.44 \times \frac{1000}{100}}{32}\ g \times 0.0224\ Nm^3/Mol = 0.0381\ Nm^3/kg\ fuel\ (D.B.)$$

Table 8-7 Pre-Performance Test Data

	Item	Unit																	
	Date		Sep. 3	Sep. 3	Sep. 3	Sep. 4	Sep. 4	Sep. 4	Sep. 5	Sep. 5	Sep. 5	Sep. 6	Sep. 6	Sep. 6	Sep. 17	Sep. 17	Sep. 17	Sep. 17	Sep. 18
	Time		1445-1445	1500-1600	1700-1800	1300-1342	1512-1544	1723-1758	1504-1531	1535-1602	1652-1604	1359-1429	1436-1534	1606-1700	1327-1459	1505-1523	1634-1722	1744-1624	1230-1330
	RUN No			A-2-1	A-2-2	A-3-1	A-3-2	A-3-3	A-4-1	A-4-2	A-4-3	A-5-1	A-5-2	A-5-3	B-1-1	B-1-2	B-1-3	B-1-4	B-2-1
	Coal Feeding		Under	Under	Under	Under	Under	Under	Under	Under	Under	Under	Under	Under	Under	Under	Under	Under	Under
Coal	Name		Sin Pun	Sin Pun	Sin Pun	Sin Pun	Sin Pun	Sin Pun	Sin Pun	Sin Pun	Sin Pun	Sin Pun	Sin Pun	Sin Pun	Sin Pun	Sin Pun	Sin Pun	Sin Pun	Sin Pun
	Size	mm	0-2.0	0-2.0	0-2.0	0-2.0	0-2.0	0-2.0	0-2.0	0-2.0	0-2.0	0-2.0	0-2.0	0-2.0	0-2.0	0-2.0	0-2.0	0-2.0	0-2.0
	Initial Charge	kg	7.00	7.00	7.00	4.00	4.00	4.00	9.00	9.00	9.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00
Lime ston	Name		Funao&Seki	Funao&Seki	Funao&Seki	Funao&Seki	Funao&Seki	Funao&Seki	Funao&Seki	Funao&Seki	Funao&Seki	Funao&Seki	Funao&Seki	Funao&Seki	Khao Tham	Khao Tham	Khao Tham	Khao Tham	Thung Song
	Size	mm	0-2.0	0-2.0	0-2.0	0-2.0	0-2.0	0-2.0	0-2.0	0-2.0	0-2.0	0-2.0	0-2.0	0-2.0	0-2.0	0-2.0	0-2.0	0-2.0	0-2.0
	Initial Charge	kg	4.00	4.00	4.00	3.16	3.16	3.16	2.40	2.40	2.40	4.20	4.20	4.20	4.40	4.40	4.40	4.40	4.00
	Ca/S Molar Ratio	-	3.00	3.00	3.00	2.00	2.00	2.00	1.00	1.00	1.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Gas Temp	In-bed(1)	°C	753.3	812.0	854.3	855.6	808.4	854.1	850.9	803.9	878.6	850.7	808.7	889.5	820.0	853.9	890.2	778.0	821.5
	In-bed(2)	°C	758.4	814.7	858.2	859.7	812.1	857.9	840.0	805.9	881.7	855.9	814.9	893.7	823.2	866.6	892.9	780.1	826.5
	Freeboard(1)	°C	673.8	782.2	819.1	813.1	755.4	819.6	773.7	734.0	818.5	801.5	764.7	842.7	808.8	850.2	833.4	769.5	797.0
	Freeboard(2)	°C	684.7	757.5	788.7	812.6	743.9	788.7	789.5	753.7	823.3	800.1	769.6	836.3	799.7	837.9	860.0	747.0	801.1
	Freeboard(3)	°C	630.4	704.1	731.0	771.9	695.3	730.9	753.2	713.4	775.9	755.4	726.1	786.2	763.4	779.4	810.2	707.9	776.7
	Freeboard(4)	°C	516.8	552.8	562.6	587.5	539.2	562.7	565.4	543.8	562.7	567.5	544.0	561.2	580.8	565.9	561.2	523.1	600.3
	Freeboard(5)	°C	492.1	520.3	528.0	557.1	504.5	528.1	532.7	511.7	522.7	532.1	506.9	518.0	555.3	529.9	545.8	486.2	571.0
	Freeboard(6)	°C	458.3	462.7	464.9	509.0	448.4	464.9	484.6	460.8	451.5	478.1	449.9	446.0	514.5	468.7	476.4	429.0	527.0
	Freeboard(7)	°C	384.1	392.3	382.2	407.0	358.2	382.2	383.3	371.2	358.9	382.7	360.9	349.9	416.3	369.3	375.0	336.3	422.8
	Wind Box	°C	44.0	52.9	56.6	55.4	56.2	56.6	51.3	51.0	52.2	54.0	51.9	55.3	52.8	57.6	50.3	55.3	46.4
	Bed Pressure Drop	mmAq	167.6	170.9	161.8	159.1	173.2	163.7	130.7	126.8	153.5	155.8	156.9	145.3	165.6	185.0	164.7	204.9	155.6
	Furnace Pressure	mmAq	111.7	114.4	105.0	72.4	64.2	105.1	71.0	102.9	98.7	96.8	105.0	111.5	90.5	60.2	68.4	65.8	84.4
	Coal Feeder Power	-	-	-	-	-	-	-	0.345	0.35	0.355	0.375	0.28	0.34	0.421	0.355	0.358	0.362	0.430
Air Flow	Fluidizing	Nm3/h	8.00	8.00	8.00	7.00	7.00	7.00	7.20	7.20	7.40	7.20	7.40	7.00	7.40	7.00	7.00	7.00	6.80
	Transporting	Nm3/h	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30
	Pres. Barancing	Nm3/h	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
	Fluidizing(real)	Nm3/h	9.42	9.42	9.42	8.24	8.24	8.24	8.48	8.48	8.72	8.48	8.72	8.24	8.72	8.24	8.24	8.24	8.01
Gas Ana.	O2	%	3.316	3.654	3.470	3.527	3.437	3.432	2.912	3.263	3.105	3.852	3.512	3.450	3.458	3.401	3.595	3.568	3.496
	NOx	ppm	93.3	137.0	279.1	245.8	203.5	280.0	297.7	277.3	309.4	327.0	264.3	307.4	228.9	255.9	277.5	139.7	253.6
	SOx	ppm	>1500	1315.5	814.4	295.1	531.3	815.7	1487.4	1487.6	1488.0	1197.8	1443.0	1483.9	1062.5	752.4	1140.0	1482.5	1281.3
	SOx(Temporary)	ppm	-	-	-	-	-	-	3416.7	3876.3	3854.5	1226.3	1644.1	1623.2	1047.1	737.4	1135.0	4225.0	1464.2
	Furnace Air Ratio	-	1.19	1.21	1.20	1.20	1.20	1.20	1.16	1.19	1.17	1.22	1.20	1.20	1.20	1.19	1.21	1.20	1.20
	In-bed Air Ratio	-	1.19	1.21	1.20	1.20	1.20	1.20	1.16	1.19	1.17	1.22	1.20	1.20	1.20	1.19	1.21	1.20	1.20
	Superficial Velocity	m/s	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
	NOx(Converted 6%O2)	ppm;6%	79	118	239	211	174	239	247	235	259	286	227	263	195	218	239	120	217
	SOx(Converted 6%O2)	ppm;6%	>1500	1139	697	253	454	696	529	1260	1247	1047	1238	1268	909	641	962	1276	1098
	SOx(Converted 6%O2)	ppm;6%	-	-	-	-	-	-	2833	3278	3230	1072	1410	1387	896	629	538	645	1255
	Coal Feed Rate	kg/h	1.08	1.018	0.96	0.75	0.73	-	0.907	0.920	0.933	0.819	0.830	0.742	0.904	0.784	0.769	0.778	0.955
	Limestone Feed Rate	kg/h	0.618	0.582	0.545	0.946	0.974	-	0.242	0.245	0.249	0.430	0.435	0.390	0.497	0.431	0.423	0.428	0.477
Cyc lone	Blowdown Rate	kg/h	0.60	0.45	0.40	0.30	0.45	-	0.20	0.35	0.27	0.40	0.40	0.40	0.45	0.30	0.45	-	0.35
	Unburned C	%	4.60	3.28	2.11	1.73	1.51	-	2.50	3.30	2.00	1.50	1.70	0.90	1.10	0.90	0.60	-	1.80
	CaO	%	7.8	14.0	22.7	28.1	23.2	-	15.8	13.9	15.6	21.9	1.4	22.2	15.4	22.2	21.8	-	15.2
	CaSO4	%	19.3	21.3	22.8	22.2	24.5	-	29.4	28.7	30.2	26.0	19.2	29.1	22.8	24.9	27.9	-	27.4
	CaCO3	%	41.1	33.5	24.4	24.2	23.0	-	12.6	16.3	10.8	15.6	27.1	11.9	26.3	13.3	11.4	-	19.5
Bed Mat.	Blowdown Rate	kg/h	0.40	0.40	0.40	0.40	0.30	-	0.10	0.25	0.25	0.55	0.45	0.60	0.30	0.75	0.50	-	0.35
	Unburned C	%	0.27	0.29	<0.1	<0.1	<0.1	-	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	-	<0.1
	CaO	%	11.6	24.4	30.9	33.8	29.8	-	13.6	16.1	18.1	18.1	21.6	26.6	27.0	24.6	20.9	-	42.3
	CaSO4	%	10.9	22.8	32.2	35.1	39.7	-	14.5	20.4	29.5	26.8	41.3	43.1	37.8	44.0	43.5	-	37.9
	CaCO3	%	33.70	14.30	1.00	3.28	7.22	-	0.66	1.65	3.20	1.70	1.25	1.00	2.20	1.40	0.90	-	1.50
	Combustion Efficiency	%	93.53	96.32	97.76	98.25	97.63	-	96.60	95.82	98.53	98.14	97.92	98.77	98.61	99.13	99.11	-	98.33

Sep. 19	Sep. 19	Sep. 20	Sep. 20	Sep. 20	Sep. 20	Sep. 20	Oct. 7	Oct. 7	Oct. 7	Oct. 8	Oct. 8	Oct. 9	Oct. 9	Oct. 9	Oct. 16	Oct. 16	Oct. 16	Oct. 16
1515-1535	1640-1753	1217-1339	1353-1508	1516-1615	1609-1704	1620-1734	1300-1400	1430-1530	1600-1700	1300-1400	1430-1530	1300-1400	1430-1530	1600-1700	1300-1400	1430-1530	1600-1730	1700-1720
B-3-1	B-3-2	B-4-1	B-4-2	B-4-3	B-4-4	B-4-5	C-1-1	C-1-2	C-1-3	D-1-1	D-1-2	D-2-1	D-2-2	D-2-3	D-3-1	D-3-2	D-3-3	D-3-4
Under	Under	Under	Under	Under	Under	Under	Over	Over	Over	Over	Over	Over	Over	Over	Over	Over	Over	Over
Sin Pun	Sin Pun	Sin Pun	Sin Pun	Sin Pun	Sin Pun	Sin Pun	Sin Pun	Sin Pun	Sin Pun	Sin Pun	Sin Pun	Sin Pun	Sin Pun	Sin Pun	Sin Pun	Sin Pun	Sin Pun	Sin Pun
0-2.0	0-2.0	0-2.0	0-2.0	0-2.0	0-2.0	0-2.0	0-2.0	0-2.0	0-2.0	0.5-2	0.5-2	0.5-2	0.5-2	0.5-2	0-2.0	0-2.0	0-2.0	0-2.0
8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00
Thung Song	Thung Song	Khao Tham	Khao Tham	Khao Tham	Khao Tham	Khao Tham	Khao Tham	Khao Tham	Khao Tham	Khao Tham	Khao Tham	Khao Tham	Khao Tham	Khao Tham	Khao Tham	Khao Tham	Khao Tham	Khao Tham
0-2.0	0-2.0	0-2.0	0-2.0	0-2.0	0-2.0	0-2.0	0-2.0	0-2.0	0-2.0	0.5-2	0.5-2	0-2.0	0-2.0	0-2.0	0-1.4	0-1.4	0-1.4	0-1.4
4.00	4.00	6.60	6.60	6.60	6.60	6.60	6.60	6.60	6.50	6.60	6.60	6.60	6.60	6.60	4.40	4.40	4.40	4.40
2.00	2.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	2.00	2.00	2.00	2.00
860.7	890.3	862.1	855.6	889.2	919.7	919.7	857.9	859.3	890.8	858.8	854.8	854.4	858.6	857.2	855.4	860.7	858.8	853.1
852.8	892.3	865.9	859.3	892.9	923.2	923.2	863.9	865.2	896.4	852.8	859.9	858.5	860.0	859.7	859.2	865.1	864.5	860.3
838.2	873.2	852.5	833.1	866.7	910.9	911.0	857.4	842.3	881.7	841.0	816.0	805.6	782.9	809.8	833.0	835.4	845.5	871.2
829.5	848.8	855.1	808.1	840.6	894.3	894.1	872.0	844.0	887.3	841.8	805.4	803.3	771.1	813.6	837.1	847.1	857.0	880.0
794.6	798.0	833.0	755.4	784.4	844.6	844.1	834.5	794.6	849.6	805.8	757.1	757.6	719.5	757.5	795.3	797.5	810.5	835.4
599.0	586.0	634.2	558.6	566.8	596.9	596.8	659.5	615.0	661.8	628.8	581.9	580.1	540.4	593.4	585.7	595.5	623.5	660.3
567.4	545.0	622.3	527.5	531.7	560.7	560.7	640.0	579.4	642.7	611.6	549.1	555.9	505.5	559.9	549.4	553.8	586.0	623.9
524.8	480.8	573.3	472.9	462.5	481.3	481.4	603.9	526.0	586.2	575.0	500.0	520.3	458.1	498.6	504.6	489.0	521.5	559.7
415.4	378.3	457.4	376.8	368.4	383.4	383.5	523.6	463.6	508.9	499.3	443.5	448.7	399.7	438.4	428.8	418.4	454.1	494.1
52.5	54.0	55.4	58.2	61.8	63.9	63.9	56.9	59.4	61.1	52.8	53.0	49.3	50.1	54.7	51.7	54.0	54.0	53.3
162.5	174.6	159.3	167.4	144.9	151.9	152.4	166.6	169.8	150.1	201.4	162.6	184.1	156.7	167.4	149.9	145.8	154.1	141.0
63.8	63.6	80.8	71.2	64.1	63.6	63.6	135.4	118.0	123.0	146.6	128.0	90.3	84.1	140.0	73.8	108.1	162.7	210.1
0.410	0.405	0.480	0.465	0.365	0.355	0.365	0.438	0.355	0.355	0.574	0.464	0.364	0.298	0.462	0.267	0.303	0.341	0.503
7.40	7.00	7.00	7.00	7.00	7.00	7.00	8.70	8.70	8.50	8.70	7.50	7.00	7.00	8.70	6.50	7.60	8.80	10.60
1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30
0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
8.72	8.24	8.24	8.24	8.24	8.24	8.24	10.25	10.25	10.01	10.25	8.83	8.24	8.24	10.25	7.65	8.95	10.36	12.48
3.414	3.470	3.384	5.888	6.069	5.960	5.968	6.124	8.103	8.236	6.289	8.405	7.007	9.212	6.153	7.308	6.514	6.186	6.323
258.4	256.9	273.1	353.2	353.1	357.4	356.8	285.1	274.7	267.3	294.5	285.9	239.7	233.6	226.8	255.2	247.8	258.8	286.4
321.1	1189.9	373.9	65.8	0.1	-0.1	-0.1	821.2	864.5	612.8	1078.8	930.1	517.6	395.4	1025.8	1353.0	1477.2	1443.8	1479.3
1276.6	1260.3	0.0	0.0	0.0	0.0	0.0	959.3	911.4	860.8	1064.7	903.3	477.9	366.0	1008.9	1439.7	1990.3	2151.1	2547.7
1.19	1.20	1.19	1.39	1.41	1.40	1.40	1.41	1.63	1.65	1.43	1.67	1.50	1.78	1.41	1.53	1.45	1.42	1.43
1.19	1.20	1.19	1.39	1.41	1.40	1.40	1.19	1.37	1.38	1.20	1.40	1.26	1.44	1.18	1.22	1.17	1.19	1.27
1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.20	1.20	1.50	1.10	1.30	1.50	1.80
220	220	233	351	355	356	356	293	320	291	300	340	261	295	226	257	254	259	306
274	1018	319	65	0	-0	-0	908	911	856	1130	1182	489	521	1169	1451	1515	1441	1554
1089	1080	0	0	0	0	0	955	1013	1198	1105	1104	448	474	1193	1626	1877	2185	2600
0.910	0.899	0.876	0.848	0.666	0.648	0.665	1.081	0.875	0.876	1.416	1.143	0.897	0.736	1.138	0.775	0.879	0.989	1.460
0.455	0.450	0.723	0.700	0.549	0.534	0.549	0.892	0.722	0.723	1.168	0.943	0.740	0.607	0.212	0.168	0.149	0.142	0.146
0.10	0.35	0.60	-	0.50	-	0.65	0.30	0.45	0.45	0.15	0.10	0.35	0.15	0.50	0.25	0.40	0.30	-
1.00	1.10	0.78	-	0.33	-	0.21	0.44	0.34	0.21	0.56	0.39	0.17	0.13	0.47	0.45	0.66	0.87	-
19.0	20.8	25.2	-	25.8	-	27.2	32.7	29.5	31.6	25.1	24.4	37.8	35.9	31.3	28.3	27.3	23.0	-
31.2	29.8	21.6	-	23.4	-	24.5	26.0	21.6	25.6	21.7	19.6	26.4	24.0	17.6	20.5	18.0	12.4	-
14.2	9.9	19.4	-	19.2	-	14.8	19.5	19.0	16.0	8.1	11.9	32.8	35.8	33.5	15.6	16.4	15.4	-
0.60	0.50	0.65	-	0.65	-	0.50	0.30	0.60	0.45	0.87	0.65	0.70	0.30	0.45	0.35	0.45	0.40	-
<0.1	<0.1	<0.1	-	<0.1	-	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	-
33.8	31.3	21.0	-	22.5	-	18.5	32.8	29.9	31.9	34.2	32.4	32.8	32.7	31.5	31.6	29.3	30.4	-
46.0	46.0	42.5	-	40.9	-	42.9	30.9	25.1	28.5	32.6	30.3	29.9	29.4	26.7	27.2	23.3	24.4	-
0.90	2.20	2.93	-	1.00	-	4.38	1.11	1.85	1.36	1.17	1.31	1.35	1.68	3.33	0.57	0.20	1.47	-
99.72	99.91	99.64	-	99.51	-	99.48	99.69	99.55	99.73	99.85	99.91	99.83	99.93	99.48	99.52	99.24	99.33	-

$$\therefore \frac{0.0381}{5.642} \times 10^6 = 6,753 \text{ ppm}$$
$$\fallingdotseq 6,800 \text{ ppm}$$

Because of the low heat value in Krabi lignite, the SOx emission density in the flue gas of Krabi lignite reaches 4,800 ppm despite of the lower content of sulfur in the lignite than Sin Pun lignite.

The result of the pre-combustion test is described as follows, in varying the bed temperature, the Ca/S molar ratio, the blend of limestone, the air ratio in bed, the lignite feeding system, the particle size of the lignite and limestone, and the space velocity.

1) Bed Temperature

DeSOx characteristic test for the high sulfur lignite was carried out with the Funao-Sekinoyama limestone which has an ample experience record on 50 MW demonstration plant in Japan.

Fig. 8-8 and 8-9 show SOx characteristic by the bed temperature. From the experience of the demonstration plant, the bed temperature range from 800°C - 820°C has most favourable, whereas the favourable bed temperature for Sin Pun lignite is abt 850°C and 40°C higher than that of the past record of the low sulfur bituminous coal.

The several laboratory tests were carried out to find the reason of the above temperature range.

The details are explained in the clause 8.6.2

2) Ca/S Mol Ratio

Fig. 8-10 and 8-11 show SOx characteristic by Ca/S molar ratio.

It was found by the test that 90% of DeSOx efficiency can be gotten by the limestone injection with Ca/S molar ratio 2 to 3 while the low sulfur bituminous coal requests the Ca/S molar

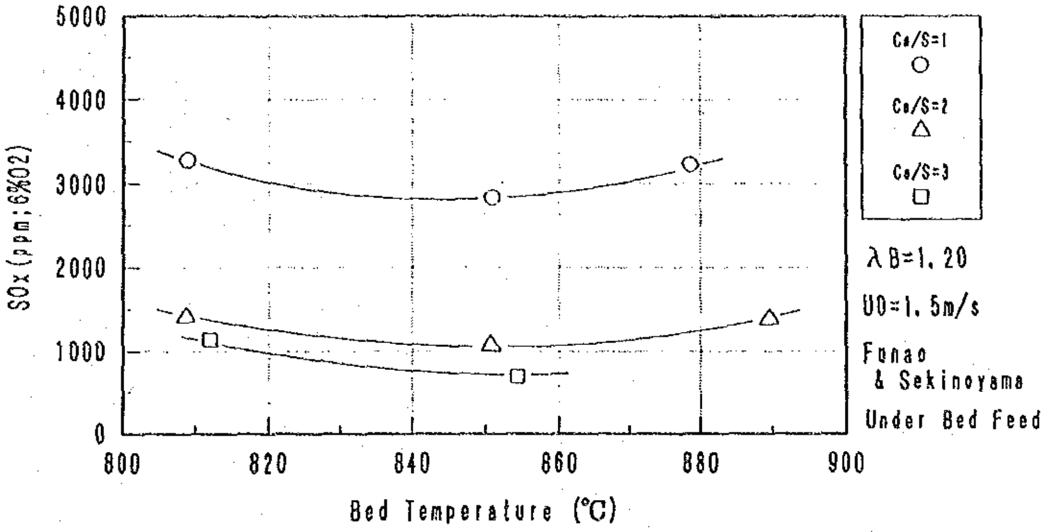


Fig 8-8 SOx emission with different bed temperatures

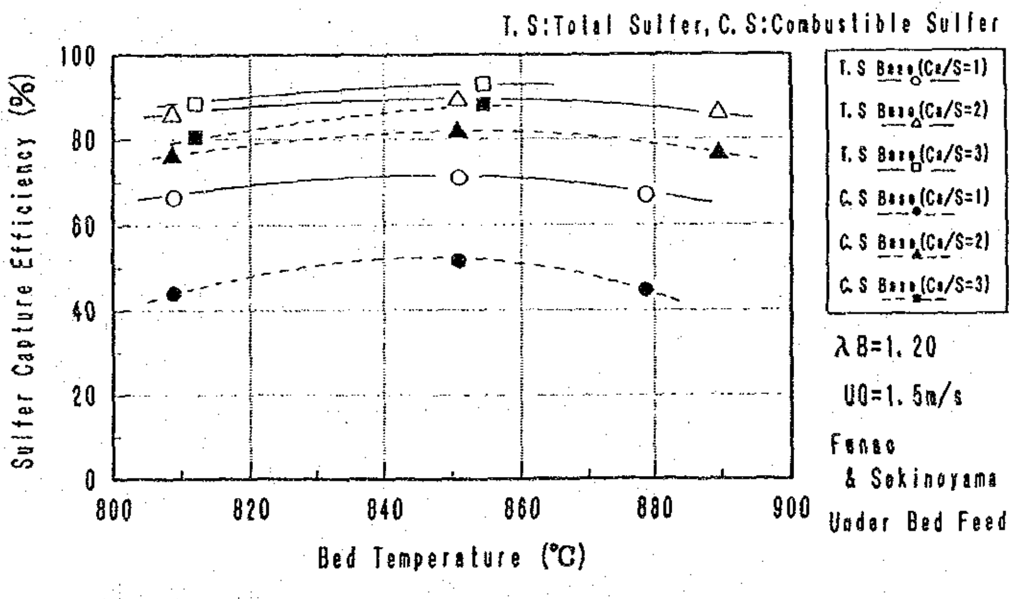


Fig 8-9 Sulfur capture efficiency with different bed temperatures

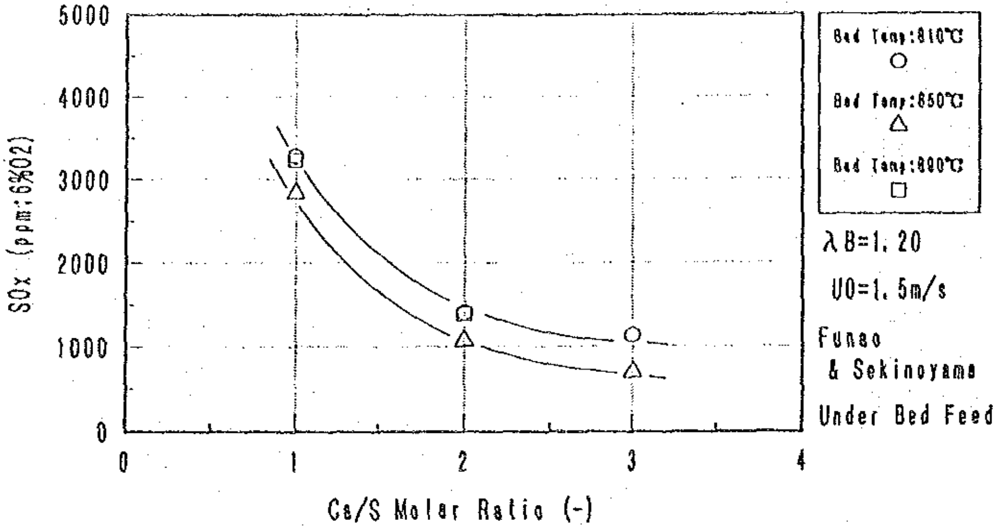


Fig 8-10 SOx emission with differnt Ca/S molar ratios

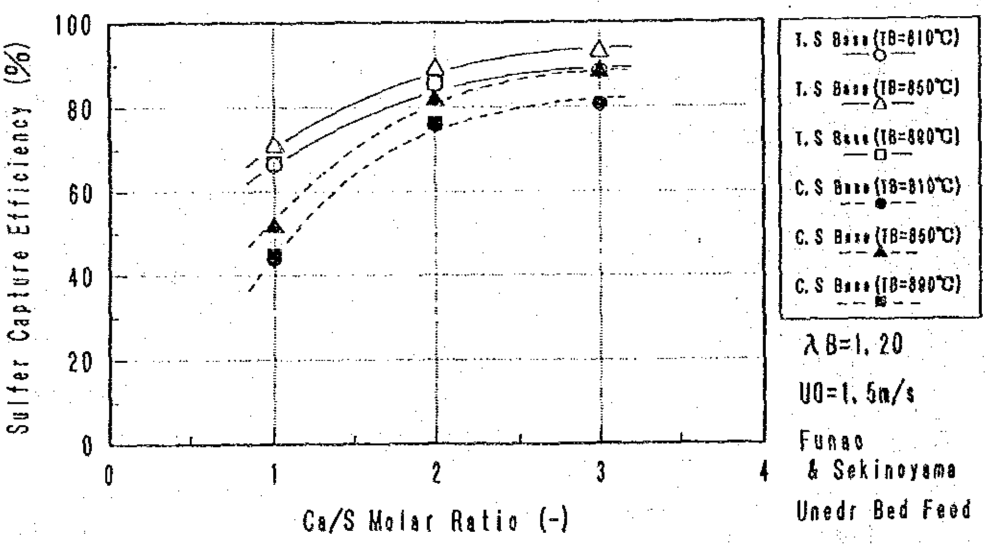


Fig 8-11 Sulfur capture efficiency with different Ca/S molar ratios

ratio 4 to 5 for 90% DeSOx efficiency during the demonstration test in Japan.

3) Brand of Limestone

Fig. 8-12 and 8-13 show the characteristic test result by two brand of the limestone in Sin Pun area.

The result shows that the Khao Tham Hora limestone has better DeSOx characteristics compared with Thung Song limestone and the limestone in Japan.

Therefore, the bench scale combustion test for Sin Pun lignite is carried out by the limestone of Khao Tham Hora.

4) Air Ratio in Bed

Fig. 8-14 and 8-15 show the characteristic test result by the air ratio in bed with Khao Tham Hora limestone.

By varying the air ratio from 1.2 to 1.4, very high DeSOx efficiency of 99% was achieved with the Ca/S molar ratio 3 and the bed temperature 850°C and the tendency is as same as that of the experience in Japan demonstration plant.

5) Coal Feeding System

Fig. 8-16 and 8-17 show the characteristic test result by the under feed system and the over feed system.

DeSOx efficiency by the over coal feeding system is at most 90% with the limestone injection of the molar ratio 3 and the bed temperature 850°C.

The high DeSOx efficiency like the under coal feeding system can not be gotten by the over feeding system even though increasing the air ratio.

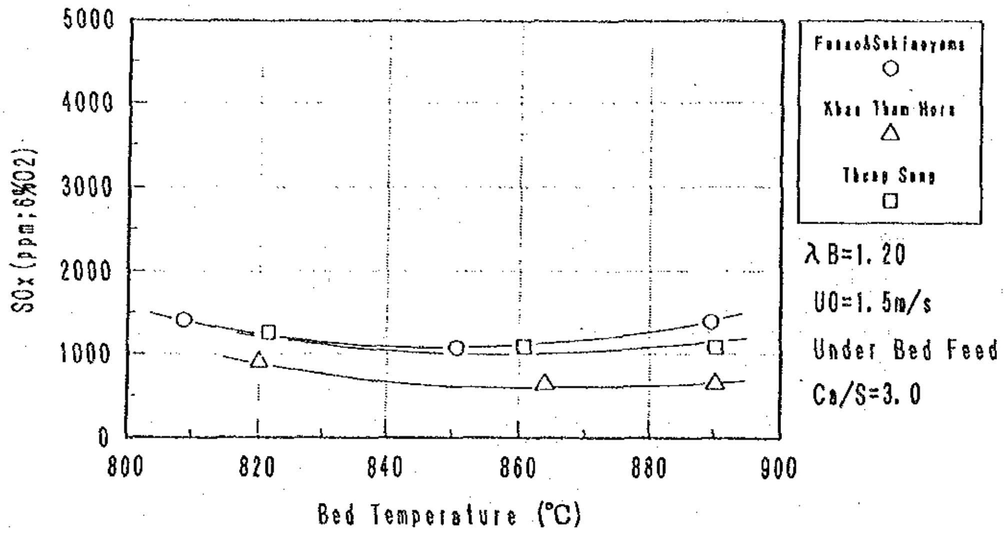


Fig 8-12 SOx emission with different limestones

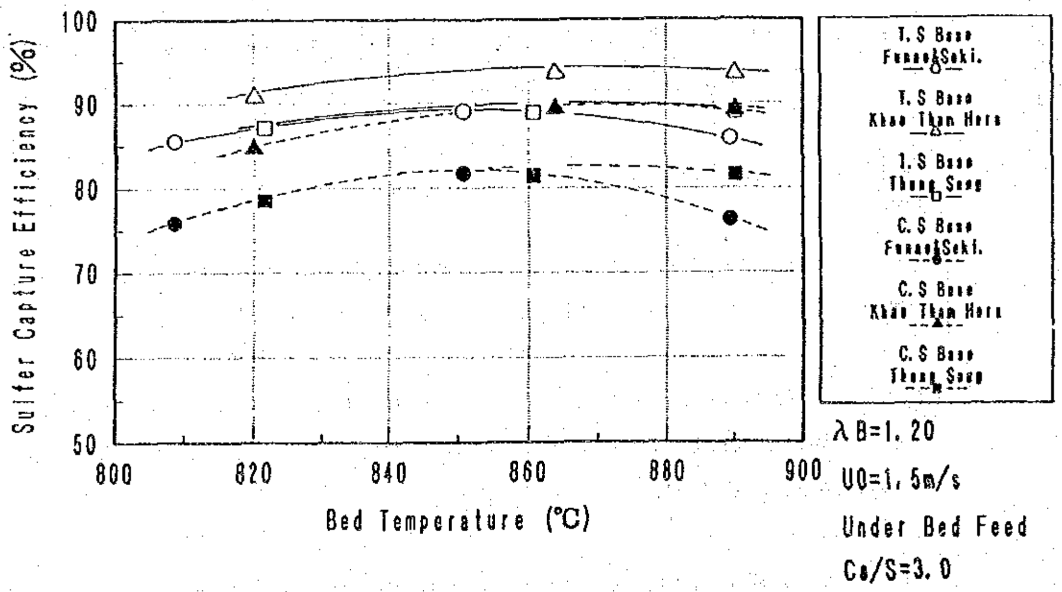


Fig 8-13 Sulfur capture efficiency with defferent limestones

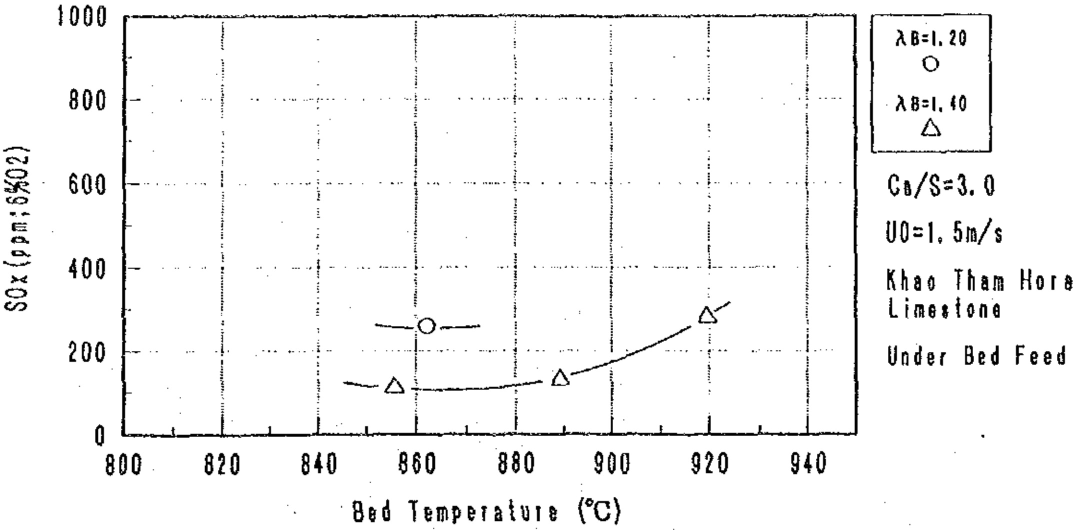


Fig 8-14 SOx emission with different air ratios

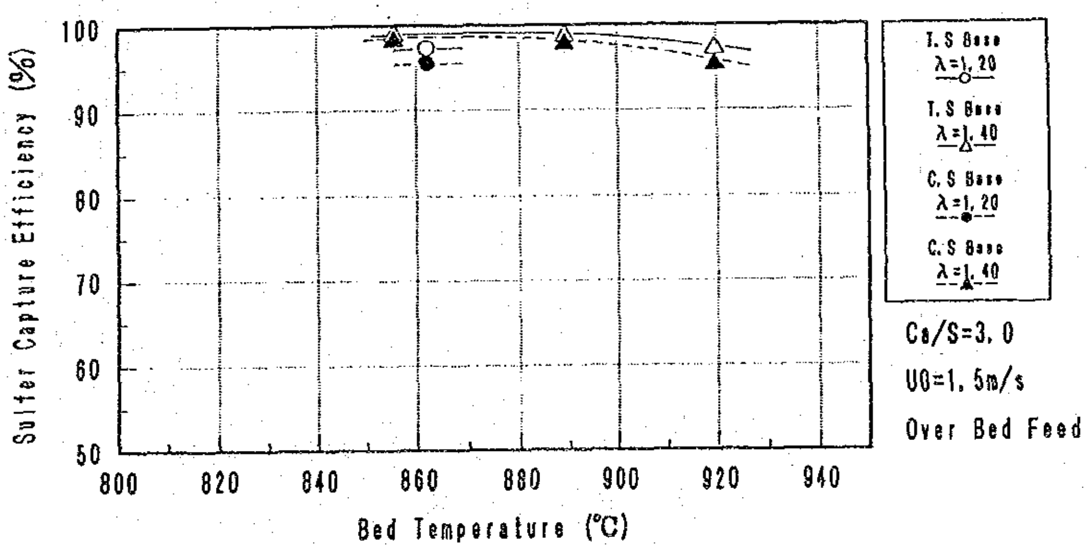


Fig 8-15 Sulfur capture efficiency with defferent air ratios

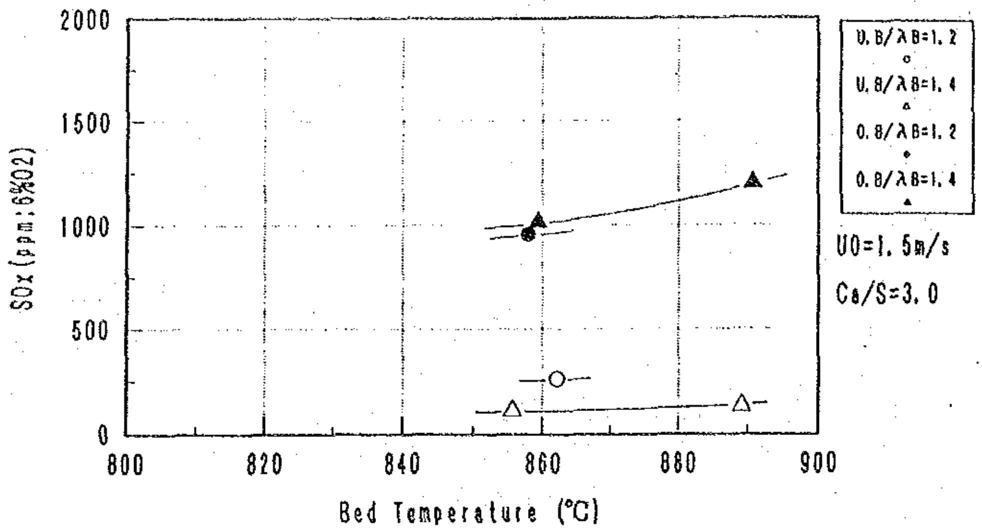


Fig 8-16 SOx emission with two different coal feed systems

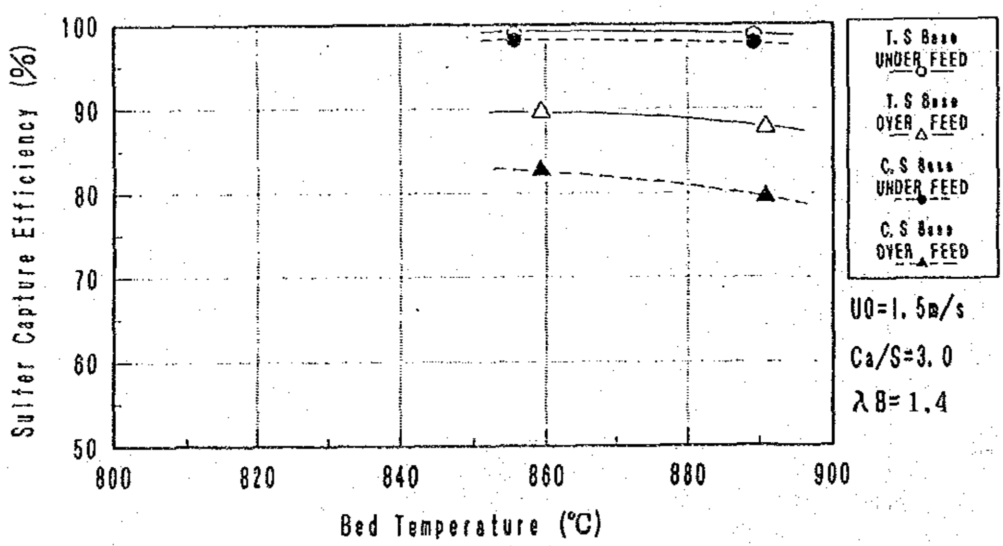


Fig 8-17 Sulfur capture efficiency with different coal feed systems

6) Particle Size of Lignite and Limestone

To aim the high DeSOx efficiency by the particle size of the lignite and limestone, the tests by varying the particle size were carried out. The result was negative as shown in Fig. 8-18, 8-19.

7) Space Velocity

To aim the high DeSOx efficiency by the increase of the residence time in the bed, the space velocity was varied to be lower.

Fig. 8-20 and 8-21 show the test result, and the target emission value 700 ppm was achieved by decreasing the space velocity to 1.2 m/s with the limestone injection of Ca/S molar ratio 3.

However, the decreasing of SOx emission is derived from the less amount of the combustion of the small particle lignite in the free board zone as mentioned later. By the decreasing of the space velocity on the over coal feeding system, many amount of the small particle lignite less than 0.5 mm is combusted in the fluidized bed instead of the free board zone, and de-sulfurized in the bed.

Therefore, the test result of the space velocity is very depend on the furnace characteristics of the bench scale which apply the lignite only 2 mm under size.

From the above test result, the performance combustion test is carried out under the condition shown in the following table.

(2) NOx

In combusting the fuel by FBC boiler, NOx is generated by the fuel nitrogen, and the thermal nitrogen could be neglected because of its low temperature combustion.

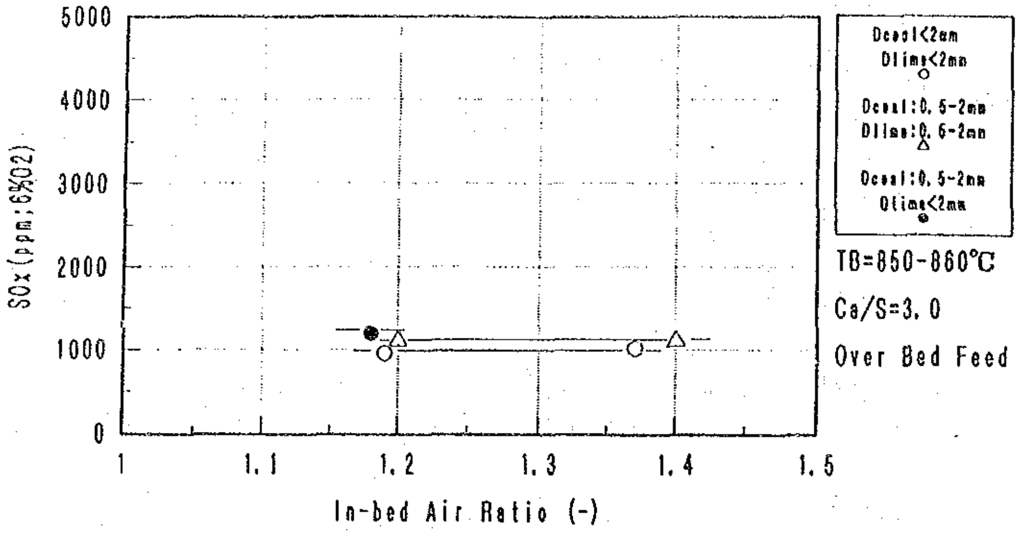


Fig 8-18 SOx emission with different coal and limestone sizes

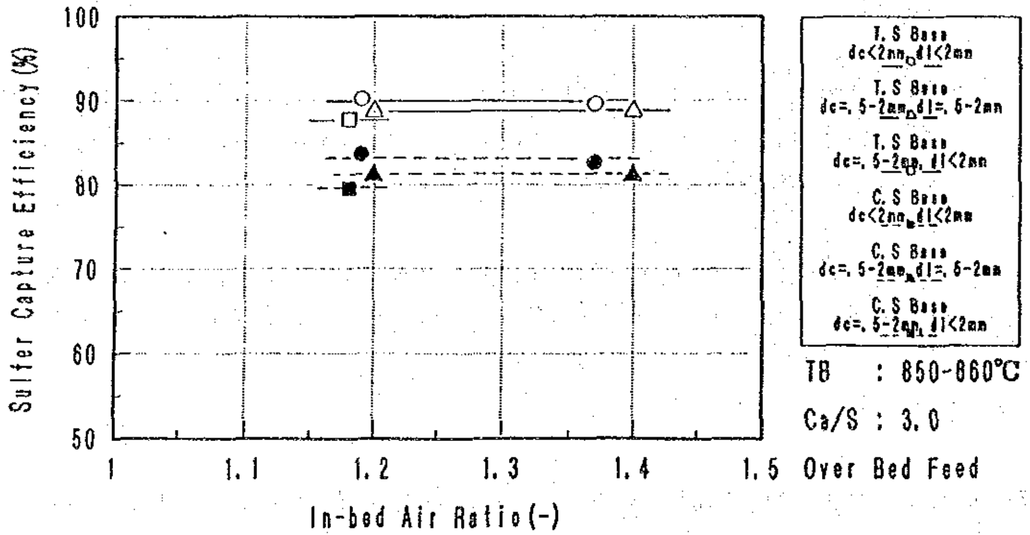


Fig 8-19 Sulfur capture efficiency with different coal and limestone sizes

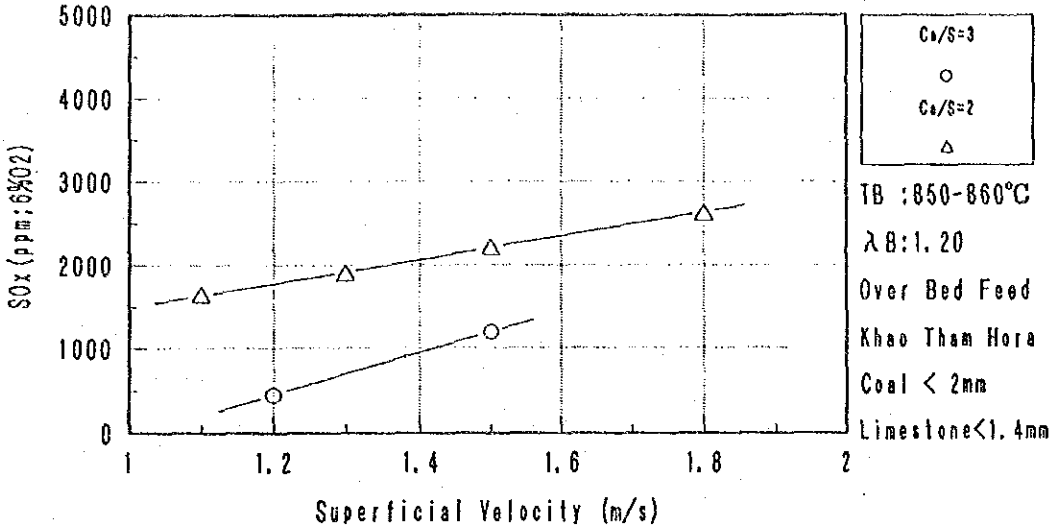


Fig 8-20 SOx emission with different superficial velocity

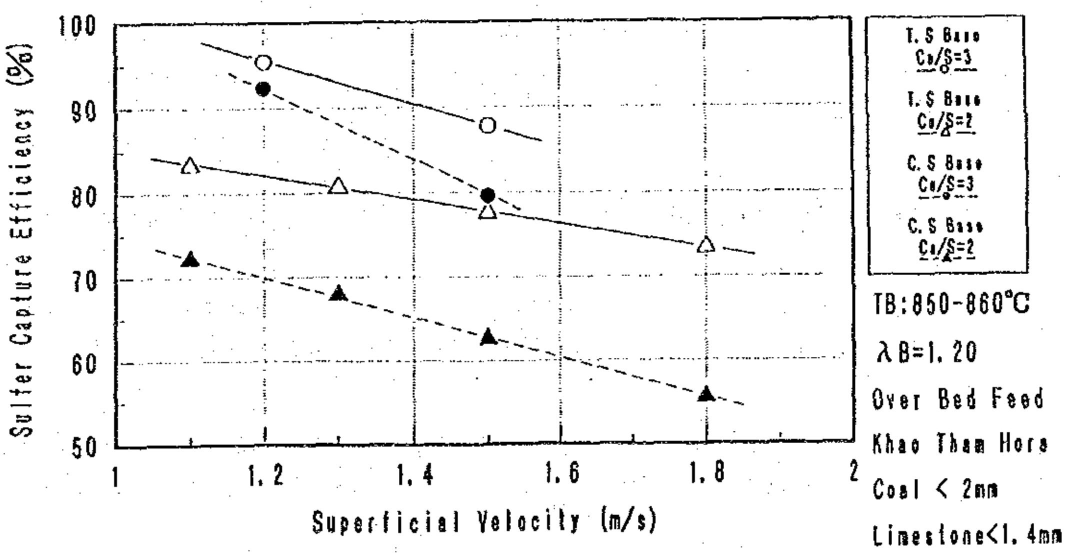


Fig 8-21 Sulfur capture efficiency with different superficial velocity

In case that the conversion rate of the fuel nitrogen is 1.0, Sin Pun lignite and Krabi lignite generate NOx as follows;

Sin Pun lignite

$$\left(\frac{0.0049}{14} \times 1{,}000\right) \text{ Mol/kg fuel (D.B.)} \times 0.0224 \text{ Nm}^3\text{/Mol}$$
$$= 0.00784 \text{ Nm}^3\text{/kg fuel (D.B.)}$$

$$\frac{0.00784}{5.642} \times 10^6 \fallingdotseq 1{,}390 \text{ ppm}$$

Krabi lignite

$$\left(\frac{0.0071}{14} \times 1{,}000\right) \text{ Mol/kg fuel (D.B.)} \times 0.0224 \text{ Nm}^3\text{/Mol}$$
$$= 0.01136 \text{ Nm}^3\text{/kg fuel (D.B.)}$$

$$\frac{0.01136}{4.135} \times 10^6 \fallingdotseq 2{,}747 \text{ ppm}$$

From the experience of the demonstration plant in Japan, NO conversion rate is kept under the range of 0.1 to 0.2, and much less amount of the above calculated value would be emitted from FBC boiler.

Herein after, the result of NOx emission characteristics is summarized based on the data collected during the SOx emission characteristics test.

Fig. 8-22 shows NOx emission characteristics by the bed temperature.

As same as the record of the demonstration plant, NOx emission value is increasing according to the rising of bed temperature.

In this figure, NOx emission characteristics is shown by the limestone injection with the mole ratio also.

Different from the experience on the demonstration in Japan, the test result shows that NOx emission is decreasing against the increasing of the Ca/S molar ratio.

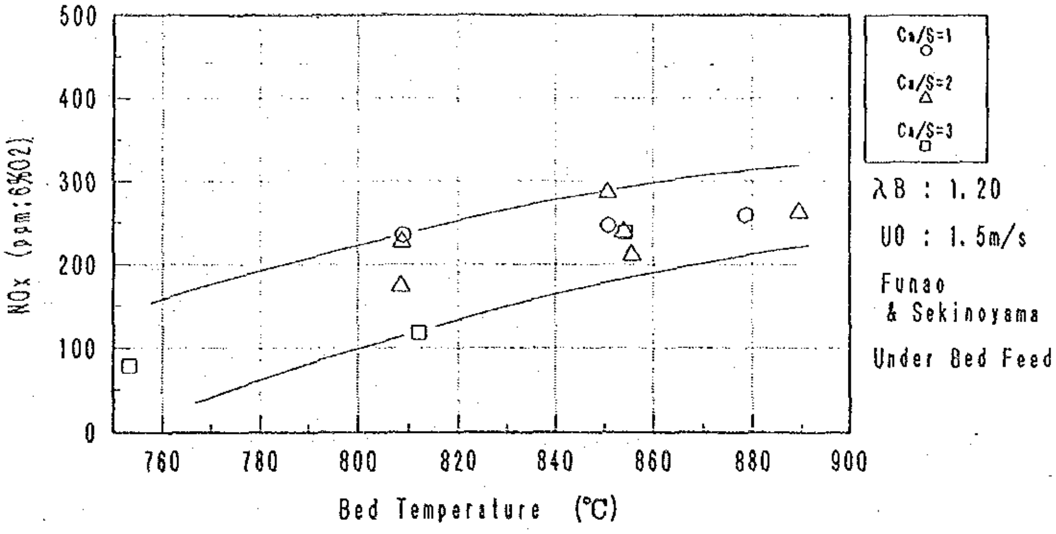


Fig 8-22 NOx emission with different bed temperatures

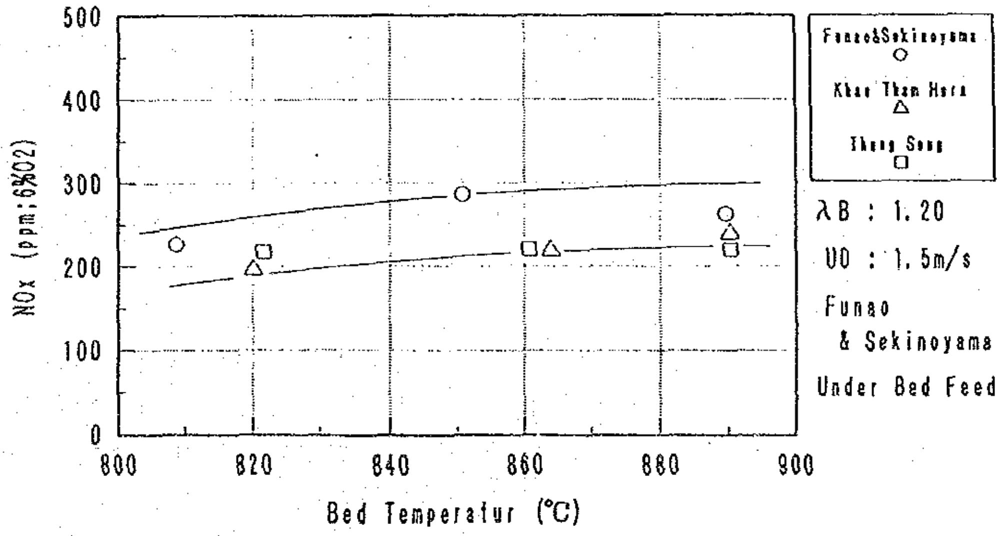


Fig 8-23 NOx emission with different limestones

The emission value of NOx is 100-300 ppm and lower than that of the experience coal which was tested in 100ϕ furnace for 50 MW demonstration plant.

Details of the reason are explained in clause 8.6.2.

Fig. 8-23 shows NOx characteristics by the brand of the limestone. Thailand limestone has better characteristics in terms of less NOx emission than the Japanese limestone.

Fig. 8-24 shows NOx characteristics by the particle size of the lignite and limestone.

NOx emission is much lesser on the condition of the coal particle size 0.5-2.0 mm and the limestone particle size 2 mm under with the B.M. particle size 1.4 mm under.

From the test result between the particle size 0.5-2 mm and 2 mm under, it can be said that the particle size of the feeding lignite and limestone does not affect NOx emission characteristics but the particle size of the B.M. affects NOx characteristics.

Fig. 8-25 shows NOx characteristics by the space velocity and the space velocity of 1.5 m/s is looks like best point for less NOx emission.

However, this low NOx emission was due to the low air ratio as shown in Fig. 8-26 since the combustion in the space velocity 1.5 m/s was continued under the reduction atmosphere.

Fig. 8-27 shows NOx characteristics by the coal feeding system. The test was resulted that NOx emission is higher on the over coal feeding than the under coal feeding with the air ratio 1.2 and under the air ratio 1.4, the result shows the opposite case.

The reason of the above result is explained in clause 8.6.2.

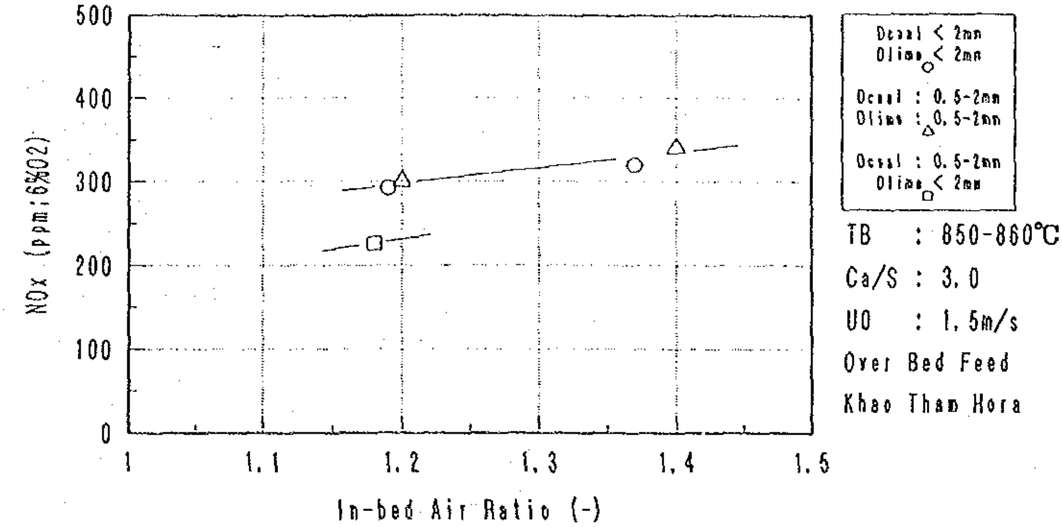


Fig 8-24 NOx emission with different coal and limestone sizes

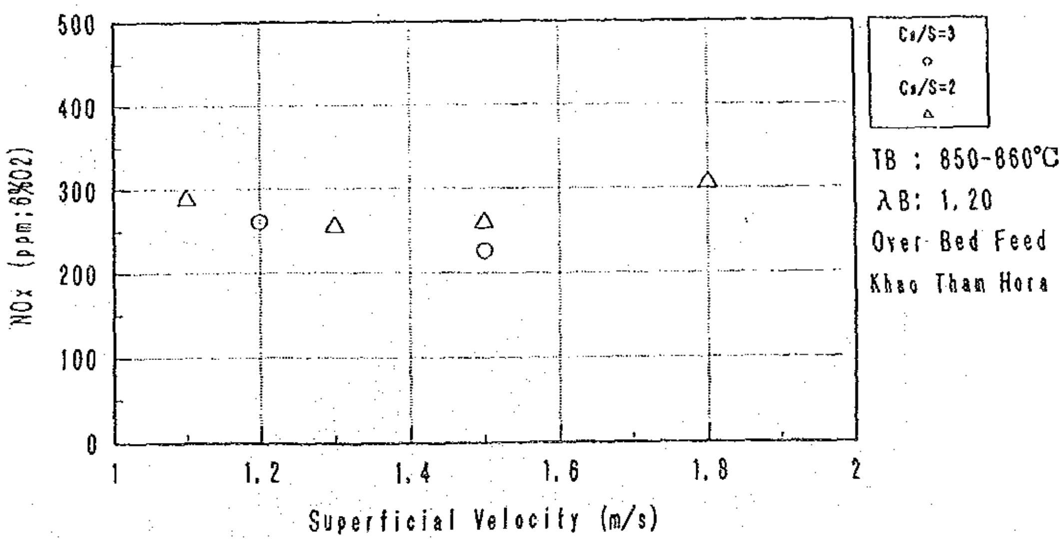


Fig 8-25 NOx emission with different superficial velocities

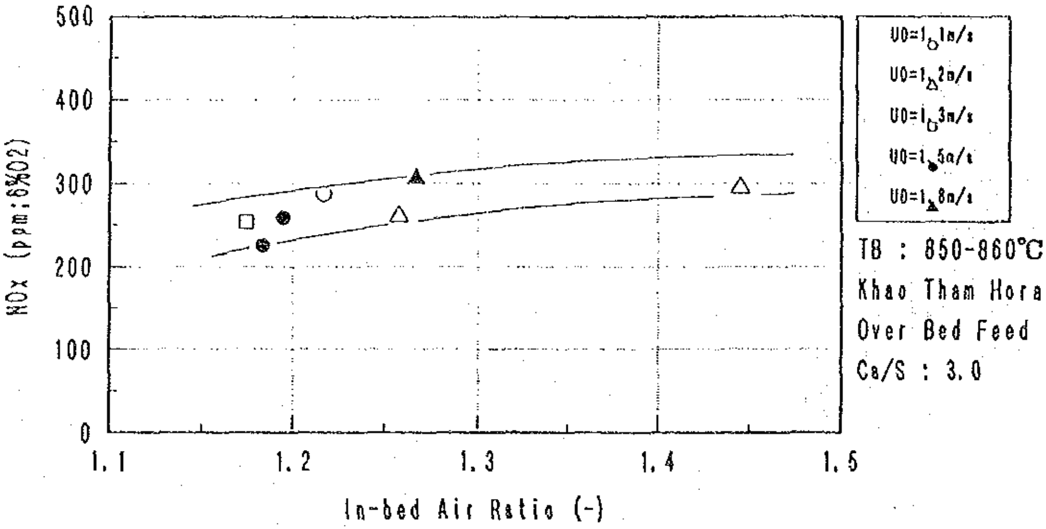


Fig 8-26 NOx emission with different in-bed air ratio

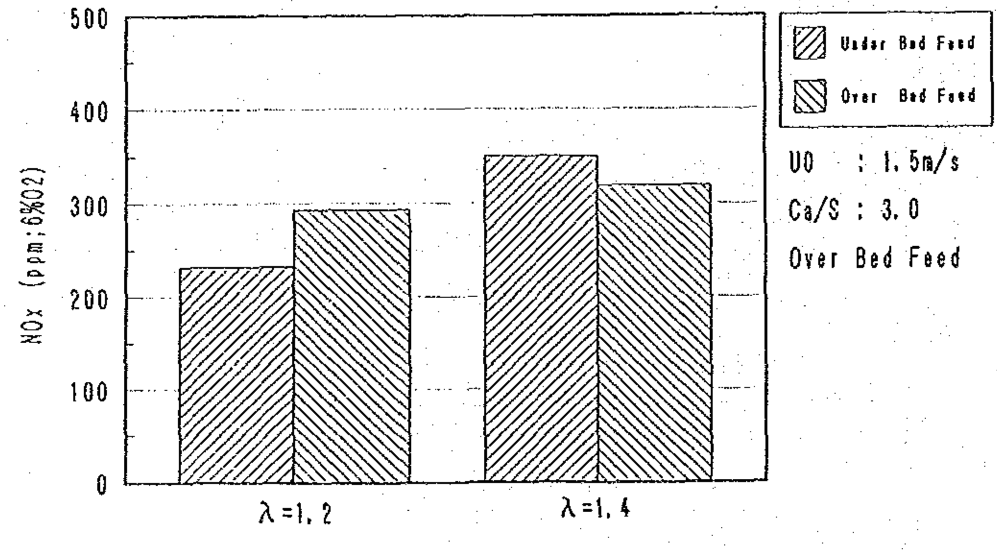


Fig 8-27 NOx emission with different coal feed systems

(3) Combustion Efficiency

The combustion efficiency has been measured from the un-burn carbon in the ash.

The combustion efficiency of the under feeding system is increasing according to the increase of the bed temperature as same as the record of the demonstration plant in Japan and more than 98% of the combustion efficiency was recorded under the bed temperature 800-900°C.

The combustion efficiency is observed to increase according to the increase of the air ratio also as same as the record experienced in Japanese demonstration plant.

Fig. 8-30 shows the characteristics of the combustion efficiency by the fuel ratio (Fixed Carbon/Volatile matter) in the experienced record in the demonstration plant.

From this figure, the lower fuel ratio can be expected higher combustion efficiency and the lignite of Sin Pun and krabi can be expected to achieve 99% of efficiency since the fuel ratio is low as 0.35 and 0.43 respectively.

Fig. 8-31 show the characteristics of the combustion efficiency by the particle size with over feeding system.

From the result, there are no significant difference whether the particle size of 0.5 mm under is existing or not because both cases record the high combustion efficiency more than 99.5%.

This result also shows that the over feeding system has the characteristics of the higher combustion efficiency than that of the under feeding system, which is contradicted to the result experienced in the bituminous coal test.

Fig. 8-32 shows the typical result of the above, especially on the lower air ratio in bed.

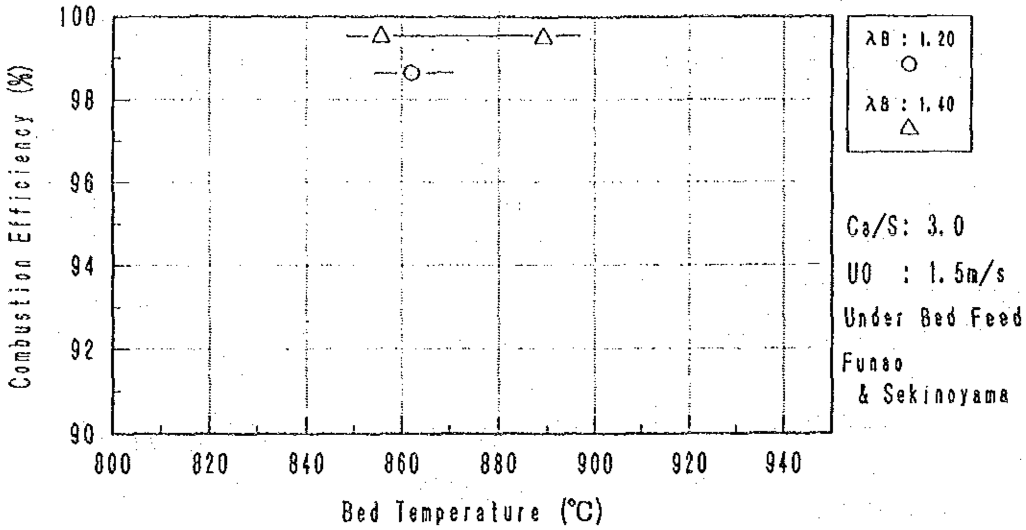


Fig 8-28 Combustion efficiency with different bed temperatures

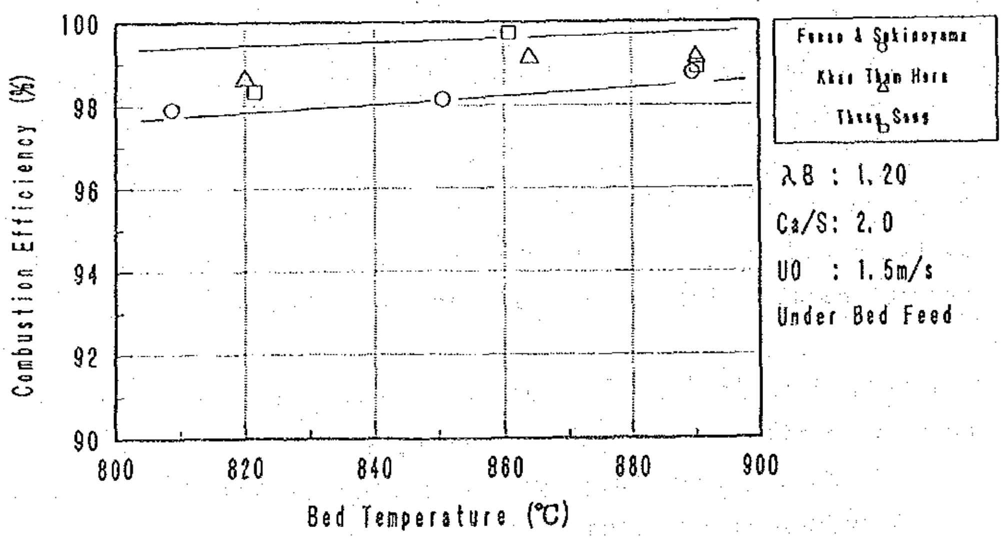


Fig 8-29 Combustion efficiency with different limestone

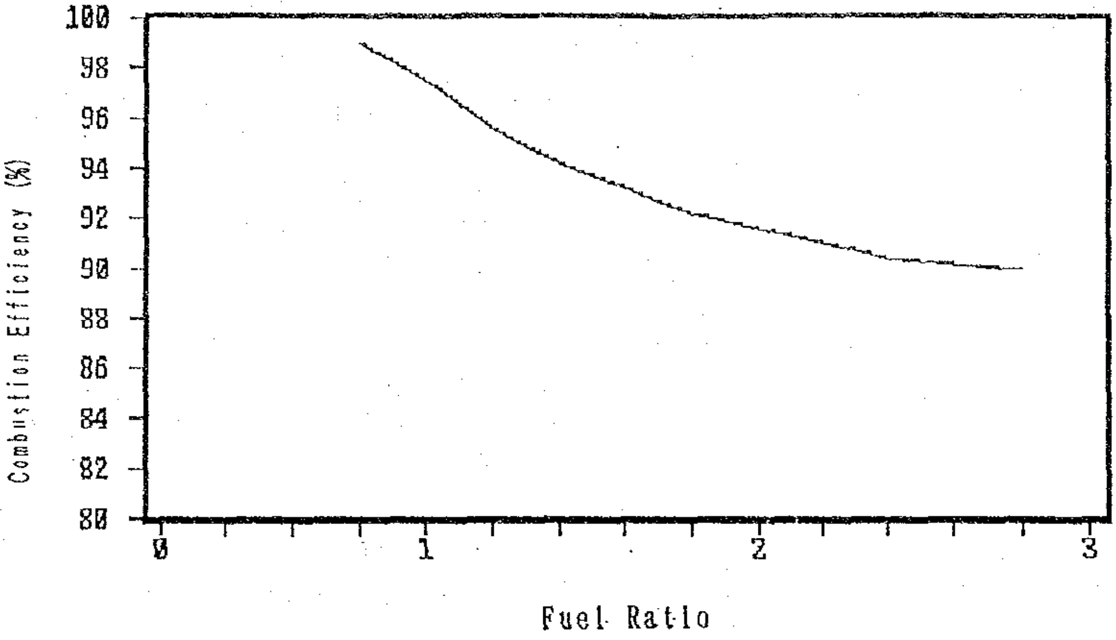


Fig 8-30 Fuel Ratio-Combustion Effi.

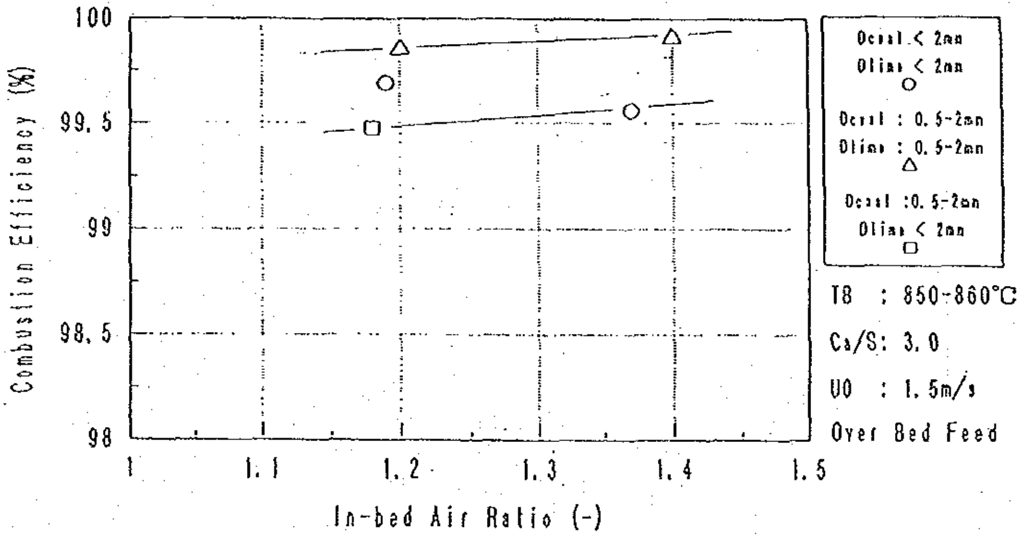


Fig 8-31 Combustion efficiency with different coal and limestone sizes

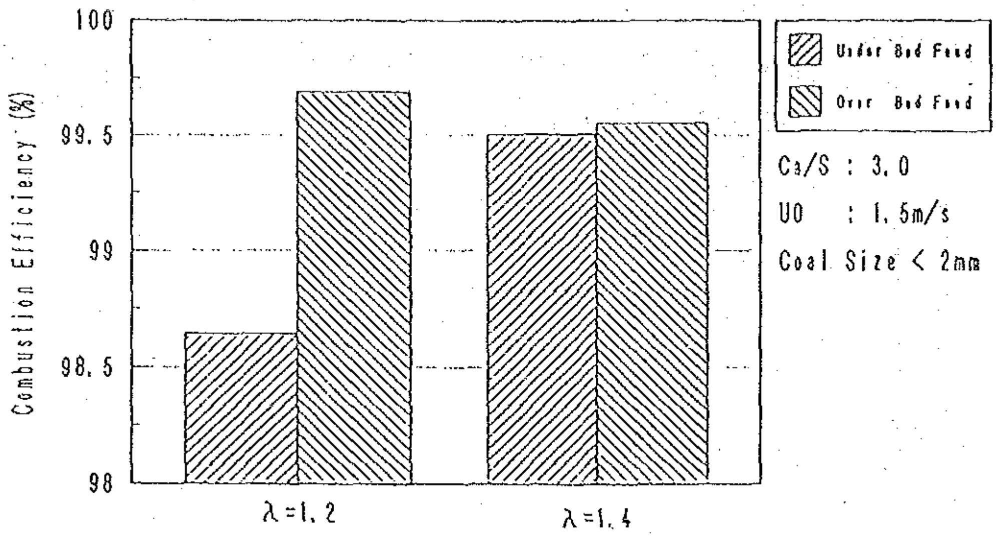


Fig 8-32 Combustion Efficiency with different two coal feed systems

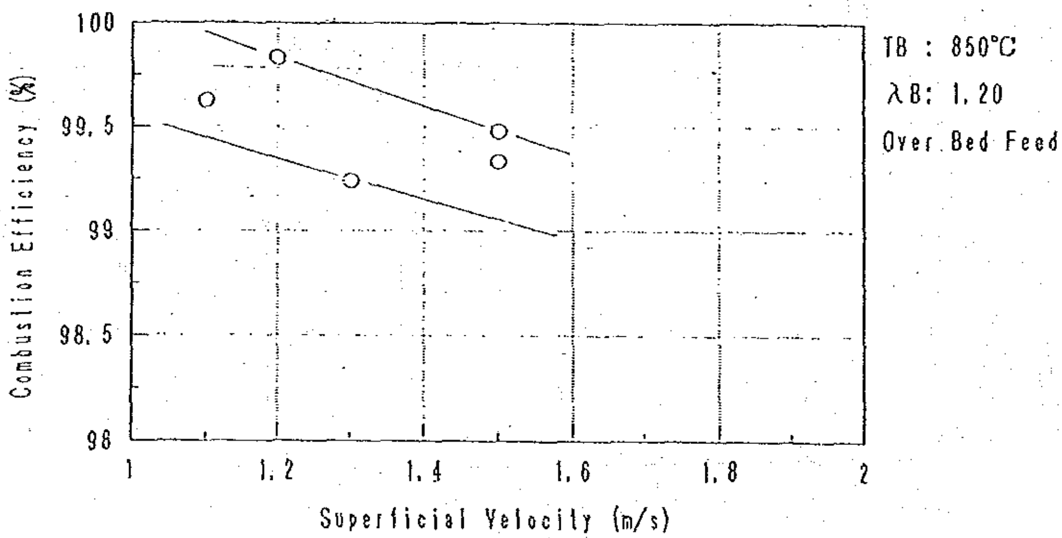


Fig 8-33 Combustion Efficiency with different superficial velocities

Since the fuel ratio of Sin Pun lignite is so low, the combustion in the bed is processing under the reduction atmosphere near the coal feeding nozzle and this tendency is typical under the under feeding system.

On the other hand, under the over feeding system, the coal transportation air occupies 15% of the total air, which resulted the two-stage combustion and high combustion efficiency.

From the above point, it can be said that the combustion efficiency may increase with the under feeding system by the suitable distribution of the air and lignite in bed.

Fig. 8-33 shows the characteristics of the combustion efficiency by the space velocity and that the increase of the space velocity decreases the combustion efficiency.

However, the combustion efficiency of 99% is achieved under the space velocity 1.5 m/s.

8.5.2 Combustion Performance Test of Sin Pun Coal

On the basis of operation parameters obtained by preparatory tests, the bed temperature, Ca/S molar ratio parameters were changed. Both the environmental characteristics and combustion efficiency were measured. Table 8-8 shows results of the combustion performance test on Sin Pun lignite. Fig. 8-34 shows the bed temperature during the combustion performance test on Sin Pun lignite and the relationship between the Ca/S molar ratio and SOx. Versus the temperature range of 800°~820°C, which has generally has induced the highest DeSOx efficiency during the demonstration test in Japan, the test indicated the 850°~860°C range as the most appropriate desulfurizing temperatures. This was also indicated by the preparatory test. With the condition of SOx<700 ppm, Ca/S molar ratio of more than 3 is necessary as verified in the preparatory tests if the over coal feeding system is to be used. When the air ratio was reduced to 1.10, from 1.20, the NOx emission decreased but slightly.