Table 3-3 Proximate analysis of Zone Ⅰ and Zone Ⅱ

Proximate analysis (as resceived)

Zone I	Moisture	Ash	V.M.	F.C.	H.V.	S
	(%)	(%)	(%)	(%)	(kcal/kg)	(%)
NG 3/40	22.90	38.05	32.17	6.88	1,814	6.90
NG 5/40	24.65	34.08	29.02	12.25	2,140	4.03
NG 10/40	20.49	34.03	32.95	12.53	2,506	7.23
NG 12/40	18.10	42.93	27.21	11.76	2,175	4.00
NG 16/40	27.80	30.10	29.96	12.14	2,300	5.96
NGG 1/40	26.83	26.12	31.86	15.19	2,467	5.67
NGG 2/40	26.17	28.64	32.99	12.20	2,158	7.48
NGG 3/40	27.20	29.41	29.95	13.44	2,435	3.99
NGG 4/40	24.91	28.19	32.63	14.27	2,656	5.81
LN1/21	33.75	11.36	25.16	11.36	2,090	2.46
LN3/21	39.44	25.32	25.33	10.06	2,088	1.92
LN11/21	30.19	30.20	26.71	12.87	2,108	3.16
LN26/21	32.84	29.13	27.74	10.28	2,134	2.16
LN27/21	19.92	52.64	20.57	6.87	1,243	3.46
LN28/21	33.69	25.52	27.88	12.92	2,495	2.77
NG3/31	12.45	51.35	26.51	9.69	1,968	3.86
NG7/31	17.52	38.64	30.79	13.06	2,225	5.63
NG9/31	22.89	39.78	27.46	9.88	2,157	3.12
NGJ1/43	31.82	25.32	27.31	15.54	2,705	5.72
NGJ3/43	26.21	37.89	24.54	11.37	2,058	5.02
NGJ5/43	31.04	33.41	22.79	12.77	2,085	2.60
Average	**26.23**	**32.96**	**28.17**	**11.78**	**2,191**	**4.43**

Zone II	Moisture	Ash	V.M.	F.C.	H.V.	S
	(%)	(%)	(%)	(%)	(kcal/kg)	(%)
NG 5/40	21.32	40.31	28.57	9.80	2,114	4.03
NGG 1/40	24.30	29.92	31.69	14.09	2,505	4.36
NGG 2/40	25.42	30.37	33.39	10.82	2,549	6.19
NGG 3/40	22.99	31.25	32.45	13.31	2,659	4.90
NGG 4/40	19.50	36.92	31.90	11.68	2,214	6.18
LN26/21	31.72	25.30	30.46	12.52	2,470	3.51
NG 3/31	14.54	42.09	29.16	14.21	2,585	4.13
NG 7/31	15.16	49.36	26.46	9.02	1,848	4.34
NG 9/31	17.75	42.91	26.30	13.04	2,101	3.76
NGJ3/43	24.37	39.07	33.90	2.66	2,207	4.37
NGJ5/43	31.44	31.71	23.90	12.95	2,256	4.29
Average	**22.59**	**36.29**	**29.83**	**11.28**	**2,319**	**4.55**

High ash value is due to the presence of many non-coal partings (shale to carbonaceous shale) in the sampling section. Not only visible partings but also invisible mineral matter (Al_2O_3, Fe_2O_3, etc) are contained in coal beds.

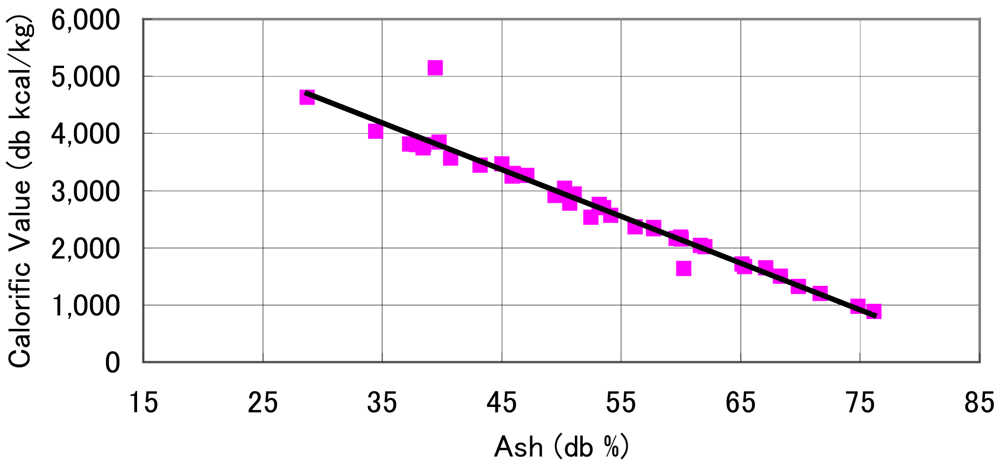
3.3.3 Volatile Matter

The average volatile matter content is about 28% on as received basis. It is converted into 38% on dry basis. Fuel ratio, which is given by dividing fixed carbon by volatile matter, is 0.44 in a similar range of that in the Lampang coalmine

3.3.4 Calorific Value

According to the iso-value contour map of calorific value on dry basis (Figure 3-4), the weighed average of calorific value in the whole Ngao area is calculated as 3,039 kcal/kg. This is converted into 2,127 kcal/kg on as received basis. Low calorific value is the effect of higher content of ash. Calorific value is usually proportional to ash content. Figure 3-4 illustrates the relationship between calorific and ash content of the coal analysis results in this exploration.

Figure 3-4 Calorific Value vs Ash Relationship



3.3.5 Total Sulfur

Figure 3-3 shows the iso-value contour map on total sulfur contents on dry basis. The weighed average of total sulfur in the whole Ngao area is 6.24 %. Total sulfur in the proposed mining Area-A tends to be rather low. Zone I in NGJ5/45 shows the sulphur content as low as about 2%. More quality data are required through drilling in the future and then areas having low sulphur content will be selected for development.

The results of analysis done in this exploration have been given the average form of sulfur in Ngao area as follows,

Sulphide (Pyrite)	2.37%	(38%)
Sulphate	0.31%	(5%)
Organic	3.56%	(57%)
Total	6.24%	(100%)

This means that a half of sulphur in Ngao presumes organic sulfur combined with hydrocarbon in texture of coal. It is confirmed that sulphide in Ngao coal exists equally as small particles as 0.01 to 0.02 mm in diameter, while large crystal pyrite as a common form of sulphide in high sulfur coal deposited under transgressional condition was not seen. Very fine-grained pyrite in Phrae coal was explained in a JICA–DMR report in 1997, that this type of sulphide form is presumes to be a characteristics of Thai coal deposited in intermountain lacustrine basins.

3.3.6 Ultimate Analysis

In general, carbon content increases as degree of coalification becomes higher, while oxygen content changes in the opposite way. From this point of view, it is supposed that degree of coalification may be higher in the northern part than in the southern part. The degree of coalification in Ngao is same as one in Mae Moh.

3.3.7 Hardgrove Grindability Index (HGI)

HGI is reported to be 46 to over 100 and generally high enough for quality requirement of steaming coal (>40-45).

3.3.8 Analysis of Ash

Composition of ash are analyzed for the purpose of predicting the effect of ash during combustion in a cement kiln, particularly estimation of the combination ratio of coal and other cement raw materials. CaO, other alkaline and SO_3 are slightly high, however those do not effect on the cement kiln and are suited for cement industry. According to the analysis result this year, the suitability indexes such as Fouling and Slugging for electric power plant were predicted. By Japanese standard on bituminous coal most of the results are over the quality requirement for combustion and then this coal is not suitable for boiler in electric power plants.

3.3.9 Coal Rank

The analytical result indicates that most coals in the study area are classified as Lignite A (ligA) or Lignite B (ligB) in coal rank according to the ASTM standard. Some of coals are ranked to subbituminous B to C (subB to subC).

4. Tests for Coal Preparation and Upgrading

4.1. Test for Coal Preparation

4.1.1. Screening and Float and Sink Test

As mentioned in the previous section, screening test and float and sink test were conducted on bulk sample and drill core sample, for the purpose of evaluating washability by conventional coal preparation method. Test result of bulk sample is illustrated in Christopher diagram of Figure 4-1.

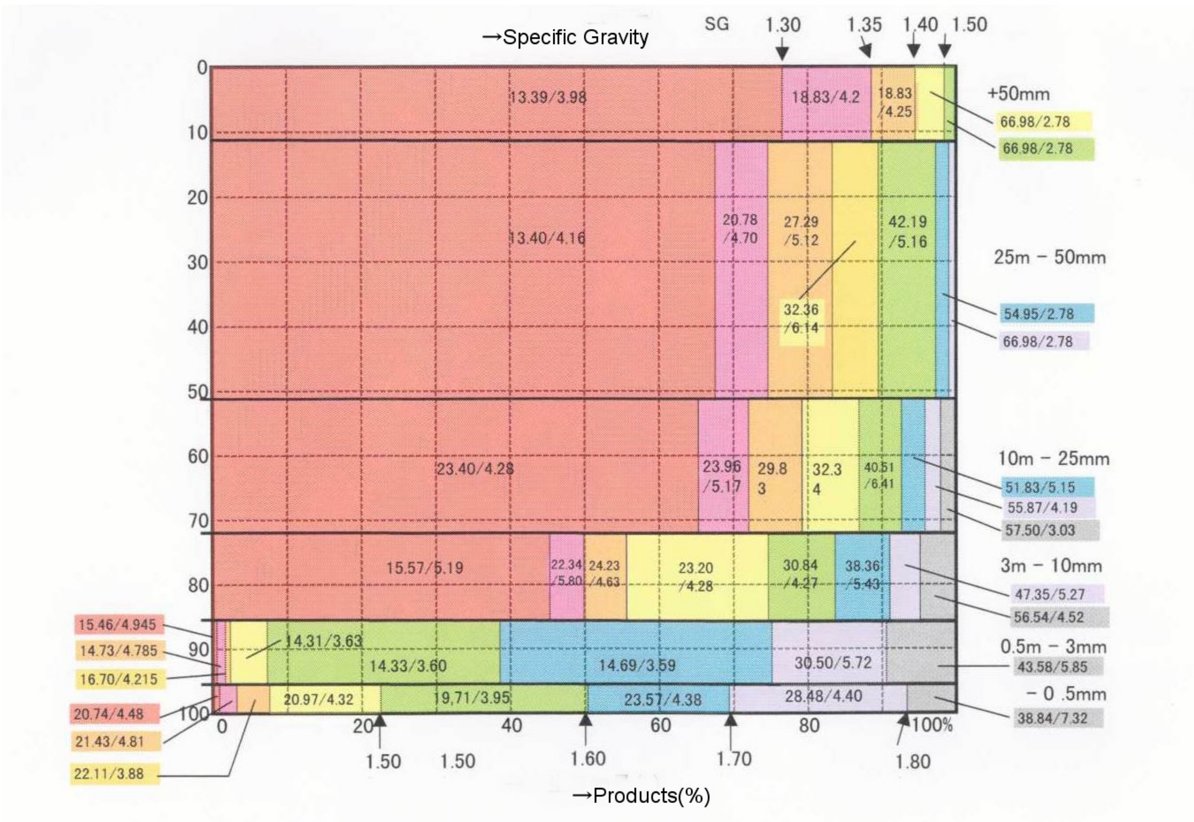


Figure4-1　Christopher Diagram

4.1.2. Washability of Ngao Coal

Judging from the test results of bulk sample, it is presumed that the conventional coal preparation method can be applied without difficulty, because a lot of coarse-grained portion with low specific gravity is contained in the sample

The analysis result of core samples shows that the sulfur content varies by the areas. In some area, sulfur content is less than 3 %(AR), and in other area, more than 6 %(AR).

Washability of ash is almost same in core sample and bulk sample. Selective mining and conventional washing method will be effective to reduce ash content.

In the stage of detailed design of coal preparation plant, more specific data may be required. But in this Study, we recommend to apply simple Jig washing method for Ngao coal preparation.

4.1.3. Advanced Coal Preparation Technology

For the purpose of evaluating further degree of coal cleaning by means of advanced technology, float and sink test was conducted on pulverized bulk coal sample. Degree of liberation of ash and sulfur by crushing was examined.

The test result revealed that liberation of ash and sulfur by crushing could not be expected so much. It seems impossible to cover the additional cost for crushing because of the low effect of liberation.

4.2. Upgrading Test by Drying Method

4.2.1. Outline

After float and sink test, each 15 kg weight of coal sample under 1.3 in specific gravity was collected for the size of 3-10 mm, 10-25 mm and 25-50 mm. This portion is the main part of the sample, and it is assumed to be the clean coal from Ngao area after preparation process.

This sample was used for the tests of drying method, including drying test and liberation test for ash and sulfur.

Thermo gravimetric analysis under the flow of air and nitrogen gas was conducted on the sample of 10-25mm in size with a small-scale apparatus for differential thermal analysis, and drying loss was measured. The results are shown in Figure 4-2and 4-3

Then drying test was conducted.

4.2.2. Drying Test

(1) Apparatus and Conditions of Test

Test was conducted with an apparatus shown in Figure 4-4 under the following conditions.

- Sample: 500g.
- Drying atmosphere: Under the flow of heated gas (Nitrogen gas - 230℃, Steam - 320℃)
- Drying time: 45, 60, 120, 240 minutes
- Sample size: 3-10, 10-25, 25-50 mm.

In addition, the effect of degradation by drying was examined by measuring ash and sulfur content in the fine-grained portion of dried sample after screening by 0.5mm and 2mm in size.

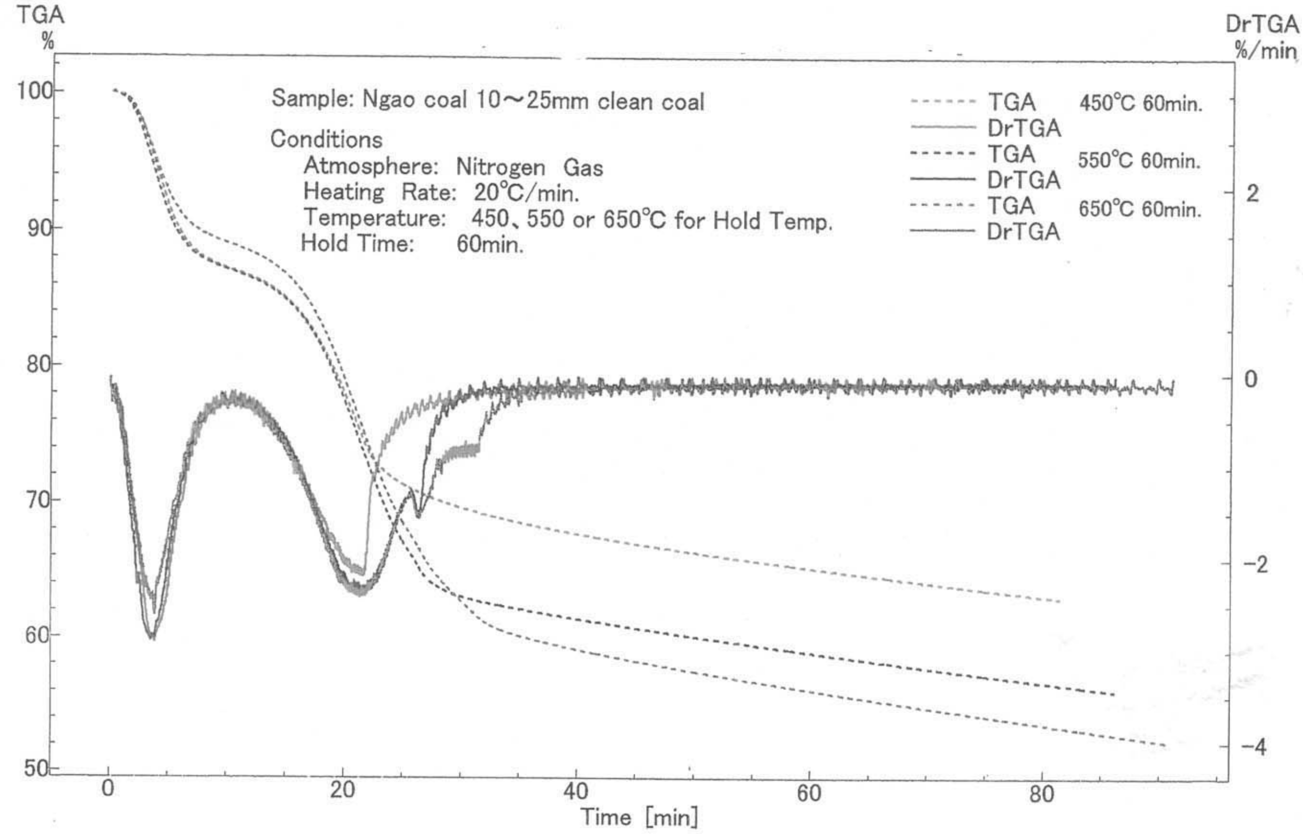


Figure4-2 Comparison of Hold Temperature(Thermogravimetoric Analysis)

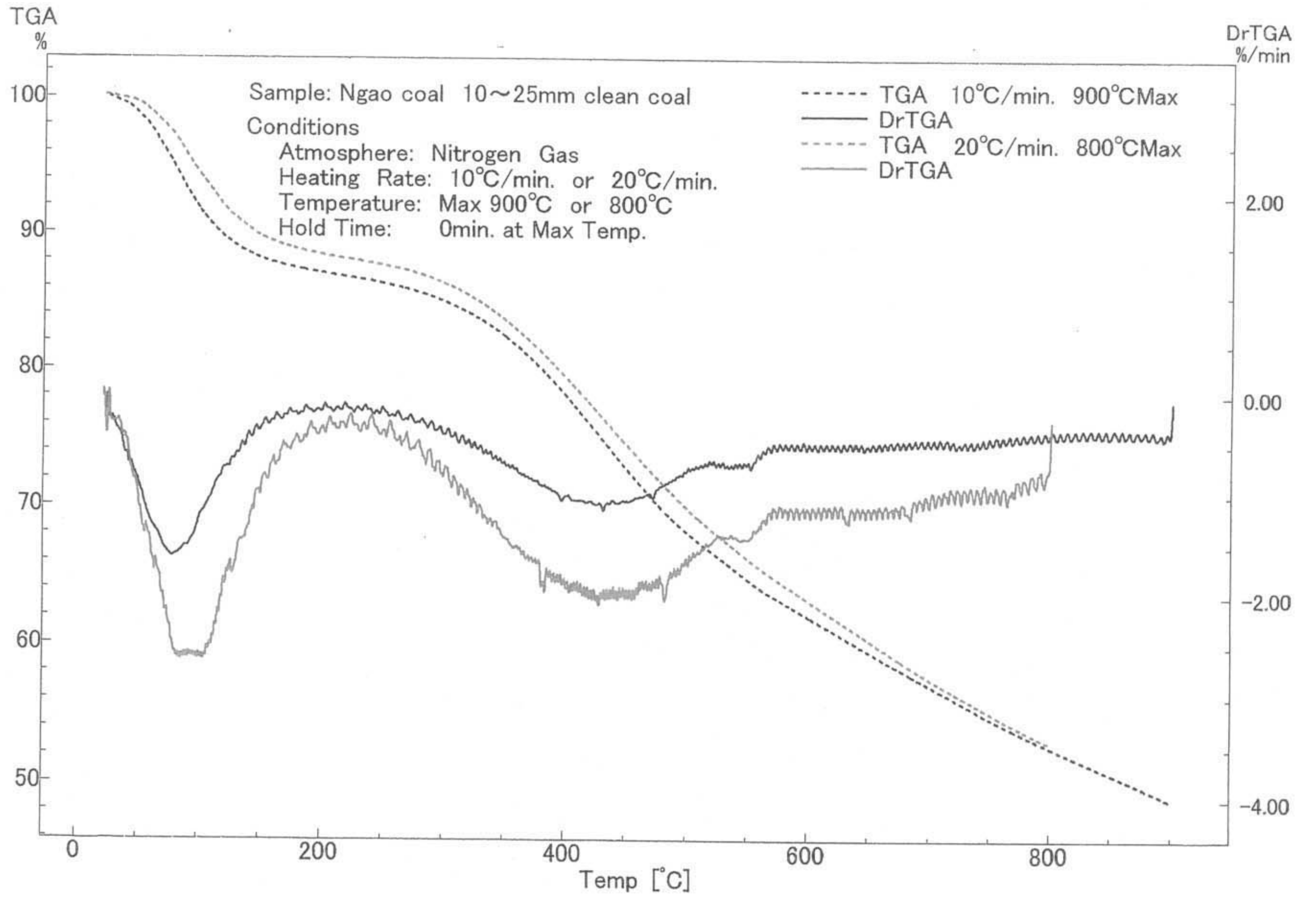


Figure4-3 Comparison of Heating Rate(Thermogravimetoric Analysis)

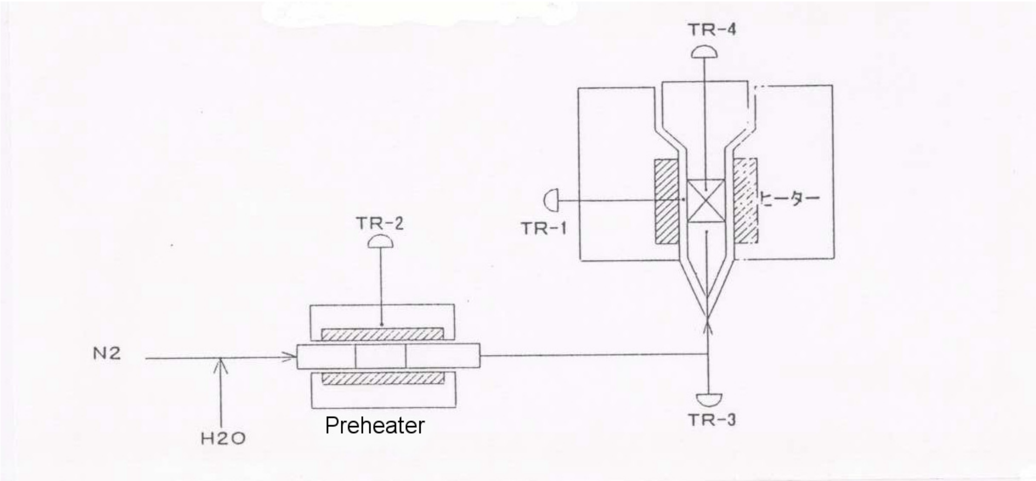


Fig. 4-6 Drying Test Apparatus

(2) Test Result

Advantages of ACC process are that de-ash and de-Sulfur are possible simultaneously with drying process. In the present test, drying was possible under the above conditions, and drying result was obtained as expected. However, the degree of degradation was low, and liberation of ash and sulfur by degradation was hardly recognized.

In the petrography analysis, we can see very fine (10~20 micron size) pyrite grain, which is homogeneously dispersed in the coal matrix. These matter also indicate the difficulty of separation of sulfur.

As a result, ACC process is not effective for Ngao coal upgrading.

Because the applicability of the process seems to be different by areas or coal quality, further study should be done on drill core samples and for the coals other than Ngao in the next stage, if needed.

4.3. Upgrading Test by Low Temperature Dry Distillation Process

4.3.1. Outline

Test of low temperature dry distillation was conducted based on the SGI process proved in USA and upgrading by this process has been examined. Coal sample of 10-25 mm in size and also less than 1.3 in specific gravity was collected from bulk sample after float and sink test and used for the test.

Thermo gravimetric analysis under the flow of nitrogen gas was conducted on the sample of 10-25 mm (－1.3 in specific gravity) with a small-scale apparatus of differential thermal analysis. Speed of de-volatile matter by dry distillation was measured to obtain the data for design of dry distillation test. The result is shown in Figure 4-5.

Then dry distillation test was conducted.

4.3.2. Dry Distillation Test

(1) Apparatus and conditions of Test

The apparatus used for the test is shown in Figure 4-6 and test conditions were as follows.

・Sample: Size; 10-25 mm, Specific gravity; under1.3(Dried under N_2 gas at 260℃,1hour)

・Sample amount: 200g(Dried)

・Dry distillation temp.(℃): 450, 550, 650, 750, 850

・Retention time (min): 30, 45, and 60

(2) Test result

Inherent moisture of bulk sample was 21 %. It is presumed that moisture

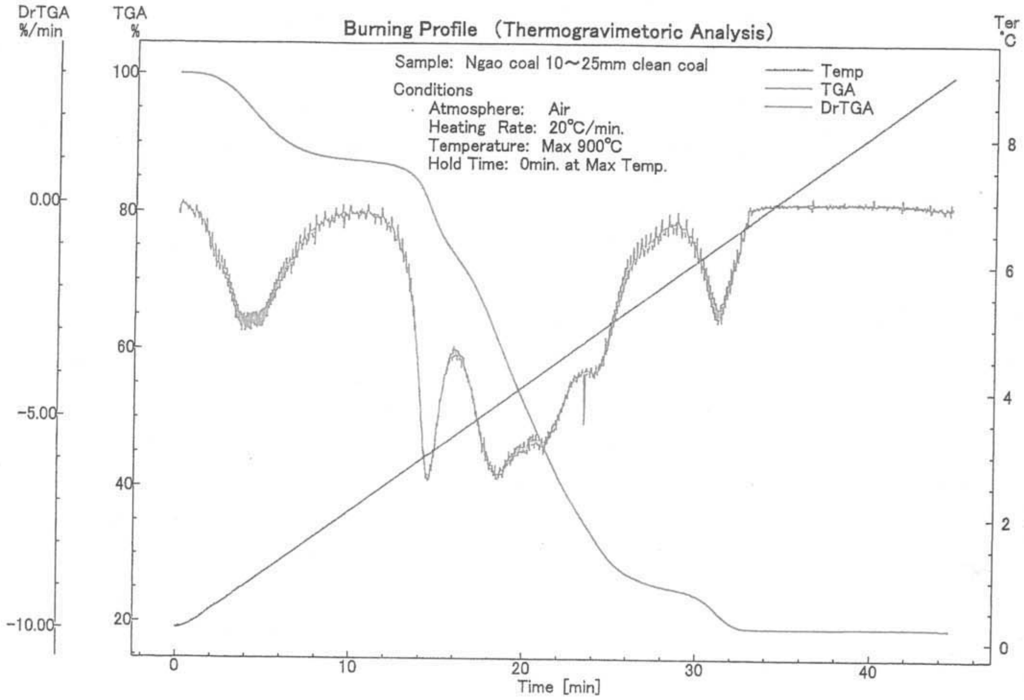


Figure4-5

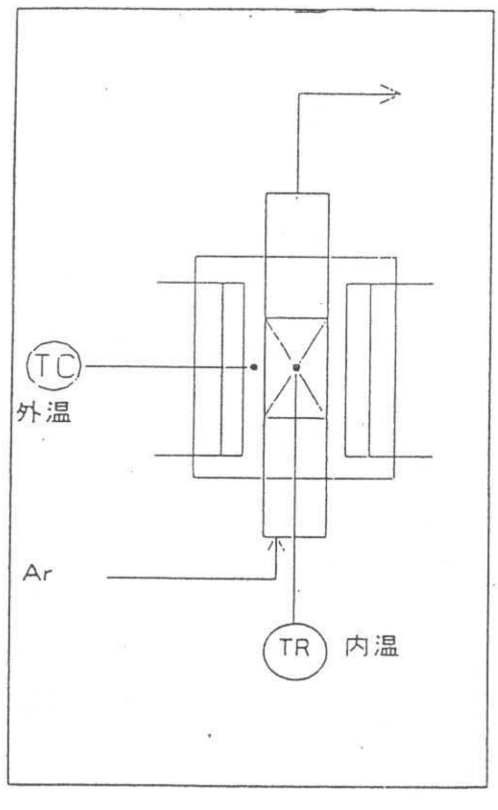


Figure4-6 Dry Distillation Apparatus

content of washed Ngao coal is about 30 %(AR). Solid product by dry distillation process is supposed to be about 50%, provided that 30% of moisture is removed by drying and remained 20% is gas and liquid.

Judging from the dry distillation test result, temperature 450~550℃ and reaction time 45minuts is appropriate..

Table 4-1 shows the test result on the relation between distillation temperature and form of sulfur of the solid product.

Table 4-1 Form of Sulfur of the Solid Product

（Comparison with Drying Coal and Dry Distillation Coal ）

Drying Coal		Inorganic Sulphur						
Condition	T.S.	sulfate	pyrite	organic	moisture	ash	Kcal/Kg	s/cal
280℃ 1.0 hour	7.18	0.17	2.53	4.48	7.70	17.69	5490	
280℃ 1.0 hour	7.39	0.15	2.99	4.25	7.10	18.56		
280℃ 1.0 hour	7.43	0.15	3.07	4.21	7.40	18.82		
300℃ 4.0 hour	7.56	0.17	3.11	4.28	2.00	18.56	5500	1.37

Dry Distillation Coal		Inorganic Sulphur						
Condition	T.S.	sulfate	pyrite	organic	moisture	ash(dry)	Kcal/Kg	s/cal
450℃ 0.75 hou	6.00	0.22	1.81	3.97	6.40	24.80	5770	1.04
550℃ 0.75 hou	5.93	0.07	0.14	5.72	5.10	27.76	6110	0.97
650℃ 0.75 hou	6.49	0.06	0.05	6.38	4.40	30.08	6010	1.08
750℃ 1.0 hour	6.34	0.10	0.03	6.21	5.60	31.72	5980	1.06
850℃ 1.0 hour	6.61	0.06	0.04	6.51	5.80	32.68	5990	1.1

By dry distillation process, 50 % of pyrite sulfur was decomposed at 450℃, and more than 90 % of that was decomposed at 550℃. These facts may mean that pyrite (or marcasite) decomposed at 450℃ to pyrrhotite and then at 550℃ decomposed to iron. Heating value of the solid product is about 6100 Kcal/Kg.

Material balance was calculated based on the test result of dry distillation at

550℃. The result is shown on Table 4-2. Ratio of sulfur content equivalent to heating value was remarkably reduced.

Table 4-2 Material Balance and Product Quality
(Ngao Bulk Sample at 550 ℃ Dry Distillation)

Bulk Sample

	Ngao Coal	(Wyoming)
Moisture	30	29.12
V.M.	29.6	30.64
F.C	27.4	34.95
Ash	13	5.29
Heating V.	3770	4527
(Kcal/Kg)	100	100
C	40.47	49.09
H	2.91	3.41
N	1.01	0.72
S	4.63	0.38
O	7.99	11.99
	57.01	65.59
s/cal	0.012281	

Char	392	
Tar(Oil)	157	
Gas	105	
C.Water	45	
	699	

Ngao coal		143
Drying		
	Vapour	43
Dried coal		100
Distill.		
	Gas	15
	C.water	6.5
	Tar	22.5
	Solid	56
	Total	100

Solid product

	Ngao Coal	(Wyoming)
V.M.	14.7	20.4
F.C.	58	69.1
Ash	27.3	10.5
Heatin V.	6000	7000
	100	100
C	64.8	75.6
H	2.3	3.1
N	1.7	1.1
S	3.8	0.3
O		9.4
	72.6	89.5
s/cal	0.006333	

Sulfur reduction rate: 0.00633／0.01228＝51.6 %

Liquid product

	Ngao Coal	(Wyoming)
C	73.9	83.8
H	8	9.6
N	1.5	0.4
S	4.5	0.3
O	12.1	5.5
Ash		0.4
	100	100

Dry distillation seems to have much advantage as upgrading technology. Concerning about the possibility of commercial plant in Ngao area, further economic study is needed.

At this point of economic consideration on very rough basis in Thailand, solid product of 5,800 Kcal/Kg (AR) may be produced by 900~1100 bahts/ton at plant site. But this cost consideration is very rough and it seems premature to make cost estimation at this stage.

Because of high sulfur content of liquid product, product-marketing study is also important.

In Thailand there are many high surfer coal seams like Ngao. It seems to be important to evaluate these seams as a candidate of upgrading feedstock.

As a next step, we recommend to select appropriate feed coal and to conduct preliminary feasibility study.

4.4. Upgrading Test by Low-Temperature Liquid Phase Cracking Process

4.4.1. Outline

This process is under development by National Institute for Resources and Environment (NIRE) of Japan, and the application of this process was studied at the temperature of about 400℃. The effect of hydrogenation was also examined to improve the yield of liquid product.

The sample of 25-50mm in size with specific gravity of less than 1.3 was collected from bulk sample and used in this test. Coal from Ban Pa Kha mine of Lanna Lignite was also tested for comparative purpose.

4.4.2. Apparatus and Conditions of Test

An autoclave of 500 ml was used for the test as shown in Figure 4-7. Test conditions are as follows.

・Sample: Ngao coal Powder: crushed into 200 mesh

Grain: crushed into 3-10mm

Ban Pa Kha Powder: crushed into 200 meshes

・Solvent : Tetralin, Decalin, LCO

・Conditions: Solvent/Coal = 2/1

Reaction temperature (℃) : 380, 400, 420, 440

Retention time: 60 minutes

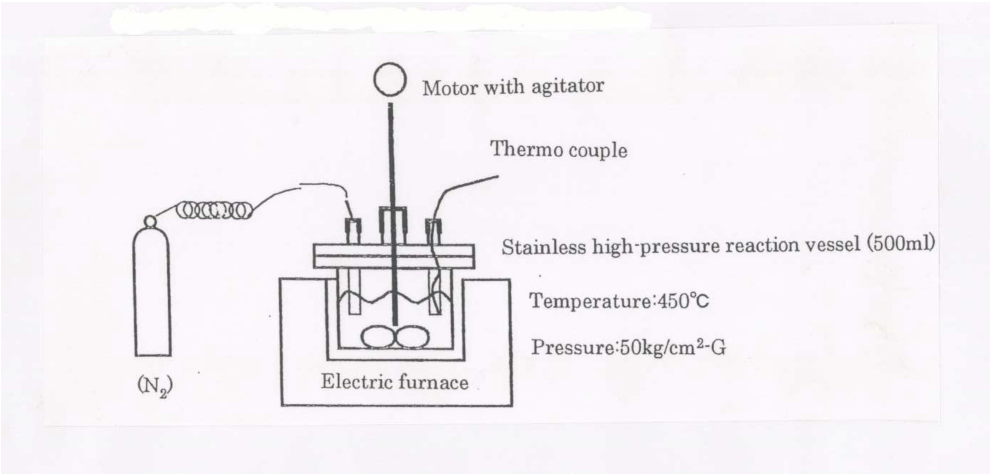


Figure4-7 Autoclave Apparatus

4.4.3. Test Result

The principle of Low-temperature liquid phase cracking process is to obtain mainly solid product by circulating use of tar, which is mainly produced from coal itself and partly supplemented by cheap solvent, for example waste oil from automobiles.

The above test revealed that Ngao coal could be treated in the same way as Japanese coal and Indonesian coal. Therefore, it is expected that solid product equivalent to bituminous coal in quality is obtained at more than 420℃ of reaction temperature.

Analysis data (Form of sulphur) of solid products obtained by liquid phase cracking is shown on Table 4-3.

After liquid phase cracking process, at 400℃ pyrite is 50% reduced and at 440℃,about 90% pyrite is reduced.

As this process is still under development stage, further development activity by NIRE of Japan is requested.

An additional test was conducted as an application of the test in direct coal liquefaction process; namely, reaction under hydrogenation pressure by using tetralin as a solvent. In this case, coal has been almost perfectly converted to liquid product in spite of high sulphur content.

Table 4-3 Result of Form of Sulphur

Sample	Total S.(dry basis)	Form of Sulfur (dry basis)			Moisture
Condition (Temp., Solvent)	%	Sulphate S. %	Pyritic S. %	Organic S. %	%
440℃、Dekalin (Ngao)	5.17	0.33	0.25	4.59	16.2
440℃、Dekalin (Lanna)	0.45	0.03	0.05	0.37	8.3
400℃、Dekalin (Ngao)	6.69	0.5	1.18	5.01	20.7
50～25mm －1.3 (Bulk Sample)	7.13	0.35	2.42	4.36	8.8
10～3mm －1.3 (Bulk Sample)	7.55	0.74	2.33	4.48	34.1
25～10mm ＋1.8 (Bulk Sample)	7.74	0.77	5.16	1.81	6.1

Technology development of liquid phase cracking is still going on.

NEDOL (Coal Liquefaction process of NEDO) Process may be well applicable technically; but substantial volume coal reserve is needed from economical standpoint.

4.5. Overall Examination and Evaluation

4.5.1. Examination of Each Process

(1) Conventional Coal Preparation

Screening and float-sink test were conducted on bulk sample. Then on core sample, float-sink test and analysis were conducted. The data obtained are sufficient for the design of coal preparation plant with conventional technology.

The facilities will be simplified and the cost will be low. The effect of coal preparation will be relatively large, although substantial improvement on the quality of Ngao coal that is high ash, high sulfur and low calorific value, cannot be expected.

(2) Advanced Technology of Coal Preparation

The test result indicates that the liberation of sulfur and ash by crushing may occur little on Ngao coal. Besides, an additional crushing cost is required for conventional plant facilities. It is suggested that an application of this technology on Ngao coal will not be effective for quality upgrading.

(3) Drying Method

Although drying result was obtained as expected, reduction of sulfur and ash content was hardly recognized in bulk sample. Independent application of this method will not be effective, but combination with dry distillation method or liquid phase cracking method will be considered in the future.

(4) Low Temperature Dry Distillation Method

Improvement of calorific value of solid product was satisfactorily recognized in this process. Sulfur content of the product remained still high in this process, owing to the high sulfur content of bulk sample. There is some drill core sample with less Sulfur content (especially in Area-A) and in general, an application of this method on Ngao coal will be hopeful. Further study will be required on yield and quality of tar and engineering study on process facilities.

(5) Low-Temperature Liquid Phase Cracking Method

This process is applicable to Ngao coal but organic sulfur remains in both of solid and liquid products. Additional process for removing sulfur will be required;

for example, hydrogenation process. In the test of hydrogenation, liquefaction reaction of coal occurred along with sulfur removal. An advantage of this method is that concentrated CO_2 gas can be extracted from raw coal.

4.5.2. Overall Evaluation

Judging from the limited study to date, the following three systems are to be considered.

① Combination of conventional preparation and low temperature dry distillation process.

Main product is solid one with high calorific value and reduced sulfur-content.

② Combination of Conventional preparation and liquid phase cracking process

Both of solid and liquid products are produced following the market demand.

③ Conventional preparation only

In this case, only relatively low sulfur coal can be used.

Option② is not practical because liquid phase cracking process is still under developing.

We recommend to conduct preliminary feasibility study based upon option①.

Because the present study is mainly based on the test result of bulk sample, further detailed examination on whole available data, including analysis of drill cores, should be carried out. And after selecting appropriate feed coal, final conclusion should be made, from not only technical point of view, but also economical and marketing points of view.