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CANMET
Canada Centre for Mineral and Energy Technology
Centre canadien de la technologie des minéraux et de l'énergie

VISIT TO THE COAL RESOURCE AND PROCESSING LABORATORY OF CANADA REGARDING THE POSSIBILITY OF FORMED-COKE PRODUCTION FROM LOW RANK COALS

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ENERGY RESEARCH PROGRAM
ENERGY RESEARCH LABORATORIES
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FORWARD

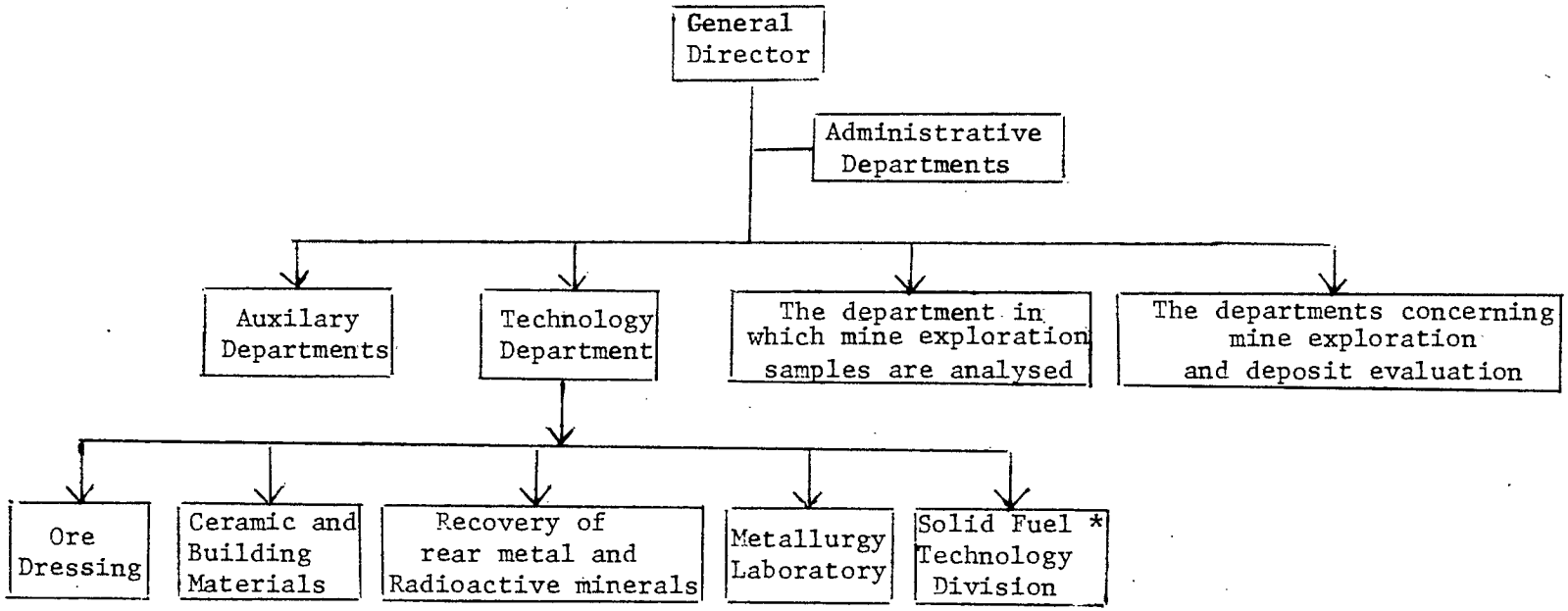
Mr. Muzaffer Saracogullari spent 6 months attached to the Coal Processing Research Section of the Research Group of the Coal Resource and Processing Laboratory, Energy Research Laboratories, CANMET, Department of Energy, Mines and Resources, Canada. He came from the MTA Enstitusu Teknoloji Dairesi (Mineral Research and Exploration Institute of Turkey - MTA) that employs about 8000 people, 4000 of which are support staff. In many ways the technical specialities of the institute are similar to those of CANMET. A schematic of the MTA organization and the objectives of the Solid Fuel Technology Laboratory are reviewed on the next page.

I hope the following comments will be useful for possible future technical visits or exchanges. During his visit, Mr. Saracogullari proved to be an excellent worker who was well thought of by all who associated with him. His project was a valuable contribution to the formed coke objective of the CANMET Energy Research Program. This exchange was most worth-while for all concerned and I would have no hesitation in becoming involved similar future training programs, provided the visiting trainee can spend sufficient time in our laboratories to achieve meaningful experimental results. Thus I estimate the minimum period necessary for the type of training at 6 months.

Ross Leeder 16/1/79

MINERAL RESEARCH AND EXPLORATION INSTITUTE OF TURKEY (MTA)

(8000 people/4000 labour)



* The projects in Solid Fuel Technology Lab. (12 Eng.)

1. Upgrading Lignites for domestic heating (smokeless fuel)
   a) Washing - Lab. scale
   b) Briquetting (There is a hot briquetting pilot-plant which is patented by MTA)
2. Carbonization research studies:
   a) Formed-coke - Lab. scale
   b) on Blending of coking coal with poor or non-coking Amasra and Amutcuk coal using 15 lbs slot-type oven
3. Combustion of lignites and oil-shale in fluidized-bed
4. Liquifaction of coal and asphaltite
5. Bio-gas - Concerning production of methane from fertilizer by fermentation. (A pilot scale fermentor is being constructed).

1. INTRODUCTION

Metallurgical coke suitable for the iron and steel industry is produced in the conventional slot-oven process that can utilize only a few types of coals referred toas coking coals. Unfortunately, the main part of world's coal resources consist of weakly-caking or completely non-coking coals and lignite, none of which are suitable to produce metallurgical coke using conventional processes. The shortage of adequate resources of coking coals is a major problem to expansion of the iron and steel industry around the world.

Currently at least twenty different processes have been developed, to various stages, as an alternative to conventional metallurgical coke making. The recent development of many formed-coking pilot plants caused a growing interest in formed coke processes. The reasons for this interest includes the following:

1. to allow the use of cheaper, lower rank coals in place of more expensive coking coals;
2. to allow a continuous or intermittent operation with a greater degree of instrumentation and automation than the conventional process;
3. to allow a totally enclosed system, reducing carbonization pollution;
4. to enable the size and shape of the product to be varied to match the blast furnace burden.

In spite of these advantages, none of the formed coke processes has yet been accepted for the full scale regular production of blast furnace fuel, principally because of engineering problems with current processes and the large high-risk investment that is required to build a large plant of unproven technology.

Like many of the coke producer countries, Turkey has run into some problems in the last few years in supplying good quality coking coal for iron and steel industry. Good quality coking coal is only being produced in the Northern part of Turkey, in Zonguldak. This resource is very limited and its production level can not meet the demand of iron and steel industry. Therefore the demand has been satisfied by importing coal. Further more, the planned expansion of Turkey's iron and steel industry will magnify the problem of coking coal supply in the future. However there are reasonably large reserves of non-coking and lignite available which could be suitable for formed coking or new carbonization techniques.

I was sent to Canada by Mineral Research & Exploration Institute (MTA) with the aim of observation the research studies concerning the possibility of formed coke production from low rank coals and extending coking coal range by means of new coke making technologies. My program was funded by the Canadian International Development Agency (CIDA) and the United Nations Industrial Development Organization (UNIDO) and took place in the Coal Resource and Processing Laboratory (CRPL) of Canada. In this Laboratory, after having been discussed the aim of my visit, a six month program was prepared by Dr. W.R. Leeder. This program can be briefly outlined as follows:

1. Analysis of Amasra and Tuncbilek Coal samples brought from Turkey;
2. A research study on the production of formed coke from pitch bound briquettes made with Saskatchewan Lignites that which has a similar properties with Tuncbilek Lignite;
3. Observing and participating the research studies in CRPL;
4. A visit to char making units of M & S Coal Company in Saskatchewan.

This report will summarize my progress towards these program objectives.

2. DESCRIPTION OF THE FACILITIES IN CRPL

Since 1959 CRPL has carried out the investigations on coal carbonization to assess the coal resources of Canada for potential uses, principally in the steel industry. These investigations also include the requirements of Canadian industry and coal companies involved in the export market. In addition, for resource assessment, the carbonization data of Canadian coals tested in CRPL have been stored in a computer memory. The facilities available in CRPL are broken down into several groups involving research and service functions. Three of the main service sections are described as follows:

2.1 Coal Treatment and Rheological Testing of Coal

This section is concerned with the processing of coal from the time it leaves the mine until it is ready for carbonization. This includes sample preparation, coal cleaning, preparation of coal and making briquettes for movable-wall oven charges, and rhelogical testing of coal.

The rheological laboratory has facilities to determine the caking properties of coal. The tests being performed for coking properties

are free swelling index and Gieseler plasticity (according to ASTM) and determination Rühr Dilatation.

2.2 Carbonization Operation Section

Technical scale evaluations of coking characteristics of coals and coal blends have been carried out by this section using conventional slot-type ovens. Pilot-scale slot type test ovens located in CRPL are:

1. The 18-inch chamber movable-wall oven with a charge capacity of 700 lbs;
2. The 12-inch chamber movable-wall oven with a charge capacity of 500 lbs.

These ovens are electrically heated with "Globar" type resistance elements, provided with a sensitive control system to adjust predetermined oven-wall temperature. The 12-in. oven walls consist of silicon carbide tile with a high termal conductivity relative to silica brick. In order to simulate the conditions of heating in a commercial oven energy input to the both test ovens can be programmed.

During the coking process, due to the nature of coal charges, sometimes excessive pressure develop which can cause structural damage to commercial coke oven walls. By means of these movable test ovens it is possible to measure the pressure generated by oven charges. These ovens also have the facilities to record continuously the pressure developed to the oven walls during the carbonization.

In addition to the movable-wall ovens mentioned above, a 30 lbs slot-type oven was constructed as a small scale test oven. Although this oven is not equipped to measure the oven wall pressure, it gives coke strength trends of what might be expected from the pilot scale oven tests.

In the section there is also an ASTM sole-heated oven to measure the expansion or contraction of coal and coal blends during the coking cycle. The oven is so designed that the charge is only heated from the floor of the oven. The tests performed from this oven gives a useful information about the charge shrinkage to determine if it is sufficient to discharge easily from an oven at the end of carbonization.

In addition, this section is responsible for evaluating the resultant coke for size and strength characteristics which are important qualities from the viewpoint of commercial uses. After discharging the resultant coke the following tests are performed on it:

1. Size analysis of coke;
2. Tumbler tests for determination strength properties
3. Specific gravite determination

In all tests, ASTM test methods are used as closely as possible.

2.3 Petrography Sections

This section includes facilities for sample preparation where the coal or coke can be crushed to the proper size, mounted in an epoxy resin pellet, with one surface polished free of scratches and relief.

For determination maceral composition of the coal, a Leitz Ortholux-Pol microscope is being used. On the other hand the reflectivity of the major macerals is determined by using a Zeiss Research microscope coupled to a PMI Digital Display Photometer.

In this section, from the maceral composition and the reflectivity of major macerals of coal, the strength of resultant coke is predicted and the optimum blends of various coals to produce high quality metallurgical coke is also calculated. The petrographic analysis techniques provide reducing the number of expensive technical scale coke oven tests and also give the opportunity to predict the strength of resultant coke using only small amount of coal samples.

3. CARBONIZATION RESEARCH STUDIES

The carbonization research studies in Coal Resource and Processing Laboratory are mainly concerned with improving metallurgical coke quality, extending coking coal range to use less expensive coals, and assessing new coke making technologies.

These research studies can be described as follows

3.1 Conventional Coke Making

Coke is the main source of heat and reductant in blast furance. It must have sufficient strength to support the iron oxide burden. To meet this requirement of blast furnace in CRPL the research studies are mainly aimed to improve coke strength.

A major parameter which effects to metallurgical coke strength is the bulk density of the charge in the conventional coke ovens. The increase in bulk density of the charge, significantly improves coke strength. Several methods have been developed to increase it.

Some of them are:

1. oiling of the oven charge;
2. mechanical densifying;
3. preheating of the oven charge;
4. agglomeration or partial briquetting of the oven charge.

All these technicques have been investigated in CRPL. Partial briquetting of the oven charge has been found to be a most effective method of utilizing less expensive coals.

Generally coke is being made using partial briquetting of the oven charge, as follows: The matrix coal and coal blend is first crushed to size consist of 80 percent passing 1/8-in. sieve. Briquettes are prepared using 6 percent binder in roll-press. The matrix coal and briquettes are mixed with a ratio of 70:30 in the feed hopper. Total moisture content of charge is adjusted to a level of 3 to 6 percent. The charge is fed from a hopper into the slot type movable-wall test oven, through a charge hole in the top. The charged mixture is then levelled by raking out any excess coal through a small levelling door located at the top of the main door. Oven bulk density is calculated from knowledge of the amount charged and oven volume. The charge is carbonized until one-half hour after the center-charge temperature reaches 1000°C. Coking time is about 16 - 20 hours. The two end door of oven are removed and the coke is pushed out. The coke is immediately cooled with quenching and dropped 10 ft. from the quenching box to the concrete floor to simulate coke handling at the commercial iron-steel plants. The coke is then dried to remove water during quenching.

By partial briquetting of coke oven charge technique it is also possible to use significant amount of non-coking coals in blends without effecting coke quality. There are three procedures which can be employed for the use of poor or non-coking coals in metallurgical coke making by this technique. These are:

1. Non-coking coal is included in the briquettes which are blended with good coking coal as the matrix of the coke oven charge.
2. Non-coking is briquetted and small amounts of non-coking coals are added to the matrix coal.
3. Coking and non-coking coal blend are blended and part briquetted. The charge all consists of the blend.

The amount of non-coking coal using in charge oven depends on the properties of raw material. But it gives an opportunity to use non-coking coal up to 30 percent.

3.2 Non-Conventional Coke Making (Formed-coke)

CRPL, has developed, laboratory scale unit facilities to assess the formed coking potential of Canadian coals by either hot briquetting or pitch binding processes.

3.2.1 Hot briquetting research studies:

In order to evaluate Canadian coals in hot briquetting, CRPL has developed the laboratory scale manual batch operated and automatic continuously operating hot briquetting units. During the my program only manual hot briquetting unit was in operation.

The manual batch-operated facility consists of a muffle furnace to dry and preheat a blend of the char and binder coal, a fluidized bed unit to heat the blend into the plastic range of the binder coal (coking coal) and a special die in which the mixture is briquetted. Hot briquettes are made as follow. The binder coal is mixed with the char in a beaker and placed in a nitrogen flushed muffle furnace at 300°C for half hour. The dried and preheated blend is then poured into a electrically heated fluidized bed and the mixture is heated to about 400 - 450°C depending on the plastic range of binder coal. The mixture is transferred to a heated (350 - 400°C) cylindrical die in which hot briquettes is produced.

Since the volatile content of the raw materials is high, hot briquettes are being heat-treated (450 - 650°C) or carbonized (800 - 900°C) in a specially constructed fluidized sand bed. This carbonizer provides a uniform temperature in the bed during coking.

3.2.2 Pitch-binding briquetting

Because of recent world wide advances in pitch binder processes, and existence of significant lignite and sub-bituminous coal deposits suitable for these types of processes, some research studies have been carried out by CRPL to investigate the variables of making pitch-bound briquettes. The process which is suitable to apply to low rank coals and coal chars consists of making briquettes in roll press using pitch as binder and hardening of the green briquettes. The aim of hardening step is to improve the strength of briquettes and to reduce the volatile

content of briquettes. The techniques being used for hardening are oxidation in air 200 - 300°C and/or treatment at 550°C in fluidized sand bed.

Both hot briquetting and pitch binding briquetting laboratory-scale research studies do not produce enough briquettes to carry out an ASTM coke tumbler test which is the main measurement to evaluate the quality of metallurgical coke. However crushing strength or a small scale laboratory tumble test of formed coke briquettes is being used as alternative measurements to determine mechanical strength. In addition to conventional and non-conventional coke making methods, there was another project in CRPL concerning a method of producing an agglomerate of iron ore and char suitable for smelting in a low shaft furnace. In this research study iron-ore and lime are briquetted in roll press using pitch as a binder. The briquettes are then cured in an oxidative step to increase the strength. The briquettes consisted of 70 percent iron-ore, 10-20 percent char, 6 percent lime and about 7-10 percent pitch. Hydrated lime addition prevents degradation problems. As a result it is also possible to briquet the iron ore with char by means of this process for smelting iron-ore.

4. ANALYSIS OF AMASRA AND TUNCBILEK COAL SAMPLES

Before coming to Ottawa, it was requested that I bring some Turkish coals which could be used in formed coke production. Five kg of Amasra and Tuncbilek Turkish coals were brought but the amount was insufficient to do any technological tests. Therefore, it is decided to do some analysis concerning the determination rank of the coals according to ASTM classification and the possibility of using these coals in formed coke processes.

For this object, during my program in CRPL, chemical analysis, hardgrove grindability index and petrographic analysis of Amasra and Tuncbilek coal samples have been done. The results of analysis of the samples are given in Appendix A of this report.

According to the results of analysis obtained, it is found that Amasra coal is a high volatile B - bituminous coal in ASTM classification.

On the other hand Tuncbilek coal was found as a sub-bituminous B - coal in the same classification.

In addition, I have been in Petrography Laboratory of CRPL with Mr. Jorgenson for two weeks to determine petrographic composition and to measure reflectance index of coal samples. From the data obtained petrographic analysis of Amasra coal predicted stability factor have been calculated as 31. This value is too low to produce a good quality metallurgical coke from the coal alone since a stability value of 50-55 is desirable. However Amasra coal could be used as a component in coking coal blend. The percentage of Amasra coal which could be used in the blend, depends on characteristics of other components.

Predicted stability factor calculation is only applied to the coals which have some caking properties. For this reason stability factor of Tuncbilek coal was not calculated. Only its petrographic composition has been determined to compare good coking coals.

In Petrography Laboratory of CRPL I spent two weeks training to recognize the macerals in different rank of coal, and learned a method of determining whether coal is oxidized or not using petrographic techniques. Oxidation effects the caking and coking properties of coal so that metallurgical coke produced from oxidized coking blends has a lower strength.

5. A FORMED-COKE RESEARCH STUDY IN MAKING PITCH-BOUND BRIQUETTES

This study is the practical phase of my program. It was an investigation of how to produce pitch-bound formed coke briquettes, using Saskatchewan lignite char. This char was chosen as it has similar properties to Tuncbilek Turkish coal.

The object of this research study is to investigate some of the variables associated with formed coke processes using pitch as binders. Pillow-shaped "green" briquettes were made by means of roll press, using char and pitch to simulate the more advanced FMC (U.S.A.) and IChPW (Poland) commercial pitch bound briquetting processes. The green briquettes were then cured by oxidation in air, to polymerize the pitch and further strengthen the briquettes. Oxidized briquettes referred to as formed-coke were crushed and tumbled to determine their crushing strength and abrasion index respectively.

In this research study, the influence of char size consist, binder

content and oxidation parameters (such as oxidation time, temperature, air flow) on the crushing strength and abrasion properties of green and oxidized briquettes was investigated. The results and the method used are presented in details in CANMET Divisional Report, ERP/ERL79-4(IR).

6. A VISIT TO MANITOBA & SASKATCHEWAN COAL COMPANY LIMITED

A one-week trip has been arranged to Manitoba and Saskatchewan Coal Company Ltd. mines to see the industrial application of char making units. This company operates two different types coal carbonization plants at their Bienfait Mine and Boundary Dam mines. All these operations are located in the lignite coal fields near Estevan, Saskatchewan.

The Boundary Dam Division of Company produces about 1.6 million tons of lignite per year. The entire production is delivered to Saskatchewan Power's Boundary Dam Generating Station located adjacent to the mine.

The Bienfait Division produces 700 to 900 thousand tons of lignite annually. A part of this production is consumed by Lurgi and Salem coal carbonization plants. The description of the char making units are as follows.

6.1 Lugi Coal Carbonization Plant

This plant is being operated by the Bienfait Division and has a capacity of 150-180 tons per day of char. The lignite, crushed to the size of 2-in. by 1-in., is fed to the Lurgi shaft furnace. The lignite passes through three zones in the shaft furnace that is open at the top and closed at the bottom by the coke discharge gear. These are the drying zone, the carbonization zone and coke cooling zone. In these three zones heat is conveyed by circulating gases which are blown into the lignite for drying and carbonizing and away from it for cooling. The temperature at the drying zone is about 250-270°C so the lignite is thoroughly dried to 2-3 percent moisture and preheated before it enters the carbonization zone which has a temperature of 850°C.

The char produced has a volatile content of 12-15 percent and tar is also collected from the carbonization off gas. The plant has a facility to make pitch-bound briquettes for domestic heating it has shut down since 1975.

6.2 Salem Carbonization Unit

The Salem-hearth carbonizer is a 26 ft. round oven with a capacity of

40 tons per day char. The top half of the oven is stationary and the bottom half of it rotates. The coal size that is used is 2-in. by ½-in., raw lignite. This coal is fed by gravity from a storage bin into the oven through a square chute. The height of chute is adjustable so the bed of coal can be varied. The necessary heat for carbonization is supplied by the combustion of the volatile matter from the coal. Inside of the oven there are eight rabbles which are water cooled. These are set on an angle and act as plows. The floor is tappered with a slope to the pit at the middle. As the lower half oven rotates these rabbles plow the coal, as it chars, toward the middle of the oven and then into the coker pit. Residence time of coal in the oven is about 4 hours. The char taken out and sprayed with water to cool down.

The Salem carbonizer is a more controlable and flexible process than the Lurgi carbonizer. It also reduces the volatile content of the char to 8 percent, lower than the 12-15 percent from the Lurgi charring unit. In spite of these advantages, the Salem carbonizer does not produce tar for briquetting as a by product. The char produced in both carbonizers is shipped to companies which make pitch bound briquettes.

7. CONCLUSIONS AND RECOMMENDATIONS

In spite of the bottleneck in coking-coal supplies for the iron and steel industry of Turkey, there are some non-coking coals such as Amasra and Amutcuk suitable to substitute as a portion of coking blend if used with new coking technologies. These technologies, which allow a greater use of marginally or non-coking coals by modifying preparation practices of oven blends, can be summarized as follows.

1. Preheating of oven blend - it increases oven bulk density and productivity and also allows the use of marginally coking coal
2. Briquette additions to coke oven charges - this technology increases oven bulk density and the pitch binder used in briquetting can improve mean blend fluidity. It allows a replacement of 5 to 30 percent of coking coal with non-coking coals without effecting the strength of resultant coke. Besides that, if the raw material is high quality coking coal, briquette addition increases the mechanical strength of coke with a potential resultant increases

in the efficiency of the blast furnace operation.

3. Use of artificial caking material - this type oven charge increaases blend caking propensity and allows to substitute for expensive strongly coking coals in blend.

Adaptation of the new coking technologies to the coal deposits of Turkey would require a detail investigation of the processes using facilities similar to those in CRPL, mentioned before. Currently the MTA Institute only has a 15-lbs slot type oven for evaluating these coking technologies. Because of its low capacity, it is not suitable for simulating industrial practice. To provide more precise and helpful knowledge to the iron and steel industry of Turkey, it is necessary to carry out research studies using pilot scale movable wall slot-type ovens with a capacity of at least 500 lbs.

Although the formed coke processes have several advantages and has been extensively developed at the pilot plant level, some doubts still remain about the technical feasibility of using formed coke in blast furnace. Trials to date have been carried out only on a small scale and as yet there has been no extensive tests in a commercial blast furnace. Formed-coke has to successfully reach a certain quality and scale, as yet unachieved, before the steel industry will accept it commercially.

In the formed-coke research study done during my program, the abrasion resistance of formed coke was found very low as comparison with conventional coke, probably due to the small size of the briquettes produced. This product could be used most successfully as a smokeless fuel for domestic heating, because of its high reactivity and uniformity. In addition it may also be suitable for industries which require less mechanical strength.

APPENDIX A

ANALYSIS OF AMASRA & TUNCBILEK COALS

TABLE A-1

CHEMICAL ANALYSIS OF AMASRA AND TUNCBILEK COAL SAMPLES

	AMASRA COAL	TUNCBILEK COAL
PROXIMATE ANALYSIS (db)		
Ash ..... %	9.3	7.7
Volatile Matter ... %	36.7	40.0
Fixed Carbon ..... %	54.0	52.3
Gross Calorific Value (db) Btu Per Pound	12,665	12,703
Ultimate Analysis (db)		
Carbon ..... %	73.2	71.9
Hydrogen ..... %	4.3	3.9
Sulphur ..... %	0.77	2.25
Nitrogen ..... %	1.1	2.3
Ash ..... %	9.3	7.7
Oxygen (by difference)%	11.3	11.9
Ash Analysis (db)		
SiO_2 ..... %	47.0	45.8
Al_2O_3 ..... %	31.2	19.9
Fe_2O_3 ..... %	7.1	20.2
TiO_2 ..... %	1.4	1.8
P_2O_5 ..... %	0.8	0.4
CaO ..... %	5.6	2.7
MgO ..... %	1.4	4.3
SO_3 ..... %	3.7	3.0
Na_2O ..... %	0.7	0.6
K_2O ..... %	1.1	1.4
Sulphur Forms		
Sulphate ..... %	0.00	0.14
Pyritic ..... %	0.21	0.53
Organic (by difference)%	0.51	1.27
T O T A L	0.72	1.94
Grindability		
Hardgrove Index	48	41

TABLE A-2

THERMAL RHEOLOGICAL PROPERTIES OF AMASRA &

TUNCBILEK COALS

		AMASRA COAL	TUNCBILEK COAL
Dilatation			
Ti - Softening Temp.	°C	-	371
Tii - Max. Contraction Temp.	°C	-	-
Tiii - Max. Dilatation Temp..	°C	-	-
Contraction	%	-	11 at 500°C
Dilatation	%	-	nil
Free Swelling Index			
F.S.I.		N.A.*	N.A.*

* Non-agglomerating

TABLE A-3

MACERAL COMPOSITION OF AMASRA AND TUNCBILEK COAL SAMPLES

Macerals	Amasra hvBb Coal	Tuncbilek Sub-bituminous
Vitrinoid	67.0	88.2
Micrinoid	5.2	6.0
Semifusinoid	8.4	0.0
Fusinoid	5.1	0.8
Exinoid	9.0	0.2
Mineral Matter	5.3	4.8
	100.0	100.0

TABLE A-4

- Prediction of stability factor of Amasra hvB bituminous coal from Petrografic Data --

Vitrinoid	Resinoid	Exinoid	Semi fusinoid		Fusinoid	Micrinoid	Mineral	Total Count
670	--	90	84		51	52	53	1000
			1/3	2/3				
67.0	--	9.0	2.8	5.6	5.1	5.2	5.3	%

Total Reactive %: 78.80 Total Inerts %: 21.20

$$\text{Prorate} = \frac{\text{Resinoid} + \text{Ekinoid} + 1/3 \text{ Semi Fusinoid}}{\text{Vitrinoid}} \text{ X Actual Volume} =$$

$$= \frac{9.0 + 2.8}{67} = 0.176$$

Type	Percent	Actual Volume	Prorate	Total Volume	Optimum Inert	Total % Optimum Inert	Strength C=21.0	Total % XC
5	6.0	4.0	0.70	4.7	3.8	1.23	2.52	11.84
6	53.0	35.5	6.20	41.7	3.5	11.91	2.67	113.33
7	28.0	18.8	3.3	22.1	3.1	7.12	2.81	62.10
8	4.0	2.7	0.5	3.2	2.8	1.14	2.94	9.40
9	1.0	0.7	0.1	0.8	2.6	0.30	3.57	2.85
10	4.0	2.6	0.5	3.1	2.4	1.29	3.79	11.74
11	4.0	2.7	0.5	3.2	2.7	1.18	4.53	14.49
	100.0	67.0	11.8	78.8		24.17		225.75

$$\text{Balance Index} = \frac{21.20}{24.17} - 0.87 = \frac{\text{Total Inert}}{\text{Optimum Inert}} \longrightarrow 0.87$$

$$\text{Strength Index} = \frac{\text{Coking Coef.}}{\text{Total reactive}} = \frac{225.75}{78.8} = 2.86 \longrightarrow 2.86$$

Stability factor: 31