CHAPTER II

LIGNITE

Coal is one of the important fossil fuels available to mankind. It uses as an energy source however account for only a few percent of the world total energy consumption, due to the availability of gas and oil which had been a source of cheap and clean fuel, until 1973 when the oil price had been raised. Many countries which have large reserves of coal have been putting a great deal of effort in the development of nonpolluting, higher economy, power-generating systems that utilize coal as fuel. Thailand is certainly one of the nations possessing coal resources in a significant amount implying high potential as non-conventional fuel. Substantial portion of coal pertains to Thailand is lignite, which is a low grade coal. Consequently, some introductory discussion about coal seems appropriate at this point.

2.1 Origin and Definition of Coal

The origin of coal might be explained adequately for some purpose by the simple statement that coal is formed from accumulations of plant materials that were preserved from complete decay and later altered by various chemical and physical agencts Coal is a rock composed of different kinds of organic matter which vary in their proportions in different coal, and no two coals are absolutely identical in nature, composition, or origin.

A prefered definition of coal is that coal is a compact stratified mass of metamorphosed plants which have in part suffered arrested decay to varying degree of completeness.[3] This definition excludes the various oil shale, canneloid shales, and carboneceous shales, all of which are deposits in which inorganic material is dominant, and also excludes isolated coalified materials such as stems, pinnules, and fronds. The definition does include the following: brown coal, lignite, sub-bituminous, and anthracite coal; and boghead, cannel, pseudocannel, and splint coal. There is some doubt whether or not this definition includes peat. It would seem that peat is excludes as not metamorphosed. However, peat is considered the parent material from which humic coals are formed and will be treated as such.

2.2 Coal Classification

Because of the widespread occurance of coal deposits, the numerous varieties which are available, and the diversity of uses, a great many methods of coal classification have been used. These classifications have been designed to serve many special interests, ranging from the scientific viewpoints of geologists, paleobotanists, and research chemists, to the practical viewpoints of transportation agencies, coal salesmen, and combustion engineers.

Emphasis has been placed on methods of classification which have received widest acceptance, or which seem to be of greatest interest and value to scientific and technical readers. These methods are classification by type, rank, and grade coal. The "type" depends upon the nature and biochemical alteration of the original plant ingredients; the "rank" upon the subsequent alteration by dynamochemical processes in the series peat to anthracite; and the "grade", upon the amount and nature of the mineral impurities associated with the coal.

2.2.1 Classification by Type

Coal is a rock, since the geologist regards as rocks all natural, solid substances, organic or inorganic, that compose the earth's crust. It is not a mineral, as such a substance is defined as an inorganic, homogeneous substance with a definite chemical composition, all of which requirements coal lacks.

It has long been known that coal is derived from plants; in fact, coal contains a large proportion of material which retains much of the original plants structure in a good state of preservation. A summary of coal paleobotany points out that three classes of plants are easily recognized in coal, namely: coniferouslike, cycadophyte or fernlike, and lycopods (which were trees related to present club mosses).

However, details of classification by type will not be described herewith because it departs from the engineering scope.

2.2.2 Classification by Rank

The rank of coal is its stage of coalification in the series peat, lignite, sub-bituminous coal, bituminous coal, and anthracite. The generally accepted theory is that the various ranks of common coals have resulted from peat deposits which were covered with layers of sedimentary rock and have been coalified to varying degree by tremendous pressures acting through long periods of times, supplemented by the effect of moderate heat in coals of the highest ranks.

Presently, there are only three main coal classification methods by rank which are widely accepted[4]. According to ASTM (the American Society for Testing of Materials) standard, BNCB (the British National Coal Board), and International coal classification systems. The ASTM method is based on fixed carbon, volatile matter, calorific value, and agglomerating characteristic of coal. The BNCB method is based on the dry, mineral matter-free volatile matter and the Gray-King coke type test. The International method, on the dry, ash-free volatile matter and moist, ash-free calorific value, that is, the basis of classification is similar to that of the ASTM system, but groups and subgroups are separated by caking and coking properties. Only ASTM standard methods will be described in detail hereafter.

The ASTM standard for classification of coals by rank (ASTM D-388-77) was published in 1980 and is shown in Table 2.1. Although this table is self-explanatory, a few records are made to state that the term "volatile matter" refers to the weight loss when dried coal samples (heated to above the boiling temperature of water) are further heated, in a covered crucible, to about 900°C. If the residue remaining is further combusted in air to produce an ash, the weight loss is referred to as the fixed carbon. Classification of medium volatile and higher rank coals is based on

TABLE 2.1 Classification of Coals by Rank[A]

Class	Group	Fixed Carbon Limits, percent (Dry, Mineral-Matter-Free Basis)		Volatile Matter Limits, percent (Dry, Mineral-Matter-Free Basis)		Calorific Value Limits, Btu per pound (Moist,[B] Mineral-Matter-Free Basis)		Agglomerating Character
		Equal or Greater Than	Less Than	Greater Than	Equal or Less Than	Equal or Greater Than	Less Than	
I. Anthracitic	1. Meta-anthracite	98	...	...	2	...	...	nonagglomerating
	2. Anthracite	92	98	2	8	...	...	
	3. Semianthracite[C]	86	92	8	14	...	...	
II. Bituminous	1. Low volatile bituminous coal	78	86	14	22	...	...	commonly agglomerating[E]
	2. Medium volatile bituminous coal	69	78	22	31	...	...	
	3. High volatile A bituminous coal	...	69	31	...	14 000[D]	...	
	4. High volatile B bituminous coal	...	...	...	...	13 000[D]	14 000	
	5. High volatile C bituminous coal	...	...	...	...	11 500	13 000	
						10 500	11 500	agglomerating
III. Subbituminous	1. Subbituminous A coal	...	...	...	...	10 500	11 500	nonagglomerating
	2. Subbituminous B coal	...	...	...	...	9 500	10 500	
	3. Subbituminous C coal	...	...	...	...	8 300	9 500	
IV. Lignitic	1. Lignite A	...	...	...	...	6 300	8 300	
	2. Lignite B	...	...	...	...	...	6 300	

[A] This classification does not include a few coals, principally nonbanded varieties, which have unusual physical and chemical properties and which come within the limits of fixed carbon or calorific value of the high-volatile bituminous and subbituminous ranks. All of these coals either contain less than 48 % dry, mineral-matter-free fixed carbon or have more than 15 500 moist, mineral-matter-free British thermal units per pound.

[B] Moist refers to coal containing its natural inherent moisture but not including visible water on the surface of the coal.

[C] If agglomerating, classify in low-volatile group of the bituminous class.

[D] Coals having 69 % or more fixed carbon on the dry, mineral-matter-free basis shall be classified according to fixed carbon, regardless of calorific value.

[E] It is recognized that there may be nonagglomerating varieties in these groups of the bituminous class, and that there are notable exceptions in high volatile C bituminous group.

From ASTM standard 1980

their volatile matter content. On a moisture-and ash-free basis, the percent of fixed carbon is defined as 100 minus the percent of volatile matter; therefore it is redundant to specify both the volatile matter and the fixed carbon. The low volatile coals are distinguished from the semianthracite coals by having less than 86 % fixed carbon and by being presumably agglomerating. Thus coals containing more than 86 % fixed carbon are regarded as nonagglomerating. However, this hypothesis is questionable because the petrographic composition of coal is also a factor which greatly influences coal agglomerating behavior. It also appears that the fixed carbon content is not the best criterion by which to classify anthracites into three groups. As the graphite-like layers of the anthracite matrix range in size from about 15 to several thousand angstorms, and they appear to fall into distinct ranges. These ranges do not , however, conform to the ASTM classification shown in Table 2.1.

High volatile B bituminous and lower rank coals are classified according to their calorific values on a mineral matter- (or ash-) free basis, as shown in Table 2.1. In addition, their volatile matter content must be greater than 31 %. The distinction between bituminous and sub-bituminous coals is also based on the agglomerating character of the former. Thus, coals having calorific value between 10,500 and 11,500 Btu/lb are classified as high volatile C bituminous if agglomerating and as sub-bituminous A if non-agglomerating. It should be mentioned that some high volatile C bituminous coal do not agglomerate if oxidized in air at moderate temperatures. Dry, mineral matter-free fixed carbon (dry, MM-free FC) and moist, mineral matter-free calorific value (moist, MM-free Btu) are the only parameters used in classifying coals by the ASTM methods. The formulas used in calculating FC and Btu are as follows:

$$\text{Dry, MM-free FC} = \frac{(FC - 0.15S)100}{100 - (M + 1.08A + 0.55S)} \quad (2.1)$$

$$\text{Moist, MM-free Btu} = \frac{(Btu - 50S)100}{100 - (1.08A + 0.55S)} \quad (2.2)$$

where MM = mineral matter, %

Btu = calorific value, Btu/lb

FC = fixed carbon, %

M = natural moisture content, %

A = ash content, %

S = sulfur content, %

The moisture content is that which is retained in coal at 96-97 % relative humidity and 30°c.

The conclusion here is that lignite, according to ASTM standard classification, is the coal contains calorific value of about from 6,300 to 3,300 Btu/lb in most, mineral matter-free basis and non agglomerating character.

2.2.3 Grade Classification

For a given rank of coal the amount and the nature of the mineral impurities associated with the coal vary greatly. Large coal seams containing over 30 % mineral impurities are not uncommon, nor are mines containing a few percent extraneous matter. Since the calorific value of the coal purchased is reduced by the mineral matter present, the concern over grading the coal is readily appreciated.

The grade of coal depends largely on the amount and nature of the mineral impurities associated with the coal. The mineral matter content is related to the ash produced upon burning,and ash is therefore commonly used in grading coals. Other parameters which affect the grade of a coal are moisture, size, and calorific value.

2.3 Reserves and Properties

Table 2.2 illustrates the world coal reserves[19]. Total geological resources are 10,125 billion tons which is equivalent to approximately 66,660.billion barrels of crude oil or, in other words, greater than 33 times of both approved and ultimately recoverable crude oil resources. As classified by rank, 7,725 billion tons or 76.30 % is hard coal (bituminous and anthracite) and the other 2,400 billion tons or 23.70 % is low grade coal, ie. brown coal or lignite. Only lignite reserves are shown in Table 2.3[5].

From the geological map of Figure 2.1 representing location of tertiary rocks[27] including lignite and oil shale. It implys that lignite resources in Thailand are quite scattered throughout the country, particularly in the northern part. The biggest is Mae Moh resource at Lampang province of which geological reserve of 1,300 million tons and economically recoverable reserve of not less than 450 million tons was estimated[20]. Other significant reserves are at Li, Lampoon province of about 25.04 million tons; Krabi, Krabi province of about 38 million tons; Mae Teep, Lampang province of about 10 million tons; Ban Hang, Lampang of about 54.60 million tons; Jae Korn, Lampang of about 35 million tons; and so on (all of these are geological

Table 2.2

World Coal Reserves[a(19)]

Countries	Geological Resources		Economically Recoverable Resources	
	(10^9 tons)	(%)	(10^9 tons)	(%)
U.S.S.R.	4,860	48.00	110	17.30
U.S.A.	2,570	25.38	178	27.99
China	1,438	14.20	99	15.57
Australia	262	2.59	27	4.25
West Germany	247	2.44	34	5.35
United Kingdom	164	1.62	45	7.08
Poland	126	1.24	21	3.30
Canada	115	1.14	9	1.42
Bosvana	100	0.99	4	0.63
India	57	0.56	34	5.35
Czechoslovakia	17	0.17	5	0.79
Yugoslavia	11	0.11	8	1.26
Brasil	10	0.10	8	1.26
East Germany	9	0.09	8	1.26
Columbia	8	0.08	0.4	0.06
Rhodesia	7	0.07	0.8	0.13
Hungary	4	0.04	1	0.16
Others	120	1.19	43.8	6.88
TOTAL	10,125[b]	100.00	636[c]	100.00

a Hard coal (bituminous and anthracite) and brown coal or lignite.

b About 7,725 billion tons as hard coal (high quality coal).

c About 492 billion tons as hard coal.

Table 2.3

World Lignite Reserves[5]

Countries	Qunntity (10^6 tons)
U.S.A.	901,000
U.S.S.R.	199,000
West Germany	56,000
Australia (Victoria)	39,000
Canada	33,000

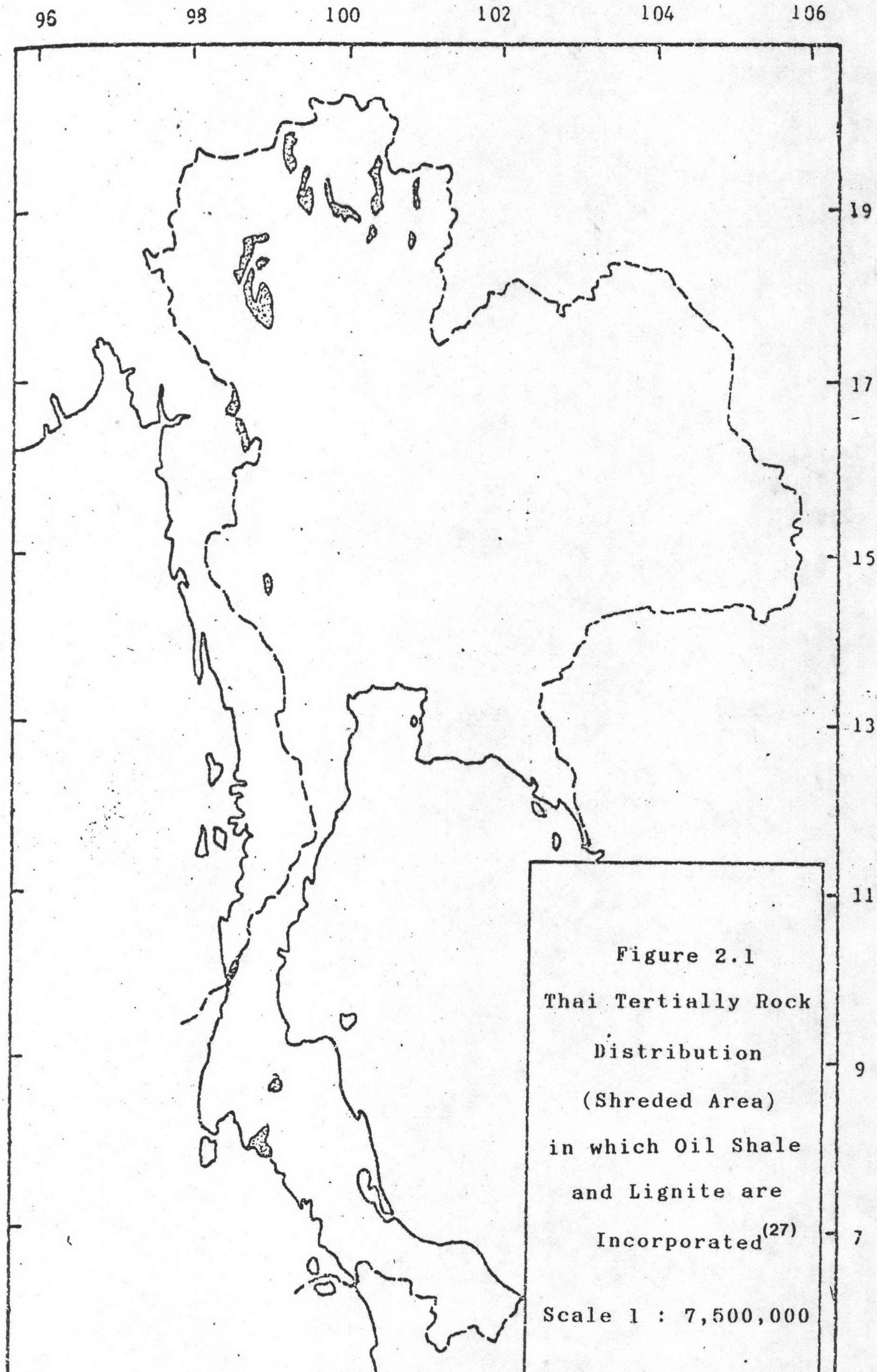

Figure 2.1
Thai Tertially Rock Distribution (Shreded Area) in which Oil Shale and Lignite are Incorporated[27]

Scale 1 : 7,500,000

Table 2.4

Properties of Mae Moh lignite[5]

Proximate Analysis

moisture(%)	ash(%)	volatile matter(%)	fixed carbon(%)
33	11	28	28

Heating Value

as received (Btu/lb)	dry ash free (Btu/lb)
6,600	11,800

Ultimate Analysis (dry basis)

C (%)	H (%)	O (%)	N (%)	S (%)
70.0	5.0	18.2	2.3	4.5

Table 2.5

Properties of Krabi Lignite (Klong Khanan)[5]

	as received	air dried	dry	dry ash free
moisture (%)	14.60-41.81	9.62-23.92	-	-
ash (%)	5.96-44.63	5.69-47.74	8.34-56.29	-
HV (Btu/lb)	4,319-8,207	5,022-8,708	5,558-10,657	8,873-12,024
AVM (%)	-	-	47.07	-
AFC (%)	-	-	41.20	-
AS (%)	2.22	2.57	3.14	3.90

where HV = heating value

AVM = average volatile matter

AFC = average fixed carbon

AS = average sulfur

Table 2.6

Properties of Li Lignite[5]

Heating Value (kcal/kg)	
average net calorific value (dry basis)	6,199
average gross calorific value (dry ash free basis)	6,964
Average Ash (%, dry basis)	11
Volatile Matter (%)	
average dry basis	41.1
average dry ash free basis	46.6
Fixed Carbon (%)	
average dry basis	58.9
average dry ash free basis	53.7

Ultimate Analysis (%, average)

C	H	O	N	S
64.1	5.8	16.2	1.0	1.41

Table 2.7

Properties of Mae Teeb Lignite[5]

Source: Hui Pon 1

	as received	air dried	dry	dry ash free
moisture (%)	24.03	18.43	-	-
ash (%)	15.43	16.57	20.31	-
HV (Btu/lb)	6,881	7,389	9,058	11,368

Source: Hui Pon 2

	as received	air dried	dry	dry ash free
moisture (%)	22.36	17.07	-	-
ash (%)	21.52	28.99	27.72	-
HV (Btu/lb)	6,318	6,742	8,129	11,848

Source: Hui Pon 3

	as received	air dried	dry	dry ash free
moisture (%)	12.71	4.47	-	-
ash (%)	68.20	74.64	78.13	-
HV (Btu/lb)	1,566	1,714	1,749	3,208

where HV = heating value

reserves). Properties of some lignites which have been used are presented in Table 2.4-2.7[5].

2.4 Utilization

Lignite, and other coals, can be used as feedstocks for several chemical industries such as fertilizer, synthetic gas, and hydrocarbon productions, as both feedstocks and heat source for, as an example, cement industry, and, as the major role, as solid fuel in modified or as received form[3].

Thailand has been using lignite for electrical generating over 20 years. Heretofore 10.23 million tons of Mae Moh lignite was consumed for that purpose. Only 5 resources as follows has been mined[23].

1. Mae Moh resource locates at Mae Moh district, Lampang province. It is expected, from geological reserve, that it can be supplied to power plants, which will be described below, for about 38 years[22].
2. Krabi resource is divided into two sub-resources at the site of Ban Bang Pu Dam, and Klong Wai Lek- Bang Mak.
3. Li resource located at Ban Pa Ka-Ban Pu, Li district, Lampoon province.
4. Mae Teeb resource at Mae Teeb, Ngaw district, Lampang province.
5. Mae Teun resource at Mae Ramad district, Tak province.

The first three resources are government resources and the other two are private ones.

In 1983 lignite at Mae Moh, Krabi, and Li were mined 1,248,432.1; 325,007.02; and 98,784.22 tons respectively[1] and overall , including private mines, of about 2.6 million tons were done. Two millions from these was used for electrical generating plants and the rest for other manufacturings, for examples, tobacco curing and cement factory[7,8].

In case of electrical generation, presently, there are five pulverized coal-fired units, at Lampang province using Mae Moh lignite, in operation. Each of the first three has a capacity of 75 MW and the other two are 150 MW each. The next two-150 MW units are under construction and three-300 MW units are in planning phase. When all these ten power plants are in operation, about 1990 A.D., 1,725 MW will be obtained. Furthermore, the first power plant using fluidized bed system of 75 MW capacity is under consultant company selection at Krabi province[24].

Cost of Thai lignite is determined by its size, ie. 0-0.5 inch costs 95 bahts per ton, 0.5-1.0 inch costs 195 bahts/ton, and 1.0-6.0 inch is 255-260 bahts/ton[7].