

Factors concerning spontaneous fires in northern Thailand coals

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Abstract: Coal deposits in northern Thailand are mainly of low quality, ranking from lignite to high volatile bituminous coal according to American Standards. Spontaneous fires in these coals are common and have caused many problems in mining practices and loss during storage.

Observations of spontaneous fires of stockpile show that the reaction starts from accumulation of heat, the direct result of absorbing energy from the sun. The dehydration reaction that first occurs is represented by disintegration of coal lumps on the surface of the stockpiles, followed by release of steam from inside of the stockpiles. The passage of steam and air flow causes oxidation, hydrolysis and hydration reactions inside the stockpiles and this gives rise to an increase in temperature from the heat of reactions, leading to partial distillation of low-temperature combustible gases such as methane and ethane. Spontaneous fires occur within 28 to 40 days for Mae Moh lignites and within 45-60 days for the coals from other places.

The prime factor causing spontaneous fires in the mining areas is the geological structures especially those related to mass movement such as faulting and slumping. These movements produce void spaces and passageways for combustible gases that originate from coalification processes and for oxygen from the outside. The low rank coals which produce low-temperature combustible gases either by coalification processes or by partial distillation as a result of increasing temperature are the major source. The spontaneous ignition could originate from a 'flash' rise in temperature which could be due to the reaction between water and sulphide minerals present in the coal. The loss can be minimized by preventing the air-oxidation through compaction both at mine fronts and stockpiles.

INTRODUCTION

Coal deposits in Thailand are mainly of low quality, ranking from lignite to high volatile bituminous coal according to American Standards (ASTM, Part 26, 1977). These low rank coal-bearing formations are reported as being deposited in more than 30 (over 50 per cent) of the Cenozoic basins which are scattered from the north through to the south of Thailand (Natalilapa and Sukonthanikorn, 1979; Ratanasthien, 1980), mostly in the western half of the country. Some small deposits of higher rank coals have also been found scattered near the northeastern border, associated with Jurassic or older rocks (Wongpornpukdee, 1980; Ratanasthien and Gibling, 1981; and Ratanasthien 1983d).

Due to low quality of the coals in most of the economic deposits, utilization of these deposits is limited, only 9 deposits are actively being mined. Two mines in the south of the country at Krabi are used for generating electricity. One in the northeast at Loei, producing graphitic-antracitic coal is mined mainly for metallurgical uses. The other six mines are located in the north, three at Li in Lumphun, two in Lampang and one at Mae Ramad in Tak. The deposits are used in tobacco curing, cement production, lime kilns, and other industries which require steam in their processes.

The serious problems concerning the utilization of these highly volatile coals are the spontaneous fires and slacking into minute pieces of coal lumps. The spontaneous fire cause trouble and heavy loss both in mining practices, during transportation and storage. The easy slacking into minute pieces will cause problems on transportation and to the firing systems as the small pieces of coal pass through the fire-grate before they are completely ignited and/or obstruct the airlet of the system. Apart from this, small pieces of coals also increase the surface area for many reactions and therefore lead to spontaneous fires.

Coalfields of Northern Thailand

Although more than 60 percent of the Cenozoic basins in northern Thailand are reported to be coal-bearing, there are only six mines actively operating (Fig. 1). These basins are mainly lacustrine or intermontane forest swamp or a combination of these two depositional environments (Ratanasthien 1983d). These coal-bearing basins were formed as a result of Cretaceous to early Tertiary differential subsidence accompanying the formation of Cenozoic granites and volcanics. Asnachinda (1978) modeled the tectonic evolution of northern Thailand, for his tin mineralization study, and suggested that collision of the Burmese-Malayan microcontinent with the Indochina Block during the Carboniferous-Triassic Period caused narrowing of the seaway and the emergence of the whole of Southeast Asia during late Triassic times (Carnian-Horian). The overthrusting Burmese-Malayan Block was uplifted and intruded by granitic magma generated as the result of the collision. The western half of the under thrusting Indochina Block subsided with accumulation of thick nonmarine clastic sediments ranging from upper Triassic to Cretaceous in age. The development of an eastward dipping subduction zone from the Indian Ocean since late Jurassic, may be the cause of the Cretaceous-Tertiary granitic rocks. By the end of the Mesozoic era, back-arc extensional tectonics lead to updoming and formation of Tertiary basins in the Gulf of Thailand as well as in the northern part of the country. These fault-originated basins were eventually filled with sediments including organic matter, the source of coal, oil shale and natural gas.

In northern Thailand, the Cenozoic strata rest unconformably on Mesozoic and older rocks. The stratigraphic sequence is similar in most of the large basins. The lower most unit (Mae Sot Formation at Fang, Mae Sot Series at Mae Sot, Mae Moh and Li Formation at Mae Moh and Li) consist of conglomerate grading upwards to gritty sandstone and micaceous sandstone, mudstone, coal and oil shale. The overlying unit consists of mudstone, sandstone, conglomerate and red beds with some gypsum or laterite in the uppermost part. At Fang, the Mae Fang Formation consists of bluish gray arkosic sand with coalified wood, reddish brown clayey sand, and some yellowish brown arkosic sand on top. The stratigraphic details indicate that the environment changed from fault-bounded basins with angular coarse clastic deposits to lacustrine environments of moderate depth, where fish, gastropod and reptile fossils accumulated, to shallow lakes and peat swamps, and finally to fluvial environment. The presence of gypsum and calcareous nodules in the uppermost laminated mudstone also suggests high salinity and pH conditions locally resulting from diagenetic processes which may have favoured organisms such as bluegreen algae which contributed to the formation of thin bedded oilshale.

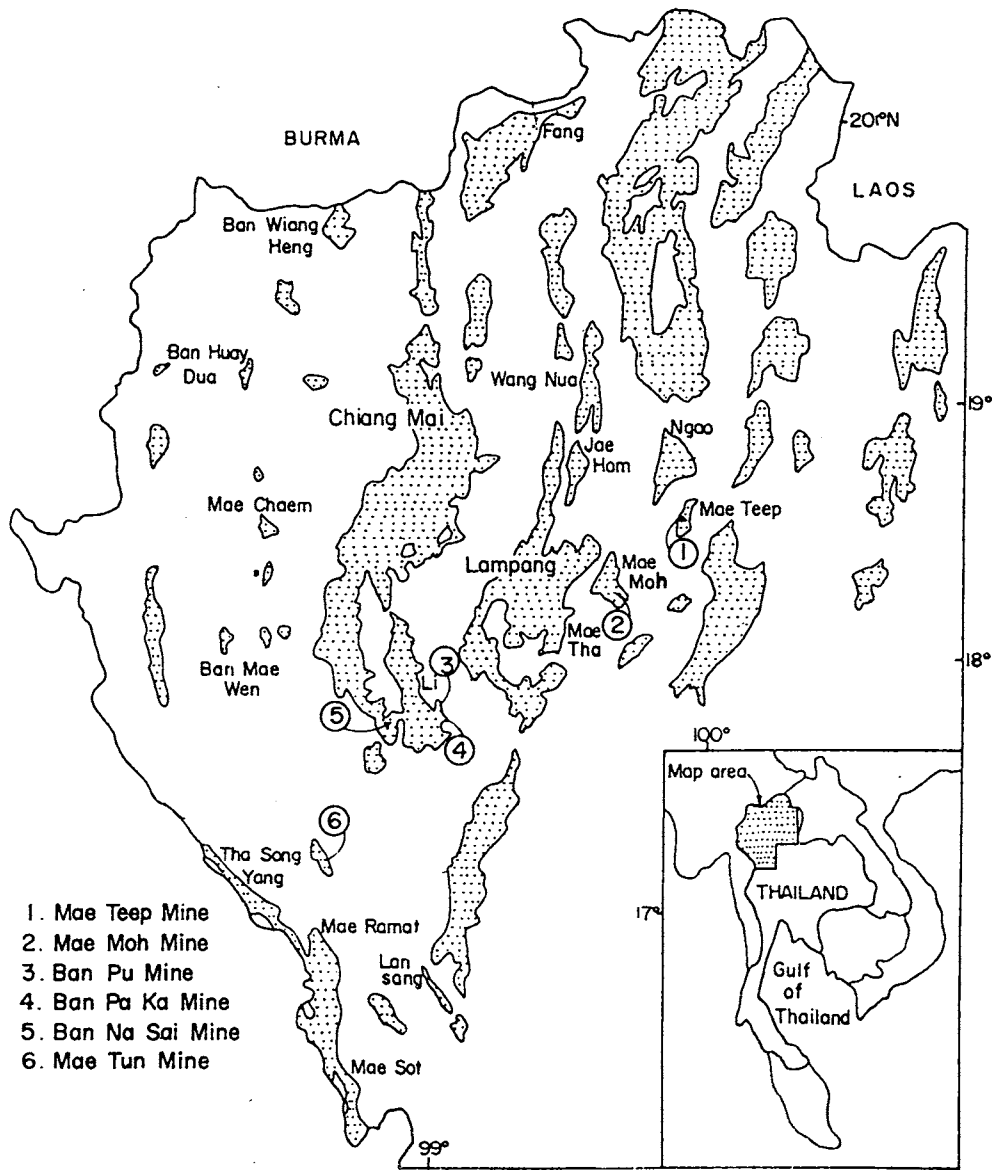


Fig. 1. Major Cenozoic basins in northern Thailand showing the location of coal mines (The name of mines are after local villages).

Coal Quality

The quality of coals in northern Thailand rank from lignite to high volatile bituminous coal according to American Standards (ASTM Part 26, 1977). The quality of coals vary from place to place depending very much on the environment at the time of deposition, leading to varying ash and sulphur content in coals. These contents play a very important role in their utilization. In general, coals associated with the intermontane forest swamps usually are of better quality than the coals at are associated with lacustrine environments (Ratanasthien 1983d). The coals of such environments are composed mainly of woody debris of land and moorland plants, tree trunks are also common in some places as clearly seen at Ban Pu, Li, and Mae Tun and Mae Ramad coalfields. In the more open-water environments especially small lacustrine ones, inorganic materials can easily be transported into the basins, and deposited together with organic debris of sedges, reeds or pond weeds and probably herbaceous plants. Aquatic and subaquatic animal remains such as fish scales, gastropod shells are also common and the decomposed parts are a good source of sulphur. Most of the deposits show a reducing condition which favours the formation of framboidal pyrite disseminated through out the coals resulting from the consumption of sulphate reduction bacteria. In the case of large lacustrine basins where less inorganic materials are transported into the basin, the coals could be low ash coals formed from the deposition of pond weed alone. Alternatively they could be high ash coals resulting from the water conditions that favour the boom of planktonic organisms such as siliceous or calcareous diatoms and hence result in diatomaceous coals as seen in Mae Moh coals.

Where the condition of environment was of the mixing type (lake and forest swamp) the levels of water move up and down, sometimes the lake is dry sometimes flooded. The quality of the coals resulting depends on the level of the water. The higher the water level, the higher the ash content in coals. These can be seen clearly in Mai Teep and Ban Pa Ka minefronts where the clay partings wedge out, thinner to the forest swamp ashore and thicker to the more open-water in the lake.

In the utilization and mining practices, high ash content coals cause some problems to the use and require ore dressing, either by hand picking or by mechanical dressing. Some layers of poor quality coals have to be discarded and cause the reduction in mineable reserves. The current methods of improving coal quality are however, considered to be satisfactory. Table 1 shows the proximate analysis of coals from 6 mines in Northern Thailand being mined during January to August, 1983.

Spontaneous Fires in Northern Thailand Coals

Spontaneous fires in Northern Thailand Coalfields had been recognized even before the mines began operation. For example, Mae Moh farmers recognized the places called 'fire ponds' in Mae Moh Basin and then were identified as dangerous areas for cattle. Spontaneous fires are also common in the pits, dumping areas and in stockpiles. Generally, ignition occurred mainly in piles of coals consisting of fragments of various sizes and fine dust piled up for sometime in the stockyard or had been abandoned in the pit or dumped after removal of overburden. At the stockyards, it has

TABLE 1
PROXIMATE ANALYSIS OF NORTHERN THAILAND COALS DATA FROM
CURRENT MINE FRONTS AS REPORTED IN RATANASTHIEN (1983 b)

Location Analyses	Ban Pu Li	Ban Pa Ka Li	Ban Na Sai Li	Mae Moh Lampang	Mae Teep Ngoa	Mae Tun Mae Ramad
Moisture %	28.3-31.8 (29.62)	18.6-21.6 (20.34)	25.0-42.4 (36.10)	22.7-30.7 (26.88)	18.7-20.7 (19.95)	10.8-14.8 (12.38)
Volatile Matter %	29.7-30.4 (30.02)	31.4-35.3 (33.34)	25.1-31.0 (29.03)	33.4-36.3 (35.04)	25.1-29.8 (28.05)	24.6-37.2 (31.01)
Ash %	5.4-0.5 (6.38)	14.5-22.8 (18.19)	12.4-16.5 (13.86)	7.5-10.3 (9.06)	22.0-28.7 (24.62)	8.8-24.0 (16.36)
Fixed carbon %	32.4-35.6 (34.13)	27.1-29.3 (28.13)	15.9-31.3 (22.05)	25.5-32.1 (29.02)	27.0-27.5 (27.38)	33.3-48.1 (40.25)
Sulphur %	2.4-2.6 (2.48)	1.3-2.3 (1.80)	1.2-2.8 (1.79)	1.1-1.8 (1.50)	0.9-1.3 (1.02)	0.9-2.1 (1.48)
Gross Calorific value cal/g	3800-4000 (3900)	4000-4400 (4250)	2600-3300 (3000)	3800-4000 (3950)	3300-3700 (3580)	4500-5800 (5050)

Number in parentheses are the average values.

been observed that ignition occurred within 28-40 days after loading for Mae Moh coals, 40-50 days for Li coals and over 60 days for Mae Tun and Mai Teep coals.

Recently, spontaneous fires in Mae Moh mine have been observed reoccur many times at a number of points in the pit, even after fires had been stopped by many processes. These points of fires had been carefully investigated and it was found that at most of these fire spots, there are at least two sets of faults, generally more (Ratanasthien 1983a). At some of these fire-spots, the displacement of faults cannot be seen but fault breccia in lignite has been noticed. But in many places, fires are associated with slumps due to slope failure caused by faults. Subsequently it was also found that fires occurred in Ban Pu Mine at Li and Mae Teep Mine at Ngoa. These were also associated with sets of faults. For a greater understanding of the mechanism whereby these high volatile coals catch fire, a study of coal stockpile spontaneous fire was carried out using Mae Moh lignite in February to April, 1983 (Ratanasthien, 1983c). In addition the composition of gases of northern Thailand coals and their ignition temperature, which were determined at the Department of Geological Sciences and Department of Chemistry, Faculty of Science, Chiang Mai University.

Factors Concerning with Spontaneous Fires in Northern Thailand Coals

The causes of such spontaneous ignition has been studied both in the fields and laboratory during the past 50 years, Kim (1977), Dunrud and Osterwald (1980) had concluded that spontaneous combustion of coals was due to the following main factors:

—availability and flow of oxygen

- particle size
- ranks of coal
- changes in moisture content
- other factors, such as pyrite content, temperature, geologic structure, and mining practices

It has been observed that fires in Mae Moh, in addition to being due to low rank of coal and piling up of fine-grained lignite which is then therefore likely to be spontaneously combusted, that they are evidently also related to the geologic structural environment especially the mass movement structures caused by faults and slumps. Movement along faults not only crushed lignite into finer pieces of fault breccia but also produced void spaces between pieces and in the adjacent sedimentary sequences. These then became more permeable and are the passage ways of combustile gases such as methane, ethane, alcohol etc., which are products of coalification processes. These combustible gases are diffused slowly through the overburden of claystones, siltstone, and accumulate in the layer where there is an impermeable cap resulting in fireable shale or claystone. When these faults or fractures penetrate the stratigraphic unit where coalification occurs, these gases are easily mobilised.

Fault systems in Mai Moh basin can be divided into four sets. The earliest set is the low angle faults of approximately 20–25° dip. This set is cut by the second set which forms a N-S trending, high angle step faults. This set is the most important for it affects up to 20–30 m different levels of lignite seams in the whole basin. The third set is the series of faults trending in an east-west direction which caused the vertical displacement of 10–50 m of lignite seams. The last set of faults is the set trending oblique to the second and the third sets, mainly north-north east direction.

Faults associated with fire spots in Mae Moh basin are those faults in third and fourth sets which are generally young and their movement are probably still active. Their displacement vary from few centimetres to more than 30 metres in some places and they are medium to high angle faults. Lignite breccia caused by fault movement assists in the oxygen penetration into the lignite beds, where, in some cases, fire was found to be active at more than 20 metres depth.

During February to April, 1983 three experimental stockpiles using 1500 tons, 80 tons and 65 tons of Mae Moh lignite were loaded to study spontaneous fires in stockpiles. The physico-chemical reactions of lignite in the experimental stockpiles were recorded from the time when the lignite was unloaded until when the piles caught fire and were removed. The reactions were similar in both the large and small stockpiles.

The first reaction which was observed was the loss of moisture which could be seen within 3 days of the lignite having been unloaded. This reaction was represented by the appearance of cracks in the lignite lumps. Three styles of slacking had been noticed in the Mae Moh lignite. The first style consisted of nearly rectangular cracks deep into the lumps of coal. This style usually occurred on the bright humic lignite with low ash

contents. The lignite was gradually slacked into small cubelike particles. The second style occurred mainly on the dull, high ash content lignite, and resulted in thin plates. The slacking ended up with small plate-like particles to fine powder. The last style, exfoliation, occurred mainly with the hard lignite and siliceous black shale or siltstone. The hard lignite, which was generally black, dense, and with a moderate ash content but high calorific value, usually produced a small exfoliation together with concoidal to subconcoidal fracture, while the siliceous black shale or siltstone produced a larger exfoliation on prolonged standing in the sun.

After the lignite had piled for approximately 10–12 days (this time was less for smaller stockpiles), steam started to be released, although this could only be noticed during the early morning. The points of release depended on the size of the stockpile. For large stockpiles (8 m height), the points were on the slopes, while for the small stockpiles they were on or near the top.

During the periods of steam production, temperatures were generally maintained at around 80–90°C. This would imply that the energy absorbed from the sun and the surroundings had been used mainly for partial distillation. These temperatures were maintained for approximately 10–15 days. The amount of steam then noticeably

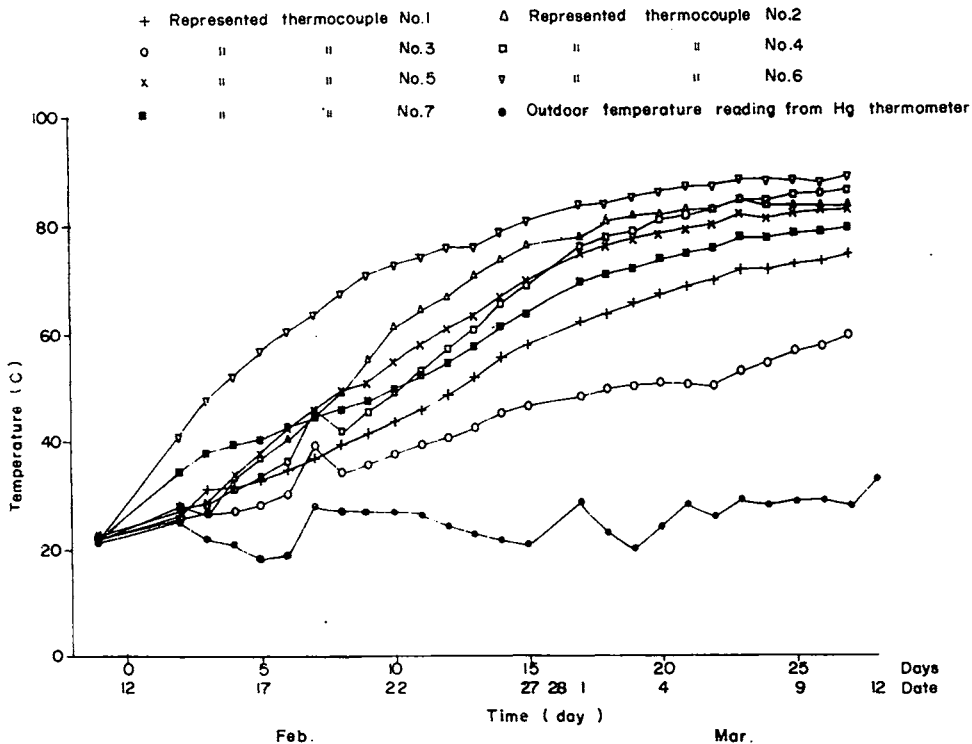


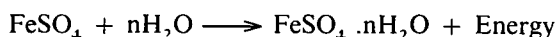
Fig. 2. Graphs show the temperatures reading at 09.00 AM of large experimental stockpile for large industrial usage. After Ratanasthien (1983c).

decreased, before the temperature started to increase again. The temperature would then again remain constant, but when it started to increase again subsequently, the rate of temperature increase was very fast. Smoke was released instead of steam and eventually the stockpile caught fire.

According to the observation from the accumulating temperature data for each thermocouple (Fig. 2) and the occurrence of steam release and fire in these experimental stockpiles, it was noticed that the major activity took place within a limited distance of not more than 3 metres from the surface of the pile where the coal was exposed to the sun. The area contained within a distance of approximately one metre from the foot of the pile may be called 'the area of dryness'. The major reactions in this area were mainly one of losing moisture with the consequence that fire usually broke out in this area. The area from above one metre up to 5 metres for the triangular shaped stock-pile may be called 'the area of reaction' since the major reactions of oxidation, hydration and hydrolysis caused by the release of steam from underneath through the upper coal pile occur mainly in this area. The oxidation reaction showed a pronounced effect on the decomposition of pyritic sulphur as follows:

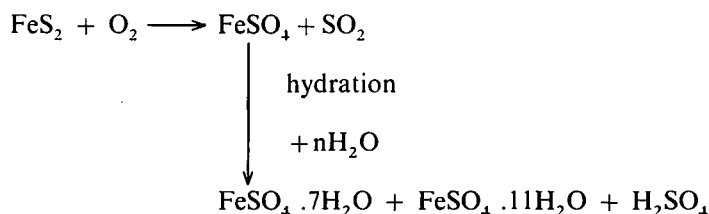


followed by the hydration reaction

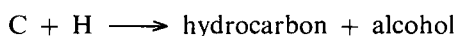


These reactions are evidenced by the development of ferrous sulphate crystals and sulfur crystals in the areas where the steam was released.

In the case of complete oxidation, the reactions would be:



These reactions involve the formation of enormous amounts of heat due to the heats of reactions as well as the heat of solution of sulphuric acid. This evolved heat would be accumulated in the stockpile if there was not enough ventilation and led to another reaction, hydrolysis, where molecules of water decomposed and reacted with the coal:



The hydrocarbon and alcohol produced by this reaction gives rise to the accumulation of low firing temperature components in addition to those already associated in the coal as "volatile matter". At the appropriate temperatures, the partial distillation of these fireable components could take place, causing fire in the areas of high temperature and low moisture. When this partial distillation occurred, it could be

observed through the stabilization of the accumulating stockpile temperature at approximately 80–90°C and again at 130°C. The results of low temperatures carbonization of the northern Thailand coals from 5 localities, Ban Pu and Ban Pa Ka, Li District, Mae Moh, Lampang Province, Mae Teep, Ngao District and Mae Tun, Mae Ramad District showed that 100 gm of coal contained 43.6–46.6 gm solid residue, 5–18 cm³ liquor, 2–3 cm³ tar and 8300–18000 cm³ gas (Table 2). The gas analyses show that methane and mercaptan are the major components 25–40% and 16.8–39%, respectively with small amounts of ethane 1.7–3.6% by volume (Table 3). When the heat accumulated in the stockpiles, these combustible gases were partially distilled off

TABLE 2

RESULTS OF LOW TEMPERATURE CARBONIZATION BY FISCHER ASSAY OF NORTHERN THAILAND COALS (USING 100 GM OF MOISTURE-FREE COALS)

Location Yield	Ban Pu Li	Ban Pa Ka Li	Mae Moh Lampang	Mae Teep Ngao	Mae Tun Mae Ramad
Solid residue (gm)	43.6–59.6 (51.82)	62.2–67.8 (65.1)	55.2–60.7 (57.33)	60.8–65.2 (63.18)	70.0–76.6 (72.69)
Liquor (cm ³)	10.0–16.0 (12.75)	5.0–9.0 (7.5)	16.0–18.0 (16.5)	10.0–16.0 (12.50)	7.0–16.0 (11.5)
Tar (cm ³)	2.0–4.0 (2.75)	10.0–13.0 (12.25)	6.0–9.0 (7.25)	6.0–10.0 (8.25)	5.0–9.0 (7.25)
Gas (cm ³)	14,000– 18,000 (16,750)	8,300– 14,500 (11,950)	15,000– 17,000 (15,875)	14,000– 16,000 (15,000)	10,000– 11,500 (10,625)

Number in parentheses are the average values.
Data from Kumpukdee (1983)

TABLE 3

COMPOSITION OF GASES (PERCENTAGE BY VOLUME) OF NORTHERN THAILAND COALS DECOMPOSED BY FISCHER ASSAY CARBONIZATION AT T = 600°C (DATA FROM KUMPUKDEE, 1983)

Location Composition of gas	Ban Pu Li	Ban Paka Li	Mae Moh Lampang	Mae Teep Ngao	Mae Tun Mae Ramad
H ₂ S	1.60	2.16	2.66	0.32	0.91
Mercaptan	39.0	25.14	23.84	24.58	16.49
CO ₂	11.4	6.0	5.5	5.8	2.6
CO	7.5	13.1	10.2	7.9	9.1
Unsatn	0.55	3.3	1.8	0.8	2.5
H ₂	9.0	8.2	11.6	11.0	10.0
CH ₄	28.0	25.0	40.0	33.0	39.0
C ₂ H ₆	1.7	2.4	3.4	3.2	3.6
Others	1.25	14.7	1.0	13.4	15.8

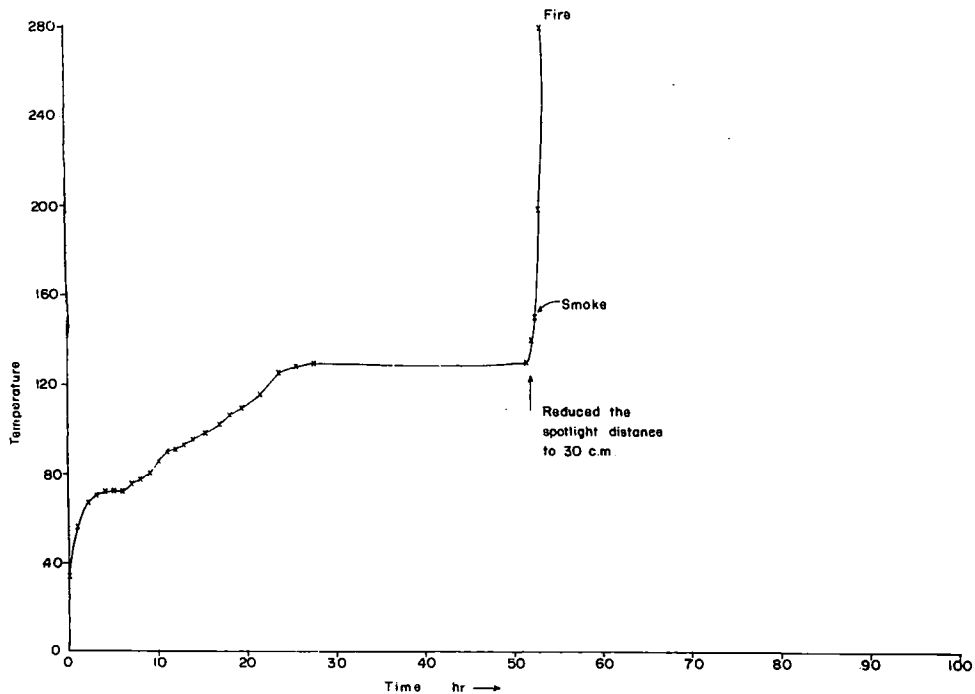


Fig. 3. Graph showing the ignition temperature of Mae Moh lignite. Noted the stabilization of temperature at 70–76°, 90–93° and 129–130°C. Fire started around 140°C. Ater Ratanasthien (1983c).

as they are a good source of fire. The partial distillation was seen clearly in the experiment to find ignition temperature (Fig. 3) where the accumulative temperature leveled out at a number of certain temperatures.

How the fire starts is not exactly known. In the pit, rain and moisture are thought to be the agents causing temperature increase by the reaction with pyrites. The heat of reaction between water and pyrite to form iron sulphate by oxidation reaction and the heat produced by hydration and dissolution of both sulphate compounds and oxides of sulphur are great enough to reach the ignition temperature of coals. The reaction is comparatively quick and may be called 'flash point' when the heat is raised sharply and subsequently catches fire. The fire starts at the point with suitable level of moisture content, then the prevailing oxygen, combustile gases, and broken pieces of coals together are a good source to expand the fire and it becomes a large spot before it can be noticed.

Suggestions for preventing spontaneous fires

1. Compact the coal to prevent the loss of moisture from the coal and to reduce the reaction surfaces.
2. Reduce the surface areas exposed to the sun by, for example, storing the lignite

under a roof. However, in practice, this could only be done for small to intermediate sized lignite stockpiles.

3. Reduce the sloping area, especially the foot of the slope where the lignite is thinly spread and from where it is easiest to lose moisture. This could be done by the aid of retaining walls which should be built on the west side.
4. Remove and use the stocked lignite before the critical time limit (28 days for Mae Moh lignite, 45 days for coals from other mines).

CONCLUSION

Factors concerning spontaneous fires in northern Thailand coals both in the coalfields and stockpiles are:

1. The coals vary from lignite to high volatile bituminous coals, that is are high of volatile rank.
2. The geological structures especially the faulting system in the coalfields. These produce passage ways for the combustile gases, the product of coalification processes, to seep to the minefront where oxygen is available together with fine-grained coals.
3. The partial distillation of combustile gases by heat accumulation in coal piles.
4. The temperature accumulation that is high enough to reach the ignition point.

Once the fire starts the prevailing oxygen, combustile gases and the coal itself are the sources to spread the fire.

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