REDUCTION OF IMPURITIES IN LIGNITE FROM MAE MOH MINE USING CHEMICAL CLEANING

Pornchai Khamhom

A Thesis Submitted in Partial Fulfillment of the Requirements for the

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การลดสารมลทินในถ่านหินลิกไนต์จากเหมืองแม่เมาะ
โดยใช้วิธีการทำความสะอาดด้วยสารเคมี

นายพรชัย คำหอม

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิศวกรรมศาสตรมหาบัณฑิต
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REDUCTION OF IMPURITIES IN LIGNITE FROM MAE MOH MINE USING CHEMICAL CLEANING

Suranaree University of Technology has approved this thesis submitted in partial fulfillment of the requirements for the Master’s Degree.

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พรชัย คำหอม : การลดสารมลทินในถ่านหินลิกไนต์จากเหมืองแม่เมาะโดยใช้วิธีการทำความสะอาดด้วยสารเคมี (REDUCTION OF IMPURITIES IN LIGNITE FROM MAE MOH MINE USING CHEMICAL CLEANING) อาจารย์ที่ปรึกษา : อาจารย์ ดร.บัณฑิตา ธีระกุลสถิตย์, 189 หน้า.

เหมืองแม่เมาะเป็นเหมืองถ่านหินที่มีขนาดใหญ่ที่สุดในประเทศไทย ซึ่งมีความเหมาะสมสำหรับการใช้เป็นเชื้อเพลิงสำหรับโรงไฟฟ้าถ่านหิน คุณภาพถ่านหินของแม่เมาะจัดเป็นถ่านหินลิกไนต์ มีปริมาณของซัลเฟอร์และโลหะหนักอยู่สูง จึงเป็นข้อจำกัดในการนำไปใช้ประโยชน์ โดยจะส่งผลถึงการเกิดก๊าซซัลเฟอร์ไดออกไซด์และสารประกอบที่เป็นพิษ ทำให้เกิดฝนกรด มลพิษต่อสิ่งแวดล้อม และการกัดกร่อนอุปกรณ์ที่เป็นโลหะ วัตถุประสงค์ของการศึกษาครั้งนี้คือเพื่อศึกษาประสิทธิภาพของสารละลายกรดไฮโดรฟลูออริก กรดไนตริก กรดไฮโดรคลอริก โพแทสเซียมไฮดรอกไซด์และโซเดียมไฮดรอกไซด์ ที่มีผลต่อการลดปริมาณซัลเฟอร์และโลหะหนักในถ่านหินลิกไนต์ของแม่เมาะ โดยการปรับปรุงคุณภาพถ่านหินถูกศึกษาที่สภาวะอุณหภูมิแวดล้อม โดยใช้สารเคมีแต่ละชนิดที่มีความเข้มข้น 1 โมลต่อลิตร และใช้เวลาในการแช่สารเคมี 24 และ 48 ชั่วโมง จากผลการศึกษาที่เวลาการแช่ตัวอย่างถ่านหินในสารเคมีที่ 24 ชั่วโมง พบว่าปริมาณสารซัลเฟอร์ลดลงได้มากที่สุดในสารละลายโพแทสเซียมไฮดรอกไซด์ ประมาณ 20% และลดลง 4% ในสารละลายโซเดียมไฮดรอกไซด์ สารละลายเบสเหล่านี้ยังส่งผลต่อการการเพิ่มขึ้นของสัดส่วนปริมาณคาร์บอนในถ่านหินด้วย ส่วนสารละลายกรดส่งผลให้สัดส่วนของคาร์บอนคงที่ในถ่านหินเพิ่มขึ้น 31.7% ในกรดไฮโดรฟลูออริก และเพิ่มขึ้น 16.1% ในกรดไฮโดรคลอริก ปริมาณความชื้นจะถูกลดลงมากที่สุดโดยการใช้สารละลายกรด ในช่วงประมาณ 40 ถึง 45 % โดยจะลดลง 41% ในสารละลายโซเดียมไฮดรอกไซด์ และ 31 % ในสารละลายโพแทสเซียมไฮดรอกไซด์ ส่วนปริมาณโลหะหนักในตัวอย่างถ่านหินที่ถูกลดลงมากที่สุดคือสารหนู ลดลงประมาณ 100% โคบอลต์ ลดลง 49% และสารตะกั่ว ลดลง 11% หลังจากผ่านการแช่ในสารละลายกรดไฮโดรฟลูออริก ปริมาณสารหนู ลดลง 52% โคบอลต์ ลดลง 9% และวาเนเดียม ลดลง 13% ตามลำดับ หลังผ่านการแช่ในสารละลายกรดไนตริก และในสารละลายกรดไฮโดรคลอริก ปริมาณโคบอลต์ ลดลง 91% และวาเนเดียม ลดลง 48% โดยในสารละลายเบสมีผลต่อการเปลี่ยนแปลงปริมาณโลหะหนักในถ่านหินน้อยมาก จากผลการเปลี่ยนแปลงของการลดปริมาณแร่ธาตุในถ่านหินส่งผลโดยตรงต่อการเปลี่ยนแปลงปริมาณซัลเฟอร์และโลหะหนักในถ่านหิน ปริมาณธาตุร่องรอยในถ่านหินจะเกิดขึ้นพร้อมกับแร่ยิปซัม เคโอลิไนต์ และอิลไลต์ การลดลงของปริมาณซัลเฟอร์และโลหะหนัก ขึ้นอยู่กับประสิทธิภาพของสารเคมี ที่จะสามารถเกิดปฏิกิริยากับแร่ต่างๆในถ่านหินได้ จากผลการศึกษาที่เวลาการแช่ตัวอย่างถ่านหินในสารเคมี 48 ชั่วโมง ไม่มีผลต่อการเปลี่ยนแปลงแร่ธาตุใน

ถ่านหินเมื่อเปรียบเทียบกับการแช่ในสารเคมี 24 ชั่วโมง แสดงถึงเวลาที่เพิ่มขึ้นจากเดิมไม่มีผลต่อการเกิดปฏิกิริยาเคมีที่เพิ่มขึ้น ซึ่งกระบวนทางเคมีของสารเคมีได้เกิดเสร็จสิ้นภายใน 24 ชั่วโมง โดยสรุปจากการศึกษาสารละลายกรดไฮโดรฟลูออริกมีประสิทธิภาพในการลดปริมาณสารมลทินในถ่านหินมากที่สุด รองลงมาเป็นกรดไนตริก และกรดไฮโดรคลอริก ตามลำดับ แต่สารละลายกรดส่งผลต่อการลดลงของโครงสร้างคาร์บอนในถ่านหินเล็กน้อย ทำให้ศักยภาพของถ่านหินลดลงตามปริมาณคาร์บอน เนื่องจากสารละลายกรดไฮโดรฟลูออริกเป็นสารละลายที่มีประสิทธิภาพสูงสุด แต่เป็นสารเคมีที่มีอันตรายสูง และยากต่อการกำจัด ดังนั้นสารละลายที่เหมาะสมต่อการปรับปรุงคุณภาพของถ่านหินจึงเป็นสารละลายกรดไนตริก รองลงมาเป็นกรดไฮโดรคลอริก ส่วนสารละลายโพแทสเซียมไฮดรอกไซด์และโซเดียมไฮดรอกไซด์มีประสิทธิภาพสูงต่อการลดลงของปริมาณซัลเฟอร์ และยังส่งผลถึงการเพิ่มขึ้นของปริมาณคาร์บอน แต่จะมีผลเล็กน้อยต่อการลดลงของโลหะหนักในถ่านหิน

สาขาวิชา เทคโนโลยีธรณี
ลายมือชื่อนักศึกษา ____________________
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ลายมือชื่ออาจารย์ที่ปรึกษา________________

PORNCHAI KHAMHOM : REDUCTION OF IMPURITIES IN LIGNITE FROM MAE MOH MINE USING CHEMICAL CLEANING. THESIS ADVISOR : BANTITA TERAKULSATIT, Ph.D., 189 PP.

IMPURITY REDUCING/ CHEMICAL CLEANING/ MAE MOH COAL FIELD

Mae Moh coal field is the largest coal in Thailand, which is suitable for use in a power plant for electricity generation. The Mae Moh coal is classified as a lignite, which the high sulfur and heavy metal contents impose severe limitations on its utilization as the sulfur oxide gases and toxic elements evolved from the combustion resulting in acid rains, environment pollution and corrosion of equipment. The objective of this study is to investigate the efficiency of HF, HNO_3, HCl, KOH and NaOH on the desulfurization and heavy metals removal from the Mae Moh lignite. This treatment was studied at ambient temperature and 1 mole per liter of a chemical concentration for 24 and 48 hours. From the result of the 24 hours leaching test, the sulfur content has reduced about 20% in KOH and 4% in NaOH. These base solutions also has highly affected by increasing of ash in coal. The acid solution can increase a fixed carbon about 31.7% in HF, increase 16.1% in HCl. Moisture content can be reduced range from 40 to 45% in acids, reduced 41% in NaOH, and 31% in KOH. The heavy metals in the coal sample mainly reduce an arsenic (As) is nearly 100%, cobalt (Co) is reduced about 49%, and lead (Pb) is reduced 11% after treating with HF. The arsenic, cobalt, and vanadium were respectively reduced by 52, 9, and 13% in HNO3, the cobalt and vanadium was respectively reduced by 91% and 48% in HCl. For the base solution made a little change of the heavy metal contents in coal.

samples. From the variation of mineral reduction in coal has affected directly on the changing of sulfur and heavy metal contents. Most of trace elements in the coal are associated with other minerals such as gypsum, kaolinite and illite. The content of sulfur and heavy metal element reduction depended on the effectiveness of chemicals that react with minerals in coal. The study at condition 48 hours of soaking time has no more significance to variety of minerals in coal than 24 hours that represents the increasing of time has not effect on increasing of reaction due to the chemical reaction have completed in 24 hours. In conclusion, HF has the highest effectiveness followed by HNO_3 and HCl, respectively. However, these acids have slightly affected the reducing of the carbon matrix in coal. Despite hydrofluoric acid is the highest effective chemical, it is a hazardous chemical and difficult to treat. From these reasons, the appropriate chemicals for coal treatment is HNO_3 followed by HCl. Potassium and sodium hydroxide are high efficiency for the sulfur reduction and also increase the carbon contents, but have a little effect on reducing of heavy metals in coal.

School of Geotechnology . Student's Signature_________________

Academic Year 2013 Advisor's Signature_________________

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Pornchai Khamhom

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SYMBOLS AND ABBREVIATIONS

af = Ash-free

ar = Ash received

d = Dry

HHV = High heating value

I, J, K, and Q = Coal seam

kg = Kilogram

kV = Kilovolt

LHV = Low heating value

M = Million

M = Molar

mA = Milli ampere

MHz = Megahertz

MJ/kg = Megajule per kilogram

mm = Millimeter

MMCF = Million cubic feet

mmf = Mineral matter-free

ppm = Past per million

Ro = Vitrinite refractan

W = Watt

wt = Weight

CHAPTER I

INTRODUCTION

1.1 Introduction

In 2010, the growing up of Thailand is approximated by GDP (Gross Domestic Product) that is raised to 4 percent by yearly. Moreover, electricity consumption is raised to 4.2 percent of yearly due to growing up the GDP of the country based on electricity using for economic development. The 70 percent of fuel source for power plants are from fossils, natural gas, coal, and oil. Thailand use 70 percent of natural gas, 20 percent of coal, 7 percent of hydro power, and 3 percent others in the power plant. The natural gas is mainly used for power plant. From considering of the natural gas reserve is expected about the next 21 years or in 2032 will empty; based on consideration of proved and probable reserve at 22.87 MMCF (Ministry Energy, 2012). The alternative energy is most important to solve these problems. The well resource should have 5 important features, must have sufficient reserve to ensure the stability, must have a distribution of source and types of fuel source to reduce the risk of production from one source, fuel must have proper cost and stable, easy to control pollution from the operation, and must use the limited resources of the country for maximum benefit. Following the above considerations and data used to study from the fuel resource. Coal can be instead of natural gas. The coal in Thailand is mainly lignite and some subbituminous. The amount of total coal reserve is 2,150 million tons, which is lignite 2,075 million tons (Ministry Energy, 2012) and almost produced from the Mae Moh Coal Field. In 2011, the Mae Moh mine was produced the 4,929 thousand tons of lignite that are raised to 2.4 percent and 13.3 percent of natural gas (EPPO organization, 2012). Because of lignite is a low grade of coal: low carbon content, high moisture content and impurities. From the following data by using of the natural gas is nearly 6 times of coal. The expensive of the pollutant removal unit make an uncertainty for investment. The resistant of community around the Mae Moh mine is one of most important topic. Because of in the past, the technology is not good enough to eliminate the pollutant from exhaust gases that make the community around the Mae Moh mine got poor health. The community has a sore throat, dizziness, suffocate, angina, sneeze, keen nose, which is the chronic disease. From this reason coal cleaning is more important, which reduces sulfur compounds, phosphate compounds, ash, metals in ash, gypsum and others. After the coal cleaning process will get high coal quality. The using of high coal quality is reducing the cost of the pollutant removal unit and get low cost of electric production, environmentally friendly production, and maximum benefit from using of the limited resource.

1.2 Study area

Mae Moh Coal Field

The Mae Moh basin is located in the Mae Moh District of Lampang Province between 18° 18’ 21” north latitude and 99° 44’ 02” east longitude, 26 kilometers east of the Lampang city and about 630 kilometers north of Bangkok (Figure 1.1). The syncline shaped basin covers an area of 104 square kilometers, 7 kilometers in east – west and 16 kilometers in north – south (Figure 1.2). Coal occurs in six zones as the S, R, Q, K, J, and I zones. A set of north – south trending faults divide the basin into western sub - basin and eastern sub – basin. The basin was flanked by marine Triassic rocks to the north, east, and west. These marine Triassic rocks constituting the Lampang Group, are mainly limestone, shale, and sandstone. The Pha Khan formation is the oldest, which consists of dark gray massive limestone and marine fossils that found at the west of the basin. At the eastern edge of a Mae Moh basin are composites of Hong Hoi, Doi Chang, and Pha Dang formation. The south of the basin was sealed by Quaternary basalt that overlains on Tertiary sediments and Triassic shale and limestone. From the exploration well in 1984 represents Tertiary sediments underlain by basement rock, including fine grained sandstone and dark gray shale of Hong Hoi formation, the Lampang Group as angular unconformity (Figure 2.1). The eastern sub – basin contain some coal and is so far exploited for a power plant operated by the Electricity Generating Authority of Thailand (EGAT). The Tertiary sediments have been named as the Mae Moh Group, which sequence has been divided into three formations such as the Huai King, Na Khem, and Huai Luang Formation. The total thickness is nearly 1,000 meters (Songtham *et al.*, 2004). The paleomagnetic study of Mae Moh stratigraphy shows that the Mae Moh Group was deposited in the Middle Miocene. It was supported by mammalian fossil, proboscidean, *Stegolophodon praelatidents* sp. found at the K zone in 1959 (lower to middle Miocene), rhino carotid, *Gaindatherium* sp., and mustelid carnivore, *Siamogle thailandica* sp. (middle to late Miocene) .

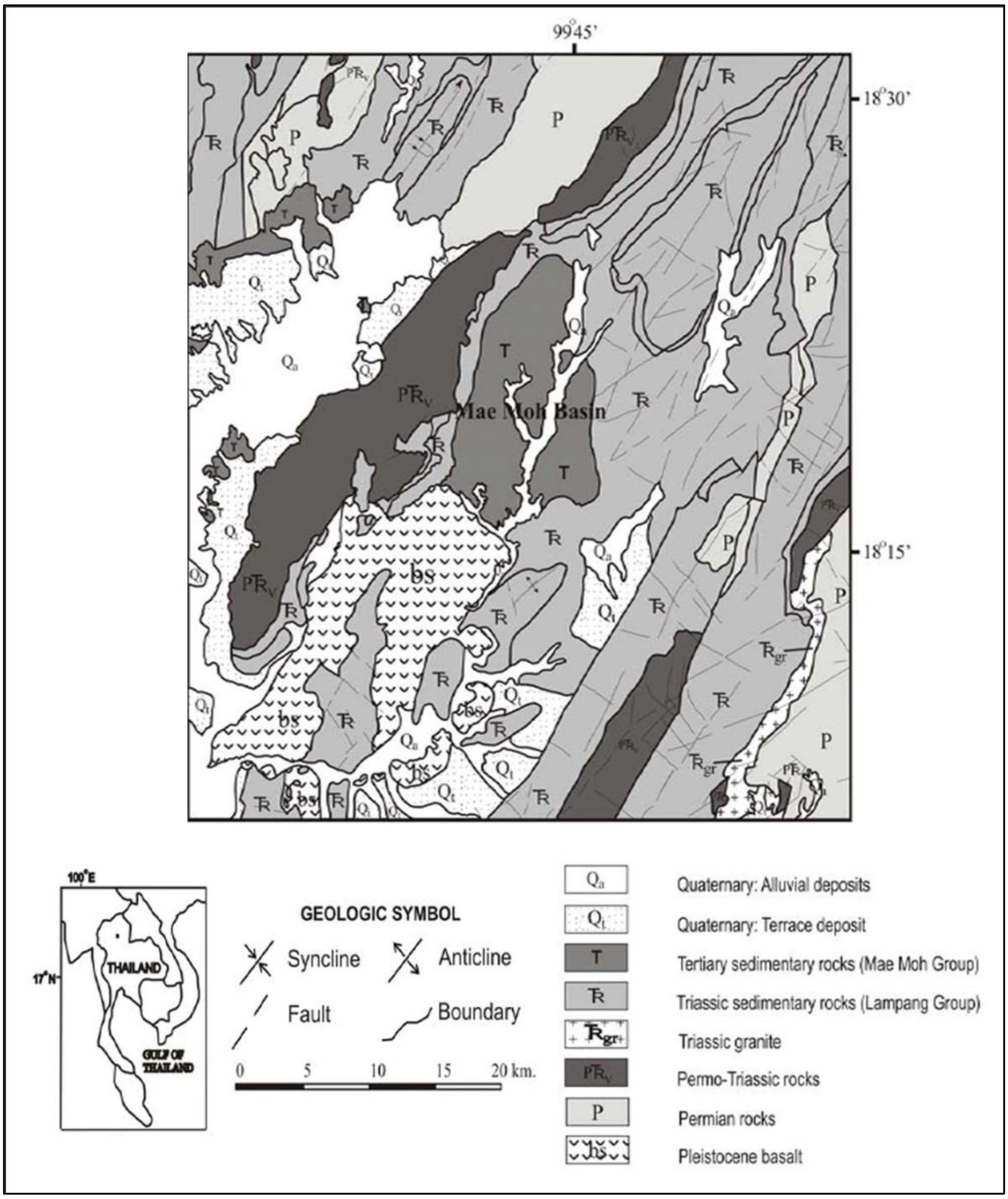


Figure 1.1 Geological map of the Mae Moh basin and surrounding rock units (Silaratana *et al*., 2003)

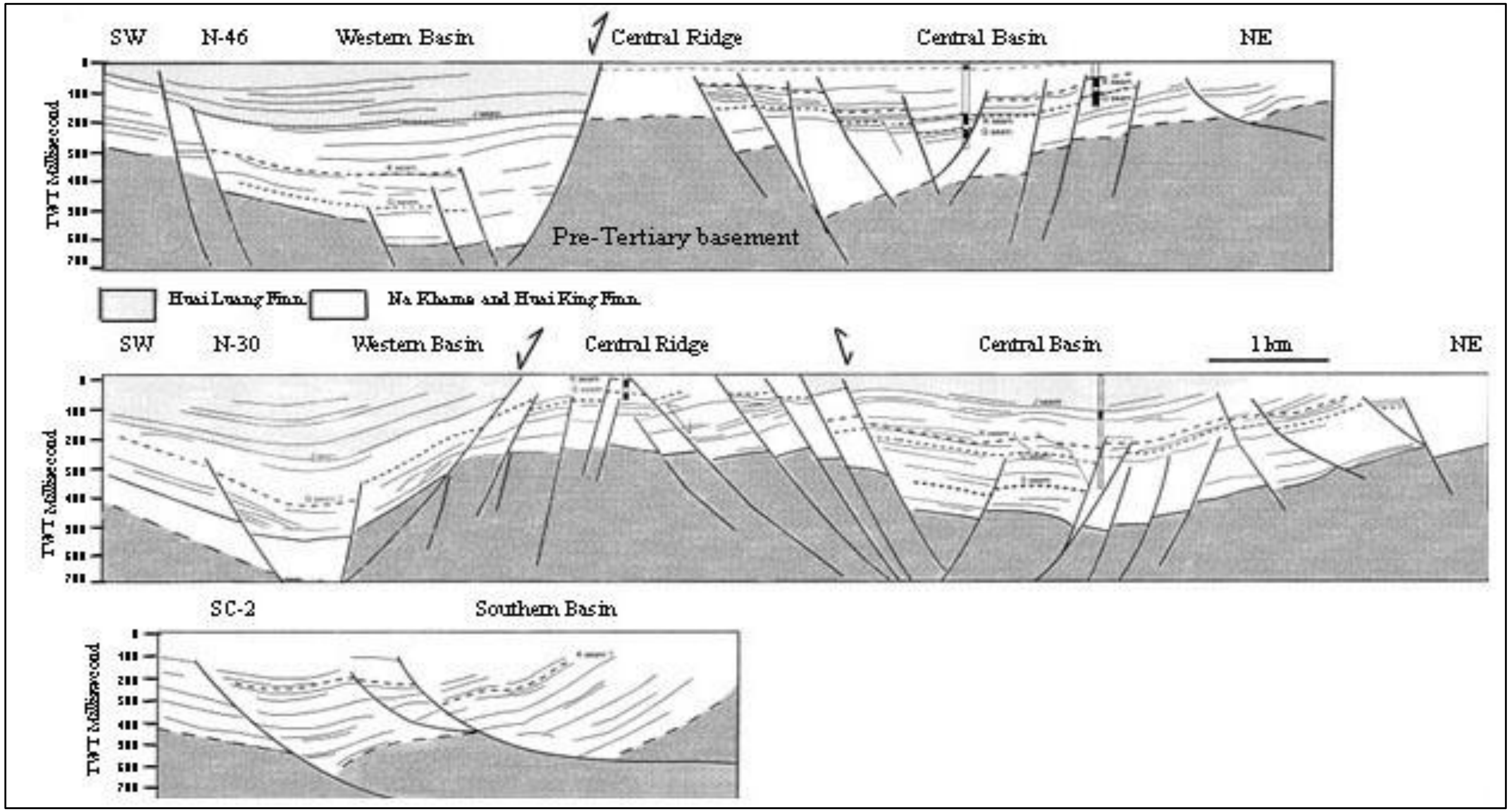


Figure 1.2 Cross-sections through Mae Moh Coal Field based on seismic reflection data acquired by EGAT prior to mining (Morley *et al.*,2001)

1.3 Research objectives

The objectives of this study are to study type of sediments in each zone of Mae Moh Basin, to study type of coal in each zone, to find the appropriate method for cleaning coal in each zone, and to be the solution alternatives for others coal field.

1.4 Scope and limitations of the study

1.Study and collect the general geologic data of Mae Moh Coal Field.

2.The samples are lignite and sediments in each zone of the Moh Coal Field.

3.The upgrading coal quality of chemical cleaning by using

- Hydrochloric acid (HCl) dissolved in water.
- Hydrofluoric acid (HF) dissolved in water.
- Nitric acid (HNO_3) dissolved in water.
- Sodium hydroxide (NaOH) dissolved in water.
- Potassium hydroxide (KOH) dissolved in water.

4. The testing is operated in the laboratory of Suranaree University of Technology.

1.5 Research methodology

This research will be performed as the following steps;

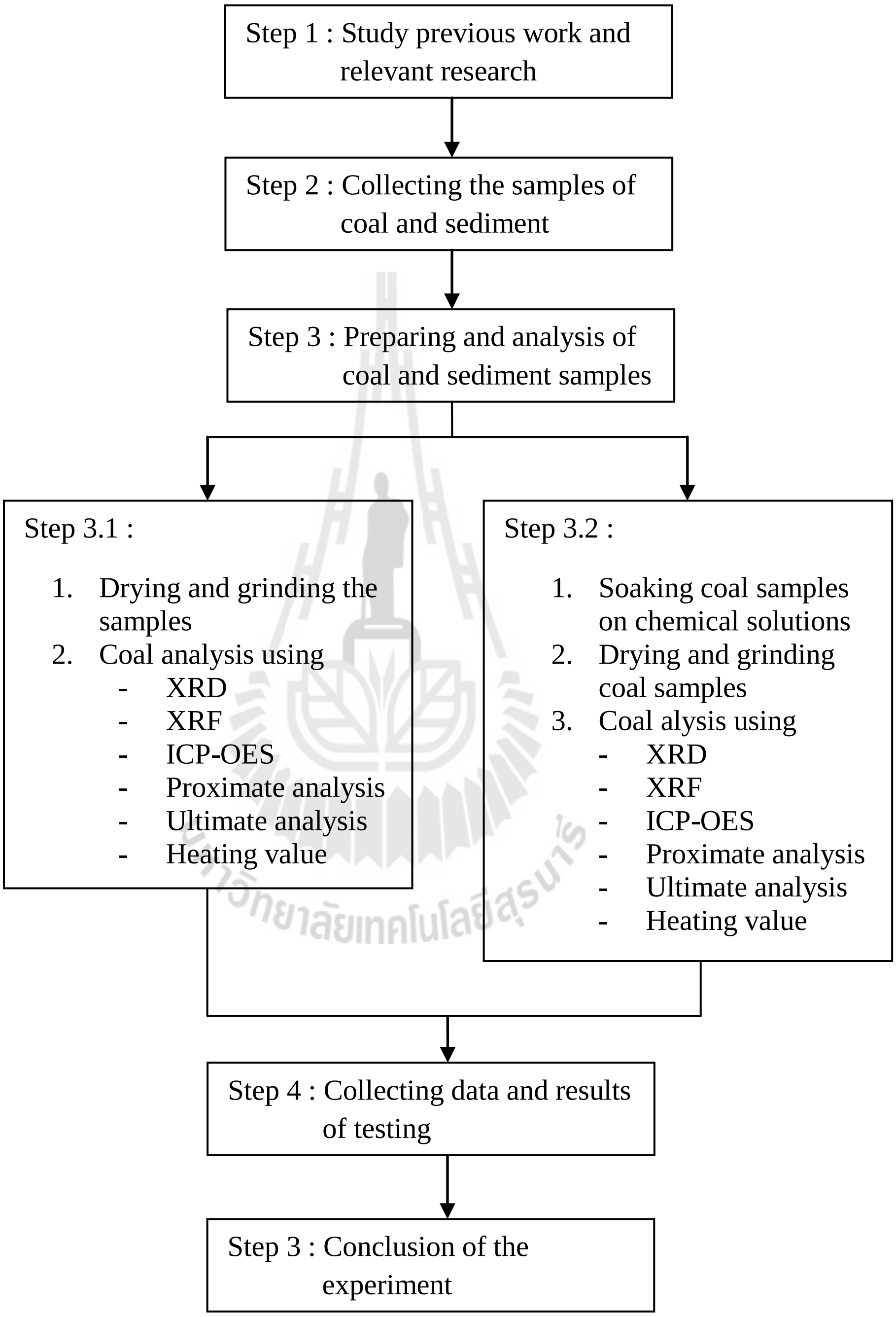


Figure 1.3 Research plan

1.5.1 Literature review

The relevant literatures will be studied, reviewed, and collected to be conclusive and data for reference. A review includes the general geology of the Mae Moh basin, stratigraphic sequences of sediments and coal, basin evolution, upgrading coal by using chemical cleaning, reducing air pollution from coal and sediments burning.

1.5.2 Collecting the samples of coals and sediments

Lignite and sediment samples are from Mae Moh Coal Field, Mae Moh district of Lampang province. The lignite of this place has high ash and sulfur content that is mainly fuel source of power plant in Thailand.

1.5.3 Preparing and analysis of coals and sediments

Samples will be prepared and tested in the laboratory of Suranaree University of Technology.

1.5.3.1 The coal is not cleaned with chemicals

Start from drying the samples in the oven. Grinding the samples and filter with sieve size is less than 75 micrometers. Determine the coal components by XRD, XRF, ICP-AES, Proximate, Ultimate, Calorific value.

1.5.3.2 The coal is cleaned with chemicals

Start from soaking the samples in chemicals such as Hydrochloric acid (HCl), Hydrofluoric acid (HF), Nitric acid (HNO_3), Sodium hydroxide (NaOH), Potassium hydroxide (KOH), which control variables are amount of coal samples, time, the amount of chemicals, and temperature. After soaking is followed drying, then grinding with sieve size 75 micrometers. Find coal components in the same as the first method.

1.5.4 Collecting data and test results

The results from preparing and analysis of coal and sediments will be compared follow these topic.

1. Coal properties, amount of ash, sulfur, and minerals in coal between passing in chemical cleaning and not passed chemicals cleaning.
2. Chemicals efficiency that appropriate for reducing ash and sulfur in coal in each zone.
3. Coal efficiency between passing in chemicals, cleaning and not passed chemicals cleaning. The results are represented in the form of table and graph.

1.5.5 Results of the experiment

Concept, detailed step, and analysis of the results and conclusions will be presented in full report when the project is finished.

1.6 Expected results

This thesis is studied about upgrading coal to high effectiveness, which is reducing impurity, ash and sulfur. The results of this thesis will be presenting the appropriate of chemicals from coal in each zone. Using the appropriate chemicals will get high coal quality to help reducing the cost of the pollutant removal unit, get low cost of electricity generation, environmentally friendly production, and maximum benefit from using of the limited resource. Also, these results can be applied to other coal field.

CHAPTER II

LITERATURE REVIEW

2.1 Literature Review

2.1.1 Stratigraphy of Mae Moh Group

The Mae Moh Group is composite of the Huai King, Na Khem, and Huai Luang Formation (Silaratana *et al*., 2003). Each formation consists of the clastic rocks that differ strongly in lithology, sedimentary structure, degree of consolidation, and fossil types. Figure 2.1 had represented the stratigraphic descriptions from the bottom to the top are as follows:

2.1.1.1 Huai King Formation

The Huai King Formation was the initial deposition during rifting of the basin. It consists of semi-consolidated, fine-grained and coarse-grained clastic rocks that have small scale fining upward sequences. It underlies the coal of the S zone of the Na Khaem Formation. The thickness of the Huai King Formation varies from less than 15 meters on the edge of the basin to 150 meters in the central part of the basin. The formation has two distinct parts. The lower part consists mainly of coarse-grained strata that grade upward from conglomeratic sandstone to clayey siltstone. Breccias of local origin occur at the base of this unit. The sandstone is green, gray, and purple and is mottled red and yellow. The siltstone is gray to red and is also mottled. Some thin carbonate layers that contain fossil shell debris occur within the siltstone sequence. The upper part of the formation is a silty claystone sequence. This fining upward sequence grades from sandstone or conglomeratic sandstone to interbedded red and gray claystone and silty claystone. Calcareous and mottled horizons also occur. The rocks in this part of the formation represent rifting and rapid filling with strong to moderate fluvial energy. The lower part of the formation was deposited in a fluvial environment of braided rivers. The upper part of the formation is a fluvial meandering river and over bank deposits.

2.1.1.2 Na Khaem Formation

The Na Khaem Formation varies in thickness from 250 to 400 meters and consists of mudstone that has five zones of coal. The mudstone is gray to greenish gray, very calcareous, and contains abundant fossils of gastropods, fish, ostracods, and plants. It also has burrowed and borings. Near the coal zones, the mudstone compose of the conglomerates, calcareous, fossiliferous, or siliceous. The formation has three major economic coal seams and divides into three members such as Member III, II. And I, in ascending order (Silaratana *et al*., 2003).

Member III (underburden) is the lowest member varies in thickness from 150 to 230 meters, consisting of claystone interbedded with the coal of the R and S zones. These beds are variously colored, very calcareous, and conglomerates. The gastropods *Viviparus* sp. and *Physa* sp. occur in the upper part. Other fossils include fish, ostracods, and plant roots (Silaratana *et al*., 2003).

Member II is middle sequence member is the most economically attractive coal sequences. It consists of the Q and K coal zones and is separated into three parts by gray claystone. The Q zone contains the stratigraphic lowest coal which currently mined in the Mae Moh mine. This claystone has abundant siliceous and calcareous white spots of diatoms, pyritized *Viviparus* sp., and plant remains. Total thickness varies from 25 to 30 meters. The coal in this zone is a massive seam in the central part of the mine, but is split in the north and south parts of the mine. Interburden: A sequence of mostly claystone separates the Q and K zones. This sequence is 10 to 30 meters thick. The claystone varies in color from brown, brownish gray, gray, green, to greenish gray. Fossils of fish, gastropods such as *Viviparus* sp., and plant roots are common but ostracods are rare. The K zone: Coal marks the upper portion of member II. It consists of 10 to 30 meters of black to brownish black, brittle coal interbedded with soft lignite and partings of light yellowish gray to gray, silty claystone. Fossils occur in the upper part of this zone. These include such gastropods as *Planobis* sp., *Viviparus* sp., and *Melanoides* sp., fish, plants, and vertebrate fossils. The coal in the zone is a massive seam in the central part of the mine, but is split in the northern and southern parts of the mine. The vertebrate fossils include proboscidean, *Stegolophodon* sp., rhinocerotid, *Gaindatherium* sp., and mustelid carnivore, *Siamogale thailandica* sp.

The upper 36 meters of this member contain 6 thin coal seam that constitute the J zone (J1 to J6). The gastropod fossils, *Melanoides* sp., *Physa* sp., and *Viviparus* sp., are common in partings of the J zone. The uppermost 15 to 20 meters of member I is a transition zone. This zone is a distinctive suite of claystone, siltstone, and silty claystone. It marks the transition from the reducing environment of lacustrine deposition typical of the Na Khaem Formation to the oxidizing conditions characteristic of the alluvial deposits of the Huai Luang Formation.

2.1.1.3 Huai Luang Formation

The Huai Luang Formation is the uppermost unit of the Mae Moh Group. It consists mainly of semiconsolidated and unconsolidated strata that are red to brownish red and have interbedded gray layers. It was named Red Bed by Longworth-CMPS Engineers. The formation is predominately claystone, siltstone, and mudstone and has some lenses of sandstone and conglomerate in the central part of the basin. The only macrofossils found in the formation are gastropods, bivalves, and plant remains in the I zone, though there is abundant gypsum and pyrite, along with rare root structures and frame structures. The thickness of the formation varies from less than 5 meters to 350 meters. Its middle part consists of gray and greenish gray claystone separated by I zone coal. The color of the formation changes upward, becoming red at the top. It is lithology indicates to a fluvial deposition in the lower part, swamp deposition in a lacustrine environment in the middle part, and braided river deposition in a fluvial environment in the upper part (Silaratana *et al*., 2003).

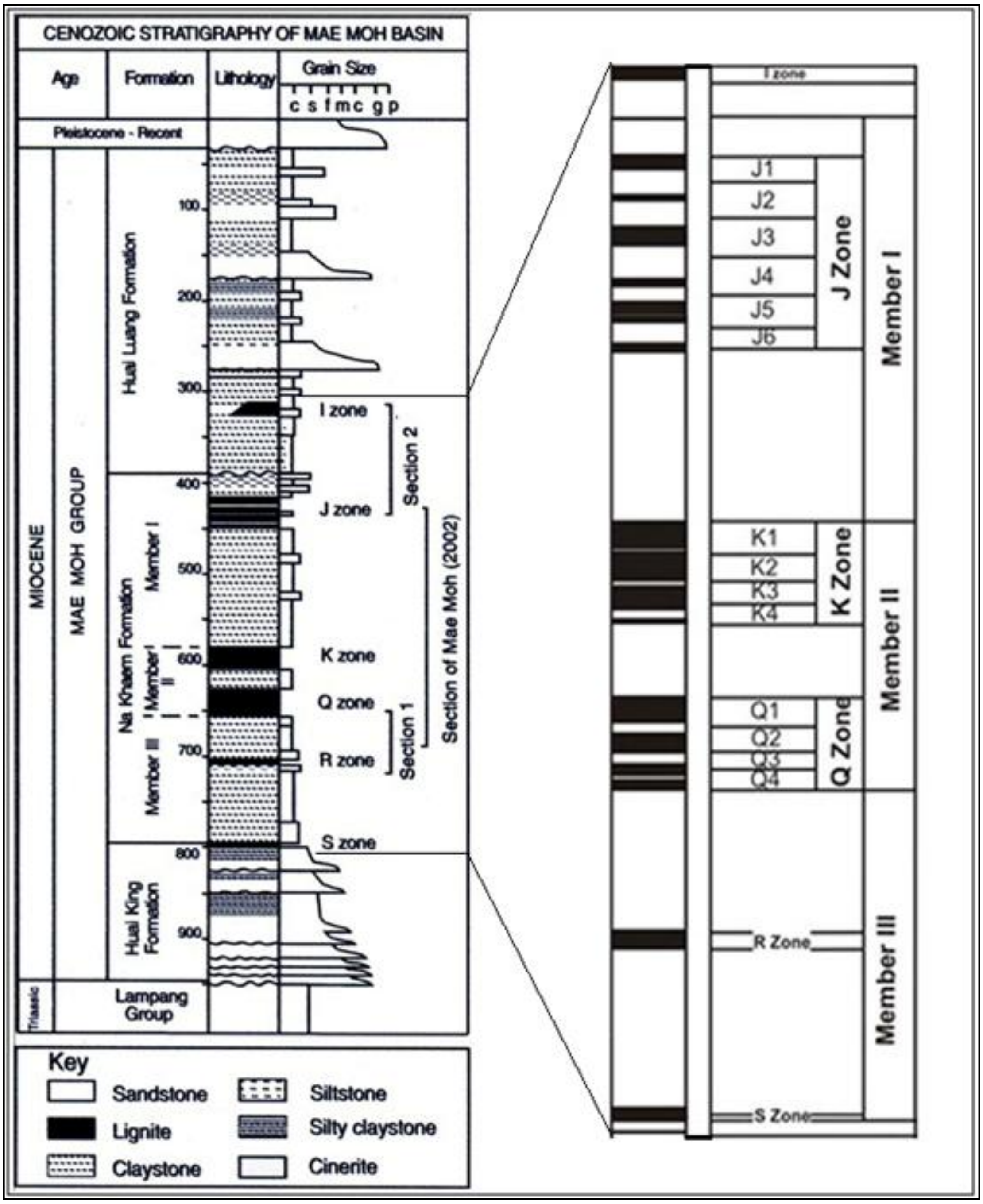


Figure 2.1 Cenozoic stratigraphy of the Mae Moh basin by the letters at the right of the column indicate the nomenclature applied to the lignite zones. The range of Sections 1 and 2 are marked along the right side of the stratigraphic column (Sompong *et al*., 1996; Chaodumrong, 1985; Corsiri and Crouch, 1985; Benammi *et al*., 2002).

2.1.2 Coal

The definition of coal is a fossil fuel. It is a combustible, sedimentary organic rock, which is in composed mainly of carbon, hydrogen and oxygen. It is formed from plant remain, which has been consolidated between other rock strata and altered by the combined effects of pressure and heat over millions of years to form coal seams.

The build-up of silt and other sediments, together with movements in the earth’s crust (known as tectonic movements) buried these swamps and peat bogs, often to great depths. With burial, the plant material was subjected to high temperatures and pressures. This caused physical and chemical changes in the vegetation, transforming it into peat bituminous, coal, and anthracite, respectively. The coal formation began during the Carboniferous Period – known as the first coal age, which spanned 360 million to 290 million years ago. The quality of each coal deposit is determined by a temperature and pressure, and by the length of time in the formation, which is referred to as its organic maturity. Initially, the peat is converted into lignite or brown coal, these are coal types with low organic maturity. In comparison to other coals, lignite is quite soft and its color can range from dark black to various shades of brown. Over many more millions of years, the continuing effects of temperature and pressure produces further change in the lignite, progressively increasing its organic maturity and transforming it into the range known as sub-bituminous coals. Further chemical and physical changes occur until these coals became harder and blacker, forming the bituminous or hard coals. Under the right conditions, the progressive increase in the organic maturity can continue until forming anthracite (Coal Geology, 2012).

2.1.3 Types of Coal

The degree of change undergone by a coal as it matures from peat to anthracite, known as coalification, has an important bearing on its physical and chemical properties and is referred to as the rank of the coal. Low rank coals, such as lignite and subbituminous coals are typically softer, friable materials with a dull, earthy appearance. They are characterized by high moisture levels and low carbon content, and therefore low energy content. Higher rank coals are generally harder and stronger and often have a black, vitreous luster. They contain more carbon, have lower moisture content, and produce more energy. Anthracite is at the top of the rankings scale and has a correspondingly higher carbon and energy content and a lower level of moisture.

2.1.4 Coal Analysis

The composition of a coal is usually reported in terms of its proximate analysis and its ultimate analysis:

The proximate analysis consists of four items: fixed carbon, volatile matter, moisture and ash, all on a weight percent basis. The ultimate analysis provides an elemental composition of the coal's organic fraction, namely: carbon, hydrogen, oxygen and sulfur contents, all on a weight percent basis. Both the proximate and the ultimate analysis may be reported on an ash received (ar) basis, a dry (d) or moist basis, an ash-free (af) basis, a mineral matter-free (mmf) basis and various combinations of those bases. The mineral matter and ash are two distinctly different entities. Mineral matter consists of the various minerals contained in the coal. Ash is inorganic solids remaining after the coal is completely combusted. The ash is usually less than the mineral matter because of the weight changes that take place during coal combustion such as the loss of gaseous carbon dioxide from mineral carbonates, loss of water from silica minerals and loss of sulfur (as gaseous sulfur dioxide) from iron sulfide or pyrites

2.1.5 Coal classification

There are many compositional differences between the coals mined from the different coal deposits worldwide. The different types of coal are most usually classified by rank which depends upon the degree of transformation from the original source (i.e., decayed plants) and is therefore a measure of a coal's age. As the process of progressive transformation took place, the heating value and the fixed carbon content of the coal increased and the amount of volatile matter in the coal decreased. The method of ranking coals used in the United States and Canada was developed by the American Society for Testing and Materials (ASTM D388) and is based on a number of parameters obtained by various prescribed tests:

2.1.5.1 Heating value: The energy released as heat when coal (or any other substance) undergoes complete combustion with oxygen.

2.1.5.2 Volatile matter: The portion of a coal sample which, when heated in the absence of air at prescribed conditions, is released as gases. It includes carbon dioxide, volatile organic and inorganic gases containing sulfur and nitrogen.

2.1.5.3 Moisture: The water inherently contained within the coal and existing in the coal in its natural state of deposition. It as measured as the amount of water released when a coal sample is heated at prescribed conditions. It does not include any free water on the surface of the coal. Such free water is removed by air-drying the coal sample being tested.

2.1.5.4 Ash: The inorganic residue remaining after a coal sample is completely burned and is largely composed of compounds of silica, aluminum, iron, calcium, magnesium and others. The ash may vary considerably from the mineral matter present in the coal (such as clay, quartz, pyrites and gypsum) before being burned.

2.1.5.5 Fixed carbon: The remaining organic matter after the volatile matter and moisture have been released. It is typically calculated by subtracting from 100 the percentages of volatile matter, moisture and ash. It is composed primarily of carbon with lesser amounts of hydrogen, nitrogen and sulfur (Coal Geology, 2012). The ASTM ranking system is presented in the Table 1.

2.1.6 Coal Quality

The coal quality at Mae Moh is classified as low coal, not only low rank but also low quality, suitable only for feeding coal-fired power plants, due to a high ash and sulfur content. The proximate analysis of Mae Moh coal varies: moisture 15-33%, ash 11-34%, volatile matter 18-40%, and fixed carbon 6-36%. The sulfur content varies from 1-5% and calorific values between 7.33-17.81 MJ/kg. Vitrinite reflectance is between 0.34-0.40 %Ro. Results of coal petrography indicates that a majority of macerals are densinite and gelinite with an abundance of alginite, sporinite, liptodetrinite, but rare inertinite. The mineral matter shows an abundance of framboidal pyrite, especially in J coal zone (Ratanasthien *et al.*, 2008).

Table 2.1 The classification of coals by rank (ASTM D388)

Classification of Coals by Rank							
Class or Rank	**Group**	**Fixed Carbon (wt % dry** mineral matter-free**)**		**Volatile Matter (wt % dry** mineral matter-free**)**		**Gross Heating Value (MJ/kg moist** mineral matter-free**)**	
		Equal or greater than	**Less than**	**Greater than**	**Equal or less than**	**Equal or greater than**	**Less than**
Anthracitic	Metaanthracite	98	98	2	2		
	Anthracite	92	92	8	8		
	Semianthracite	86			14		
Bituminous	Low-volatile bituminous	78	86	14	22	32.55	32.55
	Medium-volatile bituminous	69	78	22	31	30.23	30.23
	High-volatile A bituminous		69	31		26.74	26.74
	High-volatile B bituminous					24.41	
	High-volatile C bituminous						
	High-volatile C bituminous						
Subbituminous	Subbituminous A					24.41	26.74
	Subbituminous B					22.09	24.41
	Subbituminous C					19.30	22.09
Lignite	Lignite A					14.65	19.30
	Lignite B						14.65

Table 2.2 Air quality standard (Pollution Control Department, 2011)

Pollutants	Units	Level of air pollution		
		Coal	Oil	Gas
Sulfur dioxide Size of power plant	part per million (ppm.)			
- more than 500 MW.		320	320	20
- between 300 – 500 MW.		450	450	20
- less than 300 MW.		640	640	20
Nitrogen dioxide	part per million (ppm.)	350	180	120
Particulate matter	Milligram per cubic meter	120	120	60

2.1.7 Coal Cleaning

Cleaning coal by water reducing pyritic sulfur up to 90 wt. %. The difference of density between coal and impurities results impurities are extracted from coal.

Steel and Patrick (2000) upgraded high volatile UK coal with particle size less than 500 µm, ash content of approximately 7.9 wt.% and sulfur content of 2.6 wt.%, was treated with aqueous hydrofluoric acid followed by aqueous nitric acid at 65° C and 3 hours. Hydrofluoric acid is reducing the ash content to 2.6 wt. % and following nitric acid is reduce the ash content to 0.6 wt. % and 1.4 wt. % of sulfur content.

Steel *et al*. (2000) studied coal cleaning by using hydrochloric acid and hydrofluoric acid at 330°C that can dissolve the simple compound such as phosphate and carbonate, yet it cannot completely dissolve the clays and hydrofluoric acid reacts with almost every mineral in the mineral matter, dissolve all of the aluminosilicates, AlF_3, AlF^-_4, and $SiF_6{}^{2-}$ form, except pyrite after these process coal have impurities less than 0.1% by weight mineral matter.

The wash ability of low grade coals using sodium hydroxide followed hydrochloric or sulfuric acid was studied by Sharma *et al*. (1988) at atmospheric pressure results in a 75% demineralization of the coal. The hydrochloric and sulfuric acid are alone can also lead to an appreciable degree of demineralization

From testing of Yang *et al*. (1984) shows that the majority of the pyrite reacts with sodium hydroxide, forming Fe_2O_3 and Na_2S. The Na_2S is dissolved in the leaching liquor and Fe_2O_3 is trapped in the coal matrix, silicon and aluminum contents are lowed by reaction with sodium hydroxide. The remaining iron compounds are dissolved by nitric acid.

Mukherjee *et al*. (2002) using the potassium hydroxide at temperature between 95° to 150°C and followed acid on demineralization and desulfurization. The potassium hydroxide alone leads to 2-19% demineralization and 16-30% desulfurization. Demineralization of the coal decreases to 1- 11% and desulfurization increases to 26-43% on increasing the temperature to 150°C. The treatment almost completely removes the inorganic and up to 37% organic sulfur from the coal samples.

The results of testing of Waugh *et al.* (1983) show that the most of the ash forming mineral in bituminous coal are insoluble in water or acids, more than 90% can be extracted with aqueous sodium hydroxide solution at 200-300°C under pressure. The major minerals extracted silica and kaolin are converted into sodium aluminosilicate which from a separate insoluble phase in contact water or alkali, but which are readily soluble in aqueous acid.

Reggle *et al.* (1973) using the sodium hydroxide 50-40 grams per liter of water stirring with coal at 175-350°C, 1 atmospheric for 15 minutes to 6 hours for reduced pyritic sulfur and followed by hydrochloric acid and agitate nearly 30 minutes to 6 hours for changing form of insoluble mineral matter to be soluble mineral matter. After this process the product coal has low mineral matter and pyrite contents.

The expected reaction equation in this study is shown in equations (2.1) to (2.18). Sodium hydroxide reacts with quartz, aluminum oxide, pyrite, kaolinite, and illite following equations (2.1) to (2.5).

$$2NaOH + SiO_2 \longrightarrow Na_2SiO_3 + H_2O \qquad (2.1)$$

$$2NaOH + Al_2O_3 \longrightarrow 2NaAlO_2 + H_2O \qquad (2.2)$$

$$11NaOH + 2FeS_2 + 0.5C \longrightarrow 4Na_2S + 2NaFeO_2 + 0.5Na_2CO_3 + 5.5H_2O \qquad (2.3)$$

$$20NaOH + Al_2Si_2O_5(OH)_4 \longrightarrow 2NaAlO_2 + 2NaSiO_3 + 14NaOH + 5H_2O \qquad (2.4)$$

$$20NaOH + KAl_2[Si_3AlO_{10}(OH)_2] \longrightarrow 3NaAlO_2 + 3Na_2SiO_3 + 11NaOH$$
$$+ 5H_2O \qquad (2.5)$$

Potassium hydroxide reacts with quartz, aluminum oxide, pyrite, kaolinite, and illite following equations (2.6) to (2.10).

$$2KOH + SiO_2 \longrightarrow K_2SiO_3 + H_2O \qquad (2.6)$$

$$2KOH + Al_2O_3 \longrightarrow 2KAlO_2 + H_2O \qquad (2.7)$$

$$\mathrm{11KOH + 2FeS_2 + 0.5C \longrightarrow 4K_2S + 2KFeO_2 + 0.5K_2CO_3 + 5.5H_2O} \tag{2.8}$$

$$\mathrm{20KOH + Al_2Si_2O_5(OH)_4 \longrightarrow 2KAlO_2 + 2NaSiO_3 + 14KOH + 5H_2O} \tag{2.9}$$

$$\begin{aligned} \mathrm{20KOH + KAl_2[Si_3AlO_{10}(OH)_2]} &\longrightarrow \mathrm{3KAlO_2 + 3Na_2SiO_3 + 11KOH} \\ &\quad \mathrm{+ 5H_2O} \end{aligned} \tag{2.10}$$

Hydrochloric acid reacts with carbonate and phosphate compound following equations (2.11) and (2.12).

$$\mathrm{2HCl + CaCO_3 \longrightarrow CaCl_2 + CO_2 + H_2O} \tag{2.11}$$

$$\mathrm{HCl + Na_3PO_4 \longrightarrow NaCl + H_3PO_4} \tag{2.12}$$

Hydrofluoric acid reacts with quartz, aluminum oxide, and carbonate compound following equations (2.13) to (2.17).

$$\mathrm{6HF + SiO_2 \longrightarrow H_2SiF_6 + 2H_2O} \tag{2.13}$$

$$\mathrm{6HF + Al_2O_3 \longrightarrow 2AlF_3 + 3H_2O} \tag{2.14}$$

$$\mathrm{HF + CaCO_3 \longrightarrow CaF_2 + H_2O} \tag{2.15}$$

$$\mathrm{HF + MgCO_3 \longrightarrow MgF_2 + H_2O} \tag{2.16}$$

Nitric acid reacts with pyrite, and iron (III) oxide following equations (2.17) and (2.18).

$$\begin{aligned} \mathrm{18HNO_3 + FeS_2} &\longrightarrow \mathrm{Fe_2(NO_3)_3 + 2H_2SO_4 + 15NO_2} \\ &\quad \mathrm{+ 7H_2O} \end{aligned} \tag{2.17}$$

$$\mathrm{6HNO_3 + Fe_2O_3 \longrightarrow 2Fe_2(NO_3)_3 + 3H_2O} \tag{2.18}$$

CHAPTER III

SAMPLE COLLECTION AND ANALYTICAL METHODS

3.1 Sample collection and preparation

3.1.1 Sample collection

Mae Moh Coal Field

The coal and sediment samples were collected from the Mae Moh basin. These samples were excavated along the stratigraphic succession of Mae Moh group. The outer surfaces of the samples were cut to expose fresh surfaces before collecting samples. The coal samples were collected from appearing seams as I, J3, J4, J5, K1, K2, K3, Q1, Q2, Q3, and Q4. The sediment samples were collected from overburden (between J and K), interburden (between K and Q), and underburden (lower Q), parting 1, and parting 2 (both in K seams). The samples were separated, packed in zip lock bags, and labeled.

Table 3.1 Weight and position of samples from Mae Moh basin

Number	Samples	Mine grid north	Mine grid east	Weight (kg.)
1	I	9.74	-11.91	5
2	J3	23.11	-11.30	5
3	J4	23.08	-11.23	5
4	J5	23.06	-11.10	5
5	OB	-1.72	-2.69	5
6	K1	-1.70	-1.96	5
7	PT1	-1.70	-1.96	5
8	K2	-1.72	-1.55	5
9	PT2	-1.72	-1.55	5
10	K3	0.74	-14.64	5
11	IB	19.79	-5.63	5
12	Q1	-11.40	1.53	5
13	Q2	-11.50	1.75	5
14	Q3	-11.50	1.88	5
15	Q4	-0.17	1.22	5
16	UB	20.64	-1.90	5

3.1.2 Preparation of samples

The coal and sediment samples were air dried a few days for removing surface moisture. The preparation samples were divided into two types. 1) Coal and sediment samples were grinded and filtered with sieved size down less than 75 micrometers. Powdered samples were stored in zip lock bags. The powdered samples were analyzed major elements using X-ray fluorescence spectrometry (XRF) before using X-ray diffractometer (XRD) to analyze compounds in the samples. Trace elements were analyzed by Inductively Coupled Plasma-Optical Emission Spectrometers (ICP-OES). Moisture and ash meter were used to analyze ash and moisture content in coal samples. Percent of carbon (C), hydrogen (H), nitrogen (N), and sulfur (S) in coal samples were measured by CHNS meter. 2) Dried coal samples were crushed for reducing size. Hydrofluoric acid (HF), hydrochloric acid (HCl), nitric acid (HNO_3), sodium hydroxide (NaOH), and potassium hydroxide (KOH) were used in coal cleaning process. Coal samples were soaked in those chemicals before filtered and air dried. Dried coal samples were grinded and sieved size down less than 75 micrometers before stored in zip lock bags.

3.2 Methodology

3.2.1 Proximate Analysis

The proximate analysis is a method used to indicate degree of physicochemical coalification. This analysis analyzes the percentage of moisture, volatile, ash, and fixed carbon. Ash and moisture analyzer was used for this analysis.

Sample preparation

A hundred thirty two coal samples from 11 coal seams were filtered (in case of treatment) and air dried for 2-3 days to remove surface moisture. These coal samples were grinded and sieved size less than 75 micrometers. About 1.5 grams of powdered coal samples were stored in crucibles. Those coal samples were taken to ash and moisture analyzer on a carousel of Leco (model TGA-701) at Suranaree University of Technology.

Figure 3.1 Moisture and Ash Analyzer: Leco (TGA 701)

This instrument covered on ash, moisture, volatile and fixed carbon contents. The method of D7582 MVA in coal condition was used for analyzing. The results of this analyzing were presented in moisture, volatile, ash, and fixed carbon.

3.2.2 Ultimate Analysis

This analysis is used to analyze concentration of elements in coal samples which are carbon, hydrogen, nitrogen, and sulfur contents. The CHNS analyzer was used for this analysis.

Sample preparation

A hundred thirty two coal samples from 11 coal seams were filtered (in case of treatment) and air dried for 2-3 days to remove surface moisture. These coal samples were ground and sieved size less than 75 micrometers. The analysis was divided into two sections

Figure 3.2 Carbon, hydrogen, nitrogen, and sulfur analyzer (CHN 628 S Add-on Module)

C, H, and N analysis, EDTA (C~41%) standard samples were used to calibrate this equipment. About 0.2 grams of prepared coal samples were wrapped by aluminum foils as shape as water drop. The samples were dropped into carousel slots and operated at 1350℃.

S analysis, CRM 502-671 (S~1.06%) standard samples were used to calibrate sulfur analyzer. About 0.25 grams of powered samples were prepared in crucibles. The samples were taken to furnace for sulfur analyzing. This step was operated at 900℃. The exit gases from operation were collected and analyzed before processed by computer software. These analyzing were operated on CHNS analyzer of Leco (model CHNS 628) at Suranaree University of Technology. The results of this analyzing were presented in carbon, hydrogen, nitrogen, and sulfur percent.

3.2.3 X-ray Fluorescence Spectrometry Analysis (XRF)

Figure 3.3 X-ray Fluorescence (ED) Horiba

Sample preparation

Fifteen sediment samples and 132 coal samples from 11 coal seams were filtered (in case of treatment) and air dried for 2-3 days to remove surface moisture. These samples were grinded and sieved size less than 75 micrometers. About 0.5-1 grams of powdered samples were pressed in sample holders by a thin glass until outer surface smooth. These samples were taken to XRF analyzer on a sample holder stage of Holiba (model XGT 5200) X-ray fluorescence spectroscopy (Figure 3.3) at Suranaree University of Technology. Two hundred seconds of live time, 1.2 millimeters (mm) of XRF diameter, 30 kilovolts (kV) and 1 milli-ampere (mA) of X-ray tube were used for operation. The principle of X-ray Fluorescence Spectrometer is shown in Appendix IV.5.The results of this analysis were presented in peak of major elements before matched by software in XRF analyzer for finding quantity of major elements.

3.2.4 X-ray Diffraction Analysis (XRD)

Figure 3.4 X-ray Diffractometer: Bruker (D2 Phaser)

Sample preparation

Fifteen sediment samples and 132 coal samples from 11 coal seams were filtered (in case of treatment) and air dried for 2-3 days to remove surface moisture. These samples were grinded and sieved size less than 75 micrometers. About 1-1.5 grams of powdered samples were pressed in sample holders by a thin glass until the outer surface smooth. These samples were taken to XRD analyzer on sample holder stage of Bruker (model D2 Phaser) X-ray diffractometer (Figre 3.4) at Suranaree University of Technology. This instrument was operated about 10 minutes under parameters as follows: Ceramics X-ray tube operated with copper lamp size 0.4mm x12mm at 30 kV and 10 mA (300 watts; W). This analysis used two-theta (2θ) range from 5 to 60°, step size is 0.2 seconds and increment of each step is 0.02. Results of analysis were presented in peak of relationship between intensity (y-axis) and 2θ angle (x-axis). The quantitative analysis was determined by Topas, which is a quantitative analysis software operated on window. The final results of this analysis are shown in weight percent of mineral contents in sediment and coal samples.

3.2.5 Inductively Coupled Plasma-Optical Emission Spectrometers (ICP-OES)

Figure 3.5 Inductively Coupled Plasma-Optical Emission Spectrometers Perkin Elmer Optima 8000

Sample preparation

Three sediment and seventeen coal samples were air dried for 2-3 days to remove surface moisture. These sediment and coal samples were grinded and sieved size less than 75 micrometers. These samples will be digested before passed through the ICP spectrometer following these steps:

Sediment sample digestion using Red Clay (2) method

1) Weigh the samples as equal to 0.25 g. (0.1000g. +/- 0.0200g.) and store in plastic bottles.

2) Add the acids; 3 ml of HNO_3 65% and 9 ml of HCl 37%, wet it drop by drop and set aside for a few minute for release gas pressure of reaction between acid and sample. Close the vessels and take it into rotor segment.

3) Take the rotor segment into microwave digester under 220℃ of temperature for 30 minutes. After operation finished, cool the rotor by air until reaches room temperature.

4) Open the vessel and transfer the solution to volumetric flask and dilute by distilled de-ionized water until volume equal to 50 ml.

Coal sample digestion using Coal (partial digestion) method

1) Weigh the samples as equal to 0.25 g. (0.1000g. +/- 0.0200g.) and store in plastic bottles.

2) Add the acids; 9 ml of HNO_3 65% and 3 ml of HCl 37%, wet it drop by drop and set aside for a few minute for release gas pressure of reaction between acid and sample. Close the vessels and take it into rotor segment. After this steps will follow step 3) and 4) in part of 3.2.6.1

Standard sample preparation

The standard solutions were arsenic (As), chromium (Cr), cobalt (Co), copper (Cu), molybdenum (Mo), zinc (Zn), vanadium (V), and lead (Pb), which had the concentration of each solutions are 0.001, 0.05, 0.1, 0.5, 1, 2, 5, and 10 ppm.

After following these steps from 3.2.5.1 to 3.2.5.2, now the sample solutions ready for analysis.

The samples were analyzed in the ICP analyzer under pressure of argon 80-120 psi, nitrogen 40-120 psi, air 80-120 psi, and RF 40 MHz..

CHAPTER IV

RESULTS AND DISCUSSIONS

4.1 The original properties of coal and sediment samples (untreated)

4.1.1 Major elements in coal and sediment samples using the XRF method

The geological analysis was analyzed by using X-ray fluorescence spectrometer of the Holiba model XGT – 5200. The results from this analysis were major elements which are Na_2O, MgO, Al_2O_3, SiO_2, P_2O_5, SO_3, K_2O, CaO, TiO_2, MnO_2, Fe_2O_3, and ZnO as shown in Table 4.1, and Figure 4.1 and 4.2.

4.1.1.1 Major elements in sediment samples

Sediment samples were collected from three formation such as overbuden, interburden and underburden. The result of major elements in the sediment sample was shown in Table 4.1 and Figure 4.1.

The overburden (OB) represents mainly 54% of SiO_2, 16% of Al_2O_3, 19% of CaO, and other components are about 6%.

Sediments in K coal seam are PT1 and PT2 layers. The PT1 is the upper layer; SiO_2 and Al_2O_3 are dominant about 60 and 18%, respectively. CaO and Fe_2O_3 appeared a bit in this layer around 8%. The PT2 is the lower layer which located between K2 and K3 coal seams. This layer mainly shows about 55% CaO and 22% SiO_2, There are some of Al_2O_3 and Fe_2O_3 are about 6 and 8%, respectively.

The interburden (IB) is a sediment layer, which is between K and Q coal seams. CaO and SiO_2 are dominant in this seam about 30%. The miner of Al_2O_3, SO_3, and Fe_2O_3 contents are about 11, 10, and 8%, respectively.

The underburden (UB) is the lowest layer, which comprise mainly of CaO and SiO_2 about 40 and 31% respectively. Al_2O_3 is detected about 11%, Fe_2O_3 6%, and Na_2O about 4.7%.

Silicon component was detected highly in the upper sediment layer and slight down to lower sediment layer. Calcium compound is dominant in the lower sediment seam, especially in PT2 sediment seam. Oxide of iron is dominant in the upper seam and slight down to the bottom (Figure 4.1).

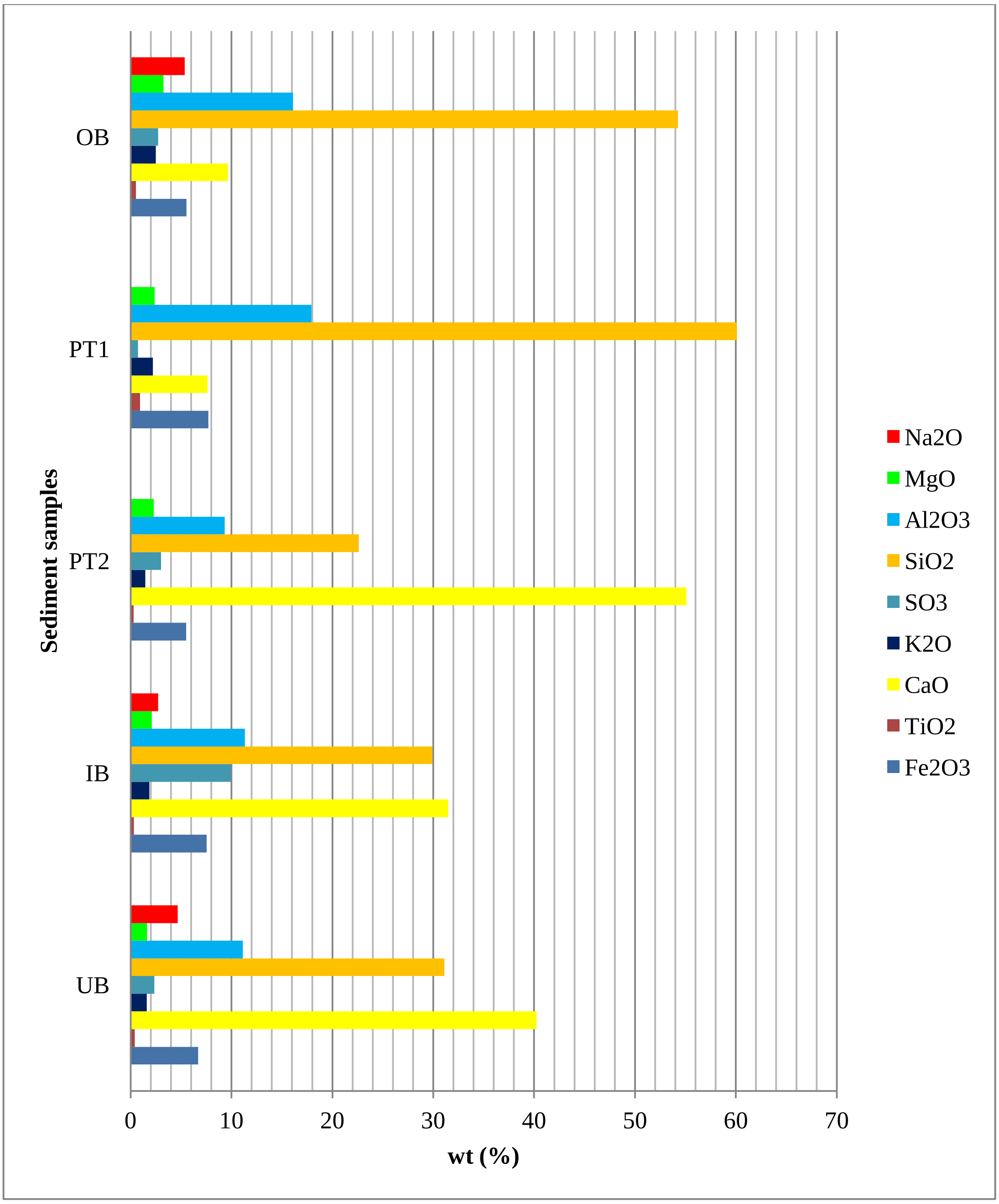


Figure 4.1 Vertical variation of major elements in sediment samples in each layer

4.1.1.2 Major elements in coal samples

The result of major elements in the Mae Moh coal seam was shown in Table 4.1 that represent the content of major elements in I, J, K, Q coal seams as follows:

The I coal seam is mainly SiO_2, Al_2O_3, and Fe_2O_3 contents are approximately 56.76, 22.67 and 6.14%, respectively. There are some MgO, SO_3, and K_2O contents in this seam approximately 4%.

The J coal seam was collected from J3, J4, and J5. All samples of these coal seams are mainly SO_3 ranges from 44.7 to 47.9%, Fe_2O_3 ranges from 17.7 to 27.1%, CaO ranges from 16.8 to 19.06%, and SiO_2 ranges from 5.2 to 8.2%.

There are four sub coal seams in K coal seam including K1, K2, K3, and K4. These coal seams can be collected samples from the K1 to K3 due to the K4 was not fresh and more weathering. From the result of analysis, the major elements content in this coal seam is different (Table 4.1). In K1 coal seam are mainly CaO content is about 76%, and other components such as SiO_2, SO_3 and Fe_2O_3 contents are approximately 6%. The major elements in K2 coal seam is mainly SO_3 which Fe_2O_3, SiO_2 and Al_2O_3 contents are approximately 34.19%, 23.73%, 21.82% and 10.23%, respectively. In the K3 coal seam consists of SiO_2, SO_3, and Al_2O_3 contents are 33%, 23% and 14%, respectively. Therefore, the major elements content in K coal seam can be concluded that CaO content ranges from 6 to 76%, SiO_2 ranges from 5.5 to 33.4%, and SO_3 ranges from 6 to 34%.

Q coal seam consisted of four sub coal seams, Q1, Q2, Q3, and Q4. The major elements content in the Q1 coal seam are dominate of SO_3, SiO_2 and Fe_2O_3 contents are 33, 20 and 18%, respectively. The major elements in Q2 coal seam are mainly of SiO_2 ranging from 27.7 to 29.8, SO_3 is approximate 26%, Fe_2O_3 ranges from 13.5 to 14.8% and CaO content ranges from 5.8 to 7.2%. In Q4 coal seam mainly consisted of CaO, SO_3 and Fe_2O_3 contents are approximate of 47.9, 24.4, and 15.1, respectively. The major elements content in the Q coal seam can be concluded that mainly consisted of SO_3 ranges from 24 to 33%, SiO_2 ranges from 4 to 29%, and Fe_2O_3 ranges from13 to 18%.

The result of SiO_2 content has been found as a dominant component in I coal seam, and followed by K2, K3, Q1, Q2 and Q3 coal seam which has the same quantity. The quantity of SO_3 has been found dominantly in J3, J4 and J5, which found slightly in the deeper coal seam and a bit in the I and K1 coal seam. In conclusion, the result of the major elements will forming ash after burned found mostly in the I and K1 coal seam following by K2, K3, Q1, Q2 and Q3, respectively.

From the result of the vertical variation of SiO_2 content between sediment and coal are much different. Because of SiO_2 content of sediment will be decreased when the depth increasing, but SiO_2 content in overall of coal seams will be increased from Table 4.1 as shown in Figure 4.1 and 4.2. The amount of SiO_2 will increase when depth decreasing in each coal seams.

In Figure 4.1 represents that the SO_3 content of sediment in each coal seams are not different when compare with the content of SO_3 in coal that represented in Figure 4.2, showing the reduction of SO_3 in the sub coal seam when the depth increase. The SO_3 content in the J3, J4 and J5 are equal.

Calcium content in the sediment will increase as the increasing of depth, which composes the results of coal seams and dominant in K1 and Q4 coal seams.

Iron oxide (Fe_2O_3) content in sediment and coal samples is not different in each depth. There is more the Fe_2O_3 content in coal than two times in sediments, which found more in the upper coal seam as shown in J followed by K, and Q coal seams.

Table 4.1 Average concentration of elements (oxide form) in coal and sediment samples from Mae Moh coal field using XRF (in wt%)

Elements	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO_2	Fe_2O_3	ZnO	BaO	Total
I	0.000	3.621	22.665	56.759	0.000	4.274	4.168	1.642	0.694	0.016	6.142	0.018	0.001	100
J3	4.397	3.125	4.142	8.216	0.000	44.675	0.662	16.840	0.147	0.072	17.708	0.017	0.000	100
J4	0.000	2.980	4.189	8.065	0.000	45.876	0.620	16.920	0.157	0.060	21.124	0.010	0.003	100
J5	0.041	2.701	2.799	5.260	0.000	47.888	0.332	19.056	0.122	0.020	21.763	0.015	0.000	100
OB	5.356	3.238	16.114	54.254	0.000	2.729	2.509	9.656	0.513	0.076	5.536	0.017	0.002	100
K1	0.000	2.290	1.888	5.532	0.713	6.033	0.297	75.945	0.222	0.932	6.322	0.006	0.000	100
PT1	0.000	2.393	17.935	60.110	0.145	0.720	2.218	7.625	0.942	0.201	7.701	0.011	0.000	100
K2	0.742	1.114	10.231	21.818	0.000	34.190	1.627	5.989	0.288	0.060	23.927	0.015	0.000	100
PT2	0.000	2.301	9.338	22.603	0.015	3.030	1.458	55.103	0.309	0.338	5.495	0.010	0.000	100
K3	1.725	1.674	14.064	33.396	0.000	22.766	2.208	11.653	0.482	0.107	11.910	0.015	0.000	100
IB	2.719	2.102	11.338	29.917	0.000	9.928	1.862	31.476	0.321	0.125	7.534	0.013	2.665	100
Q1	4.706	2.166	9.159	19.948	0.000	33.000	1.454	11.275	0.340	0.034	17.901	0.016	0.001	100
Q2	7.128	2.506	13.451	27.697	0.000	26.108	1.966	7.202	0.386	0.032	13.512	0.013	0.000	100
Q3	4.278	2.247	14.559	29.839	0.000	25.915	2.039	5.800	0.442	0.017	14.843	0.020	0.000	100
Q4	1.284	4.199	1.666	4.605	0.392	24.382	0.129	47.957	0.136	0.159	15.080	0.012	0.000	100
UB	4.657	1.636	11.137	31.111	0.000	2.343	1.593	40.245	0.398	0.189	6.682	0.009	0.000	100

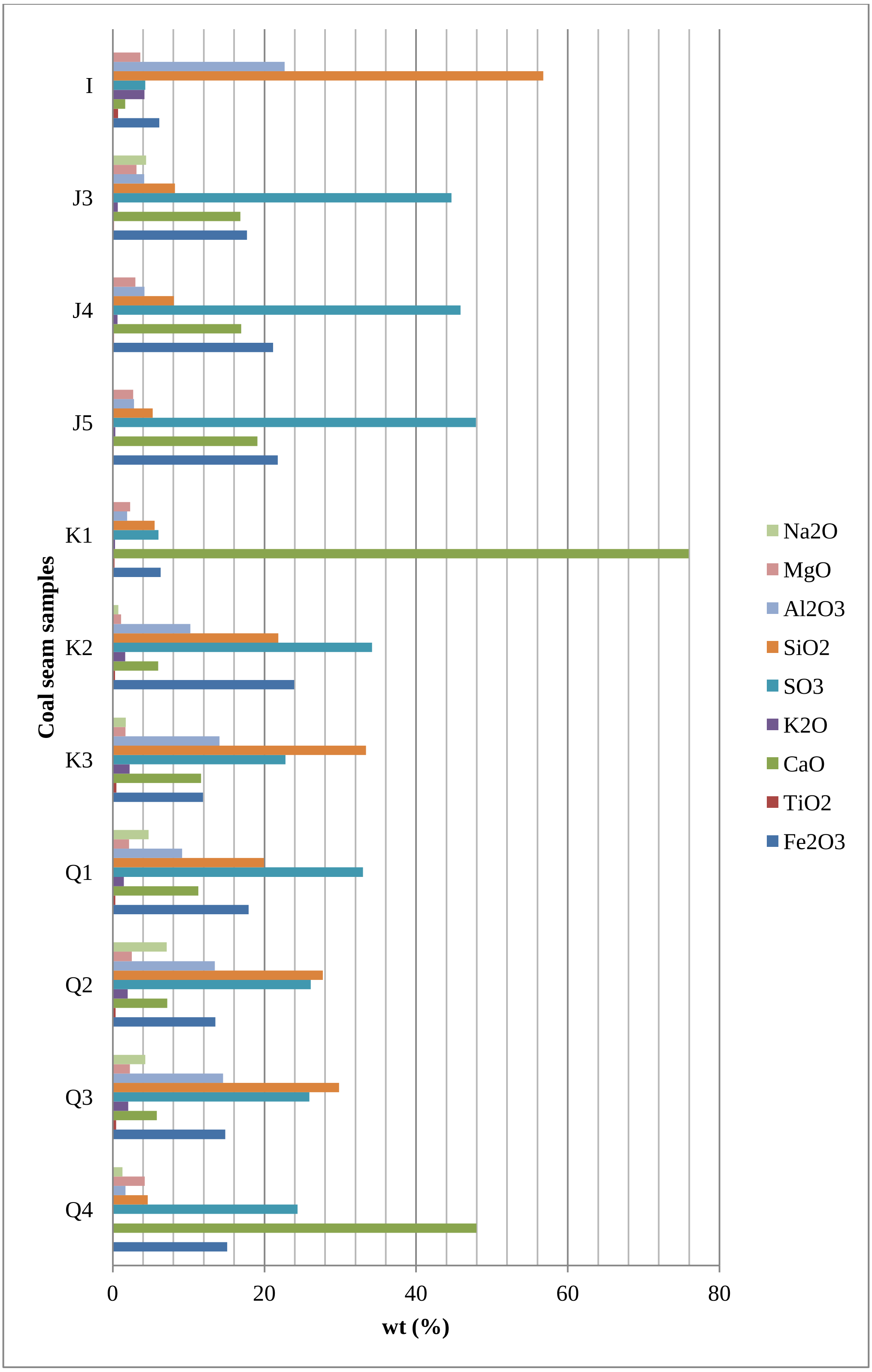


Figure 4.2 Vertical variation of major elements in coal samples in each layer

4.1.2 Minerals in coal and sediment samples using XRD method

The mineralogy analysis was analyzed by using X-ray diffractometer of Bruker model D2-phaser. The results from this analysis represented minerals, which are quartz, calcite, kaolinite, illite, pyrite, siderite, gypsum, glauconite, potassium feldspar (K-feldspar), montmorillonite and chlorite as represent in Figure 4.3 and Figure 4.4, and Table 4.2.

4.1.2.1 Minerals in sediment samples

The result of mineral content in the overburden (OB) was represented in Table 4.2 and Figure 4.3. The dominate of the K-feldspar, montmorillonite and quartz contents are 26%, 23%, and 15%, respectively. There are the other minerals content which less than 10%.

Quartz content has been found most in the PT1 sediment layer is about 32% and followed by 20% of K-feldspar content, and 16% of kaolinite content. In the PT2 sediment layer consists of 62% calcite, 11% kaolinite, 11% quartz and 4% illite.

The interburden (IB) is a sediment layer which locates between K and Q coal seam. The CaO and SiO_2 contents are dominant in this layer to about 30%. The Al_2O_3, SO_3, and Fe_2O_3 are approximate 11%, 10%, and 8%, respectively.

The underburden (UB) is the lowest layer, which composed mainly content of 40% of CaO and 31% of SiO_2. The Al_2O_3 and Fe_2O_3 also was detected about 11%, 6% of Fe_2O_3, and 5% of Na_2O.

Silicon component was detected a high in the upper layer of sediment and slight down to the lower layer. Calcium compound is dominant in the lower layer of sediment, especially in the PT2 sediment layer. Oxide of iron is dominant in the upper sediment layer and slight down to the bottom of sediment layer (Figure 4.1).

4.1.2.2 Minerals in coal samples

In the I coal seam represents to the 32.1% of K-feldspar, 17.8% glauconite content, 10.2% of quartz, and some content of montmorillonite and chlorite about 9.2%. The results of minerals content in this coal seam was shown in Table 4.2 and Figure 4.4.

In the J coal seam consists of J3, J4, and J5 coal seams. There are the similar of major minerals, with is the mainly content of montmorillonite ranges from 30 to 43% content, K-feldspar ranges from 30 to 42%, gypsum ranges from 18 to 19%, and less content of quartz and calcite.

In the K coal seam, the main mineral content in the K1 coal seam consists of 76% of calcite, and 13% of montmorillonite. In the K2 coal seam, the content of montmorillonite and K-feldspar are dominant about 68% and 14%, respectively. In the K3 coal seam, there are dominantly the mineral content such as 36% of K-feldspar, 17% of montmorillonite, 14% of gypsum, and 13% of glauconite.

In the Q coal seam, there are similarities in the mineral content of the Q1, Q2, and Q3 coal seams. The mineral in these coal seams dominates the K-feldspar ranges from 35 to 43%, montmorillonite ranges from 17 to 20%, gypsum ranges from 9 to18%, glauconite ranges from 8 to 17% and less content of calcite, pyrite, and siderite. In the Q4 coal seam consists of 40% of gypsum content, 37% of glauconite content, 28% of K-feldspar content, and 12% of montmorillonite content.

The amount of quartz component will be reduced as depth increasing except in the I and Q coal seams. The high content of quartz has found in the I coal seam and the low content of quartz locates in the lower part of the Q coal seam. The high content of pyrite has found in both of the J and K coal seam with the depth increasing, but the pyrite content in the Q coal seam is low content. This result of pyrite content represents to the high quality coal seam when compare with K and J coal seams. High calcite content was found in the K1 coal seam and low calcite content represent in the K2 and K3 resulting from the abundance of bivalve and mollusk fossils in the uppermost of the K coal seam (Silaratana, 2003). This bivalve and mollusk fossils have effect on the high calcite content in the K1 coal seam. High of gypsum content has shown in the Q4, and high content in J3, J4, and J5 are averaged at 18% of gypsum.

The elemental and mineral analysis results can be concluded that the high content of silica occurs along the high of quartz content or with other elements in kaolinite, illite, K-feldspar, glauconite, and montmorillonite. Calcium occurs directly variably with the calcite and gypsum contents. Iron occurs along with the pyrite and glauconite. Sulfur occurs directly with pyrite and gypsum.

Table 4.2 Average concentrations of minerals in coal and sediment samples from Mae Moh coal field using XRD (wt%)

Comp	Quartz	Calcite	Kaolin	Illite	Pyrite	Sider	Gyp	Glauc	Feld	Mont	Chlor	Total
I	10.24	0.16	9.36	7.18	0.36	0.28	4.22	17.78	32.07	9.10	9.24	100
J3	0.39	0.70	1.98	0.27	0.84	0.09	18.69	3.27	42.20	30.13	1.45	100
J4	0.47	0.61	1.88	0.24	0.88	0.07	17.93	3.53	32.72	40.47	1.21	100
J5	0.36	0.34	1.77	0.10	1.00	0.08	19.19	2.74	29.88	43.35	1.20	100
OB	14.55	7.78	8.93	7.46	1.26	0.26	2.00	3.81	26.38	23.43	3.96	100
K1	1.12	75.93	4.28	0.32	1.47	0.01	2.44	0.00	0.99	12.79	0.64	100
PT1	32.20	6.77	15.41	7.94	0.17	0.27	2.92	2.20	20.28	8.99	2.85	100
K2	0.85	0.13	1.93	1.37	2.74	0.00	5.18	5.50	13.58	68.15	0.56	100
PT2	4.54	61.61	10.91	4.04	1.25	0.01	1.54	0.02	4.27	8.74	3.07	100
K3	4.51	3.28	6.14	4.02	1.10	0.14	13.85	12.54	36.00	16.66	1.20	100
IB	5.71	36.62	7.92	5.13	0.00	0.09	7.11	5.84	11.32	10.34	5.31	100
Q1	2.54	0.11	4.28	1.25	0.00	0.07	17.61	8.46	42.91	20.25	0.70	100
Q2	3.01	0.02	5.04	3.37	0.00	0.06	10.94	12.05	42.44	19.54	1.35	100
Q3	4.09	0.00	7.24	4.50	0.00	0.04	8.98	16.81	35.39	16.54	2.43	100
Q4	0.54	9.10	1.44	0.00	0.00	0.02	39.65	37.12	27.94	12.40	0.22	100
UB	5.50	23.02	6.82	1.86	0.00	0.45	0.70	38.30	20.39	1.68	0.88	100

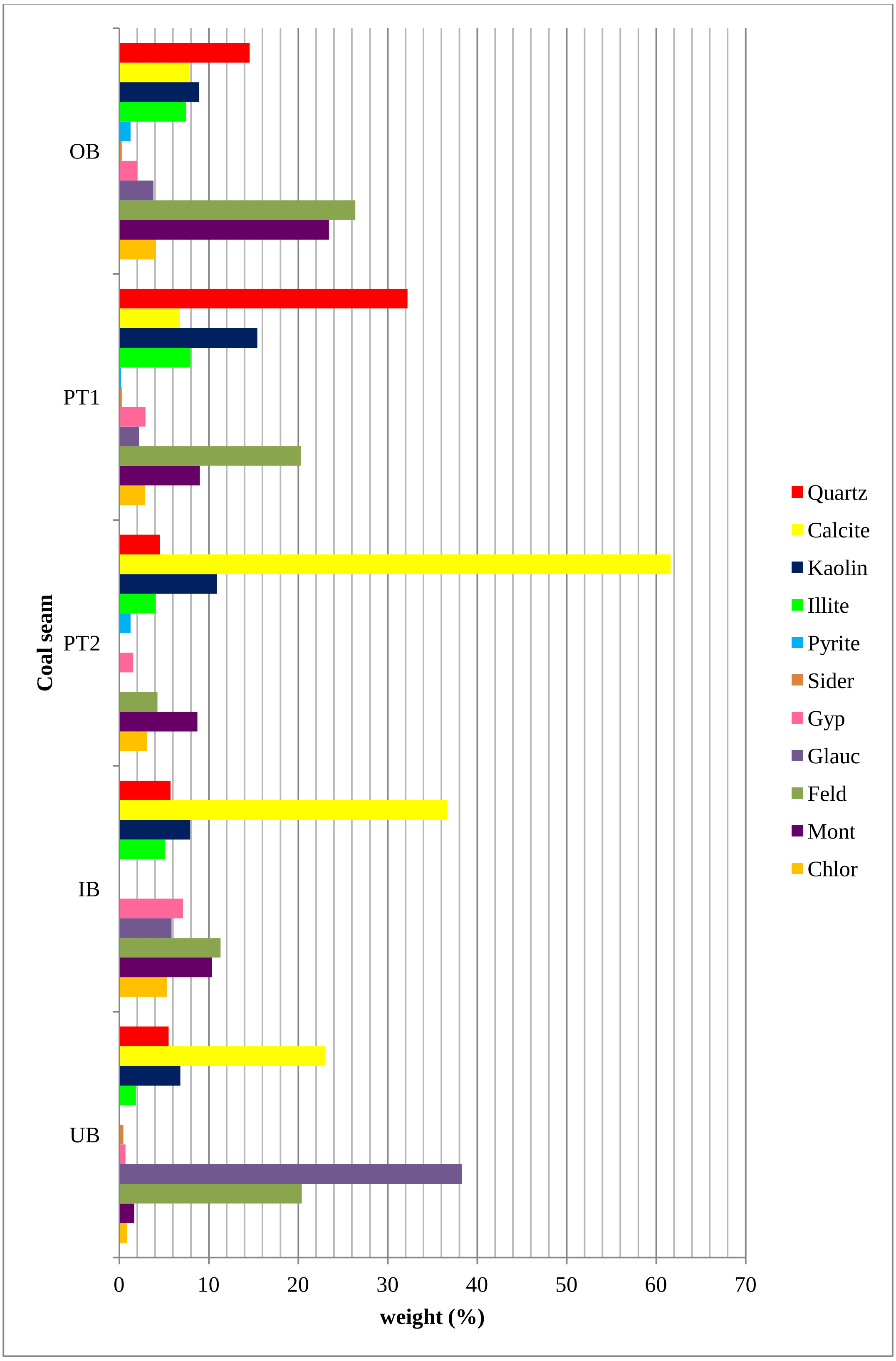


Figure 4.3 Vertical variation of minerals in sediment samples in each layer

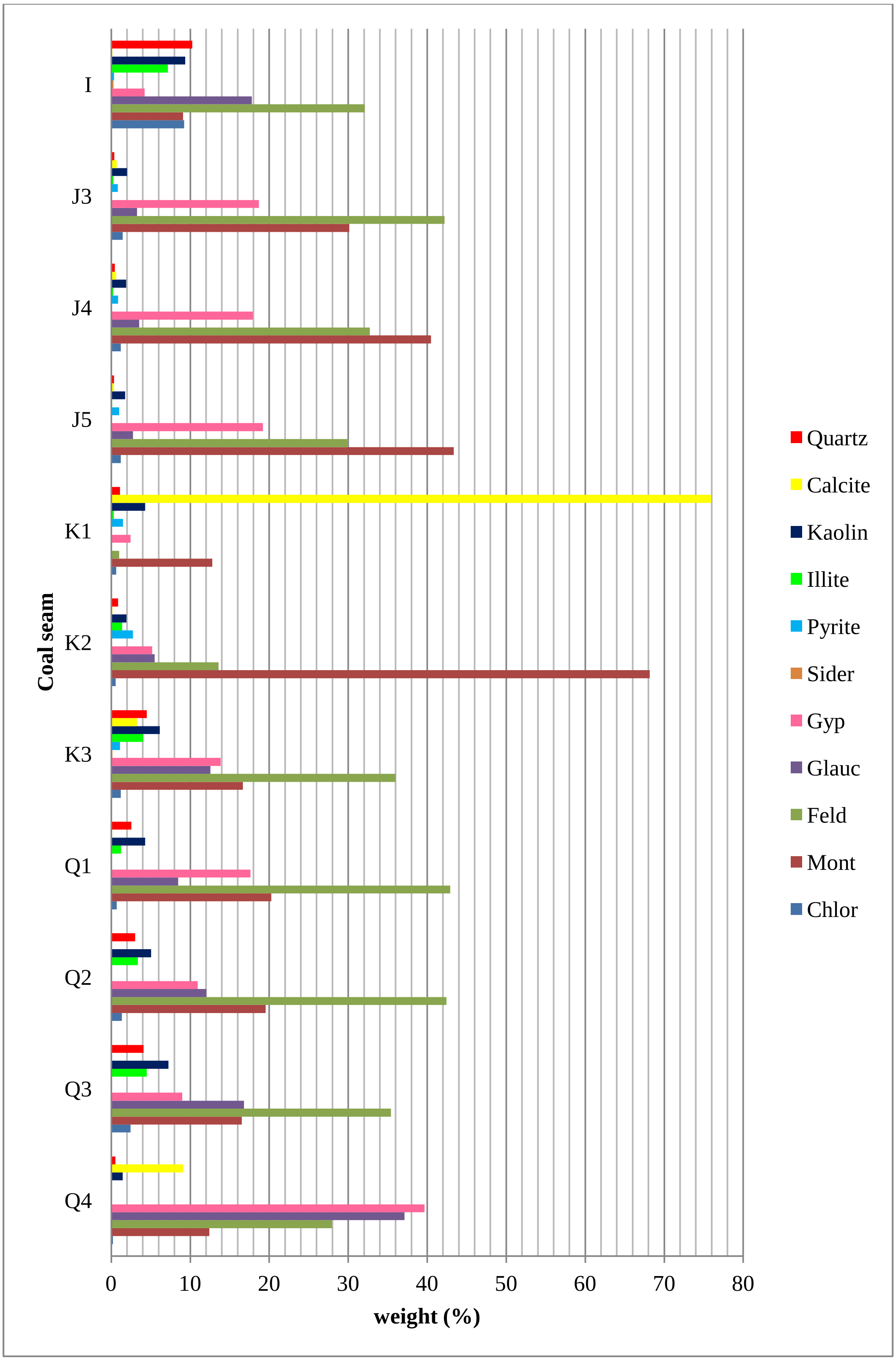


Figure 4.4 Vertical variation of minerals in coal samples in each coal seam

4.1.3 Proximate analysis

The property of coal samples was analyzed by using Leco TGA 701 that represents the content of moisture, ash, and fixed carbon. The results of proximate analysis of coal samples were shown in Figure. 4.5, Figure 4.6 and Table 4.3.

4.1.3.1 Proximate analysis of coal samples

Table 4.3 Concentration of moisture, ash, and fixed carbon contents in coal samples (weight %)

Layer	Moisture	Volatile	Ash	Fixed C	Volatile	Ash	Fixed C
					dry		
I	12.63	16.14	66.79	4.46	18.48	76.44	5.10
J3	18.03	38.24	29.93	13.81	46.65	36.50	16.85
J4	21.07	36.29	29.45	13.20	45.97	37.31	16.72
J5	20.70	36.97	29.39	12.95	46.62	37.06	16.32
K1	13.04	31.67	35.02	20.27	36.46	40.22	23.33
K2	15.90	31.39	33.55	19.17	37.32	39.89	22.80
K3	18.70	30.41	41.27	9.63	37.40	50.76	11.84
Q1	23.05	31.1	31.14	14.70	40.42	40.47	19.11
Q2	18.29	30.03	31.62	20.06	36.75	38.70	24.55
Q3	15.92	27.54	40.75	15.79	32.75	48.46	18.78
Q4	23.28	37.79	28.23	10.70	49.26	36.79	13.95

* dry is dry basis, which is calculated for each component without moisture

In the I coal seam represents the 12.63% of moisture content, 16.14% of volatile content, 66.19% of ash content, and 4.46% of fixed carbon content.

In the J coal seam represents the content of moisture ranges from 18 to 21%, volatile ranges from 36 to 38%, ash range from 29 to 30%, and fixed carbon ranges from 13 to 14%.

In the K coal seam represents the content of moisture ranges from 13 to 19%, volatile range from 30 to 32%, ash ranges from 33 to 41%, and fixed carbon ranges from 9 to 20%.

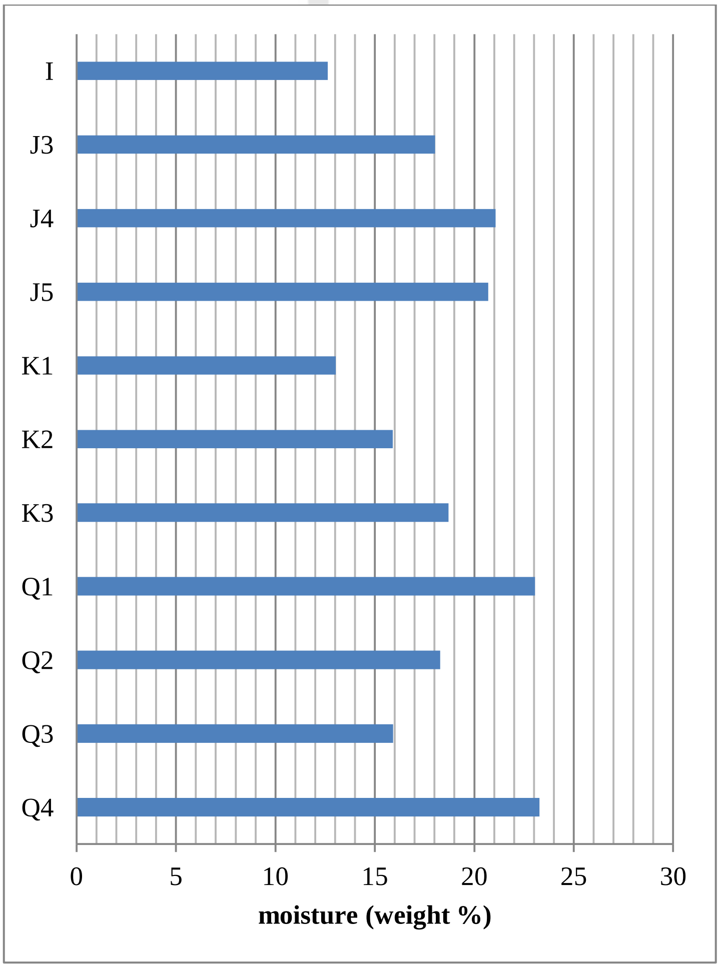
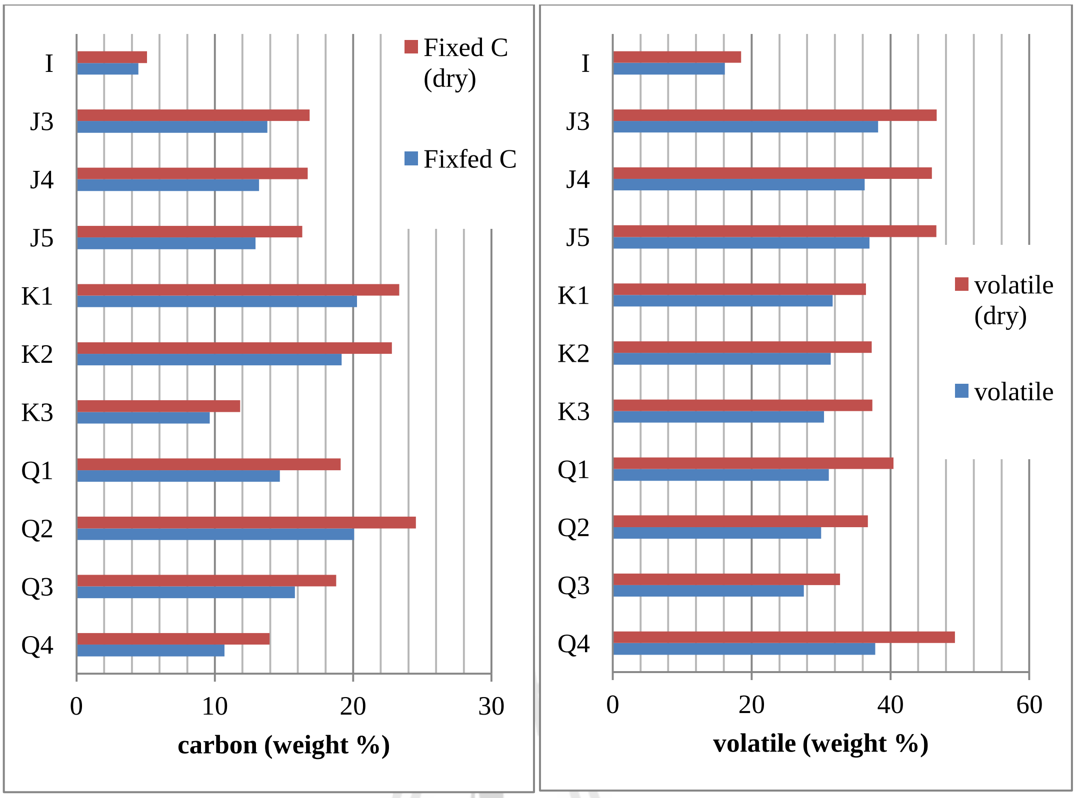


Figure 4.5 Vertical variation of moisture content in each coal seam



(a) (b)

Figure 4.6 Vertical variation of (a) fixed carbon (b) volatile in each coal seam

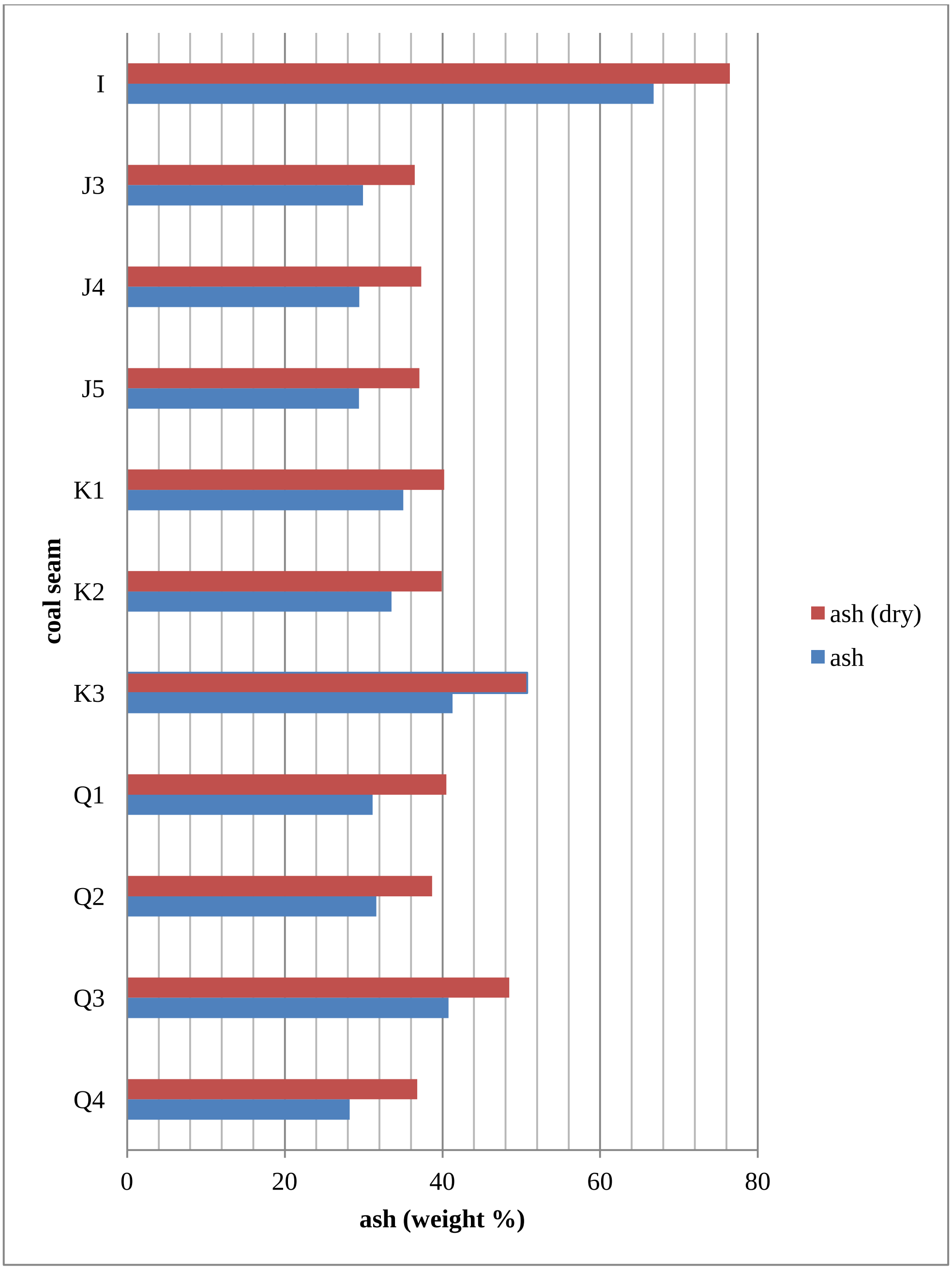


Figure 4.7 Vertical variation of ash content in each coal seam

In the Q coal seam has a moisture content ranges between 16 to 23%, volatile rages from 27 to 38%, ash ranges from 28 to 41%, and fixed carbon ranges from 11 to 20%.

The moisture content in each coal samples are nearly values in all coal seams around 15% that the graph of moisture content in coal seam has represented in Figure 4.5. The carbon content has high content in the K1, K2 and Q2 coal seam, and the lowest content is in the I coal seam. The comparison of ash content in all coal seams represents that the most ash content was found in the I coal seam.

The ash content relates directly to the elements and minerals, which mainly form of aluminum, silica and iron components. Because of these elements will be formed to be ash after burned that have the similar trend with the ash content (Figure 4.2). The ash content in the coal seam also reflects directly on a reducing of coal heating value.

4.1.4 Ultimate analysis

The property of coal samples was analyzed by using C, H, N, and S analyzer model C H N 628 S Add-on Module. The result of this analysis represents the percentage of carbon, hydrogen, nitrogen, and sulfur content which shows the results in Table 4.4 and Figure 4.8.

4.1.4.1 Ultimate analysis of coal samples

The results of ultimate analysis, which will be used in the heating value calculation is shown in Table 4.4.

Table 4.4 Variations of carbon, nitrogen, hydrogen, and sulfur in coal samples (weight %)

Seam	Carbon (C)	Nitrogen (N)	Hydrogen (H)	Sulfur(S)
I	10.250	0.52714	2.8336	1.957
J3	32.687	1.04585	4.4713	8.072
J4	31.329	0.97217	4.6373	7.772
J5	30.557	0.94557	4.4685	8.671
K1	26.151	0.77610	2.7878	5.739
K2	29.555	1.17365	4.0893	6.618
K3	26.140	1.05970	4.1860	5.509
Q1	27.540	1.02030	4.5817	5.984
Q2	30.887	1.02200	4.3747	6.600
Q3	25.024	0.85815	3.8177	5.768
Q4	32.479	0.95870	4.6613	3.041

In the I coal seam has 10% of carbon content, 0.52% of nitrogen content, 2.8% of hydrogen content, and 1.9% of sulfur content.

In the J coal seam has a carbon content ranges from 30 to 32%, nitrogen ranges from 0.9 to 1%, 4.5% of hydrogen content, and sulfur content ranges from 7.7 to 8.7%.

In the major K coal seam has a carbon content ranges from 26 to 29%, nitrogen ranges from 0.9 to 1%, hydrogen is about 4.5%, and sulfur content ranges from 7.7 to 8.7%.

The major Q coal seam has a carbon content ranges from 25 to 32%, nitrogen ranges from 0.8 to 1%, hydrogen ranges from 3.8 to 4.6%, and sulfur content ranges from 3 to 6.6%.

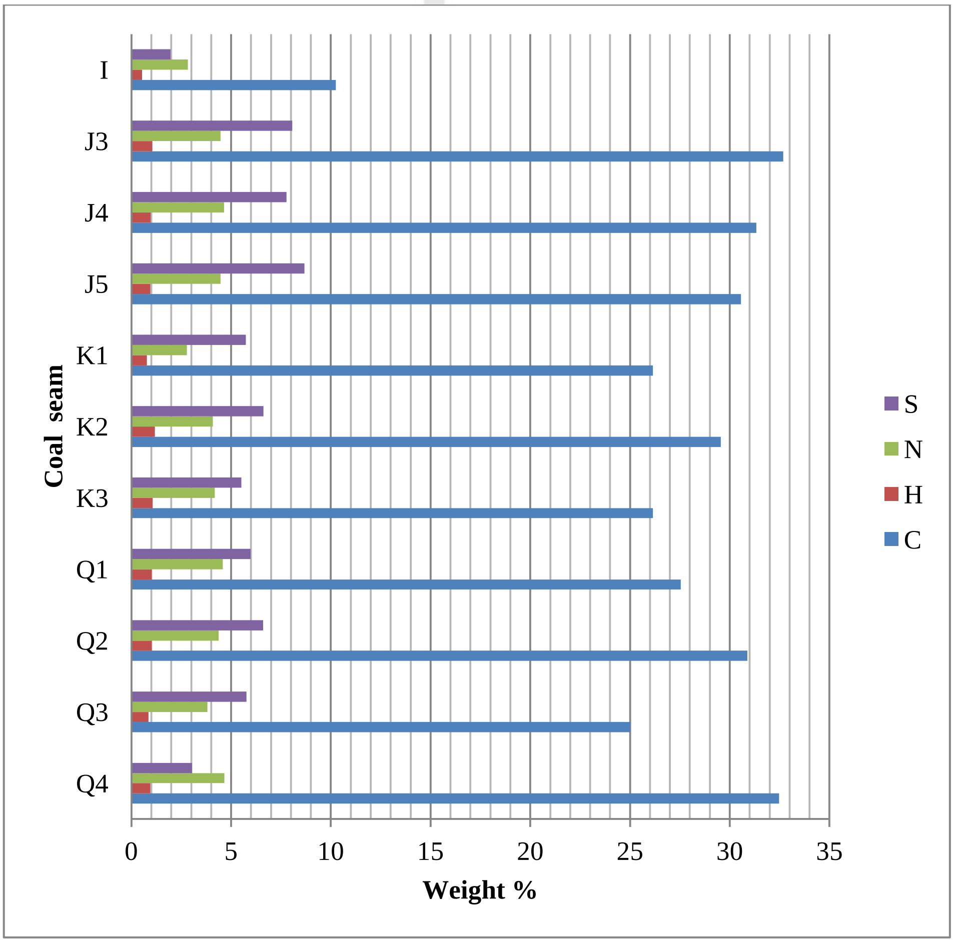


Figure 4.8 Vertical variation of carbon, hydrogen, nitrogen, and sulfur in coal samples

The result of sulfur content shows that the I and Q coal seams are lower sulfur content than K and J coal seams, which has the similar trend with the sulfur content analyzed from XRF analysis.

4.1.5 Trace element analysis

Trace elements in sediment and coal samples were analyzed by using Perkin Elmer Optima 3000 which represent concentration of As, Cr, Co, Cu, Mo, Zn, V, and Pb in part per million (ppm) unit. The coal samples J5, K2 and Q1 coal seams were studied by these coal seams is the agent of the J, K and Q, respectively. The results from this analysis were shown in Figure 4.9, Figure 4.10, and Table 4.5.

4.1.5.1 Trace elements in sediment samples

In the overburden (OB) has the highest content of trace elements which content as 641.90 ppm of Cr, 78.04 ppm of Mo, 72.13 ppm of V, 59.72 ppm of Cu, 54.79 ppm of Zn, and 10 ppm of Co and Pb, and less of As. The interburden (IB) has high content as 41.17 ppm of V and 34.61 ppm of Zn. The other elements in this layer such as Cu, Cr, and Pb content are 25.46, 20.49, and 8.35 ppm, respectively. There is also a small among of As in this layer. The underburden (UB) represents the lowest trace elements content as 37.50 ppm of V, 27.92 ppm of Zn, 23.14 ppm of Cu, 20.14 ppm of Cr, and 5.19 ppm of Pb. From the results of trace elements in sediment layer have shown that the overburden has high trace element content with decrease content when the depth increasing.

4.1.5.2 Trace elements in coal samples

The results of trace element in the J5 coal seam show the high As content about 72.54 ppm, and there are 21.18 ppm of V, and 16.19 ppm of Zn and

11.59 ppm of Cu. The arsenic content in this coal sample is higher than the soil quality control standard (Pollution Control Department, 2004) about 94.62%.

The K2 coal seam represents the high 46.11 ppm of V. There are other trace element content such as 37 ppm of As, 31.34 ppm of Zn, and 22.36 of Cu. The arsenic content in this coal seam is higher than the soil quality control standard (Pollution Control Department, 2004) about 89.60%.

In the Q1 coal seam shows the high content of 51.83 ppm of As, 31.30 ppm of V, 19.54 ppm of Zn, and 16.95 ppm of Cu. This arsenic content in this coal sample is higher than the soil quality control standard (Pollution control department, 2004)) about 92.47%.

Arsenic content has found dominate in all coal seams and there is the highest content in J5 coal seam. Amount of other trace elements (Cr, Co, Cu, Mo, Zn, V, and Pb as shown in Figure 4.10) found more in K2 followed by Q1 and J5.

The trace element analysis in the J5 coal seam shows the high arsenic content than the limit of soil quality control standard around 62.7%, which arsenic content should not more than 3.9 milligram per kilogram (mg/kg). In the Q1 and K2 coal seam, there are higher than standard 47.91 and 28.04 ppm, respectively. The Cr and Pb contents are under limited that Cr should not over than 640 ppm and 750 ppm.

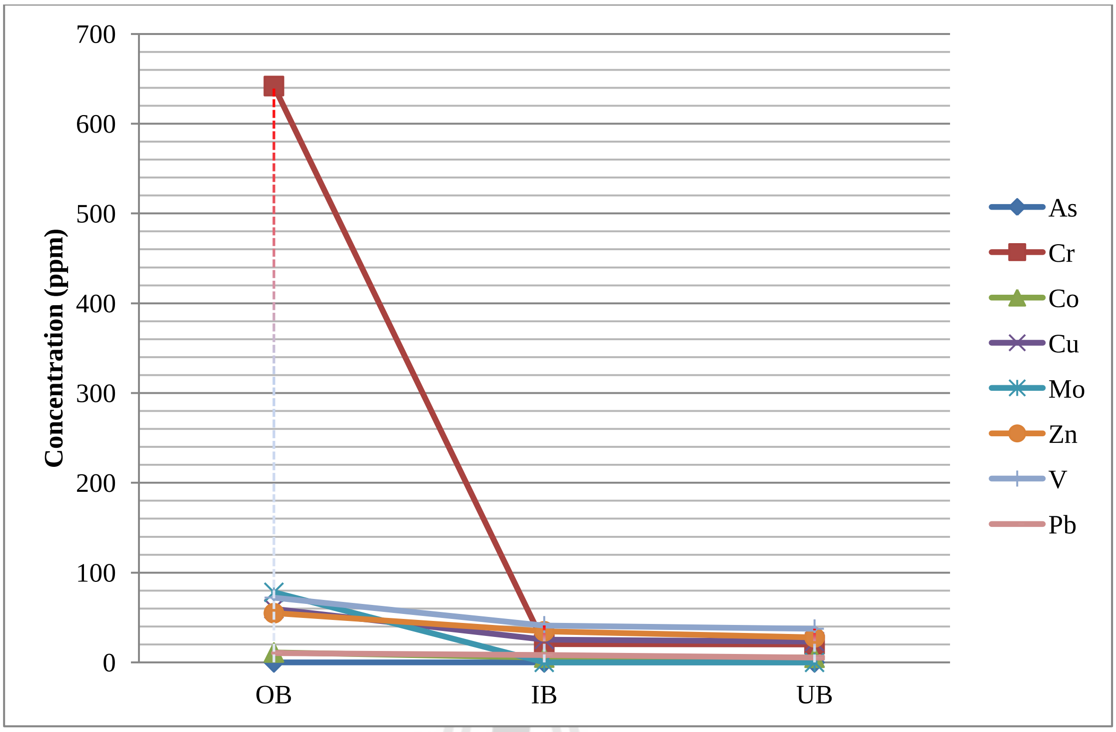


Figure 4.9 The variety of trace elements in sediment samples (ppm)

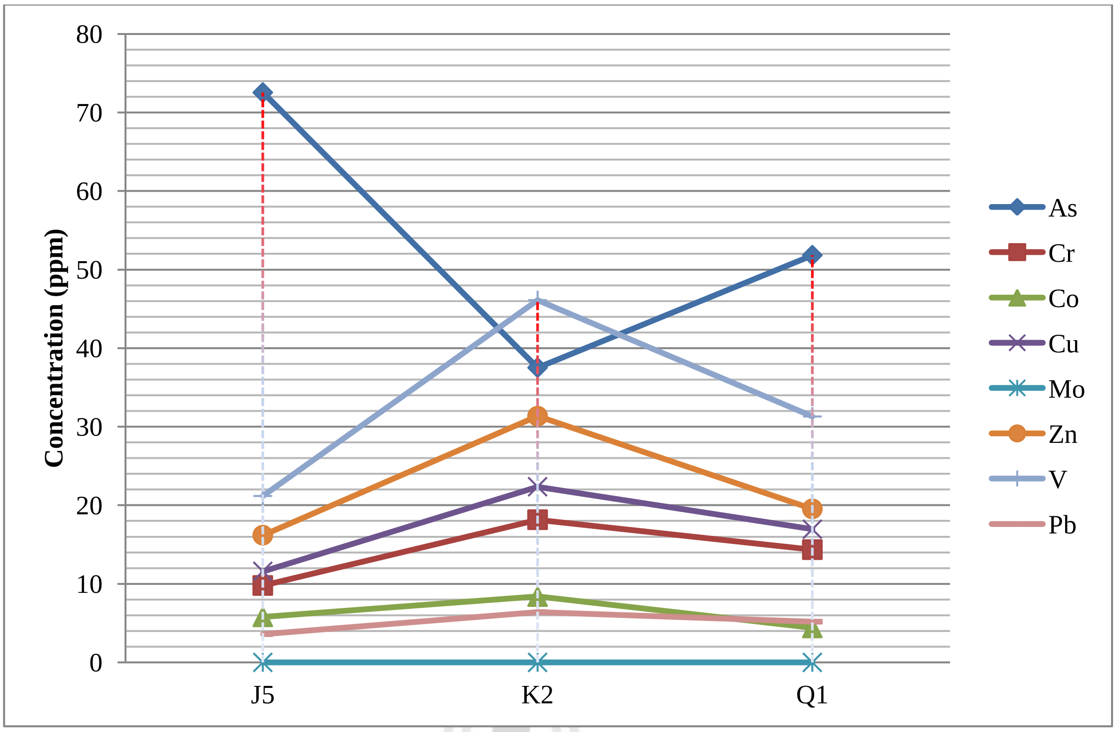


Figure 4.10 The variation of trace elements in coal samples (ppm)

Table 4.5 Concentration of trace elements in sediment and coal samples (ppm)

Elements	J5	OB	K2	IB	Q1	UB
As	72.54	0.00	37.52	0.00	51.83	0.00
Cr	9.79	641.90	18.16	20.49	14.35	20.14
Co	5.80	11.04	8.38	5.37	4.39	5.19
Cu	11.59	59.72	22.36	25.46	16.95	23.14
Mo	0.00	78.04	0.00	0.00	0.00	0.00
Zn	16.19	54.79	31.34	34.61	19.54	27.92
V	21.18	72.13	46.11	41.17	31.30	37.50
Pb	3.60	10.45	6.39	8.35	5.18	5.19

4.1.6 Heating value analysis

High and low heating values of coal samples are shown in Table 4.6, and determined by using Dulong Formular as follows:

$$Heating\ value\ \left(\frac{Btu}{lb}\right) = 145\,C\ +\ 610\left(H_2 - \frac{1}{8}O_2\right) +\ 40\,S\ +\ 10\,N \qquad (4.1)$$

where C is Carbon (wt%)

H_2 is Hydrogen (wt%)

O_2 is Oxygen (wt%)

S is Sulfur (wt%)

N is Nitrogen (wt%)

1 Btu/lb = 2.324 kJ/kg

In the I coal seam has the heating value about 4.54 MJ/kg. The J coal seam shows the heating value ranges from 12.86 to 13.91 MJ/kg by the highest in the J3 coal seam. The K coal seam shows the heating value ranges from 8.08 to 11.97 MJ/kg by the highest in the K2 coal seam. The Q coal seam represents the heating value ranges from 10.19 to 12.73 MJ/kg with the highest in the Q2 coal seam. This study can be concluded that the J coal seam is the highest heating value, followed by Q, K and I coal seams, respectively.

Table 4.6 Heating value of trace coal samples both before and after treated by chemical treatment (MJ/kg)

Seam	HHV MJ/kg	LHV MJ/kg	HF		HNO_3		HCl		NaOH		KOH	
			HHV	LHV	HHV	LHV	HHV	LHV	HHV	LHV	HHV	LHV
I	4.54	4.24	1.00	0.75	3.63	3.45	12.10	11.87	1.45	1.26	1.99	1.85
J3	13.91	13.48	9.53	9.22	9.94	9.62	7.20	6.90	9.15	8.83	11.03	10.71
J4	13.30	12.79	9.41	9.07	12.05	11.73	12.05	11.73	8.73	8.39	10.08	9.71
J5	12.86	12.36	9.91	9.58	7.49	7.14	7.49	7.14	8.73	8.39	16.55	16.11
K1	8.08	7.77	7.28	7.06	7.77	7.50	4.94	4.68	7.78	7.50	17.69	17.42
K2	11.97	11.59	9.99	9.74	9.02	8.71	9.98	9.65	9.60	9.30	21.01	20.73
K3	11.41	10.96	9.50	9.24	8.67	8.38	7.99	7.72	8.52	8.24	18.74	18.37
Q1	11.09	10.53	8.48	8.20	9.23	8.93	8.16	7.87	9.14	8.85	19.72	19.37
Q2	12.73	12.29	8.11	7.87	8.65	8.42	7.41	7.18	8.45	8.18	19.72	19.37
Q3	10.19	9.81	8.11	7.87	7.97	7.69	6.62	6.33	9.62	9.33	8.40	8.02
Q4	12.43	11.87	12.96	12.67	11.74	11.43	12.52	12.18	9.78	9.50	8.71	8.32

The results of previous analysis showing the relationship of the results in each method were represented in Figure 4.3 and Figure 4.4. The results of major elements conform to the variation of mineral in sediment and coal samples such as amount of SiO_2 occurs directly in the content of quartz or other elements in kaolinite, illite, K-feldspar, glauconite, and montmorillonite. Calcium occurs in calcite and gypsum. Iron relates to the pyrite, and glauconite. Sulfur relates to among of pyrite and gypsum. Mineral analysis indicates that the conformity of sediments and coal contents such as amount elements and minerals in the interburden are quite the same with content in the K and Q coal seams because the similarity of the depositional environment, which is type of swampy environment, at the same time. In contrast, the high calcite is in the K1 coal seam and PT1 sediment layer due to during the deposition the sediment and coal had deposited together in the same depositional environment as fresh water environmental (Ratanasthien *et al.*, 2008). This sediment represents a high spot of calcite content that affect directly on the calcite content in K1 coal seam. The relationship of elements and minerals between the overburden and J coal seam is the similar to the K and Q coal seams, and interburden that showing the deposition of coal and sediment at the same time and environment (Figure 4.3 and Figure 4.4).

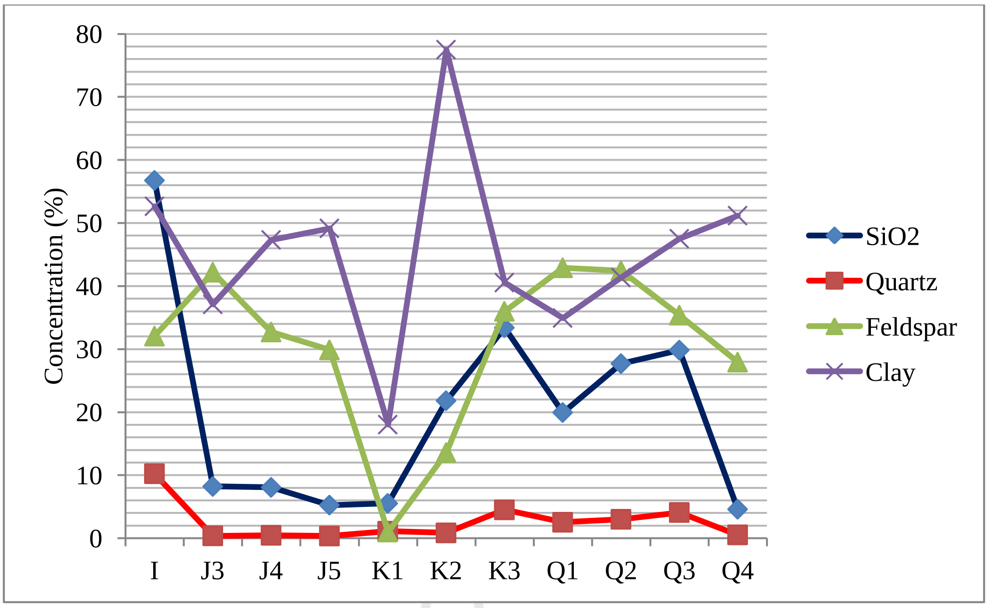


Figure 4.11 The comparison between amount of SiO_2, quartz, feldspar, and clay in coal samples

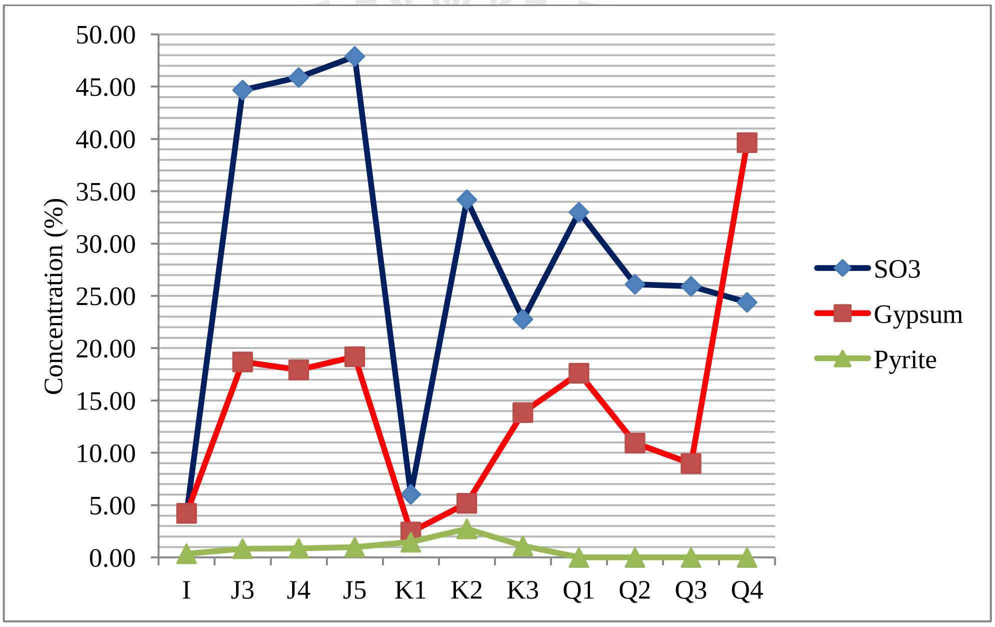


Figure 4.12 The comparison between amount of SO_3, gypsum, and pyrite in coal samples

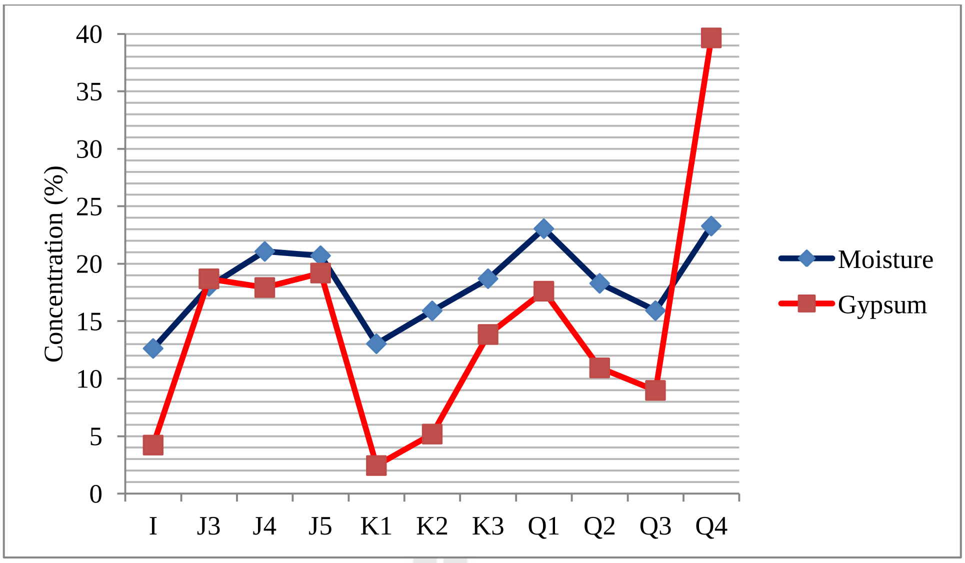


Figure 4.13 The comparison between amount of moisture content and gypsum in coal samples

The comparison between the amount of SiO_2, quartz, feldspar, and clay in coal samples that showing in Figure 4.11. The variation of SiO_2 in coal clearly conforms to the variation of quartz content. However, the amount of SiO_2 also depends on the feldspar and clay contents.

Sulfur content in coal samples is shown in Figure 4.12 that the values is the similarity trend with gypsum, showing sulfur content in coal is major from gypsum.

Variation of moisture content in coal samples in each coal seam is conforming with the amount of gypsum, which confirms that moisture in coals occur major from gypsum (Figure 4.13).

The heating value of a coal sample depends on ash content. Therefore, the high heating value will increase when lower ash content of coal.

4.2 The property of coal samples after treating

4.2.1 Major elements in coal samples using the XRF method

4.2.1.1 Major elements in coal samples in 24 hours of treatment

The results of analysis represent an element in coal samples after treating using chemicals are shown in (Table II.1.1 and Figure 4.14 to Figure 4.17).

The I coal seam, the amount of sulfur highly decreases by using HF about 83%, reduced 81% in HCl, and HNO_3 about 80%. Aluminium content highly decreases in HF as 74%, reduce 63% in HCl, and in HNO_3 61%. Iron content more reduced after leaching in HF about 96%, 93% in HCl, and 92% in HNO_3. In this coal seam can be concluded that HCl has high performance for treatment in this coal seam.

The J3 coal seam, the KOH reduces 64% of the sulfur content and 88% of silicon content. Aluminium and iron contents reduced to 41 and 81% in HCl. From these results show that HCl has the highest performance for coal treatment in this coal seam.

The J4 coal seam, HCl reduces sulfur content about 74%. Aluminium content was reduced about 90% in HNO_3 or KOH. The amount of silicon content will reduce to 90% after leaching with HNO_3 and reduced 85% in HF or KOH. The iron content in coal samples reduced 90% after treated by HF, HNO_3, and HCl.

The J5 coal seam, the sulfur content reduced 81% and iron content reduced 93% after leaching with NaOH. The aluminium content was reduced about 99% and silicon content 85% with KOH and HCl. Nitric acid effects of the major element will forming ash reduction despite is not dominant for reducing sulfur content.

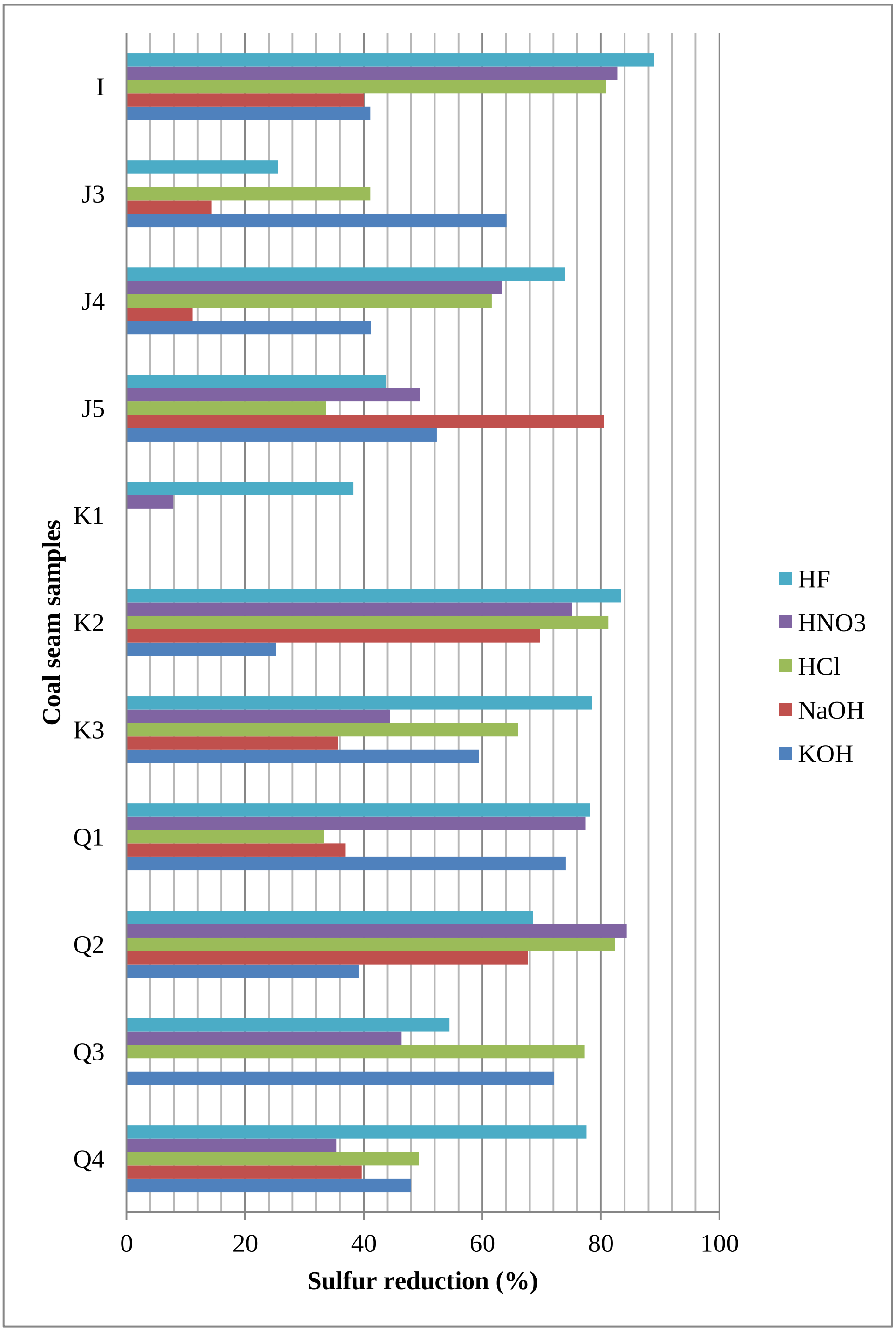


Figure 4.14 The sulfur reduction in coal samples after treated for 24 hours.

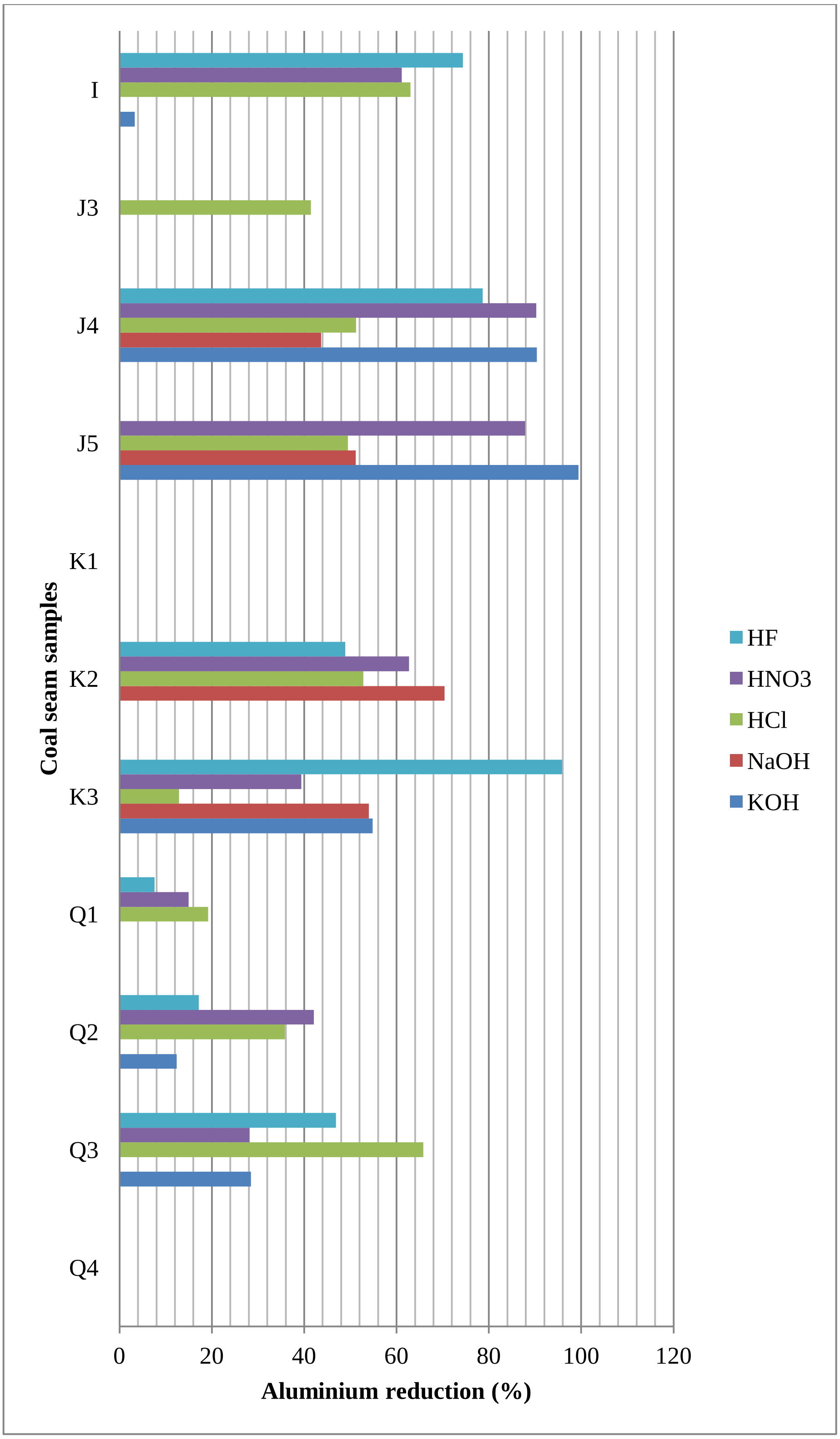


Figure 4.15 The aluminum reduction in coal samples after treated for 24 hours.

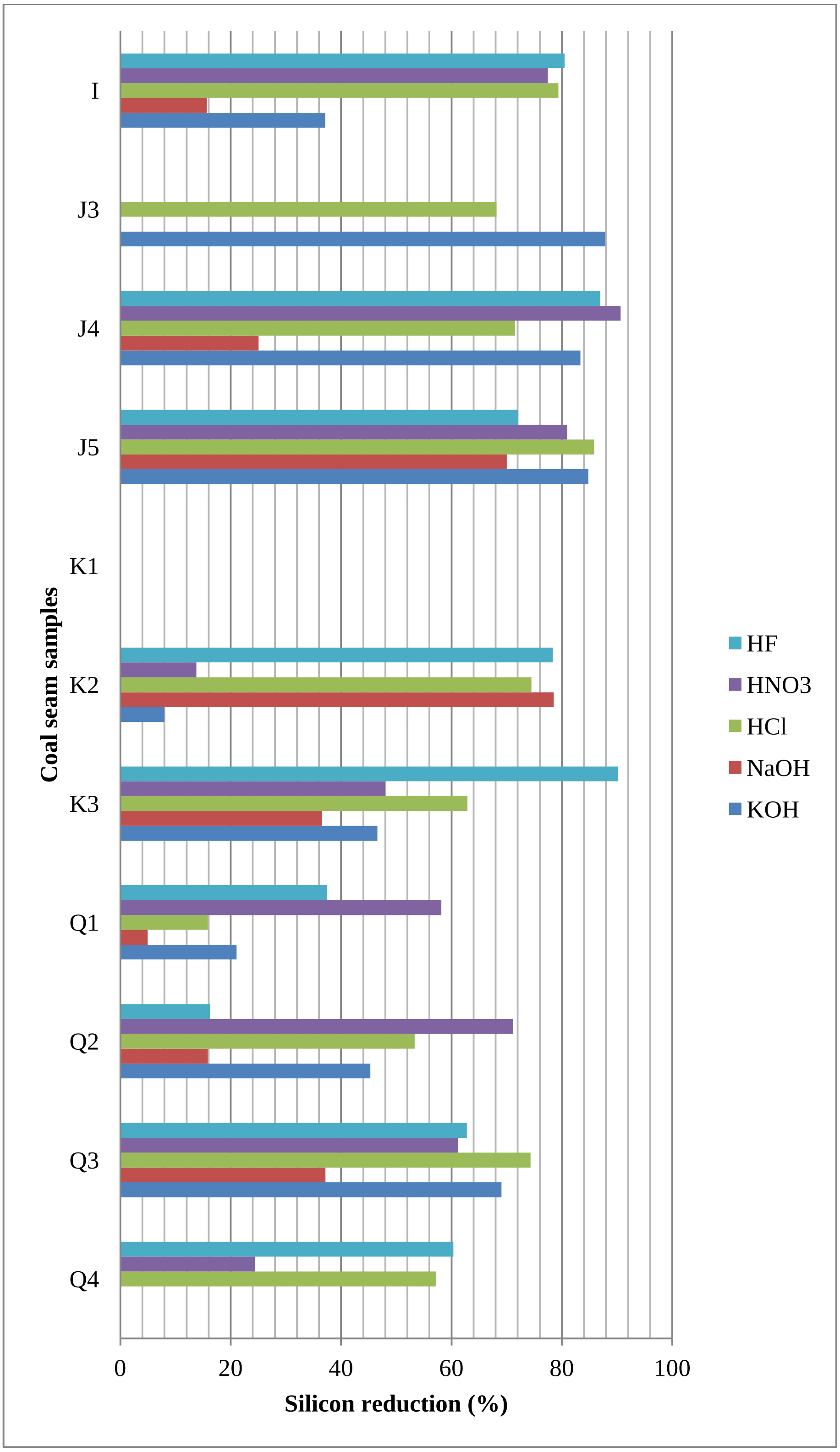


Figure 4.16 The silicon reduction in coal samples after treated for 24 hours.

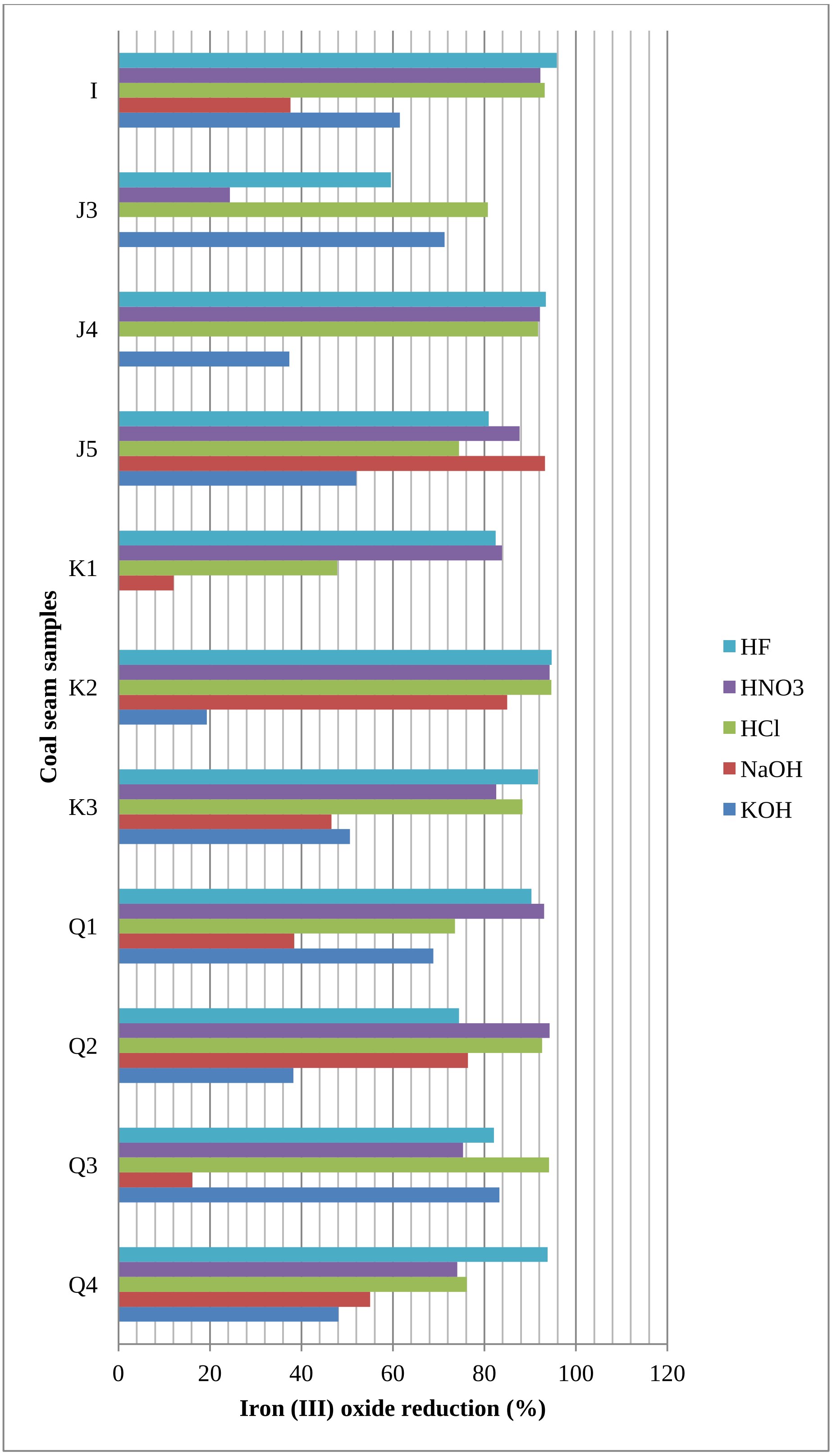


Figure 4.17 The iron reduction in coal samples after treated for 24 hours.

The K1 coal seam, HF reduces sulfur content about 38% and iron content reduced 83%, which has the results same as HNO_3 reduces 84% of iron content. From Figure 4.2 to Figure 4.5 shown that the chemical solutions are not affected on reducing of the silicon and aluminum contents by a little in the sulfur reduction because of the K1 coal seam has high the calcite content. These calcite can be reacted with the chemicals that resulting the chemical did not react cover with the other minerals.

The K2 coal seam, HF and HNO3 can reduce the sulfur content ranges from 81 to 83%. Silicon content has high reduced in KOH and HF about 78%. Iron content reduced 94% in HF, HNO_3 and HCl. The amount of ash which can be formed by major elements that has high reduce in HF, HCl and NaOH about 80%.

The K3 coal seam, HF has high performance for treatment which can reduce 79% of sulfur, 96% of aluminum, 90% of silicon, 92% of iron, and 92% of the summation of Si, Al, and Fe contents.

The Q1 coal seam, HF and HNO_3 have the highest performance in reducing 80% of SO_3, 15% of Al_2O_3, 90% of Fe_2O_3 and SiO_2 ranges between 40 to 50%, and the elements will be formed to be ash (Si, Al, and Fe) about 80%.

The Q2 coal seam, the solution of nitric and hydrochloric give the similar results that can reduce SO_3 ranges from 82 to 84%, Al_2O_3 ranges from 36 to 42%, SiO_2 ranges from 53 to 71%, Fe_2O_3 ranges from 92 to 94%, and the elements will be formed to be ash (Si, Al, and Fe) ranges from 58 to 70%.

The Q3 coal seam, the solution of hydrochloric has the highest performance for reducing 77% of SO_3, 66% of Al_2O_3, 74% of SiO_2, 94% of Fe_2O_3, and the elements will be formed to be ash (Si, Al, and Fe) about 77%.

The Q4 coal seam, HF has the highest performance for reducing 77.6% of SO_3 77.6%, 60% of SiO_2, 94% of Fe_2O_3, and the elements will be formed to be ash (Si, Al, and Fe) about 73%

4.2.1.2 Major elements in coal samples in 48 hours of treatment

The results of analysis represent elements in coal samples after treating using chemicals are shown in Table 4.7 and Fig 4.18 to Figure 4.21 as follow:

The aqueous of HF has high performance for reducing 62.5% of ZnO, 37% of CaO, 29% of Na_2O, 26% of MgO, and 25% of SO_3. Nitric acid can reduce highest of MnO and CaO about 67%, 50% of ZnO, 27% of MgO. The solution HCl is higher reduced of ZnO up to 81%, including reduce 56% of MnO_2, 38% of MgO, 31% of Fe_2O_3, 24.71% of Na_2O, 17.45% of CaO, and 17.45% of SO_3. Sodium hydroxide can reduce MgO, SO_3, and CaO contents about 62%, also reduce 59% of NaO_2 and 31% of ZnO. For the solution of KOH affects highest on CaO about 63%, next are SO_3 and MgO about 55%, but less reaction with Na_2O about 6%.

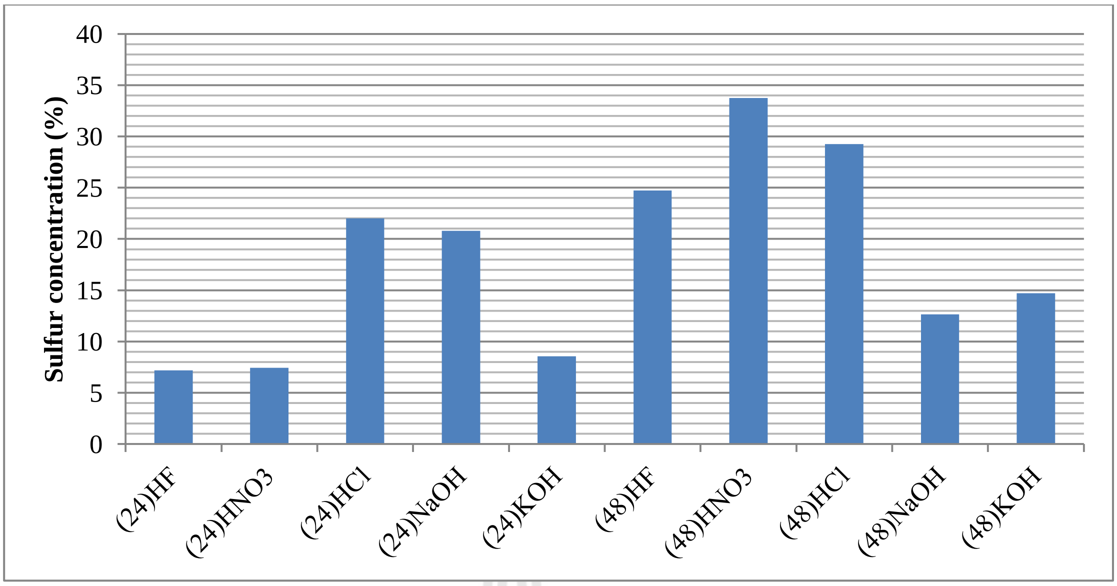


Figure 4.18 The comparison of sulfur content in Q1 between before treating, for 24 and 48 hours.

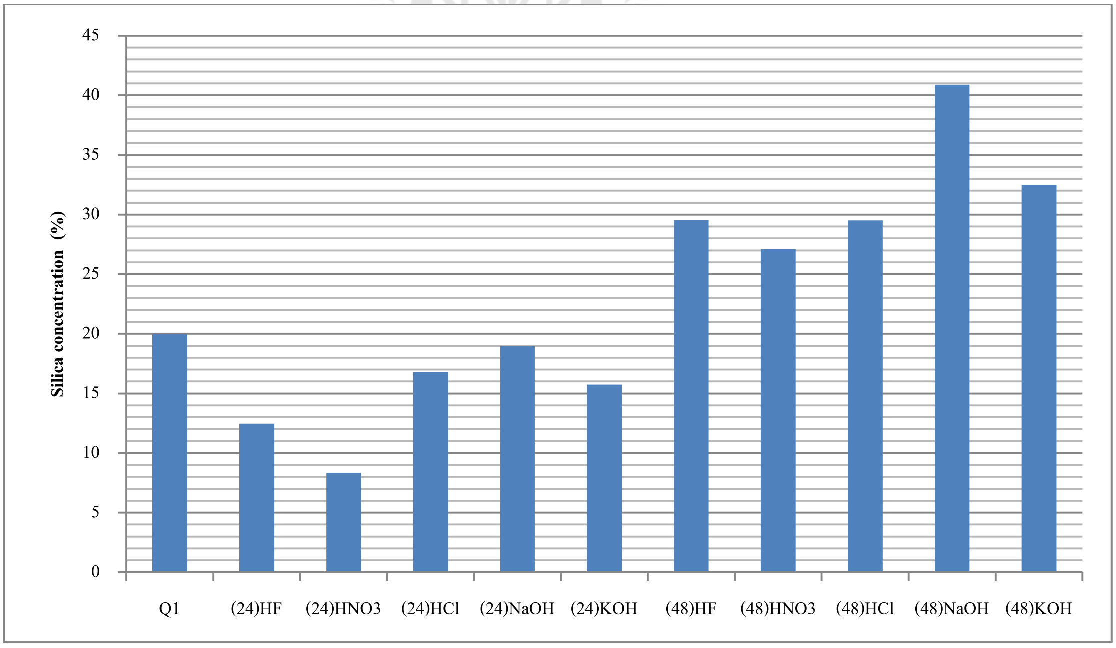


Figure 4.19 The comparison of silicon content in Q1 between before treating, for 24 and 48 hours.

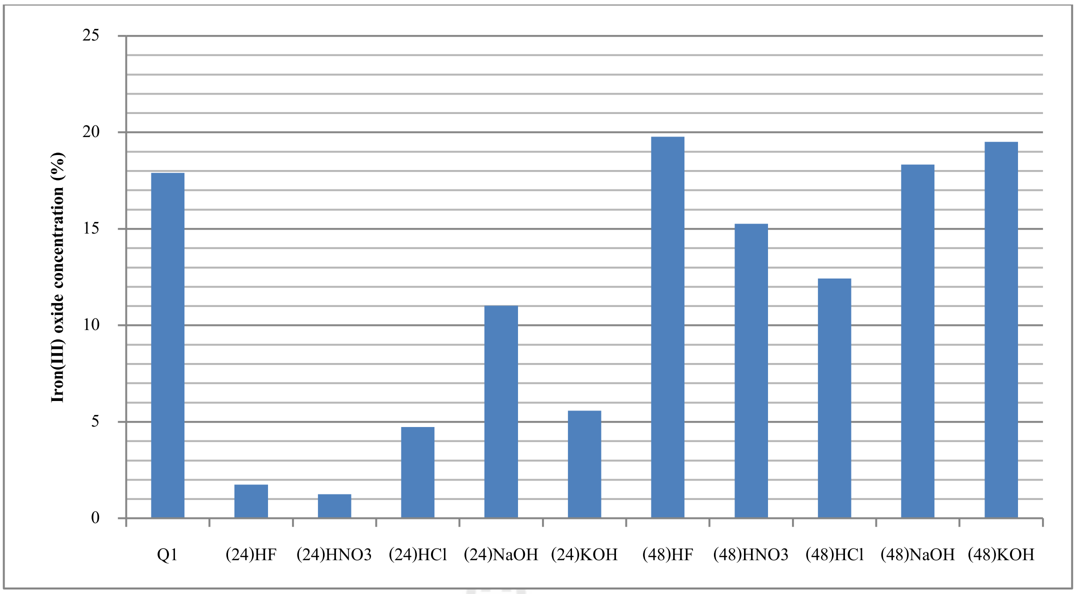


Figure 4.20 The comparison of iron content in Q1 between before treating, for 24 and 48 hours.

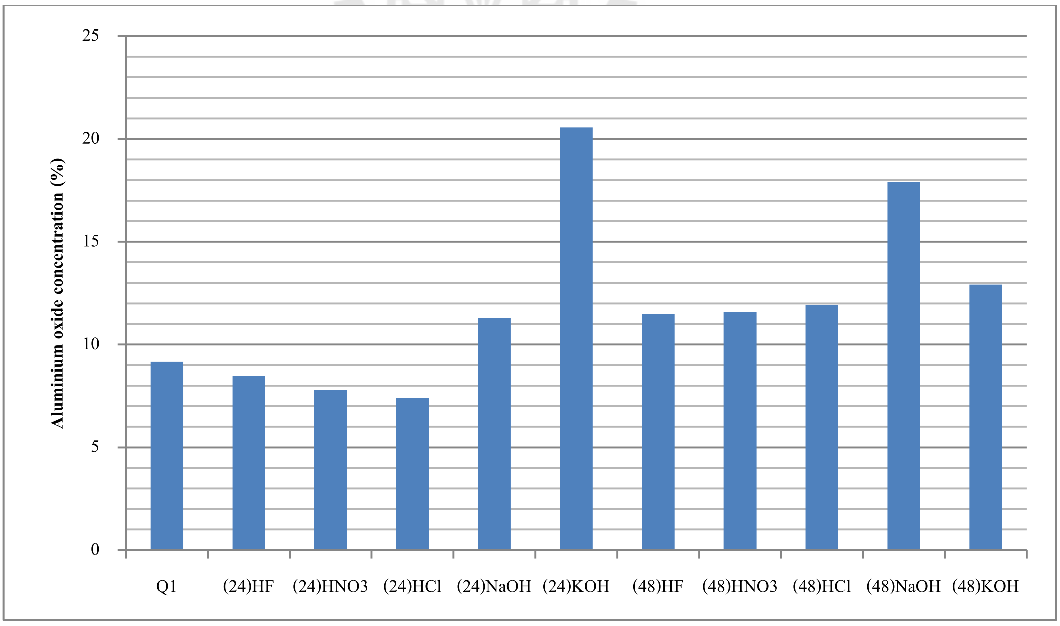


Figure 4.21 The comparison of aluminum content in Q1 between before treating for 24 and 48 hours.

The analysis from Figure 4.18 to Figure 4.21 show increasing of time to 48 hours. The results conform to the sulfur reduction is increased by using NaOH and KOH about 50%. Hydrofluoric, nitric, and hydrochloric aqueous have high performance for reducing the silicon content and less react with iron content when time increase to 48 hours. The comparison of components at 48 hours represent higher than 24 hours due to the amount of metal after reacted with chemicals which expected fully finished in 24 hours. After that, those metal ions have more time to dissolve in water. From the Table 4.7 shows the reducing of those metals which decrease to 3%, especially of calcium and potassium. In contrast, the AlO_3 and SiO_2 cannot reduce due to these metals cannot dissolve in water that it made the quantity of these metals are not changing.

Table 4.7 Variations of major elements (oxidized form) in Q1 coal seam of the Mae Moh coal field after treating 48 hours (wt %).

Element	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO_2	Fe_2O_3	BaO	ZnO	Total
HF	3.362	1.604	11.490	29.540	0.000	24.718	1.856	7.091	0.504	0.050	19.783	0.004	0.006	100
HNO_3	5.246	1.573	11.592	27.089	0.000	33.756	1.391	3.639	0.437	0.011	15.262	0.000	0.008	100
HCl	3.543	1.342	11.933	29.509	0.000	29.244	2.028	9.308	0.602	0.015	12.429	0.045	0.003	100
NaOH	1.917	0.766	17.897	40.893	0.000	12.663	2.840	4.137	0.491	0.053	18.335	0.000	0.011	100
KOH	4.421	0.971	12.910	32.501	0.000	14.710	10.324	4.091	0.473	0.056	19.516	0.000	0.029	100

4.2.2 Minerals in coal samples using XRD method

4.2.2.1 Minerals in coal samples in 24 hours of treatment

The results of analysis represent minerals in coal samples after treating using chemicals are shown in (Table II.2.1 and Fig 4.22 to 4.25)

The I coal seam is found high quartz reduction after reacted with HF about 25%. Pyrite content reduced to 93% in HCl aqueous. Calcite highly reduced in a solution of nitric acid. After leaching coal samples with HF, NaOH or KOH can reduce the gypsum content ranges from 88 to 92%.

The J3 coal seam, HNO_3 can reduce the pyrite content up to 98%. Gypsum can be reduced in HCl about 73% and 40.32% after reacting with KOH. From the graph of Figure 4.22, the J3 coal seam has high gypsum and silicate group with high quartz. Because of the quartz hardly reacts with the chemicals so that most of the reaction will react with pyrite, gypsum, and silicate group instead, which shows the results of less quartz reduction.

The J4 coal seam, the amount of quartz reduced to 50% in HF, HCl or NaOH. Pyrite is reduced about 66 to 72% in aqueous of KOH or NaOH. Gypsum can be also reduced highly in KOH. Calcite is highly reacted with HCl that can reduce content up to 64%.

The J5 coal seam, quartz is reduced in HF and HNO_3 at 75 and 73%, respectively. The amount of pyrite reduced to 91% after reacting with KOH and 74% in NaOH. Calcite reduced 15% in KOH. Gypsum after reacted with KOH and NaOH that can reduce content in coal samples to 61 and 57%, respectively.

The K1 coal seam, pyrite respectively reduced about 67 and 60% in NaOH and KOH, and 50% in HNO_3 or HCl. Gypsum can be reduced to 99% in HF, HNO_3 or HCl. Potassium hydroxide can reduce gypsum to 70%. In this coal seam has high content of calcite which can react easily with chemicals. In contrast, quartz in this coal seam is very hard to react with the chemical. Therefore, the most of reaction will occur on calcite that the same results with gypsum (Figure 4.25).

The K2 coal seam, an aqueous of KOH has high performance for reducing of quartz, pyrite, calcite, and gypsum about 42, 89, 79, and 81%, respectively. This result is the effect of the high clay content in this coal seam that hardly reacts with KOH. Therefore, the most of the reaction will instead appear with the calcite and gypsum.

The K3 coal seam, pyrite content reduced about 50% in NaOH, HNO_3 or HCl. Calcite can be reduced to 95% after reacting with HF. Potassium hydroxide can reduce gypsum about 92%.

The Q1 coal seam, quartz reduced about 63% in aqueous of NaOH. The amount of gypsum reduced 93.16% in KOH.

Quartz in Q2 coal seam reduced to 34% by using HCl. Gypsum can be reduced with aqueous of NaOH about 88%.

Q4 coal seam was detected quartz reduced to 75% after leaching with HF. Calcite reduction has high performance after soaking in HF about 90%. Gypsum can be reduced in aqueous of KOH to 99%.

This study of the chemical potential can concludes that an acid (HCl, HF and HNO_3) has high performance in the increasing of mineral reduction and can react with quartz between moderate to high potential in the coal sample. This acid is suitable for reduce the quartz content, which will also reduce the ash content in coal. For an aqueous of the base (NaOH and KOH) will not react with quartz, indicating that the most of reaction in these chemical which the reaction will occur with clay, gypsum, pyrite, and silicate groups.

The solution of hydrofluoric acid has a high effect on quartz reduction followed by NaOH, HNO_3 and HCl, respectively. The reduction of pyrite has high performance by using NaOH or KOH for treatment. The calcite reduction can be increased after leaching with HCl, HNO_3 and HF, respectively. Potassium hydroxide and sodium hydroxide also have high performance for reducing gypsum in coal samples. From the results of element in the coal sample conform to the results of mineral that an amount of SO_3 can be highly reduced in a solution of KOH and NaOH, which has the same with quartz and SiO_2 reduction in the acid treatment.

4.2.2.2 Minerals in coal samples in 48 hours of treatment

The results of analysis represent minerals in coal samples after treating 48 hours using chemicals are shown in Table 4.8, Figure 4.26 and 4.27

Hydrofluoric acid has a high performance for reducing the mineral content such as 71.43% of siderite, 56.35% of montmorillonite, 25.7% of kaolinite, and 14.71% of gypsum.

The solution of nitric acid has a high affect just the montmorillonite and kaolinite about 57.28% and 14.71%, respectively.

Sodium hydroxide can reduces a gypsum to 41.17%, siderite 28.57%, and K-feldspar 21.42%.

Potassium hydroxide has a high effect with a siderite about 85.71%, followed by gypsum, calcite, and montmorillonite about 51.85, 45.45 and 36.35%, respectively.

The results of analysis for 48 hours treatment has shown in Figure 4.26 to Figure 4.28, which represent that the increasing of time from 24 to 48 hours did not effect on the mineral reduction. On the other hand, the effect has found in the only gypsum by increase reducing content about 15% after threating with the chemical for 48 hours. Many mineral in coal (except gypsum) have the same trend of mineral reduction in each chemical, showing the reaction between minerals in coal were reacted completely for 24 hours. In contrast, a small particle of gypsum has more time for dissolved in water so that the increasing of gypsum reduction making other minerals increase.

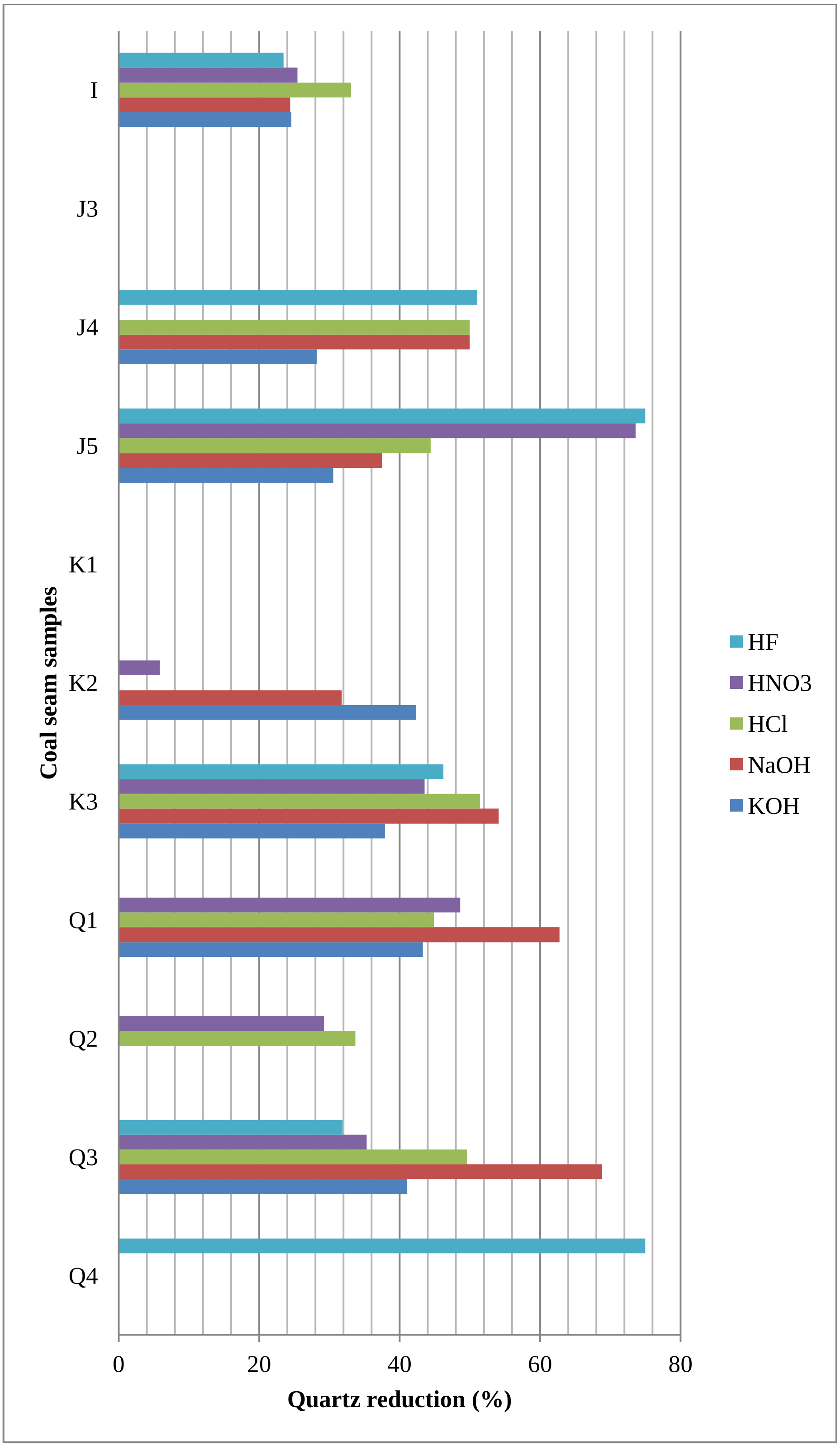


Figure 4.22 Quartz reduction after treated for 24 hours

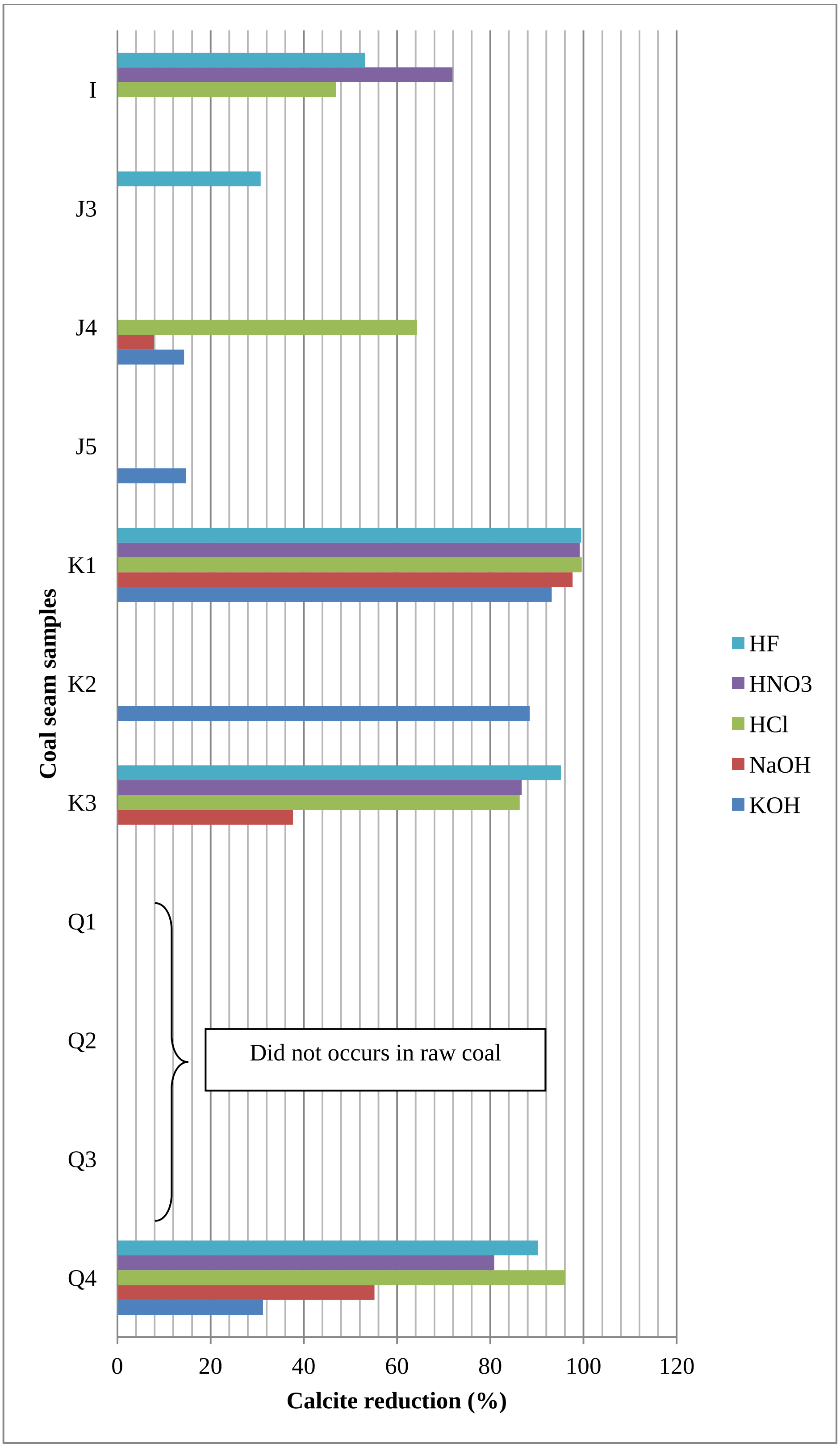


Figure 4.23 Calcite reduction after treated for 24 hours

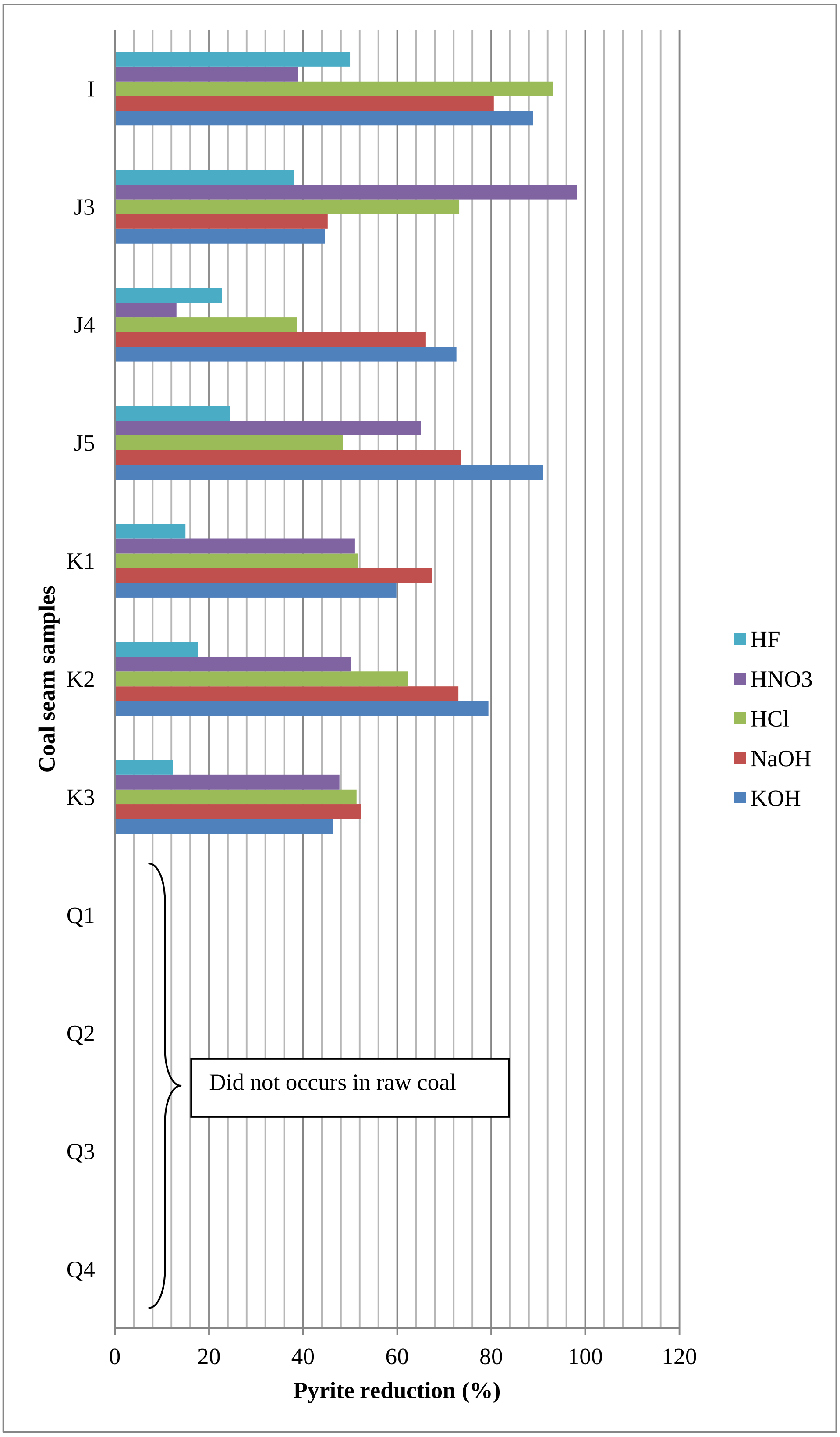


Figure 4.24 Pyrite reductions after treated for 24 hours

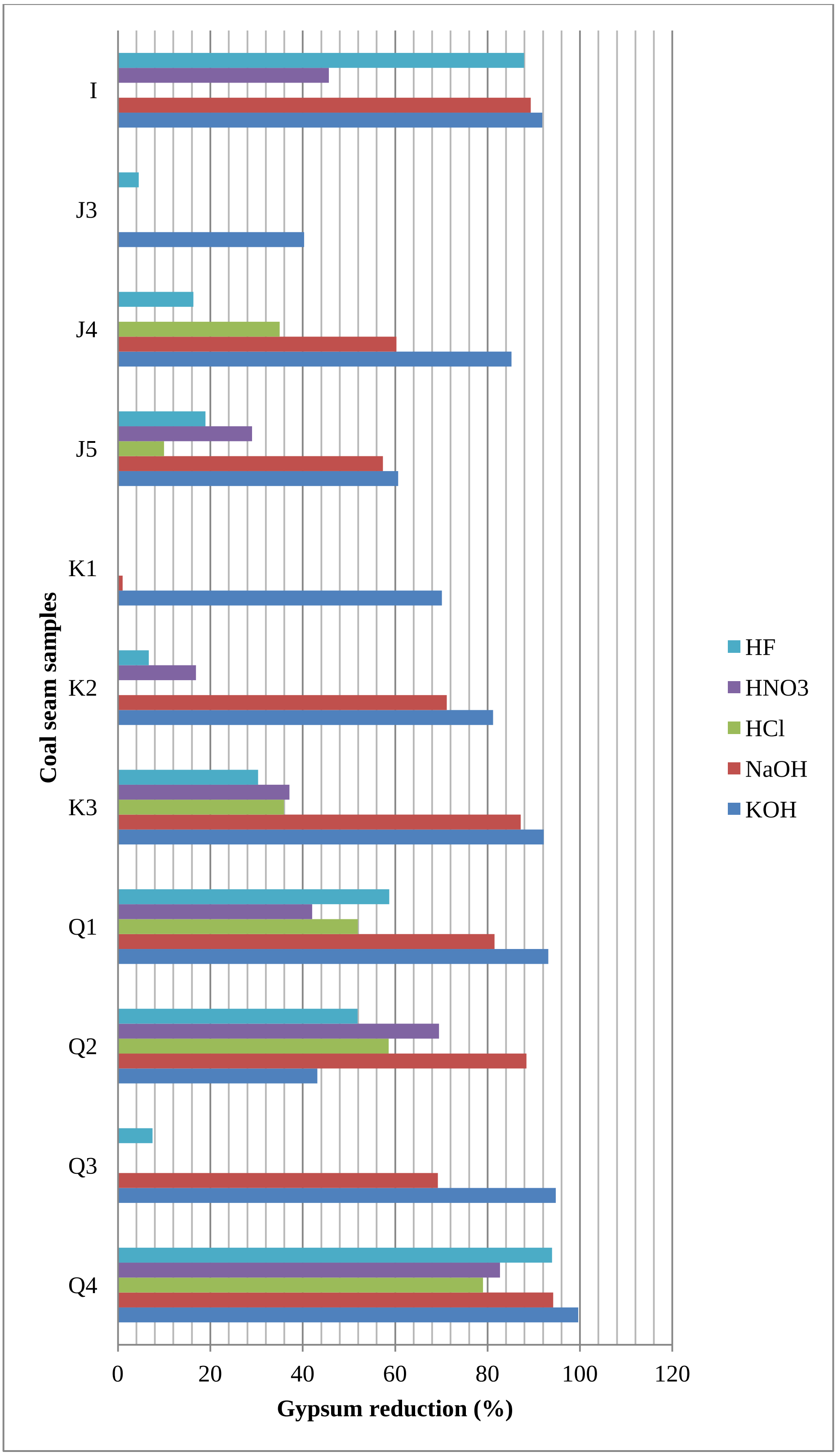


Figure 4.25 Gypsum reduction after treated for 24 hours

4.2.3 Proximate analysis

4.2.3.1 Proximate analysis of coal samples in 24 hours of treatment

The results of analysis represent properties in coal samples after treating using chemicals are shown in (Table II.3.1 and Fig 4.29 to 4.32)

The I coal seam, the moisture content highest reduced to 55% in KOH and 41% in HNO_3.

The J3 coal seam, solution of HF and HCl can reduce the moisture content about 30%. The fixed carbon increase 31.5% after leaching with HF.

The J4 coal seam, aqueous of HF, HNO_3, HCl, and NaOH can reduce the moisture content more than 33%. The nitric and hydrofluoric acid affect on increasing of fixed carbon 35 and 26%, respectively. The nitric acid can also reduce the ash content about 20%, but the hydrofluoric acid will affect a little on increasing of ash 1.6%.

Table 4.8 Variations of minerals in Q1 coal seam of the Mae Moh coal field after treating 48 hours (wt%).

Comp	Quartz	Calcite	Kaolinite	Illite	Pyrite	Siderite	Gypsum	Glauc.	K-felds.	Mont.	Chlorite	Total
Q1HF	2.95	1.08	3.18	2.28	0.53	0.02	15.02	8.20	56.27	8.84	1.66	100
Q1HNO$_3$	3.01	0.98	4.27	1.90	0.46	0.12	20.87	10.79	46.31	8.65	2.66	100
Q1HCl	3.01	0.90	5.01	1.71	0.40	0.13	21.74	9.85	46.01	8.46	2.80	100
Q1NaOH	3.59	0.66	5.78	2.98	0.31	0.05	10.36	11.34	33.72	27.15	4.07	100
Q1KOH	5.20	0.06	5.63	3.33	0.21	0.01	8.48	10.32	49.52	12.89	4.39	100

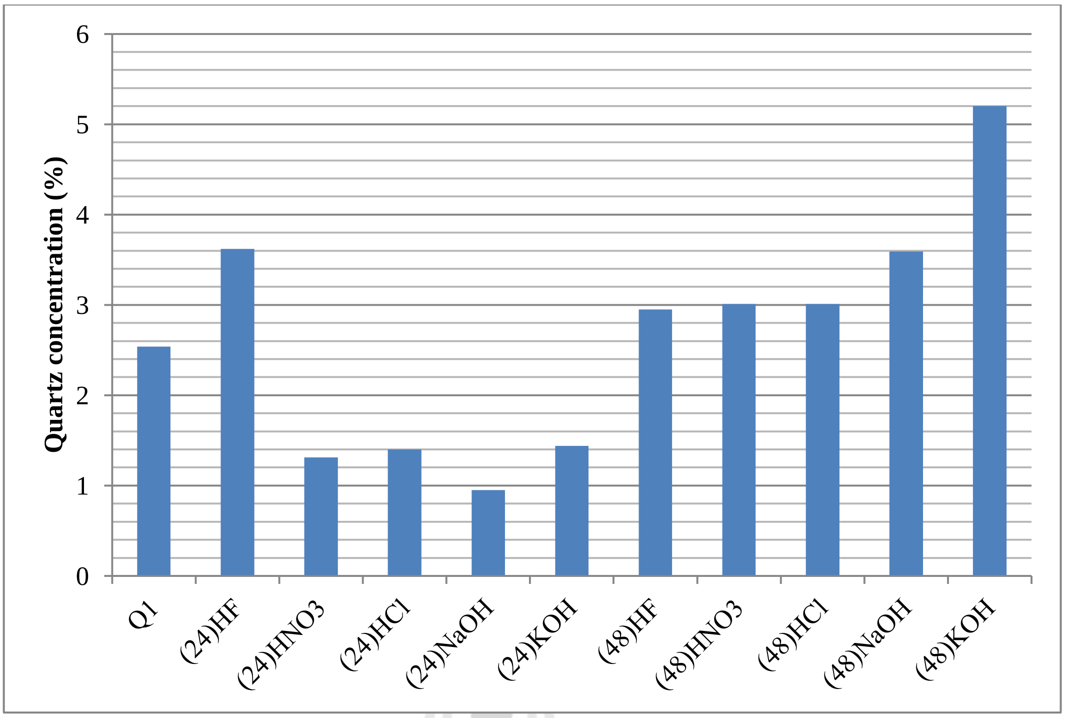


Figure 4.26 The comparison of quartz in Q1 coal seam both before and after treated

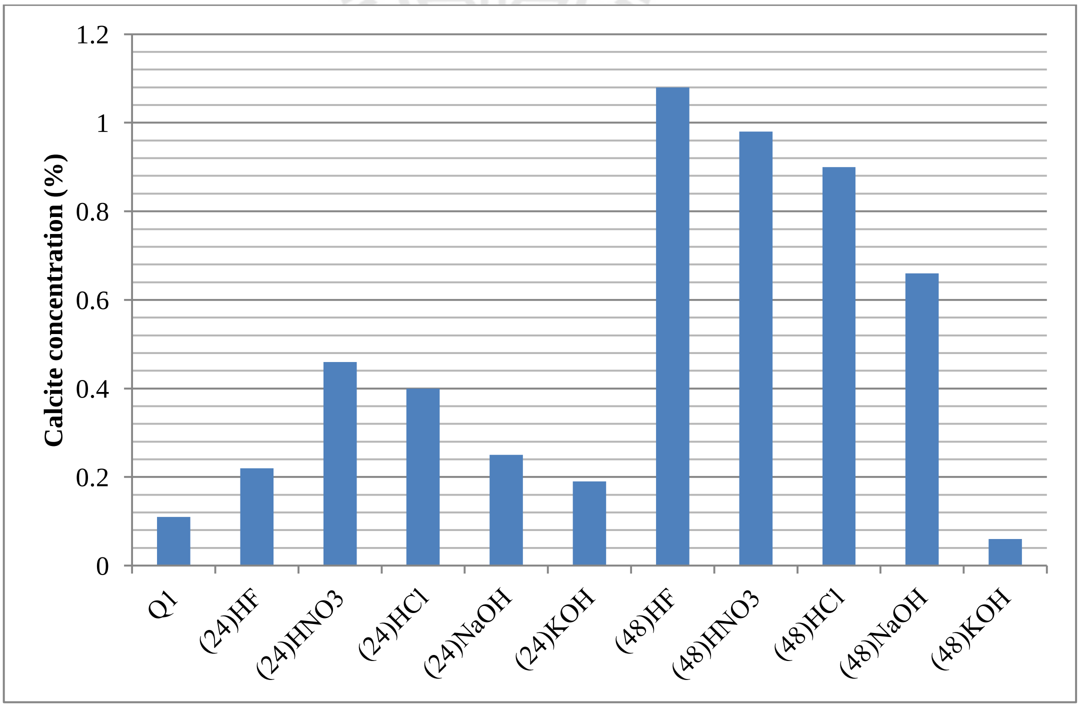


Figure 4.27 The comparison of calcite in Q1 coal seam both before and after treated

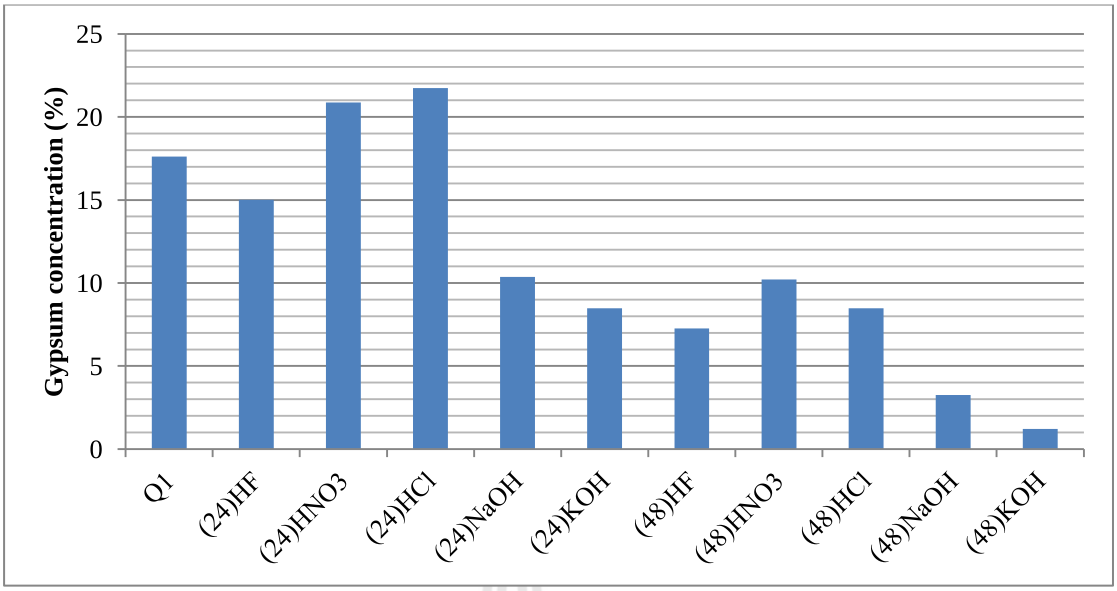


Figure 4.28 The comparison of gypsum in Q1 coal seam both before and after treated

The J5 coal seam, the hydrofluoric, hydrochloric, and sodium hydroxide can reduce the 30% of moisture content. The fixed carbon will increase 28% after leached with HF, but the ash will increase a little about 1.6%.

The K1 coal seam, the aqueous of HF can reduce the moisture content to 22% and increase a little of the fixed carbon.

The K2 coal seam, the hydrofluoric acid can reduce moisture content 35% and the fixed carbon increase 27.03%, and 17.55% in the nitric acid. The hydrofluoric acid can reduce the ash 12.04% and 7.06%.

The K3 coal seam, the hydrofluoric acid can reduce the moisture content of 42%, increase the fixed carbon up to 62.51, and reduce the ash of 29.19%.

The Q1 coal seam, the solution of hydrofluoric acid can reduce the moisture content 50% and the fixed carbon also increase of 31.07%.

The Q2 coal seam, the hydrofluoric acid can reduce the moisture content about 44% and the fixed carbon increase of 3%. The increasing of volatile due to this coal seam has the high fixed carbon, low volatile content, and moderate ash content with less content of calcite and pyrite (Figure 4.30). The almost of mineral is the silicate group that hardly react with chemicals, represents that the ash content were formed dominantly from only silicate group. Silicate group minerals is very difficult to react with chemical if coal have more these minerals the chemicals will not react to these mineral but affect on mineral that can react easily with chemical instead such as calcite and Q2 coal seam the chemical affect directly on organic matter instead of silicate group

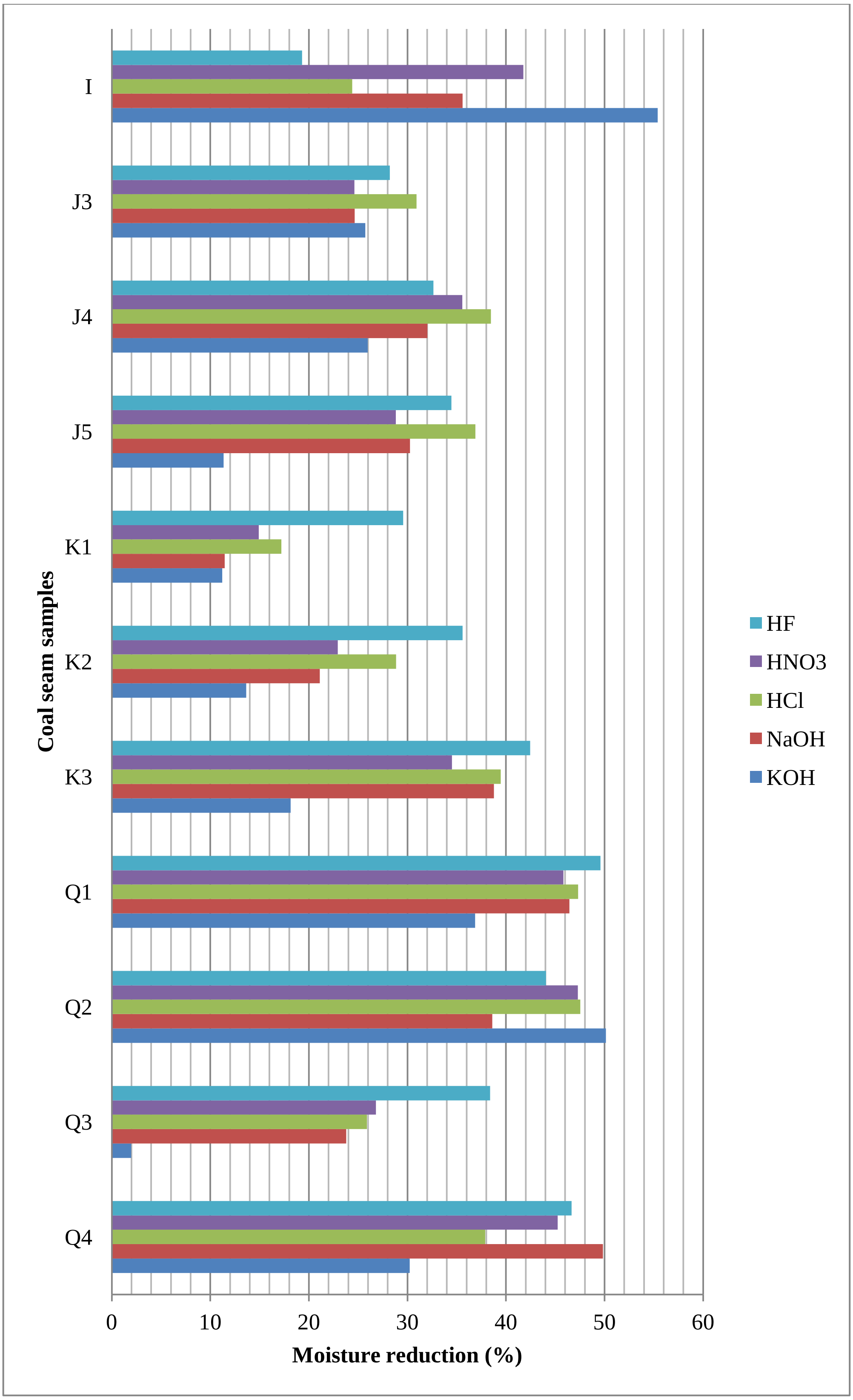


Figure 4.29 Moisture reduction after treated for 24 hours

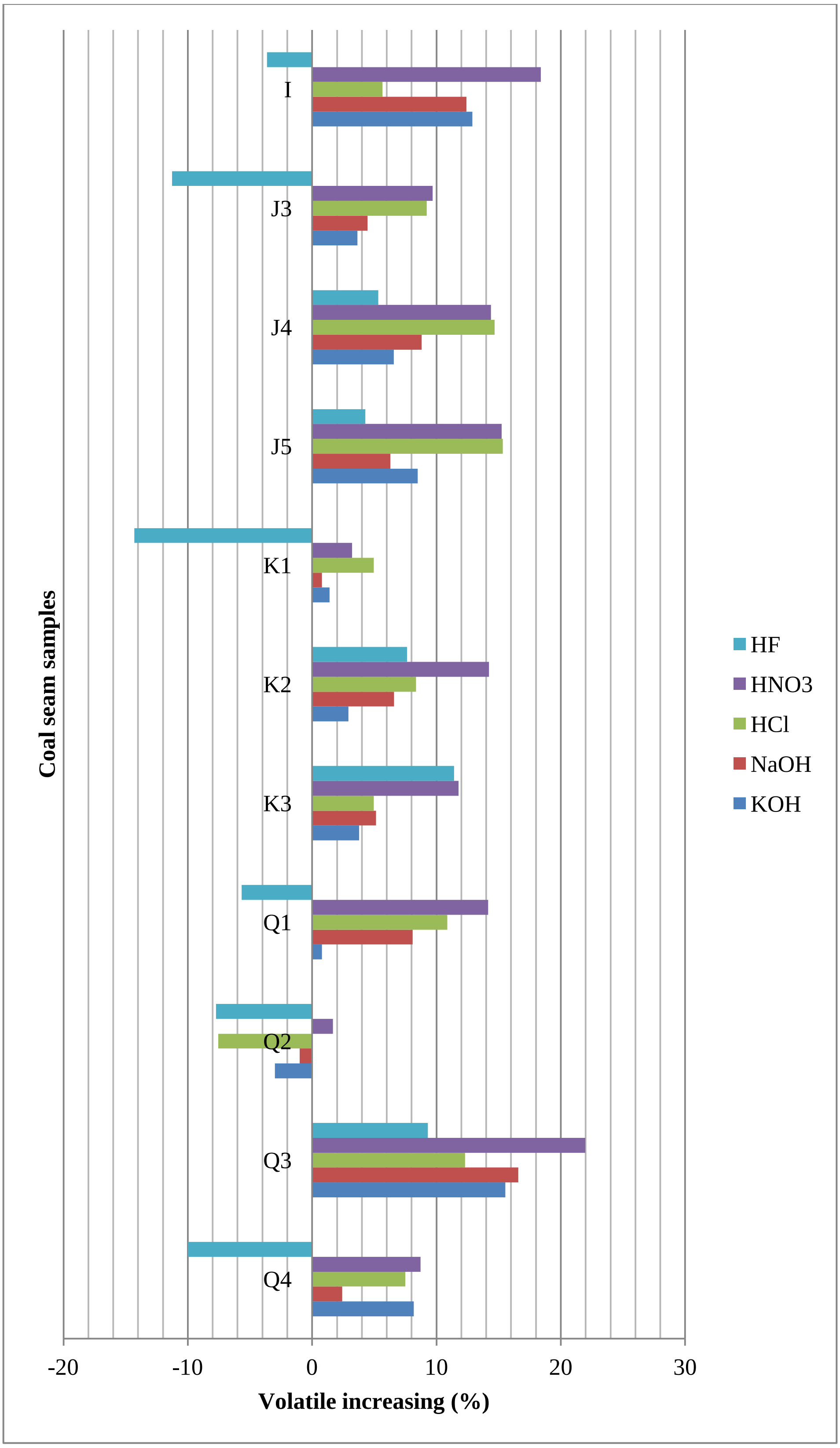


Figure 4.30 Volatile increment after treated for 24 hours

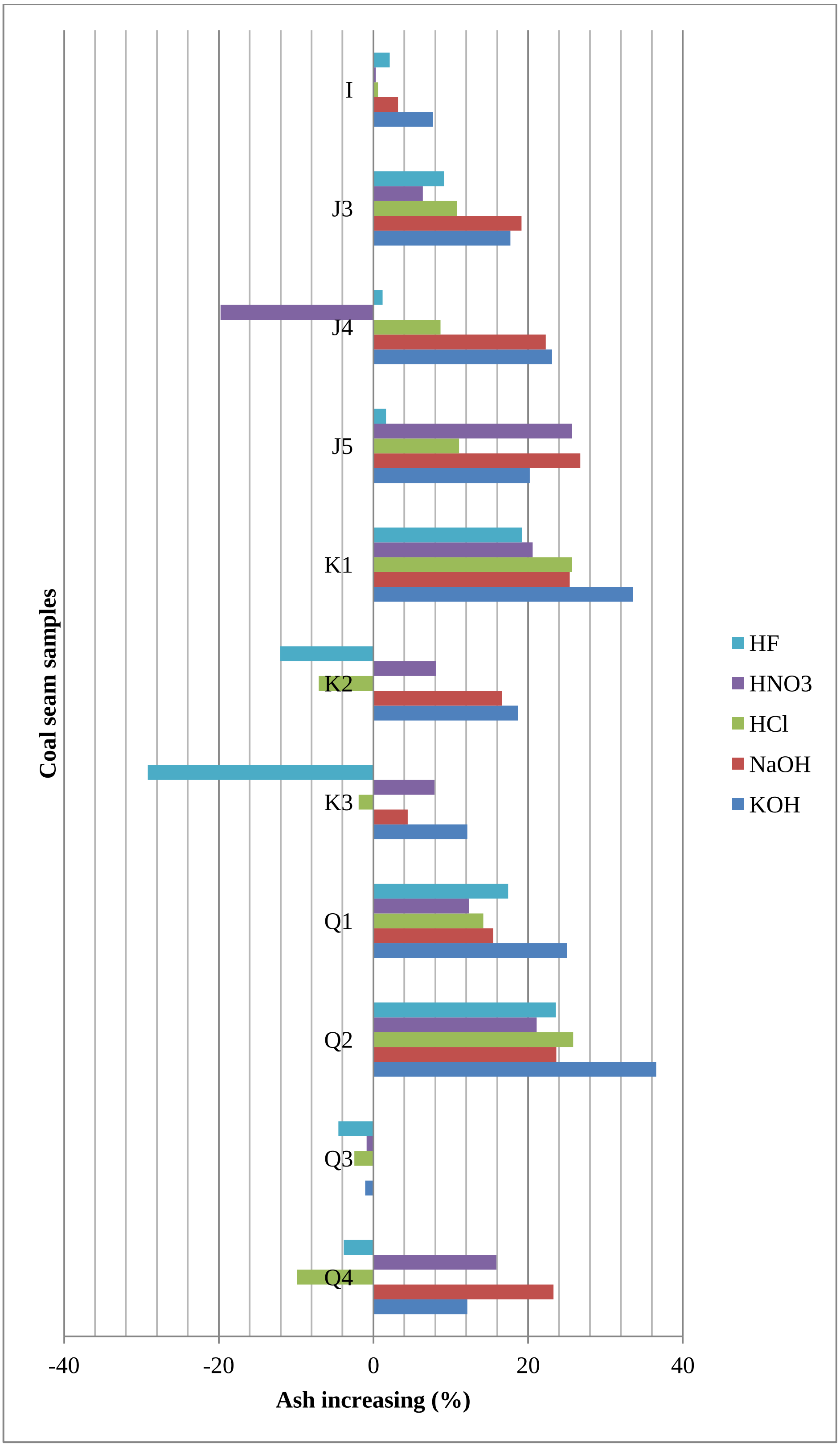


Figure 4.31 Ash increment after treated for 24 hours

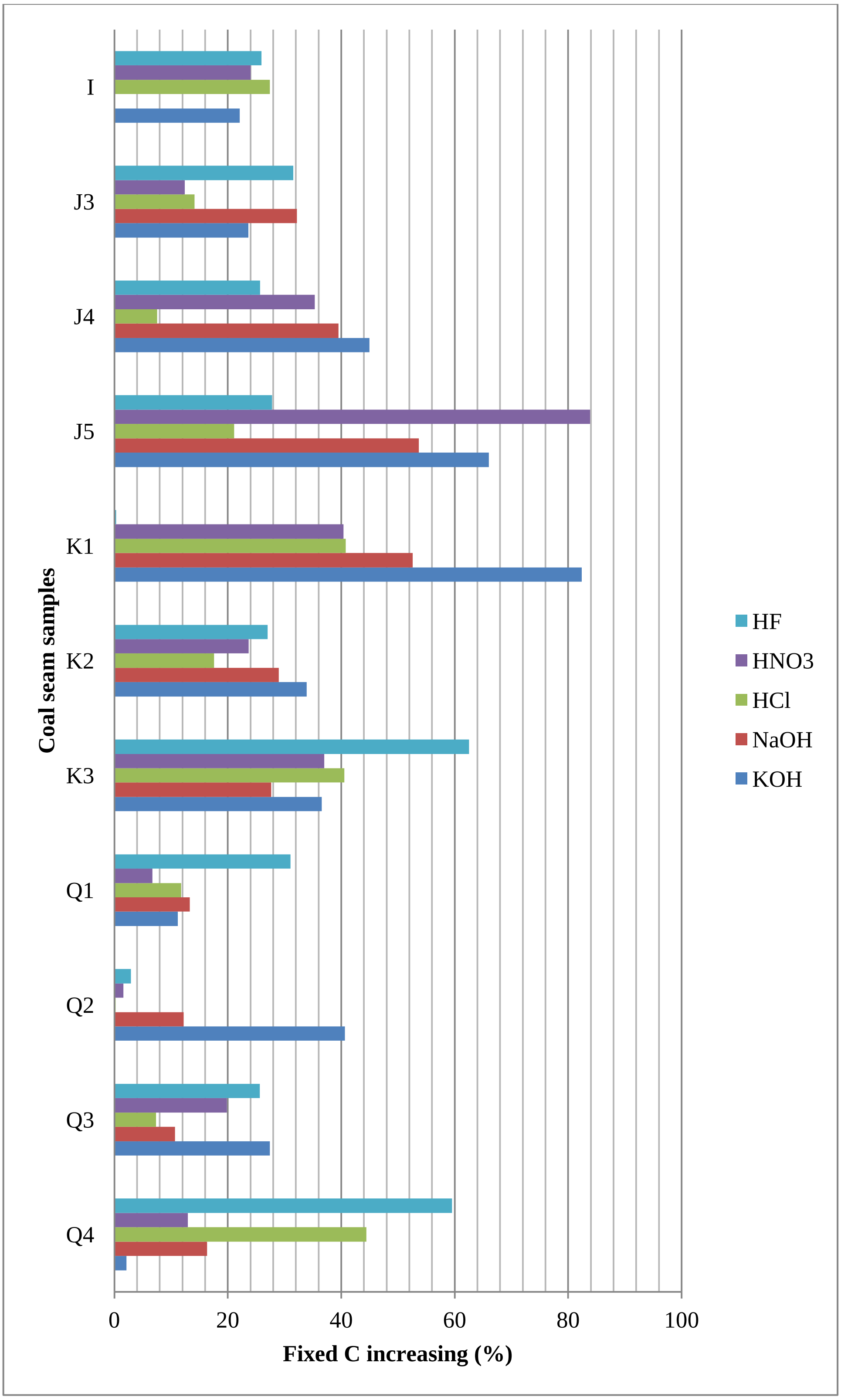


Figure 4.32 Fixed carbon increment after treated for 24 hours

The Q3 coal seam, the hydrofluoric acid can reduce the moisture content of 40% and the ash content of 4.5%, and increase the fixed carbon of 26%. There is lower K-feldspar than other coal seams, resulting in the increasing of clay ratio that can form to be the ash after burned and this coal seam found a little calcite and pyrite. From these reasons the leaching by acid solution are directly reacting to clay, which results to the ash can be reduced more than other coal seams. However, the high quartz content in this coal seam involve to the ash content cannot decrease.

The Q4 coal seam, the hydrofluoric, nitric acid, sodium hydroxide can reduce the moisture content ranges from 45 to 50%. The hydrofluoric acid can increase the fixed carbon up to 60% and reduce the ash content of 3.84%.

The results of the analysis represent that the hydrofluoric acid can reduce the volatile matter content due to this acid can react with all mineral, resulting in the increasing of clay reduction and react cover with the volatile matter in coal samples (Figure 4.30).

From this study can be concluded that the hydrofluoric acid is the highest performance for the reducing of moisture and ash contents, and the increasing of the fixed carbon content. Because the hydrofluoric acid effects on reducing of sulfur, silicon, and calcium compound, which involve to the reducing of ash content after burned. Nitric acid gives the same quality with the hydrofluoric acid, but effect of damage with the carbon matrix carbon making the fixed carbon decrease.

4.2.3.2 Proximate analysis of coal samples in 48 hours of treatment

The results of analysis represent properties in coal samples after treating using chemicals are shown in Table 4.9 and Figure 4.33.

Hydrofluoric acid affects on the reduction of the moisture content about 63%, and the increasing of 15% of ash content and 27.3% of fixed carbon content.

Nitric acid can reduce the moisture content about 45.55%, the ash content increases 12.53% and the fixed carbon content increase 16.14%.

Hydrochloric acid affects on moisture reduction 41.56%, and the increasing of ash content of 11.48% and fixed carbon content of 16.14%.

Sodium hydroxide can reduce the 36.66% of moisture content, the ash content increases 18.33%, and the fixed carbon content increase 3.73%.

Potassium hydroxide can reduce the moisture content 42.52% and 5.44% of fix carbon content, and increasing of 23.56% ash content.

Table 4.9 Variations of properties in Q1 coal seam after treating 48 hours (wt%).

Seam	Moisture	Volatile	Ash	Carbon	Volatile	Ash	Carbon
					dry		
HF	8.45	34.67	36.67	20.22	37.86	40.05	22.09
HNO_3	12.55	36.67	35.60	15.18	41.93	40.71	17.36
HCl	13.47	33.83	35.18	17.53	39.09	40.65	20.26
NaOH	14.60	32.01	38.13	15.27	37.47	44.65	17.88
KOH	13.25	31.28	41.58	13.90	36.05	47.93	16.02

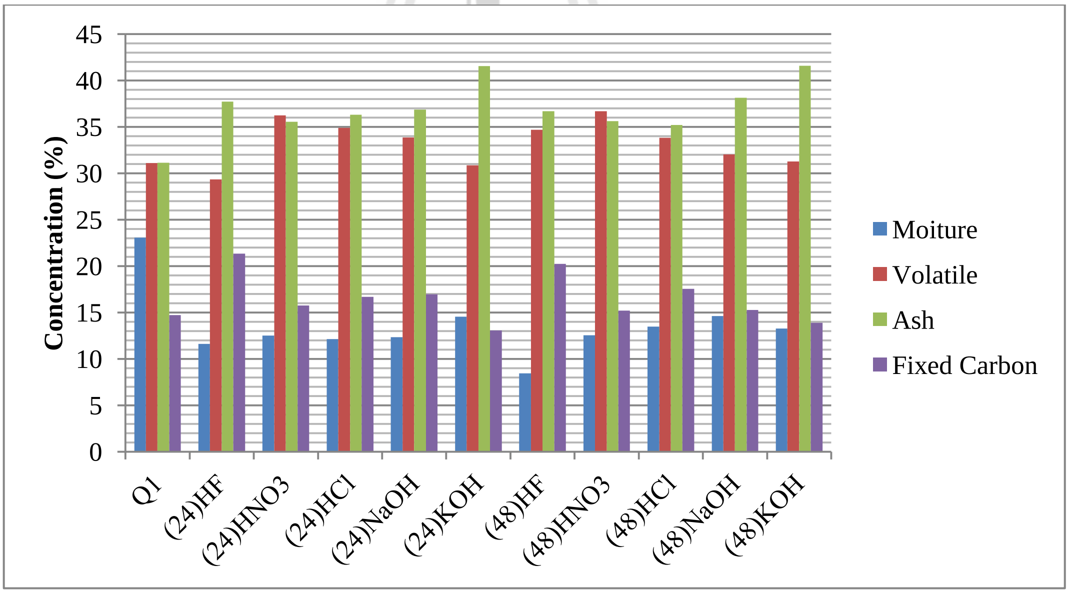


Figure 4.33 The comparison of properties in Q1 coal seam both before and after treated.

The comparison between the moisture, volatile matter, ash, and fixed carbon content show that the increasing of time did not affect on increasing or decreasing of properties in coal samples. The result coal sample properties were analyzed on 24 and 48 hours after treating with the chemical solution (Figure 4.33).

The hydrofluoric, hydrochloric, and nitric acid are suitable for coal treatment process by the results of fixed carbon can increase range from 4 to 25% when compare with other chemicals

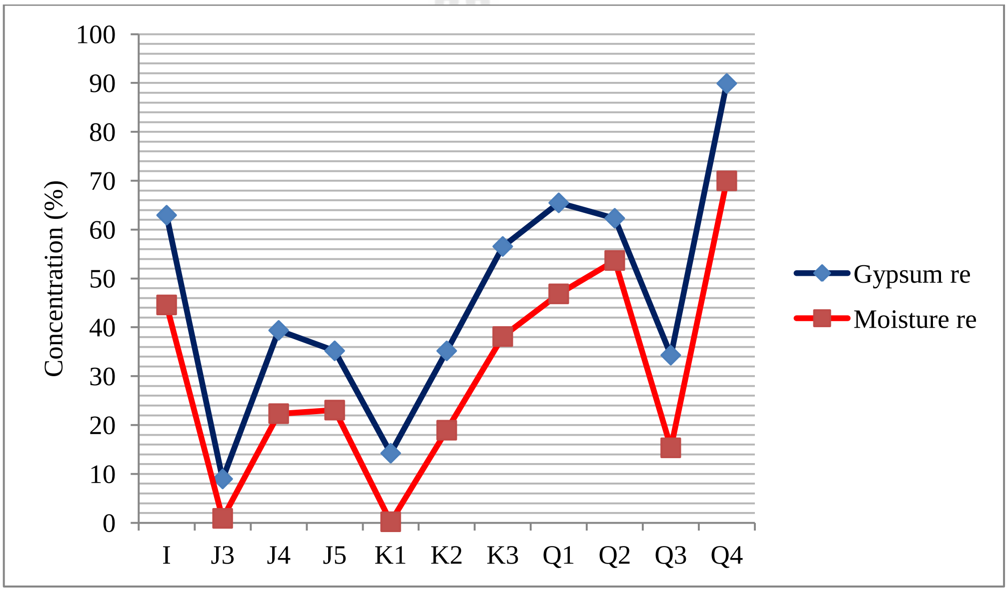


Figure 4.34 Comparison of moisture and gypsum reduction in coal after treated 24 hours

The results of elemental analysis conform to the proximate analysis that the reducing of the moisture content is the same trend in gypsum reduction. Therefore, the majority of the moisture content in coal samples is from alone the gypsum content (Figure 4.34).

4.2.4 Ultimate analysis

4.2.4.1 Ultimate analysis of coal samples in 24 hours of treatment

The results of analysis represent properties in coal samples after treating using chemicals are shown in (Table II.4.1 and Fig 4.35 to 4.38)

The I coal seam, the hydrochloric acid affects on the increasing of carbon content of 65%, and the reducing of sulfur content of 11%.

The J3 coal seam, the nitric acid is highest affected on the reducing of sulfur content of 30% and the carbon content of 5%

The J4 coal seam, the potassium hydroxide affects on the reducing of sulfur content of 34%. The sodium hydroxide also reduces the sulfur content of 27%, but the only potassium hydroxide can increase carbon content of 5.5%.

The J5 coal seam, the sodium and potassium hydroxide affect on reducing of sulfur content ranges from 17 to 48%. The potassium hydroxide can increase the carbon content of 0.9%, but the carbon content reduces 0.8% in sodium hydroxide.

The K1 coal seam, the potassium hydroxide, sodium hydroxide, and hydrochloric acid affect on the reducing of sulfur content of 53, 25.3, and 25.3% respectively, while the carbon content is increased about 1.7% in the sodium hydroxide.

The K2 coal seam, all chemicals did not have an effect on the reducing of sulfur content and only HF and HCl can increase the carbon content about 30%.

The K3 coal seam, the potassium and sodium hydroxide affect on the reducing of sulfur content of 29 and 26%, respectively, but only NaOH can increase the carbon content of 9.4%.

The Q1 coal seam, the potassium and sodium hydroxide affect on the reducing of sulfur content of 54 and 21%, respectively, and the carbon content has increased about 14% in NaOH and 7% in KOH.

The Q2 coal seam, the hydrochloric acid and sodium hydroxide are the high performance for reducing sulfur content of 29 and 16%, respectively, but reduce carbon content average about 8%.

The Q3 coal seam, the sulfur content can be reduced a little in KOH and affect on increasing of carbon content about15%.

The Q4 coal seam, the solution of potassium hydroxide affect on the reducing of sulfur about 26% and also increase carbon content about 6%.

The results of ultimate analysis represent that the solution of KOH is the highest performance for the sulfur reduction and not affect on reducing of carbon matrix.

4.2.4.2 Ultimate analysis of coal samples in 48 hours of treatment

The results of analysis represent the properties in coal samples after treating using chemicals are shown in Table 4.10 and Figure 4.39.

The results of ultimate analysis at retention time 48 hours can be concluded that the amount of carbon is the same value range between 21 to 29%. The nitric acid, hydrochloric acid and sodium hydroxide have the highest performance which can increase carbon content about 7%. The amount of nitrogen can form air pollution, which was reduced to 1% in all chemicals showing the highest in HF,

HNO_3 and HCl ranges from 12 to 19%. The amount of sulfur was reduced about 33% in NaOH and KOH. The nitric and hydrochloric acid can be applied to this chemical treatment due to the increasing of carbon content is the same result with NaOH and KOH.

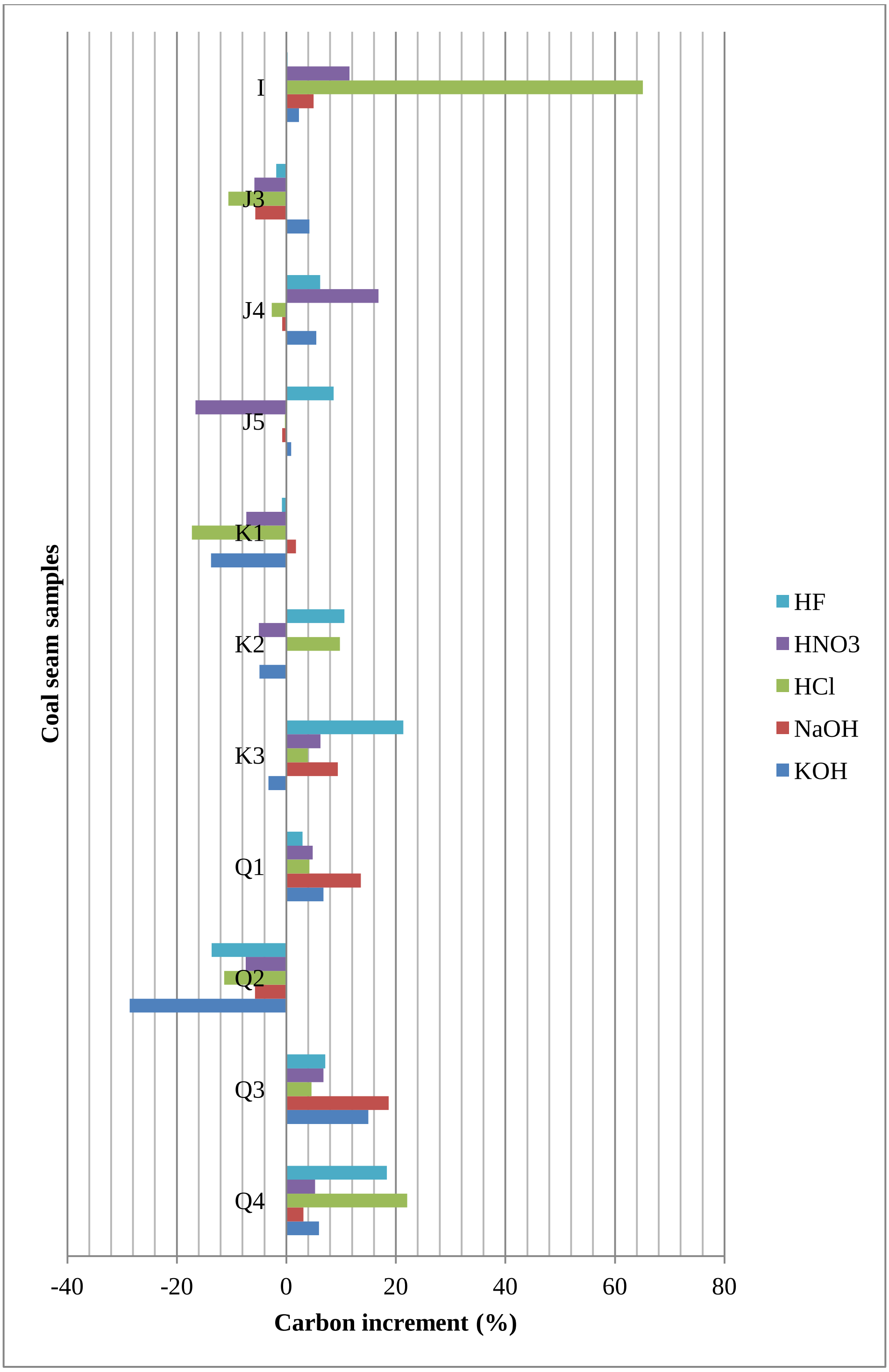


Figure 4.35 Carbon increment after treated for 24 hours

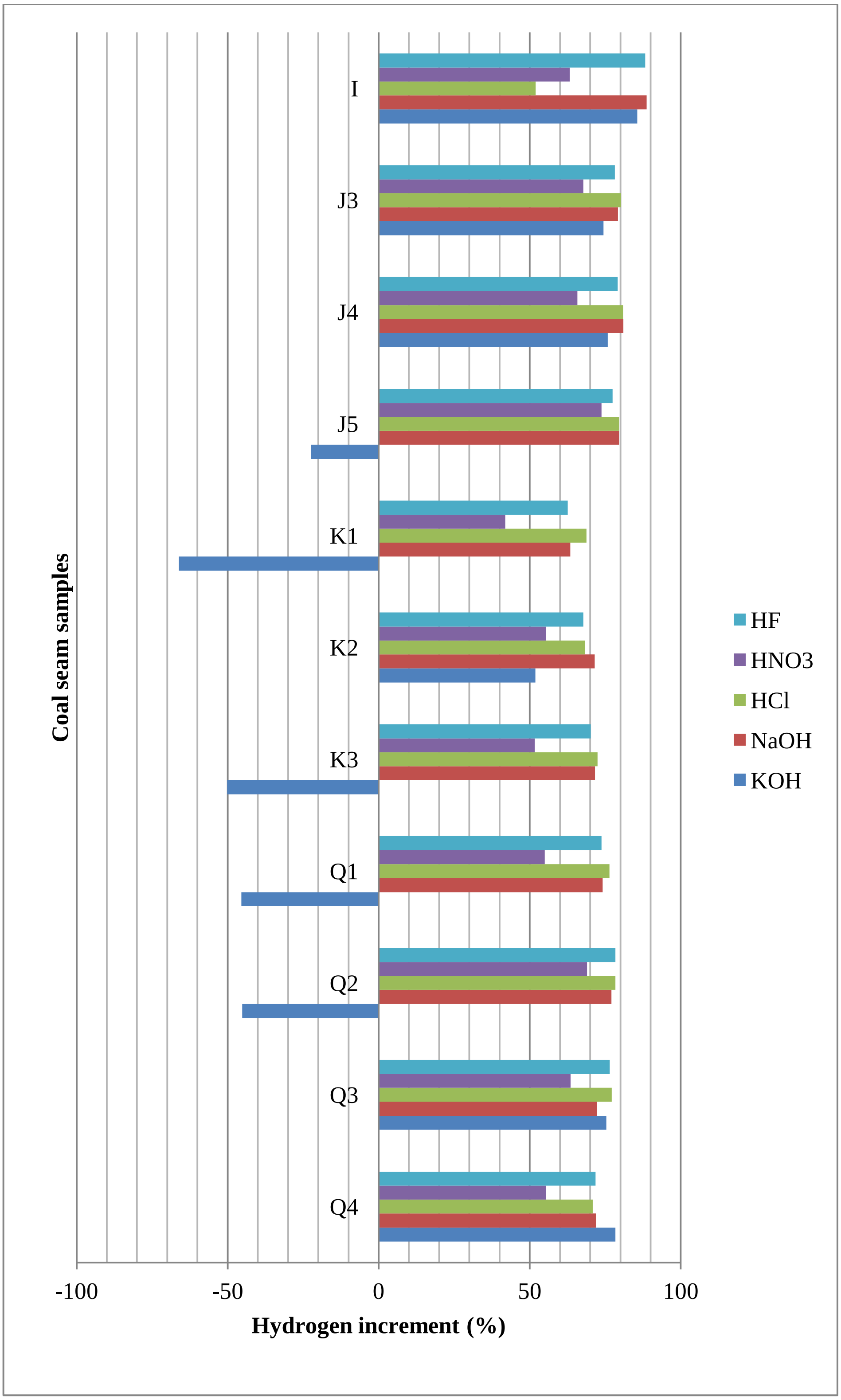


Figure 4.36 Hydrogen increment after treated for 24 hours

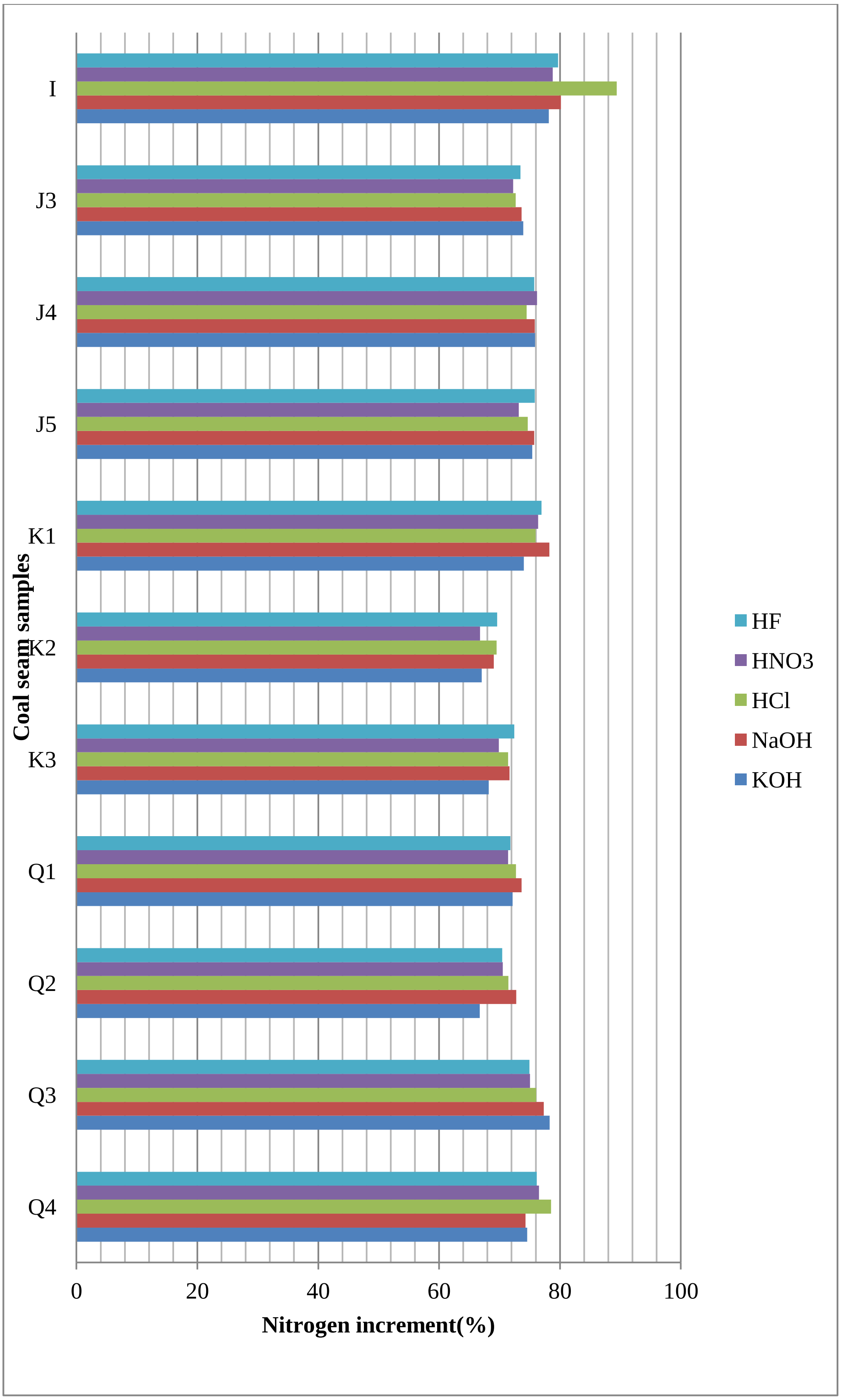


Figure 4.37 Nitrogen increment after treated for 24 hours

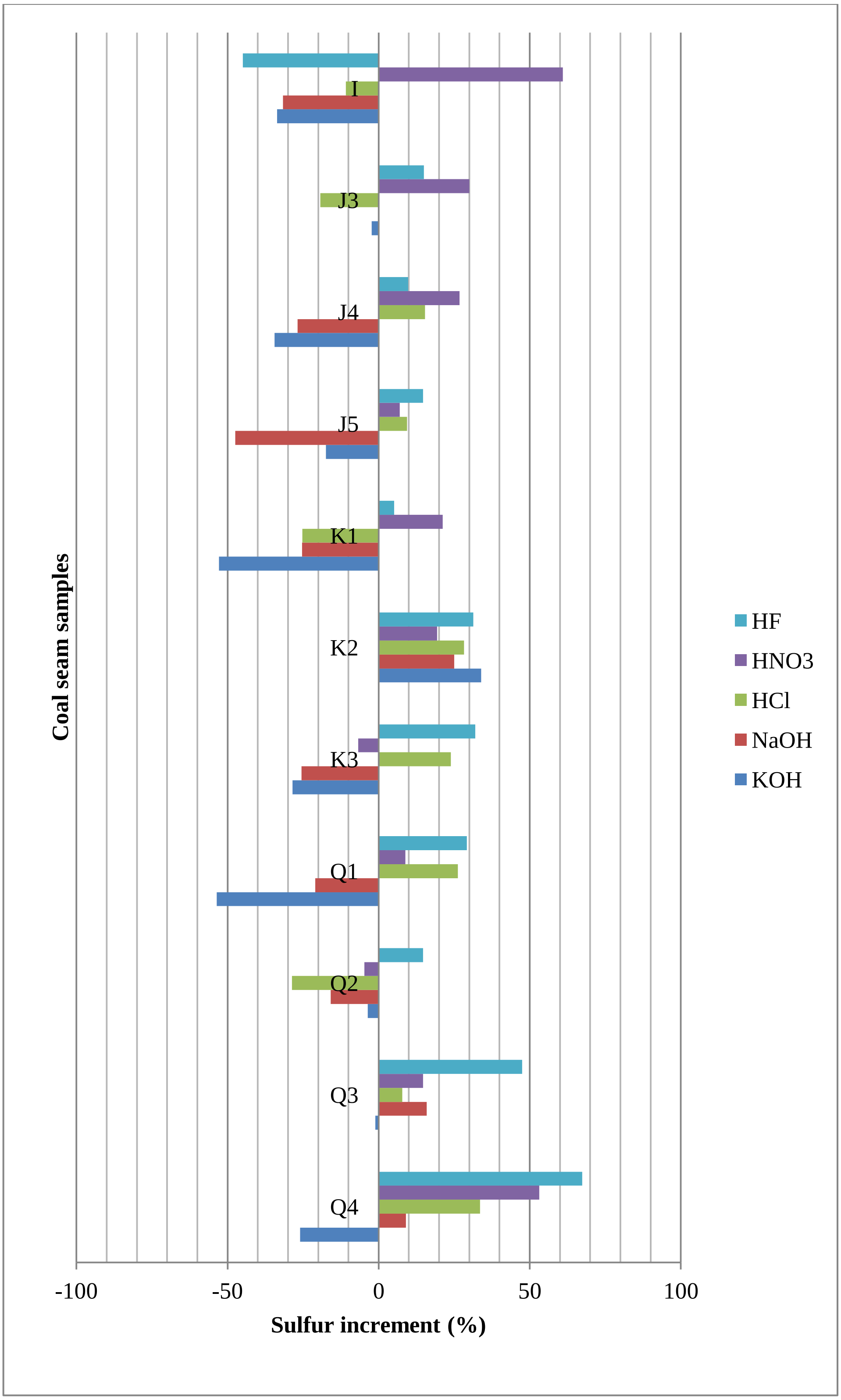


Figure 4.38 Sulfur increment after treated for 24 hours

Table 4.10 Variations of elements (C, H, N, and S) in Q1 coal seam after treating 48 hours (wt%).

Seam	**Carbon (C)**	**Nitrogen (N)**	**Hydrogen (H)**	**Sulfur (S)**
HF	26.995	1.026	3.780	7.283
HNO_3	29.531	1.481	3.970	6.972
HCl	28.340	1.043	4.040	7.238
NaOH	29.472	1.063	4.260	4.231
KOH	27.811	1.023	4.034	3.929

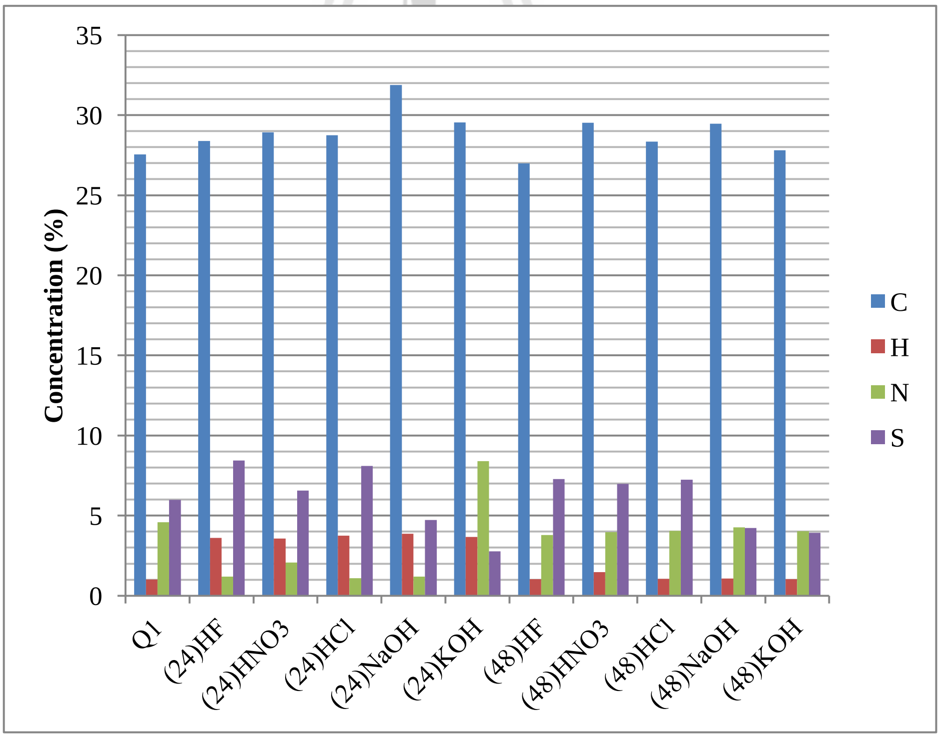


Figure 4.39 The comparison of elements (C, H, N, and S) in Q1 coal seam both before and after treated.

From Figure 4.39 represents the increasing of carbon when leaching in HNO_3 and HCl. The sulfur content highest reduced in NaOH and KOH, respectively. Time increment did not effect on the increasing or reducing of elements in coal samples.

4.2.5 Trace element analysis using ICP

4.2.5.1 Trace element analysis of coal samples on 24 hours of treatment

The results of analysis represent trace elements in coal samples after treating using chemicals are shown in Table 4.11and Figure 4.40. Only the Q1 coal seam was collected for comparison in this study. The result has shown the amount of As, Cr, Co, Cu, Mo, Zn, V and Pb.

Hydrofluoric acid can reduce 55.93 ppm of V, 25.37 ppm of Cr, 23.77 ppm of Zn, 22.57 ppm of Cu, 40 ppm of Co, 10 ppm of Pb and there are less of As.

Coal samples after leaching to HNO_3 show that V remains 27.24 ppm, As 24.45 ppm, Zn 22.07 ppm, and Cu is remaining 18.09 ppm, by As was reduced highest 50%

Coal samples after leached with HCl show that As remaining 80 ppm and Zn 35.44 ppm, by Co was reduced highest 90% and V reduce 40%.

Coal samples after leached with NaOH show that As and Zn remaining 51 ppm, and reduce V to 38.84 ppm. Heavy metals after leached with this acid were not changed concentration.

Coal samples after leaching with potassium hydroxide, Zn can be detected about 102 ppm, As remaining 84.46 ppm, and V remaining 36.65 ppm. Potassium hydroxide did not have effect with changing of trace elements.

The results of this analysis can be concluded that arsenic can be reduced highest in HF and the remaining of arsenic did not over soil quality standard, and followed by HNO_3 and HCl, respectively. Cobalt can be reduced the highest in aqueous of HNO_3, in contrast KOH and NaOH did not have effect with the heavy metals in coal samples.

Table 4.11 Concentration of trace elements in coal samples both before and after treated by chemical treatment (wt.%)

				HF	HNO_3	HCl	NaOH	KOH	HF	HNO_3	HCl	NaOH	KOH
Trace Elements	**J5**	**K2**	**Q1**	**Q1**	**Q1**	**Q1**	**Q1**	**Q1**	**Q1**	**Q1**	**Q1**	**Q1**	**Q1**
	before treatment			**soaking time 24 hours**					**soaking time 48 hours**				
As	72.54	37.52	51.83	0.00	24.45	80.25	51.00	84.46	41.83	31.15	26.39	31.86	69.42
Cr	9.79	18.16	14.35	25.37	13.32	16.33	15.74	15.14	16.53	21.23	14.19	17.32	10.91
Co	5.80	8.38	4.39	2.20	3.98	0.40	6.18	6.37	2.59	2.58	1.20	5.77	5.36
Cu	11.59	22.36	16.95	22.57	18.09	15.73	18.13	19.32	19.72	19.64	19.59	24.49	23.01
Mo	0.00	0.00	0.00	0.20	0.40	0.20	0.20	0.00	0.00	1.19	1.00	0.60	0.40
Zn	16.19	31.34	19.54	23.77	22.07	35.44	51.00	102.19	12.55	8.13	39.58	42.41	30.54
V	21.18	46.11	31.30	55.93	27.24	16.13	38.84	36.65	36.06	30.56	22.39	48.98	36.30
Pb	3.60	6.39	5.18	4.59	5.17	5.77	5.38	6.77	4.78	4.37	5.20	7.77	9.12

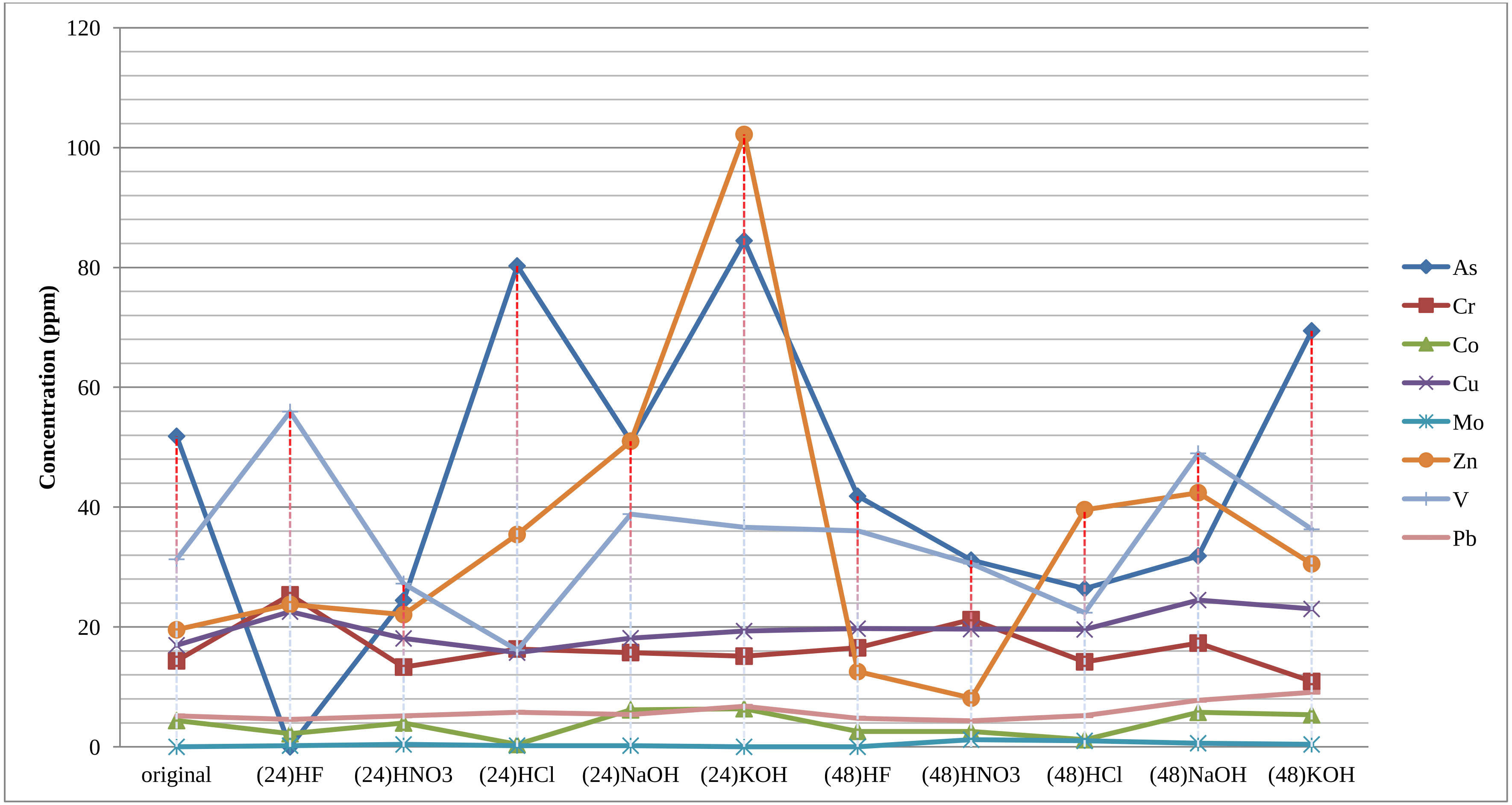


Figure 4.40 The comparison of trace elements in Q1 coal seam both before and after treated

4.2.5.2 Trace element analysis of coal samples on 48 hours of treatment

The result of analysis represents the trace elements in coal samples after treating using chemicals, which are shown in Table 4.11and Figure 4.40. The heavy metals in soil should not over soil quality standard (Pollution Control Department, 2004).

Coal samples after leached with HF found that As highest remaining 41.83 ppm and V remaining 36.06 ppm. The amount of Co, Zn, As, and Pb were reduced 41, 36, 8 and 19%, which still more than soil quality standard about 90%.

Coal samples after leached with HNO_3 found that As and V highest is remaining about 30 ppm, Cr is remaining 21 ppm, and Cu is remaining 19 ppm. The amount of Zn, Co, As, and Pb were reduced 58.36, 41.19, 39.90 and 15.79%, respectively, which As still more than soil quality standard about 87%.

Coal samples after leached with HCl found that Zn highest remaining 339.58 ppm, As remaining 26.39 ppm, and V remaining 22.39 ppm. The amount of Co was reduced highest in this acid about 72.65%, As reduced 49.09%, and V reduced 28.46%, but As still more than soil quality standard about 85%.

Coal samples after leached with NaOH found that V and Zn highest remaining 48.98 and 42.41 ppm, As remaining 31.86 ppm, and Cu remaining 24.49 ppm. Only As can be reduced to 38.54% in this base, but still more than soil quality standard about 87.7%.

Coal samples after leached with KOH found that As the highest remaining 69.42 ppm, V remaining 36.30 ppm, and Zn remaining 30.54 ppm. Only Cr can be reduced to 24.01% in this base, but the concentration of As is still more than soil quality standard about 94.38%.

The results of trace element analysis represent that after treated by chemical leaching at retention time 48 hours. Arsenic concentration was reduced the highest in HNO_3 and HCl range between 40 to 49%. Cobalt can be reduced about 72.65% in HCl and 41% in HNO_3. Nitric acid has high performance for reducing of zinc about 58.36%, in contrast the solution of base have not significant effect on heavy metals in coal samples.

In conclusion of treating retention time represents that the increasing of retention time did not affect on the reducing of heavy metals in the Q1 coal seam, which each chemical is the similar trend (Figure 4.40).

4.2.6 Heating value analysis

4.2.6.1 Heating value of coal samples in 24 hours of treatment

The results of analysis represent a changing of heating value in coal samples after treating using chemicals are shown in Table 4.12 and 4.13, and Figure 4.41 and 4.42.

The I coal seam, the solution of nitric acid has a little effect with a heating value reduction 27%, and the KOH also affect on heating value reduction 65%.

The heating value of J3 coal seam has reduced 24.8% after leached with KOH and 32.4% after leached with HNO_3.

The heating value of J4 coal seam has reduced 12.8% after leached with HNO_3 and 28.5% after leached with KOH.

The J5 coal seam, the potassium hydroxide affects on the heating value increment about 25%, and reduced 27.1% in nitric acid

The K1 coal seam, the potassium hydroxide affects on heating value increment about 116%, and reduced 9.4% in nitric acid

The K2 coal seam, the potassium hydroxide affects on heating value increment about 58.1%, and the heating value has reduced of 4.3% and 5.4% in nitric and hydrochloric acid, respectively.

The K3 coal seam, the potassium hydroxide affects on the heating value increment about 61.7%, and reduced 20.5% in nitric acid

The Q1 coal seam, the potassium hydroxide affects on the heating value increment about 74.8%. The reduction of heating value is about 19.9% in the nitric acid and 21.2% in the sodium hydroxide.

The Q2 coal seam, the potassium hydroxide affects on the heating value increment about 35.3%. The reduction of heating value is about 35.6% in the nitric acid and 38% in the sodium hydroxide.

The Q3 coal seam, the solution of NaOH has a little effect with the heating value reduction of 10.3%. The KOH effect on the heating value reduction of 23.3% and reduce 24.7% in HF.

The Q4 coal seam, the hydrofluoric acid affects on the reduction of heating value about 0.1%, followed by HCl about 2.7%, and HNO_3 of 8.5%.

Table 4.12 Comparison of heating value of coal samples both before and after treated by chemical treatment (MJ/kg)

Seam	HHV MJ/kg	LHV MJ/kg	HF		HNO_3		HCl		NaOH		KOH	
			HHV	LHV	HHV	LHV	HHV	LHV	HHV	LHV	HHV	LHV
I	4.54	4.24	1.00	0.75	3.63	3.45	12.10	11.87	1.45	1.26	1.99	1.85
J3	13.91	13.48	9.53	9.22	9.94	9.62	7.20	6.90	9.15	8.83	11.03	10.71
J4	13.30	12.79	9.41	9.07	12.05	11.73	12.05	11.73	8.73	8.39	10.08	9.71
J5	12.86	12.36	9.91	9.58	7.49	7.14	7.49	7.14	8.73	8.39	16.55	16.11
K1	8.08	7.77	7.28	7.06	7.77	7.50	4.94	4.68	7.78	7.50	17.69	17.42
K2	11.97	11.59	9.99	9.74	9.02	8.71	9.98	9.65	9.60	9.30	21.01	20.73
K3	11.41	10.96	9.50	9.24	8.67	8.38	7.99	7.72	8.52	8.24	18.74	18.37
Q1	11.09	10.53	8.48	8.20	9.23	8.93	8.16	7.87	9.14	8.85	19.72	19.37
Q2	12.73	12.29	8.11	7.87	8.65	8.42	7.41	7.18	8.45	8.18	19.72	19.37
Q3	10.19	9.81	8.11	7.87	7.97	7.69	6.62	6.33	9.62	9.33	8.40	8.02
Q4	12.43	11.87	12.96	12.67	11.74	11.43	12.52	12.18	9.78	9.50	8.71	8.32

Table 4.13 Reduction of heating value from coal samples both before and after treated by chemical treatment for 24 hours (%)

Seam	HHV	LHV	HF		HNO_3		HCl		NaOH		KOH	
	MJ/kg	MJ/kg	HHV	LHV	HHV	LHV	HHV	LHV	HHV	LHV	HHV	LHV
I	4.45	4.14	78.0	82.2	20.1	18.6	62.5	61.8	68.0	70.3	56.2	56.3
J3	13.73	13.29	31.5	31.6	28.5	28.7	48.3	48.8	34.2	34.5	20.7	20.6
J4	13.13	12.62	29.3	29.1	9.4	8.3	9.4	8.3	34.4	34.5	24.2	24.1
J5	12.69	12.19	22.9	22.5	41.7	42.2	41.7	42.2	32.1	32.2	28.7	30.3
K1	7.95	7.63	10.0	9.2	3.9	3.5	38.9	39.7	3.8	3.5	118.9	124.1
K2	11.76	11.38	16.5	15.9	24.7	24.8	16.6	16.7	19.8	19.7	75.5	79.0
K3	11.22	10.77	16.7	15.7	24.0	23.6	30.0	29.6	25.3	24.8	64.2	67.6
Q1	10.91	10.35	23.6	22.2	16.7	15.2	26.4	25.3	17.5	16.0	77.8	83.8
Q2	12.55	12.11	36.3	35.9	32.1	31.5	41.8	41.6	33.6	33.5	54.9	57.6
Q3	10.03	9.65	20.4	19.7	21.7	21.5	35.0	35.4	5.5	4.8	17.6	18.2
Q4	12.26	11.70	4.3	6.7	5.6	3.7	0.7	2.6	21.3	20.0	30.0	29.9

* gray cell is increasing and white cell is reducing of heating value

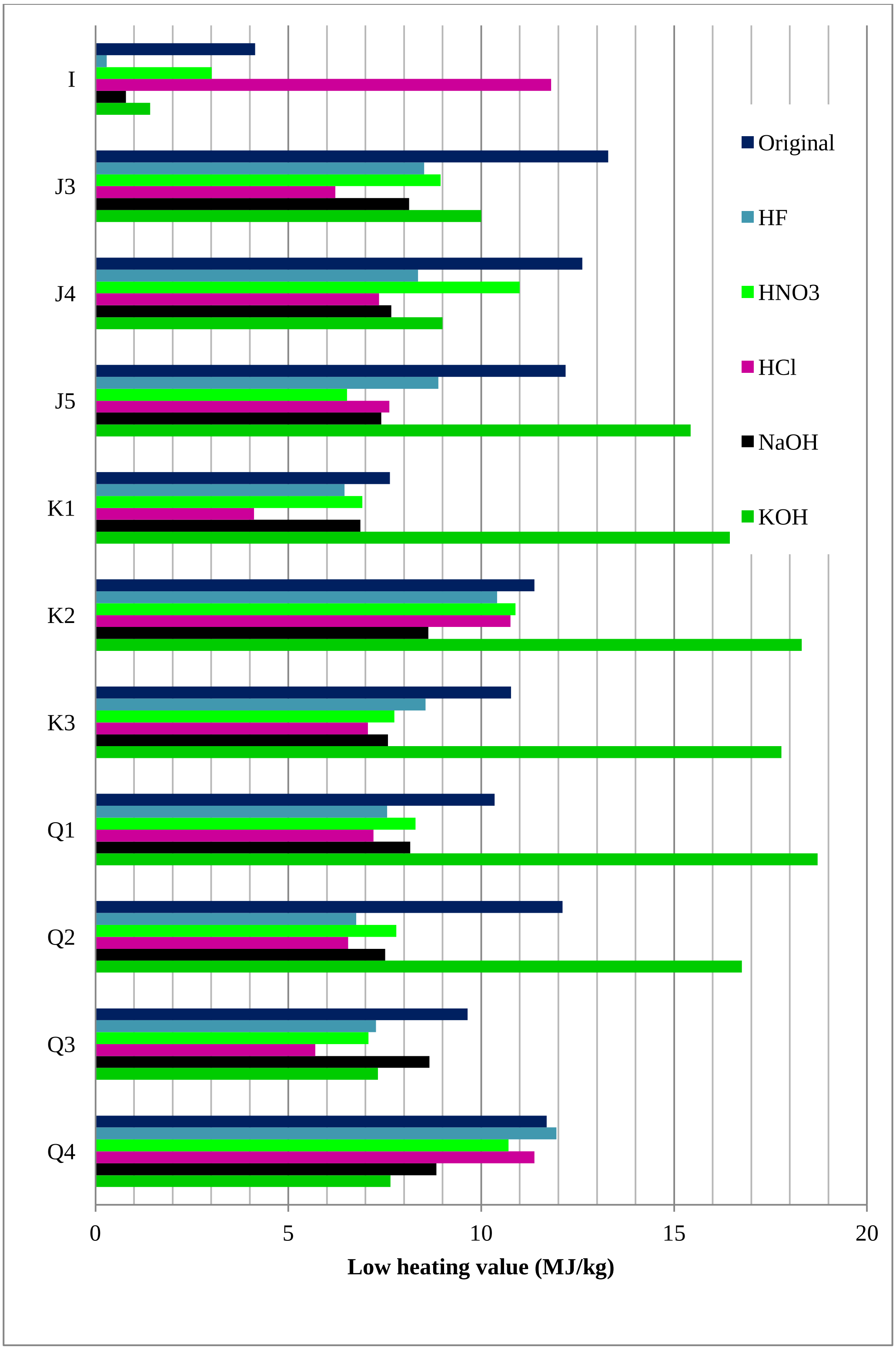


Figure 4.41 The variation of heating value of coal samples both before and after treated by chemicals for 24 hours

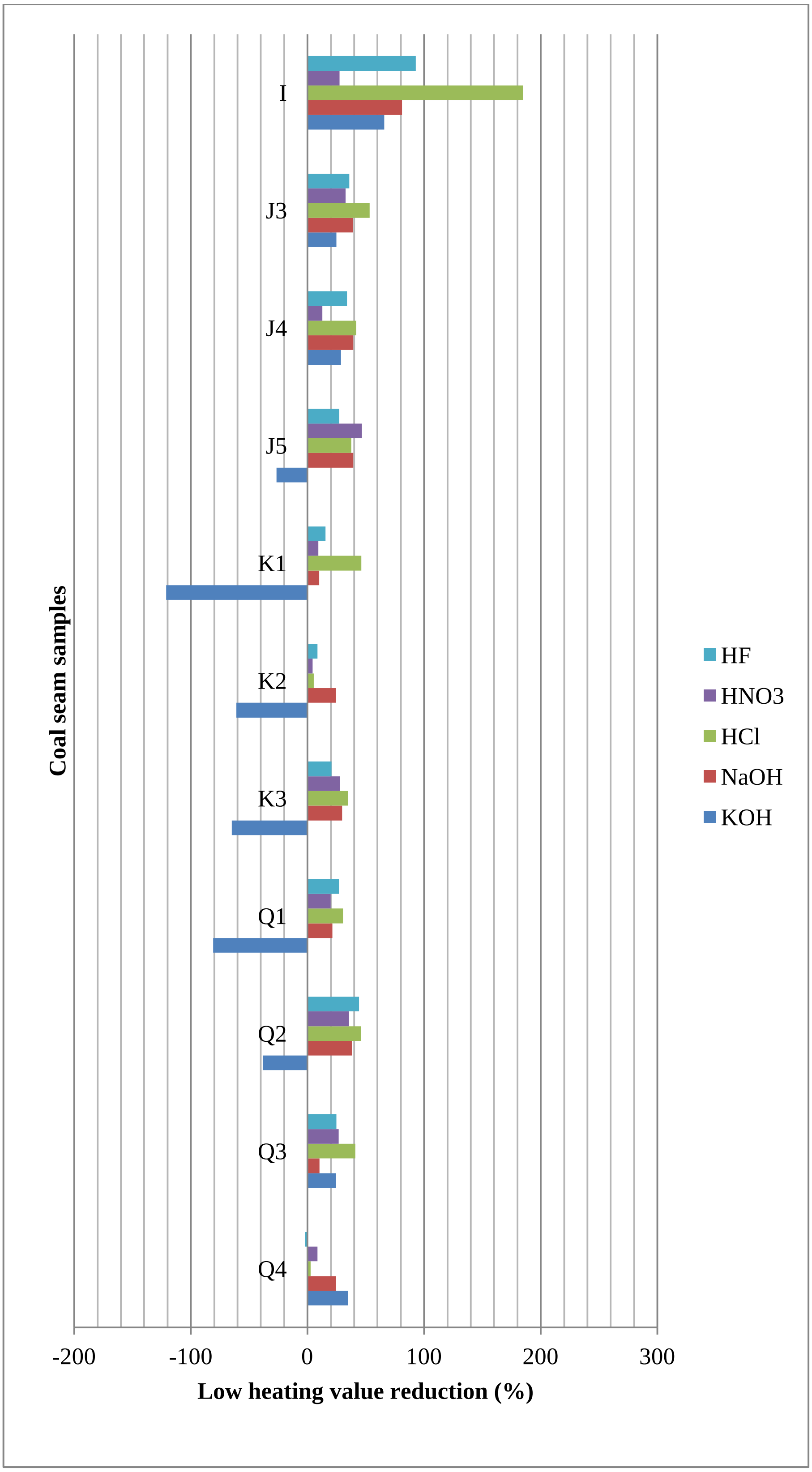


Figure 4.42 Reduction of heating value of coal sample after treated for 24 hours

A solution of potassium hydroxide has an effect on the increasing of heating value in coal samples ranks from 28 to 119%, followed by the nitric acid has an effect on heating value reduction about 4 to 46% because these chemicals have a little effect with carbon matrix .

4.2.6.2 Heating value of coal samples in 48 hours of treatment

The results of analysis represent a changing of the heating value in coal samples after treating using chemicals are shown in Table 4.14 and Figure 4.43.

Potassium hydroxide has a highest effect with the heating value reduction about 14%, followed by HNO_3, and HCl about 14 and 8%, respectively. All of the other chemicals except HF make increasing the heating value reduction due to those chemicals can react easily with the carbon matrix (Mukherjee and Borthakur, 2002) and reducing the heating value in coal samples.

Therefore, the comparison of heating values in Figure 4.43 both before and after treating can be concluded that at retention time 24 hours in the coal samples have lost a little heating value in all chemicals, but the heating value was increased highly in aqueous of KOH. Treatment at the 48 hours retention time, the results have shown that the increment of heating value reduction due to the samples have more time for soaking in solution after finishing 24 hours. This effect on hydrogen in wet sample is decrease that showing the hydrogen reduction as time increases (Figure 4.39). The increasing of nitrogen and oxygen from this reason has an effect on the reduction of heating value, which calculated from Dulong formula.

Table 4.14 Variations of heating value of Q1 coal seam after treating (48 hours)

MJ/kg	HF	HNO_3	HCl	NaOH	KOH
HHV	10.86	12.28	11.69	12.34	11.65
LHV	10.66	11.98	11.37	11.99	11.33
HHV %reduct.	2.05	10.80	5.47	11.31	5.06
LHV % reduct.	1.17	13.76	7.94	13.82	7.56

*gray cells are increment and white cells are reduction of heating value

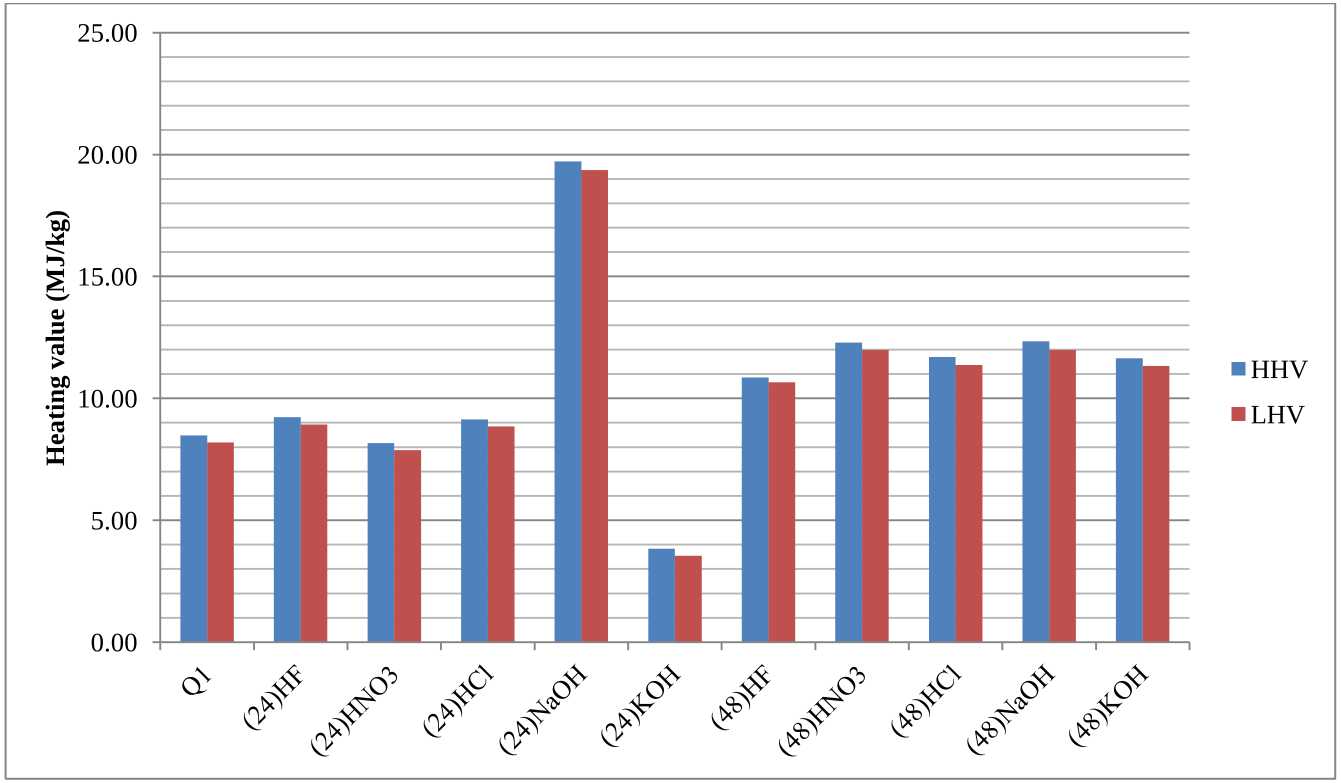


Figure 4.43 Heating value of Q1 coal seam both before and after treated

4.3 Cost of chemicals

4.3.1 The study of coal using in combustion process of power plant

The Mae Moh power plant has 13 units for electricity production. The amount of coal about 17.5 million tons are used every year, which distributed to 13 units, unit 1, 2, and 3 all about 1.5 million tons and other unit are shown in Table 4.15

Table 4.15 Amount of coal using in each unit of Mae Moh power plant.

Unit	Amount of coal used yearly(M ton)
1	1.5
2	
3	
4	1.0
5	1.0
6	1.0
7	1.0
8	2.0
9	2.0
10	2.0
11	2.0
12	2.0
13	2.0
Total	17.5

4.3.2 Amount of chemicals and cost for treatment process

Five chemicals were used in this study such as, hydrofluoric acid (HF), hydrochloric acid (HCl), nitric acid (HNO_3), sodium hydroxide (NaOH), and potassium hydroxide (KOH). Costs of chemicals in this study are shown in Table 4.16.

Table 4.16 Cost of chemicals which have a concentration of 1 M (Baht/liter)

Chemicals	Quality	Quantity	Cost (Baht)	Cost per liter (Baht/L)
HF	49%	1000cc	1000	39.18
HNO_3	68%	450cc	80	4.63
HCl	37%	450cc	60	4.93
NaOH	100%	350g	110	12.57
KOH	100%	350	120	19.24

*Price from Virote vittayapun; 589 Yommarat Rd. Mueang district, Nachonratchasima 30000

Table 4.17 Cost of chemicals will used in treatment process for 1 year

Chemicals	Amount of coal (Million tons/yr)	Quantity of chemicals (M liters)	Cost (Million Baht)
HF	17.5	17,500	86,317
HNO_3	17.5	17,500	81,025
HCl	17.5	17,500	86,275
NaOH	17.5	17,500	219,975
KOH	17.5	17,500	336,700

The results of coal treatment by using chemicals after cost has been estimated and shown in Table 4.1.7 found that now a day this method is still high cost of the treatment process. Sodium hydroxide has the highest cost of treatment followed by potassium hydroxide, in contrast nitric acid has the lowest cost about 81,025 million Baht. Hydrofluoric acid is not suitable for treatment because HF is one of the most dangerous acids and hardly eliminates or treat after using.

Coal treatment by using chemicals can reduce high sulfur and ash contents, although the high cost of investment which are advantage for reducing pollution from coal combustion. This method can increase the acceptable from the community.

CHAPTER V

CONCLUSION AND RECOMMENDATION

5.1 Element and mineral contents in samples

The results of compound and element analysis found that coal has silicon content range between 4.6 to 56.7%, sulfur 4.3 to 47.9%, iron 6 to 18%, calcium 1.6 to 75.9%, aluminium 1.6 to 22.7%, and other elements found a little 7%. From the results of mineral analysis can be concluded that silicate group is mainly content in coal such as, montmorillonite, K-feldspar, glauconite, illite, and kaolinite range between 18 to 82%. Calcite has range about 0 to 2% by found highest in K1 and K2 coal seam. Quartz is the mainly content in I coal seam. Pyrite was found highest in K2 coal seam.Variation of minerals similar to a varity of elements such as, amount of SiO_2 can occur in quartz, kaolinite, illite, K-feldspar, glauconite, and montmorillonite. Amount of Fe_2O_3 can occur in the form of pyrite and glauconite. SO_3 can occur in pyrite or gypsum.

Amount of minerals and elements which occur in coal and sediment samples can be concluded that IB sediment seam was deposited in the same environment with Q and K coal seams, so that amount of content in sediment seam affect directly on coal seam.

Coal of Mae Moh Coal Field has moisture content 12 to 33%, ash content 9 to 67%, volatile content 16 to 38%, and fixed carbon 4.5 to 20.3%. The low heating value of coal is about 4.5 to 13.7 MJ/kg. Trace elements are found highest of arsenic 38 to 72 ppm, vanadium 21 to 46 ppm, zinc 16 to 31 ppm, and copper 11 to 22 ppm. The variation of trace element will depend on clay minerals such as in K coal seam has the high clay with the same high concentration of trace elements.

5.2 Variations of ash content

The amount of ash can be reduced highest in HNO_3 26%, HCl 25%, and HF 23.6%. These results from ash was formed by burning of silicate group minerals, quartz, and calcium compound when reacted with nitric acid will occur new form of metals which can dissolve in water not only major element but also the results in trace elements following (6.1) and (6.2); iron compound.

$$18HNO_3 + FeS_2 \longrightarrow Fe_2(NO_3)_3 + 2H_2SO_4 + 15NO_2 + 7H_2O \quad (6.1)$$

$$6HNO_3 + Fe_2O_3 \longrightarrow 2Fe_2(NO_3)_3 + 3H_2O \quad (6.2)$$

For example of heavy metal in (6.3) and (6.4)

$$4HNO_3 + Cu \longrightarrow Cu(NO_3)_2 + 2NO_2 + 2H_2O \quad (6.3)$$

$$4HNO_3 + Pb \longrightarrow Pb(NO_3)_2 + 2NO_2 + 2H_2O \quad (6.4)$$

These elements are major elements which will form ash after burned (oxide of metal). Solution of HF after reaction with coal samples will appear precipitate of metal sulfide which affect on increasing of ash following equation (6.5) to (6.8).

$$6HF + SiO_2 \longrightarrow H_2SiF_6 + 2H_2O \quad (6.5)$$

$$6HF + Al_2O_3 \longrightarrow 2AlF_3 + 3H_2O \quad (6.6)$$

$$HF + CaCO_3 \longrightarrow CaF_2 + H_2O \qquad (6.7)$$

$$HF + MgCO_3 \longrightarrow MgF_2 + H_2O \qquad (6.8)$$

Nitric acid and hydrochloric acid have low performance in high gypsum coal seam because gypsum can react a little with these acids. Solution of base has lowest performance for reducing ash because after reacting with metal group or silicate group will appear new insoluble compound which affect on increasing of ash such as the reaction of sodium and potassium hydroxide with quartz, aluminium oxide, pyrite, kaolinite, and illite following equation (6.9) to (6.15).

$$2NaOH + SiO_2 \longrightarrow Na_2SiO_3 + H_2O \qquad (6.9)$$

$$2NaOH + Al_2O_3 \longrightarrow 2NaAlO_2 + H_2O \qquad (6.10)$$

$$11NaOH + 2FeS_2 + 0.5C \longrightarrow 4Na_2S + 2NaFeO_2 + 0.5Na_2CO_3 + 5.5H_2O \qquad (6.11)$$

$$20NaOH + Al_2Si_2O_5(OH)_4 \longrightarrow 2NaAlO_2 + 2NaSiO_3 + 14NaOH + 5H_2O \qquad (6.10)$$

$$20NaOH + KAl_2[Si_3AlO_{10}(OH)_2] \longrightarrow 3NaAlO_2 + 3Na_2SiO_3 + 11NaOH + 5H_2O \qquad (6.11)$$

$$2KOH + SiO_2 \longrightarrow K_2SiO_3 + H_2O \qquad (6.12)$$

$$2KOH + Al_2O_3 \longrightarrow 2KAlO_2 + H_2O \qquad (6.13)$$

$$11KOH + 2FeS_2 + 0.5C \longrightarrow 4K_2S + 2KFeO_2 + 0.5K_2CO_3 + 5.5H_2O \qquad (6.14)$$

$$20KOH + Al_2Si_2O_5(OH)_4 \longrightarrow 2KAlO_2 + 2KaSiO_3 + 14KOH + 5H_2O \qquad (6.15)$$

5.3 Variations of sulfur content

The results of the desulfurization show that the solution of NaOH and KOH have the highest performance in reducing sulfur 80% as the results of equation (6.11) and (6.14). Nitric and hydrochloric acid has performance about 40 to 60% but performance of NaOH and KOH will be decreased if use with high calcite coal seam (example in K1 shows in Table 6.1) because the massive of clay and calcite affect on leaching of pyrite or other minerals, in contrast if react with HF or HNO_3 will affect highest on increasing performance of sulfur reduction because calcite can reacted easily with these acid following equation (6.16) and (6.17).

$$CaCO_3 + HNO_3 \xrightarrow{\qquad\qquad} CO_2 + Ca(NO_3)_2 + H_2O \tag{6.16}$$

$$CaCO_3 + HCl \xrightarrow{\qquad\qquad} CO_2 + CaCl_2 + H_2O \tag{6.17}$$

Table 5.1 Variations of sulfur in K1 coal seam on 24 hours of treatment (wt.%)

Element	**HF**	**HNO_3**	**HCl**	**NaOH**	**KOH**
SO_3	38.306	7.882	0.000	0.000	0.000

5.4 Variation of volatile content

The amount of volatile in coal is the most important to making natural ignition in coal while stored before waiting for feed to power plant. Hydrofluoric acid can reduce volatile 3.6 to 14% because clay mineral can be reduced in this acid, but hydrochloric can reduce a little volatile in some coal seams.

5.5 Variations of heating value

Potassium hydroxide has high performance for increasing heating value 25 to 116%, followed by nitric acid, which affect lowest on reducing of heating value about 4 to 46%. After leaching acid for 48 hours the results show that coal has increasing of heating value reduction about 25% which results similar to all coal seams. Leaching coal with chemicals for 48 hours, solution after reacted had more time for stored in water have an effect with variation in coal such as increasing of hydrogen reduction and increasing of nitrogen and oxygen in coal making coal were reduced heating value after calculated following Dulong's formula.

5.6 Variations of carbon content

The ratio of carbon is increased after leaching with NaOH and KOH 5 to 15%. Nitric acid and hydrochloric acid increase carbon content to 20%, especially in I coal seam, which has a silicate compound, gypsum, pyrite, and calcite that affect on performance of reaction. The leaching of coal with HF affect on increase of ash content. Carbon reduction affect on coal after leached with HNO_3 and HCl as a result of these acids can react easily with carbon matrix (Mukherjee and Borthakur, 2002).

5.7 Variations of properties when increasing time

The increasing of time from 24 to 48 hours has not effect with changing of properties in coal samples under concentration 1 mole/L of chemicals. This study can conclude that the reaction of coal with chemical (1M) finished completely in 24 hours so that 24 hours is suitable for the treatment process.

5.8 Variations of trace elements when increasing time

Results of time condition in this study divided into 2 cases are 24 and 48 hours. The increasing of time did not affect on changing of trace elements. The adequate chemicals for reducing heavy metals in coal are HNO_3 and HF because these acids have potential for reacting with many minerals (Economides and Nolte, 2000). Because of the heavy metals in coal are associated with gypsum, kaolinite and illite (Robert, 1996), which nitric acid can reduce Arsenic 40 to 53%, chromium reduced 7%, cobalt reduced 9 to 41%, vanadium reduced 2 to 13%, and lead reduced to 1 to 15%. Hydrochloric acid can reduce arsenic about 49%, chromium reduced 1%, cobalt reduced to 41 to 91%, vanadium reduced 2 to 48%, and lead reduced 0.2 to 16%.

5.9 Summary of the results of treatment process

From the study can conclude that nitric acid is suitable for reducing ash and the element will forming ash, followed by HCl, in contrast hydrofluoric acid has high performance for reducing ash but very dangerous and difficult to eliminate so difficult and unsuitable for using. Potassium and sodium hydroxide has the highest performance for reducing the sulfur content in coal, which quite the similar to the result of sulfur reduction in HNO_3 and HCl, but have an effect by reducing the carbon content so that if users want to treating coal by alone chemicals, nitric acid is highest suitable for using.

The results of acid solution are nitric acid can reduce arsenic 40 to 53%, chromium reduced 7%, cobalt reduced 9 to 41%, vanadium reduced 2 to 13%, and lead reduced to 1 to 15%. Hydrochloric acid can reduce arsenic about 49%, chromium reduced 1%, cobalt reduced to 41 to 91%, vanadium reduced 2 to 48%, and lead reduced 0.2 to 16%.

The results of base solution are reducing sulfur to 80%, arsenic reduced 2 to 39%, and chromium reduced 24%, in contrast making affect an increasing of ash.

5.10 Cost of chemicals

The expectation of economic can help investor about investment from the study can conclude that chemical cleaning sill have high costs for investment in the short term if compare with current equipment, by finding higher of cost in using of NaOH followed by KOH. The lowest cost of chemical treatment is HNO_3 followed by HCl and HF but HF is more dangerous for using.

5.11 Suggestions for experimental

The study of coal properties in the future should have more re-tested in the same sample for accuracy. The study should be confined about the chemical using just highest performance, which can be applied clearly to the power plant. The variable of time and temperature are important of study, and should study deeply about the behavior of reactive in each step.

Leaching coal in nitric or hydrochloric acid in the first step in reducing ash and sulfur, after that, followed by soaking in the base solution for reducing the sulfur content again from the expectation sulfur content will be reduced close to 100%.

The area of this study cover only Mae Moh Coal Field which can be applied to other coal fields, in the future should collect coal samples from many coal fields for comparison the results and apply to all coal fields in Thailand.

Table 5.2 Showing the suitable chemicals for using in the treatment process of each coal seam by comparison of sulfur and silicon content from XRF and XRD, including the summation of major elements will forming ash (XRF), ash from proximate analysis

Seam	SO_3	S	SiO_2	Quartz	Sum of major element (Fe, Ca, Al)	Ash	Increasing carbon
I	HF	HCl	HF,HCl	HCl	HF	HNO_3,HCl,HF	HCl,HF,HNO_3
J3	KOH	HNO_3	KOH,HCl	-	HCl	-	HF
J4	HF	KOH	HNO_3,HF,KOH	HF,HCL,NaOH	HF,HNO_3	HNO_3,HF	HNO_3,HF
J5	NaOH	NaOH	HCl,KOH,HNO_3,HF	HF,HNO_3	HNO3,HCl,HF	HF	HF
K1	HF	KOH	-	-	-	HF,HNO_3	HF
K2	HF	-	HF,NaOH,HCl	KOH,NaOH	HF,NaOH,HCl	HF,HCl	HF,HCl
K3	HF	KOH,NaOH	HF	All	HF,HNO_3	HF,HNO_3	HF
Q1	HF,HNO_3	KOH,NaOH	HNO_3,HF	NaOH, all	HNO_3,HF	HNO_3	HF
Q2	HNO_3,HCL, HF,NaOH	HCl,NaOH	HNO_3,HCl,KOH	HNO_3,HCl	HNO_3,HCl,KOH,HF	-	HF,HCl
Q3	HCl,KOH,HF	KOH	HCl,KOH,HF,HNO_3	HF	HCl,HF,HNO_3	HF,HNO_3	HF,HCl
Q4	HF	KOH	-	NaOH,HCl	HF,	HCl,HF	HF,HCl

REFERENCES

Benammi, M., Urrutia-Fucugauchi, J., Alva-Valdivia, L.M., Chaimanee, Y., Triamwichanon, S., and Jaeger , J. (2002). **Magnetostratigraphy of the middle Miocene continental sedimentary sequences of the Mae Moh Basin in northern Thailand: Evidence for counterclockwise block rotation.** Earth and Planetary Science Letters. v. 204, 373–383.

Chaodumrong, P. (1985). **Sedimentological studies of some Tertiary deposits of Mae Moh Basin, Changwat Lampang.** [M.S. thesis]: Thailand, Department of Geology, Chulalongkorn University.

Charoenprawat, A., Chuaviroj, S., Hinthong, C. and Chonlakmani, C. (1994). **Geologic Map NE47-7 Changwat Lampang.** Report of Investigation. Department of Mineral Resources, Thailand.

Coal Geology. (2012). **Coal Classification and Analysis: Coal Rank, Classification by Heat value** [on-line]. Available: http://coalgeology.com/coal-classification-and-analysis-coal-rank-classification-by-heat-value/8603/.

Corsiri, R., and Crouch, A. (1985). **Mae Moh coal deposit**: Geologic report, Volume 1: Thailand/Australia Lignite Mines Development Project, EGAT, 448

Coster, P., Benammi, M., Chaimanee, Y., Yamee, C., Chavasseau, O., Emonet, E-G., and Jaeger, J. (2010). **A complete magnetic-polarity stratigraphy of the Miocene continental deposites of Mae Moh Basin, northern Thailand, and a reassessment of the age of hominoid-bearing localities in northern Thailand.** Geological Society of America. America, 1-12.

Department of mineral resources. 2001. **General Geology of Thailand.** Thailand, 445-464.

Economides M. J. and Nolte, K. G. (2000). **Solubility of common minerals in acid**, Reservoir Stimulation, 3rd edition. 14-29.

Energy Forecast and Information Technology Center. (2011). **Thailand energy situation in 2011.** In Annual Report. Ministry of Energy, Thailand.

EPPO Organization. (1999). **Energy and fuel consumption in Thailand.** In Annual Report. Ministry of Energy, Thailand.

EPPO Organization. (2012). **Electric consumption and production of electricity.** In Annual Report. Ministry of Energy, Thailand, 3-40.

Karen, M. S., and John W. P. (2000). **The production of ultra clean coal by chemical demineralization.** Department of Chemical Engineering, Loughborough University. UK, 2019-2023.

Karen M. S., Besida, J., Thomas A. O., and David G. W. (2000**). Production of ultra clean coal: Part I-Dissolution behavior of mineral matter in black coal toward hydrochloric and hydrofluoric acids.** School of Chemical, Nottingham University. UK, 1917-1920.

Karen M. S., and John W. P. (2002). **The production of ultra clean coal by sequential leaching with HF followed by HNO_3.** School of Chemical, Nottingham University. UK, 1917-1920.

Kaushik, S. M., Norton, G. A., and Markuszewski, R. (1988). **Behavior of ash-forming mineral matter in coal during chemical cleaning with molten caustic.** Ames Laboratory, Iowa State University, Ames, Iowa. Journal.

Morley, C. K., Woganan, N., Sankumarn, N., Hoon, T. B., Alief, A., and Simmons, M. (2001). **Late Oligocene-Recent stress evolution in rift basins of northern and central Thailand: implications for escape tectonics,** Tectophysics, 334, 115-150

Mukherjee, S., and Borthakur, P. C. (2002). **Effect of leaching high sulphur subbituminous coal by potassium hydroxide and acid on removal of mineral matter and sulphur.** Regional Research Laboratory. India, 783-788.

Pollution control department, Ministry of natural resources and environment Thailand. (2011). **Air quality standard**, [on-line] Available://www.pcd.go.th/info_serv/reg_std_airsnd03.html

Pollution control department, Ministry of natural resources and environment Thailand. (2004). **Soil quality standard**, [on-line] Available://www.pcd.go.th/info_serv/reg_std_airsnd03.html

Ralph, T. Y., Subho, K. D., and Benjamin, M. C. T. (1984). **Coal demineralization using sodium hydroxide and acid solution.** Aluminum company of America. USA, 735-742.

Ratanasthien, B., Takashima, I., and Matsubaya, O. (2008). **Paleaogeography and Climatic Change recorded on Viviparidae Carbon and Oxygen Isotope in Mae Moh Coal Mine. Northern Thailand.** Geological Survey of Japan. 327-338.

Reggel, L., Raymond, R., and Blaustien, B. D. (1973). **Removal of mineral matter including pyrite from coal.** Washington, D.C.

Robert M. (1996). **Trace elements in coal**, IEA Coal Research, London, United Kingdom

Sharma D. K., and Sanjay G. (1988). **Chemical cleaning of low grade coal through alkali-acid leaching employing mild conditions under ambient pressure.** Indian Institute of Technology. India, 663-665.

Silaratana, T., Ratanasthien, B., Takayasu, K., Fyfe W. S., Asnachinda, P., Kandharosa, W., and Kusakabe, M. (2003). **Sulfur Isotopic Implication of Middle Miocene Marine Incursion in Northern Thailand.** Science Asia, 43-58.

Songtham, W., Ugai, H., Imsamut, S., Maranate, S., Tansathien, W., Meesook, A., and Saengsrichan, W., 2004. **Middle Miocene Molluscan Assemblages in Mae Moh Basin, Lampang Province, Northern Thailand.** Department of Mineral Resources. Thailand, 183-191.

Sompong, W., Springbelt, G. M., and Evans, P. R. (1996). **Lignitemine development project, Mae Moh coal deposit:** Geological Report, prepared by the Australian Agency for International Development (AusAID)/ Electricity Generating Authority of Thailand (EGAT)/ Landslide Mitigation Demonstration Project (LMDP) Phase III.

Tankaya, W. (2004). **Implication of Geochemistry on Depositional Environments in Mae Moh Coal Field Changwat Lampang.** Faculty of Science, Chaing Mai University

Waugh A. B. (1983). **Removal of mineral matter from bituminous coals by aqueous chemical leaching.** CSIRO Division of Energy Chemistry, Lucas Heights Research Laboratories. Australia, 217-233.

World Coal Association. (2012). **What is Coal.** [on-line]. Available:http://www.worldcoal.org/coal/what-is-coal/.

APPENDIX A

COAL AND SEDIMENT SEAMS

A.1 Coal and sediment seams in Mae Moh coal field

Figure A.1.1 Overburden sediment which is the upper most K and Q coal seam

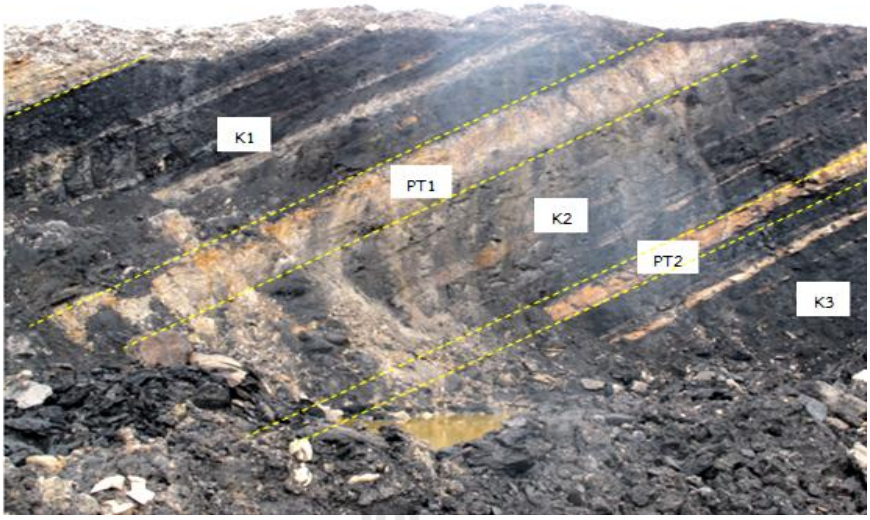


Figure A.1.2 K coal seam which is divided, by two sediment seams are P1 and PT2, into 4 sub coal seams

Figure A.1.3 Interburden sediment seam which is between K and Q coal seams

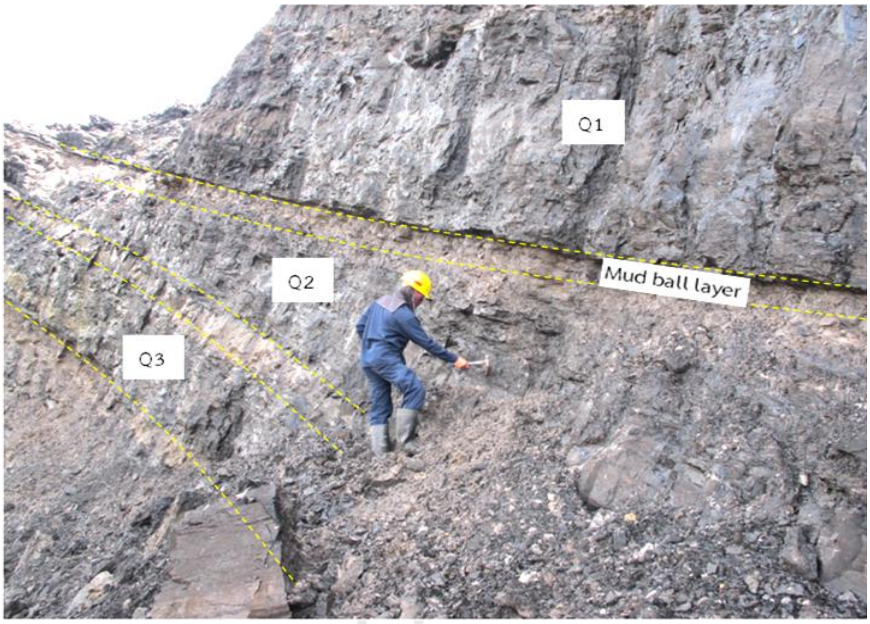


Figure A.1.4 Showing coal bed of Q1, Q2, and Q3 coal seams

Figure A.1.5 Collection coal samples of Q4 coal seam

Figure A.1.6 Underburden sediment which is the lowest seam next to Q coal seam

A.2 Coal samples in Mae Moh basin

Figure A.2.1 Coal samples of I coal seam from Mae Moh coal field

Figure A.2.2 Coal samples of J3 coal seam from Mae Moh coal field

Figure A.2.3 Coal samples of J4 coal seam from Mae Moh coal field

Figure A.2.4 Coal samples of J5 coal seam from Mae Moh coal field

Figure A.2.5 Coal samples of K1 coal seam from Mae Moh coal field

Figure A.2.6 Coal samples of K2 coal seam from Mae Moh coal field

Figure A.2.7 Coal samples of K3 coal seam from Mae Moh coal field

Figure A.2.8 Coal samples of Q1 coal seam from Mae Moh coal field

Figure A.2.9 Coal samples of Q2 coal seam from Mae Moh coal field

Figure A.2.10 Coal samples of Q3 coal seam from Mae Moh coal field

Figure A.2.11 Coal samples of Q4 coal seam from Mae Moh coal field

APPENDIX B

RESULTS OF TESTING

B.1 Results of analysis from XRF method

Table B.1.1 Variations of major elements in coal samples after treated by 7 chemicals at 24 h of treatment time

Element	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO_2	Fe_2O_3	BaO	ZnO
IHF	81.568	0.000	5.810	11.085	0.000	0.473	0.439	0.198	0.057	0.000	0.255	0.000	0.000
$IHNO_3$	66.569	9.636	8.817	12.803	0.086	0.736	0.535	0.267	0.214	0.000	0.476	0.000	0.000
IHCl	65.614	12.206	8.388	11.705	0.030	0.817	0.472	0.159	0.063	0.001	0.421	0.000	0.000
INaOH	0.000	3.771	23.869	47.851	0.008	2.564	3.317	1.588	0.505	0.007	3.832	0.000	0.013
IKOH	18.744	10.273	21.922	35.696	0.030	2.516	6.936	1.158	0.343	0.008	2.364	0.000	0.012
ICaO	38.306	17.178	14.827	22.008	1.006	1.597	1.142	2.787	0.167	0.003	0.980	0.000	0.004
IH2O	0.093	18.597	20.305	47.921	0.278	3.950	2.830	2.095	0.452	0.010	3.446	0.000	0.016
J3HF	13.846	0.000	13.862	9.112	0.407	33.255	0.537	11.819	0.039	0.000	7.165	0.000	0.000
$J3HNO_3$	2.925	1.120	5.518	13.160	0.000	46.643	1.029	15.970	0.220	0.017	13.394	0.000	0.007
J3HCl	55.698	1.396	2.426	2.619	0.125	26.292	0.267	7.723	0.047	0.001	3.404	0.007	0.000
J3NaOH	4.324	2.984	5.708	12.159	0.000	38.281	0.833	13.618	0.169	0.061	21.858	0.000	0.007
J3KOH	42.911	21.272	4.470	0.996	0.014	16.022	4.221	4.953	0.038	0.023	5.080	0.000	0.002
J3CaO	41.976	10.795	3.962	5.818	0.190	21.903	0.287	11.431	0.036	0.007	3.957	0.000	0.001
J3H2O	37.875	7.343	5.821	2.791	0.116	26.549	0.628	8.147	0.111	0.016	10.571	0.000	0.000
J4HF	80.373	0.337	0.895	1.053	0.634	11.948	0.075	3.301	0.001	0.000	1.385	0.000	0.000
$J4HNO_3$	76.257	0.177	0.409	0.754	0.015	16.810	0.059	3.832	0.023	0.000	1.665	0.000	0.000
J4HCl	62.081	9.529	2.043	2.298	0.062	17.616	0.113	4.488	0.020	0.000	1.750	0.003	0.000
J4NaOH	6.812	2.599	2.359	6.043	0.000	40.769	0.318	19.242	0.125	0.062	21.661	0.000	0.012
J4KOH	36.290	0.175	0.403	1.343	0.728	26.959	8.623	12.097	0.101	0.049	13.230	0.000	0.005
J4CaO	54.235	18.758	2.793	2.426	0.039	14.151	0.074	6.014	0.012	0.006	1.493	0.000	0.006
J4H2O	31.627	10.783	2.235	4.398	0.681	29.851	0.146	10.985	0.049	0.011	9.233	0.000	0.003

Table B.1.1 Variations of major elements in coal samples after treated by 7 chemicals at 24 h of treatment time (Continues)

Element	**Na_2O**	**MgO**	**Al_2O_3**	**SiO_2**	**P_2O_5**	**SO_3**	**K_2O**	**CaO**	**TiO_2**	**MnO_2**	**Fe2O3**	**BaO**	**ZnO**
J5HF	44.054	8.836	3.293	1.467	1.017	26.923	0.143	9.376	0.044	0.000	4.149	0.000	0.000
$J5HNO_3$	59.515	3.406	0.508	1.536	0.180	24.183	0.103	7.934	0.031	0.000	2.595	0.011	0.000
J5HCl	25.735	0.347	2.117	1.142	0.197	31.780	0.133	10.847	0.154	0.001	5.395	0.018	0.000
J5NaOH	68.132	13.760	2.046	2.418	0.266	9.299	0.083	2.551	0.017	0.000	1.431	0.000	0.000
J5KOH	41.658	9.956	0.026	1.229	0.093	22.819	4.378	9.620	0.067	0.016	10.141	0.000	0.001
K1HF	72.796	0.564	7.838	11.630	0.145	3.722	0.519	1.598	0.082	0.000	1.109	0.000	0.000
$K1HNO_3$	74.981	0.086	6.034	10.352	0.002	5.558	0.404	1.501	0.065	0.000	1.020	0.000	0.000
K1HCl	39.016	1.524	8.968	14.529	0.130	11.679	0.973	3.920	0.143	0.006	3.298	0.000	0.000
K1NaOH	2.013	22.403	14.762	22.168	1.599	12.798	1.257	6.758	0.252	0.017	5.561	0.002	0.006
K1KOH	12.175	3.361	13.185	26.386	0.850	11.591	7.085	16.322	0.324	0.098	8.617	0.000	0.009
K2HF	75.736	6.296	5.231	4.719	0.037	5.689	0.203	0.782	0.030	0.000	1.278	0.000	0.000
$K2HNO_3$	62.361	16.742	3.819	18.808	0.008	8.502	0.241	1.805	0.013	0.000	1.369	0.020	0.000
K2HCl	59.425	21.234	4.831	5.571	0.163	6.413	0.223	0.828	0.031	0.000	1.279	0.005	0.000
K2NaOH	75.214	0.222	3.027	4.691	0.469	10.369	0.418	1.933	0.057	0.011	3.592	0.000	0.002

Table B.1.1 Variations of major elements in coal samples after treated by 7 chemicals at 24 h of treatment time (Continues)

Element	**Na_2O**	**MgO**	**Al_2O_3**	**SiO_2**	**P_2O_5**	**SO_3**	**K_2O**	**CaO**	**TiO_2**	**MnO_2**	**Fe2O3**	**BaO**	**ZnO**
K2KOH	0.421	2.983	13.017	20.081	0.971	25.568	10.884	6.399	0.290	0.064	19.312	0.000	0.013
K3HF	87.575	1.082	0.582	3.275	0.205	4.883	0.225	1.177	0.013	0.000	0.987	0.000	0.000
$K3HNO_3$	52.767	2.208	8.531	17.363	0.051	12.667	0.787	3.419	0.131	0.006	2.074	0.000	0.000
K3HCl	48.536	15.059	12.255	12.402	0.028	7.734	0.458	2.048	0.079	0.002	1.388	0.016	0.000
K3NaOH	34.667	8.198	6.467	21.189	0.108	14.652	1.251	6.777	0.269	0.052	6.366	0.000	0.006
K3KOH	22.625	22.314	6.354	17.851	0.201	9.239	5.759	9.429	0.252	0.091	5.883	0.000	0.005
Q1HF	59.129	7.478	8.466	12.475	0.261	7.201	0.479	2.661	0.099	0.008	1.745	0.000	0.000
$Q1HNO_3$	71.811	1.150	7.789	8.341	0.036	7.445	0.317	1.805	0.028	0.000	1.247	0.033	0.000
Q1HCl	40.333	1.548	7.403	16.782	0.101	22.027	0.909	6.000	0.165	0.000	4.736	0.000	0.000
Q1NaOH	25.314	4.126	11.295	18.960	0.714	20.810	1.153	6.289	0.271	0.039	11.023	0.000	0.008
Q1KOH	40.083	2.415	20.562	15.743	0.274	8.558	3.498	3.097	0.171	0.021	5.579	0.000	0.003
Q2HF	36.827	13.849	11.141	23.207	0.003	8.200	1.171	1.905	0.246	0.000	3.453	0.000	0.000
$Q2HNO_3$	78.412	0.025	7.792	7.981	0.004	4.077	0.292	0.580	0.052	0.000	0.778	0.011	0.000

Table B.1.1 Variations of major elements in coal samples after treated by 7 chemicals at 24 h of treatment time (Continues)

Element	**Na_2O**	**MgO**	**Al_2O_3**	**SiO_2**	**P_2O_5**	**SO_3**	**K_2O**	**CaO**	**TiO_2**	**MnO_2**	**Fe2O3**	**BaO**	**ZnO**
Q2HCl	58.115	13.471	8.628	12.929	0.172	4.592	0.406	0.607	0.087	0.000	0.996	0.000	0.000
Q2NaOH	18.706	25.686	18.022	23.305	0.159	8.450	0.873	1.451	0.151	0.004	3.192	0.000	0.004
Q2KOH	41.350	1.698	11.790	15.149	0.292	15.882	3.806	1.497	0.186	0.005	8.341	0.000	0.001
Q3HF	61.537	0.245	7.734	11.111	0.528	11.803	0.588	2.250	0.047	0.000	2.659	0.000	0.000
$Q3HNO_3$	36.731	15.506	10.459	11.577	0.061	13.899	0.537	4.897	0.153	0.007	3.661	0.002	0.000
Q3HCl	77.299	1.575	4.980	7.665	0.337	5.888	0.203	1.155	0.033	0.001	0.870	0.000	0.000
Q3NaOH	2.426	13.312	15.372	18.756	0.655	26.622	1.145	8.941	0.283	0.039	12.440	0.000	0.010
Q3KOH	39.428	24.428	10.420	9.232	1.618	7.241	3.087	1.994	0.062	0.009	2.481	0.000	0.004
Q4HF	73.440	8.684	3.013	1.827	0.239	5.461	0.009	6.387	0.008	0.000	0.935	0.000	0.000
$Q4HNO_3$	47.571	7.579	4.149	3.481	0.130	15.756	0.223	8.981	0.084	0.014	3.914	0.000	0.000
Q4HCl	44.597	6.530	3.818	1.973	1.845	12.375	0.039	8.678	0.035	0.008	3.593	0.000	0.000
Q4NaOH	11.788	27.790	9.249	7.349	1.743	14.719	0.641	19.768	0.114	0.052	6.786	0.000	0.004
Q4KOH	16.581	5.921	11.882	6.792	1.791	12.692	8.139	28.203	0.112	0.064	7.826	0.000	0.002

Table B.1.2 Reduction of elements in coal samples of I coal seam after treated (24 h)

Chemicals	HF	HNO_3	HCl	NaOH	KOH
S	88.933	82.780	80.884	40.021	41.132
Al_2O_3	74.364	61.101	62.991	0.000	3.278
SiO_2	80.470	77.443	79.379	15.694	37.110
Fe_2O_3	95.856	92.250	93.154	37.618	61.511
$Al_2O_3+SiO_2+Fe_2O_3$	79.957	74.177	76.027	11.704	29.900

Table B.1.3 Reduction of elements in coal samples of J3 coal seam after treated (24 h)

Chemicals	HF	HNO_3	HCl	NaOH	KOH
S	25.564	0.000	41.149	14.312	64.137
Al_2O_3	0.000	0.000	41.441	0.000	0.000
SiO_2	0.000	0.000	68.129	0.000	87.883
Fe_2O_3	59.541	24.362	80.777	0.000	71.315
$Al_2O_3+SiO_2+Fe_2O_3$	0.000	0.000	71.902	0.000	64.927

Table B.1.4 Reduction of elements in coal samples of J4 coal seam after treated (24 h)

Chemicals	HF	HNO_3	HCl	NaOH	KOH
SO_3	73.956	63.358	61.602	11.132	41.236
Al_2O_3	78.635	90.248	51.229	43.686	90.392
SiO_2	86.944	90.657	71.507	25.071	83.354
Fe_2O_3	93.443	92.118	91.716	0.000	37.370
$Al_2O_3+SiO_2+Fe_2O_3$	90.014	91.530	81.751	9.932	55.135

Table B.1.5 Reduction of elements in coal samples of J5 coal seam after treated (24 h)

Chemicals	HF	HNO_3	HCl	NaOH	KOH
SO_3	43.779	49.502	33.638	80.583	52.350
Al_2O_3	0.000	87.873	49.463	51.170	99.391
SiO_2	72.110	80.955	85.840	70.019	84.768
Fe_2O_3	80.938	87.715	74.463	93.226	51.995
$Al_2O_3+SiO_2+Fe_2O_3$	70.129	91.530	81.751	9.932	55.135

Table B.1.6 Reduction of elements in coal samples of K1 coal seam after treated (24 h)

Chemicals	**HF**	**HNO_3**	**HCl**	**NaOH**	**KOH**
SO_3	38.306	7.882	0.000	0.000	0.000
Al_2O_3	0.000	0.000	0.000	0.000	0.000
SiO_2	0.000	0.000	0.000	0.000	0.000
Fe_2O_3	82.458	83.866	47.841	12.045	0.000
$Al_2O_3+SiO_2+Fe_2O_3$	0.000	0.000	0.000	0.000	0.000

Table B.1.7 Reduction of elements in coal samples of K2 coal seam after treated (24 h)

Chemicals	**HF**	**HNO_3**	**HCl**	**NaOH**	**KOH**
SO_3	83.361	75.135	81.243	69.674	25.219
Al_2O_3	48.871	62.677	52.781	70.413	0.000
SiO_2	78.371	13.798	74.466	78.499	7.964
Fe_2O_3	94.661	94.281	94.657	84.990	19.288
$Al_2O_3+SiO_2+Fe_2O_3$	79.942	57.134	79.133	79.796	6.371

Table B.1.8 Reduction of elements in coal samples of K3 coal seam after treated (24 h)

Chemicals	HF	HNO_3	HCl	NaOH	KOH
SO_3	78.554	44.360	66.030	35.641	59.418
Al_2O_3	95.865	39.342	12.863	54.017	54.824
SiO_2	90.193	48.009	62.865	36.554	46.549
Fe_2O_3	91.717	82.590	88.350	46.549	50.605
$Al_2O_3+SiO_2+Fe_2O_3$	91.843	52.893	56.133	42.696	49.323

Table B.1.9 Reduction of elements in coal samples of Q1 coal seam after treated (24 h)

Chemicals	HF	HNO_3	HCl	NaOH	KOH
SO_3	78.179	77.441	33.252	36.939	74.068
Al_2O_3	7.572	14.958	19.178	0.000	0.000
SiO_2	37.465	58.186	15.874	4.953	21.082
Fe_2O_3	90.252	93.034	73.543	38.422	68.834
$Al_2O_3+SiO_2+Fe_2O_3$	51.742	63.034	38.479	12.190	10.901

Table B.1.10 Reduction of elements in coal samples of Q2 coal seam after treated (24 h)

Chemicals	**HF**	**HNO_3**	**HCl**	**NaOH**	**KOH**
SO_3	68.592	84.384	82.413	67.636	39.170
Al_2O_3	17.173	42.075	35.860	0.000	12.349
SiO_2	16.213	71.186	53.322	15.857	45.306
Fe_2O_3	74.445	94.246	92.629	76.377	38.270
Al_2O_3+SiO_2+Fe_2O_3	30.844	69.723	58.741	18.554	35.456

Table B.1.11 Reduction of elements in coal samples of Q3 coal seam after treated (24 h)

Chemicals	**HF**	**HNO_3**	**HCl**	**NaOH**	**KOH**
SO_3	54.455	46.367	77.281	0.000	72.061
Al_2O_3	46.878	28.165	65.794	0.000	28.433
SiO_2	62.765	61.202	74.312	37.143	69.061
Fe_2O_3	82.086	75.339	94.142	16.189	83.285
Al_2O_3+SiO_2+Fe_2O_3	63.702	56.625	77.187	21.393	62.640

Table B.1.12 Reduction of elements in coal samples of Q4 coal seam after treated (24 h)

Chemicals	HF	HNO_3	HCl	NaOH	KOH
SO_3	77.604	35.379	49.247	39.634	47.947
Al_2O_3	0.000	0.000	0.000	0.000	0.000
SiO_2	60.326	24.408	57.155	0.000	0.000
Fe_2O_3	93.800	74.045	76.177	55.003	48.103
$Al_2O_3+SiO_2+Fe_2O_3$	72.954	45.932	56.051	0.000	0.000

B.2 Results of analysis from XRD method

Table B.2.1 Variations of minerals in coal samples after treated by 7 chemicals at 24 h of treatment time

Comp	Quartz	Calcite	Kaolin	Illite	Pyrite	Sider	Gyp	Glauc	K-Feld	Mont	Chlor
IHF	7.84	0.08	11.39	6.38	0.18	0.21	0.51	25.03	31.17	16.15	1.09
$IHNO_3$	7.64	0.05	8.89	7.88	0.22	0.19	2.30	22.20	28.06	15.57	7.03
IHCl	6.85	0.09	8.73	6.95	0.03	0.19	4.26	19.00	31.24	16.01	6.70
INaOH	7.74	1.27	9.41	7.83	0.07	0.14	0.45	20.96	31.01	12.29	8.84
IKOH	7.72	1.62	9.85	9.94	0.04	0.10	0.35	23.13	22.06	16.72	8.51
J3HF	0.48	0.49	1.86	0.67	0.52	0.02	17.85	5.65	47.90	24.03	0.44
$J3HNO_3$	0.60	1.18	2.57	0.69	0.02	0.08	29.14	9.67	42.98	11.98	1.11
J3HCl	0.51	0.93	1.98	0.44	0.23	0.06	21.61	6.33	37.86	28.85	0.92
J3NaOH	0.46	1.02	1.70	0.52	0.46	0.09	21.24	4.59	34.36	34.63	0.95
J3KOH	0.86	1.07	2.81	1.65	0.47	0.05	11.16	0.19	37.61	42.75	1.40
J4HF	0.23	0.76	1.09	0.67	0.68	0.03	15.00	6.98	42.93	31.27	0.23

Table B.2.1 Variations of minerals in coal samples after treated by 7 chemicals at 24 h of treatment time (Continues)

Comp	Quartz	Calcite	Kaolin	Illite	Pyrite	Sider	Gyp	Glauc	K-Feld	Mont	Chlor
J4HNO$_3$	0.50	0.96	1.40	0.44	0.73	0.06	21.50	3.04	32.65	38.24	0.51
J4HCl	0.20	0.25	0.75	0.20	0.52	0.04	12.15	3.16	30.99	51.26	0.52
J4NaOH	0.20	0.65	0.66	0.09	0.29	0.04	7.43	1.61	20.02	68.47	0.58
J4KOH	0.28	0.60	0.46	1.61	0.23	0.03	2.77	0.00	19.92	73.90	0.21
J5HF	0.09	0.79	0.89	0.40	0.76	0.03	15.55	6.72	46.19	28.07	0.33
J5HNO$_3$	0.10	0.44	0.78	0.16	0.35	0.06	13.63	2.31	20.30	61.62	0.24
J5HCl	0.20	0.60	1.05	0.31	0.52	0.08	17.28	2.61	19.68	57.39	0.32
J5NaOH	0.23	0.80	1.09	0.34	0.27	0.05	8.19	1.25	11.47	75.88	0.46
J5KOH	0.25	0.29	0.71	0.52	0.09	0.03	7.55	0.06	10.11	80.08	0.31
K1HF	5.14	0.37	4.12	3.07	1.25	0.00	5.20	18.35	39.00	22.53	0.76
K1HNO$_3$	2.36	0.64	3.62	1.74	0.72	0.07	9.73	7.87	17.27	55.36	0.65

Table B.2.1 Variations of minerals in coal samples after treated by 7 chemicals at 24 h of treatment time (Continues)

Comp	Quartz	Calcite	Kaolin	Illite	Pyrite	Sider	Gyp	Glauc	K-Feld	Mont	Chlor
K1HCl	2.36	0.31	3.81	2.00	0.71	0.05	8.27	9.88	18.47	53.69	0.66
K1NaOH	1.64	1.80	2.82	1.93	0.48	0.06	2.42	14.69	8.50	65.21	0.48
K1KOH	2.26	5.20	3.29	2.23	0.59	0.00	0.73	14.60	5.02	65.60	0.49
K2HF	1.20	0.25	1.77	1.19	2.26	0.00	4.84	5.48	23.43	59.40	0.27
K2HNO$_3$	0.80	0.15	1.40	0.98	1.37	0.02	4.31	41.51	19.99	29.18	0.32
K2HCl	1.05	0.24	1.95	1.14	1.04	0.02	8.51	46.37	20.41	18.84	0.46
K2NaOH	0.58	0.35	1.18	1.13	0.74	0.04	1.50	45.06	17.14	31.93	0.36
K2KOH	0.49	0.02	0.74	2.41	0.57	0.01	0.98	51.49	8.25	34.91	0.17
K3HF	2.43	0.16	2.28	1.48	0.97	0.00	9.65	7.68	43.48	31.35	0.38
K3HNO$_3$	2.55	0.44	3.34	2.11	0.58	0.04	8.71	53.85	18.79	9.21	0.42
K3HCl	2.19	0.45	3.09	2.19	0.54	0.03	8.88	55.68	18.72	7.79	0.48

Table B.2.1 Variations of minerals in coal samples after treated by 7 chemicals at 24 h of treatment time (Continues)

Comp	Quartz	Calcite	Kaolin	Illite	Pyrite	Sider	Gyp	Glauc	K-Feld	Mont	Chlor
K3NaOH	2.07	2.05	3.23	2.47	0.53	0.05	1.78	54.74	10.04	22.71	0.36
K3KOH	2.80	4.89	4.01	2.92	0.59	0.06	1.09	57.87	8.07	17.10	0.64
Q1HF	3.62	0.22	3.42	2.32	0.91	0.00	7.27	16.58	39.45	25.53	0.53
Q1HNO$_3$	1.31	0.46	2.33	1.32	0.59	0.06	10.21	57.07	25.81	0.43	0.44
Q1HCl	1.40	0.40	2.37	1.39	0.41	0.05	8.47	58.95	25.40	0.75	0.44
Q1NaOH	0.95	0.25	1.49	1.21	0.39	0.04	3.26	71.85	19.46	0.79	0.33
Q1KOH	1.44	0.19	1.96	1.57	0.30	0.02	1.21	80.23	11.53	1.23	0.33
Q2HF	5.48	0.28	5.30	3.56	1.80	0.00	5.27	13.83	45.26	18.57	0.59
Q2HNO$_3$	2.13	0.19	3.47	2.05	0.85	0.02	3.34	67.78	18.01	1.77	0.41
Q2HCl	2.00	0.04	3.56	2.05	0.90	0.04	4.53	58.39	26.18	1.91	0.44
Q2NaOH	4.78	0.54	8.62	6.28	1.40	0.10	1.27	22.41	36.41	16.96	1.29

Table B.2.1 Variations of minerals in coal samples after treated by 7 chemicals at 24 h of treatment time (Continues)

Comp	Quartz	Calcite	Kaolin	Illite	Pyrite	Sider	Gyp	Glauc	K-Feld	Mont	Chlor
Q2KOH	5.37	0.18	11.31	7.32	2.78	0.13	6.22	11.32	37.75	14.94	1.19
Q3HF	2.79	0.58	3.60	2.47	2.39	0.00	8.31	13.41	60.90	4.44	0.73
Q3HNO$_3$	2.65	0.22	6.21	3.16	2.27	0.06	18.12	16.27	41.60	8.48	0.99
Q3HCl	2.06	0.28	4.22	2.29	1.52	0.05	13.93	45.42	27.47	2.14	0.64
Q3NaOH	1.28	1.99	2.35	1.77	1.19	0.12	2.77	67.43	18.56	2.08	0.51
Q3KOH	2.41	1.25	4.74	3.80	0.92	0.02	0.47	64.47	15.28	5.72	0.92
Q4HF	0.14	0.89	0.01	0.44	0.73	0.02	2.40	18.99	75.21	0.01	0.24
Q4HNO$_3$	0.58	1.75	0.53	1.44	0.37	0.05	6.86	57.90	28.74	3.01	0.20
Q4HCl	0.58	0.37	1.06	0.65	0.38	0.05	8.32	66.18	22.09	0.02	0.33
Q4NaOH	0.59	4.08	0.90	0.57	0.23	0.02	2.31	70.68	20.46	0.00	0.19
Q4KOH	0.43	6.26	0.30	0.14	0.21	0.02	0.15	73.71	18.62	0.00	0.18

Table B.2.2 Reduction of quartz, pyrite, calcite, and gypsum in I coal seam after treated by 7 chemicals at 24 h of treatment time

Chemicals	**HF**	**HNO_3**	**HCl**	**NaOH**	**KOH**
Quartz	23.49	25.44	33.11	24.41	24.61
Pyrite	50.00	38.89	93.06	80.56	88.89
Calcite	53.13	71.88	46.88	0.00	0.00
Gypsum	87.91	45.62	0.00	89.34	91.82

Table B.2.3 Reduction of quartz, pyrite, calcite, and gypsum in J3 coal seam after treated by 7 chemicals at 24 h of treatment time

Chemicals	**HF**	**HNO_3**	**HCl**	**NaOH**	**KOH**
Quartz	0.00	0.00	0.00	0.00	0.00
Pyrite	38.10	98.21	73.21	45.24	44.64
Calcite	30.71	0.00	0.00	0.00	0.00
Gypsum	4.49	0.00	0.00	0.00	40.32

Table B.2.4 Reduction of quartz, pyrite, calcite, and gypsum in J4 coal seam after treated by 7 chemicals at 24 h of treatment time

Chemicals	**HF**	**HNO_3**	**HCl**	**NaOH**	**KOH**
Quartz	51.06	0.00	50.00	50.00	28.21
Pyrite	22.73	13.10	38.69	66.07	72.62
Calcite	0.00	0.00	64.29	7.86	14.29
Gypsum	16.34	0.00	35.02	60.27	85.21

Table B.2.5 Reduction of quartz, pyrite, calcite, and gypsum in J5 coal seam after treated by 7 chemicals at 24 h of treatment time

Chemicals	**HF**	**HNO_3**	**HCl**	**NaOH**	**KOH**
Quartz	75.00	73.61	44.44	37.50	30.56
Pyrite	24.50	65.00	48.50	73.50	91.00
Calcite	0.00	0.00	0.00	0.00	14.71
Gypsum	18.97	29.00	9.95	57.35	60.66

Table B.2.6 Reduction of quartz, pyrite, calcite, and gypsum in K1 coal seam after treated by 7 chemicals at 24 h of treatment time

Chemicals	**HF**	**HNO_3**	**HCl**	**NaOH**	**KOH**
Quartz	0.00	0.00	0.00	0.00	0.00
Pyrite	14.97	51.02	51.70	67.35	59.86
Calcite	99.52	99.16	99.59	97.63	93.15
Gypsum	0.00	0.00	0.00	1.02	70.08

Table B.2.7 Reduction of quartz, pyrite, calcite, and gypsum in K2 coal seam after treated by 7 chemicals at 24 h of treatment time

Chemicals	**HF**	**HNO_3**	**HCl**	**NaOH**	**KOH**
Quartz	0.00	5.88	0.00	31.76	42.35
Pyrite	17.70	50.18	62.23	72.99	79.38
Calcite	0.00	0.00	0.00	0.00	88.46
Gypsum	6.66	16.89	0.00	71.14	81.18

Table B.2.8 Reduction of quartz, pyrite, calcite, and gypsum in K3 coal seam after treated by 7 chemicals at 24 h of treatment time

Chemicals	HF	HNO_3	HCl	NaOH	KOH
Quartz	46.23	43.57	51.44	54.10	37.92
Pyrite	12.27	47.73	51.36	52.27	46.36
Calcite	95.12	86.74	86.28	37.65	0.00
Gypsum	30.32	37.15	35.92	87.15	92.17

Table B.2.9 Reduction of quartz, pyrite, calcite, and gypsum in Q1 coal seam after treated by 7 chemicals at 24 h of treatment time

Chemicals	HF	HNO_3	HCl	NaOH	KOH
Quartz	0.00	48.62	44.88	62.80	43.31
Pyrite	0.00	0.00	0.00	0.00	0.00
Calcite	0.00	0.00	0.00	0.00	0.00
Gypsum	58.72	42.02	51.93	81.52	93.16

Table B.2.10 Reduction of quartz, pyrite, calcite, and gypsum in Q2 coal seam after treated by 7 chemicals at 24 h of treatment time

Chemicals	**HF**	**HNO_3**	**HCl**	**NaOH**	**KOH**
Quartz	0.00	29.24	33.72	0.00	0.00
Pyrite	0.00	0.00	0.00	0.00	0.00
Calcite	0.00	0.00	0.00	0.00	0.00
Gypsum	51.87	69.47	58.59	88.44	43.14

Table B.2.11 Reduction of quartz, pyrite, calcite, and gypsum in Q3 coal seam after treated by 7 chemicals at 24 h of treatment time

Chemicals	**HF**	**HNO_3**	**HCl**	**NaOH**	**KOH**
Quartz	31.91	35.33	49.63	68.83	41.08
Pyrite	0.00	0.00	0.00	0.00	0.00
Calcite	0.00	0.00	0.00	0.00	0.00
Gypsum	7.46	0.00	0.00	69.21	94.77

Table B.2.12 Reduction of quartz, pyrite, calcite, and gypsum in Q4 coal seam after treated by 7 chemicals at 24 h of treatment time

Chemicals	**HF**	**HNO_3**	**HCl**	**NaOH**	**KOH**
Quartz	75.00	0.00	0.00	0.00	0.00
Pyrite	0.00	0.00	0.00	0.00	0.00
Calcite	90.22	80.82	95.99	55.16	31.21
Gypsum	93.95	82.70	79.03	94.17	99.62

B.3 Results of analysis from proximate analysis

Table B.3.1 Variations of moisture, volatile, ash, and fixed carbon in coal samples after treated by 7 chemicals at 24 h of treatment time

Seam	Moisture	Volatile	Ash	Fixed Carbon	Volatile (dry)	Ash (dry)	Fixed C (dry)
IHF	10.19	15.56	68.24	6.02	17.32	75.98	6.70
J3HF	12.95	33.94	32.95	20.17	38.99	37.85	23.16
J4HF	14.20	38.33	29.81	17.77	44.62	34.70	20.68
J5HF	13.57	38.62	29.88	17.94	44.68	34.57	20.75
K1HF	9.19	27.14	43.35	20.34	29.88	47.73	22.39
K2HF	10.24	33.99	29.51	26.27	37.86	32.87	29.27
K3HF	10.76	34.33	29.23	25.69	38.47	32.75	28.79
Q1HF	11.62	29.34	37.72	21.33	33.19	42.68	24.13
Q2HF	10.23	27.71	41.39	20.67	30.87	46.11	23.02
Q3HF	9.81	30.37	38.91	21.24	33.55	42.99	23.46
Q4HF	12.42	34.01	27.15	26.44	38.83	30.99	30.18
IHNO3	7.36	19.78	67.00	5.87	21.34	72.32	6.34
J3HNO3	13.59	42.34	31.98	12.10	49.00	37.00	14.00
J4HNO3	13.58	42.39	23.63	20.41	49.05	27.34	23.61
J5IHNO3	14.74	43.62	39.55	2.09	51.16	46.39	2.45
K1HNO3	11.10	32.72	44.11	12.08	36.80	49.61	13.59
K2HNO3	12.26	36.59	36.52	14.64	41.70	41.62	16.68
K3HNO3	12.25	34.47	38.02	15.28	39.27	43.32	17.41
Q1HNO3	12.49	36.23	35.53	15.76	41.39	40.60	18.01

Table B.3.1 Variations of moisture, volatile, ash, and fixed carbon in coal samples after treated by 7 chemicals at 24 h of treatment time (Continues)

Seam	Moisture	Volatile	Ash	Fixed Carbon	Volatile (dry)	Ash (dry)	Fixed C (dry)
Q2HNO3	9.64	30.54	40.08	19.75	33.80	44.35	21.85
Q3HNO3	11.66	35.30	40.39	12.66	39.95	45.72	14.33
Q4HNO3	12.75	41.40	33.57	12.29	47.44	38.47	14.09
IHCl	9.55	17.11	67.20	6.15	18.92	74.29	6.79
J3HCl	12.46	42.13	33.56	11.86	48.12	38.33	13.55
J4HCl	12.97	42.54	32.25	12.21	48.90	37.07	14.03
J5HCl	13.07	43.67	33.05	10.22	50.23	38.02	11.75
K1HCl	10.80	30.10	47.09	12.01	33.75	52.79	13.46
K2HCl	11.32	34.25	31.18	23.25	38.62	35.16	26.22
K3HCl	11.32	32.00	40.49	16.20	36.08	45.65	18.27
Q1HCl	12.14	34.89	36.30	16.67	39.72	41.31	18.97
Q2HCl	9.60	27.76	42.63	20.02	30.71	47.15	22.14
Q3HCl	11.80	31.41	39.75	17.05	35.61	45.07	19.33
Q4HCl	14.46	40.86	25.44	19.25	47.76	29.74	22.50
INaOH	8.14	18.43	68.98	4.46	20.06	75.09	4.85
J3NaOH	13.59	40.03	37.03	9.37	46.32	42.85	10.84
J4NaOH	14.32	39.79	37.91	7.99	46.44	44.24	9.32
J5NaOH	14.44	39.45	40.12	6.00	46.11	46.88	7.01

Table B.3.1 Variations of moisture, volatile, ash, and fixed carbon in coal samples after treated by 7 chemicals at 24 h of treatment time (Continues)

Seam	Moisture	Volatile	Ash	Fixed Carbon	Volatile (dry)	Ash (dry)	Fixed C (dry)
K1NaOH	11.55	31.92	46.93	9.61	36.09	53.05	10.86
K2NaOH	12.55	33.60	40.25	13.61	38.42	46.02	15.56
K3NaOH	11.45	32.06	43.18	13.31	36.21	48.76	15.03
Q1NaOH	12.35	33.84	36.86	16.96	38.60	42.05	19.34
Q2NaOH	11.23	29.73	41.43	17.62	33.49	46.67	19.84
Q3NaOH	12.14	33.02	40.75	14.10	37.57	46.38	16.05
Q4NaOH	11.68	38.73	36.81	12.79	43.85	41.67	14.48
IKOH	5.64	18.53	72.37	3.48	19.63	76.69	3.68
J3KOH	13.39	39.69	36.38	10.55	45.82	42.01	12.17
J4KOH	15.60	38.84	38.30	7.27	46.02	45.37	8.61
J5KOH	18.35	40.41	36.85	4.40	49.49	45.13	5.39
K1KOH	11.58	32.12	52.73	3.57	36.33	59.64	4.04
K2KOH	13.73	32.34	41.27	12.67	37.48	47.83	14.69
K3KOH	15.31	31.61	46.98	6.11	37.32	55.47	7.21
Q1KOH	14.55	30.86	41.54	13.06	36.11	48.61	15.28
Q2KOH	9.12	29.13	49.84	11.91	32.05	54.84	13.11
Q3KOH	15.61	32.61	40.32	11.47	38.64	47.78	13.58
Q4KOH	16.25	41.15	32.14	10.47	49.13	38.37	12.50

Table B.3.2 Increment and reduction of moisture, volatile, ash, and fixed carbon in I coal seam after treated by 7 chemicals at 24 h of treatment time

Chemicals	HF	HNO3	HCl	NaOH	KOH
Moisture	19.32	41.77	24.39	35.59	55.38
Volatile	3.62	18.38	5.67	12.40	12.87
Ash	2.12	0.31	0.61	3.17	7.70
Fixed carbon	25.91	24.02	27.42	0.00	22.09

* grey cell represents increasing and white cell represents reducing of coal contents

Table B.3.3 Increment and reduction of moisture, volatile, ash, and fixed carbon in J3 coal seam after treated by 7 chemicals at 24 h of treatment time

Chemicals	HF	HNO3	HCl	NaOH	KOH
Moisture	28.20	24.63	30.92	24.65	25.73
Volatile	11.26	9.68	9.22	4.46	3.64
Ash	9.17	6.40	10.82	19.16	17.73
Fixed carbon	31.52	12.42	14.12	32.19	23.64

* grey cell represents increasing and white cell represents reducing of coal contents

Table B.3.4 Increment and reduction of moisture, volatile, ash, and fixed carbon in J4 coal seam after treated by 7 chemicals at 24 h of treatment time

Chemicals	HF	HNO3	HCl	NaOH	KOH
Moisture	32.63	35.57	38.47	32.04	25.96
Volatile	5.31	14.38	14.68	8.80	6.57
Ash	1.19	19.76	8.68	22.31	23.10
Fixed carbon	25.70	35.31	7.54	39.51	44.96

* grey cell represents increasing and white cell represents reducing of coal contents

Table B.3.5 Increment and reduction of moisture, volatile, ash, and fixed carbon in J5 coal seam after treated by 7 chemicals at 24 h of treatment time

Chemicals	HF	HNO3	HCl	NaOH	KOH
Moisture	34.47	28.82	36.88	30.27	11.35
Volatile	4.27	15.25	15.33	6.29	8.50
Ash	1.64	25.69	11.07	26.74	20.23
Fixed carbon	27.79	83.86	21.12	53.67	66.02

* grey cell represents increasing and white cell represents reducing of coal contents

Table B.3.6 Increment and reduction of moisture, volatile, ash, and fixed carbon in K1 coal seam after treated by 7 chemicals at 24 h of treatment time

Chemicals	HF	HNO3	HCl	NaOH	KOH
Moisture	29.56	14.92	17.22	11.46	11.20
Volatile	14.30	3.21	4.96	0.78	1.40
Ash	19.22	20.60	25.63	25.37	33.59
Fixed carbon	0.32	40.40	40.77	52.59	82.39

* grey cell represents increasing and white cell represents reducing of coal contents

Table B.3.7 Increment and reduction of moisture, volatile, ash, and fixed carbon in K2 coal seam after treated by 7 chemicals at 24 h of treatment time

Chemicals	HF	HNO3	HCl	NaOH	KOH
Moisture	35.60	22.92	28.84	21.10	13.65
Volatile	7.64	14.21	8.35	6.58	2.92
Ash	12.04	8.13	7.06	16.64	18.70
Fixed carbon	27.03	23.66	17.55	29.00	33.91

* grey cell represents increasing and white cell represents reducing of coal contents

Table B.3.8 Increment and reduction of moisture, volatile, ash, and fixed carbon in K3 coal seam after treated by 7 chemicals at 24 h of treatment time

Chemicals	HF	HNO3	HCl	NaOH	KOH
Moisture	42.46	34.52	39.47	38.77	18.16
Volatile	11.42	11.77	4.95	5.15	3.78
Ash	29.19	7.89	1.90	4.42	12.15
Fixed carbon	62.51	36.98	40.56	27.65	36.55

* grey cell represents increasing and white cell represents reducing of coal contents

Table B.3.9 Increment and reduction of moisture, volatile, ash, and fixed carbon in Q1 coal seam after treated by 7 chemicals at 24 h of treatment time

Chemicals	HF	HNO3	HCl	NaOH	KOH
Moisture	49.59	45.84	47.33	46.42	36.88
Volatile	5.68	14.15	10.86	8.08	0.79
Ash	17.43	12.36	14.20	15.52	25.03
Fixed carbon	31.07	6.73	11.79	13.30	11.16

* grey cell represents increasing and white cell represents reducing of coal contents

Table B.3.10 Increment and reduction of moisture, volatile, ash, and fixed carbon in Q2 coal seam after treated by 7 chemicals at 24 h of treatment time

Chemicals	**HF**	**HNO3**	**HCl**	**NaOH**	**KOH**
Moisture	44.07	47.29	47.54	38.60	50.14
Volatile	7.73	1.67	7.56	1.00	3.00
Ash	23.60	21.10	25.83	23.67	36.56
Fixed carbon	2.93	1.57	0.22	12.19	40.63

* grey cell represents increasing and white cell represents reducing of coal contents

Table B.3.11 Increment and reduction of moisture, volatile, ash, and fixed carbon in Q3 coal seam after treated by 7 chemicals at 24 h of treatment time

Chemicals	**HF**	**HNO3**	**HCl**	**NaOH**	**KOH**
Moisture	38.38	26.79	25.88	23.78	1.98
Volatile	9.30	21.97	12.31	16.58	15.55
Ash	4.53	0.88	2.45	0.00	1.06
Fixed carbon	25.64	19.82	7.36	10.70	27.39

* grey cell represents increasing and white cell represents reducing of coal contents

Table B.3.12 Increment and reduction of moisture, volatile, ash, and fixed carbon in

Chemicals	HF	HNO3	HCl	NaOH	KOH
Moisture	46.65	45.23	37.89	49.83	30.22
Volatile	10.00	8.71	7.50	2.41	8.17
Ash	3.84	15.89	9.88	23.30	12.15
Fixed carbon	59.52	12.94	44.42	16.34	2.15

* grey cell represents increasing and white cell represents reducing of coal contents

B.4 Results of analysis from ultimate analysis

Table B.4.1 Variations of carbon (C), nitrogen (N), hydrogen (H), and sulfur (S) in coal samples after treated by 7 chemicals at 24 h of treatment time

Seams	Carbon (C)	Nitrogen (N)	Hydrogen (H)	Sulfur (S)
IHF	10.270	2.593	0.335	1.077
IHNO_3	11.583	2.489	1.043	5.014
IHCl	29.343	4.981	1.362	1.745
INaOH	10.786	2.657	0.320	1.338
IKOH	10.494	2.416	0.408	1.300
J3HF	32.088	3.939	0.978	9.497
J3HNO_3	30.771	3.771	1.444	11.533
J3HCl	29.233	3.826	0.885	6.513

Table B.4.1 Variations of carbon (C), nitrogen (N), hydrogen (H), and sulfur (S) in coal samples after treated by 7 chemicals at 24 h of treatment time (Continues)

Seams	Carbon (C)	Nitrogen (N)	Hydrogen (H)	Sulfur (S)
J3NaOH	30.834	3.969	0.929	8.076
J3KOH	34.123	4.009	1.143	7.883
J4HF	33.389	4.011	0.970	8.613
J4HNO$_3$	37.666	4.085	1.588	10.609
J4HCl	30.499	3.808	0.885	9.180
J4NaOH	31.085	4.022	0.882	5.683
J4KOH	33.143	4.030	1.123	5.096
J5HF	33.441	3.912	1.009	10.166
J5IHNO$_3$	25.492	3.529	1.174	9.323
J5HCl	30.479	3.734	0.912	9.568
J5NaOH	30.316	3.897	0.911	4.556
J5KOH	30.822	3.845	5.760	7.159
K1HF	25.942	3.366	1.045	6.049
K1HNO$_3$	24.236	3.285	1.620	7.283
K1HCl	21.632	3.231	0.871	4.287
K1NaOH	26.609	3.570	1.019	4.287
K1KOH	22.551	2.989	8.241	2.708
K2HF	33.059	3.865	1.319	9.638

Table B.4.1 Variations of carbon (C), nitrogen (N), hydrogen (H), and sulfur (S) in coal samples after treated by 7 chemicals at 24 h of treatment time (Continues)

Seams	Carbon (C)	Nitrogen (N)	Hydrogen (H)	Sulfur (S)
K2HNO$_3$	28.065	3.531	1.824	8.208
K2HCl	32.755	3.848	1.299	9.225
K2NaOH	29.533	3.793	1.164	8.826
K2KOH	28.106	3.565	8.491	10.010
K3HF	33.242	3.847	1.249	8.098
K3HNO$_3$	27.878	3.521	2.023	5.137
K3HCl	27.215	3.709	1.154	7.237
K3NaOH	28.851	3.737	1.188	4.105
K3KOH	25.290	3.332	8.401	3.941
Q1HF	28.375	3.617	1.201	8.446
Q1HNO$_3$	28.928	3.570	2.063	6.565
Q1HCl	28.754	3.739	1.084	8.108
Q1NaOH	31.872	3.871	1.184	4.728
Q1KOH	29.540	3.665	8.403	2.777
Q2HF	26.668	3.460	0.947	7.733
Q2HNO$_3$	28.601	3.469	1.357	6.291
Q2HCl	27.382	3.585	0.947	4.708
Q2NaOH	29.119	3.753	1.004	5.552

Table B.4.1 Variations of carbon (C), nitrogen (N), hydrogen (H), and sulfur (S) in coal samples after treated by 7 chemicals at 24 h of treatment time (Continues)

Seams	Carbon (C)	Nitrogen (N)	Hydrogen (H)	Sulfur (S)
Q2KOH	22.051	3.070	7.985	6.359
Q3HF	26.929	3.424	0.898	10.990
Q3HNO$_3$	26.837	3.438	1.392	6.762
Q3HCl	26.234	3.589	0.873	6.261
Q3NaOH	30.764	3.785	1.060	6.860
Q3KOH	29.436	3.957	0.942	5.703
Q4HF	39.768	4.019	1.316	9.330
Q4HNO$_3$	34.275	4.087	2.078	6.490
Q4HCl	41.684	4.466	1.360	4.576
Q4NaOH	33.516	3.733	1.311	3.344
Q4KOH	34.534	3.771	1.010	2.250

Table B.4.2 Increment and reduction of carbon (C), nitrogen (N), hydrogen (H), and sulfur (S) of I coal seam after treated by 7 chemicals at 24 h of treatment time

Chemicals	**HF**	**HNO_3**	**HCl**	**NaOH**	**KOH**
%C	0.195	11.508	65.068	4.965	2.320
%H	88.187	63.186	51.930	88.690	85.593
%N	79.669	78.818	89.417	80.163	78.182
%S	44.992	60.969	10.858	31.630	33.572

* grey cell represents reducing and white cell represents increasing of coal contents

Table B.4.3 Increment and reduction of carbon (C), nitrogen (N), hydrogen (H), and sulfur (S) of J3 coal seam after treated by 7 chemicals at 24 h of treatment time

Chemicals	**HF**	**HNO_3**	**HCl**	**NaOH**	**KOH**
%C	1.833	5.863	10.568	5.670	4.208
%H	78.133	67.716	80.201	79.227	74.427
%N	73.452	72.266	72.665	73.651	73.910
%S	15.005	30.007	19.314	0.043	2.348

* grey cell represents reducing and white cell represents increasing of coal contents

Table B.4.4 Increment and reduction of carbon (C), nitrogen (N), hydrogen (H), and sulfur (S) of J4 coal seam after treated by 7 chemicals at 24 h of treatment time

Chemicals	**HF**	**HNO_3**	**HCl**	**NaOH**	**KOH**
%C	6.168	16.824	2.649	0.779	5.472
%H	79.078	65.747	80.905	80.984	75.778
%N	75.760	76.201	74.471	75.826	75.876
%S	9.759	26.738	15.338	26.879	34.438

* grey cell represents reducing and white cell represents increasing of coal contents

Table B.4.5 Increment and reduction of carbon (C), nitrogen (N), hydrogen (H), and sulfur (S) of J5 coal seam after treated by 7 chemicals at 24 h of treatment time

Chemicals	**HF**	**HNO_3**	**HCl**	**NaOH**	**KOH**
%C	8.623	16.576	0.257	0.790	0.858
%H	77.420	73.734	79.600	79.605	22.417
%N	75.831	73.203	74.678	75.738	75.408
%S	14.702	6.988	9.370	47.457	17.437

* grey cell represents reducing and white cell represents increasing of coal contents

Table B.4.6 Increment and reduction of carbon (C), nitrogen (N), hydrogen (H), and sulfur (S) of K1 coal seam after treated by 7 chemicals at 24 h of treatment time

Chemicals	**HF**	**HNO_3**	**HCl**	**NaOH**	**KOH**
%C	0.799	7.325	17.282	1.721	13.766
%H	62.524	41.879	68.741	63.453	66.173
%N	76.942	76.371	75.981	78.263	74.035
%S	5.117	21.195	25.294	25.309	52.814

* grey cell represents reducing and white cell represents increasing of coal contents

Table B.4.7 Increment and reduction of carbon (C), nitrogen (N), hydrogen (H), and sulfur (S) of K2 coal seam after treated by 7 chemicals at 24 h of treatment time

Chemicals	**HF**	**HNO_3**	**HCl**	**NaOH**	**KOH**
%C	10.598	5.043	9.768	0.076	4.904
%H	67.751	55.385	68.227	71.531	51.842
%N	69.630	66.762	69.498	69.057	67.079
%S	31.331	19.366	28.256	25.017	33.883

* grey cell represents reducing and white cell represents increasing of coal contents

Table B.4.8 Increment and reduction of carbon (C), nitrogen (N), hydrogen (H), and sulfur (S) of K3 coal seam after treated by 7 chemicals at 24 h of treatment time

Chemicals	**HF**	**HNO_3**	**HCl**	**NaOH**	**KOH**
%C	21.363	6.233	3.948	9.395	3.252
%H	70.165	51.663	72.437	71.620	50.173
%N	72.456	69.907	71.425	71.645	68.199
%S	31.967	6.753	23.872	25.495	28.472

* grey cell represents reducing and white cell represents increasing of coal contents

Table B.4.9 Increment and reduction of carbon (C), nitrogen (N), hydrogen (H), and sulfur (S) of Q1 coal seam after treated by 7 chemicals at 24 h of treatment time

Chemicals	**HF**	**HNO_3**	**HCl**	**NaOH**	**KOH**
%C	2.943	4.796	4.220	13.592	6.769
%H	73.789	54.964	76.347	74.154	45.474
%N	71.791	71.417	72.709	73.645	72.162
%S	29.146	8.850	26.192	20.998	53.593

* grey cell represents reducing and white cell represents increasing of coal contents

Table B.4.10 Increment and reduction of carbon (C), nitrogen (N), hydrogen (H), and sulfur (S) of Q2 coal seam after treated by 7 chemicals at 24 h of treatment time

Chemicals	**HF**	**HNO_3**	**HCl**	**NaOH**	**KOH**
%C	13.659	7.403	11.349	5.724	28.609
%H	78.360	68.983	78.361	77.040	45.213
%N	70.462	70.539	71.493	72.767	66.712
%S	14.651	4.689	28.667	15.879	3.652

* grey cell represents reducing and white cell represents increasing of coal contents

Table B.4.11 Increment and reduction of carbon (C), nitrogen (N), hydrogen (H), and sulfur (S) of Q3 coal seam after treated by 7 chemicals at 24 h of treatment time

Chemicals	**HF**	**HNO_3**	**HCl**	**NaOH**	**KOH**
%C	7.072	6.756	4.612	18.658	14.987
%H	76.480	63.533	77.121	72.233	75.318
%N	74.941	75.038	76.087	77.329	78.314
%S	47.516	14.700	7.867	15.912	1.136

* grey cell represents reducing and white cell represents increasing of coal contents

Table B.4.11 Increment and reduction of carbon (C), nitrogen (N), hydrogen (H), and sulfur (S) of Q4 coal seam after treated by 7 chemicals at 24 h of treatment time

Chemicals	**HF**	**HNO_3**	**HCl**	**NaOH**	**KOH**
%C	18.329	5.239	22.083	3.093	5.949
%H	71.766	55.430	70.818	71.871	78.325
%N	76.145	76.540	78.535	74.317	74.579
%S	67.406	53.140	33.545	9.047	26.028

* grey cell represents reducing and white cell represents increasing of coal contents

B.5 Results of analysis heating value determination

Table B.5.1 Heating value (MJ/kg) both before and after treated by 7 chemicals at 24 h of treatment time

Seam	HHV MJ/kg	LHV MJ/kg	HF		HNO_3		HCl		NaOH		KOH	
			HHV	LHV	HHV	LHV	HHV	LHV	HHV	LHV	HHV	LHV
I	4.54	4.24	1.00	0.75	3.63	3.45	12.10	11.87	1.45	1.26	1.99	1.85
J3	13.91	13.48	9.53	9.22	9.94	9.62	7.20	6.90	9.15	8.83	11.03	10.71
J4	13.30	12.79	9.41	9.07	12.05	11.73	12.05	11.73	8.73	8.39	10.08	9.71
J5	12.86	12.36	9.91	9.58	7.49	7.14	7.49	7.14	8.73	8.39	16.55	16.11
K1	8.08	7.77	7.28	7.06	7.77	7.50	4.94	4.68	7.78	7.50	17.69	17.42

Table B.5.1 Heating value (MJ/kg) both before and after treated by 7 chemicals at 24 h of treatment time (Continues)

Seam	HHV MJ/kg	LHV MJ/kg	HF		HNO_3		HCl		NaOH		KOH	
			HHV	LHV	HHV	LHV	HHV	LHV	HHV	LHV	HHV	LHV
K2	11.97	11.59	9.99	9.74	9.02	8.71	9.98	9.65	9.60	9.30	21.01	20.73
K3	11.41	10.96	9.50	9.24	8.67	8.38	7.99	7.72	8.52	8.24	18.74	18.37
Q1	11.09	10.53	8.48	8.20	9.23	8.93	8.16	7.87	9.14	8.85	19.72	19.37
Q2	12.73	12.29	8.11	7.87	8.65	8.42	7.41	7.18	8.45	8.18	19.72	19.37
Q3	10.19	9.81	8.11	7.87	7.97	7.69	6.62	6.33	9.62	9.33	8.40	8.02
Q4	12.43	11.87	12.96	12.67	11.74	11.43	12.52	12.18	9.78	9.50	8.71	8.32

APPENDIX C

RESULTS OF ANALYSIS (XRD)

.1 Results of analysis from XRD method

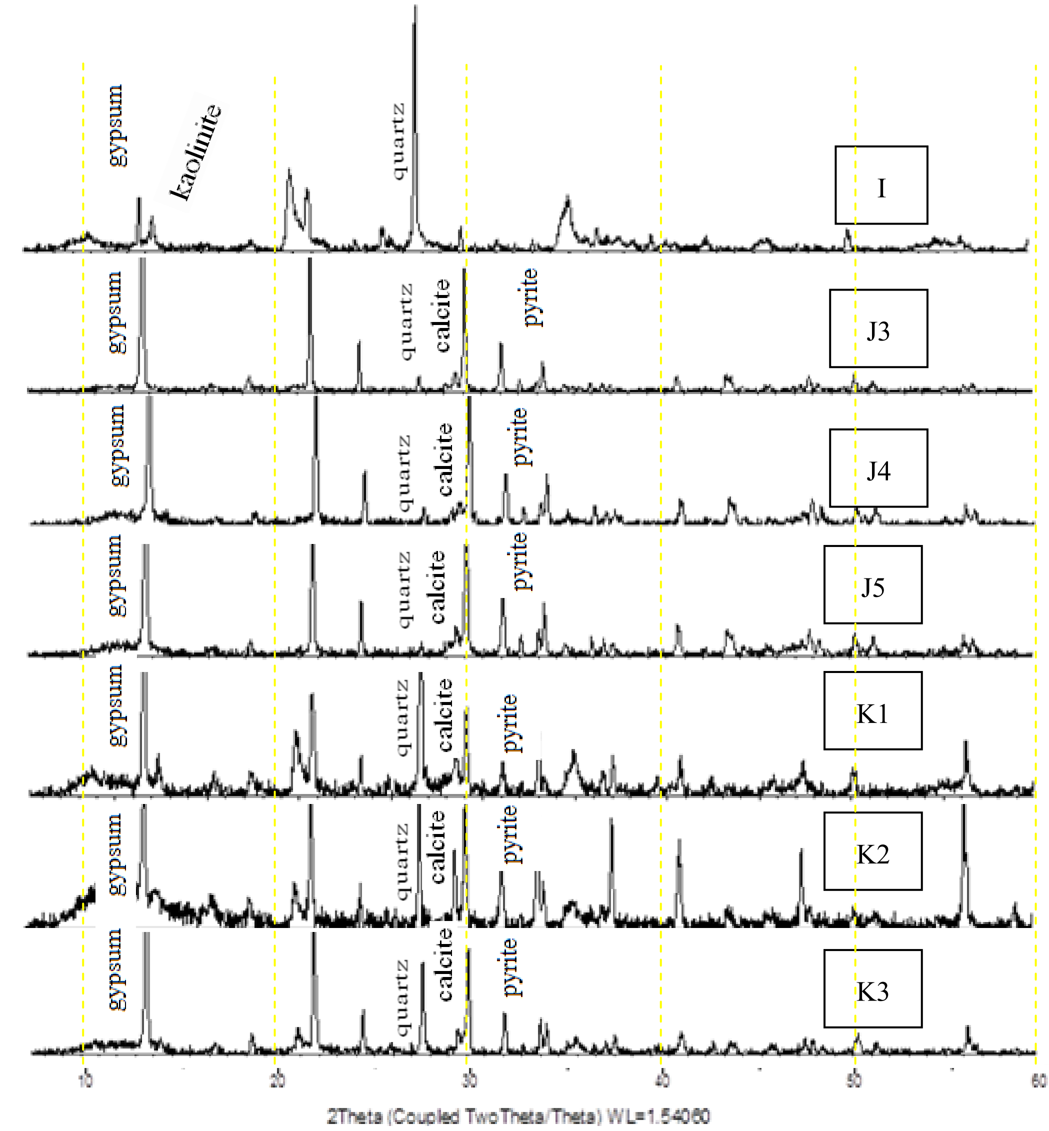


Figure C.1.1 The selected diffractograms of Mae Moh coal field

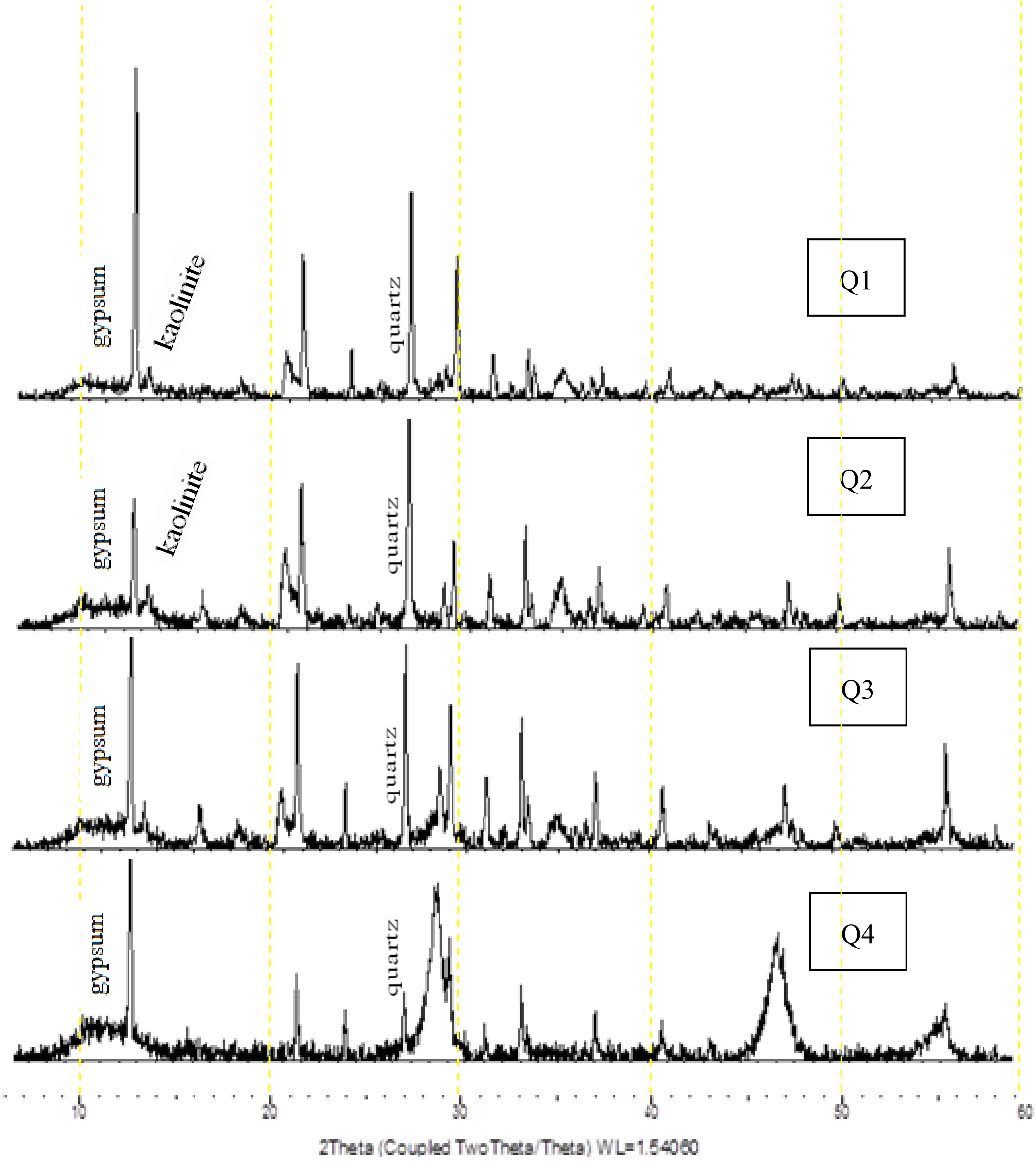


Figure C.1.1 The selected diffractograms of Mae Moh coal field (Continues)

BIOGRAPHY

Mr. Pornchai Khamhom was born on the 26th of January 1988 in Bangkok province. (SUT). He earned her Bachelor’s Degree in Chemical Engineering from King Mongkut’s University of Technology North Bangkok (KMUTNB) in 2010 After graduation, he continued with his master’s degree in the School of Geotechnology, Institute of Engineering at SUT with the major in Petroleum Engineering. During 2010-2014, he was a teaching assistant and research assistant at SUT. His expertise is in the areas of engineering which are drilling engineering, production operation and others.