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ENGLISH
December 1986

COAL-WATER MIXTURE - PREPARATION TECHNOLOGY

DP/ROK/82/029/11-52/32.1.J

KOREA

Technical Report*

Prepared for the Government of Korea
by the United Nations Industrial Development Organization
acting as executing agency for the United Nations Development Programme

Based on the work of Shiao-Hung Chiang
Expert

Backstopping officer: R. Williams, Chemical Industries Branch

United Nations Industrial Development Organization
Vienna

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INTRODUCTON

In September 1985, I received an inquiry from the UNIDO/UNDP Vienna office concerning my interest to serve as a consultant to provide technical assistance to the Republic of Korea in the preparation of coal-water mixture. Subsequent correspondence resulted in my acceptance (on March 21, 1986) of the appointment as an expert on "Coal and Coal Slurry Beneficiation (Cleaning Technology)" at the Korea Institute of Energy Resources (KIER), Daejeon, Korea. My mission to the Republic of Korea commenced on November 22, 1986 and was successfully completed on December 12, 1986. A detailed itinerary of the mission is attached at the end of this report.

OBJECTIVES

The primary objective of the mission was to provide technical consultation to KIER in the general area of coal slurry technology with special emphasis on the aspect of fine coal beneficiation. In addition, I was to participate in general discussion of research in coal utilization and related fields as well as to consider areas for future collaboration.

ACTIVITIES

I arrived in Seoul, Korea on November 24, 1986. On the next day, I reported to the UNIDO office in Seoul prior to my travel to Daejeon City, where I was met by Dr. Dong-chan Kim of the Korea Institute of Energy and Resources (KIER).

During my stay at KIER, I presented a series of six (6) lectures on fine coal processing and related subjects. The topics of discussion are summarized below:

1. **Particle Basis for Fine Coal Processing.** It has been well recognized that properties of coal particles are the most important characteristics influencing the physical coal cleaning processes and related operations. This is particularly true when advanced new coal beneficiation techniques for fine and ultrafine coal are considered. A number of key physical properties of coal particles play increasingly important roles as the particle size decreases. These properties include,

   - Particle size/size distribution
   - Particle shape - morphology
   - Particle association (with mineral particles)
   - Particle porosity

   These properties individually or in combination would affect the tendency of settling, agglomeration, flotation, and adsorption of fluid or chemical reagent, which in turn would influence the rate and the degree of separation of "impurities" from "clean" coal. Thus, a clear understanding of these properties is a prerequisite for effective operation as well as for developing new improved coal cleaning processes.

   Because of limited time, only the first two properties (particle size/size distribution and particle shape - morphology) are discussed. Experimental results of fine coal dewatering and oil agglomeration are used to illustrate the importance of the particle characteristics in fine coal processing. Special measurement techiques based on automated image analysis together with pertinent mathematical methods (stereology and fractal geometry) are introduced as the basis for theoretical modeling.

A network model for fine coal dewatering has been successful applied to predict experimentally determined values. The fractal dimension has provided a new and unique means for correlating permeability of filter cakes during filtration and growth rate of flocs in oil agglomeration process.

Perhaps, most importantly, these preliminary findings have revealed a very fertile area for further exploration and research which may lead to new advances in particle technology in general and fine coal processing in particular.

2. Surface and Interfacial Properties of Fine Coal Particles. The discussions are divided into three parts: (1) concept of interface and its key properties, (2) methods of measurement, (3) experimental results (contact angle and heat of immersion).

(1) Concept of Interface and Its Key Properties: A surface or an interface is defined as an apparent discontinuity dividing a pair of phases from one another. It is in reality a thin stratum of material whose properties differ in certain fundamental ways from those bulk phases it separates.

Two key properties, namely, surface or interfacial tension and contact angle play a major role in separation processes involving particulate materials, including fine coal processing. Typical examples are flotation, flocculation and dewatering of fine coal. Capillary force induced fluid movement and film drainage are cited as the basis for these operations.

(2) Methods of Measurements: Techniques for measuring surface (or interfacial) tension and contact angles are presented and compared.

These include the following:

A. Capillary Rise Method (surface tension and contact angle)

B. Drop Weight Method (surface tension)

C. Ring Method (surface tension)

D. Wilhelmy Slide Method (surface tension and contact angle)

E. Pendant Drop Method (surface tension)

F. Sessile Drop or Bubble Method (contact angle)

G. Tilting Plate Method (contact angle)

H. Oscillating Jet Method (dynamic surface tension)

Relative advantages and disadvantages of each of these methods are discussed.

(3) <u>Experimental Results</u>: To illustrate the practical importance of interfacial properties in fine coal processing, the experimental results of contact angle measurements for the water-coal-liquid CO_2 system are presented. The data clearly show that variations in contact angle can be related to the hydrophobicity of coal and ash particles.

In addition, heat of immersion data are presented to further demonstrate the usefulness of interfacial property data in fine coal processing. A direct correlation between heat of immersion and flotability of a given coal sample is shown.

Based on these discussions, it is fair to conclude that the major differences in the surface properties of coals can be used to one's advantage in the selection as well as understanding of operations employed for fine coal processing.

3. **Graphite Beneficiation.** Graphite is a very versatile industrial material because of its unique physical and chemical characteristics. In particular, graphite can be used as structural material for ultra-high temperature applications, where most of all other materials (including metals) fail. Also, because of its unusual electrical and thermal conductivities, graphite finds its applications to electrical and electronic systems. Other important applications include its use as special lubricant, anti-corrosion/anti-fouling coatings, nuclear reactor control-rod, etc.

Natural graphite ore can be divided into two major categories: crystalline and cryptocrystalline. The crystalline type is easily treatable by flotation process and can be upgraded to better than 90% carbon content. On the other hand, the cryptocrystalline type is difficult to be upgraded by flotation. Nevertheless, presently, flotation is the only method used by the graphite industry (with mixed results, however).

The upgraded graphite product from flotation treatment generally contains 85-95% carbon. Further refining is required for a number of applications, e.g., electronic components, nuclear application, pencil manufacturing, etc. Two refining methods are available: (l) Electrical Method and (2) Chemical Method. The latter (i.e., Chemical Method) has been widely used to produce pure graphite (99^{+}%).

Similar to coal, graphite ores exhibit distinct characteristics from different sources. Beneficiation (and refining) methods must be carefully selected to suit the special requirement of each ore type and its final application(s).

4. **LICADO Process for Fine Coal Cleaning**. The LICADO process uses liquid CO_2 as the processing medium for the separation of "clean" coal particles from refuse materials. The mechanism of this process is basically a combination of agglomeration and flotation. The liquid CO_2 acts as the agglomerating agent and serves as the source of in-situ bubble generation at the fine coal surfaces. Laboratory results have shown that high grade coal can be produced using the LICADO process.

The key advantages of the LICADO process are: (1) Liquid CO_2 is cheap and readily available (in the USA), (2) Liquid CO_2 exhibits very low surface tension and viscosity, (3) Liquid CO_2 poses no environmental problems, (4) Liquid CO_2 tends to leave an inert blanket on product coal to protect it from ready oxidation, and (5) LICADO process can be integrated with liquid CO_2 slurry transport system (which has been proposed as an alternative to coal water slurry pipeline system).

A recent economic analysis showed that LICADO process can be used to produce clean premium quality coal at reasonable cost (~ $15/ton).

5. **Recent Development in Coal Beneficiation**. In conventional coal preparation plants, eight different types of beneficiation techniques are used. These include: Baum jig, heavy medium vessel, heavy medium cyclone, concentration table, batac jig, water only cyclone and froth flotation. With the exception of froth flotation, all other techniques are based on the principle of gravity separation and designed for processing particle size larger than 500 μm. Froth flotation is the only technique (relying on differences in surface properties of coal vs. mineral matter) capable of processing fine coal with particle size less than 500 μm.

In general, none of these conventional coal beneficiation techniques are suitable for dealing with ultrafine or micronized coal (i.e., particle size less than 75 μm) which is used for the preparation of coal-water slurry fuel. Thus, advanced coal preparation techniques must be sought. A survey shows that a large number of new techniques have been developed in recent years. These may be classified as physical or chemical processes. A selected list of these advanced coal cleaning methods is given below.

I. Advanced Physical Methods

- Electrostatic Separation
- High Gradient Magnetic Separation
- Advanced Flotation
- Oil Agglomeration
- Selective Coalescence

II. Advanced Chemical Methods

- Partial Oxidation
- Chemical Leaching
- Purged Carbon Process
- Magnex Process

Most of these techniques, particularly chemical methods, are very effective in removing mineral matter (ash), including pyritic sulfur, from coal. However, the improved separation is usually associated with higher cost. Thus, in order to select a proper coal beneficiation method for a given application, both the quality of product coal and the overall economics of the process must be carefully considered.

6. <u>Coupled Diffusional Processes and Interfacial Phenomena</u>. Basic concept of thermodynamic coupling in transport processes, particularly heat and mass

transfer, is discussed. Practical examples of Dufour and Soret effects are presented with experimental evidences.

Methods for analytic solution of coupled linear processes are shown. Absorption with large heat effect (e.g., ammonia-H_2O and light-hydrocarbon-decane system) is examined both experimentally and analytically.

The phenomenon of interfacial turbulence (instability) induced by the diffusional fluxes is discussed separately. The significance of interfacial turbulence and its effect on rate of mass/heat transfer are demonstrated in numerous natural and industrial operations.

In addition to these formal lectures, I held informal discussions with a number of researchers at KIER over a wide range of topics in energy related fields.

On December 3, 1986, I travelled to Sanju with Dr. Kim and Mr. Lee of KIER to visit the Kyerim Graphite Mining Company and its graphite preparation plant. Several major problem areas pertaining to graphite beneficiation were discussed.

On December 5, 1986, I visited Professor Bo-sung Rhee of chemical engineering at the Chungnam National University in Daeduk Science Town. Of special interest was Professor Rhee's research laboratory for carbon fiber fabrication.

Prior to my departure from Korea, I met with Mr. A. S. Nasir, Project Manager and UNIDO-Coordinator of UNDP in Seoul on the morning of December 8, 1986. I made a brief oral report of my mission to Mr. Nasir and discussed potential areas for future industrial development in Korea.

I left Seoul, Korea and returned to Pittsburgh, PA, USA, on December 8, 1986.

CONCLUSION

Personally, I felt this was indeed a very successful mission. It afforded me an opportunity not only to make a direct contribution to the development of coal technology in Korea but also to pave the way for future research collaboration in this important field. In fact, several topics, including the graphite beneficiation and purification, were identified as potential UNIDO projects for the Republic of Korea.

Expert on Mission

at

Korea Institute of Energy and Resources

Shiao-Hung Chiang

5435 Hobart Street
Pittsburgh, PA 15217
USA

Itinerary
(11/22/86 - 12/12/86)

Date		
11/22	LV Pittsburgh AV San Francisco	9:59 a USAir 31 12:10 p
11/23	LV San Francisco	12:50 p United 53/807
11/24	AR Seoul	8:20 p (via Tokyo)
11/24-11/25	Seoul, Korea	Report to the UNIDO Office in Seoul
11/25-12/6	Dae Jeon City Korea	Korea Institute of Energy & Resources Host: Dr. Dong-Chan Kim
12/6	LV Dae Jeon City AR Seoul, Korea	1:30 p by train 3:15 p
12/7-12/8	Seoul, Korea	Briefing at the UNIDO Office in Seoul (Mr. A. S. Nasir)
12/8	LV Seoul, Korea AR San Francisco	2:40 p United 800/58 10:45 a (via Tokyo)
12/8	LV San Francisco AR Pittsburgh	1:00 p USAir 30 8:36 p
12/9-12/12	Pittsburgh	Report Preparation

26 April 1985

revised according to UNDP letter of 21/5/85

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

UNIDO

JOB DESCRIPTION

DP/ROK/82/029/11-52/3?.1.I

Post title Expert on Coal-Water Mixture (CWM) (Preparation Technology)

Duration One month

Date required October 1985, or depending on expert's availability

Duty station Korea Institute of Energy and Resources (KIER)
Daejeon, Korea

Purpose of project The long-term objective of the project is to reduce the dependence of the Republic of Korea on foreign supplies of energy (oil and natural gas) through scientific research and experimentation into combustion techniques of lower grades of anthracite coal, a natural resource found in abundance on the Korean peninsula.

The immediate objectives of the project are:

1. To further KIER's technical capability by introducing its staff to the most recent scientific advances and techniques in properties analysis and utilization of coal.
2. To establish the economic feasibility of the various coal technologies either singly or in combination with one another and/or other energy sources, with special consideration of the Korean pattern of energy use.
3. To associate KIER's research results more closely with the coal and other related industries to encourage commercial application, and thereby benefit both producers and consumers.

..../..

Duties

The expert will be assigned to Korea Institute of Energy and Resources (KIER), Ministry of Energy and Resources, and, in consultation with the Korean authorities he will be expected to develop and establish CWM preparation/combustion technology applicable to existing oil-fired boilers and industrial furnaces.

Specifically he will be expected to perform the following tasks:

1. Development of the fluidity-enhancing chemical additives for highly load CWM and the stabilizing agents for long-term storage of CWM.
2. Design/modification of wet grinding ball mill system.
3. Optimum particle size distribution control method in the wet grinding ball mill.
4. Technology of the storage, pumping, and transportation of CWM.

The expert will submit a brief report on his findings during the assignment at KIER and on recommendations for activities to be carried out at KIER after his departure.

Qualifications

Experienced expert with extensive knowledge who has been engaged in CWM preparation technology sector for several years and can review, advise, consult, and comment on that area.

Language

English

Background Information

Although exploration for oil and uranium is continuing, coal is the only energy resource that is present in abundance in the Republic of Korea, reserves are estimated at 1.4 billion tons, of which 600 million are recoverable with present technology.

There are 15 large coal fields in Korea. The Samcheog coal field is the nation's largest coal producer, with 11 million tons (55% of total production) in 1981. The heating value of Samcheog coal is high, ranging from 4,500 to 6,500 kilocalories per kilogram, averaging about 5,300 kcal/kg. Resources of the field are known to be 471 million tons. This mine alone contains 33% of the nation's total coal reserves and 44.5% of its presently-recoverable coal resources. Altogether three mines were responsible for 75% of 1981 production. This pattern of highly concentrated production controlled by a very limited number of firms is unlikely to change in the foreseeable future, but is a positive factor in the introduction of new coal mining and processing techniques.

Of the total reserves, 34% are estimated to be of low calorific value, below 3,500 kcal/kg. It is not known what percent of recoverable reserves are of this nature, and its relationship to economics in the mining process. Therefore it is anticipated that by the development of new technologies will have economic impact towards industries.

National policy toward coal has varied dramatically in close correlation with the price and availability of its most immediate substitute, oil. Annual coal production of less than 5 million tons in the late 1950's doubled in the 1960's to exceed 10 million tons in 1965. The number of mines in operation rose from 131 in 1960 to 171 just five years later. In the latter half of the 1960's coal mining declined as a result of the Government's emphasis on oil and the development of domestic refining capacity. The Government reconsidered its position in 1973 as a result of the first oil crisis, and offered subsidies and tax holidays to spur development. Coal production increased rapidly between 1973 and 1975, outstripping demand. By 1977 demand and supply were in harmony. But in 1981, partly as a result of additional oil price hikes, demand exceeded supply. Twenty million tons of coal were mined in 1981 but 4.3 million more had to be imported.

The trend toward increased use of coal will continue. The Government plans to more than double the use of coal in electricity generation by 1991 (from 9.2% to 19.1%). Household consumption (90% of coal produced in 1979 was used by individual households in the form of briquettes, "yontan", for the traditional "Ondol" heating system) will rise with income and population. Last, industry is adapting its plant and equipment to burn coal as a cheaper and more readily-available fuel source. As an example, from 1979 the cement industry began to use a mixture of coal and oil in its production process; the cost of modifications to plant and equipment has been approximately Won 129 billion to date. But the cement industry manufacturers' association estimates that in 1982 alone the industry saved Won 30 billion in fuel costs.

In order for the country to make the most of what it has, and to reduce dependence on imported oil as industrialization advances, research, both technical and economic, must be undertaken into scientific and industrial technologies to utilize lower grades of coal as an energy source. Preliminary results have indicated that the methods most likely to accomplish this task are fluidized bed combustion and coal slurry (coal-oil or coal-water mixing). The Korea Institute of Energy and Resources (KIER), the Government Co-operating Agency, has already begun a pilot project in fluidized-bed combustion research with a view toward the practical application of these technologies is the principal aim of this project.

KIER's primary function is to maximize utilization of all locally-available new, renewable, and traditional energy sources, to determine appropriate mixes of imported and domestic fuels, and to encourage through research and development the use of all other Korean natural resources in lieu of imports.

In energy, KIER's responsibilities include:

- Research and development on new and renewable sources of energy and other alternative energy sources;

- Research and development on energy conservation technology;

- Research and development of fossil energy, especially in coal conversion and utilization;

- Selection, assessment and adjustment of energy research and development projects and establishment of assessment criteria;

- Test and inspection of energy equipment and facilities.

In resource development, KIER's responsibilities include:

- Geological research on land and at sea;

- Exploration, development and optimum utilization of mineral and fuel resources;

- Research and development of resources policy analysis;

- Consultation and training as requested by the Government, end-users, etc.

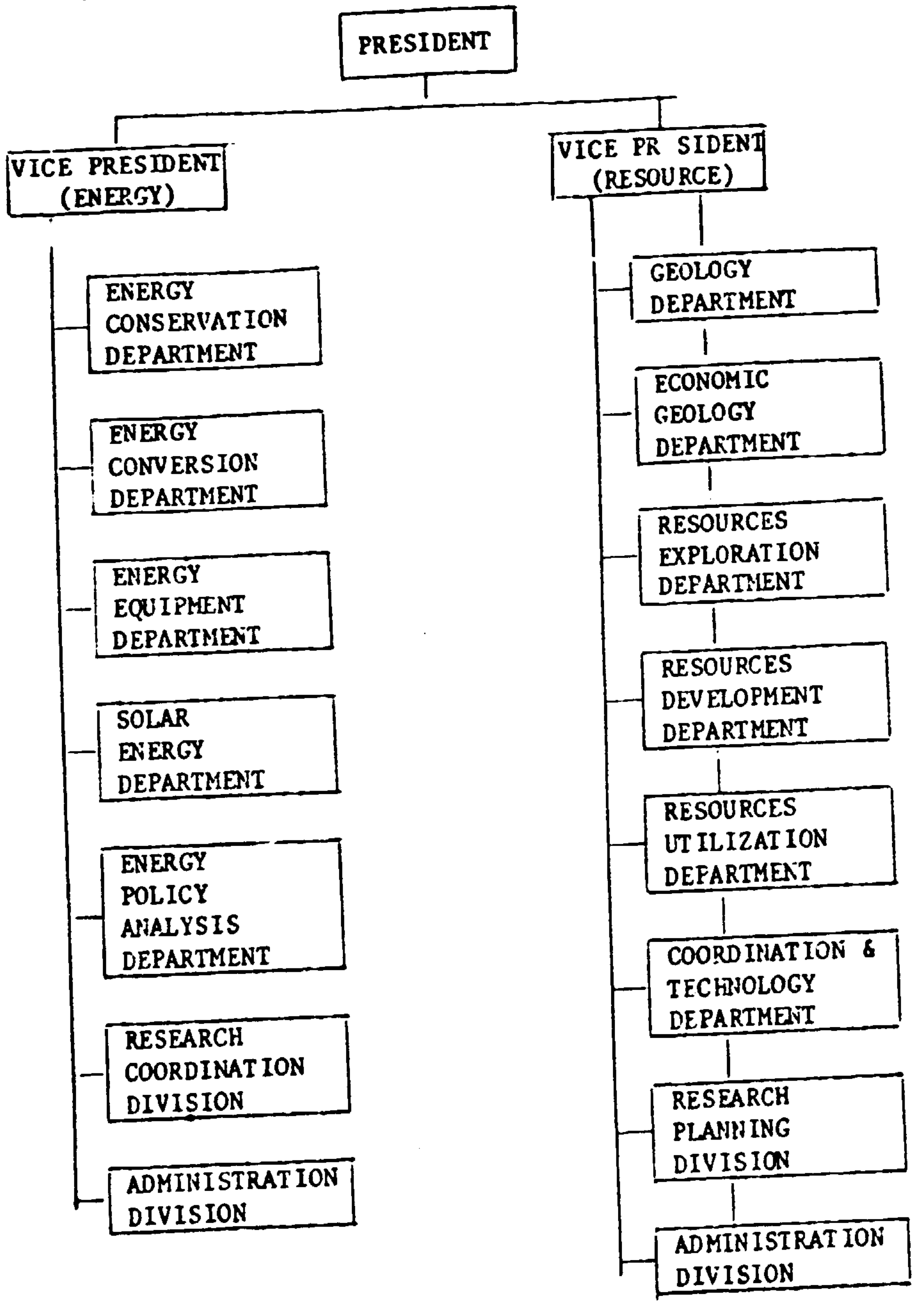
The Energy Laboratory at KIER is divided into the seven departments of Energy Conservation, Energy Conversion, Energy Equipment, Solar Energy, Energy Policy Analysis, Research Coordination, and Administration. It has 302 staff members, 267 of whom are considered technical and 35 of whom are considered non-technical. The Resources Laboratory is divided into the eight departments of Geology, Economic Geology, Resources Exploration, Resources Development, Resources Utilization, Coordination and Technology, Research Planning, and Administration. It has 354 staff members, 319 of whom are technical staff, 35 of whom are non-technical. An organization chart is attached as ANNEX I.

The proposed work on CWM and related areas is described in ANNEX II.

Annex I

ORGANIZATION AND PERSONNEL OF THE KOREA INSTITUTE OF ENERGY AND RESOURCES

a. ORGANIZATION



b. PERSONNEL

	ENERGY LAB.	RESOURCES LAB.
TOTAL	302	354
TECHNICAL	267	319
NON-TECHNICAL	35	35

3. Coal slurry (COM/CWM)

To prepare CWM/COM fuel utilizing low-grade domestic anthracite coal and to employ as an industrial fuel.

a. Workscope

1) Development of the chemicals and equipments for coal-ash removal

2) Preparation of CWM/COM fuel

3) Combustion technology development of CWM/COM fuel

4) Retrofit criteria establishment of the existing oil fired boilers

b. Elements of the test plan

1) CWM/COM preparation test

1) Measurement of coal-ash removal rate

2) Fluidity measurement of the fuel

3) Stability measurement of the fuel

2) CWM/COM combustion test

1) Flue gas analysis

2) Measurement of combustion efficiency

3) Evaluation of boiler efficiency

C. Facilities

1) Bench test

1) Continuous-type ash removal equipment Disposal of approx. 10kg/hr of coal is available

2) Continuous CWM/COM preparation facilities preparation of approx.
50kg/hr of fuel is available

D. Work Schedule

Item	1984	1985	1986
1. Coal-Ash Removal Test			
1) Oil agglomeration effect test	——		
2) Additives development for ash removal		——	
3) Oil agglomeration devices development		——	
2. CWM/COM Preparation test			
1) Redispersion of the agglomerated clean coal	——	——	
2) Fluidising.stabilizing additives development		——	——
3) Coal concentration test in coal/liquid mixtures		——	——
3. CWM/COM Combustion test			
1) Findings of the appropriate combustion & retrofitting conditions of the burner	——	——	
2) Performance/retrofit test of the boiler	——	——	
3) Trouble confirmation in long-term combustion period		——	——
4) Establishment of the oil boiler retrofit criteria			——
5) Demonstration combustion test			——
4. Final report preparation			——