A Large-Scale Demonstration of a CAER Fine Coal Cleaning Process

B.K. Parekh

A column flotation process has been developed at the CAER which enables the economical recovery of coal fines from fine refuse. Laboratory process design was extrapolated to pilot and commercial scales. The Powell Mountain Coal Company has successfully installed this technology at their Mayflower Coal Preparation Plant Complex.

Fine refuse solids that are high in mineral matter content are usually discarded by U.S. coal preparation plants. This is because the recovery of clean coal using the conventional froth flotation method, more commonly used in mineral processing industries, has proven uneconomical and inefficient. In the coal industry, flotation techniques are practiced very sparingly. The principles of coal flotation utilize the differences in the surface chemistries of the coal and mineral matter (which includes pyrite) to enable their separation. In a typical arrangement, air is sparged into a vessel containing a suspension of coal in water to which a small amount of fuel oil and an alcohol (methyl ethyl ketone) are added. These additives, respectively, act to make the coal hydrophobic (repels water) and to stabilize the bubbles in the froth. The coal then preferentially attaches to the air bubbles, while mineral matter being hydrophilic (having an affinity for water) stays in the aqueous phase. The coal fines are carried with bubbles and removed from the suspension surface as a froth.

Engineers at the Center for Applied Energy Research (CAER) have developed an advanced column flotation technique (Ken-Flote) for the recovery of the fine and ultra-fine coal from high ash fine refuse. The laboratory process equipment consists of a circular tube about 20 feet high, with an internal diameter of 2 inches. The coal slurry mixture is introduced to the column at about two thirds of the distance from the bottom where it contacts air bubbles rising from the bottom of the column in countercurrent flow. This action provides an effective separation mechanism in which ultra-fine coal attaches to the air bubbles. Separated coal fines are carried upwards with the air bubbles above the slurry very near the top of the column near a gentle spray of wash water. This removes any residually entrained mineral matter. The clean froth is taken off at the top of the column. The mineral matter travels downward towards the bottom of the column where it is removed.

Based on the in-house research results, a pilot plant study was conducted at the Powell Mountain Coal Company (PMCC) coal preparation facility in St. Charles, Virginia on their fine clean coal cyclone overflow (minus 150 mesh) slurry. The plant processes about 300 tons per hour of raw coal from multiple seams and produces compliance (low-sulfur) coal for the utility industry and non-compliance (high-sulfur) coal for gasification to make chemicals. The pilot plant study used a Spellman 6-inch internal diameter column and showed that, for the fine refuse from both these coals, a clean coal product containing 5 percent ash was obtained at about 80 percent combustible recovery.

Based on this study, PMCC Superintendent of Coal Preparation W.J. (continued next page)

Eastern U.S. Oil Shale Development Program at the CAER

Thomas Rohl, Aurora Rabel, Scott Carter, & Darrell Taubbee

A multiple, fluidized-bed process (KENTOR II) for eastern oil shales has been under development since 1984, at the University of Kentucky Center for Applied Energy Research (CAER). An integrated experimental system has demonstrated the process will enhance oil yields, generate saleable by-products (sulfur, ammonia, hydrogen-rich gas), and mitigate environmental problems associated with oil shale development (SO2 emissions, potential acid mine drainage).

Introduction

Eastern oil shale is a major untapped energy resource, with deposits in Kentucky, Ohio, Indiana, Michigan, Alabama, and Tennessee. An understanding of the potential importance of this resource was developed during the early 1980's when the notion faced liquid fuel shortages. Much effort was expended in the study of eastern oil shales and it was discovered that: 1) the resource in Kentucky and other eastern U.S. states is very large (~600 million barrels of oil equivalent), of the same order as that of the more thoroughly documented western U.S. oil shales, and 2) eastern oil shales have a significantly different chemistry from that of western U.S. oil shales. In particular, eastern U.S. oil shales produce oil which is much more susceptible to cracking and cracking reactions. Because of these chemical differences, it was found that the optimum (continued next page)
Coal Cleaning Process (continued)

Process decided to build and install wider 8-foot diameter columns. CAER engineers (J.G. Groppo and B.K. Parekh), in cooperation with W.J. Peters, designed the larger column using scale-up criteria developed in the pilot plant study.

In November 1989, four 8-foot diameter columns were installed at the Mayflower Coal Preparation Plant Complex, and were successfully operating by December 15, 1989. Each column is capable of processing up to 1000 gallons per minute of the fine refuse slurry (5 tons per hour of solids). The columns process about 20 tons per hour of fine solids and recover approximately 6 to 8 tons per hour of clean coal. The clean coal product from the columns averages 6 percent ash with about 75 percent combustible recovery, and is sent to a high speed dewatering centrifuge where it is dewatered with the coarse (28 mesh by 100 mesh) clean coal cyclone underflow product. The total moisture content of the final blended product increases by about 0.5 percent.

Presently, the PMCC and the CAER are evaluating three different types of air sparging systems on the columns. After the complete evaluation of the data, one sparging system will be selected for initial parametric study. A technical paper describing the details of the PMCC project will be presented at the 11th International Coal Preparation Congress in Tokyo, Japan in October, 1990.

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Eastern U.S. Oil Shale (continued)

Economic performance could not be analyzed from eastern oil shale using those technologies which were developed for oil shales from other regions. A process (KENPORT II) specifically designed to maximize the oil yield and product recovery from eastern oil shales has been under development at the University of Kentucky Center for Applied Energy Research (CAER) since 1984. The technology is currently being demonstrated in a 5-Hour (scale) integrated reactor system, and is supported by the Laramee Project Office of the Morgantown Energy Technology Center, U.S. Department of Energy. A larger scale system is essential if the development of this process is to continue. It will allow for the collection of data for scale-up to commercial size, and a realistic evaluation of anticipated technical problems. Moreover, larger scale systems enable the generation of products and wastes in sufficient quantity to permit more extensive research and development in areas like crude shale oil upgrading and spent shale disposal and reclamation. Also, operation on a larger scale will provide an authentic simulation of commercial-scale conditions, necessary for further refinement of the concept. A proposal is currently pending with the U.S. DOE to develop a second generation process at a scale of 50-100 lb of shale per hour. The Process

Specifically, the process is a multiple, integrated, fluidized-bed system designed to improve oil yields, is thermally efficient and generates useful chemical by-products (sulfur, ammonia, and hydrogen-rich gas). (continued next page)
Dr. Peters also serves as Professor of Chemical Engineering Department where her research interests include atmospheric chemistry and transport. Her team is involved in the development of multi-disciplinary centers and institutes focused on applied research goals. The University of Kentucky has over twenty such multi-disciplinary centers and institutes designed for these purposes. One such multi-disciplinary area concerns energy supply and utilization. Studies needed for the safe and efficient production of energy are very diverse and require attention from chemists, engineers, geologists, economists, environmental scientists, materials scientists, and toxicologists; this list is not exhaustive but yet illustrates the breadth of disciplinary involvement. UK faculty, students, and staff have been doing energy research for many years and have focused on the multi-disciplinary aspects for over fifteen years. These activities have been in many departments, but also in multi-disciplinary units like the Institute for Mining and Minerals Research and Kentucky Geological Survey, and more recently, the Center for Applied Energy Research and the Environmental Systems Research Program. Research efforts have had a strong applied, fossil energy focus, but have also included investigation of advanced energy systems and fundamental models for the basic molecular structure of coal.

The strengths of UK’s energy research programs will continue to be multi-disciplinary where researchers are sharing knowledge and expertise that are complementary. At the same time, research will continue to be well-founded in the basic science and engineering disciplines. Many knowledge bases are available, and the multi-disciplinary centers and institutes have been used and can continue to be effective structures to bring experts together.

KENTOR I

KENTOR II

Conventional

Gas (SO2) 16% Gas (SO2) 29%

16% 29%

Gas (SO2) 16%

61%

Solid Waste 24%

Elemental S 25%

Solid Waste 62%

61%

16%

24%

25%

62%

Elemental S 29%

Conventional

KENTOR II

Conventional

Waste 1%

Oil 47%

Gas or Methanol 20%

Heat 10%

Waste 52%

Oil 35%

Gas 5%

Heat 10%

Comparison of sulfur conversion between KENTOR II process and conventional/rotating technologies.

Comparison of carbon conversion between KENTOR II process and conventional/rotating technologies.

Eastern U.S. Oil Shale (continued)

gases) while mitigating environmental problems. A unique feature is the integration of the pyrolysis with the gasification and the combustion steps.

Pyrolysis. Crude shale oil, the proximal product of the process, is generated in the pyrolysis zone. Fluidized-bed technology is capable of enhancing oil yields up to 50% or more above the process designed for western U.S. shales. Other important advantages include rapid reactions, complete utilization of mixed values and efficient heat and mass transfer characteristics. The fluidized bed pyrolyzer is operated at atmospheric pressure, thus simplifying processing operations and reducing costs.

Gasification. The intermediate gasification zone is a unique feature of the process which is particularly suited to eastern oil shales. The gasification cargo is central to the high heat transfer efficiency of the system. Rectifying hot shale from the gasifier to the pyrolyzer provides the best by direct solid-solid contact to drive the pyrolysis reactions. Thereducting atmosphere in the gasification zone removes the inorganic sulfur from the shale as hydrogen sulfide, which can then be converted with existing technology to elemental sulfur, a valuable by-product. The removal of sulfur prior to combustion is important because it lessens the emission of sulfur dioxide and the need for elaborate scrubbing systems. Gasification has other advantages in that iron species are converted to forms that will not cause particle agglomeration during combustion. Additionally, 15 to 20% of the residual carbon following pyrolysis can be converted to hydrogen-rich gas which can be used directly as a fuel or as a source of hydrogen for upgrading.

Combustion. In the combustion zone, the carbon from pyrolysis and gasification is burned supersonically to produce the process heat requirements. The hot

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Eastern U. S. Oil Shale (continued)

combined shale attains a temperature of at least 750°C, and makes an excellent heat transfer medium, providing an efficient, direct source of heat to the pyrolysis and gasification zones.

This configuration (pyrolysis, gasification, and combustion) facilitates the management and reduction of waste streams (solid, liquid, and gas) at the source, through the control of reactor conditions. This approach has directly addressed the issues of environmental control and resource utilization, and is inherently more efficient and cost-effective than early processes designed to operate with other styles.

Recent Findings

The viability of the KENTOR II process has been demonstrated at moderate gasification temperatures and shale residence times. The gasification step removes up to 90 percent of the original sulfur as hydrogen sulfide while converting 30 percent of the starting carbon to a hydrogen-rich gas. Sufficient carbon (15 to 20) percent of the original remains after pyrolysis/gasification to provide process heat via combustion. Fully integrated operation has demonstrated that enhanced offtakes can be maintained with a high-quality product and a high-grade product from a single reactor. A final spent shale product which contains little residual carbon and sulfur and small solid-denting capacity has been produced. Thus it has been demonstrated that the KENTOR II process can recover most of the energy potential of eastern oil shales, while producing a spent shale suitable for environmentally safe disposal.

Thomas Ried is the Program Manager for the eastern U.S. oil shale processing project. Scott Carter is the Principal Investigator on the project, and is a senior engineer responsible for the development of the process system design. Aurora Raibl is a Co-principal Investigator responsible for the development of fundamental pyrolysis, gasification, and combustion information from bench-scale reactors. Darrel Taquet is a Co-principal Investigator responsible for product characterization and interpretation of process chemistry.