Commercialization of Previously Wasted Coal Mine Gob Gas and Coalbed Methane

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CONTRACT INFORMATION

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Period of Performance: August 7, 1992 to December 6, 1993

Schedule and Milestones

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OBJECTIVES

The objectives of the project were to: (i) conduct an assessment of the commercial potential of the gob gas and coalbed methane resources associated with coal mining operations, and (ii) evaluate alternative gas utilization technologies. The end results to be achieved are the exploitation of an energy resource that is presently being wasted as it is vented to atmosphere and the mitigation of methane liberations for improved environmental quality.

BACKGROUND INFORMATION

Methane contained in coal seams has plagued coal producers for centuries due to safety problems caused by gas emissions into underground workings. To cope with this problem, mine operators dilute methane concentrations by circulating large volumes of air through ventilation systems and vent gas to atmosphere through gob ventilation boreholes and other methane drainage systems (Trevits et. al, 1991). Unfortunately, most of this gas is contaminated with air and/or is inaccessible to pipelines. As a result, the resource has generally been regarded as unsuitable or uneconomic for use as a primary energy source.

An immense resource is presently being vented to atmosphere from coal mines throughout the world. For example, in 1988 an estimated 5.2 to 8.0 billion cubic meters (BCM) of methane was liberated from coal mining operations worldwide. Of this amount, 4.9 to 7.8 BCM was vented to atmosphere and only 0.4 BCM was utilized. This is a waste of a valuable energy resource and may be deleterious to the environment. Methane is deemed to be a large contributor to global warming since it is twenty times more effective at trapping heat in the atmosphere than carbon dioxide (over a one hundred year time frame). Furthermore, methane concentrations in the atmosphere have more than doubled during the past two centuries (EPA, 1993). Therefore, the economic potential and environmental benefits that would be realized through the use of methane produced in conjunction with coal mining activities are vast.

Recognizing an opportunity to exploit this gas resource, in 1984 Resource Enterprises, Inc. (REI) set out to identify potential commercial applications. The obvious utilization options involved use of the gas in direct combustion processes such as electric power generation and coal drying (Von Schonfeldt, 1982). REI's objective was to identify an alternative through which the value added to the gas resource could be maximized, thereby enhancing the economics of methane commercialization. The Public Utilities Regulatory Policies Act (PURPA), enacted by the US Congress in 1978, created a favorable environment to develop independent electric power generation projects in the US. This situation influenced REI's focus on using "waste" gas produced from coal mines for electric power production and ultimately resulted in REI's formation of a venture with a gas turbine manufacturer to develop independent power projects at various coal mine sites (Owen, 1988).

However, economic conditions were very depressed throughout the industrialized areas of the US during the 1980's and into the 1990's. This was especially pronounced in coal regions and caused a surplus of power generation capacity that discouraged electric utilities to acquire additional supply. Although PURPA required the utilities to purchase power at their "avoided cost" of producing electricity, REI quickly discovered that perspectives on the value of avoided cost varied widely. Despite support from various sources to develop electric power generation projects using the waste resource, acceptable power sale agreements (or back-up power purchase agreements for on-site use of produced electricity)
could not be secured. This situation is believed to be peculiar to conditions that existed in the US at that time; power generation projects in other countries (and in the US under different circumstances) may be conducive to this methane commercialization option. As a consequence of the power generation experience gained by REI, REI began investigating non-electric alternatives for commercializing methane produced in conjunction with mining.

PROJECT DESCRIPTION

A non-electric coal mine gas utilization approach was expected to be well received by the coal industry since the gas would potentially displace other natural gas supplies (as opposed to coal). The targeted resources were gob gas (contaminated gas produced from mined-out areas), and pipeline quality methane produced in advance of mining. Methane contained in ventilation air was only expected to have some potential for use as combustion air (Glickert, 1991), and was disregarded due to its limited potential for commercialization using current gas conversion and separation technology. This pursuit resulted in a project co-funded by the US Department of Energy, Morgantown Energy Technology Center (DOE) and REI to evaluate gas conversion and enrichment technology options. REI was the project manager and prime contractor for the project that was initiated in late 1992. REI subcontracted the University of Utah Chemical and Fuels Engineering Department to assist REI in its evaluation of gas conversion and enrichment technology options. The technology alternatives considered by REI under both the conversion and enrichment scenarios would be required to accommodate relatively low volumes (50,000 to 100,000 cubic meters per day) of methane flow and varying gas quality. The primary contaminants of the untreated gas stream would be air, carbon dioxide and water vapor. Since one of the priorities established for the project was to consider only commercially available technologies, the principal problem to be addressed was that of downsizing the applications and tailoring the gas processing system to the characteristics of the fuel source. Processes that

broader application (as pipeline access would not be required).

The project was divided into two phases. The purpose of Phase 1 (the subject of this work) was to evaluate the gas resource associated with mining, and identify and evaluate various gas utilization technologies. Phase 2 would consist of a pilot demonstration of the technology deemed to have the most promise for commercializing this resource. Phase 1 was comprised of seven tasks, as summarized below:

Task 1: Evaluate the Gob Gas and Coalbed Methane Resources

REI evaluated the gas resource associated with US coal mining activities to characterize the potential fuel/feedstock source. This included an assessment of: (i) existing methane drainage techniques and opportunities for improving methane drainage effectiveness, (ii) coal mine characteristics, (iii) area logistics, (iv) environmental considerations, and (v) gas ownership implications. This task was primarily directed at addressing project development considerations.

Task 2: Evaluate Gas Utilization Options

The technology alternatives considered by REI under both the conversion and enrichment scenarios would be required to accommodate relatively low volumes (50,000 to 100,000 cubic meters per day) of methane flow and varying gas quality. The primary contaminants of the untreated gas stream would be air, carbon dioxide and water vapor. Since one of the priorities established for the project was to consider only commercially available technologies, the principal problem to be addressed was that of downsizing the applications and tailoring the gas processing system to the characteristics of the fuel source. Processes that
traditionally have a high gas feedstock cost as a relatively large component of the total product cost were deemed to be the most desirable. This was because methane has a relatively low production/acquisition cost when it is extracted as a requirement of mining operations and, therefore, would result in lower overall product costs. Additionally, high value-added products (specialty chemicals, etc.) that could be produced from the gas were targeted since they could be readily marketed.

**Task 3: Environmental Review**

An assessment of the expected impact on the environment of the most favorable technologies was investigated. This included an estimate of the potential reduction of methane emissions to atmosphere and the identification of incremental environmental effects that would result from the application of the technologies.

**Task 4: Market Assessment and Economic Analysis**

The market potential for the gas conversion and enrichment options preliminarily determined to be feasible was evaluated. This included an investigation of the demand for the resulting product, pricing, shipping and other factors affecting marketability and economics. An economic model was constructed and utilized to incorporate this information with facility investment and cost information to perform an economic analysis of the most promising alternatives identified.

**Task 5: Final Selection of Utilization Options**

The information developed under Tasks 1 through 4 were integrated and evaluated to refine the appraisal of the gas conversion and enrichment options investigated. This resulted in a ranking of the technologies and overall recommendation for the Phase 2 demonstration.

**Task 6: Selection of Candidate Phase 2 Demonstration Sites**

Based on the results of Task 5, candidate sites for a Phase 2 demonstration were identified and preliminarily evaluated to determine their potential for satisfying the Phase 2 project objectives.

**Task 7: Technology Transfer and Final Report**

The results of Phase 1 are being transferred to industry through various mechanisms including the Final Report.

**RESULTS**

The following gas conversion technologies were evaluated: (i) transformation to liquid fuels, (ii) manufacture of methanol (and perhaps further processing to acetic acid), (iii) synthesis of mixed alcohols, and (iv) conversion to ammonia and urea. All of these processes involve a two-step conversion; synthesis gas is produced from the gas stream and then converted to the ultimate products. Synthesis gas, a mixture of CO and H$_2$, can be produced either by steam reforming or by methane partial oxidation. In practice, a combination of steam reforming and partial oxidation is used to generate CO and H$_2$ in the right proportion for the hydrocarbons/chemicals product slate of interest. Natural gas steam reforming typically produces a hydrocarbon-rich synthesis gas, the hydrogen from which, in principle, can be separated and used in a furnace. The synthesis of hydrocarbons or chemicals from the synthesis gas is governed by the catalysts employed, reaction conditions and type of reactors...
used. Specifically for hydrocarbon synthesis, two types of reactors have been used; a packed-bed reactor and a slurry reactor. It was determined that for the gob gas conversion application, a slurry reactor would be more appropriate.

Most of the conversion technologies evaluated were found to be mature processes operating at a large scale. A major drawback in all of the processes was the need to have a relatively pure feedstock, thereby requiring gas clean-up prior to conversion. As a result, gas enrichment would be needed in any conversion application and could not be avoided. Despite this requirement, the conversion technologies evaluated were preliminarily found to be economic with varying degrees of facility cost amortization. However, the prohibitively high estimated investment for a combined gas enrichment/conversion facility (greater than US $20 million for a typical mine site installation) required that REI refocus the project to gas enrichment.

Enrichment of a gas stream with only one contaminant is a relatively simple process (depending on the contaminant) using available technology. Most of the gas separation technology developed to date addresses this problem. However, gob gas has a unique nature, consisting of five primary constituents, only one of which has any significant value. These constituents are: methane, nitrogen, oxygen, carbon dioxide and water vapor. Each of the four contaminants may be separated from the methane using existing technologies that have varying degrees of complexity and compatibility. However, the operating and cost effectiveness of the combined system is dependent on careful integration of the clean-up processes.

Rejection of nitrogen from methane is one of the more difficult problems from a gas separation perspective. The nitrogen rejection unit was determined to be the most critical and costly component of the system. Three technologies were identified as being suitable for nitrogen removal: (i) cryogenics, (ii) selective absorption, and (iii) pressure swing adsorption (PSA). Cryogenic separation has been a standard process of choice for this separation, on a larger scale (e.g., exceeding 500,000 cubic meters per day of flow). This process was not expected to be competitive at a small scale with the other two processes. However, preliminary conclusions from another investigation indicated that at processing capacities of 50,000 to 150,000 cubic meters of gas per day, the cryogenic process would compete with PSA (GRI-91/0092). However, the cryogenics process was found to be very sensitive to the presence of impurities such as water and oxygen and, therefore, was considered to be inappropriate for the gob gas application.

The application of the selective absorption process for nitrogen rejection from a conventional natural gas source has been performed (Mehra, 1993). The process utilizes different solubilities of nitrogen and methane in specific solvents to effect the separation. The solvent-feed contacting is carried out in a conventional packed-column system, common in the chemical engineering process industry. The PSA process has been under development for the last five to ten years, and the concept and results have been published (Meyer, 1990; D'Amico, 1993). The process generally consists of the following four steps: (i) pressurization, (ii) adsorption and subsequent recycle, (iii) depressurization, and (iv) purge or evacuation. The separation is accomplished using wide-pore molecular sieves which exploit different equilibrium adsorption capacities for different gases, such as methane and nitrogen. Typically, four to five adsorbent beds would be used for the expected flow rates for the gob gas application. The selective absorption process responds to the variable composition and flow rate of the feed by adjusting the solvent/feed ratio. In PSA, the cycle times and the recycle ratio are adjusted to maintain
a specified product composition for changing feed flow rates and compositions.

Both the selective absorption and PSA processes were assessed to be acceptable from both technical and economic perspectives. The overall hydrocarbon recoveries in both processes were similar and the capital and operating costs were also comparable. A primary difference between the selective absorption and PSA processes is their ability to handle oxygen. The selective absorption process requires oxygen removal prior to nitrogen rejection, whereas the PSA process removes part of the oxygen during the nitrogen separation process. Therefore, a smaller quantity of oxygen would have to be treated in the gas stream using PSA, thereby simplifying the operation and reducing the cost. Extreme caution must be exercised in designing a PSA nitrogen rejection system to ensure that gas mixtures passing through the explosive range are handled appropriately to maintain adequate operating safety.

The oxygen separation component added complexity to the integrated gas enrichment concept. Catalytic combustion was the process determined to be the best suited for the gob gas application. The process could be performed adiabatically or at lower temperatures using hydrogen as additional fuel. The adiabatic approach was favored due to safety and cost considerations. The adiabatic combustion unit would generally be designed to handle the maximum concentration of oxygen expected in the gas stream.

Technologies for carbon dioxide and water removal are well established. Carbon dioxide rejection may be accomplished using an amine absorption process, membrane separation (or possibly, a PSA process). Either the amine or membrane processes were determined to be suitable for the gob gas application. The PSA process was anticipated to still be experimental in nature and not as mature as the other alternatives. Therefore, PSA was not recommended for initial use to remove carbon dioxide. Conventional water removal techniques (e.g., glycol dehydration, membrane separation, etc.) are very adequate.

In summary, the system design that is expected to be the most favorable from both technical and economic viewpoints is a facility consisting of: (i) a PSA nitrogen rejection unit, (ii) a catalytic combustion deoxygenation process, (iii) an amine or membrane carbon dioxide removal system, and (iv) a conventional dehydration unit, as depicted in Figure 1.

![Figure 1. Generalized Gas Enrichment Facility Schematic](image)

**FUTURE WORK**

REI is proceeding with a pilot demonstration of a waste gas enrichment facility using the approach described above. This is expected to result in the validation of the commercial and technical viability of the facility.
and the refinement of the design parameters. REI intends to develop subsequent projects on a global scale to facilitate the commercialization of a previously-wasted resource and the enhancement of environmental conditions.

REFERENCES


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