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RESEARCH STRATEGY TO PERMIT GREATER UTILIZATION OF DOMESTIC FOSSIL ENERGY RESOURCES

BROOKHAVEN NATIONAL LAB.
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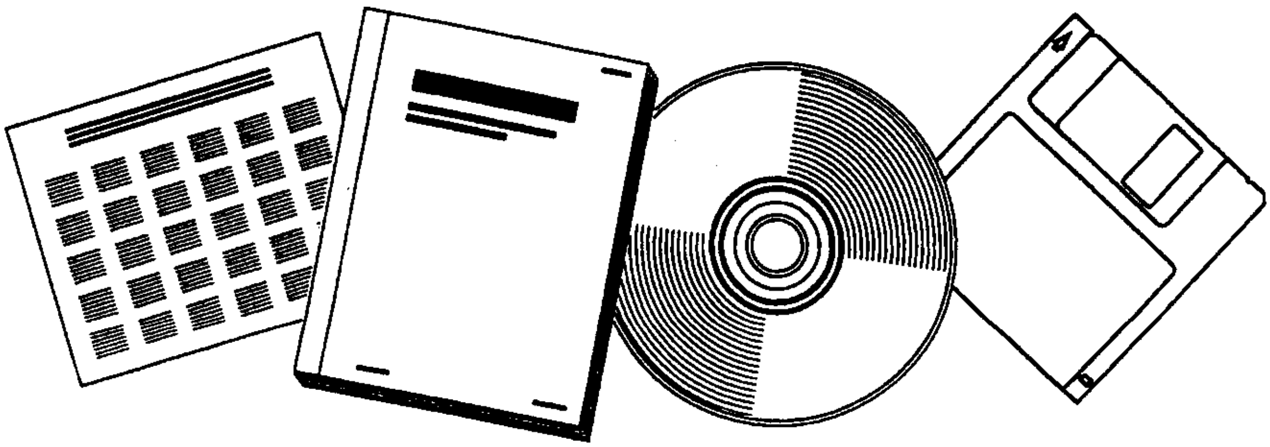

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A RESEARCH STRATEGY TO PERMIT GREATER UTILIZATION OF DOMESTIC FOSSIL ENERGY RESOURCES

March 30, 1982

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RESEARCH EMPHASIS

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CARBON MONOXIDE - RESOURCE OF THE FUTURE - CATALYSIS

Abstract

The economic strength and security of the nation would be well served by having available a clean multipurpose feedstock for use as a source of future industrial raw materials and fuels. Carbon monoxide and synthesis gas (mixtures of carbon monoxide and hydrogen) qualify as such key materials. Easily produced on a commercial scale from many different sources of carbon, carbon monoxide can be the basic building block for fuels and chemicals production. The development and improvement of synthesis methods based on this future feedstock are necessary to realize its full potential as a common resource within a reasonable time frame.

Introduction

Although the need for kerosene for illumination purposes provided the first motivation for the development of the petroleum industry, it soon became evident that petroleum would provide an almost unlimited source of raw materials for the production of many and varied products. The development of the internal combustion engine changed the product emphasis from illuminants to fuels while commercial and military needs drastically changed the requirements for fuels and introduced demands for new products such as synthetic rubber, solvents, coatings, and explosives. The petroleum industry had to adjust to the changed requirements. Every variation in supply or utilization has a multiple impact, but it took an oil crisis before the general public became aware of this relationship and its importance to the world economy.

But what about the future? U.S. Department of Interior Geological Surveys estimate we have a forseeable depletion (30-40 years) of recoverable resources of conventionally producible oil with a potentially longer lasting supply of natural gas. We have abundant reserves of coal and shale oil, but lack economical technologies to have these substitute directly for petroleum in the immediate (30-40 years) future. This depletion concept, however, completely ignores the substitution of alternative resources. Thus, there may never be a time when we pump the last drop of oil.

Needed are short and medium range approaches which emphasize increasing the availability and flexibility of raw materials for the chemical and energy industries within the context of available resources. Long-term goals should focus on replacing fossil raw materials in the energy sector with regenerable sources to extend their availability to the chemical industry.

A step by step replacement of oil by other resources is necessary. Increasing price and scarcity will compel this substitution strategy. This change is possible if direct coal utilization for power and heat production is increased, if there is further development of process technology to accommodate more varied feedstocks for petroleum products, and if a versatile, multi-sourced, long-term feedstock such as carbon monoxide is available to augment these alternatives.

The future of carbon monoxide as this key material seems to be assured since it can be produced on a commercial scale from virtually any source of carbon. It has been manufactured by both steam reforming and partial oxidation of natural gas, naphtha, heavy fuel oil and coal. In fact, it can be obtained by similar treatment of almost any organic material including agricultural and forestry wastes, tar sands, oil shales, and even garbage. It should also be noted that proponents suggest that the initial application of nuclear process heat in the chemical industry be used for the production of synthesis gas.

The revival of carbon monoxide chemistry will pave the way to the synthesis of fuels and chemicals. Commercially important today for the production of carboxylic acids, ketones, formamides, and ureas, carbon monoxide can be converted to virtually any organic commodity from methane to margarine. Thus, the resource of the future is, in reality, carbon monoxide. The generation and utilization of this key reactant forms the basis for ongoing and future research.

Future Aspects of Energy and Raw Material Supply

Product and resource substitution has been the lifeblood of the chemical industry. This is an evolutionary process with long lead times so it is necessary to begin planning before an urgent need exists. One should not expect massive breakthroughs in technology such as those attributed to the space effort. This means continued dependence on the petroleum processing infrastructure.

A priori, natural gas is the most economically attractive alternative to crude oil. There is more gas available worldwide at reasonable prices than there is oil. In a comprehensive two-year assessment, the American Gas Association Supply Committee concluded that sufficient conventional natural gas will be available in the year 2000 to supply 25-35% of the nation's total need for energy. These estimates do not include the so-called non-conventional sources such as tight-gas formations, Devonian shales, coal seams, geopressured aquifers, and gas hydrates which cannot be estimated. These resources are not recoverable under current economic conditions, but advanced technology and future energy prices may permit their eventual exploitation, with the potential of doubling current estimates of remaining recoverable resources.

Currently, 95% of natural gas is used as a fuel, but with conservation measures such as improved residential insulation and the greater use of coal for utilities and for industrial heating, a shift in natural gas usage is likely. The direct chemical utilization of methane, the major component of natural gas, is limited by its chemical stability and molecular simplicity. The best approach for the large-scale chemical utilization of natural gas is through synthesis gas. This conversion process is inexpensive, efficient, and based on well-known technology. Although the substitution using synthesis gas chemistry is based on known technology, innovative R&D will be needed to provide products with an economic substitutive advantage.

Focusing on the medium-term, the substitution of other energy sources for oil and natural gas is the most prudent solution if we are to avoid competition for resources by energy and feedstock users. Petroleum will become solely a chemical feedstock but the overall infrastructure could remain virtually unchanged if coal based technology can successfully substitute in certain areas. Economies of scale dictate a coal program be centered around a single but versatile, multipurpose raw material. Coal gasification to yield synthesis gas or carbon monoxide is the most promising and environmentally acceptable approach and would sequentially and economically replace some of the natural gas generated feedstock. Other coal-based contributions such as the terephthalic acid process, carbide and acetylene production or direct coal liquefaction will be minor. The large scale of operation needed for acceptable economics is difficult to visualize for these processes.

The long-term situation will demand widespread utilization of the so-called infinite energies: solar, geothermal, nuclear fusion or nuclear breeder reactors. (The free world supply of fissionable uranium is inadequate for nuclear fission to qualify as a major or long-term energy source.) At the same time however, energy storage and transportation problems must be solved.

Gas and oil, will only be employed as raw materials. Coal will supplement the production of energy (particularly electric) by infinite sources and more importantly, serve with oil and gas as a raw material. Nuclear might combine with coal for the manufacture of synthesis gas via coal gasification and serve in the manufacture of hydrogen from water which could result in a wider use of hydrogen as an energy source and in the replacement of hydrogen manufactured from fossil materials.

Although not mentioned in this scenario, any substitution strategies using biomass, shale oil, and oil sand technologies, other than direct combustion, are functionally dependent on synthesis gas technologies as well.

This perspective of future energy supply depends heavily on the development of new and improved technologies based upon synthesis gas and carbon monoxide - the true resource base of the future.

The New "Mixed" Petrochemical Economy

Fuels are the most important products of petroleum refineries but the manufacture and use of chemicals has a major impact on the economy of the country. Although a small percentage of the total oil consumed now, various studies have indicated the projected U.S. demand for petrochemicals will grow enormously. How can carbon monoxide chemistry help provide the needed change in refinery patterns?

Transportation Fuels

It is possible to design refineries specifically to convert a barrel of oil only into chemicals making no fuels whatsoever. With this, how can our country's large transportation fuel appetite (amounting to 25% of all energy consumption goes for transportation) be met? The answer lies in the production of synthetic fuels by the catalytic reactions of carbon monoxide. The major limitation of this chemistry is usually the degree of selectivity with which desired fuel composition ranges can be met although this restriction is not very severe since fuels have reasonably broad composition ranges.

Over the last five years, the greatest impact on the synthesis of fuels has been the development by Mobil of a gasoline synthesis process. In a two step process, synthesis gas is first converted to methanol and the methanol is selectively converted, over a strongly acidic shape-selective zeolite cage catalyst, directly into a high octane gasoline. Thus, this process alone may radically alter refinery patterns away from converting petroleum into gasoline, the largest end use. The process has the advantages of simple operation, mild reaction conditions, and high efficiency with a minimal environmental impact. The product is of high quality containing neither sulfur nor nitrogen while having few byproducts and requiring no special refinery treatment.

Although a near-commercial development, the methanol to gasoline process has some limitations and future research in this area should be pursued. If analagous upgrading technologies could be developed for other initial synthesis products, including the direct reaction of carbon monoxide, the possibilities for economical couplings of synthesis conditions, catalysts and products are greatly increased. Improvements in the methanol synthesis (to be discussed later) would also have great impact in this area.

One limitation of the shape-selective processes is that straight-chain hydrocarbons, the major components of diesel and jet fuels, cannot be produced. In the event of a national emergency, there would be a tremendous demand for jet fuels. This requirement could potentially be met using the Fischer-Tropsch synthesis, a process used by Germany during World War II to supplement her small supplies of crude oil which consists of hydrogenating carbon monoxide in the presence of a suitable catalyst. The broad product distribution and low activity of the catalysts are the major limitations of this chemistry.

Since the Fischer-Tropsch reaction generates straight-chain hydrocarbons, fractions of the products in the diesel boiling range usually possess exceptionally high cetane numbers. (The ignition properties of diesel fuels are expressed in terms of cetane number, analogous to the octane number ratings for gasoline.) The straight-chain structure is also important in jet fuels. The low sulfur and nitrogen content of the product combined with this structural feature makes possible environmentally higher quality fuels than are currently available. For example, less sooting would be an added benefit of a Fischer-Tropsch derived diesel fuel. A variation of this type of reaction using carbon monoxide and water instead of carbon monoxide and hydrogen, the Kolbel-Engelhardt synthesis, is also possible. Much research needs to be done in these areas with regard to the development of improved catalysts.

Finally, the concept of large-scale production of fuel-grade methanol should be considered. Interest in methanol has been high because of methanol's clean burning qualities, but its low energy content and problems with fuel distribution will delay acceptance of methanol transportation fuels. Instead, methanol could serve as a ready replacement for petroleum fuels used in power generation and, more importantly, as a chemical feedstock.

Chemicals

Fuels have been the most important products of petroleum refineries, but the increasing demand for petrochemicals will accentuate the value of petroleum as a feedstock. In the U.S., chemicals and related products account for about 6% of the total energy consumption.

Over 250 billion pounds of chemicals per year come from petroleum and natural gas. That is almost 1200 pounds of chemicals per year for every man, woman, and child in the U.S. Variation of the raw material supply for these chemicals or a large change in product demand would reflect seriously throughout the economy. In general, the future petrochemical infrastructure could remain virtually unchanged if carbon monoxide and synthesis gas products are introduced into the market place.

Synthesis gas is an already important feedstock for the production of major chemical intermediates. Some of the leading volume chemicals such as ammonia and methanol are currently manufactured from synthesis gas. These two chemicals alone could be future chemical intermediates.

Ammonia, on which our fertilizer industry centers, is the largest volume chemical derived from petroleum. Industrial applications of ammonia are growing slowly but its ties to the polymer and plastics industries are enormous. Synthesis gas provides the hydrogen for ammonia synthesis via the water-gas shift reaction. Improvements in catalysts for this reaction are needed. Present systems have the disadvantage of operating at high temperatures where the equilibrium is not favorable. A catalyst which could operate efficiently at low temperatures and under low carbon monoxide pressure would represent a substantial advance, alleviating multiple pass operation and the need for incorporating carbon dioxide adsorption in order to force the equilibrium. It should be noted that carbon monoxide derived hydrogen is needed for the important hydrocracking and hydrotreating refinery steps and future oil shale usage.

In the long term, methanol represents the most promising commodity chemical. The synthesis of methanol from carbon monoxide is a large scale and commercially proven process. Technology development and marketing efforts for current and developing chemical syntheses based on methanol indicate its dramatic growth and potential as a feedstock. It is a key chemical in the synthesis of esters, formaldehyde, acetic acid, MTBE (octane additive), and higher alcohols. Future processes for the production of light olefins, glycols, vinyl acetate, chloromethanes, and polymers represent exciting new developments. The Mobil methanol-to-gasoline process and related reactions demonstrate more specifically the enormous potential of this intermediate. Even single cell proteins (SCP) can be derived via methanol. Methanol can also be viewed as an easily transportable energy intensive substitute for synthesis gas, allowing commodity trading and facile storage.

New methanol catalyst developments could result in a more economical process by minimizing the operating pressures and increasing throughputs. This possibility is especially significant if the acceptable product spectrum is expanded to include higher alcohols and other compounds which could be used in the Mobil process.

The Fischer-Tropsch and Kolbel-Engelhardt syntheses deserve additional mention. These reactions can be adapted for the production of a wide variety of chemical products in the future including, perhaps, ethylene, propylene, and naphtha. Although the ordinary synthesis centers on its ability to produce diesel and jet fuels, techniques have been and are being evolved which make possible the production of polymers, lubricants, waxes, fatty acids, edible fats, soaps, synthetic detergents, and other miscellaneous chemicals of almost any chain length, degree of unsaturation and structure depending upon the choice of reaction condition and catalyst employed. This flexibility provided Germany with a degree of self-sufficiency from imported petroleum sufficient to foster her economic and social development and to eventually allow her to wage World War II.

Much catalyst research and development work in this area is needed with particular emphasis on high alcohols, alpha-olefins, and polyethylene manufacture. These chemicals alone form a major part of the petrochemical industry.

There are many other recently recognized routes to chemicals from carbon monoxide and synthesis gas which go beyond the scope of this report. In general, these represent only the "tip of the iceberg" and extensive research should continue to generate new downstream processes which could greatly affect the future petrochemical industry. As an example, the synthesis of polyethylene involves 8% of U.S. oil consumption, but the direct synthesis of this important polymer can be accomplished using carbon monoxide and hydrogen. This approach, using the original noble-metal catalysts, could not compete with current ethylene based processes, but new, lower cost catalysts could make the synthesis gas route an important process.

Finally, synthesis gas and carbon monoxide can become a substitute building block, with petroleum-derived reagents replacing chemicals for other needs. For example, acetonitrile might be derived from synthesis gas and ammonia, terephthalic acid from toluene and carbon monoxide, and higher alcohols and higher amines from Fischer-Tropsch reactions modified with methanol or ammonia.

These future trends and examples illustrate the change of feedstocks which will occur in the chemical industry. Just as coal derived acetylene, an important feedstock from 1910-1950, was replaced due to cheaper, more readily accessible and workable petroleum-derived olefins and dienes, these, in turn, will be and are being replaced by multi-sourced synthesis gas and carbon monoxide.

Conclusions

The extent to which the petroleum industry will be able to follow along the lines of present technology depends profoundly on the extent to which synthesis gas and carbon monoxide processes can succeed. Incentives for research lie in cost increases, supply reductions and disruption of conventional raw materials.

Although a research area currently receiving major attention from academic, industrial, and government laboratories, efficient catalysts for the activation of carbon monoxide need to be designed and their fundamental reaction mechanisms understood. This chemistry is presently associated with coal, where an almost inexhaustible supply is a compelling advantage but where overall economics are poor in the near term. However, carbon monoxide and hydrogen are readily derived from natural gas offering decided economic advantages for the near term with the possibility of a longer term shift to coal if needed. This marriage offers new challenges and versatility for the step by step replacement of oil during the next energy generation. Even in the long-term, carbon monoxide chemistry appears to offer the way to future organic substances which today comprise 90% by value of all the products of man's labor. The central role of carbon monoxide in this view of our energy future results from its production from a wide range of sources, its versitale reaction chemistry and the resulting chemical and fuel product possibilities.

COAL-WATER SLURRIES - POOR MAN'S SYNFUEL

Coal-water slurry fuels can provide the keystone piece of the energy structure we have been building to free our country from its dependence on improted oil. Conservation measures, adjustments in price structure to promote domestic supplies, and the use of alternative and regenerable energy sources have demonstrated a measurable short term effect on our consumption of petroleum products. These efforts will continue to improve our position with time but, unless coal can be introduced relatively quickly into applications which have been heretofore limited to oil fuels, we will continue to see ourselves under an economic threat. To accomplish this, coal must be put into a liquid form with properties which will allow it to be handled and burned in equipment designed for petroleum fuels. Further, it must be made available at a cost comparable to present fuel costs. Coal-water slurry fuels can accomplish this and do it without incurring the high capital costs involved in the conversion of coals to synfuels or in the conversion of industrial plants to handle solid coal fuel. The coal-water slurry fuel is in effect a "poor man's synfuel," a fuel which could make practical the use of coal in oil-fired utility boilers and in industrial heaters, boilers and furnaces which utilize nearly 3 million barrels of oil per day, close to the amount of oil now imported from OPEC nations.

What is an Acceptable Coal-Water Slurry Fuel?

The coal-water slurry fuel is to be used in a variety of industrial and utility applications where petroleum fuels are now used. It will replace distillate and residual fuel oils which have properties that are well speicifed so that they can be purchased and used confidently in equipment designed for their use. Therefore, coal-water fuels will have to have an effective specification that will permit this use with only minor equipment modifications.

Fuel oil properties are adjusted at the refinery by blending to meet purchase specifications. The American Society for Testing Materials (ASTM) has established standards for these fuels which specify physical properties such as flash point, ash content, viscosity, distillation temperature, and specific gravity. Knowledge of these properties confirms the heating value of the fuel and assures the plant operator that he will be able to handle and store the fuel in his equipment. Acceptable coal-water slurry fuels will require the development of a similar specification system based on proven technology for the intended applications.

Preparation of Specifications for Coal-Water Slurry Fuels

A coal-water slurry differs from fuel oil in that it is a suspension of a solid in a liquid while fuel oil is essentially a true liquid. As a result, its physical and combustion properties will vary depending on factors or combinations of factors which need no consideration when dealing with fuel oils. These include the following:

- Type of coal used in preparation of the slurry.
- Coal size, shape, and particle size distribution.
- Amount of ash in the coal after cleaning and sizing.
- Weight percent of coal in the mixture.
- Coal properties after cleaning (density, hardness, etc.).
- Stability of the suspension.
- Chemical additives present to modify viscosity or stability.

Factors such as these will influence the flow and atomization characteristics of the fuel and its flame characteristics, storability, transportation, heating value, and emissions. These factors and characteristics will be important in developing a suitable specification. The final specification will have to describe in detail the information mentioned above and, actually, will be very much like the present ASTM specifications for fuel oil described earlier.

To proceed with the actual preparation of a specification for an industrial boiler or process heater, it will be necessary to determine the amount and composition of ash which can be tolerated in the equipment. The effect of the factors described above will have to be established in combustion tests and in use in various components of the fuel system such as atomizers, pumps, tanks, piping, etc. The result of this process should be the development of specifications for coal fuels which will be functionally equivalent to distillate and residual fuel oils.

Does Coal-Water Slurry Fuel Technology Exist?

Coal-water slurries have been used in tests designed to determine the feasibility of firing this type of fuel. These tests are described in the literature and include work done in the United States, Germany, and Russia. The equipment used was designed for coal firing and test conditions varied considerably. With those reservations, the work demonstrated the feasibility of using coal-water slurry fuel. Experiments ranged in nature from the engineering scale to more fundamental and theoretical studies. The work did not provide a technology base for use in designing slurry systems and not enough information is available to provide assurance that coal-water slurries will perform satisfactorily in equipment designed to fire only oil fuels. For either oil or coal designed equipment, available information regarding the suitability of pumps, piping, valves, and instrumentation is not sufficient to allow prediction of long term operability. A number of research and development tasks must be accomplished before such information can be made available.

Currently, tests are being mounted in the U.S. which will add to the experience already gained. Short tests in oil fired systems have been made which show feasibility but which are not adequate for use in developing specifications.

Retrofit of Oil-Fired Equipment

The replacement of oil by coal is limited severely by factors such as the space available for storing and handling a solid fuel and by the design of the combustion equipment itself. Coal requires a considerable land area for storage and, since the transportation of coal is not as certain as pipelined oil, extra storage is needed to offset supply interruptions. The presence of ash in coal requires waste handling capability. Pulverizers are necessary to reduce the size of coal to that needed for combustion. These needs also create a type of environmental situation that does not exist with the use of oil, namely, the coal storage and waste areas need to be secure against the leaching of hazardous materials by water runoff from wet coal and from the release of fines to the air by wind action or dust formation in handling.

Plants designed for fuel oil have no provision for such things. Some plants designed for coal use have been converted to oil; the space formally allocated to storing and pulverizing coal is used for other purposes and is no longer available for reconversion. Consequently, the only economical option for retrofit of such plant will be a coal fuel which can be transported, stored, and fired as a liquid.

Combustion equipment designed specifically for oil firing uses a smaller combustion chamber volume and cannot accommodate the longer length of a pulverized coal flame. Even assuming that a somewhat overdesigned unit could handle the pulverized coal, the presence of coal-ash would interfere with heat transfer surfaces as a result of slag formation and fouling. The inclusion of an ash removal system for the combustion chamber itself as well as soot blowers, and perhaps modified tube spacings, in the heat exchanger sections would be necessary. The costs involved in such a brute-force retrofit would be, in most cases, unreasonable. Actually, in many cases technical or space factors would make such an effort impossible.

Two possibilities exist for avoiding the cost of attempting to retrofit using solid coal. One of these is to use synthetic fuels derived from coal such as SRC liquid or the products of other liquefaction processes (formed either directly from coal or from coal derived synthesis gas). The other possibility, and the least cost approach, is to slurry cleaned coal with water to produce a coal-water mixture fuel.

Coal liquefaction processes are costly high-risk ventures which have only moved forward when industry was able to obtain some form of government support for the effort. The scale of any meaningful production plant is such that the costs involved in its construction are not likely to be recovered unless conventional fuel costs increase to disastrous levels. The time required for such construction, the location, and environmental concerns all point to this approach as being unrealistic in terms of our near-term supply problems.

On the other hand, a coal-water slurry fuel can become available for some applications in a matter of a few years while improvements in coal cleaning technology and the development of rigorous specification fuel slurries could lead to widespread adoption of the fuel over a ten year period. The cost of these fuels would start with that of nominally cleaned and pulverized coal, allowing the wide margin between the price of coal and fuel oil to be applied to the development of improved preparation techniques. Coal suppliers would not have to wait for a lengthy process development and plant construction phase to be completed before being able to move coal into this market.

Research and Development Needs for Coal-Water Slurry Fuels

The key to development of a coal-water slurry fuel lies in the need to establish a specification for these fuels. The factors which influence the physical and combustion properties of the fuel were described in a previous section of this discussion. If is the effect of these factors on the use of the fuel, as well as specific application factors, which have to be studied and evaluated to produce a suitable specification. The nature of these investigations are described here.

1. Stability in Storage and Handling

Questions here include whether or not stability is a necessary specification for particular applications. If the storage tanks can be equipped to cause resuspension of settled slurries, then stability is not an improtant characteristic. Where stability is needed, this may be achieved through study of the interplay of particle size distributions, coal surface properties, chemical additive effects, water and coal quality, and solids concentration. Devices for measuring and monitoring stability may need development. Based on various studies, long-term stability will not be required in most cases.

2. Flow Properties and Transportation

Flow properties of various slurry mixtures must be measured and design correlations developed in order to predict in-plant piping and equipment flow behavior and for development of transportation piping systems. Variables include particle size distributions, the presence of additives, etc. This type of study is relatively staightforward and will be mostly an extension of already available design data.

3. Combustion Control

Atomization characteristics of the coal-water slurry fuel can affect burner design, the combustion of the coal, ash formation, the extent or degree of carbon burnout, heat transfer, and ash slagging and fouling effects. The ash content of the coal can have a significant effect on the combustion properties and the feasiblity of using the fuel in oil designed equipment. A significant R&D effort is necessary in this regard.

4. Mineral (Ash) Specification

The affect of coal minerals on the various boilers and furnaces used in the utility and industrial sectors has to be evaluated in order to establish the optimum degree of coal cleaning required. Both the quantity of ash and the quality (specific minerals present) are important. Essentially, the goal is the development of a specification fuel which could, to a large extent, overcome the variability of coal from different sources.

5. Emissions

Coal-water slurry fuels can minimize the need for emissions control usually considered necessary in using coal. These fuels are expected to be useful in many installations where space is at a premium and emission standards may be very rigid. The key to reduced emissions is in the cleaning of the coal or the adoption of ash removal procedures during or after combustion. Emission levels, including NO_x and particulates, must be quantified.

Conclusions

All the R&D tasks delineated above have a high probability of success. For a minimal investment, compared to coal-derived synthetic fuel technology, a viable infrastructure with new satellite industries can be developed for the coal-water mixture fuel. The fuel, with rudimentary specifications, can be used relatively quickly in oil-fired equipment originally designed for pulverized coal. Building on this limited market, improved specifications will be developed to permit the use of the fuel in oil-designed equipment. The need in this effort will be for the improvement of coal preparation techniques and for an extensive evaluation of industrial fuel capability. Success in this effort could make practical the use of the fuel in the commercial sector as well. With success will come a reduction in oil imports of up to 3 million barrels of oil per day and freedom from the cost and threat which imports entail - a respectable achievement for a "poor man's synfuel."

ASH: A DETERRENT TO THE USE OF COAL

Coal ash, the residue left from the burning of coal, has been considered a burden since man first started to harness the energy in coal to heat homes and provide power for his industrial efforts. Some remember hauling the barrels of ash from the basements of homes heated by coal, adding in the process another type of dust to the coal-dust released when the coal was delivered to homes and apartments. Unfortunately, this romantic example illustrates only one problem presented by the presence of ash in coal - that of dealing with its disposal.

More serious problems result from the effect of ash on the equipment in which it is used, its effect on the products where coal is used to provide energy for their manufacture, and its effect on people if the ash is released to the environment. These effects can be equated to the costs associated with counteracting them; the cost of maintenance, of environmental control equipment and the cost of contaminated products.

Consequently, the rapid displacement of coal by petroleum in the first half of this century was not caused simply by the ease with which fluid fuel could be handled but also by the fact that petroleum is an inherently cleaner fuel containing a relatively minor amount of ash. Coal is currently used to generate about half of the electrical energy supplied by utilities. The plants in which it is used have been designed for coal use and generally for specific coals in order to accommodate the ash levels present in the coal. If coal is to be introduced to the remaining power plants not designed for coal or if coal is to be established again as a significant industrial fuel with a potential for use as a retrofit fuel for existing equipment, then its ash content has to be controlled.

What is Coal Ash?

Ash is comprised of the minerals which became associated with vegetative or carbonaceous materials during their conversion through the ages to coal. They came from sediments deposited with the plant materials, from elements incorporated in the plant structures and from ground water mineral deposits. As a result, they are intimately associated with the organic constituents in coal. Added to these, are minerals in rock adjacent to the seams taken during the mining process. The actual composition and quantity of coal ash depend heavily on the geographic source of the coal but includes the elements silicon, aluminum, iron, sulfur, calcium, magnesium, sodium, potassium, and a number of elements present in trace quantities. Ash quantities range up to 15% or more in selected cases.

It is the composition of the ash which determines the behavior of the ash in various types of equipment. Depending on its composition, the ash of one coal will soften at a temperature which is lower than that of another, leading perhaps to its deposition on hot surfaces in a combustor. If sufficiently hot, ash will form a liquid slag. Depending on its constituents and the manner and conditions under which it deposits in boilers and heat exchangers, ash can be corrosive. It can also be erosive if carried at sufficiently high velocities through the convection tube banks of a power plant.

In processes such as the manufacture of glass where the direct heating of the product is desired, the ash will come in contact with the molten glass and, depending on the ash composition, cause discoloration or leave imperfections.

The presence of sulfur and its impact on the environemnt is well known. A major part of the current direction in coal cleaning research is the result of the desire to remove sulfur from high sulfur coals.

How Ash Affects Boiler Design

In considering how coal ash will influence the design of equipment, the characteristic behavior of ash associated with conventional pulverized coal firing can be used as a point of reference. If furnace surface temperatures are too high, slag deposition will occur in the furnace. If the temperature of ash particles leaving the combustion section is too high, fouling of the convection sections will occur or, if ash fusion temperatures are too low, the result will be the same. If this takes place, the efficiency or capability of the unit will be reduced. To compensate for the characteristics of the ash, a designer will adjust his design to accommodate the type of coal to be used in the facility.

The velocity of the flue gas through the convection tube sections and the tube spacing have a considerable effect on the rate of heat transfer from the gas to the heated fluid and consequently, the size of the installation for a give heat load. High velocities are desireable. The presence of ash, which can be erosive at high velocities, limits the gas velocity in coal fired boilers and, combined with the fouling tendency, affects tube spacings and the total tube surface required.

The design of oil-fired units varies considerably from coal units. Fuel oil ash levels are quite low and, as a result, the entire oil-fired boiler design can be more compact in regard to furnace volume and tube spacing than is the case for coal fired systems. This means that a boiler or furnace designed for oil firing will not be able to use coal containing large amounts of ash without some major changes in convection section components. More likely, this retrofit option would not be reasonable.

Finally, despite the best design practice in regard to minimizing problems associated with ash, it is difficult to construct a boiler which can accommodate coals from a variety of sources because ash composition, slagging temperature, and volatile mineral constituents will vary from coal to coal. Under the best of circumstances, coal-ash creates a need for increased maintenance and a more complicated overall operational requirement than would be the case for oil-fired components.

The Potential of Ash-Free Coal

If a sufficient amount of ash, including the most troublesome ash components, are removed from coal, the potential for using such coal is reasonably high. The problem of ash slagging and convection section fouling would be eliminated for the most part and, if the length and characteristics of the coal flame could be accommodated in the smaller combustor volume (for coal-water slurry firing there is evidence that this is a reasonable assumption), then the replacement of oil by coal could be accomplished in existing installations. Well cleaned and sized coal would consist of small particles on the order of the size of pulverized coal (80% through 200 mesh) or less. The best approach to handling the finely divided material after cleaning would be as a coal-water slurry suitable for direct firing in essentially conventional oil designed burners. Otherwise, the high surface area and vulnerability to oxidation would make the shipment and storage of the dry fine coal quite hazardous.

The Degree of Cleaning Needed

The amount of ash which could be accommodated in any particular installation such as an industrial boiler, process heater, or utility boiler would vary according to the operating conditions of temperature, heat flux and gas velocity. It is necessary to set an ash specification which would be acceptable for all cases or establish several specifications to accommodate various classes of equipment.

Currently, no such specification can be written for the case in which oil designed equipment in the field is to be fired by coal. The information needed to prepare these specifications is not available. Data and correlations used for the design of coal fired equipment would be useful to estimate allowable ash levels for use in equipment designed for oil firing but a number of tests and some experimental work would have to be done to confirm these estimates. Specifications for fuel oils and operating experience with various fuel oils would provide a lower limit for ash specifications for coal fuels.

Cleaning Technology

Coal cleaning technology has been, for the most part, directed toward the removal of sulfur and some toxic elements. Physical cleaning methods include crushing, screening, froth flotation, heavy media separation, and jigging. These methods result in the production of coals with reduced mineral matter content which are reduced in size to simplify handling and shipping. The coal may then be pulverized at the point of use for firing in power plants. Low-sulfur, low-ash coals receive little cleaning but are sized to some extent for transport. In the cleaning process, some loss of coal occurs ranging from a few percent for minimum cleaning to as much as 60-75% for deep cleaning. New approaches to cleaning are primarily chemical in nature and involve the treatment of physically cleaned coal by various reagent chemicals. Again, the purpose has been to remove sulfur, not necessarily other mineral constituents. Consequently, if the degree of ash removal and the quality (composition) of ash remaining in the coal are to be specified for it to be used in oil fired systems, a review of cleaning technology and the consideration of cleaning process modifications will be necessary. It is possible that with this modified cleaning objective, more effective and economical approaches to deep cleaning might result.

The Oil-Fired Refit Market

On the basis of the current use of oil in the industrial and utility sectors, primarily distillate and residual fuel oil consumption, the total replacement of oil by coal could amount to about 3 million barrels a day. Of this, 50% would be in the utility sector. In the combined sectors approximately 40% is accounted for by existing oil fired units which would normally not be able to be refit to coal use. With effective coal cleaning and a coal handling and transportation system such as that provided by coal water slurries, much of this industrial and utility oil consumption could be displaced.