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Subtask 3.16 -Low-Cost Coal-Water Fuel for Entrained-Flow Gasification

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EXECUTIVE SUMMARY

One of gasification's main advantages over combustion systems is that gasifiers operate under pressure, requiring much smaller systems, making them attractive for modular and pollution control systems. Coal selection is critical with the reduced volumes and residence times of gasification systems, making reactive low-rank coals an attractive gasification feedstock. Some entrained-flow gasifiers require the fuel to be a slurry form or a coal–water fuel (CWF). Recent technological advances at the Energy & Environmental Research Center (EERC) have led to potential means for improving efficiency for gasifiers that utilize CWF.

Hydrothermal treatment or hot-water drying was developed by the EERC for low-rank coals to produce a CWF that has an elevated solids content, which reduces the amount of water fed to the gasifier, thereby decreasing the amount of oxygen needed to gasify the coal.

The specific objective of this research project was to assess the potential process efficiency benefits that may occur by applying the hydrothermal, or hot-water-drying, process to low-rank coals as related to entrained-flow gasification systems or pressurized combustion systems. Project emphasis was on identifying more efficient coal-dewatering and CWF formulation methods prior to utilization.

Prior to 1996, the proposed method of dewatering hydrothermally treated slurries was using centrifuges or filtration equipment. These methods were somewhat cumbersome since the pressurized slurry was flashed to atmospheric conditions, dewatered, and then pressurized again prior to gasification. In a quest to develop a one-step process which used the available pressure and temperature to complete the needed partial dewatering, the EERC contacted numerous filtration/separation equipment vendors. The best option was identified as using hydroclone system or Type TMC cyclones, currently being manufactured by Dorr-Oliver Inc. Type TMC units allow the user to recover minerals at particle sizes as low as the 5-micron range at temperatures up to 450°C.

A pilot-scale test system consisting of two stainless steel cyclones connected to the autoclave system charged with coal slurry was constructed at the EERC for slurry testing. Nitrogen was used to pressurize the autoclave to force the slurry through the cyclone, and valves adjusted the back pressure on the underflow. The degree of separation was a function of the solids concentration, pressure, and temperature of the slurries. Limited difference between the specific gravity of coal and water reduced dewatering at lower-pressure conditions. Tests indicated a concentration of the treated slurry up to 5 wt%, with minimal process losses to overflow streams. This advancement in CWF technology should enhance process efficiencies and economics that will make hydrothermally treated CWF an attractive option for gasification and combustion applications.

SUBTASK 3.16 – LOW-COST COAL–WATER FUEL FOR ENTRAINED-FLOW GASIFICATION

1.0 INTRODUCTION

The high moisture content of low-rank coals has limited their use in gasifiers owing to the substantial increase in oxygen required to evaporate excess water in the slurry feed and the resulting derating of system performance. Based on heat and material balance calculations, the oxygen requirement expressed as moles O_2/C is increased by 30% as coal moisture increases from 10% to 40%. The gas heating value is correspondingly reduced from 265 to 227 Btu/scf for dry product gas—and from 226 to 131 Btu/scf for moist product gas as used in a noncondensing hot-gas-cleaning system. At still higher coal moisture levels above about 48%, the moist gas heating value drops below the nominal 100 Btu/scf level required for stable combustion in a gas turbine.

Predrying the low-rank coal feed would be far more economical than increasing oxygen to the gasifier if the moisture were not reabsorbed in slurrying the coal. Unfortunately, the equilibrium coal moisture content (as a measure of the intrinsic moisture in the slurried coal particulate) is only slightly reduced by gas drying in a roto-louvre or entrainment-type dryer, from 33% to 29% moisture for lignite and from 26% to 22% for Wyoming subbituminous coal. For this reason, conventional drying methods are not of practical use in this application.

Predrying in steam or in hot water has been shown to reject water irreversibly to produce a concentrated coal–water fuel (CWF) with up to 63% dry solids content. CWFs produced from North Dakota and Texas lignites and Wyoming subbituminous coals by nonevaporative thermal dewatering were evaluated for use in a Texaco entrained-flow gasifier in an Electric Power Research Institute (EPRI)-sponsored study completed in 1985 (1). The EPRI study performed by the Energy & Environmental Research Center (EERC) confirmed that hot-water drying or hydrothermal treatment produced a concentrated pumpable slurry having a solids loading and viscosity suitable for feed to a Texaco gasifier of the type used on the Tampa Electric IGCC (integrated gasification combined-cycle) project. Subsequent studies performed independently by the EERC and Texaco have confirmed the broad technical applicability of this approach for producing concentrated slurries from a wide range of high-moisture coals, including brown coals containing up to 60% moisture, and from a combination of coal and sewage sludge or municipal waste.

The cost of hot-water drying is a recognized barrier to be overcome if this technology is to be adopted in IGCC applications. Cost can be reduced to a significant degree by integrating the heat supply and recovery requirements of the process into the design of the overall power system.

The favorable estimate of incremental cost for integrated hydrothermal drying depends, in part, on increasing the particle size of the feed coal from minus 100 to minus 28 mesh for the purpose of simplifying slurry concentration. The high reactivity of the low-rank coal should allow the coarser slurry feed to be gasified satisfactorily.

2.0 OBJECTIVES

The specific objective of this research project is to assess the potential process efficiency and pollution control benefits that may occur by applying the hydrothermal, or hot-water-drying, process to low-rank coals as related to entrained-flow gasification systems. Project emphasis is on identifying more efficient coal dewatering and CWF formulation methods prior to gasification.

A favorable estimate of incremental cost for integrated hydrothermal drying depends, in part, on increasing the particle size of the feed coal from minus 100 to minus 28 mesh for the purpose of simplifying the slurry concentration process. Two options will be reviewed for dewatering or concentrating the processed slurry: 1) depressurization and then concentration with sieve bends or 2) partial dewatering at system pressure with hydroclones. Both have their own merits, sieve bends being a low-cost alternative, while hydroclone application would not require additional pumping sections prior to gasification. Various CWF samples with different particle-size distributions and solids concentrations will be sent to equipment vendors for application review. Also, EERC cost models will be used to calculate the integral cost of adding the partial dewatering to the hydrothermal technology for a commercial-size facility.

3.0 INTEGRATION OF HYDROTHERMAL DRYING IN THE DESTEC GASIFIER

The integration of hydrothermal treatment with a clean coal gasification project is currently under evaluation. The DESTEC gasifier is already a slurry-fed entrained gasifier, which is oxygen-blown, producing a gas with more than 150 Btu/scf. The DESTEC gasifier is a two-stage system that currently uses subbituminous slurry at 53 wt%. Based upon previous work conducted at the EERC, this slurry's viscosity is 5000 to 6000 cP. DESTEC uses sludge pumps to pressurize the slurry to 400 to 500 psig and then heat-treats the slurry to approximately 400°F to lower the viscosity to approximately 500 cP. This lower viscosity allows for more efficient atomization at the 53 wt% solids content. Without the heating process, the solids content would be reduced to under 50 wt%, which would affect system efficiencies and heat content of the medium-Btu gas. The current system advantages include that it operates at gasification pressure (not requiring additional pressure) and does not require partial dewatering of the fuel.

The application of a hydrothermal or hot-water-drying process to the current gasification system presents an opportunity to use reactive low-rank coals at an elevated solids content, thus reducing the amount of water fed to the gasifier, thereby decreasing the amount of oxygen needed to gasify the coal. The hot-water-drying process would increase the solids content from 53 to 63 wt%, a 20% improvement in the slurry's energy density. Figure 1 depicts the implementation of the proposed system to the DESTEC system.

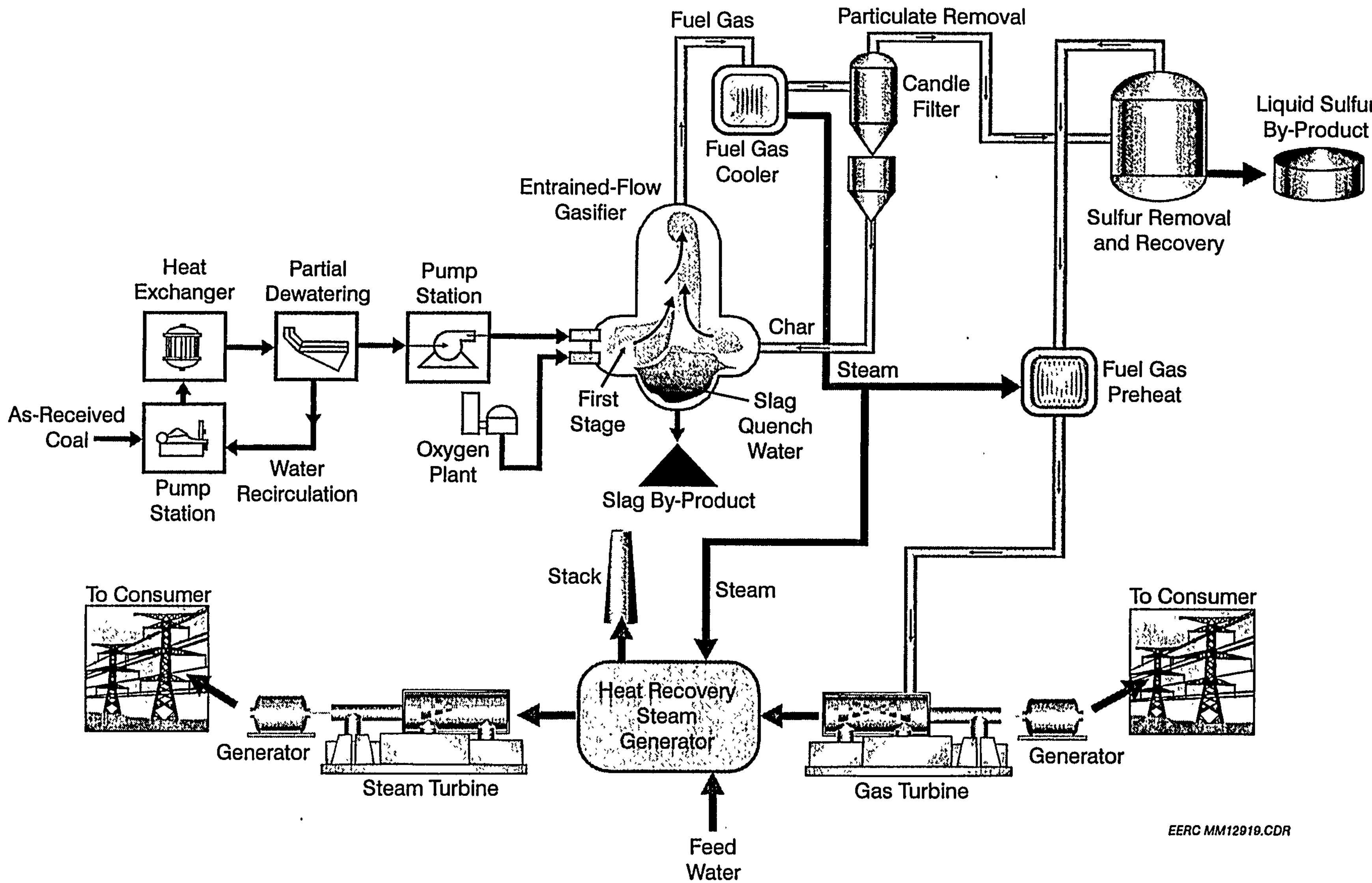

Figure 1. Integration of the hydrothermal treatment process with the DESTEC gasifier.

To accomplish the hot-water drying for the gasification applications, the EERC focused on three major unit operations: size reduction, partial dewatering, and pumping systems. With entrained gasifiers, particle size is normally limited to less than 100 mesh to get adequate slurry atomization and conversion properties. With low-rank coals, the user can utilize a bigger coal particle-size distribution, resulting in an increase in the attainable solids content while, owing to their friable nature, still having an acceptable coal conversion. The proposed system would use a 28-mesh × 0 particle-size distribution. This particle size was chosen since it would not complicate pump requirements or result in sedimentation problems if a minimal velocity was maintained and could be effectively dewatered. The hot-water-drying process is similar to the pressure and heating operation of DESTEC, however, at pressures of approximately 1500 psi and 575°F. This would require replacement of the sludge pumps with higher-pressure pumps and require more heat. In terms of the 660 psi and 700°F superheated steam currently being used in plant applications, the proposed treatment would require an additional 40,000 lb/hr of steam to heat the slurry. Currently, the plant recovers approximately 200,000 lb/hr of steam. The energy necessary for the additional pressure conditions would be an additional cost; however, going with a larger particle size would permit the rod mill energy requirements to be reduced to half of that used by the current operation.

4.0 VENDOR SOLICITATION

Numerous filtration/separation equipment vendors were consulted to determine the more appropriate equipment to use to dewater the hydrothermally treated slurry at pressure and temperature. The vendor response was that more than likely for fine coal dewatering, the line pressure would have to be released, the slurry dewatered and, finally, the slurry pumped into the slurry gasification systems. After initial dewatering, the product solids may also have to be reconcentrated to the pumpable slurry. The level of dewatering will, of course, vary dramatically with the type of separation equipment that is selected.

Initial efforts were focused on hydrothermal processing of particle size 28 mesh × 0 and partial dewatering with sieve bends or hydroclones. Hydroclones, according to two different vendors, would be able to handle the pressure and the particle size, but may not be able to dewater to above 50 wt% solids. Based on previous experience with other slurries, both vendors estimated the limit to be less than 40 wt% solids because of viscosity increases at higher solids concentrations. Bench-scale testing was recommended by both vendors to verify test conditions for coal slurries.

The sieve bend application cannot handle the line pressure. Similar to other filtration options, the slurry would have to be depressurized and fed to a system by a centrifugal pump from surge tanks. In addition, a larger particle-size distribution is required for high efficiencies. Because of these factors, further research was not conducted on the sieve bend option. Instead, the EERC identified additional technology improvements and constructed a bench-scale test rig for hydroclone testing at conditions.

5.0 HYDROTHERMAL SYSTEM DEVELOPMENT

Based on the latest round of discussions, the EERC altered the existing hydrothermal system to process larger particle sizes and elevated temperatures. The particle-size increase was to possibly open up the dewatering step to more conventional technologies such as sieve bends. The larger particle-size testing required a batch process mode since it is not feasible to continuously heat-treat lump coal in a slurry because of coal particle settling properties and slurry pump and valve limitations. Elevated temperature tests will review the ability to reduce trace metals and sulfur fractions in the coal for better pollution control by removing contaminants prior to utilization. In addition, membrane separation technology was also suggested to be a dewatering technology which may work for pressure applications.

5.1 Larger Particle Size and Extended Temperatures

Both existing bench-scale and pilot-scale hydrothermal process systems were modified to process larger-particle-size material (¼-in. × 0) instead of pulverized coal and higher-temperature conditions. The bench-scale modifications included a multigram unit, a 40-cm^3 reactor which was built as an extraction vessel and charged with 10–20 g of coal during experimentation. Bench-scale extractions were performed on the multigram apparatus (Figure 2) that was assembled to increase the scale of the process from the milligram to the 10–20-g scale. A pneumatically operated pump capable of continuously pumping water at 10 to 300 cm^3/min through the fixed bed of coal was used. Results of multigram testing showed that operating conditions of subcritical water at 350°–420°C and 2300 psig consistently reduced the coal sulfur content by over 50%, with yields ranging from 50% to 90% depending upon temperature.

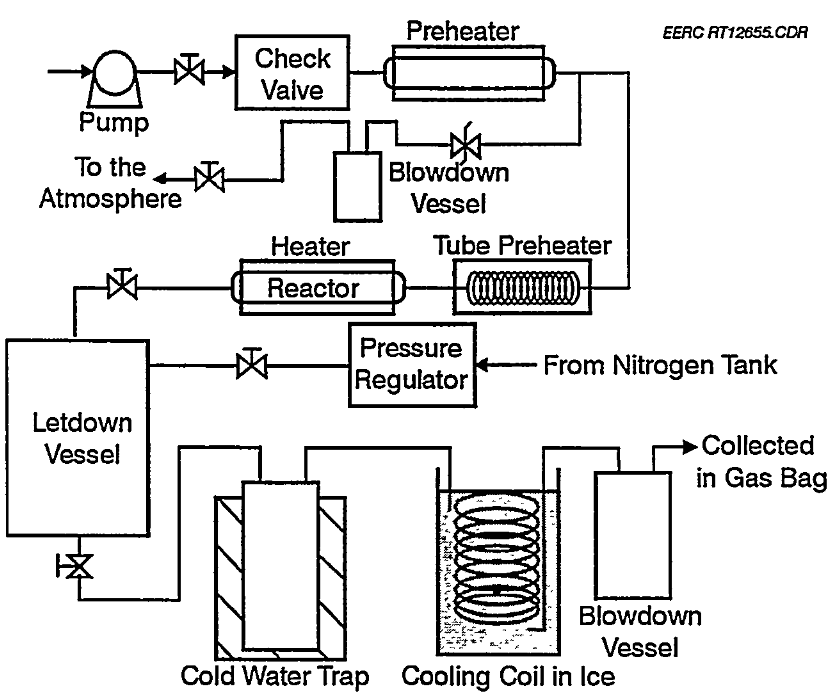

Figure 2. Schematic of the multigram subcritical fluid extraction apparatus.

Scaleup from the multigram unit to the pilot scale was accomplished by reproducing the batch process of the multigram unit in the pilot unit, resulting in an approximately 1000-fold increase in coal capacity. A schematic of the hydrothermal setup in the batch-processing mode is shown in Figure 3. A superheater was installed for heating water to final temperature after it leaves the Dowtherm heaters and just prior to its entering the reactor. Top and bottom frits prevented the coal from leaving the reactor and allowed the water to carry away the extracted sulfur and hazardous air pollutants (HAPs). A water-cooled condenser was selected for collecting the effluent water. Although a less desirable process from the commercial perspective, it had some advantages during the initial stages. Some of those advantages included the following:

- The batch unit provided a much broader range of temperatures (ambient to 500°C) and pressures (ambient to 6000 psig) with which to experiment.
- The batch unit generated smaller amounts of process water containing sulfur and HAPs.
- The batch unit allowed for treatment of larger coal particle sizes.

Two tests with 25 lb of raw −¼-in. × 0 North Dakota lignite and Illinois bituminous coal were processed at 400°C using the modified pilot-scale batch system. For these initial tests, water flowed through the fixed bed of coal at a rate of approximately 60 lb/hr for 60 min. The heaters were then turned off, and water continued to flow through the coal bed for an additional 4 hours. After the sample had cooled, the solids were recovered and analyzed. Despite reduced water to coal exchanges compared to the multigram system, the results from the pilot scale for both coal types were encouraging. The initial test results indicated more than 55% reduction in

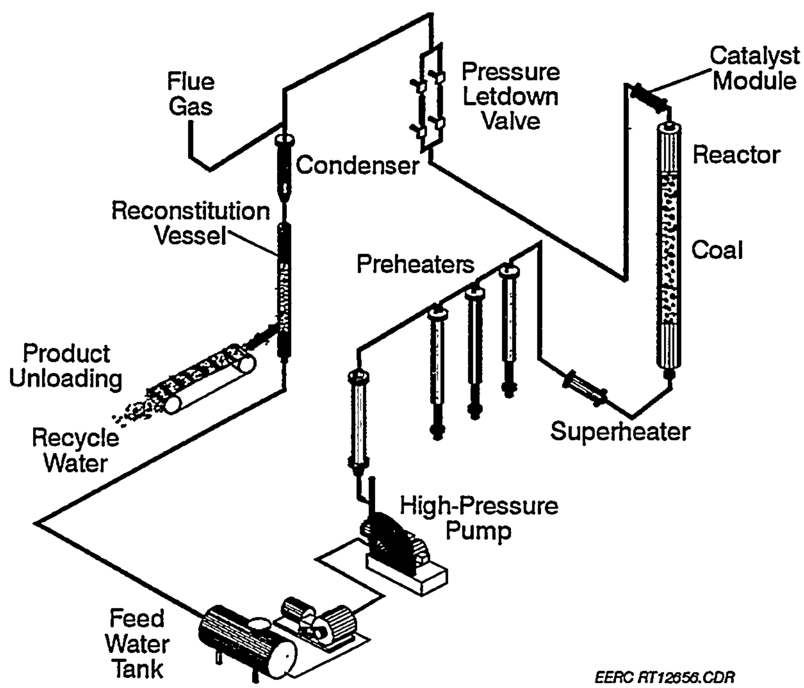

Figure 3. Schematic of pilot-scale high-pressure and -temperature unit for subcritical water batch mode extraction coal experiments.

sulfur for the Illinois coal. The volatile content of the lignite was reduced from 43 to 15 wt%, and the fixed carbon was concentrated from 48 to 76 wt%. The lignite moisture content was reduced from 32.7 to less than 1 wt%. The lignite-drying test was conducted at too high of a temperature, indicated by the level of devolatilization. This lignite char product had better adsorption characteristics, like activated carbon.

The existing continuous slurry system was also modified to include higher temperatures for extended residence time. The continuous mode allowed processing of the fine coal at a reduced residence time. The continuous configuration bypassed the superheater used in batch processing and included a second reactor to increase the residence time to 20 minutes at temperature. In this mode, the pulverized coal was slurried with water, and the final product was collected as a filter cake. Tests were conducted on the two different Illinois coals at temperatures as high as 340°C. Solids recoveries were approximately 85% for both coal types. Periodic samples of water, gas, and product slurry were taken at each condition to determine sulfur and material balances. The volatiles content of the product remained essentially unchanged, and the sulfur level was decreased by more than one-third. In addition, the mercury content was 87% less than in the feed, and the selenium content was 46% less than in the feed.

5.2 Membrane Separation Technology

The Illinois Clean Coal Institute (ICCI) recently made funding available for Williams Technologies, Inc. (WTI), and Clarke Rajchel Engineering (CRE) to complete an investigation producing high-quality coal–water slurries from preparation plant fine coal streams using high-shear cross-flow separation (3). This technology was proposed to replace or enhance conventional thickening processes by surpassing normally achievable solids loadings. Dilute ultrafine (minus 100 mesh) solids slurries can be concentrated to greater than 60 wt% and remixed, as required, with dewatered coarser fractions to produce pumpable, heavily loaded coal slurries. Since the technology seems to work best with preheated, finely ground slurries, the EERC requested information for the potential application to the hydrothermal system.

According to literature provided by CRE, this dewatering technology utilizes cross-flow membrane separation and heat and feed pulsation to effect a separation of water from the fine-particle slurries. The separation of water from coal–water slurry is effected by pumping the slurry across a fine pore membrane surface. The membrane is vibrated radially at high frequency (50–60 Hz), which prevents the pores from being blinded by the finest slurry particles. The product is a thickened slurry. In previous laboratory work, fine particle slurries approaching 60 wt% coal have been produced (2). Major advantages of the technology include the following:

- It eliminates flocculants required by both filtration and thickening processes.

- It achieves higher solids concentrations than those achievable in conventional thickeners.

- Slurry concentration equipment is compact in comparison to other fine-particle dewatering/thickening equipment. The footprint of the commercial machinery is approximately 8 by 8 ft, including pumps.

- Equipment is simple, requiring maintenance similar to that required by a pump.

- It provides a pumpable fuel for coal gasification and combustion technologies.

- It has a high potential for use as an NO_x-reducing reburn fuel.

According to CRE, the system can be modified to treat pressurized and heated slurries in the range of hydrothermal process. CRE has also had discussions with DESTEC on using this technology with its gasification systems. After further review of technical information and project summaries, the membranes do concentrate coal slurries; however, the technology requires the slurries to be run several times through the membranes. Because of limited success, no testing will be considered with the hydrothermal treatment coupled with membrane separation to concentrate hydrothermally treated coal slurries.

5.3 Hydroclones

Probably the best partial dewatering method that was identified during the vendor solicitation was the use of Type TMC, currently being manufactured by Dorr-Oliver. Type TMC produces separations in the 5-μm range at temperatures up to 450°C. It is highly resistant to abrasion and thermal shock. The Type TMC DorrClone is available in manifolds of 60, 162, and 300 10-mm cyclones. The cyclones—arranged in parallel—are formed in aluminum oxide and encapsulated in metal. They are housed in ASME (American Society of Mechanical Engineers)-code-designed steel or stainless steel pressure vessels. The cyclones have the following features:

- Material of construction (aluminum oxide) is highly abrasion resistant and ensures long wear life.

- Metal encapsulation safeguards the cyclone against thermal shock and mechanical abuse.

- Each cyclone is individually gasketed to compensate for thermal expansion.

- Housing design meets ASME pressure vessel code.

There are two ways to manifold cyclone systems—externally and internally. All but the very smallest cyclones are usually manifolded externally. Internally manifolded systems usually are clusters of 25-mm cyclones and smaller. Manifolding accommodates high-volume processing needs by operating cyclones in parallel. Since the size of the cyclone cannot be increased to handle greater capacity, because this would change the separation size, the only way to accommodate high volumes is to get a group of cyclones working in parallel.

There is a further distinction in the way systems are manifolded. A radial configuration is best for slurries containing coarse solids which segregate in the distribution system. Radial manifolding assures uniform feed and pressure distribution which makes for optimum performance. For slurries that do not segregate, equal feed distribution for all cyclones can be accomplished by mounting the cyclone in line. In an in-line system, the distributing and receiver pipes are designed with gradually reduced diameters so that the feed can be accepted and distributed at approximately even flow velocity. In-line manifolds are cheaper to fabricate and take up less space than radial designs. Differential pressure is critical for proper operation since this provides the energy. The higher the differential pressure is, the more efficient the separation action is. The differential pressure is the drop from the feed pressure to that of the overflow. The hydrothermal process application may be an ideal situation because of the high pressure available from process lines.

Feed from the pump discharge (for our application this is line pressure) is piped into the inlet which enters tangentially to the cyclone cone. The liquid rotates at a high velocity, very much like a whirlpool. Fine solid particles are thrown to the wall of the Type TMC-style cyclone and pass downward and out the underflow discharge. Cleaned liquid spins into the center of the cyclone and is forced upward and out of the overflow discharge.

After numerous discussions with the Dorr-Oliver engineers, it was decided to design a pilot-scale test system with the use of one or more Doxie A stainless steel cyclones connected to the autoclave system charged with coal slurry. The degree of separation will be determined by specific gravity of both solid and liquid, feed solids concentration, and underflow concentration. Cyclones arranged in series may be considered for sharper separations. The goal of the testing will be to determine the optimum feed and underflow concentration required to produce the desired classification or near 60 wt% coal slurries. Figure 4 illustrates the hydroclone test assembly.

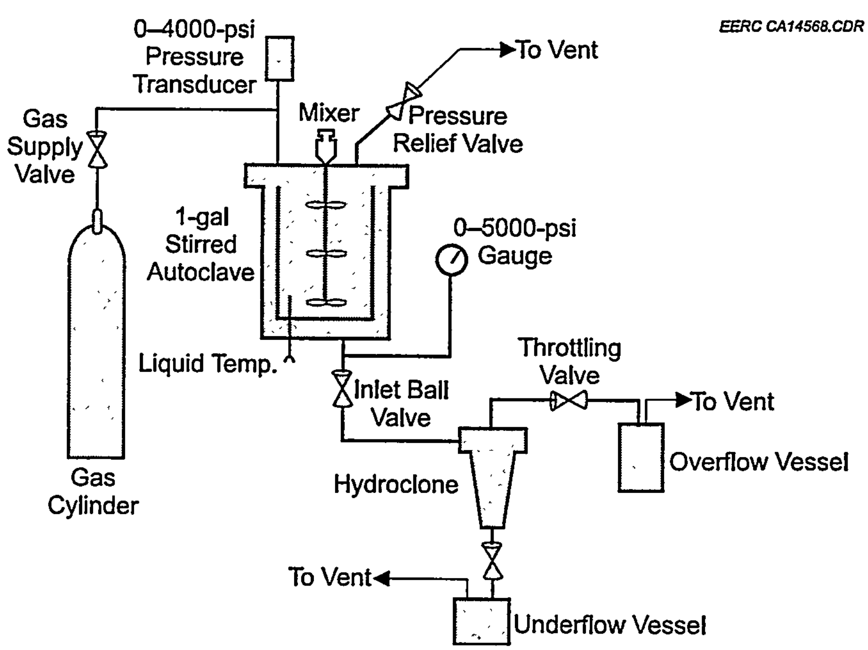

Figure 4. Hydroclone test assembly.

Tests were conducted at 500 and 1500 psig and at 300°C slurry temperature. For the tests without temperature, nitrogen was used to pressurize the autoclave to force the slurry through the cyclone, and valves were used to adjust the back pressure on the underflow. When the slurries were heated, water vapor pressure served to pressurize the slurries. The feed slurries were concentrated to 45 wt% for each test, and coal particle size was −60 mesh. The results indicated that the hydroclone successfully dewatered the slurries at 300°C; however, slurries which were pressurized with nitrogen and not thermally treated did not dewater. Underflow product from hydrothermal tests indicated a 5 wt% increase in solids concentration, with only minor coal loss to overflow stream. Being the processing was conducted with stirred autoclaves, slurry feed conditions were not always the same nor were hydroclone conditions optimized.

5.4 EERC CWF Intellectual Property

Through its extensive development activities, the EERC has been able to optimize the hydrothermal process to maximize desirable slurry characteristics. These efforts have resulted in valuable knowledge that the EERC considers its property. This information includes, but is not limited to, a provisional patent application that was filed on June 14, 1996, entitled "Methods to Enhance the Characteristics of Hydrothermally Prepared Slurry Fuels." The knowledge considered as proprietary information in this patent application includes the effect of shear force and time on the viscosity of hydrothermally treated solid fuel; the effect of temperature on the quality of coal–water fuel produced by hydrothermal treatment; partial dewatering at pressure with hydroclones; and the use of mixed feedstocks, including different particle sizes, to produce enhanced slurries. The patents and technology identified above have been transferred by the Energy & Environmental Research Center Foundation to benefit the state of North Dakota, the University of North Dakota (UND), the EERC, and the inventor and technical staff of the EERC involved in the development. Additionally, the EERC has proprietary knowledge on the scaleup relationship between bench autoclave to pilot- to full-scale systems and the applicability of carbonized slurry fuels to advanced power systems.

5.5 Estimated Process Cost for Advanced CWF Dewatering

Using available computer cost models for hydrothermal drying, the EERC determined "back-of-the-envelope" cost data for adding hydroclones or sieve bends to concentrate coal slurries. Even though hydroclones were determined to be the best options, cost information for sieve bends was added as a cost reference point. In addition, if the EERC can develop a process which treats larger coal particles, sieve bends may be the most efficient, low-cost slurry dewatering option.

Basic assumptions for integration of hydrothermal to IGCC applications was that portions of existing equipment and piping can still be utilized. The EERC highlighted pumping stations, heat exchangers, and dewatering as the main areas which would need retrofitting to hydrothermally treat coal slurries at elevated conditions prior to gasifiying. The estimated capital cost for the retrofit would be $30,000,000 to $40,000,000. The corresponding incremental operating cost for the integrated system for ranges between $0.3/MMBtu to $0.4/MMBtu, assuming 7000 Btu/lb for CWF heat content injected into the gasifier. The operating cost appreciates maintenance, finance charges, electricity, and other plant utility considerations for an advanced dewatering stage. For hydroclones, a commercial-scale assembly capable of treating 1000 gpm consisting of 300 separate hydroclones would cost between $150,000 to $250,000, depending upon materials of construction. The sieve bend option involves reducing system pressure and then particle dewatering. The initial design considered sieve bends in conjunction with a horizontal vibrating screen. The operating cost for this dewatering option is likely to be higher than hydroclones since it requires additional electricity and maintenance costs owing to the more complex depressurization and equipment needs.

6.0 RECOMMENDATIONS

To date, the EERC has conducted limited hydroclone testing with an autoclave test assembly operated in batch mode. Despite initial success, more testing is needed to confirm test conditions and optimize separation efficiencies. The next phase of testing should be completed using the continuous coal–water fuel technology demonstration facility located at the EERC. Instead of flashing the slurry to atmospheric conditions and concentrating with a filter press, hydroclones would replace letdown valve assembly. To reduce chances for excessive erosion, staged letdown may be an option. Upon successful completion of a more comprehensive test plan using the pilot-scale system and refined cost estimates, the technology will be ready for full-scale demonstration and commercial consideration. This advancement in CWF technology should enhance process efficiencies and economics to make hydrothermal CWF an attractive option for gasification and combustion applications. Slurry-fed entrained gasifiers being developed by Dow Chemical and Texaco would be ideal candidates for the new technology. Heat engines designed to fire on slurry fuels are also excellent candidates for this CWF technology.

Testing hydrothermally treated CWF at one of the DOE clean coal IGCC projects would provide additional technical information needed for designing and evaluating such an integrated system. Preliminary cost calculations shown in Section 5.5 for modifying the existing slurry preparation system included in the IGCC design indicate an incremental cost for a 250-MW_e plant in the range of $152 to $176/kW capital investment, depending on the method used to reject water and concentrate the slurry. The corresponding increase in fuel cost (assuming that all incremental capital and operating costs are assigned to the fuel) is in the range of $0.3 to $0.4 per MMBtu, which is within the range of variation in prices for run-of-mine coal.

7.0 CONCLUSIONS

- Sieve bends may not be technically feasible for dewatering hydrothermal products since they require larger coal particle-size distribution. Tests conducted by the EERC indicate that larger coal particles can be effectively treated with a batch mode system.

- Hydroclones, which are specially configured by Dorr-Oliver, may represent the best opportunity to partially dewater the coal slurries at pressure. A slurry-processing system was designed and constructed using hydroclones attached to an autoclave assembly. The circuit was designed to handle 2 gpm of slurry flow at 400°F and 2000 psig. Tests results indicate that both elevated temperature and pressure were required to effectively dewater coal slurries with a hydroclone.

- Pilot-scale subcritical water extraction of fine coal in the continuous mode at temperatures up to 340°C at approximately 2300 psig for extended residence time reduced the sulfur by as much as one-third. In addition, results also indicated removal of more than 87% of Hg and 46% of Se.

- Membrane separation technology was identified as a candidate for dewatering hydrothermal slurries at pressure and temperature. However, available technical information indicated that dewatering coal slurries requires numerous passes through the membranes.

- Provisional patent was developed by the EERC to advance the hydrothermal treatment of low-grade slurry fuels.

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