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SLURRY PUMPING TECHNIQUES FOR FEEDING HIGH-PRESSURE COAL GASIFICATION REACTORS

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ABSTRACT

Operating experience in pumping coal and coal char slurries at pressures up to 1500 psig at the Institute of Gas Technology Pilot Plants will be discussed. Coal feed at rates up to 3.7 tons/hr using aromatic light oil and water mediums have been pumped successfully at solids concentrations as high as 50 weight percent. Slurry preheating and vaporization at temperatures up to 600°F have been achieved with a high pressure char-water slurry feed stream. The design specifications for the mixing tanks, pumps, piping and slurry heaters will be discussed and system operating experience and maintenance will be reviewed. Pressure drops and minimum flow velocity data on water-lignite slurries also will be discussed.

1. Introduction

The Institute of Gas Technology has developed the HYGAS® and Steam-Iron Processes to convert coal to a high-Btu substitute natural gas and for producing hydrogen. These processes require reactor pressures in the range of 1000 to 1500 psig, which is typical of other coal gasification processes for producing substitute natural gas. An integral part of all these high-pressure processes is the mechanism for pressurizing and feeding the coal into the reaction zone. The conventional way to feed solids into a pressurized reactor is to use lockhopper feeding systems. However, lockhoppers require large volumes of pressurizing gas and tend to leak through their pressure sealing valves. These valves must operate under dusty and abrasive atmospheres, while sealing at high pressures. Because lockhoppers had disadvantages in feeding solids to our reactor systems, we decided to investigate using a slurry feed system to pump the coal slurry to high pressure for direct introduction into the reactors.

2. Design Considerations for the HYGAS® Slurry Feeding Systems

The HYGAS Process uses a fluidized-bed contacting system. The preferred solids feed is in the particle size range of 10 to 100 mesh USS., which easily lends itself to feeding solids into the reactor using slurry pumping. Four major areas of design must be considered once the particle size range has been determined for a slurry pumping system.

1. The combined heat balance of the feed and reactor systems must be considered. Dry, pulverized solids are needed for fluidized-bed contacting, therefore, the slurry medium must be vaporized and removed from the solids. The heat duty this requires can be handled in many ways, but it is an important design consideration because the method chosen affects the overall process.

2. Erosion characteristics of the particular slurry must be considered. The systems for piping and pumping, and the components of the overall feed system, must be designed with erosion-resistance in mind.

3. The velocity requirements for the particular slurry must be determined to maintain the proper flow without solids settling and causing plugging in the pipes. However, too high a velocity will cause increased erosion rates and higher horsepower requirements for pumping.

4. Instrumentation for measurement and control of the slurry pumping system must be considered.

The elements of the slurry pumping system which are incorporated in the HYGAS Pilot Plant are shown in Figure 1. Initial heat balance considerations for the HYGAS slurry feed system indicated there was insufficient sensible heat in the reactor itself to evaporate a water slurry and prepare a dry coal feed. Therefore, an aromatic light oil, which is a byproduct of the HYGAS reaction, was selected as the slurry medium. The heat of vaporization for the aromatic oil is approximately 25% that of water and sufficient heat is available in the HYGAS reactor to completely evaporate the oil, if a small amount of preheat is added to the slurry before it is pumped into the reactor.

Char is added (by weighing) to a 3000 gallon slurry mix tank with a top-entering mixer. The slurry is completely pumpable at concentrations of up to about 50 wt % coal or coal char in oil. The thoroughly mixed slurry is withdrawn at the bottom of the mix tank. A low-pressure centrifugal pump circulates the slurry through the suction manifold of a high-pressure positive-displacement plunger pump which pumps it up to reactor pressure. The centrifugal slurry-feed pump operates at a discharge pressure of 25 to 35 psig and has a capacity 2 to 3 times the maximum capacity needed for reactor feed. excess slurry is returned to the slurry mix tank; it aids in the agitation and maintaining a homogeneous slurry. The high-pressure plunger pumps are single-stage, reciprocating, and raise the slurry from the inlet pressure of approximately 25 psig to the reactor pressure of 1000 to 1500 psig. The slurry is pumped through a high-pressure steam heat exchanger to preheat the oil-coal mixture. Then slurry is pumped through a simple spray head inside the reactor and into a fluidized-bed drying zo There, the slurry vehicle is vaporized, leaving the dry coal available for feed into the lower stages of the reactor. The vaporized slurry oil exits with the raw gas stream out of the top of the reactor. It is recovered in downstream condensing and separation equipment and recycled back to the slurry mix tank and remixed with more fresh coal feed.

Initial experiments with the slurry feed system indicated that velocities of 5 to 10 feet/sec were sufficient to keep the slurry thoroughly mixed while in the piping system, thus preventing settling of solids and eventual plugging of the pipes. Therefore, after the feed requirements and total volumetric

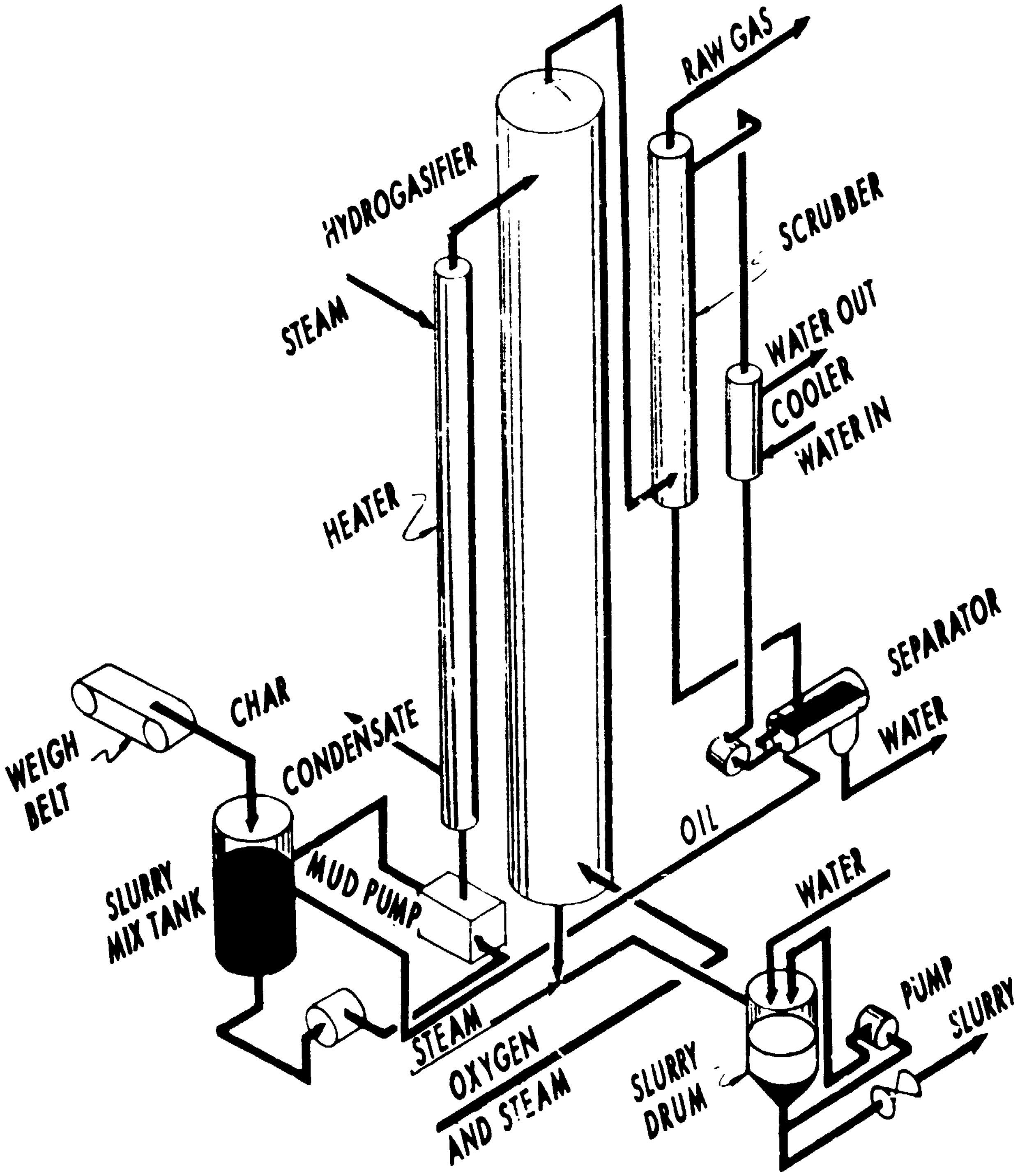

Figure 1. SCHEMATIC DIAGRAM OF SLURRY FEED SYSTEM OF THE HYGAS® REACTOR

flow rates were set by reactor design considerations, the piping was sized to obtain a 5 ft/sec flow rate with an average reactor feed. The piping system layout uses 90 degree directional changes. All control valves and shutoff valves were installed in short, vertical lengths of pipe to prevent accumulation of solids in valve seats if an emergency caused shutdown of the slurry system before it could be properly drained. The 90 degree directional changes were made up of tees and/or crosses. Long-radius elbows with long sweep distances were avoided because of their poor erosion resistance.

Initial equipment specifications of the HYGAS pumping equipment called for a chromia-oxide coating on the impeller and casings of the centrifugal pumps, to combat the erosive conditions we knew would exist. The reciprocating pump was to have polyurethane elastomer check valves; these had been very successful in coal and water slurry pumping systems.

Instrumentation was designed to measure the flow in the low-pressure circulation system using venturi flow meters and nuclear density measurement. The combination of flow and slurry density could then be calculated to give a check on the mass feed rate measured by the weigh belt. We also successfully applied the venturi meters to the high-pressure slurry feed system downstream of the positive-displacement plunger pump.

3. HYGAS® Operating Experience

The slurry feed system used in the HYGAS Pilot Plant has evolved into a highly reliable and maintenance-free operation. However, several initial problems were overcome to obtain the final design configurations routinely used today.

Initially, the low-pressure slurry circulation pumps operated at too high a speed (3500 rpm) and the chromia-oxide erosion-resistant coating was ineffective for the particle size range and the type of slurries being handled. Erosion rate is proportional to a power of the speed: Some investigators have suggested that this could be as high as the fifth or sixth power. We found that reducing the pump speed from 3500 to 1750 or slightly lower caused a significant decrease in erosion rate in the centrifugal pumps. Weld-applied stainless steel or stellite coatings also successfully combated erosion on the impellers and the casing of the centrifugal pumps.

Considerable development effort has been expended to improve check valve designs for the reciprocating plunger pumps. The original polyurethane elastomer check valve material was attacked by the aromatic light oil used in our slurry system and did not hold up at all in operation. The next design used on area-type, metal-to-metal check valve where hardened steel replaced the elastomer. This gave very poor wear resistance and quickly deteriorated. Next, we tried a hemispherical check valve. This gave much better service life; the concept of a line seal rather than an area seal should be used in slurry-pumping systems. The line contact is much less susceptible to hold-up of particles under the sealing surface, which leads to leakage and fast erosion of the check valve parts. Recently, experiments with full ball type check valves in the reciprocating pumps gave very good results. The full ball check valve allows random selection of a different sealing surface for each pump stroke. This prevents the excessive wear on a particular part of the check valve which occurs with the hemisperical-type design.

Carbon steel piping has given adequate erosion resistance and we have had essentially no problems with slurry pumping systems in carbon steel pipe at the 5 to 10 ft/sec velocity.

The instrumentation has worked satisfactorily. Venturi meters have been proven to be erosion-resistant and quite adaptable to measuring slurry flow rates. In adapting any type of a differential pressure meter to this service, it is important that the pressure tap lines to the transmitter be purged with a clear liquid, in our case oil, to keep them free of particles that would plug the taps and interfere with the differential pressure readings.

The centrifugal pumps that we now use are relatively low-speed (1400 to 1500 rpm) and are typically sand or gravel-type pumps constructed of Ni-hard material. They have removable wear plates so that the impellers and certain parts of the wetted end of the casing can be replaced as erosion occurs, rather than applying an overlay of stellite or other hard-faced material to the pump casing directly. All the pumps that we now use have double mechanical seals, which have been flushed with a clear seal flush liquid, rather than packed seals. The mechanical seal is definitely preferred for slurry pumping service.

4. Experimental Data

The oil-coal system used for slurry feeding to the HYGAS reactor is operating quite satisfactorily. However, consideration of other types of slurry vehicle systems led us to investigate a water-coal slurry system. We designed a series of tests to determine the lowest practical velocity for slurry pumping and the maximum concentration of coal in water that could be handled. A test loop was set up as shown in Figure 2. The slurry mix tanks and the positive displacement pumps of the HYGAS Pilot Plant were briefly used and lignite coal-water slurries were prepared in about 15% to 50% coal in water. The test loop consisted of two straight runs of pipe and a series of return bends made up with 90 degree weld ells and 5-foot straight pipe sections. The entire test loop was installed in a single horizontal plane to avoid head differences. We wanted to determine if a minimum velocity existed, at which the slurry solids tend to settle out in the pipeline. We also wanted to determine the pressure drop per unit length of pipe, for design of large-scale slurry systems, to obtain an idea of the horsepower required for pumping. Pressure taps were set up over two of the straight pipe sections and across the return bend section to obtain an idea of the pressure drops there. Data from these tests are presented in Figures 3 and 4. These figures illustrate the typical curves of head loss as a function of velocity of the slurry liquid. The plots are on log-log paper and are compared to the pressure drop exhibited by the system with pure water. The data is fairly uniform and indicates that as the slurry concentration is increased from 17.3 wt % to 53.1 wt % lignite coal in water, the pressure drop increases with the slurry concentration and as a function of the velocity in the pipe. We deliberately studied the low flow range because we were interested in minimum velocity requirements. At the lowest flow rate obtainable with the given equipment, slightly less than 2 ft/sec, no plugging occurred because of settling of solids from the flowing stream. Our general conclusions are that velocities as low as 2 ft/sec are sufficient for the particle size range used in these tests and for up to about 50% coal in water.

The particle size range is shown in Figure 5 for three samples selected from the slurry mix tank at different time periods. All of these data were accumulated over a two-week period and the slurry was simply returned to the mix tank after it had gone through the test loop. We sampled the slurry at the start, the middle, and the end of the test series. There was very little deterioration of the slurry particle size through impact and erosion; for all practical purposes the materials are identical. The average particle size range was between 35 and 45 mesh.

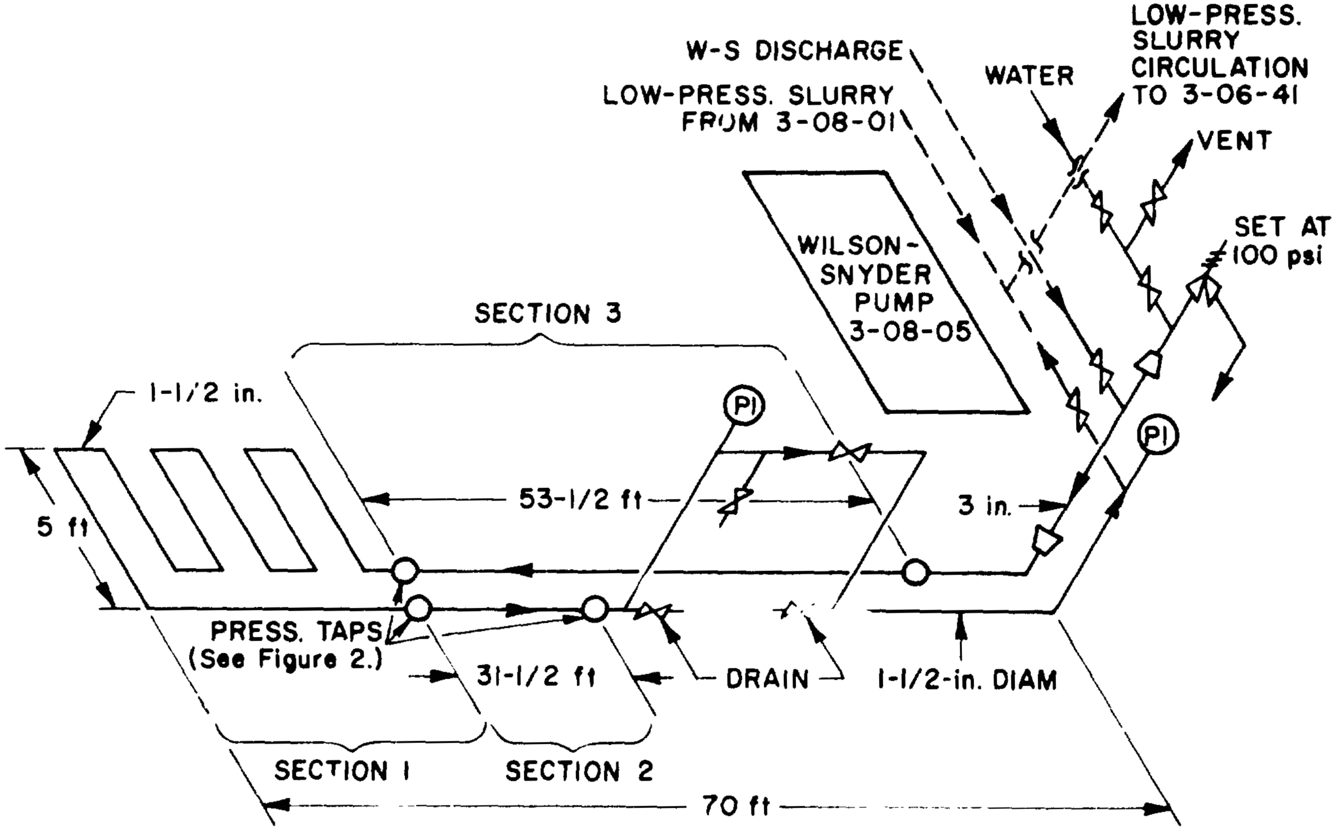

Figure 2. SLURRY TRANSPORT TEST LOOP

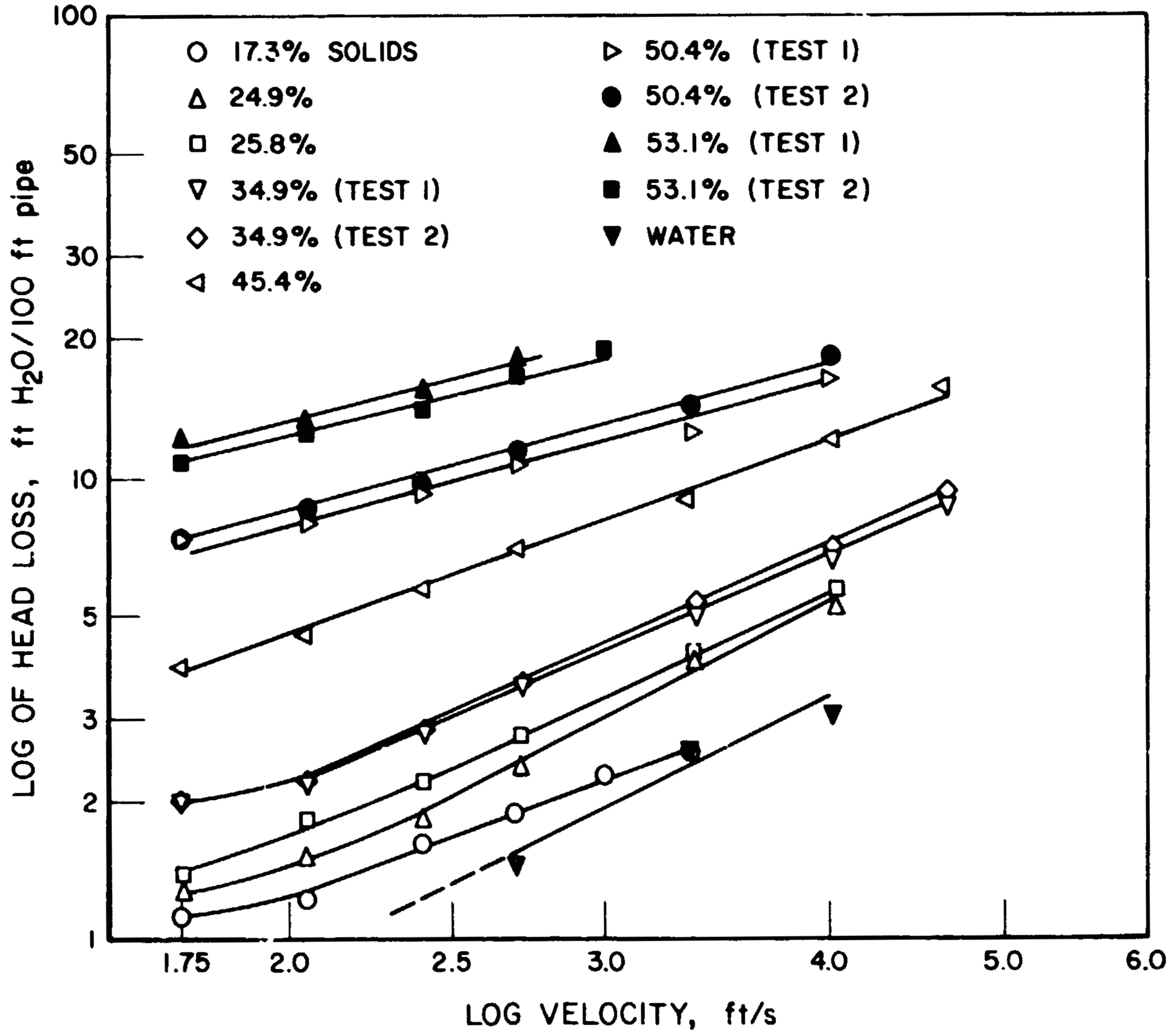

Figure 3. PRESSURE LOSS OF LIGNITE-WATER SLURRY IN 1-1/2 in. SCHEDULE 80 PIPE – DIFFERENTIAL PRESSURE INDICATOR 1

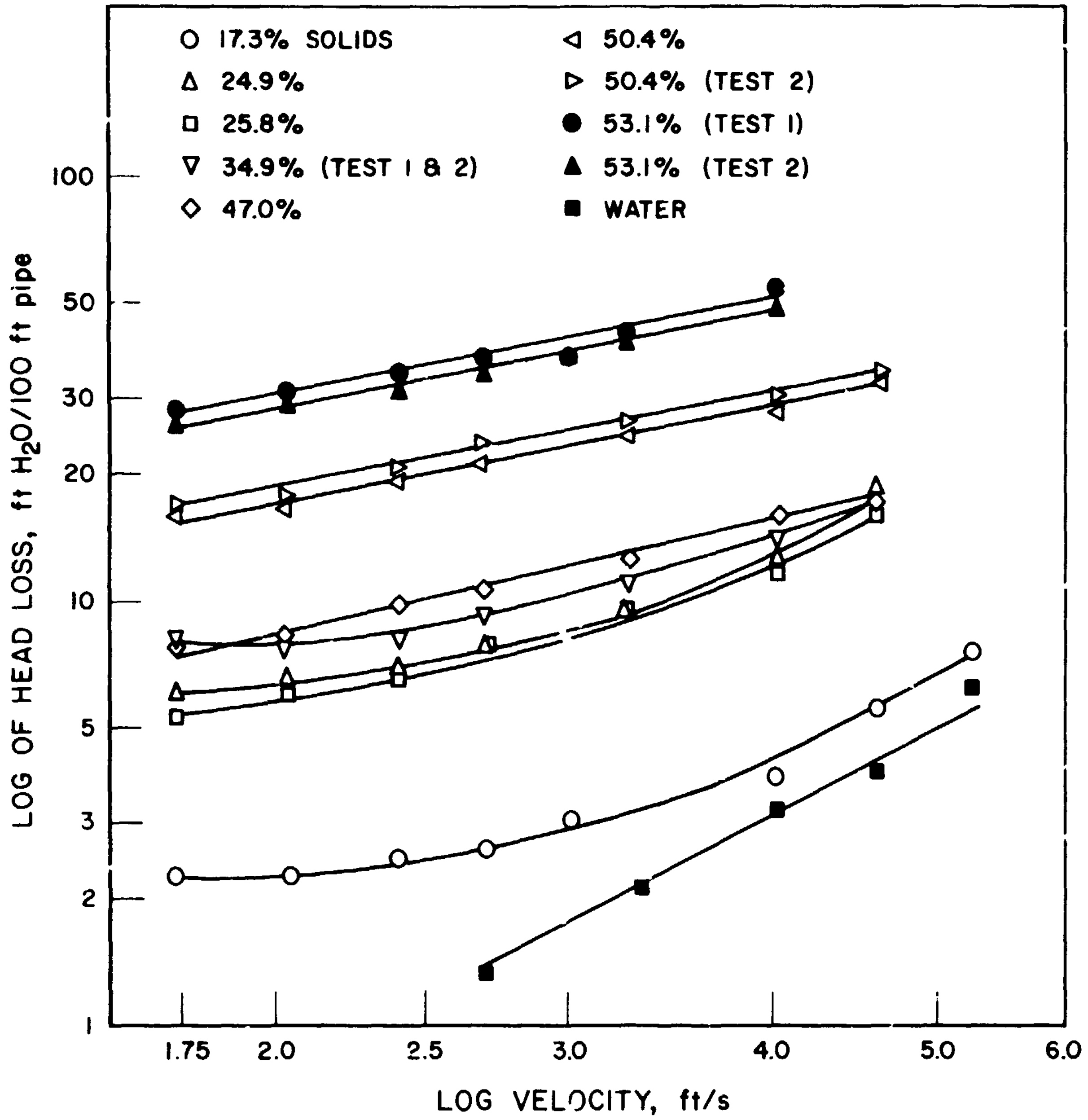

Figure 4. PRESSURE LOSS OF LIGNITE-WATER SLURRY IN 1-1/2 in. SCHEDULE 80 PIPE – DIFFERENTIAL PRESSURE INDICATOR 2

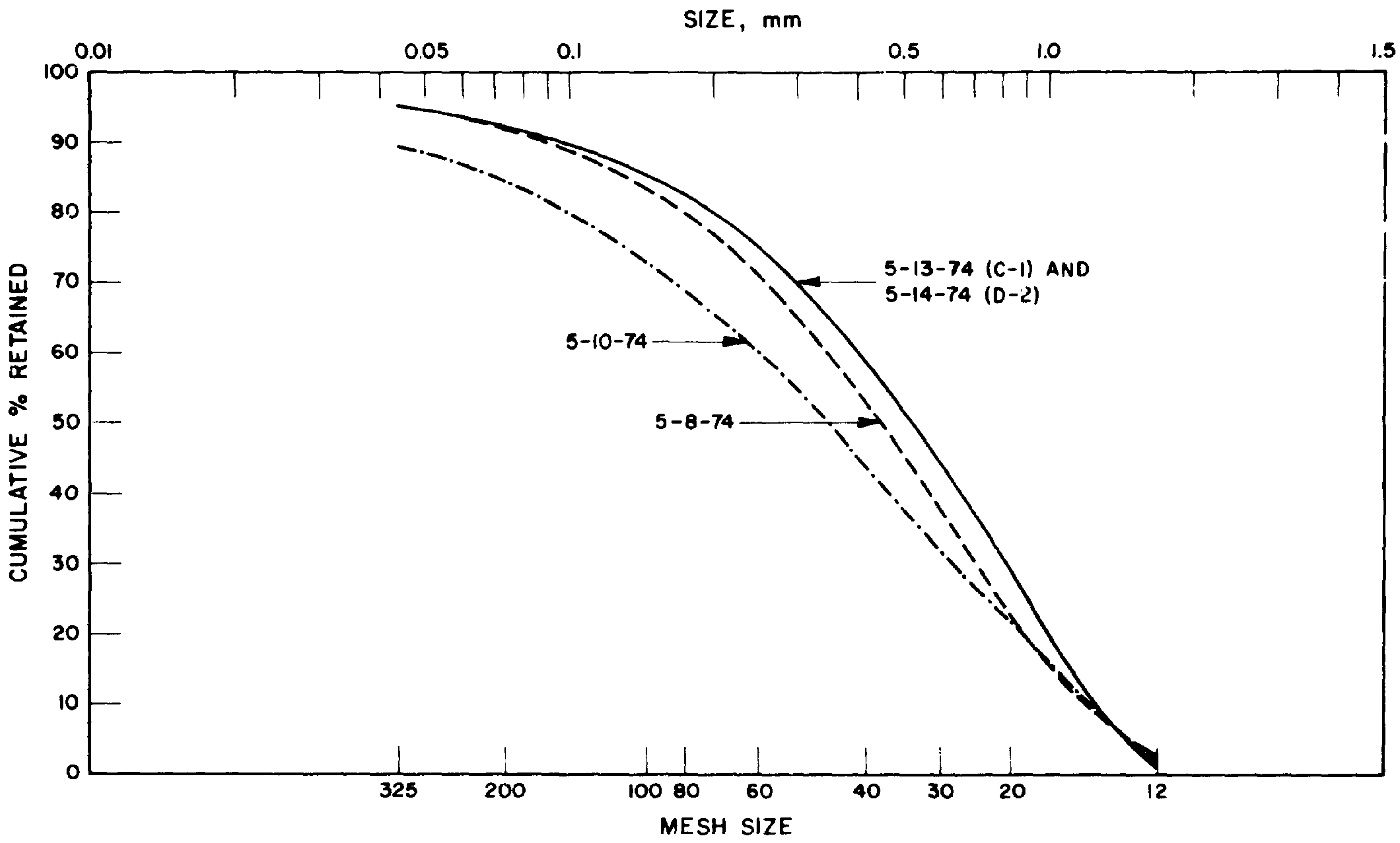

Figure 5. TYPICAL PARTICLE-SIZE DISTRIBUTION

We found pulsation dampeners highly desirable on the suction and discharge lines of the positive-displacement reciprocating pumps. The original piping system for the pilot plant did not contain these pulsation dampeners. Excessive vibration problems occurred during several tests, especially at extremely high slurry-feed rates. Pulsation dampeners were later installed on both the suction and discharge lines. The discharge dampener was fabricated from a 2-foot piece of 6-inch Schedule 160 pipe and installed in a vertical position,as close as possible to the actual pump discharge. A high-pressure nitrogen cushion is maintained in the top of the dampener by adding nitrogen as necessary. The low-pressure suction stabilizer is a 2-foot section of 8-inch schedule 40 carbon steel pipe installed in the pump suction line, as close as possible to the inlet. Again, a blanket of low-pressure nitrogen is maintained on the top of the pulsation dampener to provide a cushion for volumetric changes.

5. The Steam-Iron Slurry Feed System

Unlike the HYGAS pilot plant, the Steam-Iron pilot plant uses a slurry vaporizer in its high-pressure char feed system. Vaporizing the slurry water allows the direct feeding of dry char to a high-pressure producer reactor. This moves the evaporative heat load from the producer reactor; in commercial operation the high-level heat in the producer off gas could be used for other purposes. This would allow using low level plant heat to evaporate the slurry medium. In the Steam-Iron pilot plant, however, the slurry vaporizer is fired with natural gas because the objective is to prove system operability, not demonstrate heat economies.

Figure 6 shows the location of the slurry vaporizer in the char feed system. The char-water slurry is prepared in a mix-tank and the slurry is pumped to high pressure using equipment similar to that described for the HYGAS process. The char-water slurry is fed to the bottom of a helical coil contained inside an 11-ft diameter, 30-ft high, refractory-lined fired heater. Here, the water is vaporized and the resulting steam transports the char 100 ft, to the top of the producer reactor. The heater is designed to supply about 50°F superheat in the exit steam to inhibit condensation in the exit piping. In addition, the exit piping is steam-traced for winter operation.

The temperature of the slurry heater is controlled by the exit steam temperature, which is used to adjust the firing of 4 burners located in the base of the slurry heater. The burners are automatically shut down by a safety switch located in the stack of the slurry heater.

In operation, the approximately 200 psi pressure drop across the slurry heater means the slurry pump system operates at about 1200 psig when the producer operates at 1000 psig. Discharge pressures and flows of the high-pressure slurry pumps are continuously measured. Excessively high discharge pressures (indicating the onset of plugging within the coil) or high flow (indicating tube rupture), will automatically shut down the system. In shutdown, the slurry feed system is isolated from the reactor system, the high pressure pumps are shut down, and the fuel to the slurry heater is cut off. After a 10-second delay, the entire contents of the slurry coil and exit piping are rapidly discharged into a high-pressure holding pot located upstream of the slurry heater. This procedure effectively back-blows the coil and tends to dislodge any plug which may have formed. It also prevents possible sintering of a plug which would otherwise overheat because of the large quantity of heat stored within the coil and the refractory walls of the furnace.

The helical coil consists of three sections with increasing internal pipe diameters. The bottom coil preheats the slurry to its vaporization temperature. The middle coil supplies the evaporative duty and the final coil superheats the steam above its boiling point. The preheat portion of the coil is standard 1-1/2 inch Schedule XX pipe with a 1.100-inch internal diameter. This pipe size was chosen to ensure a velocity of 2 to 5 ft/s; this had been previously determined as the minimum velocity necessary to prevent settling of the char over the range of operating conditions expected. The top portion of the coil is 2-1/2-inch Schedule 160 pipe with an internal diameter of 2.125 inches. This diameter was chosen to limit the exit steam velocity to about 25 to 50 ft/s and thereby minimize erosion in the exit transport piping system. The middle portion of the coil is 2-1/2-inch Schedule XX pipe with an internal diameter of 1.7[illegible]1 inches. All piping within the heater is 1-1/4 chrome-1/2 moly steel (ASME SA 335-p 11). Stainless steel construction was unnecessary because operating temperatures will be below 650°F.

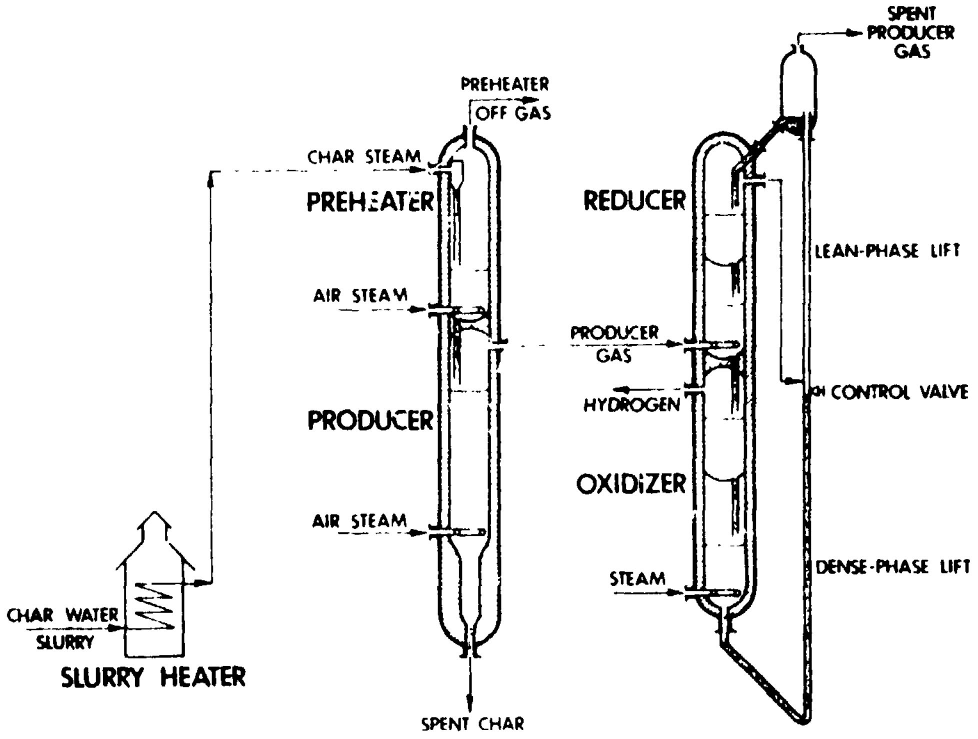

Figure 6. LOCATION OF SLURRY VAPORIZER IN THE STEAM-IRON SYSTEM

As in the HYGAS plant, all turns in the external piping are made with crosses instead of elbows. These allow rodding of the pipe in both directions and, more importantly, provide a pocket of solids which forms its own elbow for the high velocity char. This design greatly minimizes erosion which would be severe if regular piping elbows had been used.

The slurry heater is designed to feed from 1 to 206 tons/hr of char at concentrations of 20 to 43 wt % solids and at pressures of 500 to 1000 psig. Operating velocities range from 2 to 5 ft/s at the inlet to 25 to 50 ft/s at the exit. The inlet velocity is sufficient to prevent settling of the char and subsequent plugging for char particles ranging in size from 10 to 80 mesh. The exit velocities are sufficient to transport the char in lean-phase through the exit piping to the top of the producer reactor, but are low enough to minimize erosion of the transport piping. In designing the coiled heater, heat transfer coefficients similar to those for preheating and vaporizing water were used.

The coil was initially tested using coke and with direct discharge to the atmosphere. This testing at low pressure caused excessive velocities in the super heat coil section and portions of the uppermost coil were eroded. This coil was replaced and operating pressures were increased to within the design range using a temporary restriction orifice.

In subsequent operations, the system was reconnected to the reactor and the slurry vaporizer has worked very well. Complete vaporization has been achieved at char feed rates up to 1.75 tons/hr and concentrations up to 32 wt %. Accumulated operating time to date has been about 2000 hours with steady-state periods as long as 200 hours. Overall operation of the system has been very smooth and only momentary plugging of the coil has been experienced. In all instances, the plugs were easily cleared.

6. Conclusions

A vaporizing water-slurry feed system and a nonvaporizing oil-slurry feed system have been successfully applied to high-pressure coal gasification reactors. Initial operating problems have been overcome and valuable data on slurry-system design has been obtained. Slurry systems will have many applications for solids feeding in the emerging high-pressure coal processing technology.

7. Acknowledgements

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