

# LOCK HOPPER VALVES FOR COAL GASIFICATION PLANT SERVICE

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One complication common to most coal gasification processes presently under development or at the pilot plant stage is the injection of coal solids into a reactor vessel which is under significant pressure (generally in the range of 400 to 1600 psi or 28 to 110 bar). Similarly, spent solids, some of which are valuable by-products of the conversion process, must be removed from the high-pressure reactor vessel to some lower pressure for further processing or disposal. Among the variety of schemes presently used for accomplishment of these tasks, the lock hopper concept is probably the most widely accepted and simplest form.

Although details and equipment requirements of the lock hopper concept may differ from plant to plant, the operating principle generally involves use of pressure equalization and grav-

ity movement of the solids in question. A schematic showing one example of the operating principle is in Figure 1.

Coal, or other reaction material, is loaded into a holding bin, typically referred to as a weigh hopper, at atmospheric pressure by conveyor or other transport means. Valves A and B are in the closed position and the lock hopper between the valves is at atmospheric pressure. Valve A is opened and the solids fall from the weigh hopper to the lock hopper. Upon depletion of the solids from the weigh hopper, Valve A is closed and the lock hopper is pressurized to the reactor vessel pressure using inert gas. Valve B is opened and the solids flow into the reactor vessel. Valve B is closed and the lock hopper is depressurized for the subsequent feed cycle. Cycling continues according to the charging requirements of the

reaction process.

Removal of spent solids from the reactor vessel follows a reversal of the feed cycle. With Valves C and D closed, the lock hopper between them is pressurized to the reactor level. Valve C is opened and the spent solids fall from the reactor to the lock hopper. Valve C is closed and the lock hopper is depressurized. The spent solids are exhausted to atmosphere or a transport system by opening Valve D. Typical systems involve some type of quenching of the char before the lock hopper valves, but char discharge service inherently involves higher temperatures than coal feeding. It may be understood that there are many detail variations in design of lock hopper systems. Common features are the need for valves which must withstand high pressures when closed but must operate (open

and close) only at a zero or relatively low differential pressure. In each valve the flow of solids is in one direction only, but it is the direction of increasing pressure in coal feed valves while in the direction of decreasing pressure in char discharge valves.

Although the operating principle of the lock hopper system can be seen to be extremely simple, valve applications involving this service for coal gasification plants are likewise extremely difficult. The difficulties center on the requirement of handling highly erosive pulverized coal or char (either in dry or slurry form) combined with the requirement of providing tight sealing against high-pressure (possibly very hot) gas. Operating pressures and temperatures in these applications typically range up to 1600 psi (110 bar) and 600F (316C), with certain process requirements going even higher. In addition, and of primary concern, is the need for reliable operation over long service periods with the provision for practical and economical maintenance. Currently available data indicate the requirement for something in the order of 20,000 to 30,000 open-close cycles per year and a desire to operate at least that long without valve failure.

### Rockwell Approach

The Rockwell International interest in new valve developments for coal gasification plants was stirred in the early part of 1972 by inquiries concerning valves for coal and char lock hopper service. Since these inquiries involved applications in relatively small pilot plants, many of the requirements were found to have possible satisfaction by incorporation of customizing features into existing product lines. However, when the size range of valves required for full scale plants was recognized, it became clear that many valves considered suitable for pilot plants would not scale up practically. Consequently, evaluation of the fundamental needs for full scale plant valves was undertaken.

It was recognized that certain fundamental elements of similarity existed between problems involved in this application and those encountered in the development of primary coolant valves for the Fast Flux Test Facility (FFTF). The hostile internal environment (molten sodium) inspired a new concept in gate valve design which provided for rotary transport of the closure element to and from the seat to minimize the need for sliding of functional components against one another. These valves, like the lock hopper valves, have the requirement to provide a clear through-port in the open posi-

tion and tight sealing at high temperatures in the closed position.

It was believed that operating requirements for high-pressure lock hopper valves would yield more readily to this type of approach than to any attempt at adaptation of conventional valve concepts which are generally characterized by their reliance on substantial relative motion of contacting or closely proximate operating parts.

### Basic Concepts

Basic concepts in Rockwell's lock hopper valve development program had their beginning with the approach shown in Figure 2. Problem solving efforts were focused primarily on the pulverized coal feed system, in which flow of material is in the direction of gate opening and applied pressure differential is in the direction of gate closing. Valving for other systems in the gasification process, in which material flow and pressure differential are in the same direction, were de-emphasized temporarily with the view that their solution hinged upon this primary effort.

It should be pointed out that certain practical considerations are inherent in the Rockwell concept approach. Opening of the valve is assumed to occur with zero or very low gate differential pressure. Closing of the valve is assumed to occur in the absence of falling coal. Neither of these requirements are believed to pose serious system design problems. The latter, which is possibly the more difficult to achieve, can generally be handled with proper valve sequencing. For example, if Valve A in Figure 1 is closed only after the weigh hopper is empty, there is no problem. However, assurance of meeting this requirement can be accomplished by inclusion of a "dirty valve" preceding the lock hopper valve for the purpose of shutting off the solids stream. This component could be of relatively simple design, since it would not be subject to differential seat pressure.

Recognizing that the high cycle life demands on the valve require extreme attention to all areas of potential wear, the reference design attempted to illustrate in a simplified manner, methods of possible solution. The potential wear areas can be considered in three categories: (1) seating surfaces; (2) internal closure element transport mechanism, and (3) stem seal surfaces.

To protect seating surfaces, the reference design provides straight lifting and lowering of the gate from and to the seat. Additional protection

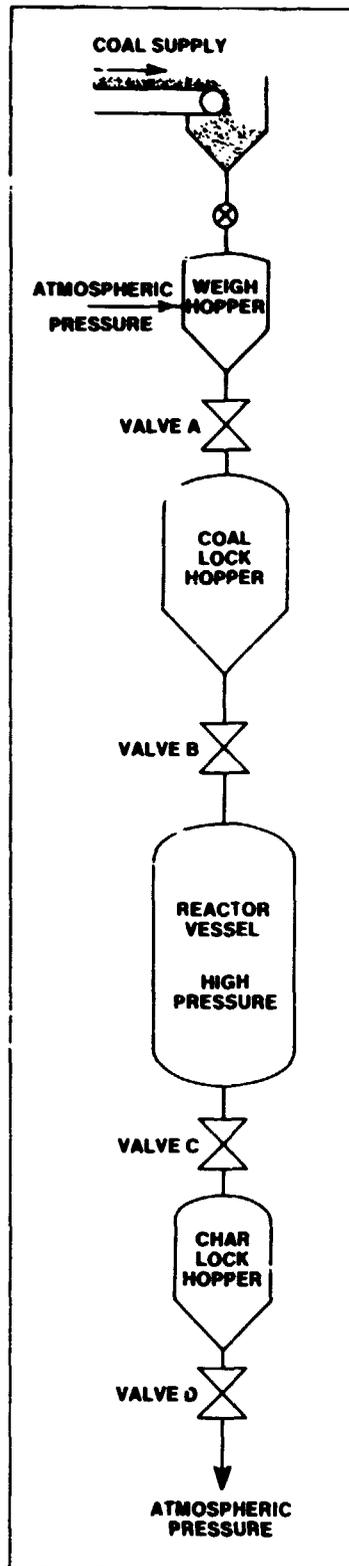


Figure 1:  
Schematic of Lock Hopper system.

against damage is supplied with the provision for a clean gas purge of the local seating surfaces during closure prior to the instant of contact. Possibilities of local distortion from thermal expansion or mechanical loadings are minimized by use of maximum center-line symmetry in the design of both the seat and gate. The principal seating force is provided by contained pressure and by local design of the seating surface, therefore, optimization of seat contact stress is possible for every size and pressure.

To provide a clear through-port in the open position, it is necessary to transport the closure element from its seated position to an alternate position outside of the flow stream. By use of rotation rather than translation, the reference concept minimizes the force-distance parameter of the required bearing surfaces, and makes it convenient to provide substantial protection against the contamination of the bearing interface by coal or char particles. The provision for positive clean gas purging of the journal bearings maximizes the effectiveness of this protection.

Since sealing force is provided primarily by the pressure differential on the gate, mechanical loading on the journal bearings is limited basically to the weight of the hinged parts, plus a moderate margin to insure tight seating when differential pressure is low. This makes it possible to provide for generously proportioned bearing surfaces, with relatively low contact loading. Since service temperatures

preclude the use of organic lubricants, a dry bearing of suitable material was contemplated to provide adequate wear life.

In the matter of stem seals, it is apparent that the problem of preserving a satisfactory seal over an extreme cycle life can be more easily handled with a fractional turn rotating stem than with a long-travel translating stem. Rockwell's experience and comprehensive experimental programs involving performance of packing materials at elevated temperatures provided confidence in obtaining a solution to this problem area.

A key observation, with regard to the reference design of Figure 2, is that the concept lends itself to quantifiable scaling between prototypical small valves and larger valves, which may ultimately be used in full scale coal gasification plants. It follows, therefore, that experience gained with any reasonably-sized valve in a pilot plant application could be extrapolated to apply to much larger valves in full scale plants.

### IGT Valve Test Program

During the latter part of 1973, Rockwell proposed a cooperative valve test program with the Institute of Gas Technology (IGT) in Chicago, Illinois, to demonstrate the working principles involved in the above conceptual approach to coal gasification lock hopper valving.

IGT is a research and educational organization affiliated with the Illinois Institute of Technology. It specializes

in development of energy systems, economic evaluation of comparative systems, and dissemination of this information to a diversified group of industry, international and government clients. IGT has one of the largest total programs underway in the world for conversion of coal to synthetic pipeline gas via three alternate HYGAS processes.

An agreement was reached to test two size 3 "scale model" valves in a simulated coal feed lock hopper system operating between atmospheric and 1000 psig (69.0 bar) pressures and ambient temperature. Rockwell agreed to furnish the two valves mounted in a lock hopper simulator complete with controls for sequencing the operation and pressure cycling. IGT agreed to furnish a coal feed mechanism to the lock hopper entrance valve, the pressurizing medium source, a dummy reactor vessel and technicians for operating and monitoring the tests. The IGT test program was viewed as an important "ground breaking" effort in providing valuable technical and marketing support in the event of future demands for lock hopper valves.

Work was begun immediately in an effort to deliver and have the valves ready for testing in the midpart of 1974. The valves were designed and detailed at the Rockwell Valve Engineering and Research Headquarters in Pittsburgh and fabricated at its Kearney, Nebraska, plant. While the valves were being fabricated, the bearing/seal arrangement utilized in the valves was cycle tested in a laboratory mockup under simulated operating conditions, and the control system for the lock hopper simulator was designed and fabricated. Upon valve delivery in Pittsburgh, the lock hopper simulator was completed and the operating system debugged. The assembly was then subjected to operational tests on coal at IGT which were closely monitored by IGT and Rockwell personnel.

### From Concept to Design

The size 3 prototype lock hopper valve design shown in Figure 3 was the result of an engineering study based on foreseen requirements of future full scale coal conversion plants in which typical lock hopper valves may be required in size 24 or larger. Basic features of the valve were developed from the "reference" design discussed earlier. Essentially, the size 3 valve is a "scale model" of a larger valve. Deviations from the "scale model" ideal were necessary in the valve body closure area because of the practical necessity of handling internal parts manually at assembly, however, all functional

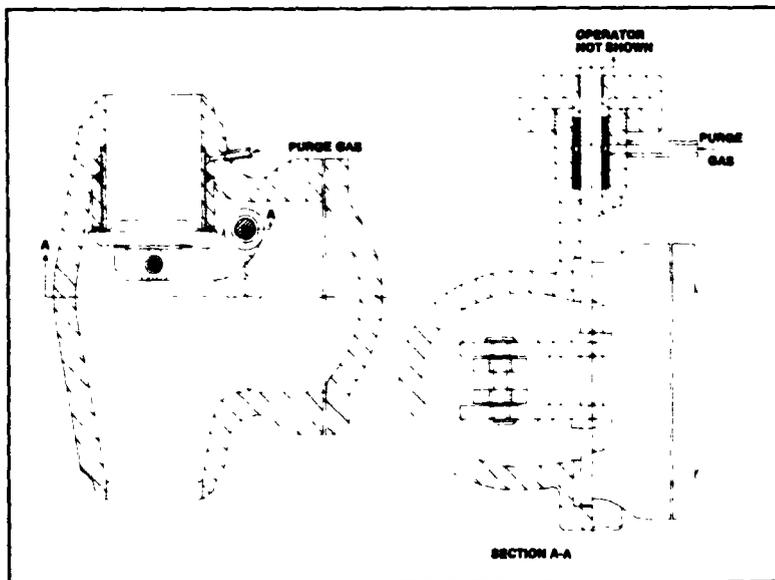


Figure 2:  
Rockwell conceptual approach to Lock Hopper valving.

parts were to scale.

No specifications were issued for the valve other than requirements of size and ANSI rating of the body and end flanges. Class 900 was designated for conservatism because of the abrasive internal environment and the long term pressure cycling to which the valves would be subject. Actual operating conditions for the valve called for pressures of atmospheric and 1000 psig (69.0 bar) and ambient temperature.

The materials of the valve and trim construction are in most instances carbon steel. A 17-4 PH stainless steel was selected for the stem to utilize its high yield strength in obtaining a smaller diameter in addition to its corrosion resistance. Selection of 316 stainless steel for the stuffing box spacer and lantern rings was also based on corrosion resistance qualities. Cobalt-washed stellite hardfacing was chosen for the seating areas as well as the gate/pin bearing because of its high strength, wear resistance and machinability.

Operating requirements imposed on actual plant valves were of primary importance in selection of stem seal and bearing materials. A carbon-graphite material was selected for the bearings because of its high-temperature resistance, self-lubricating properties, low coefficient of friction, and good load carrying qualities. In a similar manner, an all-graphite material was chosen for the stem packing because of its wear qualities, high temperature range, and exceptional sealing characteristics.

Each valve was furnished with a pneumatic, quarter-turn operator. The only direct force acting against opening or closing the valve is friction developed by the stem packing and bearings and inherent friction in the operator itself. The valve was designed to open

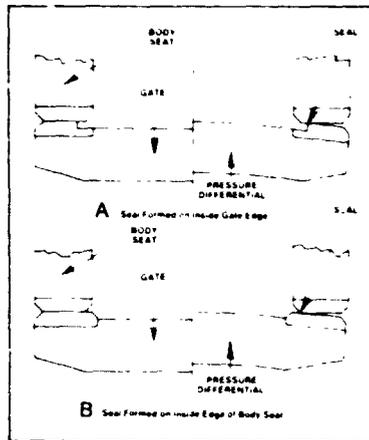


Figure 4  
Lock Hopper valve seating arrangements showing exaggerated effects of pressure

with no pressure differential across the gate and close in the absence of falling coal. In order to achieve initial gate sealing at pressures below the design level, the gate is loaded through the operator to achieve a predetermined seating force. Through proper design of operator control valving, quick opening was accomplished so that gate contact with falling coal was essentially eliminated. Slow closing was employed to insure proper timing for the seat purge cycle and to avoid unnecessary impacting of the seating surfaces.

The basic seating arrangement employed in the valve is a "flat" seat. This feature, more than any other, was a source of questioning and discussion by proponents of a "line" contact seal. It is concluded that a line seal would be more gas-tight in a clean gas medium or where only a few sealing/unsealing cycles are required (as in a gasket); however, durability of such a seal in a frequently operated valve in an extremely dirty environment is question-

able. As designed, the sealing surface incorporated in the valve does in fact tend towards line contact under elastic deflection of the gate upon application of pressure. This type of seal has been demonstrated to be more resistant to degradation in service than a seal depending on an initially highly stressed "knife edge."

Two different arrangements were employed in the seat design as shown in Figure 4. Figure 4A produces an immediately higher stressed seating by the reduction in area. In operation, the seal is formed on the inside edge of the gate seat. Figure 4B has slightly more seating area and thus produces a lesser contact stress and sealing is accomplished on the inside edge of the body seat. Both arrangements exhibited good sealing qualities during preoperational and operating tests. Tests on air at 1000 psig (69.0 bar) gave leakage

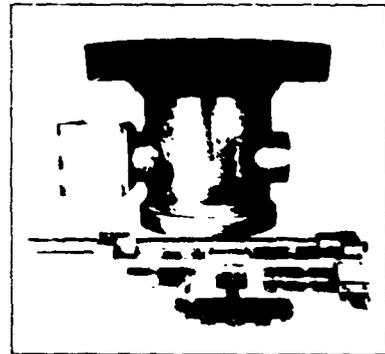


Figure 5  
Fixture used in testing the effectiveness and durability of the stem bearing/seal arrangement

rates of well under 1 scfh ( $2.83 \times 10^{-2}$  scmh) on the "as built" valves.

An important feature contributing to success of the valve seating arrangement is the method of attachment of the gate to the pivot arm. The gate is provided 360° of freedom in the plane of seating. This is accomplished through the use of a modified ball and socket joint which permits the gate to "find" the body seat in the event of misalignment.

The stuffing box arrangement of the valve is somewhat unconventional and deserves attention. At first glance, cost savings appear possible by dead-ending the stem internally rather than providing a seal arrangement for both ends. However, symmetry in body design was considered as utmost in importance in preventing unbalanced elastic and thermal deformations during valve operation. In addition, the design produces a pressure balanced stem and eliminates the need for lock-

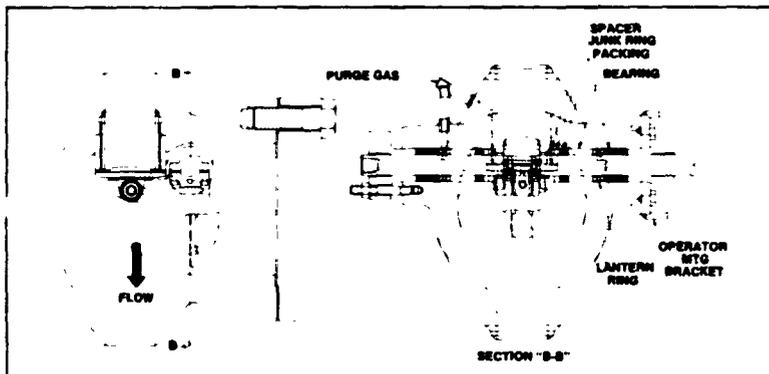


Figure 3  
Sections thru Size 3, Class 900, Lock Hopper valves which were cycle tested at the Institute of Gas Technology

ing devices and thrust bearings. Further, the symmetrical body affords the possibility that either "right hand" or "left hand" operators might be furnished as a convenience in production valves.

Two internal packing rings act as dirt seals for the bearings. The bearing compartment between the divided packing arrangement is pressurized at some level higher than the valve internal pressure. Any leakage that may occur past the dirt packing, therefore, is towards the inside of the valve which further acts in keeping the bearings clean. Junk rings, like the bearings, are a carbon-graphite composition and spacer rings are provided to eliminate shear loads on the junk rings.

### Bearing/Seal Testing

Prior to complete valve fabrication, the effectiveness and durability of the stem bearing and seal design was tested in the laboratory mockup configuration shown in Figure 5. The arrangement and dimensions of all working parts were made identical to those used in the actual valve.

Pulverized coal (acquired from the U.S. Bureau of Mines at Bruceton, Pennsylvania—presently ERDA) was loaded into the fixture and kept "stirred-up" during cycling by a paddle arm arrangement to simulate an operating plant valve internal environment. Torque and bending loads were imposed on the stem through the oper-

ator and a stop which engaged the paddle arm at a location equivalent to the moment arm distance between the stem and body seat of the actual valve. Loads applied were equivalent to the foreseen operating loads of the size 3 valve.

A 20,000 cycle test was performed on the mockup. External gland leakage throughout the test was negligible, and the bearings remained free of coal dust particles and showed no evidence of developing excess clearances. Final inspection of the stem, packing and bearings revealed no unusual signs of wear or damage. The test verified the effectiveness of the bearing purge in keeping the bearings clean of coal particles and demonstrated the durability of the bearing arrangement and stem packing over a long service period of cyclic loading.

### Lock Hopper Simulator

The lock hopper simulator consisted of the two size 3 valves mounted in series with the space between the two valves being used to represent a lock hopper at the coal feed side of a typical gasification plant. The two valves were operated and sequenced through a pneumatic control system which was part of the total assembly supplied by Rockwell. The simulator was designed for installation between a dry coal feed unit operating at atmospheric pressure and a dummy reactor collection vessel operating at a constant 1000 psig (69.0 bar). These latter

units were supplied by IGT. Coal travel was accomplished by gravity feed and the valves were installed with their flow passages vertical.

Figure 6 shows valve working pressures as a function of lock hopper cycle events. Body pressure of the top valve (Valve "A") fluctuated from atmospheric to 1000 psig (69.0 bar) which was the reactor pressure. Bearing purge pressure of Valve "A" always remained higher than the body pressure. Seat purge pressure remained at atmospheric except during Valve "A" closing.

Body pressure of the bottom valve (Valve "B") remained constant at the reactor level (1000 psig or 69.0 bar). Bearing purge pressure of Valve "B" remained constant at a predetermined level above the reactor pressure. Seat purge pressure followed the body pressure of Valve "A" except during Valve "B" closing.

Basically, operation of the system was quite simple. While the top valve was at atmospheric pressure, it could be opened to allow coal to enter the lock hopper compartment. Upon closing, the compartment was pressurized to the same level as the reactor vessel. The lock hopper outlet valve could then be opened to allow coal to enter the simulated reactor vessel. Opening and closing of both valves was, therefore, accomplished in the absence of gate pressure differential.

Figures 7 and 8 show the lock hopper simulator which was built by Rockwell and tested at IGT.

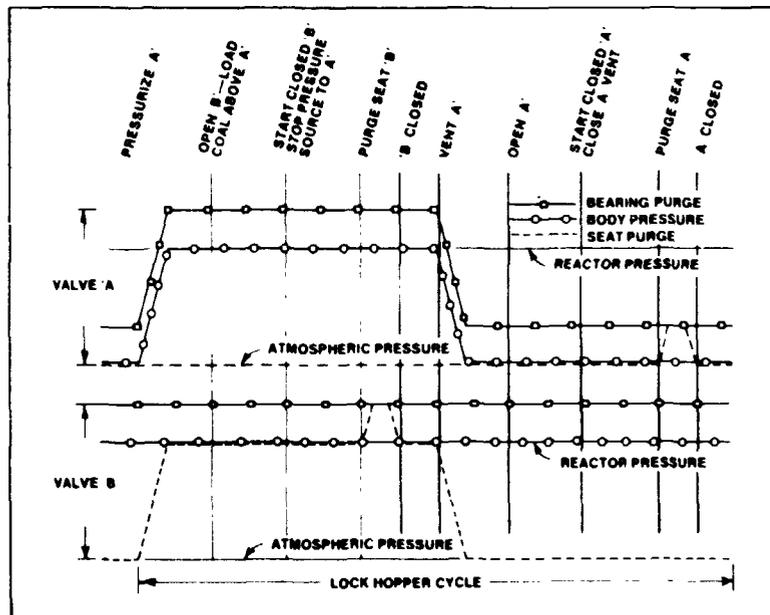


Figure 6  
Valve working pressures as a function of Lock Hopper valve cycle events

### Functional Testing

During the latter part of 1974, final installation and initial dry run cycling of the assembly described above were performed at IGT. Although the control system had been previously operated and adjusted at Rockwell's Pittsburgh location, additional runs were necessary to insure proper system sequencing and to train personnel on operation procedure. More than 600 cycles were made on the assembly at design pressures but without coal. Some problems were intermittently experienced with system hardware, but these were generally minor in nature and easily corrected.

The assembly was subjected to cycling with coal over a period of several months. Operations generally proceeded eight hours a day, five days a week, with interspersed downtimes for leak rate testing, system hardware adjustment, and various other reasons generally unrelated to the test valve performance.

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Figure 7:  
Control panel view of the Lock Hopper simulator ready for shipment to IGT.

Valve seat leakage tests were accomplished in the following manner. All flow passages upstream (to the direction of coal flow) of the seat to be leak tested were sealed to the atmosphere, and a flow meter was connected directly to the area above the seat through the seat purge port. Valve body pressure was increased slowly while leak measurement readings from the flow meter were recorded. Data was collected at various pressure levels up to the 1000 psig (69.0 bar) design pressure.

Performance of both valves during the functional tests with coal were closely monitored. Operation was continuously smooth and trouble-free. Stem packing and seat leakage tests were made at prescribed intervals with results which were very encouraging. Stem leakage remained negligible and packing gland adjustment was required only once—on the top valve at the operator side. Bottom valve seat leakage remained constantly moderate and top valve seat leakage was undetectable for most of the test span. After approximately 3600 coal feed cycles, bottom valve seat leakage was measured at 21.8 scfh (0.62 scmh) at 1000 psig (69.0 bar) seat differential.

The test was stopped after 4400 coal feed cycles (actual operating cycles on each valve exceeded 5000) when the seat leakage rate of the lower valve (valve at entrance to reactor simulator) became excessive (over 200 scfh or 5.7 scmh). The higher seat leakage rate of this valve was later determined caused by an inadvertent error

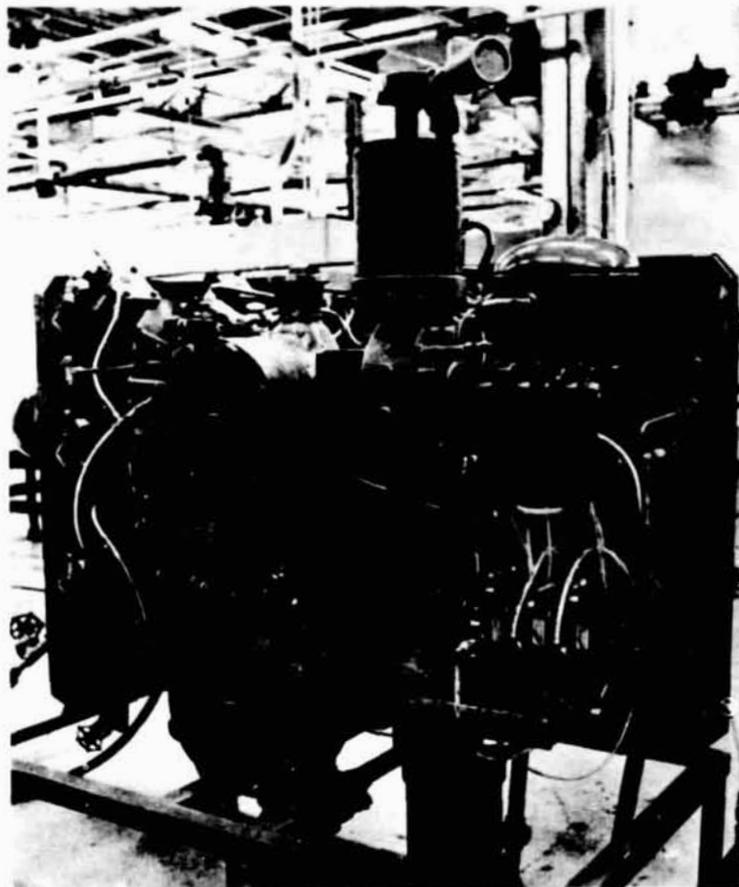


Figure 8:  
Control system view of the Lock Hopper simulator showing the two valves used in IGT tests.

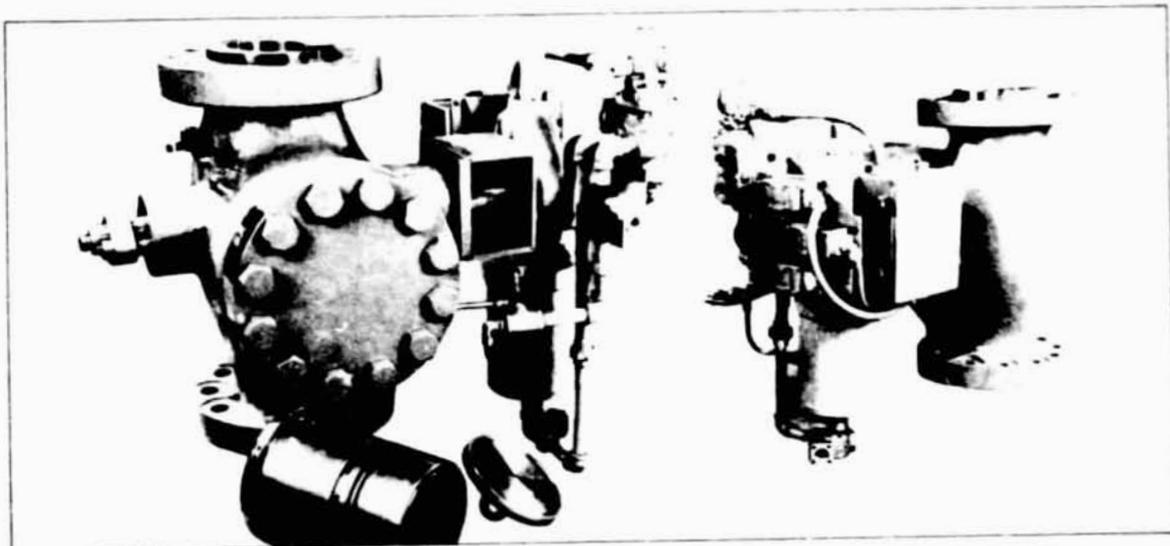


Figure 9.  
Size 6, Class 900 Lock Hopper valves.

in setting the seat purge pressure which allowed coal particles to become trapped between the seating surfaces at the time of the leak test.

The valves were disassembled for seat and gate inspection. (This was readily accomplished by access through the valve maintenance cover.) The seating areas, particularly of the top valve, contained numerous indentations and wear areas. The surface edges (refer back to Figure 4), which perform the actual sealing function, were in fair condition. It was decided to have the valves returned to Rockwell's Pittsburgh location for further test and evaluation.

Seat leakage tests were again performed on the valves in the "as received" condition with results showing reasonable leakage rates. Both valves exhibited seat leakage rates of less than 20 scfh (0.57 scmh) at full differential pressure. The valves were completely disassembled and thorough inspection was made of the stem, bearings, packing, etc. All working parts of the valve were shown to be in good working order with no unusual signs of wear or damage, but seat reconditioning was obviously required.

Although original plans called for return of the valves to IGT for further cycling tests, the small scale of the size 3 valves frustrated attempts to lap the seats to their original finish and the effort was abandoned. It was decided instead that data collected over the span of the test program was adequate for evaluation of the design principles employed and had established solid groundwork from which improvements could be generated.

## Conclusion

The basic concepts employed in the two size 3 valves which were cycle tested at IGT were successful, even though testing fell short of the 20,000 cycle goal. The excessive leakage rate which resulted in discontinuation of the test was determined to have been caused by inadvertent control system failure related to one of the basic features of the design—that of effective seat purging. The valves otherwise demonstrated good performance and durability, but showed need for improved maintainability. Reliability of the shaft bearings and seals was further demonstrated through successful long-term laboratory tests conducted at Rockwell's Valve Engineering and Research Center in Pittsburgh.

Data collected from the tests conducted at IGT has resulted in certain design improvements addressed mainly to valve maintainability. Cited improvements in design are as follows:

- The seat is on a separate removable sleeve permitting easier maintenance of the Stellite seating surface than was possible with the integral body seat in the size 3 valve. In addition, valve maintainability is improved because a spare seat and disk can be put in a valve to permit it to be returned to service quickly.
- The gate shape has been modified to permit lapping on a flat plate.
- The outlet end of the seat purge annulus has been modified to provide more effective seat purging.

Two size 6, Class 900 lock hopper valves employing the basic features of

the size 3 valves and the above cited improvements have been fabricated by Rockwell and are scheduled for installation in the coal feed system of the Energy Research and Development Administration's (ERDA's) Synthene Pilot Plant at Bruceton, Pennsylvania. Photos of these valves before shipment to ERDA can be seen in Figure 9. Like the size 3 valves tested at IGT, these valves are actually "scale models" of larger valves and the design concepts employed are based on requirements for full scale plant valves. Design conditions for the valves have been set at 1000 psig (69.0 bar) pressure and 250F (121C) maximum temperature. Laboratory seat leak rate tests on the "as-built" valves showed an average leak rate of 1.3 scfh (0.03 scmh) with design differential pressure across the gate. It is expected that additional valuable information on lock hopper valving will be made available by this important pilot plant application.