Achieve Continuous Injection of Solid Fuels into Advanced Combustion System Pressures

TOPICAL REPORT - PHASE III PROGRAM

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Abstract

The overall objective of this project is the development of a mechanical rotary-disk feeder, known as the Stamet Posimetric ® High Pressure Solids Feeder System, to demonstrate feeding of dry granular coal continuously and controllably into pressurized environments of up to 70 kg/cm^2 (1,000 psi). This is the Phase III of the ongoing program. Earlier Phases 1 and II successfully demonstrated feeding into pressures up to 35 kg/cm^2 (500 psi). The final report for those phases was submitted in April 2005.

Based on the previous work done in Phases I & II using Powder River Basin coal provided by the PSDF facility in Wilsonville, AL, a Phase III feeder system was designed and built to accomplish the target of feeding the coal into a pressure of 70 kg/cm^2 (1,000 psi) and to be capable of feed rates of up to 550 kilograms (1,200lbs) per hour. The drive motor system from Phase II was retained for use on Phase III since projected performance calculations indicated it should be capable of driving the Phase III pump to the target levels. The pump & motor system was installed in a custom built test rig comprising an inlet vessel containing an active live-wall hopper mounted on weigh cells in a support frame, transition into the pump inlet, transition from pump outlet and a receiver vessel containing a receiver drum supported on weigh cells. All pressure containment on the rig was rated to105 kg/cm^2 (1,500psi) to accommodate the final pressure requirement of a proposed Phase IV of the program. A screw conveyor and batch hopper were added to transfer coal at atmospheric pressure from the shop floor up into the test rig to enable continuous feeding up to the capacity of the receiving vessel. Control & monitoring systems were up-rated from the Phase II system to cover the additional features incorporated in the Phase III rig, and provide closer control and expanded monitoring of the entire system.

A program of testing and modification was carried out in Stamet's facility in CA, culminating in the first successful feeding of coal into the Phase III target of 70 kg/cm^2 (1,000 psi) gas pressure in March 2007. Subsequently, repeated runs at pressure were achieved, and comparison of the data with Phase II results when adjusted for scale differences showed further power reductions of 40% had been achieved from the final Phase II pressure runs.

The general design layout of a commercial-scale unit was conducted, and preliminary cost estimates made.

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Introduction

The overall goal of this project was to provide and confirm an alternative technological solution for solid fuel injection into proposed advanced combustion systems. Operators and designers of high-pressure combustion systems universally agree that one of the major problems inhibiting the success of this technology relates to solid materials handling at high pressures. Continuing problems feeding coal into high-pressure gas environments and the well-recognized complexity of existing handling systems has limited acceptance of advanced combustion and gasification technology. Limitations inherent in the batch process character of existing lock hopper and piston pump paste systems prevent controlled, continuous level delivery of the coal, imposing gas losses, high maintenance costs and substantial risks of downtime. This program is aimed at developing the Stamet Posimetric ® High Pressure Solids Feeder to provide the simple, accurate and reliable feed system needed to maintain the lead of the U.S. in advanced combustion system design and supply.

The Posimetric® feeder has only one moving part, a rotating spool forming three sides of an annular duct, which rotates within a stationary housing. Material entering the feeder becomes locked between the disks and is carried round as the spool rotates until it reaches the outlet port. This principle of lockup means the pump experiences virtually no wear on components with no relative motion. At the outlet a moving solids seal is continuously created, used as a seal and then dismantled as it is displaced by fresh material as the feeder operates into pressure. The solids pass through the feeder in a continuous unbroken stream, at a rate directly proportional to the speed of rotation.

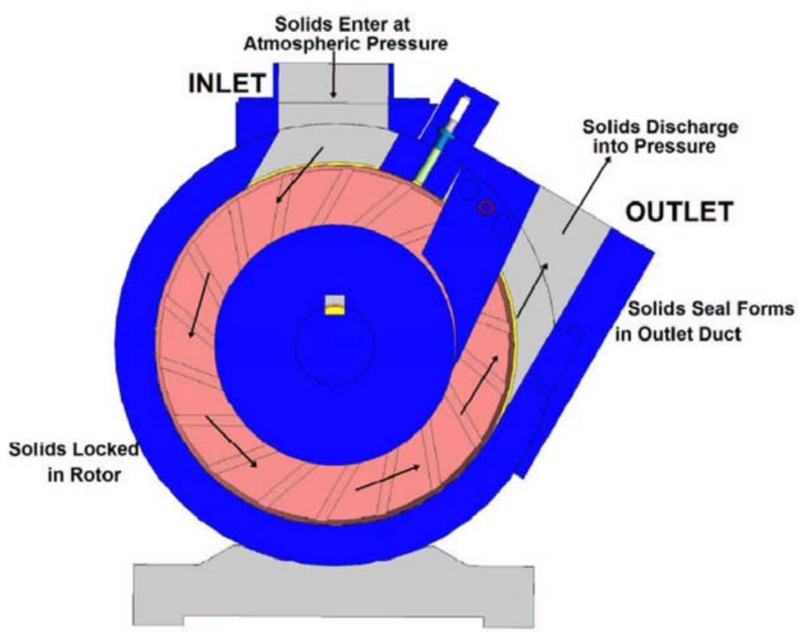

Fig. 1. Layout of Stamet Posimetric® Pressure Feeder

Previously reported work on Phases I & II has demonstrated the ability of the Stamet Posimetric ® High Pressure Solids Feeder to pump coal successfully into pressures as high as 35 kg/cm^2 (500 psi). The plan for the current phase of the project was to extend this capability to achieve feeding into pressure levels of up to 70 kg/cm^2 (1,000 psi) as follows:

Confirm a suitable coal material specification for feeder testing which maintains relevance to the requirements of existing high-pressure combustion and gasification processes and has feed characteristics compatible with the scale of the test feeders to be used in the program.

Test and evaluate design concepts and elements for internal pump configuration including inlet and outlet arrangements to build confidence in design for higher pressures.

Design, manufacture and testing of a feeder and test rig capable of discharging at the full operating pressure of 70 kg/cm^2 (1,000 psi)

Evaluate a general design layout and estimated costing for a commercial-scale feeder.

This report documents the work done on the project between July 2005 and Mar 2007 culminating in the successful feeding of coal into 70 kg/cm^2 (1,000 psi) and generation of a preliminary commercial-scale design.

Executive Summary

The overall objective of Phase III of this project is the development of a mechanical rotary-disk feeder, known as the Stamet Posimetric ® High Pressure Solids Feeder System, to feed dry granular coal continuously and controllably into pressurized environments of up to 70 kg/cm^2 (1,000 psi).

The Posimetric® feeder has only one moving part, a rotating spool forming three sides of an annular duct, which rotates within a stationary housing. Material entering the feeder becomes locked between the disks and is carried round as the spool rotates until it reaches the outlet port. This principle of lockup means the pump experiences virtually no wear. At the outlet a moving solids seal is continuously created and then dismantled as it is displaced by fresh material as the feeder operates into pressure. The solids pass through the feeder in a continuous unbroken stream, at a rate directly proportional to the speed of rotation.

The program was to be accomplished as follows:

Confirm suitable coal material specification for feeder testing to minimize material handling issues affecting the program while maintaining relevance to the requirements of existing high pressure combustion and gasification processes.

Test and evaluate design concepts and elements for internal pump configuration including inlet and outlet arrangements to build confidence in design for higher pressures.

Design, manufacture and testing of a modified feeder and test rig capable of discharging at the full operating pressure of 70 kg/cm^2 (1,000 psi)

Generate a general design and preliminary cost estimate for a commercial-scale feeder.

The first task was to confirm that material specifications compiled for existing coal preparation processes and specifications at the commencement of the program were still valid & applicable to current and projected gasification processes. A review of users indicated little had changed in material specifications in the interim so commercial grind Powder River Basin coal supplied by the PSDF facility in Wilsonville, AL which had been used in the Phase II testing, was retained as the main feed material for the program. To supplement the data from the Powder River Basin coal, some preliminary testing was done with lignite and some biomass mix fuels, and overall results were used as the basis for the feeder design and test program.

Based on the material property information, a Phase III feeder system was designed and built to accomplish feeding the coal into pressures up to 70 kg/cm^2 (1,000 psi) at feed rates up to 550 kilograms (1,200lbs) per hour. Whilst the pump was designed and built within the operational limits of Stamet's North Hollywood facility, it still represented a 5:1 scale up of flow capability compared with Phase II of the program. The drive motor system from Phase II was retained for use on Phase III since projection calculations indicated it should be capable of driving the Phase

III pump to the target levels. The pump & motor system was installed in a custom built test rig comprising:

- an inlet vessel containing an active live-wall hopper mounted on load cells in a support frame,
- transition into the pump inlet,
- transition from the pump outlet
- a receiver vessel containing a receiver drum supported on weigh cells.

All pressure containment on the rig was rated to 105 kg/cm^2 (1,500psi) to accommodate the final pressure requirement of a proposed Phase IV of the program. A floor mounted hopper supplying a screw conveyor feeding a load cell mounted supply hopper above the inlet vessel were added to transfer coal at atmospheric pressure from the shop floor up into the test rig. This enabled continuous feeding up to the capacity of the receiving vessel.

Control & monitoring systems using custom LabVIEW programming were up-rated from the Phase II system to cover the additional features incorporated in the Phase III rig, provide closer control and expanded monitoring of the entire system

A program of successive testing and modification was carried out in Stamet's facility in CA, feeding coal into progressively increasing pressure, culminating in successful feeding of coal into the Phase III target of 70 kg/cm^2 (1,000 psi) gas pressure in March 2007.

Repeated runs at pressure were achieved, and comparison of the data with Phase II results, when adjusted for scale differences, showed further power reductions of 40% had been achieved from the final Phase II pressure runs.

This demonstrated the feasibility of using the Stamet Posimetric® High Pressure Solids Feeder System up to the target 1,000psig pressure level, and provided data on power and sizing requirements to be projected for commercial applications. The general design layout of a commercial-scale unit was conducted, and preliminary cost estimates for manufacture of a commercial scale unit made.

Experimental.

Test Pump:

Whilst the Phase I/II pump was designed to minimize the cost to achieve the target pressure level, for Phase III the pump design was sized to provide a scale-up of approx 5:1 on volumetric capacity from the requirements of Phase II, while still being small enough to allow testing in Stamet's facility and reasonable costs of development modifications. Also, the machine design configuration was closer to that of a commercial system, rather than utilizing the large replaceable inlet & outlet inserts that had been used to provide maximum flexibility of pump configurations for Phases I & II. The pump used separate end caps with outboard bearings to provide full separation from any material that may enter the pump body cavity. As with all Posimetric® feeders, the research pump has only one moving part – the spool which rotates inside the body housing to transport material from the inlet to the outlet. A replaceable outlet insert was still incorporated in the design, as it is anticipated that this would be the case for a commercial unit where service replacement components would be provided.

Fig. 1 shows the general arrangement of the pump.

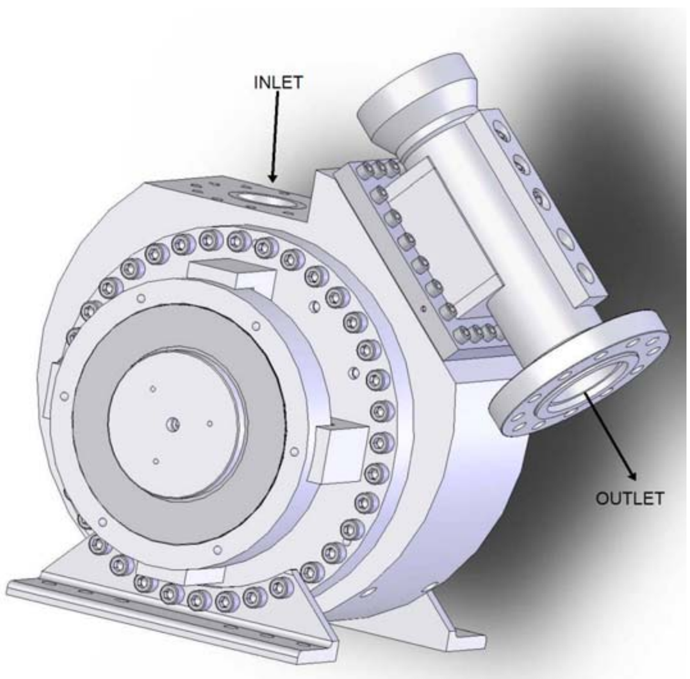

Fig. 1 Pump General Arrangement

Pump Test Rig:

The pump was mounted on a platform and coupled to an electric motor/gearbox unit via a drive chain. The motor/gearbox unit was mounted on the underside of the platform to provide a compact installation and was powered via a variable frequency drive to provide speed control from 0 to 5 rpm. This arrangement is shown in Fig. 2.

Fig. 2. Pump and Drive Arrangement

The pump & motor system was installed in a custom built test rig comprising an inlet vessel containing an active live-wall hopper mounted on load cells, the pump itself, a transition from pump outlet and a receiver vessel containing a receiver drum supported on weigh cells. The pump platform was designed to position the motor as high as possible, allowing space for the height of the equipment to be mounted above, so that the size of the receiver vessel could be maximized. Low profile actuated isolation valves were provided on the entry to the inlet vessel and between the outlet transition and receiver vessel. All pressure containment on the rig was rated at 105 kg/cm^2 (1,500psi) to accommodate the final pressure requirement of the proposed future Phase IV of the program. A floor mounted hopper supplying a screw conveyor feeding a supply hopper above the inlet vessel, also mounted on load cells, were added to transfer coal at atmospheric pressure from the shop floor up into the test rig. This enabled continuous feeding up to the capacity of the receiving vessel. Fig. 3 shows the test rig arrangement in the solid modeler and Fig.4 shows a picture of the actual system as installed.

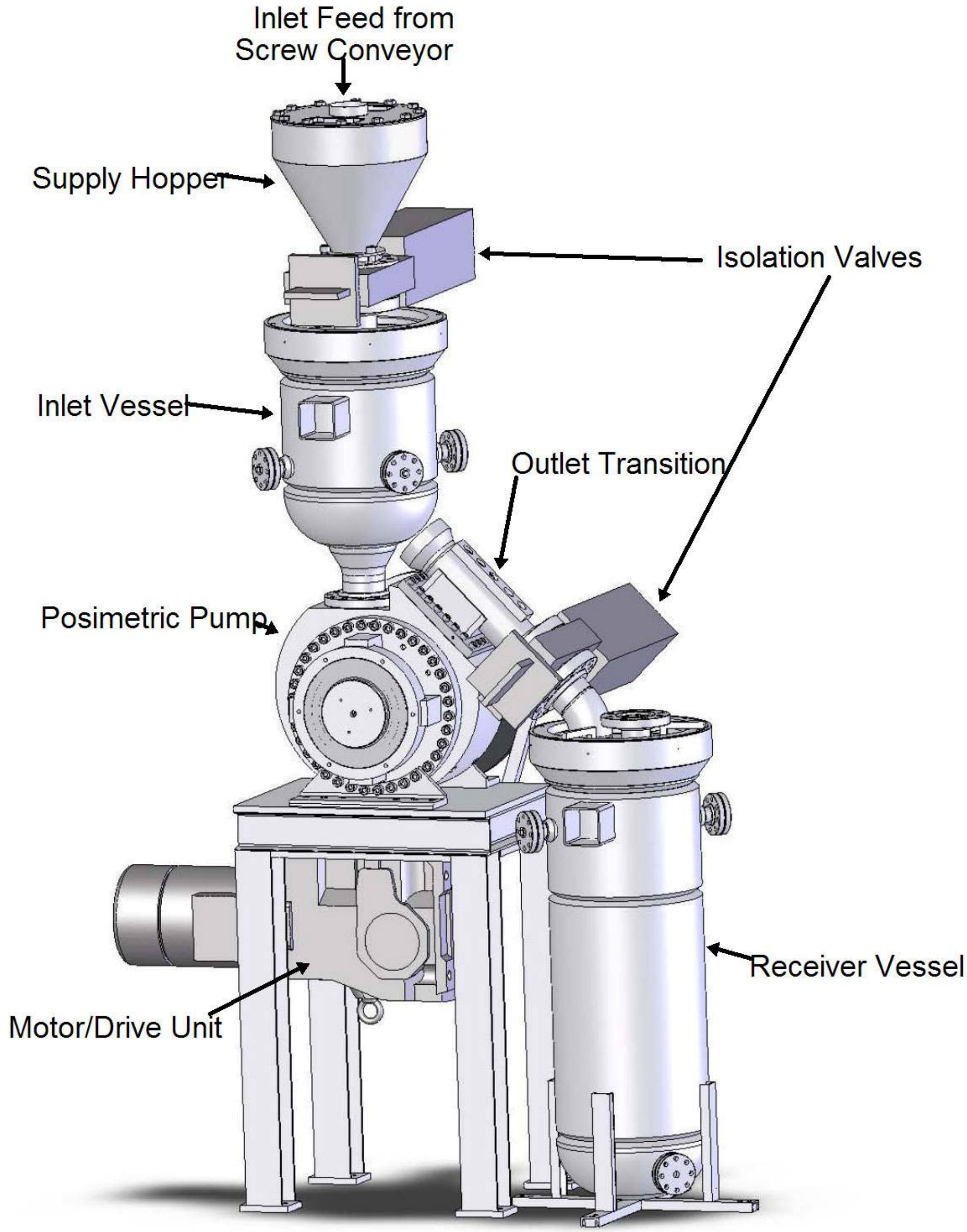

Fig. 3 Test Rig Arrangement

Fig. 4 Actual Test Rig Installation

The rig was instrumented to monitor pressures throughout the system, material presence and flow-rates, gas flow-rates, speed, and drive torque. The system was controlled from a PC using custom LabVIEW programming, which also recorded and graphed the sensor data in real time. Mpeg & Video recordings were also made during testing to capture the outlet feed condition, inlet flow and system control screen.

Fig.5 Primary Dataq & Control Screen

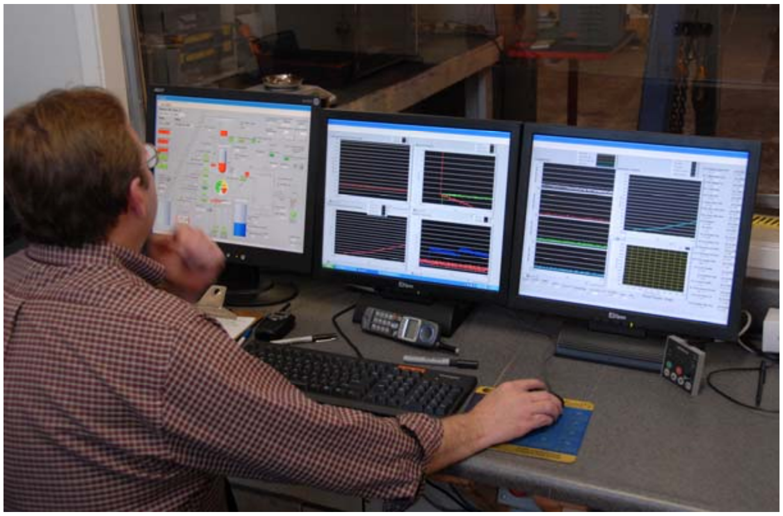

Fig. 6 Multiple Screens Tracking Test Rig Operation

Results and Discussion.

At the beginning of Phase I of the program a detailed evaluation of feed materials had been carried out. At that time a standard commercial grind of PRB was selected as the main feed material to be used in the program. A review of users carried out at the commencement of Phase III confirmed that in the interim commercial feedstock requirements had not changed significantly, so the commercial PRB grind was retained as the main feed material for this phase. Again, this was supplied by Power Systems Development Facility in Wilsonville, AL and used without any further processing. Other feed materials were tested to confirm pump operation with alternative feed-stocks, but the majority of the work was done with the commercial grind PRB coal.

Fig. 7 shows typical sieve analyses obtained for the PRB material as received.

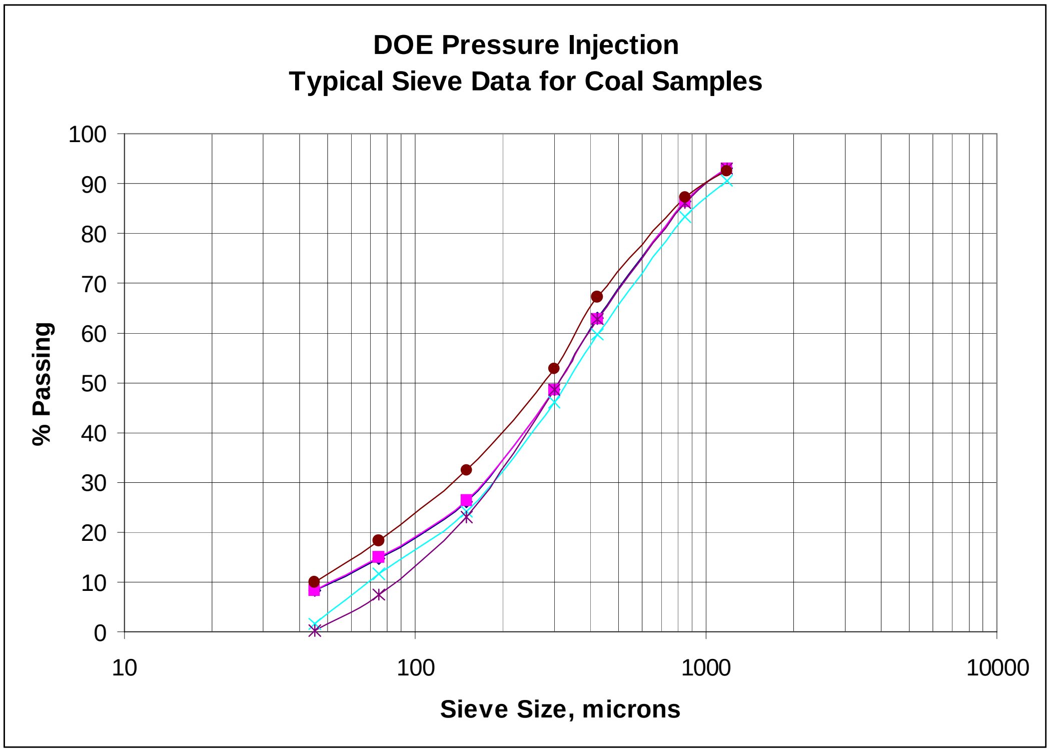

Fig. 7. Typical Sieve Analysis of as Received PRB.

Whilst the sieve analysis data showed some variation from batch to batch the overall data was consistent with the coal used in the earlier phases.

Upon completion of the pump design, manufacture and rig assembly, initial checks were carried out to confirm the basic functionality of the pump mechanicals and operation of the revised control and data acquisition systems. After initial shake-down all systems operated successfully and initial data was obtained on the basic torque characteristics of the pump as originally configured, both empty and feeding coal into atmospheric pressure at a range of speeds. The new test rig had been designed to allow the use of a symmetrical live-wall hopper design, unlike the Phase I & II rig which had required an asymmetrical design to gain access to the pump inlet. This was expected to give improved inlet flow characteristics, and indeed the results demonstrated very consistent flow-rates across the full available speed range. Fig. 8 shows the very close agreement of theoretical and actual feed-rates obtained when feeding into atmospheric pressure across the full speed range available from the drive system (0 – 5 rpm).

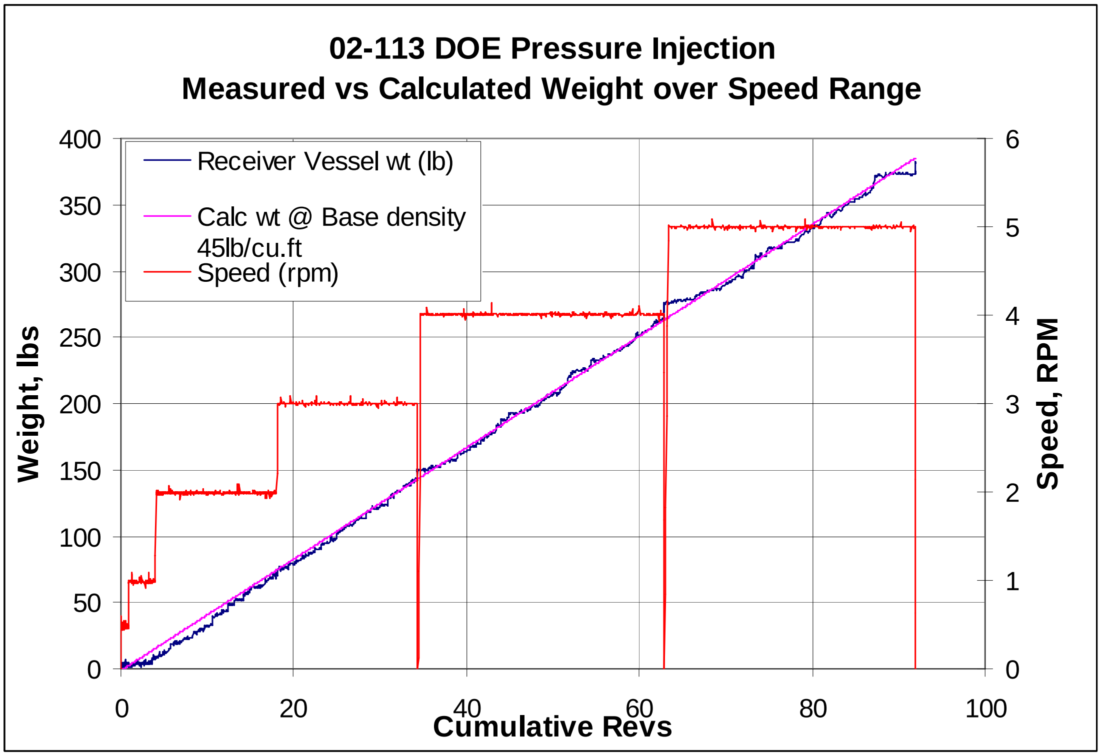

Fig. 8. Flowrate Comparison with Calculated across Speed Range.

After confirming adequate inlet feed capability, the feeder was run with a mechanical load blocking the outlet to confirm that sufficient grip was available from the design to allow feeding into the target pressure. The data obtained is shown in Fig. 9. This shows that available torque capacity exceeded 25,000 ft.lbs, and that material flow was maintained against an outlet resistance that required that level of torque to overcome. This was believed adequate to achieve the intended 1,000psi target.

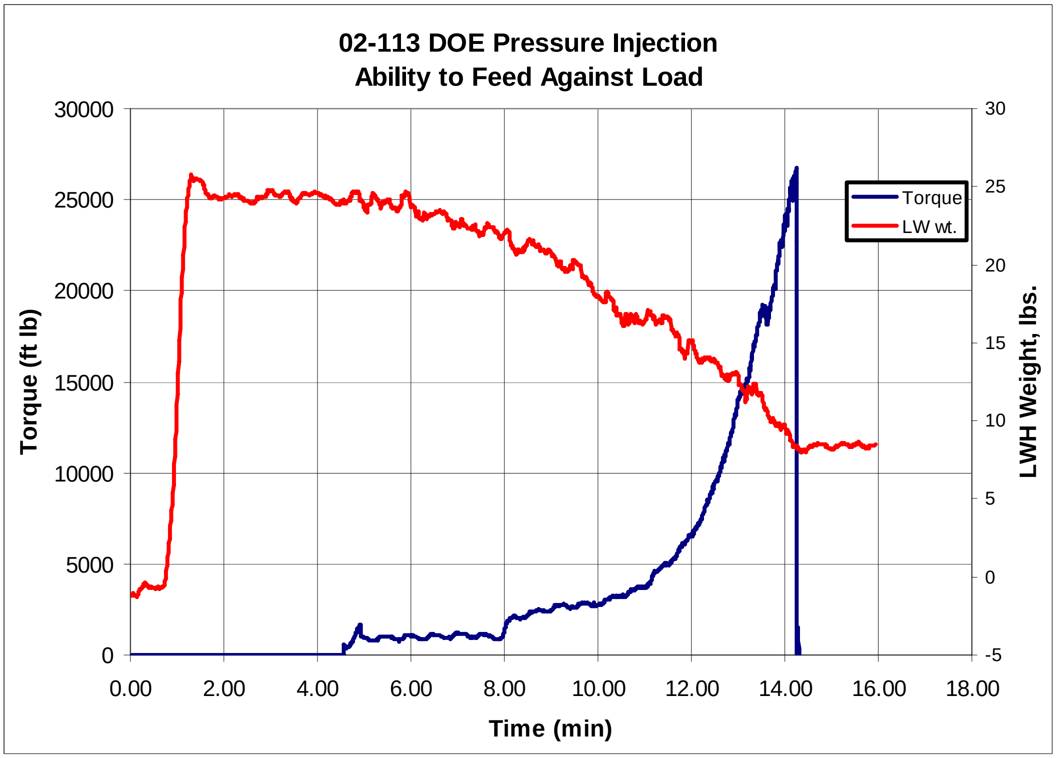

Fig. 9 Feeding Against a Mechanical Load.

An extended program of successive testing, feeder geometry modification and re-testing was then carried out in the Stamet facility in CA, feeding coal into progressively increasing pressure. This culminated in the successful feeding of coal into the Phase III target of 70 kg/cm^2 (1,000 psi) gas pressure in March 2007.

Fig. 10 shows typical data obtained from a run up to 1,000psi. In this case an earlier run had been completed leaving a sealing plug of coal in the pump outlet, so the pressure was able to be brought up to 350psi before the machine was started. After starting the pump the pressure was steadily ramped up to 1,000 psi, during which time the torque steadily increased with the output pressure, and the pump continually fed coal into the receiver at a steady rate.

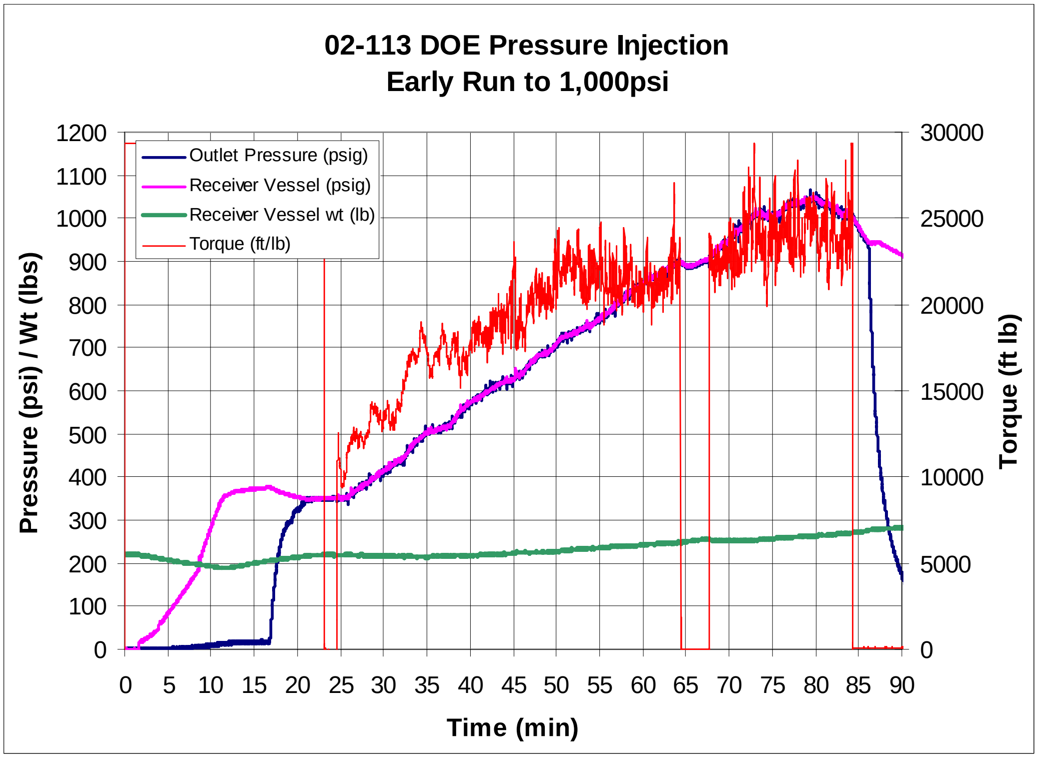

Fig. 10. Typical Data from Early Run into 1,000psig.

Close examination of the receiver weight readings shows some variations in the weight reading even before the pump was started. This was discovered to be an inherent error in the load cell reading associated with the pressure changes. The original receiver load cells were in-line diaphragm type, providing easy in-line mounting. When the pressure of the environment changed, the external pressure reacted on the load cell diaphragm area affecting the reading. Since the units were hermetically sealed, it had been anticipated that this effect could be corrected for based on the pressure applied. However, in practice it was found that the pressure effect was inconsistent and would balance out with time. This was presumably due to the load cell sealing being ineffective at high applied pressures, allowing some slight leakage into & out of the units, changing the offset due to the applied pressure and resulting in some inconsistency in results. Subsequently the receiver load cells were changed to beam type to eliminate this effect. For earlier tests using these load cells, the load cell readings from the supply and Live-Wall hoppers were available for comparison with the receiver weight data to avoid any large errors.

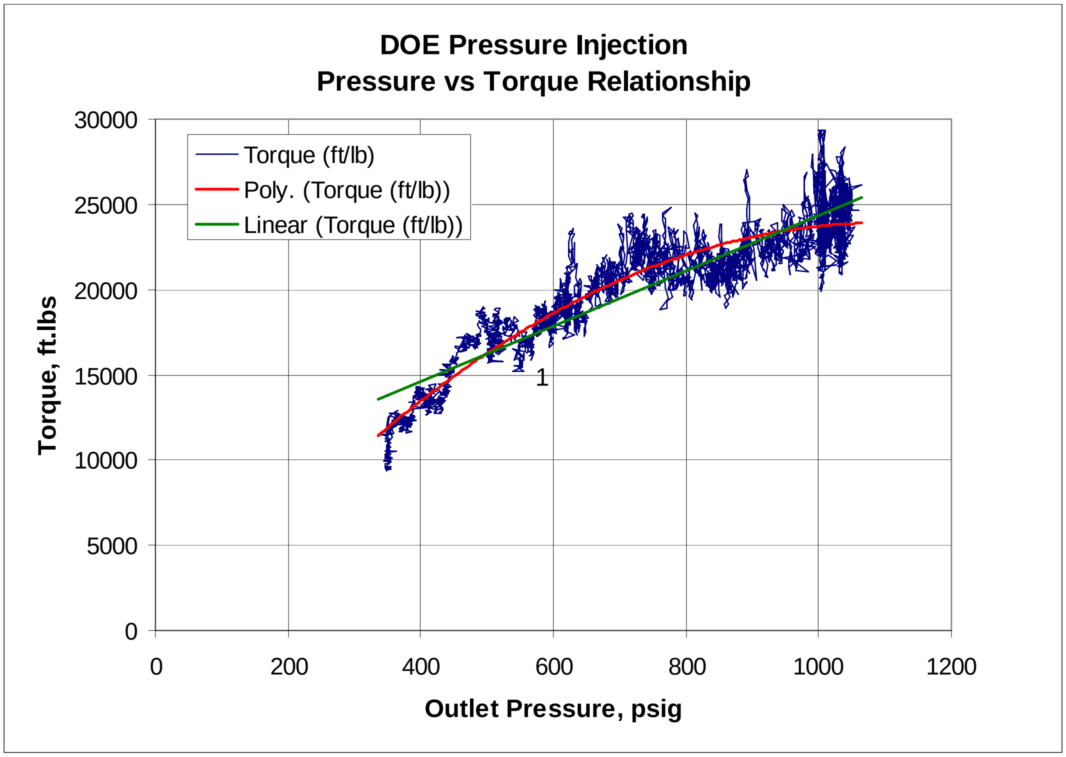

Fig. 11 Effect of Increasing Pressure on Torque Requirement.

Fig. 11 shows a typical relationship of the torque required to feed into the outlet pressure applied. As expected this increases with applied pressure, though at a less than linear rate as evidenced by the curve fits shown. Earlier tests at lower pressures had indicated a substantially linear torque increase with output pressure, but the slope appears to reduce at higher pressure levels. Further investigation of this effect will be pursued in Phase IV of the program.

In comparison with the geometry of the Phase II pump, the Phase III pump has a larger diameter and a larger outlet pressure area, both of which would be expected to required a higher drive torque at a given outlet pressure. The final arrangements of the Phase II pump had achieved feeding into 500psi at a torque of approx.10,000 ft.lbs. Factoring in the diameter and area increases on the Phase III pump would predict a drive torque requirement of approx. 2.5 times that of the smaller Phase II pump at a given pressure condition. The actual measured torque values of less than 15,000 ft.lbs for the Phase III pump at 500psi, therefore represent a further efficiency improvement from the status at the end of Phase II.

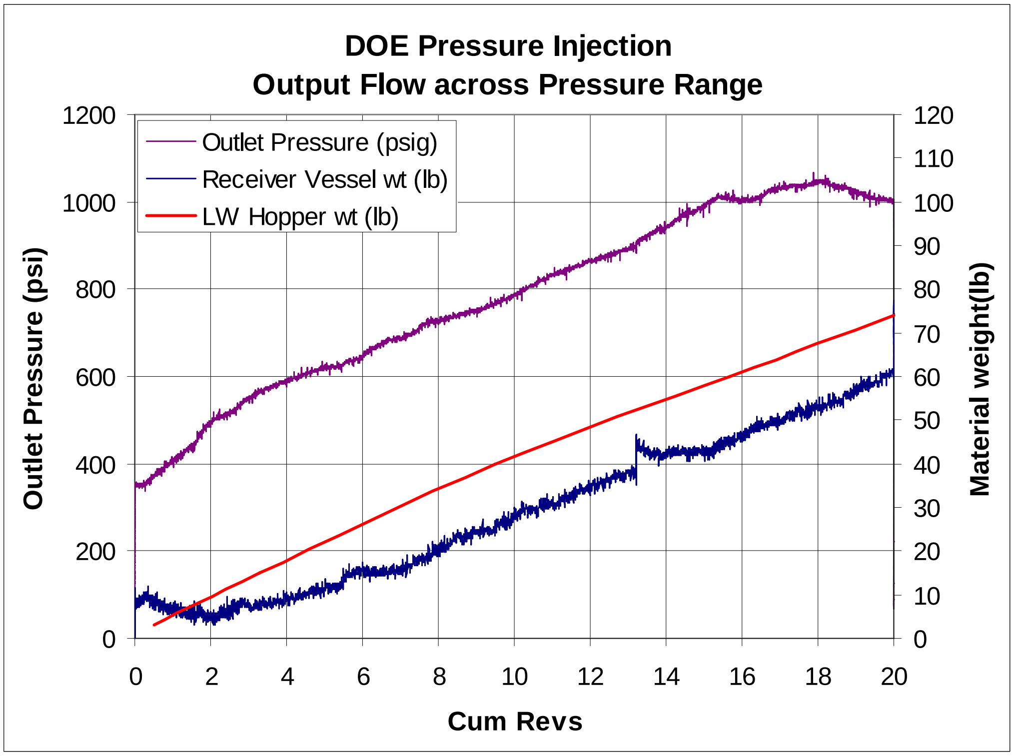

Fig. 12 Material Output Flow against Varying Pressure

Fig. 12 shows typical output flow recorded as the outlet pressure was increased. The weight pumped is plotted against cumulative revs, so that a straight line indicates constant throughput independent of the outlet pressure. This graph shows the recorded throughput measured both by loss in weight of the live-wall hopper on the inlet, and increase in weight of the receiver vessel on the outlet. Both show a generally straight line as the pressure changes. The lower overall level recorded in the receiver is accounted for by material filling the outlet transition at the start of the run before spilling over into the receiver vessel. At the end of the run approx 12 lbs of material was held in the outlet transition, close to the measured difference between the two sets of readings.

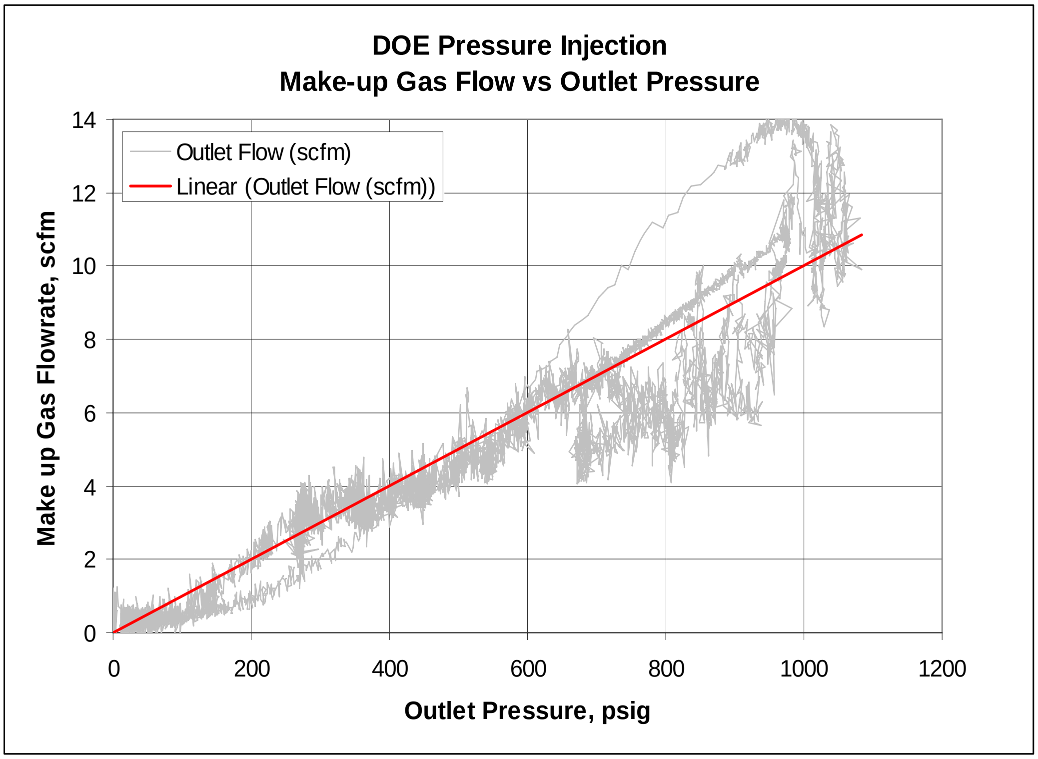

Fig. 13. Make-up Gas Requirements at Increasing Pressure.

Fig. 13 shows the amount of make-up gas required to maintain the outlet pressure through 1,000psig. This shows gas requirements to increase generally linearly with pressure to a maximum of around 10 scfm at 1,000psig. The gas that permeated down the outlet plug was captured by ducted vents on the pump body and could be contained or redirected to other storage. The peak values up to 14scfm were measured when the pump was stopped with no outlet valve closed. The lower values were measured with the pump running and results generally showed total gas requirements reducing as pump speed increased. This is expected, since the rate of gas permeation down the pump outlet would be reduced by the movement of the sealing plug in the opposite direction.

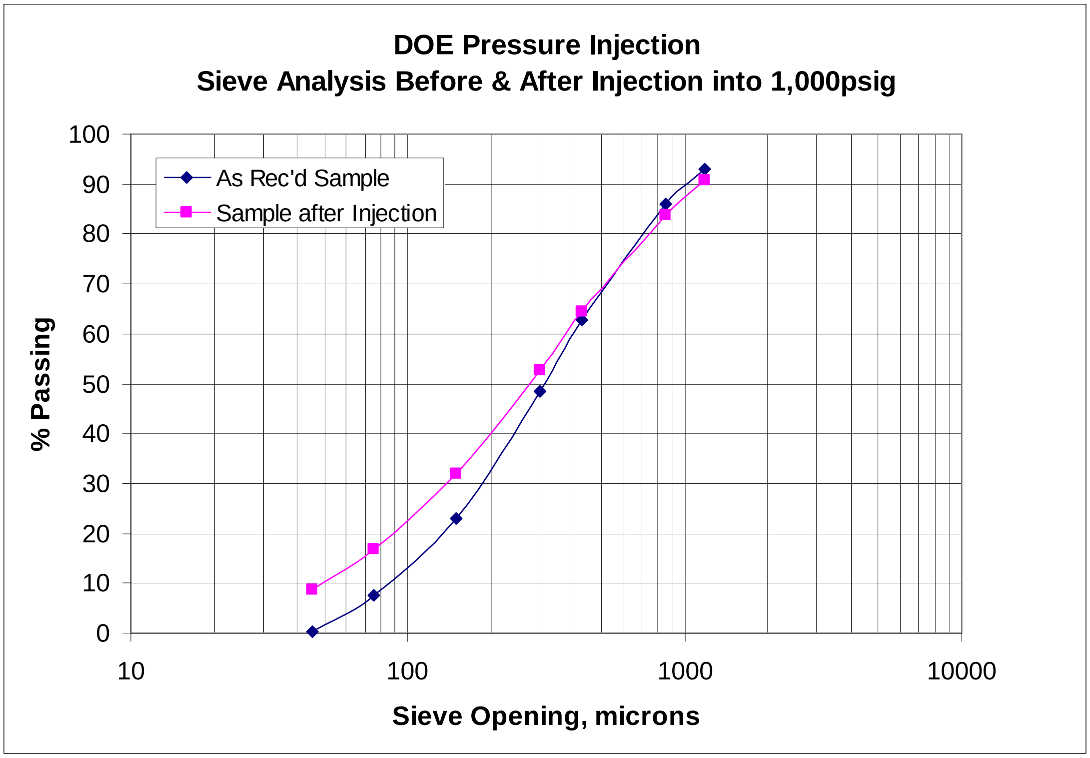

Fig. 14 Comparison of Sieve Analysis before and after Injection into 1,000psi.

Fig. 14 shows a comparison of typical sieve analysis data taken before and after an injection run into 1,000psi. This shows very similar distributions to that shown in Fig. 7 for the original as received material. The before and after comparison indicates that there is little agglomeration of material as it passes through the pump since there is very little change in the % passing the larger sieve sizes. The increase in fines passing through the smaller sieves after injection suggests some attrition of particles during transit through the pump due to the forces applied. These results may vary with different source materials depending on particle hardness, original distribution etc. Further characterization will be made as more data is obtained.

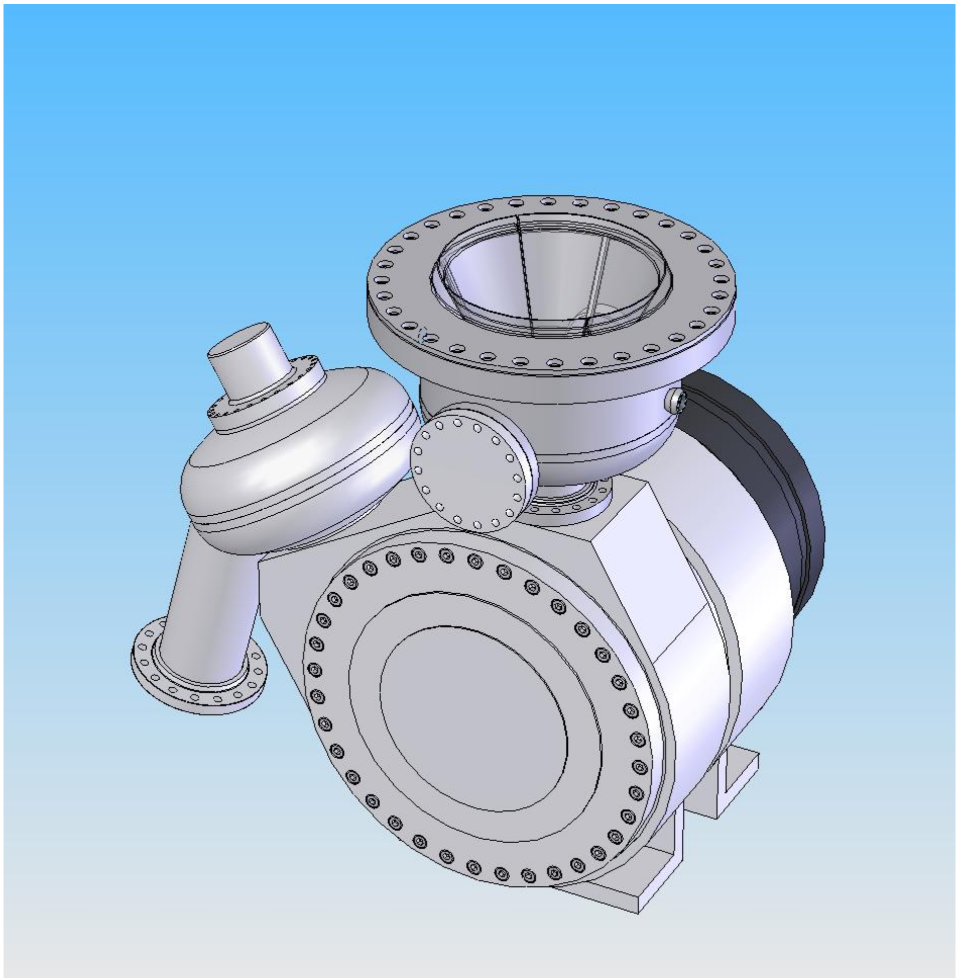

Fig. 18. Commercial Feeder Layout

Estimated specifications for a 30 TPH feeder are as follows:

Feed rate for pre-pulverized PRB, Bituminous or Lignite fuel	30TPH
Fuel Size	50% -100#
Fuel Moisture Content	2-16%
Disc diameter:	1.5m
Number of Discs:	4
Pressure capability:	70 kg/cm^2 (1,000psi)
Feeder footprint:	
Feeder Height:	3m
Feeder Width:	1.2m
Feeder Weight:	15t
Motor Power:	350kW
Feeder Cost of Manufacture	$550,000*

Other components required as part of a feeder system will include inlet transition live-wall hopper and inlet transition pressure vessel, inlet isolating valve, outlet isolating valve and PLC control system. Cost for these components is estimated at $75,000*.

*Actual costs will be dependent on specification requirements and manufacturing volume

Conclusions.

The program successfully demonstrated the ability of the Stamet Posimetric® High Pressure Solids Feeder System to feed dry granular coal into pressures exceeding the 70 kg/cm^2 (1,000psi) target.

The pump was able to stop & start under load while retaining a stable gas seal.

Material feed-rate was shown to be proportional to pump speed, and independent of output pressure.

The requirements for make-up gas were very small compared with usage in existing lock-hopper systems.

A general design and preliminary cost estimate for a commercial-scale feeder capable of 30tph into 70 kg/cm^2 (1,000psi) of pressure was generated, indicating unit costs of the order of $550,000.