**Proof of Principal Test to Feed and Meter
Granular Coal into 450 psig Gas Pressure.**

1st Quarterly Technical Progress Report

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Abstract

The objective of this project is to demonstrate proof of principal to feed and meter granular coal into 450 psig gas pressure for use with pressurized fluidized bed combustors. This report summarizes work undertaken in the first quarter of 1999 in support of that objective.

Materials testers have been designed and built to assess properties relevant to performance in the Stamet pump. Testing has been carried out to evaluate these properties for materials to be pumped.

A small scale pump has been modified and preliminary testing has been carried out to assess the effectiveness of the sealing and venting modifications, and the effect of outlet material sealing plug length on required HP and gas leakage. The sealing and venting modifications worked well, and measurements of gas leakage and power requirements were in line with predictions made from the measured materials properties and pump geometry.

Changes to the large scale pump test rig to upgrade to the necessary 450 psig pressure rating have been defined and components ordered. The data from the materials and small scale pump testing is being used to define the necessary changes to the large scale SBIR test pump to reach the 450psig target.

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Introduction

This is the first quarterly report by STAMET INC. describing the initial progress of their work toward the successful proof of principal test to feed & meter granular coal into 450 psig gas pressure.

The work reported in this document covers the preparation of the initial project plan and schedule, modifications to existing experimental pumps and test rigs, and initial evaluation testing of a small scale pump to test concepts and provide data for use in finalizing the design of the large scale pump to achieve the 450psig target pressure. Some additional experimental evaluation of materials properties was undertaken to provide data to assist in the correlation of experimental data and aid in the projection of anticipated performance of the test pumps.

Executive Summary

This summarizes the work done in the first quarter of 1999 in support of efforts to demonstrate proof of principal to use a Stamet pump to feed and meter granular coal into 450 psig gas pressure for use with pressurized fluidized bed combustors.

Work has been done to design and build test rigs to evaluate important materials characteristics and properties relevant to their performance in a Stamet High Pressure Pump. These facilities have been used to test samples of coal to be used in the pump testing program. The objective is to correlate actual pump performance with pump geometry and materials properties, so that some predictive capabilities can be developed. The first use of this is to aid in defining the changes to be made to the existing SBIR test pump in order to achieve the 450psig objective.

Preliminary testing has been carried out on a small scale pump to evaluate the effect of sealing and venting modifications proposed for incorporation in the full scale pump. In testing the sealing and venting worked well and as expected up to 50psi. Higher pressures cannot be attained in the small scale rig, but the correlation of the data with anticipated results indicates that the systems should work well on the full scale SBIR pump.

Sealing characteristics of the outlet plug and HP required to drive the pump were compared with expectations from materials data and geometry. Leakage rates correlated well, whilst HP predictions were somewhat higher than actually measured. This is believed to be at least partially due to the inability of the small scale test rig to maintain a steady state condition. Since the preliminary testing was carried out increasing loads with time, the actual measured HP at any point will be lower than at a steady state condition, since a portion of the material has passed through the pump at lower loads with consequently less friction. Further work is required to confirm this, and to test and refine the performance predictions over a wider range of conditions.

The necessary modifications to the full scale test rig and pump have been defined and rig modifications are in process. Implementation of the internal modifications to the pump is being held pending imminent test data at higher pressures to further confirm their applicability for the 450 psig application, and ensure that the changes incorporate the latest knowledge available.

Experimental

The initial work breakdown structure and schedule were prepared at the commencement of the project in January 1999. Copies are provided in appendix 1.

In addition to the workload planned in January, test rigs have been designed and manufactured to test relevant transport properties of materials to be pumped. This includes measurement of bulk density, compressibility, friction coefficients and permeability.

A new friction tester was made to measure friction coefficients of bulk materials against various solids, and the internal friction of the bulk material itself under typical conditions anticipated inside the Stamet pump. A new permeameter was made which also allowed for measurement of the rate of pressure decay through a material column. This was supplemented by the modification of an existing test rig to measure the applied force required to move a column of material through tubes of various materials. These values are required to support efforts to predict pump output, HP requirements and sealing characteristics with different materials.

The planned modifications have been incorporated into the small scale pump rig to enable more accurate monitoring of direct pump HP requirements to be made during test runs by measuring hydraulic pressure drop directly across the motor inlet and outlet ports. Instrumentation was added to allow dynamic measurement of gas pressure and leakage rate to be made. The existing outlet arrangement does not allow for a mass flow measurement of material being pumped into pressure. A level indicator was therefore provided to measure the outlet sealing column height as a test progressed, enabling pump output flow rate to be measured incrementally by volume, each revolution of the pump displacing 6.86 cu. ins of material at inlet conditions.

The test pump also incorporates seals on the disk OD to prevent spillage of material from the pump duct, and includes vents in transition of the pump outlet duct. These vents are intended to allow the gas diffusing through the outlet sealing column to be vented prior to entering the pump section, so as not to upset the locking of the material in the duct, and to preclude any gas leakage affecting the material flow at the pump inlet. These modifications are proposed for inclusion on the full scale pump and testing has been carried out to evaluate their effectiveness in the small scale unit prior to incorporating the changes in the large pump.

The modifications required to increase the pressure capability of the large scale SBIR pump test rig to 450 psig have been defined, and the components required have been selected. The detailed modifications to the pump internals and outlet configuration have been identified, and implementation is awaiting further test results to confirm that the best options have been selected based on all latest available data.

Results & Discussion

As stated earlier, additional work was added to the planned program to enable measurement of important materials properties to be made to support data correlation of measured and predicted performance. The coal was tested to establish these values for the conditions expected in the test pump.

Preliminary testing was carried out to establish baseline HP requirements to drive the pump empty so that this could be isolated from the additional load to pump the materials. Test runs were then successfully carried out pumping coal under a range of operating conditions into gas pressures up to 50psi. The effects of the outlet column sealing plug length and applied gas pressure on leakage and drive HP requirements were evaluated. A pulverized coal was chosen for this series of tests so that any potential problems with sealing material spillage or plugging of vent filters would be readily apparent.

The disk seals worked well to contain the fine coal used for the small scale pump tests. Once a minimum length of sealing plug had been established in the outlet duct, gas pressure could be applied to the top of the column. The vents placed at the pump outlet were able vent the gas leaking back down the coal column, successfully limiting the gas pressure at the pump outlet so that leakage did not flow back through the pump duct and affect material flow at the pump inlet. The measured gas leakage rates through the outlet column were in line with the anticipated values based on the permeability measurements taken prior to the pump testing.

As anticipated, the HP required to drive the pump rose rapidly as the outlet column length and applied gas pressure increased. However, some inconsistencies were present in the results from tests carried out at apparently the same conditions. At this time it is believed that this results from the fact that a stable condition cannot be maintained in the small test pump as configured, since the outlet column length is always changing. Also the pump speed varied somewhat during these initial tests, slowing as the load increased resulting in some stick/slip effects in the outlet column. Consequently tests did not have the same load/time history so that compaction of the coal in the pump duct and outlet column, and hence the friction and HP requirements, were not the same in each test. In these first tests this variation was borne out by qualitative examination of the packed coal when the test rig was stripped and cleaned after the tests. At no time did we reach the condition where the complete column and compaction was formed under the full applied load at the time the readings were taken, so the potential maximum resistance may never have been reached. Further tests on this small test rig will be required to assess these effects. In the

planned tests with the large pump, steady state conditions should be more readily attainable since this test rig provides for a fixed length outlet sealing plug and material collection and weighing within the pressurized outlet.

The pump output volume measurements showed volumetric efficiencies falling to approx. 70% under load. This is consistent with the expected values based on the compressibility of the coal entering the duct and does not indicate that any significant slippage was taking place inside the pump.

Initial attempts to predict the performance of the pump, and in particular the torque and power requirements for a given condition, are based on the work done to date on the mechanics of flow through the pump, and the restrictions of forcing a column of material through a pipe. The approach taken was to work backwards from the top of the outlet sealing column and sum the resistance to flow at each section, accumulating the load. The load calculation currently contains a number of assumptions, verification of which will take considerable further work. It also requires values for friction coefficients (μ) and the effective ratio of axial to radial forces transmitted through the coal (Z) so the values measured in the frictional test rigs for μ & Z were input into this calculation. A further assumption was made of a 50% efficient divergent in the transition region from the pump duct outlet to the round outlet pipe.

This combination of data and assumptions results in predicted HP levels somewhat higher than the readings obtained in the initial tests. This is what would be expected since, as has been previously stated, the testing never achieved a condition where the material had been fully loaded throughout its travel through the pump. Although much refinement and confirmation of the assumptions is needed, the correlation is very encouraging at this stage. However, it has only been tested for a very limited range of operation so work is needed to test other conditions and check the correlation across a wider range of operation.

These same predictive calculations are being applied to the large scale SBIR pump as an aid to assess the modifications being proposed to allow the 450psi target pressure to be achieved and currently these changes are being finalized. Final incorporation of the modifications is being held pending imminent test data at higher pressures.

In addition to the above work, a method of directly measuring the particle pressure inside a running pump is being investigated. If successful this will provide a means of further confirming or correcting some of the assumptions made in the current calculations. It is hoped to have the device available for use during the full size SBIR pump testing.

At this point in time the program is running approx. 3 weeks behind the original planned schedule, due partly to the additional materials properties testing work undertaken to aid in the development of performance predictive capabilities and partly to the decision to delay incorporation of the final modifications to the SBIR pump until the latest test data is available. This delay is felt to be justified since it will allow the incorporation of the latest

information and knowledge in the final SBIR pump design, improving the final product and reducing the likelihood of further, more expensive changes being required later.

Conclusion

- 1) Facilities have been provided to test critical materials properties affecting performance in the Stamet pump.
- 2) Preliminary testing on a small scale pump has proven the effectiveness of sealing and venting techniques to be incorporated in the SBIR pump.
- 3) Initial correlation of small scale pump results with predicted performance are encouraging, and are being used to support design changes on the full scale unit.
- 4) The changes required to the SBIR pump and test rig have been defined and implementation is under way.

APPENDIX 1.

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Work Breakdown Structure & Schedule.

27th Jan 1999

1. Planning and Reporting

Project planning and reporting will last for the duration of the entire project. All plans and reports will be submitted according to the reporting requirements listed in the Federal Assistance Reporting Checklist.

2. Test Rig Development

This task includes all activities required for the engineering, design, procurement, fabrication, installation, and shakedown testing of the new 450 psi test rig. It also covers work required on a smaller pressure test rig to provide preliminary information to be used in finalizing the design of the 450psi pump.

2.1 Design modifications to pumps & rigs

2.1.1 Small Scale Test Pump & Rig:

A smaller pressure test rig is available at Stamet and will be used for initial development testing to aid assessment of outlet sealing plug length, pressure and sealing characteristics of the coal to be used. The rig is not capable of the target 450psi pressure, but the data obtained will be used to predict requirements for the full scale test rig.

This smaller rig uses a gravity and gas pressure loaded outlet pipe so effects of outlet plug length and loading pressure can be assessed. This information will be used to select the initial design modifications required to the larger high pressure pumping rig, particularly regarding disk and outlet geometry, for the higher 450 psi testing. It will also allow some preliminary correlation of HP requirements necessary to achieve successful pumping at the desired conditions.

To enable the collection of the data required, the instrumentation on the rig must be modified and upgraded. Currently pump speed and the outlet pressure pumped can be measured adequately, but on-line measurement of the sealing characteristics of the outlet plug with length and pressure will require additional instrumentation, as will accurate measurement of pump HP requirements.

The necessary documentation will be produced defining modifications and instrumentation requirements to be incorporated.

2.1.2 SBIR Test Pump & Rig:-

The original SBIR pump casing was designed to withstand 450psi gas pressure, as was the main pressure vessel. However, several valves and associated piping must be replaced to safely withstand the intended pressure. Support frame modifications will be needed to install the SBIR pump above the HP receiver vessel, and to provide access for testing.

Whilst the casing of the pump will safely contain 450psi gas pressure in the event of leakage back through the outlet, a review of detailed internal parts and geometry is

required to ensure adequate strength for this duty and control leak paths. In particular we anticipate a requirement to strengthen the areas around the beak, plough and that re-ducting of the vent area and outlet duct will also be required. Disk, hub & body modifications will be required to incorporate additional sealing inside the pump to contain spillage.

The necessary documentation will be produced to detail the changes required to update the pump and test rig for the 450psi program.

2.2 Manufacture/Purchase Buy-out Parts

All components defined as necessary for the completion of the project will be either manufactured or purchased by Stamet. The make/buy decisions will be made based on cost and time frame considerations. It is anticipated that local suppliers already familiar with Stamet pump requirements will be used for manufactured components wherever practicable.

2.3 Fabrication of pump & rig modifications

2.3.1 Small Scale modifications & set-up

Additional pressure transducers need to be provided to allow more accurate measurement of motor HP and a means of dynamically measuring the outlet plug length during a test run must be added.

2.3.2 SBIR modifications & set-up

Currently an 0560 pump is installed in the test facility that will be needed for the SBIR high pressure tests. This must be removed and re-located prior to installing the rig for the SBIR tests.

The detailed modifications required to the rig plumbing will be incorporated, and the rig frame modifications made. The HP vessel and the rails necessary to allow movement for emptying after a test will be installed in the pit.

The SBIR pump will be stripped down so that components can be modified to incorporate the additional sealing required.

The existing inlet spacer, plow and beak will be reworked or replaced as necessary to handle the higher loads of the increased pressure program and control gas and solids leakage.

The outlet and drive system will be modified in accordance with the results of the small scale tests carried out as part of this project.

2.4 Installation, Shakedown & Initial start-up testing

2.4.1 Small Scale Pump

Stamet technicians will install the instrumentation upgrades and functionally check the operation of all components and instrumentation in situ.

2.4.2 SBIR Pump

Stamet technicians will install all modifications to the SBIR pump and reassemble the pump. Additional instrumentation will be transferred from the small scale test rig as required to ensure adequate data acquisition. All components and instrumentation will be functionally checked in situ to ensure all is operating as required prior to commencing the testing program.

2.5 Prepare Status report

3. Solids Pump Testing

This task includes all activities required for the implementation of the Test Plan as developed in Task 1.

3.1 Implement Test Plan

3.1.1 Small Scale Pump Tests

Testing will be conducted to assess the baseline HP requirement to drive the pump without pumping material so that material friction loads may be assessed for varying conditions in later tests.

A series of tests will then be undertaken to investigate the effect of material plug length and outlet gas pressure on gas leakage rate and HP requirements.

The data will be evaluated and the findings will be applied to the design of the outlet configuration and drive system on the full scale SBIR pump to be tested. This approach will allow selection of an initial balance between outlet friction loads and adequate outlet sealing to reduce the number of configuration modifications and improvements needed to the full size SBIR pump during the testing program.

3.1.2 SBIR Pump Tests

A series of tests will be undertaken at progressively increasing outlet pressures.

As test pressures increase Stamet anticipates the need to make improvements to accommodate the higher loads and gas pressures in efforts to reach the target.

Particular attention will be paid to outlet plug sealing and venting characteristics for the geometry chosen to confirm or refine the predictions made in the small scale tests, and of techniques to control undesirable leakage within the pump. Effects of outlet pressure on material throughput will be monitored.

3.2 Prepare Status report

4. Data Analysis & Technical Evaluation

The test data acquired will be analyzed to identify the major factors affecting pump performance at elevated outlet pressures. Significant trends will be identified and, within the scope of the available data, performance projections will be attempted.

5. Final report

The final report will be prepared as required under the SBIR grant specifications. A draft version will be submitted to DOE following completion of the previous tasks. Following review by the DOE, the Final Report will include a complete technical evaluation and summary of the work performed

Items to be included in the technical evaluation will include:

- a summary of all major experimental data, engineering analyses, computations and test results,
- a synopsis of the individual and combined capabilities of the various unit operations in terms of product yield, quality, separation efficiencies, and throughput capacity,
- a review of the scale-up procedures and the reliability estimation of the procedures,
- a listing of deficiencies that may still exist after this testing is completed.