Energy Research and Development Division
FINAL PROJECT REPORT

DEVELOPMENT OF STEAM HYDROGASIFICATION PROCESS DEMONSTRATION UNIT-5 LB/HR PDU DESIGN REPORT

Appendices

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PREFACE

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Development of Steam Hydrogasification Process Demonstration Unit-5 lb/hr PDU Design Report is the final report for the Hydrogasification Process project contract number 500-09-008 conducted by the University of California. The information from this project contributes to Energy Research and Development Energy-Related Transportation Research Program.

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ABSTRACT

The increasing cost of transportation fuel along with increasing concerns about greenhouse gas emissions globally, including California, underlies a critical need to develop sustainable alternative transportation fuels. California needs to produce nearly 2.4 billion gasoline gallon equivalents per year of alternative transportation fuels in order to meet the State Alternative Fuels Plan 2017 petroleum reduction objectives. Currently, California imports more than 95 percent of the biofuels it uses. Ramping up in-state biofuel production without competing with existing cropland will be difficult unless other, non-crop biomass resources can be used. Thermochemical production of alternative transportation fuels such as substituted natural gas, synthetic diesel or synthetic gasoline derived from renewable sources offers a viable solution for addressing these concerns. This project successfully demonstrated steam hydrogasification reaction technology using co-mingled biosolids and biomass as the feedstock in a laboratory scale process demonstration unit. The steam hydrogasification technology was able to produce various forms of energy products from carbonaceous resources. The researchers also completed a preliminary modeling evaluation and design for a pilot plant with a capacity of five tons per day using the process demonstration unit technology. The plant design included a block flow diagram with process mass, energy balance and process and utility flow diagrams. In addition, the researchers conducted preliminary economic analyses for a 3,500 bone dry tone per day substituted natural gas plant using biosolid and green waste as feedstock. The authors concluded that the results of this project warranted moving forward with plans for a demonstration pilot plant at a waste treatment facility.

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Feedstock Pretreatment-Hydrothermal Pretreatment Process

Appendix A: Feedstock Pretreatment-Hydrothermal Pretreatment Process

1. Introduction

The College of Engineering, Center for Environmental Research and Technology (CE-CERT) has proposed to use a renewable feedstock of co-mingled wood wastes and biosolids in its Steam Hydrogasification Process (SHR, also referred to as the CE-CERT Process) and to produce energy products, such as syngas. In 2009, CE-CERT was awarded by California Energy Commission (CEC) to demonstrate the CE-CERT process with a feedstock capacity of 10lb/hr in a dry basis. This test report is part of the CEC project, and it is about an experimental investigation of the optimum operational conditions of Hydrothermal Pretreatment Process (HTP) to prepare a high solid content comingled wood wastes and biosolids slurry.

2. Experimental results and discussion

2.1 <u>Leak test of the hydrothermal reactor</u>

The stirred batch hydrothermal reactor is rated with a Maximum Allowable Water Temperature (MAWT) of 350˚C and a Maximum Allowable Water Pressure (MAWP) of 3000psi. The approximate operation temperature and pressure of the HTP, based on a lab scale batch test, are 240~270˚C and 1200~1400psi, respectively. The operation temperature and pressure were simulated by heating 3 liters (equally 5.7 lb) of water to 300˚C. Head space in the reactor was kept at 200psi by pressurizing nitrogen before it was heated. When the temperature in the reactor reached 300˚C, it was kept constant for over an hour, such that the pressure in the reactor was also kept constant at 1245psi. Experimental result of the leak test is shown in Figure A1.

The leak test results showed that reactor was sealed during the entire process, and the pressure was well kept constant at 1425psi with a constant temperature of 300˚C.

2.2 <u>Heating and cooling rate of the hydrothermal reactor</u>

It is essential to examine the heating and cooling rates of the stirred batch hydrothermal reactor. There are two reasons for this: 1) the operation time of the pretreatment process is important to meet the requirement of a continuous feeding in the downstream fluidized bed Steam Hydrogasfication Reaction (SHR); 2) energy consumption of the pretreatment process is dependent on its heating rate. The heating capacity and heating rate, cooling capacity and cooling rate of the HTP reactor were tested with water and wood wastes. The heating and cooling ramp were then calculated and plotted out in Figure A2.

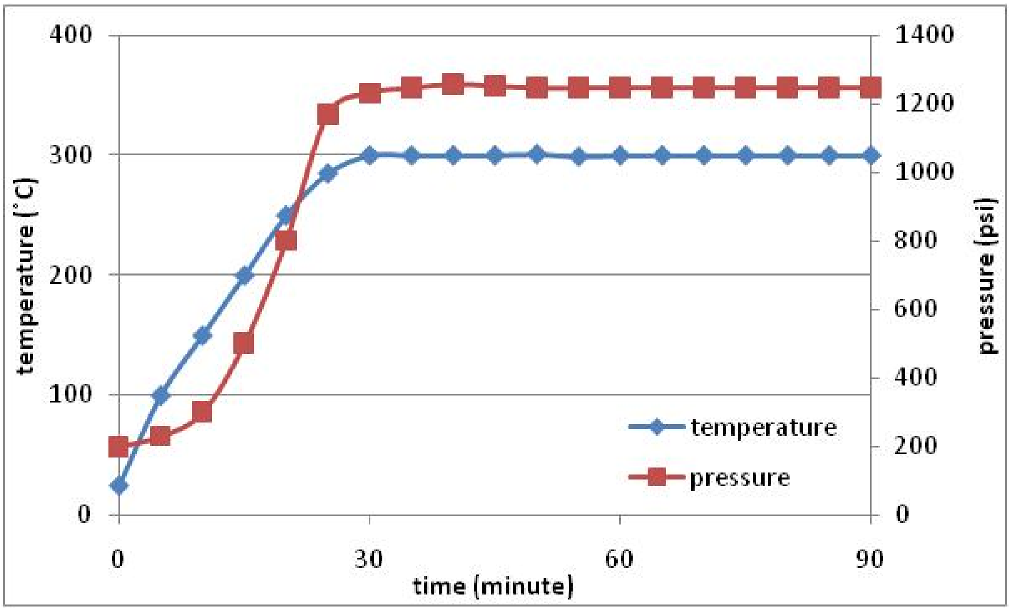

Figure A1: Leak test result of stirred batch hydrothermal reactor

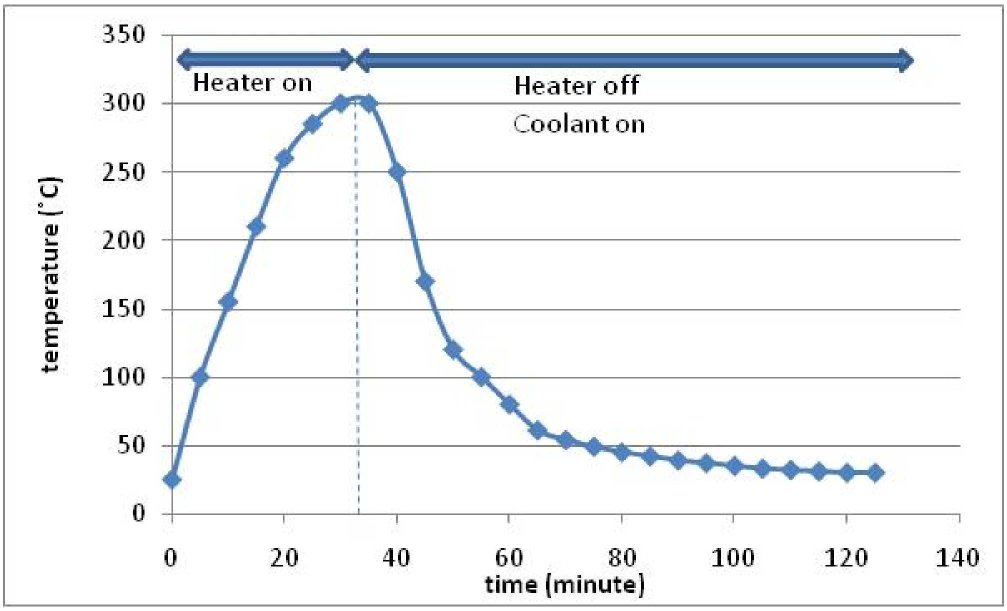

Figure A2: Heating and cooling rate of the stirred batch hydrothermal reactor

It is shown in Figure A2 that heating of the stirred batch reactor from room temperature to 300˚C takes about 30minutes. Cooling of the stirred batch reactor from 300˚C to 30˚C takes about 1.5hrs. If hydrothermal pretreatment is set to be 2hrs, the entire HTP process would take about 4hrs to complete.

2.3 Agitator test result

Stirring test was performed with a total of 2.7kg water and 0.3kg wood wastes. Such a slurry had a viscosity value of 1.3Pa·s. The purpose of the agitator test was to examine agitator speed and motor capacity when feedstock was pretreated. A 60 in/lb footless heavy duty magnetic stirrer was used to power the agitator. The magnetic stirrer coupled with agitator had been tested to be capable of stirring a paste with viscosity value of 10Pa·s by vendor. The agitator test result is shown in Figure A3.

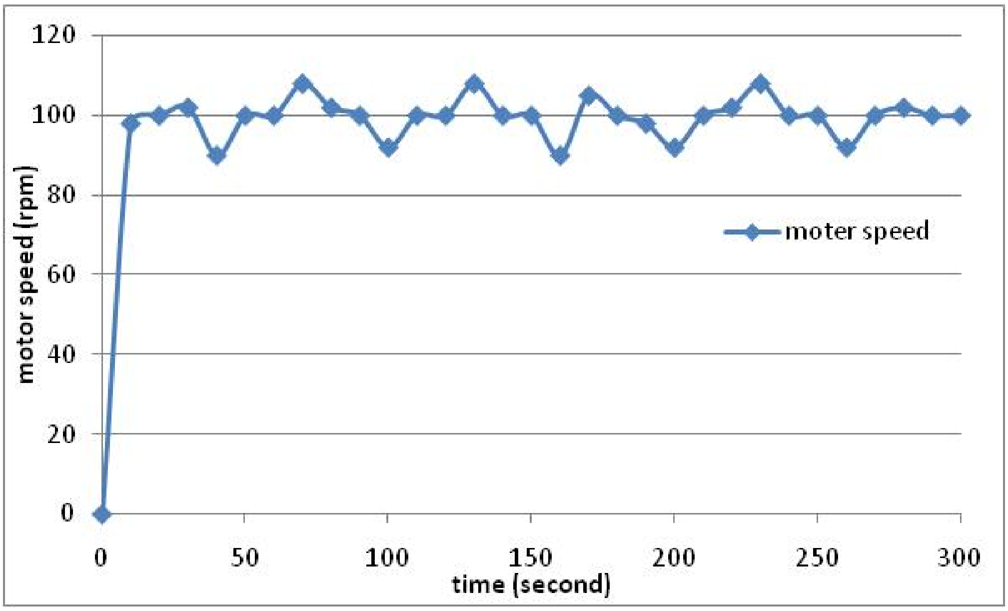

Figure A3: Agitator test result

Test results show that within a test time of 5 minutes, motor speed was kept constant around at 100rpm.

2.4 Optimum operation conditions of HTP of comingled wood wastes and biosolids feedstocks

Within the scope of this report, pine saw dust was used as a representative of wood waste. Dissolved Air Floatation Thickener (DAFT: discharged from Riverside Wastewater Treatment Plant, Riverside, CA) was used as a representative of biosolids. Wood wastes were first crushed in a laboratory mill (Thomas – Willey model 4, Arthur H. Thomas Company). The crushed wood particles were then grinded in a coffee grinder (Braun KSM-2W). All wood particles passed through a 35 mesh sieve (<500 μm). Particles were then dried in oven at 105°C to reduce inherent moisture. After that, the dried wood particles were mixed with biosolids to prepare comingle wood wastes and biosolids mixture. The mixture was then loaded into the hydrothermal reactor to be hydrothermally pretreated. Head space gas inside reactor before HTP was controlled by vacuuming and pressurizing with 200psi of hydrogen for three times. Then the vessel was heated up to a desired temperature and was thermally treated for 1 hour. Agitator was on thru the entire test. After the HTP, vessel was convectively cooled off by pumping coolant through the cooling coil inside the reactor.

A total of 13 tests of HTP of comingled wood wastes and biosolids were carried out. Impact of several operation conditions were tested, such as initial total solid loadings, initial wood wastes to biosolids ratios, initial head space gas composition and operation time. Test results are listed in Table A1.

Table A1: Results of optimum operation conditions tests of HTP of comingled wood wastes and biosolids

Test number	Slurry form (y/n)
1	Y
2	Y
3	Y
4	N
5	Y
6	Y
7	N
8	N
9	Y
10	N
11	Y
12	N
13	N

Slurry formation described in Table A1 was determined by visualizing the free water in the resultant mixtures after HTP. Flowable slurry was defined as such that there was noticeable amount of free water in the resultant mixture when the mixture was tilted in a transparent glass beaker. And non-flowable mixture had no or unnoticeable free water. Figure A4 shows the Comparison of flowable and unflowable mixtures after HTP.

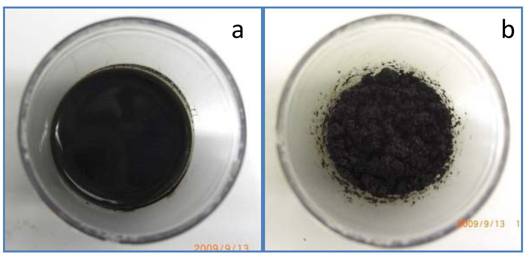

Figure A4: Comparison of flowable and non-flowable mixtures after HTP:

a) Biosoilds and biomass mass ratio of 1.5:1, pretreatment temperature of 240 °C;

b) Biosolids and biomass mass ratio of 2:1, pretreatment temperature of 240 °C.

It is important to point out that the flowable slurry is different from pumpable slurry which is defined as slurry with a viscosity value of less than 1.5Pa·s. Optimum operation conditions were found when the highest initial solid loading was achieved to produce a flowable slurry, and is listed in Table A2.

Table A2: Optimum operation condition of HTP in PDU

Parameters	Operation conditions
Initial wood wastes to biosolids ratio	1:1.5
Initial solid loading	43wt.%
Temperature	270˚C
Initial head space pressure	200psi
Operation time	2 hrs

Initial solid loading had a major impact on the product slurry formation. Results show that with an initial wood wastes to biosoilds ratio of 1:3 (initial solid loading of 28.8wt.%), slurry can be produced when the comingled feedstock was hydrothermally pretreated with a temperature at 210˚C. With an initial wood wastes to biosoilds ratio of 1:2 (initial solid loading of 36.7wt.%), slurry can be produced when the comingled feedstock was hydrothermally treated with a temperature at 240˚C. And with an initial wood wastes to biosoilds ratio of 1:1.5 (initial solid loading of 43wt.%), slurry can be produced when the comingled feedstock was hydrothermally treated with a temperature at 270˚C. So it was concluded that in order to produce comingled wood wastes and biosolids slurry with an initial solid loading of over 40wt.%, required temperature of HTP should be set above 270˚C. At 270˚C, the initial pressure of hydrogen in the head space gas needed was over 200psi. Operation time was also an important not only because it affected the product formation, but it affected the continuous feedstock production rate as well. It was found that with an operation time of 2hrs, slurry form of product was successfully produced, and the total feedstock production rate was able to meet the requirement of a continuous running of the downstream fluidized bed SHR Process.

2.5 <u>Rheology properties of pretreated wood wastes and biosolids slurry at the optimum operation conditions</u>

2.5.1 Data consistency

The first concern over the rheology test of slurries with settling issues is the consistency of the test results. To evaluate the data consistency in rheology tests in this study, a pretreated wood-water slurry with 20wt.% solid content was continuously tested for 3 times, as shown in Figure A5. It was first sheared with an increasing shear rate, and then followed by a reciprocative step, and was sheared again with an increasing shear rate. The viscosity to shear rate curve of 3 runs exhibited fairly good consistency with a shear rate of over 110s^{-1}. However, an error of 11% was observed at shear rate of 27s^{-1}, which was due to the particle settlement at a low shear rate. But, because rheology tests were carried out for over 3 minutes, the rheology tests results had a fairly good consistency.

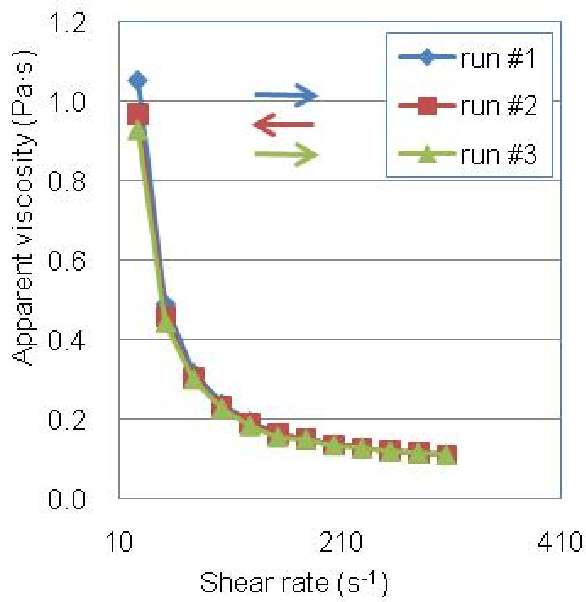

Figure A5: Data consistency (20wt.% wood wastes-water slurry after HTP)

2.5.2 Rheology properties of comingled wood wastes and biosolids slurry after HTP

As the CEC proposal states, one of the target product composition is that the viscosity value of resultant slurry should be less than 1.0Pa·s while its solid loading should be over 30wt.%. This target viscosity value is 0.5 Pa·s lower than a pumpable viscosity criteria which is suggested in another research [1, 2]. The rheology properties of comingled wood wastes and biosolids slurry with initial solid loading of 43.wt% are plotted out in Figure A6. This slurry was pretreated at the optimum operation conditions, which were that the pretreatment temperature was 270˚C, initial head space gas was 200psi of hydrogen and pretreatment time was 2hrs.

Before the rheology tests, rheometer was calibrated with standard oil. And the rheology tests results show that at the optimum operation conditions, the resultant slurry has a viscosity of less than 1.0 Pa·s when shear rate was greater than 80s^{-1}. According to other research, the shear rates of pump during slurry mixing, pipe flow and injection are 10-1000 s^{-1}, 1-1000 s^{-1} and 1000-10000 s^{-1}, respectively [3]. So it is concluded that the comingled wood wastes and biosolids slurry produced after HTP at the optimum operation condition is pumpable.

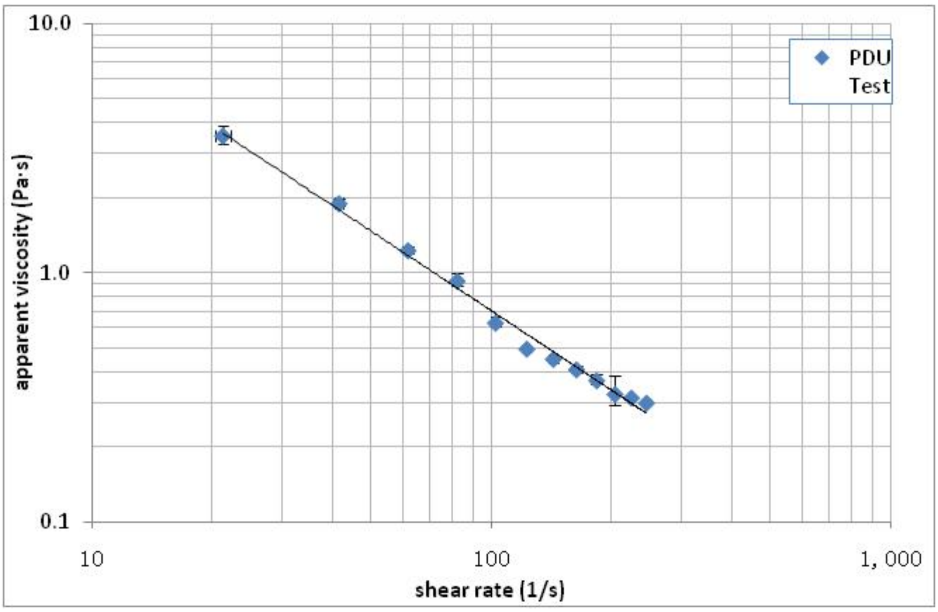

Figure A6: Rheology properties of comingled wood wastes and biosolids slurry after HTP at optimum operation conditions

2.5.3 Settlement of comingled wood wastes and biosolids slurry after HTP

Additional information of the pretreated wood wastes and biosolids slurry besides its rheology property was provided by testing its settlement tendency. In this study, settlement tests were carried out as such: 1) the stirred resultant slurry was first filled into a volumetric cylinder; 2) The cylinder was then placed against a light source for clear vision of its interface between solid and liquid; 3) Height of solid interface in slurry was recorded over time and was plotted out. Solid fraction in the resultant slurry was used to quantify the settlement of a slurry, and it is defined as follows:

$$\Phi_s(t) = \frac{H(t)}{H_0} \times 100\% \qquad (1)$$

Where $\Phi_s(t)$ is solid fraction of slurry as a function of time, $H(t)$ is height of solid interface as a function of time, H_0 is initial height of slurry in volumetric cylinder. Results of settlement tests of slurries were plotted out as solid fraction versus time, as shown in Figure A7. From the settlement test results, it was concluded that biosolids is stable over time. Fast settlement was observed for larger particle in slurry. Packed solid volume of slurries decreased with an increase of particle sizes. Pretreated wood-water had less settlement than untreated wood-water slurry. And the packed solid fraction in wood-water slurry after pretreatment was smaller than that without pretreatment. Complete settlement of pretreated wood-water slurries was around 7 minutes. And 65% to 77.8% of solid settled completely for the pretreated wood-water slurries in the first 3 minutes. It may cause serious problems in rheology tests of such slurries and that was also the reason that modification was performed in our rheology tests. Additional information about the modification of rheometer can be found in the "Pretreatment Process Test Plan". To avoid settlement, continuous stirring of slurries will be required in real applications. Alternatively, dispersant could be added to elongate settlement time.

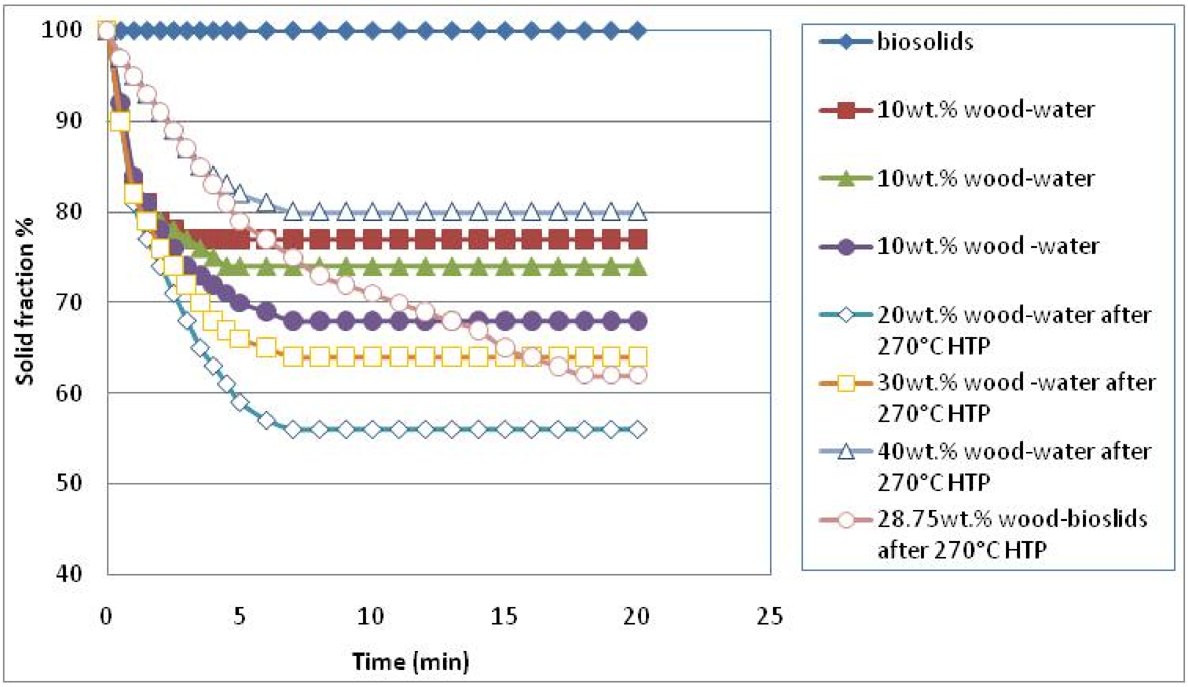

Figure A7: Settlement test results

2.6 Carbon loss through gas phase after HTP

Another target specification for the product composition in the CEC proposal is the maximum material loss through the gas phase. CO_2 in the gas phase should be less than 10 vol.%, and total concentration of hydrocarbon with carbon number C_1 to C_5 should be less than 500ppmv. To analyze the carbon composition in the exhaust gas, Gas Chromatography with a Thermal Conductivity Detector (GC-TCD) and a Flame Ionization Detector (GC-FID) were used. An Alltech 8100/2 packed column was coupled with GC-TCD in the detection of CO and CO_2. And a RT-QPLOT (cat.# 19718) capillary column was coupled with GC-FID in the detection of hydrocarbons. Hydrocarbons with carbon number up to 5 were detected in the exhaust gas after HTP. That is because exhaust gas was collected under room temperature and any hydrocarbons with a carbon number larger than 5 would condense in the liquid phase. Typical GC-TCD and GC-FID results are shown in Figure A8.

As shown in the diagram of the GC-FID result, it is clear that peaks were separated into several sections. And due to the properties of the coated capillary column, the sequence of hydrocarbon species left the column followed the sequence of carbon numbers in its molecular. In other words, carbon species leaves the column follow the sequence from C_1 thru C_5. There was more than one peak for hydrocarbon species

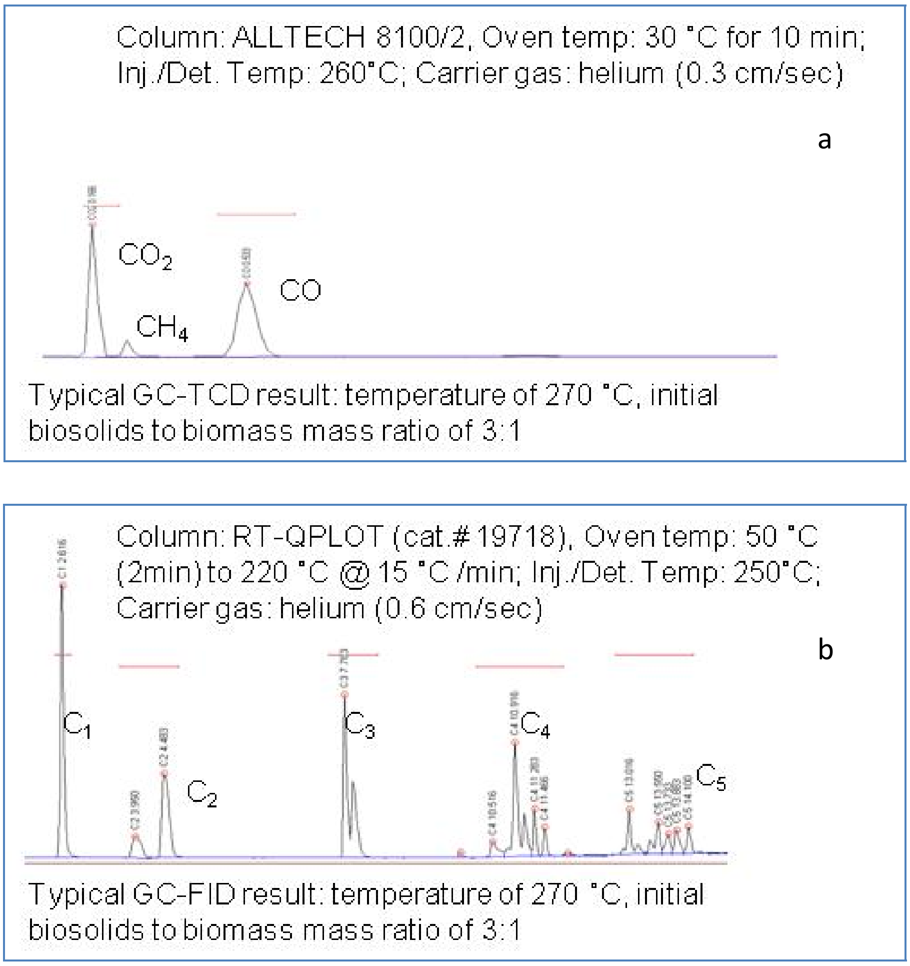

Figure A8: Typical GC results

with carbon number over one, but for the interest of carbon composition in the gas phase, components with same carbon number were not analyzed. The carbon concentration or the total loss of carbon through the gas phase was then calculated based on the concentration of each group of gas species with the same carbon number. Table A3 shows the carbon loss thru gas phase in the forms of carbon oxide (CO and CO_2) and hydrocarbons (C_xH_y) at optimum operation conditions. Carbon percentage in gas phase is defined as:

$$Carbon\ percentage = \frac{carbon\ in\ gas}{carbon\ loaded} \times 100\% \qquad (1)$$

Experimental results show that total carbon loss thru gas phase after HTP at the optimum operation condition was 1.10%, which means over 98% carbon was conserved in the slurry after the HTP. This is due to the fact that exhaust gas was vented at room temperature and carbon species with carbon number larger than 6 were condensed back into the slurry.

Table A3: Carbon loss in gas phase after HTP of comingled wood wastes and biosolids at optimum operation conditions

Carbon species	unit	Concentration
CO	%	0.24
CO_2		0.68
C_1	ppmv	140
C_2		113
C_3		123
C_4		125
C_5		119
Total carbon	%	1.10

3. Conclusion

A demonstration scale Hydrothermal Pretreatment (HTP) process has been set up by CE-CERT. The optimum operation conditions of a HTP of comingled wood wastes and biosolids to produce a pumpable slurry feedstocks with high solid content was experimentally investigated. Rheology properties of pretreated slurries were analyzed, and carbon loss thru gas phase after the HTP process was detected and calculated. The following conclusions were drawn based on such study:

1) The stirred batch reactor has a high heating and cooling rate to meet the requirements of a continuous operation of Steam Hydrogasification reaction;
2) The optimum operations conditions to produce a pumpable wood wastes and biosolids slurry with an initial solid loading of over 40wt.% are: temperature over 270˚C, initial head space gas pressure over 200 psi and pretreatment time of 2 hrs;
3) The pretreated comingled wood wastes and biosolids slurry, with an initial solid loading of over 40wt.% at the optimum operation conditions has a viscosity value of less than 1.0Pa·s at a shear rate of over $80s^{-1}$, and such a slurry is pumpable;
4) Carbon compositions thru the gas phase after HTP are CO, CO_2, C_xH_y ($x<5$), and the total carbon loss thru exhaust gas at the optimum operation conditions, is 1.10%.

Reference
[1] McMahon, M.A.S., R. M. McKeon, R. J. Brent, A., *Partial oxidation of sewage sludge*. 1991: USA.
[2] Shimojo, M.I., Kazunobu. etc., *Method of reforming biomass and reforming apparatus*. 2006.
[3] Natarajan, V.P. and G.J. Suppes, *Rheological studies on a slurry biofuel to aid in evaluating its suitability as a fuel*. Fuel, 1997. **76**(14-15): p. 1527-1535.

Appendix B:
Hydrothermal Reactor Fabrication and Experiment Design

Appendix B: Hydrothermal Reactor Fabrication and Experiment Design

1. Introduction

Biosolids discharged from waste water treatment facilities is a wasted water and energy source. Its disposal requires processing such as dewaterization and stabilization, which adds up to the operation cost in waste water treatment plant [1, 2]. Meanwhile, there are growing public concerns over the land use and the potential environmental issues caused by biosolids disposal [3]. Therefore, there is an economical and environmental incentive to reclaim water and energy from biosolids and to use it as a feedstock in gasification processes. Such application would cause environmental benefits to gasification processes, such as an offset of carbon footprint [3]. The College of Engineering, Center for Environmental Research and Technology (CE-CERT) has proposed to use a renewable feedstock of co-mingled wood wastes and biosolids in its Steam Hydrogasification Process (CE-CERT Process) and to produce energy products, such as synthetic liquid oil, electricity, and so on. In CE-CERT process, wood wastes and biosolids are co-gasified and converted into a methane rich syngas (a gas mixture of carbon monoxide and hydrogen), which is further converted into synthetic liquid fuels and/or electricity.

A preliminary research reveals that the feeding of biomass feedstock, such as wood wastes and biosolids, into a pressurized reactor poses technical challenges [4, 5]. Conventional methods of feeding materials into pressurized gasifier, such as screw feed and locker hoper, are unreliable and operational expensive [4, 6]. To handle and transport biomass feedstocks in a cost and energy efficient manner, pumpable slurry of biomass feedstocks with high energy and carbon content is much more favorable [7, 8]. Additionally, the high moisture content in biomass feedstocks also favors wet feeding method. However, such biomass slurries are not readily available simply by mixing of wood wastes and biosolids. There are two reasons for this: 1) the low energy and carbon content in wood wastes and biosolids, 2) hygroscopic and hydrophilic nature of wood wastes. So, in order to prepare pumpable wood wastes and biosolids slurries with high energy and carbon content, a pre-processing step has to be implemented. And this is achieved by using a Hydrothermal Pretreatment (HTP) process invented by CE-CERT.

CE-CERT was awarded by California Energy Commission to demonstrate the CE-CERT process with a feedstock capacity of 10lb\hr in dry basis. This test plan is a subtask of the CEC proposal: “Process Demonstration Unit of CE-CERT Steam Hydrogasification Process”. In this test plan, a demonstration unit of HTP Process, which is capable of prepare comingled wood wastes and biosolids slurry in 10lb\hr, is designed, fabricated, and tested at CE-CERT.

2. Objectives

The primary objectives under this test plan are to:

(1) Demonstrate operation of a HTP system using a 5 gallon stirred hydrothermal reactor,

(2) Obtain a pumpable co-mingled wood wastes and biosolids slurry with a solid loading of above 30 wt.%,

(3) Measure the material loss in the HTP process and calculate the carbon loss.

To this end, the HTP system assembly shown in Figure 1(a) will be operated in the stirred batch configuration. The hydrothermal reactor with temperature and pressure transducer and controller, 3 zone electric heater, serpentine cooling coil were designed by CE-CERT and fabricated by Parr Instrument Company. The coolant recycling system was designed and set up by CE-CERT. The system controller box, magnetic stirrer with electric motor and the pneumatic lift support frame were designed and fabricated by Parr Instrument Company.

The hydrothermal reactor is made of 316-stainless steel. 316-stainless steel is the chosen material of the HTP reactor because of its high nickel and molybdenum concentration and the resultant corrosive resistance to sulfuric, phosphoric, and acetic acids. A preliminary test results from a mini batch HTP reactor showed slightly acidity of the slurry products (pH of 3 to 4), which is mainly due to acetic acid produced from the wood wastes and biosolids. The hydrothermal reactor has a volumetric capacity of 5 gallons. A magnetic stirrer which is powered by an electric motor is implemented to rotate the agitator inside. The reactor is heated by a 3 zone electric heater jacket, as shown in Figure 1(a). A serpentine cooling coil with a coolant circulating system is implemented to transfer heat out of the hydrothermal reactor, as shown in Figure 1(b). Upon receiving the hydrothermal reactor assembly, the installation was performed in CE-CERT lab 705, a field point picture was taken in front of the reactor after its installation, as show in Figure 2. Other onsite installations include gas, coolant supply and power cord installation. A computer assisted control system with remote control software is provided by Parr Instrument and is connected with the hydrothermal slave box controller.

Prior to the operation of the HTP, the following tests were carried out within the scope of this test plan:

1) Leak test of the HTP system at working temperature and pressure,

2) Test of heating capacity and heating rate of HTP system with feedstocks,

3) Test of cooling capacity and cooling rate of HTP system with feedstocks,

4) Stirring test with feedstocks,

5) Optimum operating condition test,

6) Pumpability test of resultant slurries.

In the preliminary tests 1 through 3, water was used as a replacement of biosolids. Such replacement is validated by a Huffman proximate analysis of the biosolids, in which it was showed that 95 wt.% of biosolids is water, and the rest 5wt.% of solid in the biosolids has negligible impact on pretreated products.

Leak test was performed to the assessment and insurance of operation safety. It was performed under the operating temperature and pressure of HTP reaction. The estimation of such operating conditions was achieved by heating 3 liters (equally 5.7 lb) water to 300˚C. Then the temperature was maintained at 300˚C for 1 hr, and pressure was simultaneously kept constant at approximately 1245 psi. Readings of pressure numbers in the HTP from pressure transducer and a bubble test of possible leak points were performed to prove the reactor seals well under the operating conditions.

Heating capacity and heating rate, cooling capacity and cooling rate of the HTP reactor were tested with two different feedstocks: water and wood wastes. The heating and cooling ramp were calculated and plotted out after the tests.

Stirring test was performed with a total of 3.6 kg wood wastes and 1.2 kg water. The purpose of such test was to determine agitator speed and motor capacity when feedstock was pretreated. There were scheduled to be at least 13 hydrothermal pretreatment tests with this hardware in the current project using wood wastes and biosolids.

It was expected that the Chemical characteristics of biosolids vary between treatment plants and, to a limited extent, within the same plant over time. Huffman tests were performed with two biosolids samples collected in spring and summer from Riverside waste water treatment plant, which represents the biosolids sample in rainy seasons and dry seasons. The results showed unnoticeable changes. The wood saw dust was purchased from market which was also tested of its components by Huffman analysis, see Table B1.

Details about test conditions of 15 experiments are shown in Table B2 below. According to the reactor's operation manual, the maximum loading of feedstocks in reactor is restricted to be less than two thirds of its total volume. And when wood wastes and biosolids were mixed, it was found that volume of mixture had an unnoticeable change when compared with the volume of initial wood wastes.

Table B1: Results of Huffman analysis on wood wastes and biosolids

Analysis	Compound	Woody Waste (Pine)	Biosolids #1 [a]	Biosolids #2 [b]
			Weight %	
Proximate	Moisture, M	5.65	94.8	95.2
	Volatile Matter, VM	81.52	3.65	3.45
	Fixed Carbon, FC	12.58	0.44	0.36
	Ash	0.26	1.11	0.99
	Higher Heating Value, HHV (Btu/lb)	8093	N/A	N/A
Ultimate (Dry Basis)	C	47.56	40.80	40.67
	H	6.31	6.22	6.54
	O	45.81	23.14	22.76
	N	0.05	7.47	7.50
	S	0.01	1.04	1.11

a: biosolids sample collected Jul. 2008 from Riverside waste water treatment plant
b: biosolids sample collected Feb. 2009 from Riverside waste water treatment plant

This could be explained by the hygroscopic and hydrophilic properties of wood particles, which allow the biosolids to saturate and occupy the inter-particle space in wood. In all experiments, 1.2 kg of wood wastes was loaded. The volume of feedstocks was slightly less than two thirds of total volume of the reactor. The initial solid loadings in feedstocks were controlled over by changing the weight of biosolids. 3.6kg, 2.4kg and 1.8kg of biosolids were added into 1.2kg of wood particles, and were mixed up to obtain initial solid loadings of 28.8 wt.%, 36.7 wt.% and 43.0 wt.%, respectively. The ratios of biosolids to wood wastes by weight in such feedstocks were calculated, which were 3:1, 2:1 and 1.5:1, respectively.

The impact of head space gas and its pressure on the pretreatment performance was tested. The head space gas in the reactor was controlled over by pressurizing hydrogen at 100 psi, 200 psi and 400 psi.

The impact of pretreatment time on the pretreatment performance was investigated by changing the pretreatment time to be 1 hr, 1.5 hrs and 2 hrs.

If after completion of this test matrix additional time and funding remain, a series of tests with different initial head space gas (nitrogen), and controlled wood particle sizes range (<1mm and <250μm) will be attempted. This would offer extra operation options when hydrogen is not easily available, and the grinding and sieving of wood wastes could offer better cost efficiency, etc.

Table B2: Test plan in the 5 gallon stirred batch pretreatment vessel

Test #	1	2	3	4	5	6	7	8	9	10	11	12	13
Total load (kg)	4.8	4.8	4.8	3.6	3.6	3.6	3	3	3	3	3	3	3
Biosolids load (kg)	3.6	3.6	3.6	2.4	2.4	2.4	1.8	1.8	1.8	1.8	1.8	1.8	1.8
Wood waste load (kg)	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Biosolid to wood waste ratio	3:1	3:1	3:1	2:1	2:1	2:1	1.5:1	1.5:1	1.5:1	1.5:1	1.5:1	1.5:1	1.5:1
Initial solid load (wt.%)	28.8	28.8	28.8	36.7	36.7	36.7	43.0	43.0	43.0	43.0	43.0	43.0	43.0
Initial headspace gas and pressure	H_2@ 200 psi	H_2@ 200 psi	H_2@ 200 psi	H_2@ 200 psi	H_2@ 200 psi	H_2@ 200 psi	H_2@ 200 psi	H_2@ 200 psi	H_2@ 200 psi	H_2@ 100 psi	H_2@ 400 psi	H_2@ 200 psi	H_2@ 200 psi
Pretreatment time (hr)	2	2	2	2	2	2	2	2	2	2	2	1	1.5
Pretreatment Temp (˚C)	210±10	240±10	270±10	210±10	240±10	270±10	210±10	240±10	270±10	270±10	270±10	270±10	270±10

3. Hydrothermal Pretreatment System Setup

The HTP system has been designed for use as a high pressure reactor system. It has been designed, built, and tested to strict physical and electrical standards. The HTP system includes following components, as shown in Figure B1.

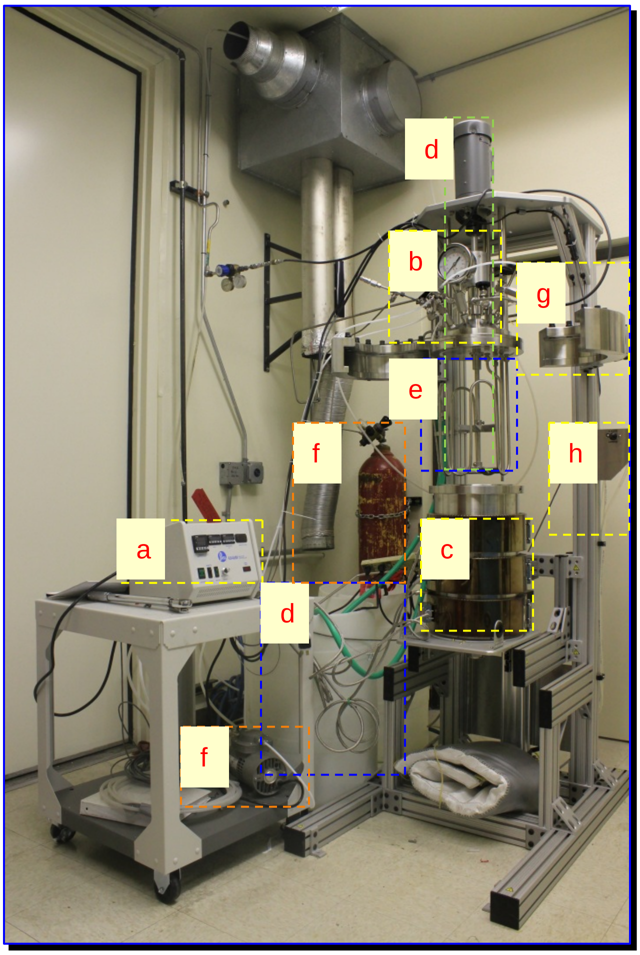

Figure B1: Hydrothermal Pretreatment System

Components:

a) Master slave box controller

b) Temperature and pressure sensor

c) Electric heater

d) Magnetic agitator assembly

e) Internal cooling assembly

f) Gas supply and vent

g) Seal and safety rupture disc

h) Pneumatic lift and support

Pressure caused by vapor expansion is dangerous in high temperature system. To prevent damage from such vapor expansion, the amount of water placed in any sealed pressure vessel should not exceed the volume determined from the following formula for Maximum Allowable Water Loading (MAWL):

$$MAWL = \frac{0.9 \times \text{vessel volume}}{\text{volume multiplier at Max.Temp.}}$$

In which the maximum operating temperature of the hydrothermal reactor in this test plan is 300˚C, and volume multiplier is 1.4. Following the calculation, MAWL in this test plan is set to be no more than 3.2 gallons, which is about two third of the total volume of the hydrothermal reactor.

#

3.1 `Master slave box controller

A 3-zone slave control box is used in conjunction with a Master controller to monitor and control online temperature, pressure and motor speed of the agitator. The slave box handles the high amperage components of the system. And it has control inputs from the 4840 series temperature controller. The slave box control requires 230V, 50/60 Hz, 50A service receptacle for connection. It has two 25A fuses on the electric heater, which provides a total of 50A electric power to the electric heater. There are four selectable zone switches in the slave box controller, which gives a wide range of heating rates available within a single heater assembly. Wiring of control box is configured as: zone 1 is wired with bottom side heater, zone 2 is wired with middle side heater, and zone 3 is wired with top side heater.

3.2 Temperature and pressure sensor

Temperature is detected by thermocouples. Two Type J (iron-constantan, stainless steel sheath, 1/8" diameter) thermocouples were installed with the hydrothermal reactor. One is buried into reactor by a thermowell penetrating through the head of the reactor. It reads real time temperature of inside the reactor. The other one is installed in the heater and controls heater power and protects heater from overheating. The total resistance of the thermocouple and the lead wires should not exceed 20 Ohms. If the resistance of the thermocouple circuit is higher, it will reduce the sensitivity of the control system.

A pressure gage, typically a 0-2000 psi with a T316 stainless steel Bourdon tube, is mounted on the head. A PDM Pressure Display Module w/Transducer is also mounted on the head. The transducer is connected with master slave box which enables online reading of the pressure inside the reactor.

3.3 Electric heater

A 3-zone heater is installed in the jackets surrounding the hydrothermal reactor. Each heating zone is rated 230V, 50/60 Hz, 15A. The entire heating assembly is powered by the master slave box controller. Type J temperature sensor is installed with zone #2 to inspect operating temperature of heater. Which is also programmed to shut the heat off when overheat is inspected.

3.4 Magnetic agitator assembly

A 60 in/lb footless heavy duty magnetic stirrer is mounted in fixed head support stand. Homogeneity of feedstocks could have been achieved by using such design. In the magnetic drive, magnets for the inner rotor to which the stirrer shaft is attached are enclosed in stainless steel housing, permanently sealed by laser welding and supported by graphite-filled, PTFE bushings. Such design avoids the leakage problems which can arise with a packed gland stirrer drive, as shown in Figure B2. A direct drive is used to power the magnetic impeller. The direct drive has the motor mounted vertically above the reactor with the drive coupler connected to the motor shaft. The direct drive includes a motor to provide variable speed of the impeller. Maximum power output of the direct drive is 3/4 hp. Speed of the motor ranges from 0 to 400 RPM.

3.5 Internal cooling assembly

Three parts of the HTP system requires external cooling. They are the hydrothermal reactor, the direct drive motor and the PDM pressure transducer.

Cooling coil (ID: 3/8") with serpentine configuration runs through the hydrothermal reactor. Two openings on the head of the reactor allows coolant be introduced and pass through the cooling coil after hydrothermal pretreatment is done, as shown in Figure B3. Coolant tank is designed and positioned next the reactor. Coolant is pumped through the cooling coil pipe by a submersible pump. The flow rate of coolant could be controlled over by a SVM Solenoid Valve Module.

Coolant pipe (ID: 1/4") also runs serially through the director drive motor and the PDM pressure transducer. Coolant is pumped through the coolant pipe by a submersible pump. Its flow rate could be controlled over by a hydraulic flow meter.

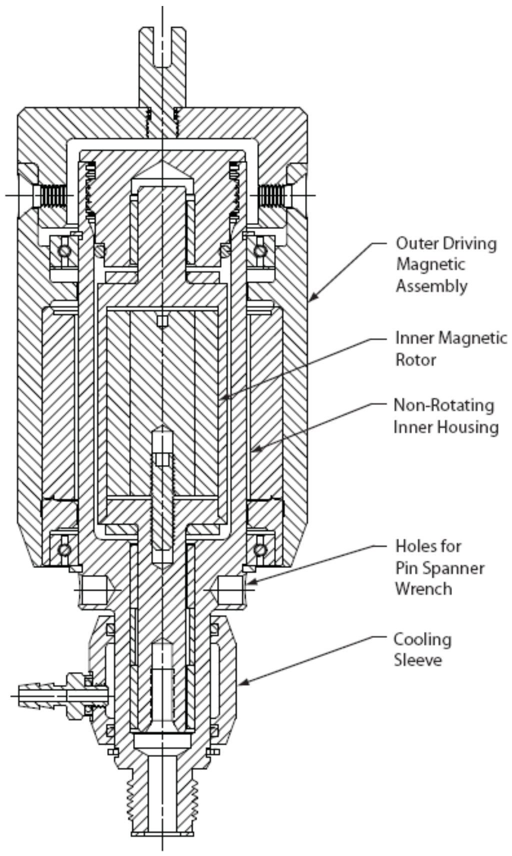

Figure B2: Parr magnetic drive

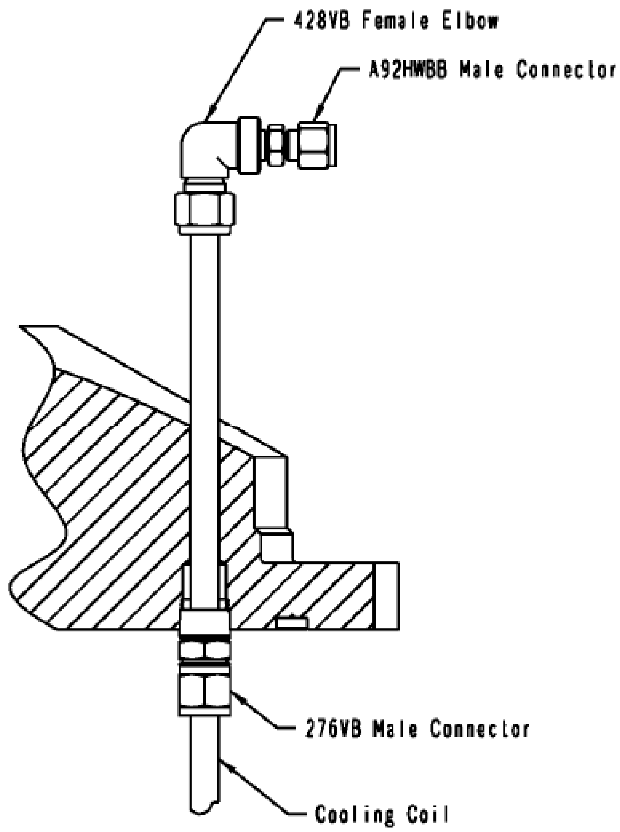

Figure B3: Welding of cooling coil on head of the hydrothermal reactor

Due to the massive amount of heat that is transfer out by coolant after the hydrothermal reactor, it is found coolant temperature could reach up to 100˚C. In order to obtain high heat transfer rate and efficiency in the cooling system, a secondary cooling coil is installed in the coolant tank in which tap water runs through.

3.6 Gas supply and vent

Hydrogen is supplied by a size-K hydrogen tank purchased from Praxair. A full size-K hydrogen tank can supply enough hydrogen gas for Gas is introduced into the reactor through a dip tube on the head, as shown in Figure B4. For future test, nitrogen is also supplied by using the pressure hose furnished with the reactor. When pretreatment is finished, gas is released through a releasing valve (needle type). An extra port is also provided when the exhaust gas needs to be sampled and analyzed. A vacuum pump is installed in the exhaust line which is used to vacuum the reactor before the HTP for head space gas pressurization and after the HTP for ventilation of hazardous exhaust gas.

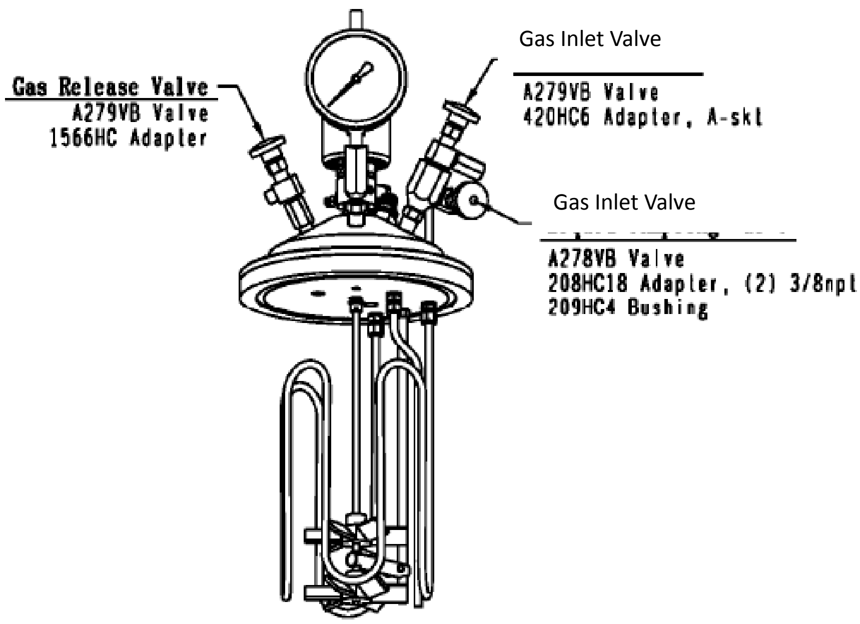

Figure B4: Gas inlet and release pipeline

3.7 Seal and safety rupture disc

A PTFE flat gasket is installed in a recess in the vessel head and a machine pilot on the cylinder closes the recess to completely contain the gasket. The split ring closure used with this gasket has compression bolts which are tightened to develop loading on the gasket. The closure is designed so that the compression bolts in the split ring sections make contact within a lip on the compression ring which will bring the split sections into their proper position. Torque wrench is applied to tighten the compression bolts in such a manner that proper torque is recommended for sealing a vessel with the gasket. The coordinate torque of maximum operating pressure achieved in the reactor can be found in Table B3. When high torque is required as operating pressure in reactor is high, the tighten procedure cannot be done in just one step. For example, to achieve a seal on the flat gasket for an operating pressure of 1500 psi, compression needs to be done in three steps: first, tighten all hex bolts with torque of 35lb; second, tighten all hex bolts with torque of 70lb; lastly, tighten all hex bolts with torque of 100lb.

Table B3: Bolt torque selection follows instructions below:

Pressure (psi)	Torque (ft-lb)
500	35
1000	70
1500	100
1900	135

There are in total 16 bolts on the head, which needs to be tightened in a crisscross fashion as shown in Figure B5. Such tightening sequence ensures evenly reinforcement on the metal seal plate in the head flange and avoids possible leak due to uneven seals. Failure to follow such tighten sequence may result in leak, or even more severely, permanent deformation of the seal plate on the head of the reactor.

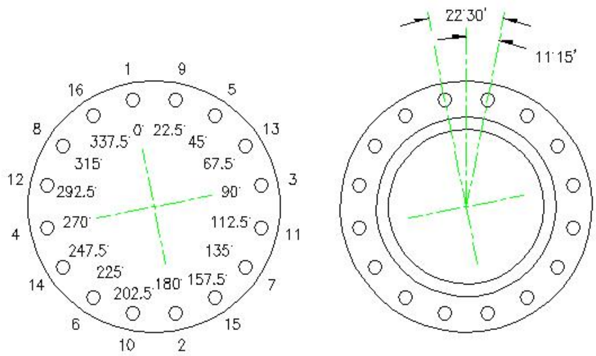

Figure B5: Crisscross fashion for tightening 16 bolts

There is a safety rupture disc attached to the head which is intended to rupture and release the pressure before it reaches a dangerous level, as shown in Figure B6. Outlet of rupture disc is connected to vacuum vent, which ensures safe evacuation of hazardous gas exhaust if maximum operating is exceeded. A metal tag wired to the safety head identifies the burst pressure at room temperature for that particular disc. A similar tag is furnished with each replacement disc.

3.8 <u>Pneumatic lift and support</u>

The base of the frame support is securely fastened to the floor by four 3-hole inside corner brackets. The hydrothermal reactor is installed on the upright frame support, as shown in Figure B7 (a). The direct motor drive is mounted on top of the support, with

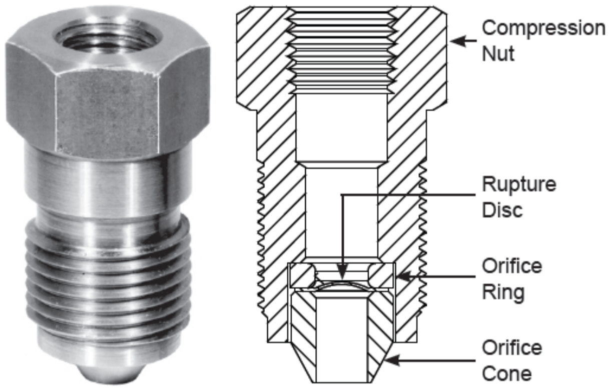

Figure B6: Rupture disc assembly

the impeller fixed below the motor drive, as shown in Figure B7 (b). The fixed head support stand features hinged split-rings that swing to either side allowing the head to remain fixed to the stand while a pneumatic lift (see Figure B7 (c))allows the cylinder to be raised and lowered, as shown in Figure B7 (d). When lowered, the cylinder can be slid forward along a sliding cart for cleaning and servicing. The pneumatic lift is driven by compressed air at 110 psi.

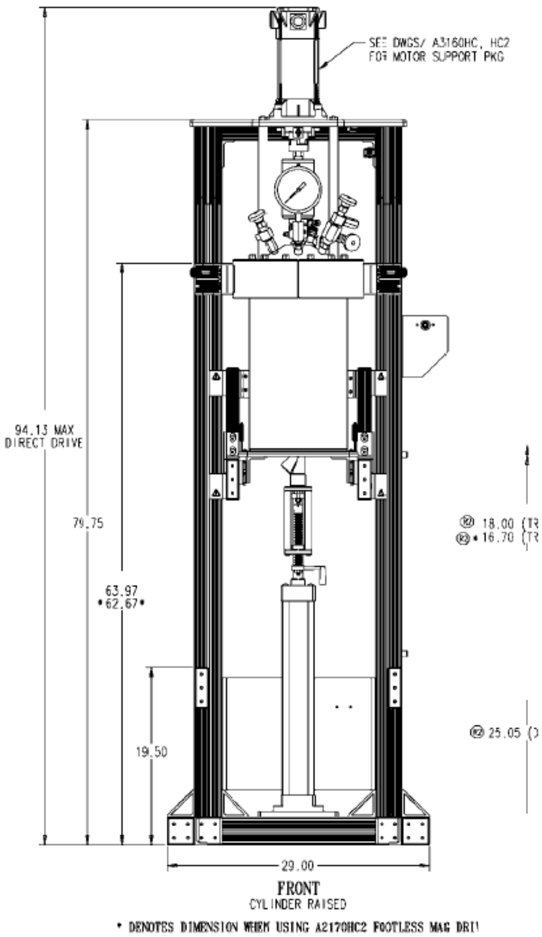

Figure B7 (a), Support frame of hydrothermal system

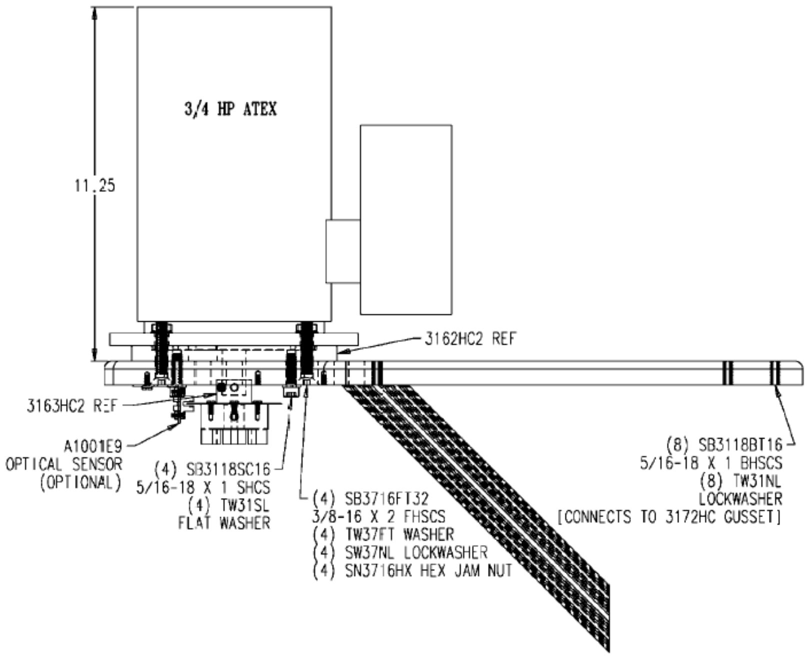

Figure B7 (b), Motor support platform assembly

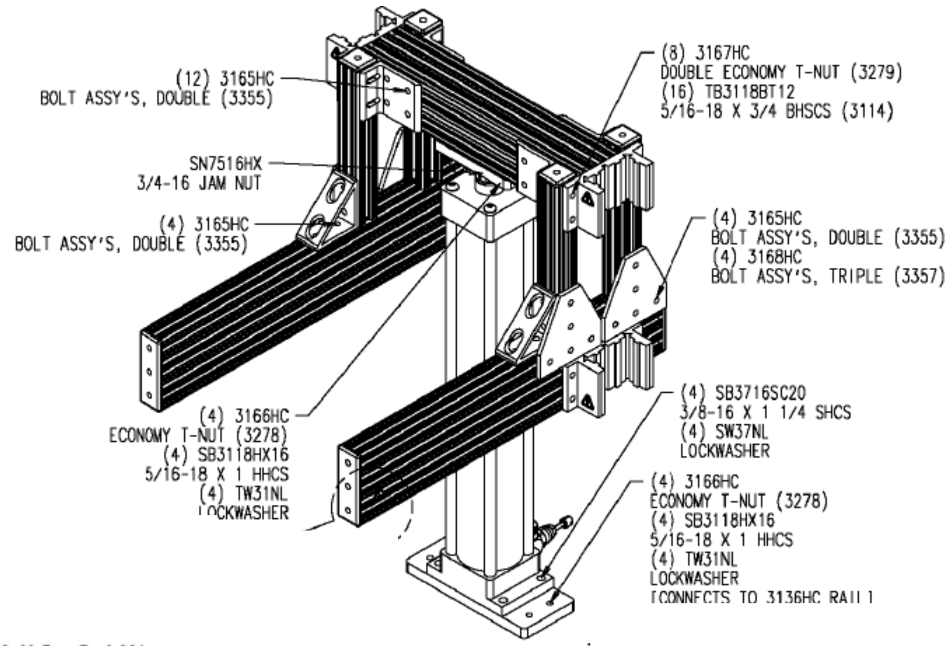

Figure B7 (c), Pneumatic vertical lift assembly

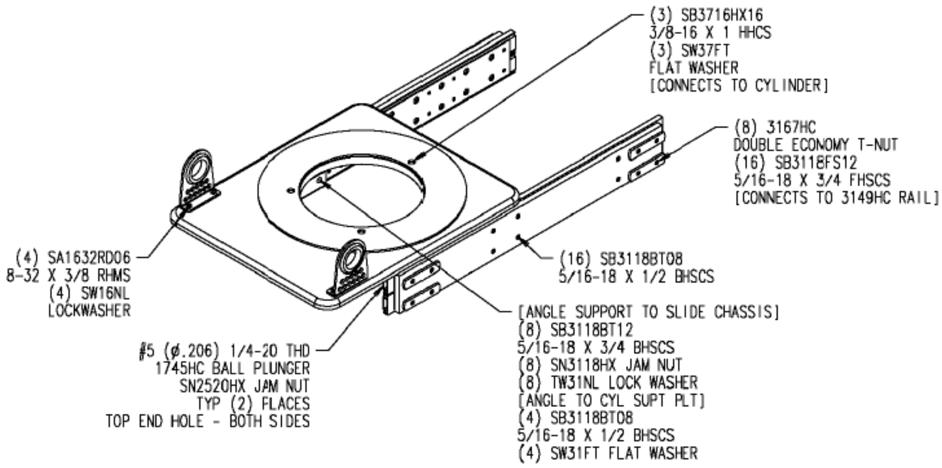

Figure B7 (d), Horizontal slide

4. Instrumentation and data recording

The primary data that is observed and recorded in this test plan is the operation data. These data include: 1) total weight of wood wastes and biosolids; 2) mass ratio of solid in the wood wastes and biosolids mixture as calculated by measuring the weight of wood wastes and biosolids in the feedstocks; 3) temperature profile in the hydrothermal reactor during hydrothermal pretreatment process as indicated by the master slave box; 4) pressure profile in the hydrothermal reactor during hydrothermal pretreatment process as indicated by the master slave box readings. Weight of the wood wastes and biosolids are measured on an electric balance and recorded in operation log sheet. Temperature and pressure profile are recorded in a computer with preinstalled software.

Pumpability test is performed on the pretreatment wood wastes and biosolids slurries. It is done by testing the rheological properties, such as viscosity, shear rate and shear stress of slurries. Such rheology tests were performed in a RheoLab QC rheometer (by Anton Parr Inc). Vane-cup geometry is a simpler geometry in rheometer. And, more importantly, it could minimize wall-slip effect in rheology test of slurry. A six blade spinner is used as rotor. It has been proved to be accurate for testing slurries with big particle suspension. Some adjustments were done to make the rheometer suitable for testing slurries with settlement issues. First, the inner diameter of cup was enlarged. Distance between the inner wall of cup and edge of the six blade spinner was adjusted to be greater than 2mm. This is because wall effect could be sufficiently reduced with a gap greater than 10 times the particle size in slurry. The depth of the cup was also adjusted to obtain a distance of less than 2mm between the cup bottom and the six blade spinner. Purpose of such modification is to minimize the particle settling during test. Slurries were gently stirred before the rheology tests until particles were evenly dispersed. Then the slurries were agitated to force out air bubbles. Viscosity of slurry was tested with an increase of shear rate. Data was automatically collected by a computer, as shown in Figure B8.

Figure B8: Rheolab QC rheometer

As was stated in the CEC proposal, material and carbon loss of wood wastes and biosolids feedstocks in HTP need to be determined. Mass loss can be determined simply by weight difference of feedstocks before and after the pretreatment process. Because hydrothermal reaction is carried out in a batch reactor, the only pathway of material loss is through exhaust gas. Carbon loss is then calculated by subtracting carbon fraction in the gas phase after the HTP process from the initial carbon loading in the feedstock. Carbon concentration in the exhaust gas is measured by using Gas Chromatography (GC). Preliminary research showed that carbon exhibits in the exhaust gas in forms of carbon oxide (CO and CO_2) and hydrocarbons (C_xH_y, y<6). Any other hydrocarbon species with carbon number over 6 is condensed in liquid phase as product is collect at room temperature. Flame Ionized Detector (GC-FID) and Thermal Conductivity Detector (GC-TCD) were used in the carbon species detection for carbon oxide concentrations and hydrocarbon concentrations, respectively. Figure B9 shows the HP 5890 Series II GC with FID and TCD.

Figure B9: HP 5890 Series II GC

5. Test procedure

Each hydrothermal test includes the following steps:

1) Wood particle preparation

2) Pre-mixing of wood and biosolids

3) Feedstock loading

4) Hydrothermal pretreatment

5) Cooling cycle

6) Sample collection

7) Cleaning

Wood particles were prepared through two steps: grinding and drying. Pine wood saw dust was first grinded in a lab mill, with a size reduction to about 1mm. Then it was further grinded in a blade grinder, which reduced the particles sizes to less than 500μm. Following the grinding step, wood particles were dried in a vacuum oven. The reason of performing the drying procedure is to precisely control the moisture content in the comingled feedstocks. It is an optional step and requires energy input, so it will be skipped in mass production.

After wood wastes were prepared, they were then mixed with biosolids in a mixing tray. The control of solid content in the comingled mixture was by weighting of wood wastes and biosolids before mixing. For example, to obtain a comingled mixture with solid content of 43 wt.%, wood wastes and biosolids were mixed by a mass ratio of 1:1.5.

The comingled wood wastes and biosolids mixture was then fed into the hydrothermal reactor, which were then hydrothermally pretreated at desired temperature. Before hydrothermal reaction happened, head space gas in the reactor needed to be replaced by hydrogen. It is performed by vacuuming and pressurized the reactor with hydrogen three times. Final pressure of the head space gas is controlled by setting up the pressure supply in the hydrogen tank.

Convective cooling was applied after the HTP process which is by running coolant through an internal cooling coil inside the reactor after the HTP. Reactor needs to be cooled down to room temperature before reactor was depressurized.

When temperature of the hydrothermal reactor deceased to room temperature, exhaust gas in the head space is vented or sampled if necessary. Then the reactor is vacuumed by a vacuum and is opened. Sample is collected from a 1 1/2" drainage hole on the bottom of the reactor.

Following the sample collection, reactor is cleaned up for next run.

A standard operating procedure for the HTP reactor is attached in the appendix A.

5.1 Test program

The test program consists primarily of the thirteen HTP tests listed in Table 2 in addition to various systems checkouts conducted prior to these thirteen tests.

5.2 Results and discussion

The program will test HTP of comingled wood wastes and biosolids with an initial solid loading of over 40 wt.%. Effect of following parameters on the slurribility of resultant comingled wood wastes and biosolids mixtures will be experimentally analyzed:

1) Pretreatment temperature,

2) Initial total loading,

3) Initial solid loading,

4) Pretreatment time,

5) Initial head space gas.

Test results will be reported in a subsequent Optimum Operation Condition Report.

5.3 Conclusion

CE-CERT has designed a stirred batch hydrothermal reactor. Comingled wood wastes and biosolids mixture is hydrothermally pretreated in such a reactor in a rate of 5 lb\hr. Continuous operation of two parallel hydrothermal reactor offers capability of demonstrating continuous operation of a fluidized Steam Hydrogasification reactor at a capacity of 10 lb\hr.

6. Standard Operation Procedure for the Batch Pretreatment Unit

Test related activities will be conducted in accordance with established standard operation procedures (SOP) and generally accepted industry safety practices.

PREPARATION

1) Turn on "Parr" computer program
   - Connect USB cable to the computer
   - Click on the computer icon and check if values are correct
     a) COM PORT >> COM 3
     b) BAUDRATE >> 9600 bps
     c) PARITY BIT >> Even
     d) DATA LENGTH >> 7 bits
     e) STOP BIT >> 1 bit
     f) FORMAL >> ASC 11
   - Click on the second icon "Monitor Program"
   - Change the "Address" to 1, 2, and 3
   - Click "Connect"

2) Open chiller isolation valve outside and turn on chiller switch inside

3) Open the hydrogen tank
   - Set outlet to 200 psi

4) Turn on "pre-treatment control box"

5) Make sure the bottom cap is secured tightly on the bottom of the vessel

6) Turn on exhaust vent

START-UP/TESTING PROCESS

1) Prepare feedstock sample

2) Check to see if there is pressure on the back of the pneumatic lifting device (roughly 100 psi).
   - Lift the vessel up, push the vessel against the support
   - Leave enough room for sample loading

3) Turn on the pump for the agitator

4) Turn on the agitator and set the rpm to 50 (be sure that the local/remote switch is set to local)

- Load feedstock
- Clean off all debris from the top and bottom of the seal

5) Turn off agitator

- Lift the vessel up completely while pushing the vessel against the support

6) Close clamps on the vessel and check for gaps

- Hand loose the agitator by rotating the motor, turn the agitator on, and set the rpm to 100.
- Hand tight all 16 bolts
- Tighten bolts in a criss-cross fashion (see picture below) using 30 foot lbs.
- Increase the torque of the wrench to 70 foot lbs. and tighten it in a criss-cross fashion
- Increase the torque of the wrench to 100 foot lbs. and tighten it in a criss-cross fashion for three times.

7) Evacuate vessel and backfill with hydrogen

- Make sure to close the vacuum valves
- Check the rpm of the agitator to be at 100

8) Pressurize the vessel with hydrogen to about 200 psi

- Check for leaks (observe the pressure numbers on the monitor for a minimum of 5 minutes)
- Vacuum out the vessel (slowly vacuum and slowly pressurize)

9) After vacuuming, put on the vessel jacket

- Turn on the heater (all 3 zones)

ON THE CONTROL BOX:

- Green numbers are the default values and should always be at
  - a) 270°C
  - b) 1000 rpm
  - c) 2400 psi

- Red numbers are the actual values (depends on the testing parameters)

EX:

  - a) 270°C
  - b) 100 rpm
  - c) About 1300-1500 psi

10) When the temperature is reached, run the test for 2 hours

SHUT DOWN AND COOLING

1) Set temperature on the control box to 25°C

2) Remove the vessel jacket

3) Turn on pumps for cooling and balancing (inside and outside chiller)

4) Turn off the agitator

5) When the temperature is less than 100°C, it is safe to turn off pumps for cooling coils and pumps for the agitator and pressure sensor

6) Make sure to record all information into the log sheets
   - Temperature
   - Pressure

COLLECTING FEEDSTOCK

1) Vent the head-space gas to depressurize the vessel to 0 psi,

2) Vacuum the vessel,

4) Unbolt the vessel and remove the clamps,

3) Lower the vessel and pull the vessel out from the support,

5) Scoop the solid fraction of the feedstock and put it into the sample bucket,

6) Carefully unscrew bottom cap to release remaining liquid fraction of the feedstock.

CLEANING AND DRYING

1) Apply rags on the heater to protect from water,

2) Use water supply from the outside and install the nozzle ,

4) Thoroughly rinse the vessel using water first (make sure you have a tray on the bottom to store the waste water) ,

3) Clean the cooling coil and impellers (make sure you have a tray on the bottom to store the waste water) ,

5) Dry vessel, cooling coil, and impellers using an air gun

6) Push the vessel back against the support.

SAFETY

1) Proper ground needs to be provided with reactor to avoid electric shock,

2) Upper limit of reactor is designed as: 350°C, 3000 psi,

3) Keep hydrogen tank closed unless reactor is being pressurized.

Reference

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Appendix C:
Pump Specification

Appendix C: Pump Specification

Table C1: Pump technical specification

NEMO® pump with base plate and drive: N-ELOR® NM015BO02S12B

Product:		***Content***	***nominal***	***minimum***	***maximum***
Name / Composition	Waste slurry w/ wood chips				
Product temperature		°C	25		
Specific gravity	approx.		1.2		
Particle size		um	<150		
pH value	approx.		5-7		
Solids content (w/w)	approx.	% TS	40		
Dynamic viscosity	approx.	CPS	1000		
Vapour pressure		PSI	N/A		

Application details:		***Content***	***nominal***	***minimum***	***maximum***
Flow rate (Q)	approx.	GPH		4.0	5.3
Differential pressure		PSI		150	150
Suction pressure	assumed	PSI		flooded	flooded
Discharge pressure	approx.	PSI		150	150
Pump operating speed	approx.	RPM		94	127
Sliding velocity	approx.	ft./s		0.21	0.25
Frequency	approx.	Hz		44	60
Power required at drive shaft	approx.	HP		0.1	0.1
Running torque	approx.	ft./lbs		2.14	2.14
Starting torque	approx.	ft./lbs		2.07	2.07

Assembly specification

installation	horizontal

General operating conditions

Installation area	inside
ambient Temperature	approx. 20°C / 70 F
humidity	up to 75%
application type	Continuous operation
operating hours	8 hours/day
service voltage	1/60/115

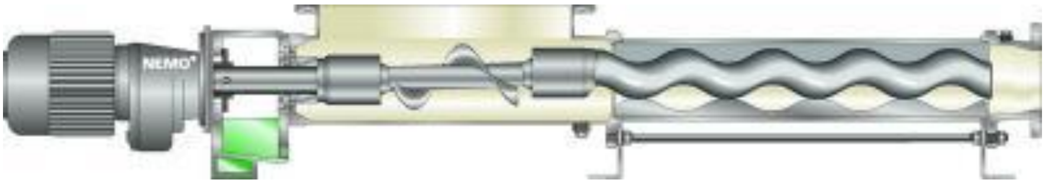
Painting	coating system	NIL System I – RAL 7031 – NETZSCH GRAY NCS 355B60G – TEAL (stator only)

Operating and Maintenance Instructions

Standard documentation in accordance with the 98/37/EG Machinery Directive.
Special documentation is available on request and would be charged for.

number	1
medium	Paper
language for O&M's and spare parts list	English
dispatch method	shipped with pump

NEMO® NM015BO02S12B Pump



Characteristics and benefits of the NEMO® N-ELOR® BO pump:

1) suitable for all media from watery to pasty
2) suitable for waste water sludge up to 15% solid content
3) feeding auger on coupling rod to increase total efficiency
4) feeding rate approx. 170%
5) robust design
6) temperature range according to materials in use
7) continuous flow rate depending on pump speed
8) easy mounting
9) joints sealed to the product
10) optimum pumping of highly viscous product, also media with gas phase
11) conveying from a vacuum possible
12) high wear resistance

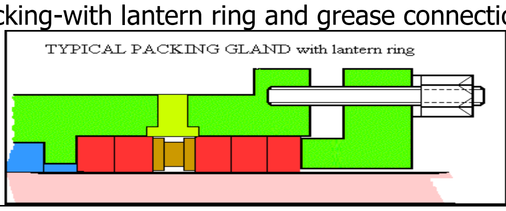
General characteristics	
name plate on the pump	in English (Stainless steel)
direction of rotation	to the left, counter clockwise (as viewed from drive end)

Pump Pedastal	
material	Cast iron 0.6025

Pump housing / End connection	
housing material	316 stainless steel
flange position	vertically upwards
function of housing connection	suction connection
flange design	Open throat with **special auger***
nom. dia. & pressure for pump housing	204 x 104 mm
discharge flange design	
nom. dia. & pressure of discharge flange	1.25" NPT
function of end connection	pressure connection
housing seals	FPM

***Special non-overfeeding auger to be supplied with a design capacity of 0.23 US gal. / 100 rev.**

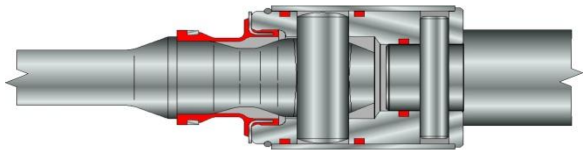
Shaft seal	
type	Gland packing
shaft seal materials	Teflon / kevlar
shaft seal type	Packing-with lantern ring and grease connection



Page:	3/5
Offer:	**007256 Rev 1**
Date:	**06/16/10**
Customer No.:	**932465**

Rotating parts		
	rotating parts materials	316 stainless steel
	coupling rod with auger	316 stainless steel

Joints		
	joint type	pin joint
	sealing type	SM Pin joint
	joint sealing material	Viton/316 Stainless Steel
	joint lubrication	Mineral oil



Rotor		
	rotor material	chrome plated 316 stainless steel(4401VCP -20C)
	temperature range	0 - 44 ºC

Stator		
	stator material	NEMOLAST® S65L

Drive

Helical gearmotor		
	manufacturer	Nord
	type	SK172.1F-71L/4
	flange ø mm	160
	shaft ø mm	19
	output speed n_2 @60Hz	127 rpm
	output speed n_2 @ min/max frequency	25.4 / 127 rpm
	mounting position	M1
	motor HP	0.5
	winding voltage	230/460
	voltage range	230/460
	frequency	60 Hz
	min / max frequency	12 / 60 Hz
	number of poles / phases	4 / 3
	motor speed n_1 @60Hz	1750 rpm
	motor speed n_1 @ min/max frequency	350 / 1750 rpm
	protection type / insulation class	IP55 – TEFC / F

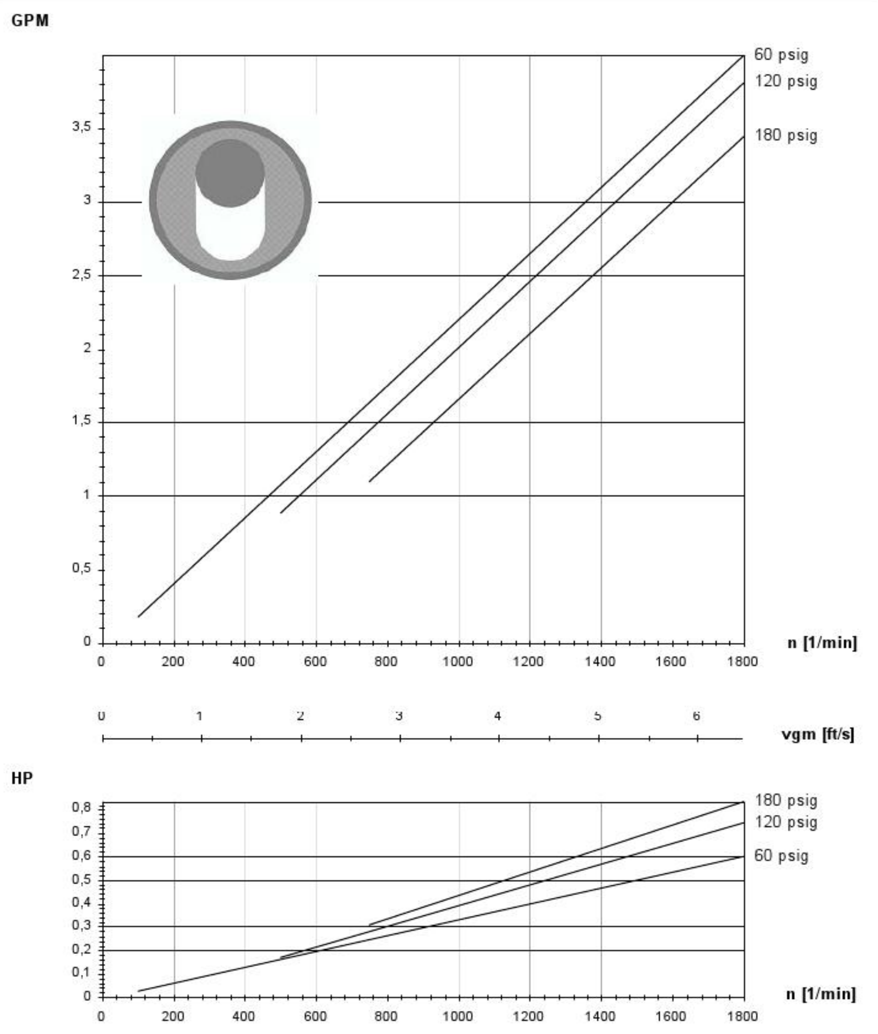
Variable Frequency Drive		
	manufacturer	AC Tech
	type	M1105SB
	VFD HP	0.5
	input signal (voltage / no. of phases)	115 V / 1
	output signal (voltage / no. of phases)	230 V / 3
	enclosure rating	NEMA 1

Baseplate

assembly specification - material	Structural steel base plate

Approximate weight	108 lbs

Performance curve:



starting torque T(L) = 2,072 lbft

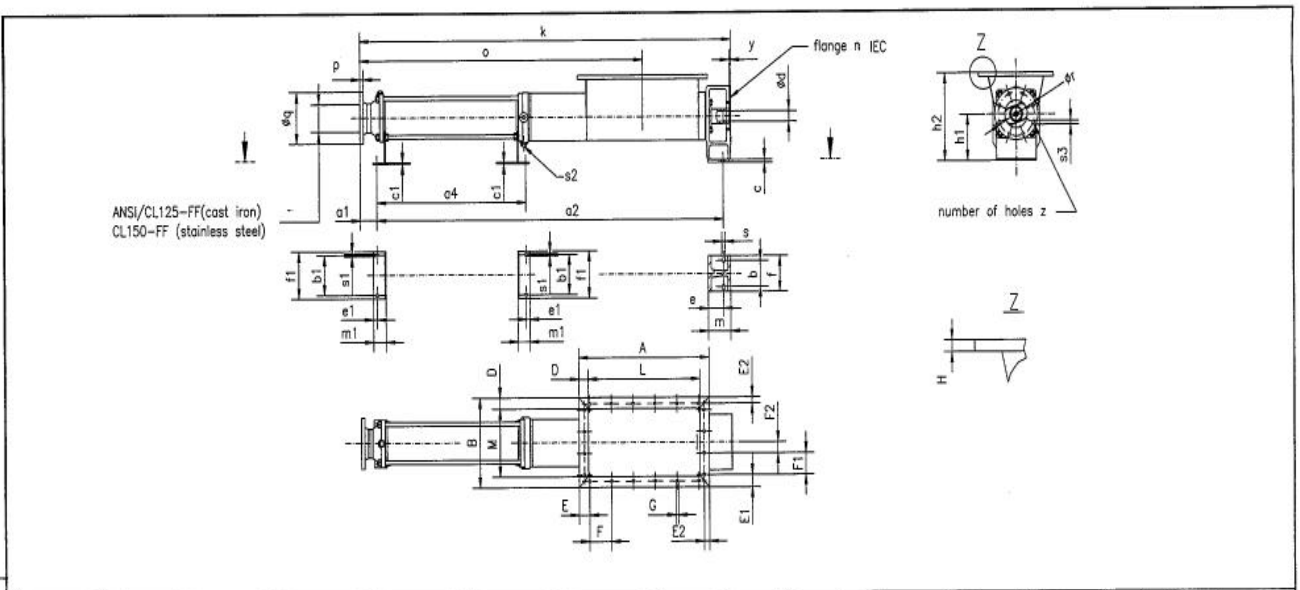
pressure	T
60 psig	1,554 lbft
120 psig	1,924 lbft
180 psig	2,368 lbft

Valid for water (1 cP) at 20 °C (70 °F). Tolerances are in accordance with VDMA 24284 (+10%/-5%).

Rev.: 03/2007 Technical changes reserved. www.netzsch-pumpen.de

Figure C1: Pump performance curves

Pump drawing:



TYPE	a_1	a_2	a_4	b	b_1	c	c_1	e	e_1	f	f_1	h_1	h_2	k	m	m_1	o	s	s_1	s_2	y
	Basic dimension																				
NM015BO 02S12/01L06 –	41	611	-	95	50	8	5	28	15	125	80	100	205	671	55	40	449	12	9	NPT 1/2"	5
NM021BO 02S12/01L06 –	41	687	-	95	50	8	5	28	15	125	80	100	205	747	55	40	525	12	9	NPT 1/2"	5
NM031BO 02S12/01L06 –	77	935	-	115	69	10	5	27	20	150	100	112	242	1047	60	50	759	12	11	NPT 3/4"	5
NM038BO 02S12/01L06 –	85	1055	-	115	95	10	6	35	20	150	130	132	262	1167	60	55	889	14	11	NPT 3/4"	5
NM045BO 02S12/01L06 –	84	1270	-	115	115	10	6	42	17,5	150	150	160	320	1384	70	55	1053	14	11	NPT 3/4"	5
NM053BO 02S12/01L06 –	89	1505	-	115	125	10	6	50	22	150	160	170	330	1616	70	60	1195	14	13,5	NPT 3/4"	8
NM063BO 02S12/01L06 –	119	1766	-	125	145	12	6	60	22	175	180	200	400	1907	100	70	1430	18	13,5	NPT 1"	8
NM076BO 02S12/01L06 –	129	2011	-	125	195	15	6	90	22	175	230	225	425	2186	120	70	1673	18	13,5	NPT 1"	8
NM090BO 02S12/01L06 –	122	2349	-	160	200	18	8	95	21	210	250	250	470	2521	143	80	1974	18	17,5	NPT 1"	10
NM105BO 02S12/01L06 –	133	2850	1265	200	220	18	8	100	21	250	270	280	560	3038	153	80	2404	18	17,5	NPT 1"	10

TYPE	A	B	D	E	E_1	E_2	F	F_1	F_2	G	H	L	M	ANSI	p	q	r	s_3	z	d x l	IEC
	Hopper dimension													Pipe connection						Shaft end	
NM015BO 02S12/01L06 –	310	210	53	62	62	32	93	0	43	9	10	204	104	Int. Thread 1.1/4" NPT						19X40	120/140/160
NM021BO 02S12/01L06 –	310	210	53	62	62	32	93	0	43	9	10	204	104	Int. Thread 1.1/4" NPT						19X40	120/140/160
NM031BO 02S12/01L06 –	360	260	53	62	62	32	118	0	68	9	10	254	154	2"	15,7	152,4	120,6	19	4	19X40	160/200/250
NM038BO 02S12/01L06 –	360	260	53	62	62	32	118	0	68	9	10	254	154	2,5"	17,5	177,8	139,7	19	4	30X60	200/250
NM045BO 02S12/01L06 –	456	346	53	60	60	30	112	103	0	13,5	10	350	220	3"	19,1	190,5	152,4	19	4	30X60	200/250
NM053BO 02S12/01L06 –	606	346	53	59	60	30	122	113	0	13,5	10	500	240	3"	19,1	190,5	152,4	19	4	35X70	200/250
NM063BO 02S12/01L06 –	706	386	53	59	60	30	147	133	0	13,5	10	600	280	4"	23,9	228,6	190,5	19	8	40X80	250/300
NM076BO 02S12/01L06 –	756	436	53	60,5	60,5	30	127	105	52,5	13,5	10	650	330	6"	25,4	279,4	241,3	22,2	8	50X110	250/300/350
NM090BO 02S12/01L06 –	806	436	53	63	60,5	30	136	105	52,5	13,5	10	700	330	6"	25,4	279,4	241,3	22,2	8	60X120	250/300/350
NM105BO 02S12/01L06 –	950	476	53	62,5	61	30	165	118	59	13,5	15	844	370	6"	25,4	279,4	241,3	22,2	8	65X130	300/350/400/450

2004	Date	Name
Draw.	12/05	Clayton
Check.	12/05	Behling
Appr.	12/05	Behling

Ind. | Revision | Date | Name

NEMO–PUMP (P)
Range NM–––BO 02S12/01L06 –
Execution with feeding chamber

NETZSCH

CAD

Drawing Nr.: NDB4916345

Replaces:

Figure C2: Pump drawing

Appendix D:
PDU Fabrication Drawings

Appendix D: PDU fabrication drawings

Unit : inches

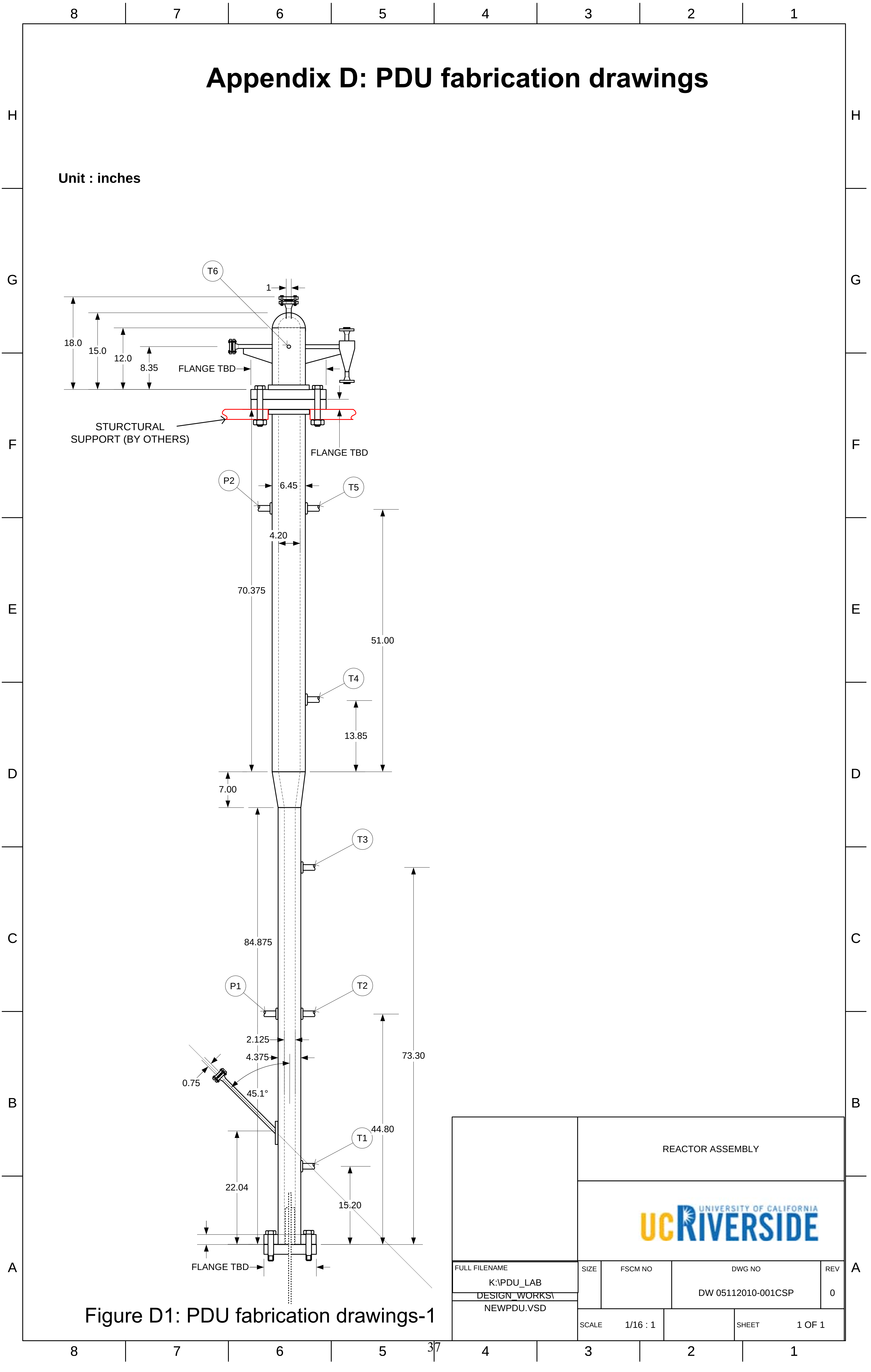
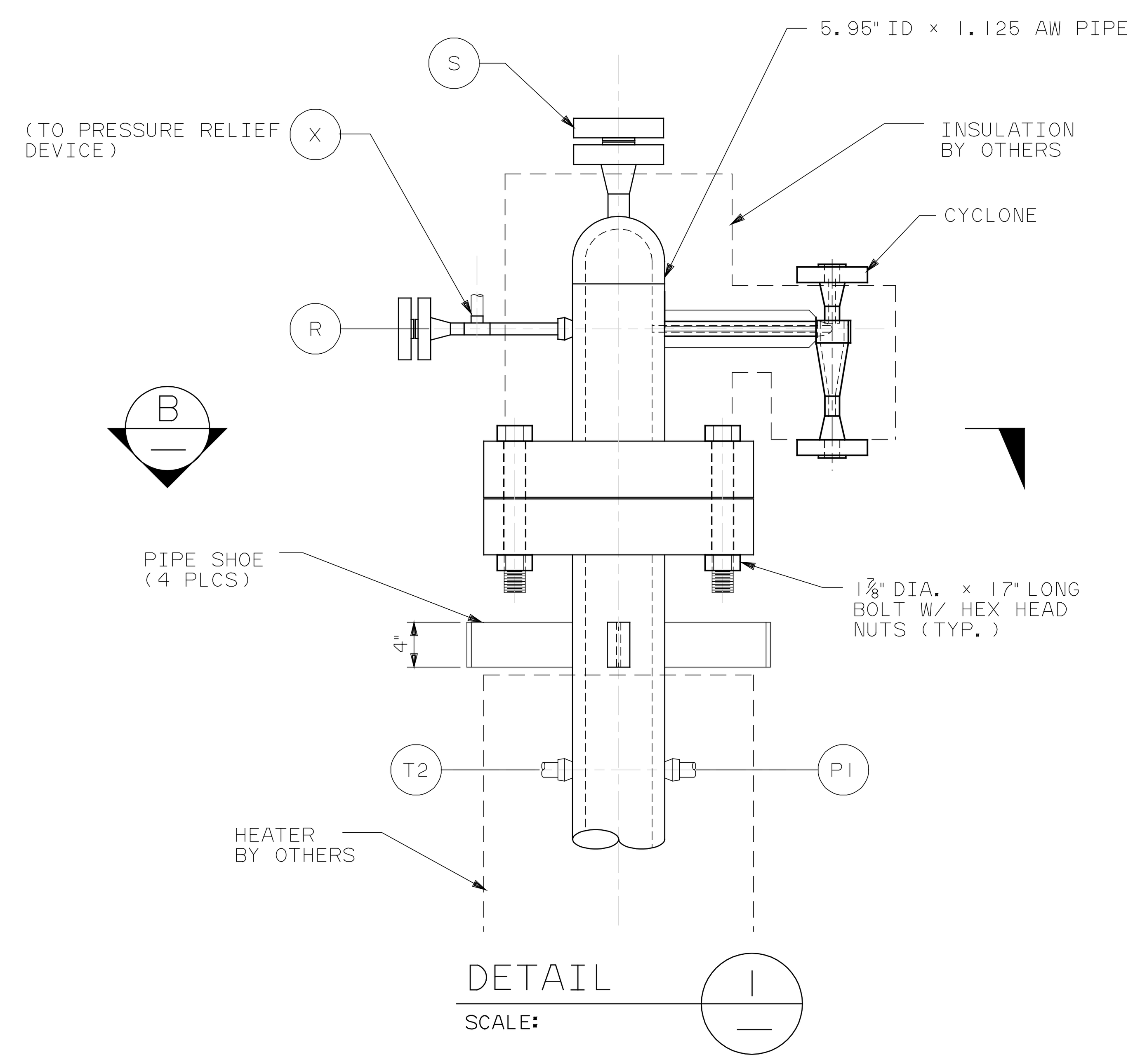


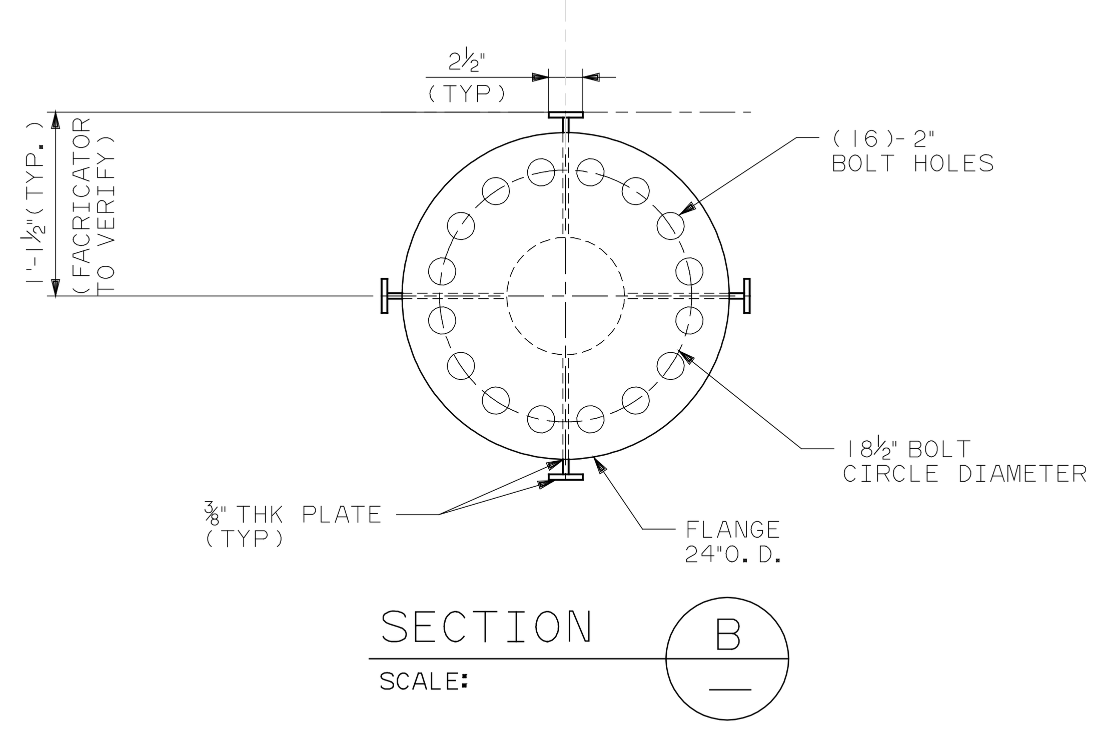
Figure D1: PDU fabrication drawings-1

	REACTOR ASSEMBLY			
	UC RIVERSIDE UNIVERSITY OF CALIFORNIA			
FULL FILENAME K:\PDU_LAB DESIGN_WORKS\ NEWPDU.VSD	SIZE	FSCM NO	DWG NO DW 05112010-001CSP	REV 0
	SCALE 1/16 : 1		SHEET 1 OF 1	

NOZZLE SCHEDULE

NOZZLE TAG	DESCRIPTION	MATERIAL	REMARKS
S	SAND FEED	INCOLOY 800HT (UNS-N08811)	1½" XXS HEAVY PIPE, 1½" 2500 # B16.5 WNRF FLANGE, W/ BOLTS AND NUTS AND BLIND FLANGE
T1-T7	THERMOCOUPLE CONNECTION	INCOLOY 800HT (UNS-N08811)	BY FABRICATOR
P1-P3	PRESSURE CONNECTION	INCOLOY 800HT (UNS-N08811)	BY FABRICATOR
H	FLUIDIZING GAS CONNECTION	INCOLOY 800HT (UNS-N08811)	½" SCH 80 PIPE, ½" 2500# B16.5 WNRF FLANGE W/ BOLTS AND NUTS
R	RODDING PORT	INCOLOY 800HT (UNS-N08811)	¾" SCH 80 PIPE, ¾" 2500# B16.5 WNRF FLANGE W/ BOLTS AND NUTS AND BLIND FLANGE
F	ALTERNATE FEED PORT	INCOLOY 800HT (UNS-N08811)	½" SCH 80 PIPE, ½" 2500# B16.5 WNRF FLANGE W/ BOLTS AND NUTS
G	INJECTOR FEED GUN NOZZLE	INCOLOY 800HT (UNS-N08811)	SEE DW-0839-001 FOR DETAIL
Q	SLURRY FEED NOZZLE	INCOLOY 800HT (UNS-N08811)	SEE DW-0839-002 FOR DETAILS
W	WINDBOX NOZZLE	INCOLOY 800HT (UNS-N08811)	SEE DW-0811-002 FOR DETAIL
X	TO PRESSURE RELIEF DEVICE	INCOLOY 800HT (UNS-N08811)	¾" SCH. 80 PIPE TOE NPT
C	CYCLONE GAS OUTLET	INCOLOY 800HT (UNS-N08811)	SEE DW-0811-001 FOR DETAIL
D	CYCLONE SOLIDS DISCHARGE	INCOLOY 800HT (UNS-N08811)	SEE DW-0811-001 FOR DETAIL





NOTES:

1. FOR DESIGN BASIS REFER TO DOC. NO. LA714418 000 JSD 0411 001 REV 0
2. ALL MATERIAL TO BE 800HT (UNS N08811) OR EQUIVALENT.
3. USE INCO 82 FILLER METAL FOR ALL WELDS.
4. ALL CONTINUOUS WELDS TO BE GAS TIGHT. ALL WELDS TO BE FULL PENETRATION (UNO).
5. VESSEL WELDS TO BE 100% RADIOGRAPHED.
6. 800HT FLEXITALLIC CGI GASKETS WITH CERAMIC FILLER TO BE USED AT ALL FLANGED CONECTIONS (OR APPROVED EQUIVALENT).
7. REINFORCEMENT FOR THE PRESSURE TAP NOZZLES, THERMOWELLS, AND THE ALTERNATE FEED NOZZLE TO BE CALCULATED BY FABRICATOR. SOCKOLET TYPE FITTINGS SHOULD BE USED TO REINFORCE THE PRESSURE TAP NOZZLES AND THE THERMOWELLS. A WELDOLET TYPE FITTING SHOULD BE USED TO REINFORCE THE ALTERNATE FEED NOZZLE AND RODDING PORT.
8. VESSEL HYDROTEST TO BE PERFORMED AT 4420 PSI IN THE SHOP.
9. LEAK SENSITIVE PNEUMATIC TEST AT 75 PSI TO BE PERFORMED AT ROOM TEMPERATURE PRIOR TO START UP.
10. RELIEVE HEATERS 3.5" ABOVE EACH NOZZLE AND STUFF GAPS WITH MINERAL WOOL.
11. PRESSURE RELIEF DEVICE TO BE VENTED TO SAFE LOCATION (BY OTHERS).
12. SHELL TEMPERATURE NOT TO EXCEED 900°C BY SKIN TEMPERATURE THERMOCOUPLE MEASUREMENT.

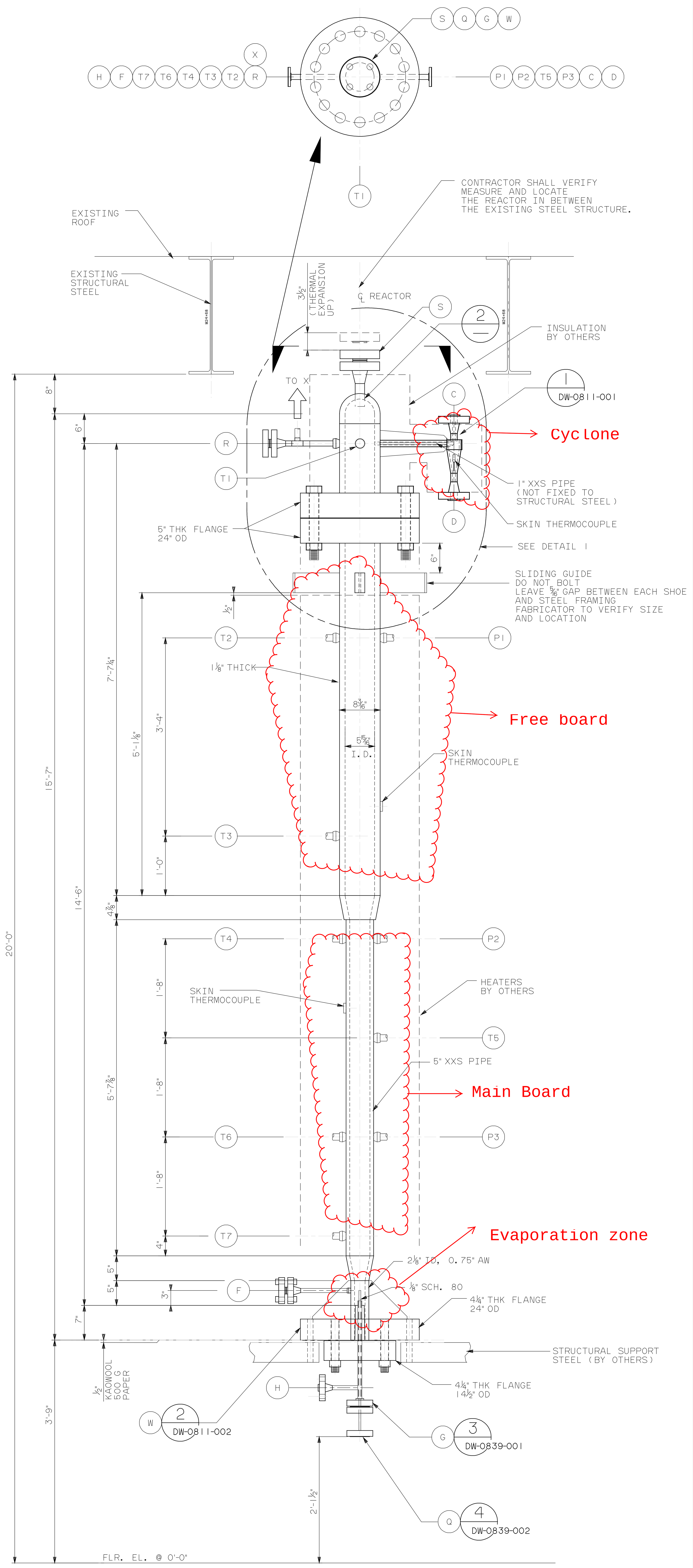
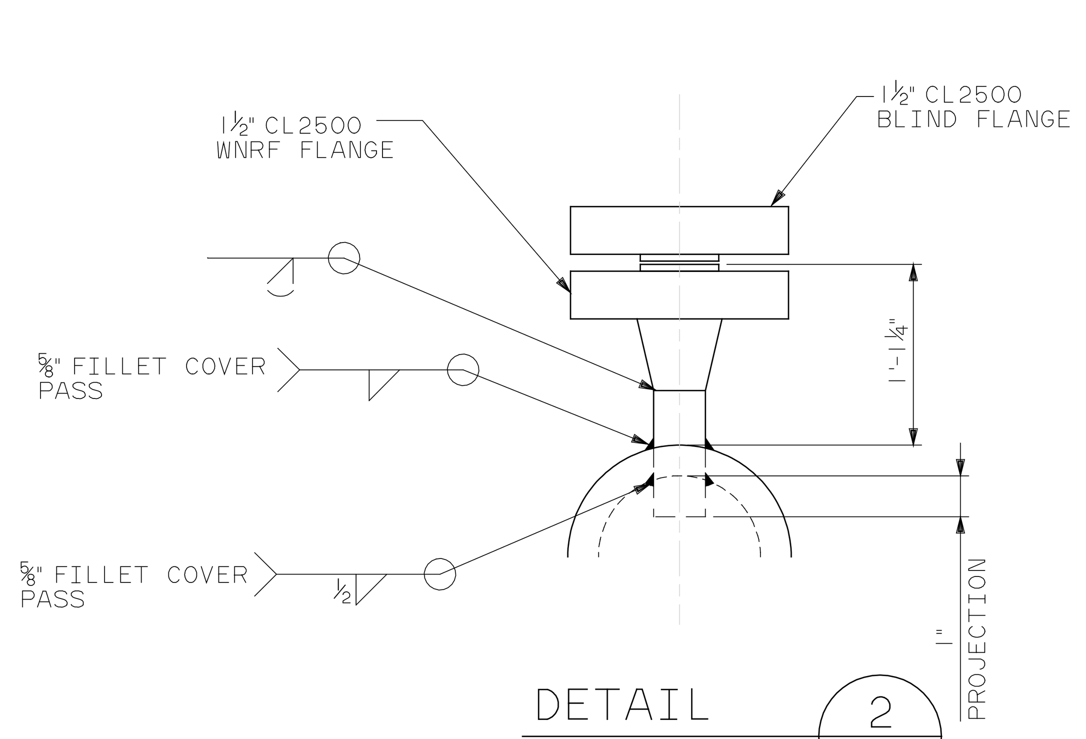


Figure D2: PDU fabrication drawings-2

ELEVATION



REV	DATE	DESCRIPTION	PREP	CKD	APPR	DM/PM
A	08-21-09	FOR INFORMATION	BB	XP	KK	EER/EW
B	10-01-09	REVISED	BB	XP	KK	EER/EW
0	10-06-09	ISSUED FOR APPROVAL	BB	XP	KK	EER/EW

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REACTOR ASSEMBLY AND DETAILS PLAN AND ELEVATION

SCALE	DRAWING NO.	PAGE	REV
NTS	LA714418 000 DW 04 11 001 (PROJECT / UNIT / DOC TYPE / DISC / SUBJ / SER.NO)	1	0

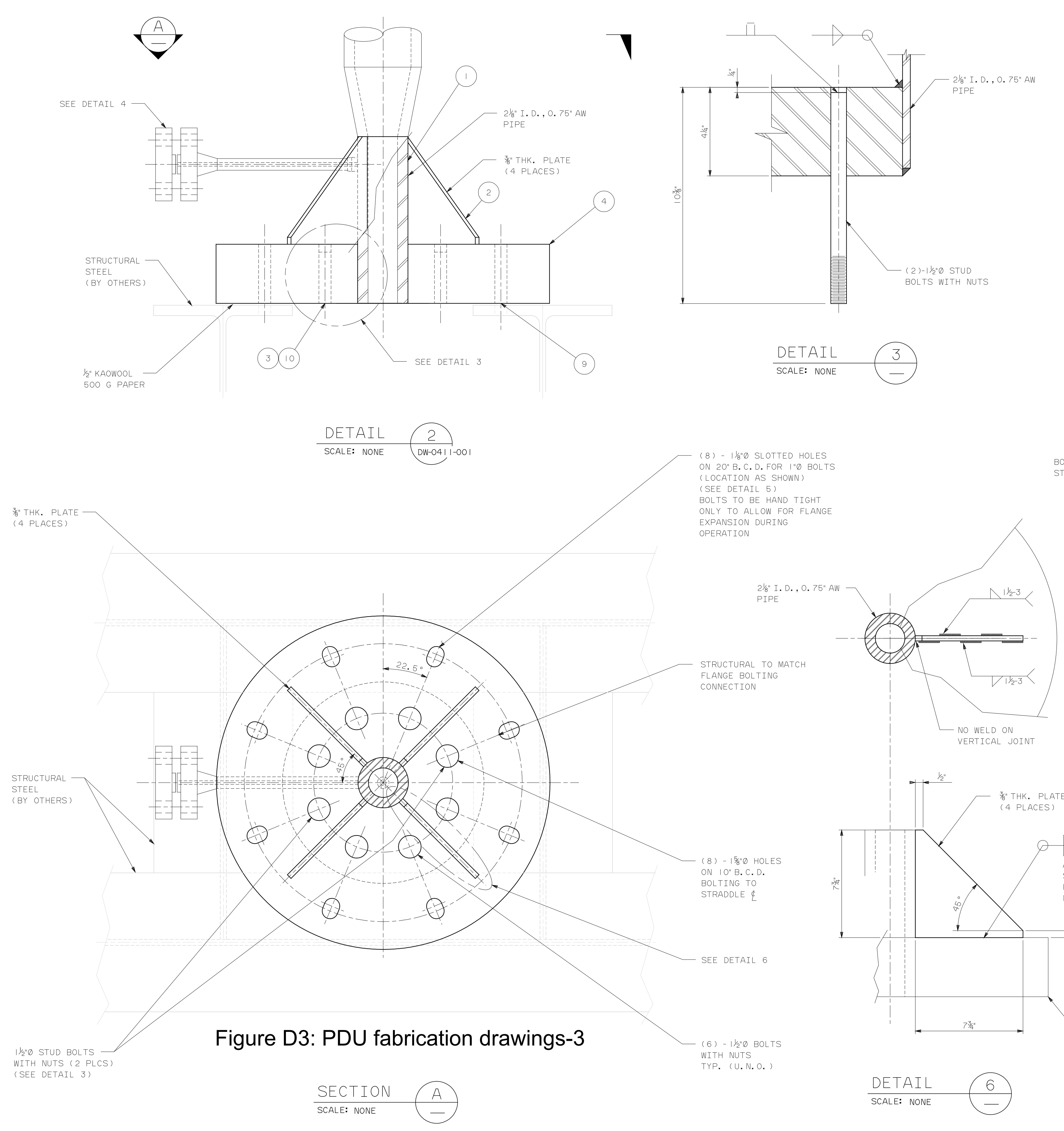
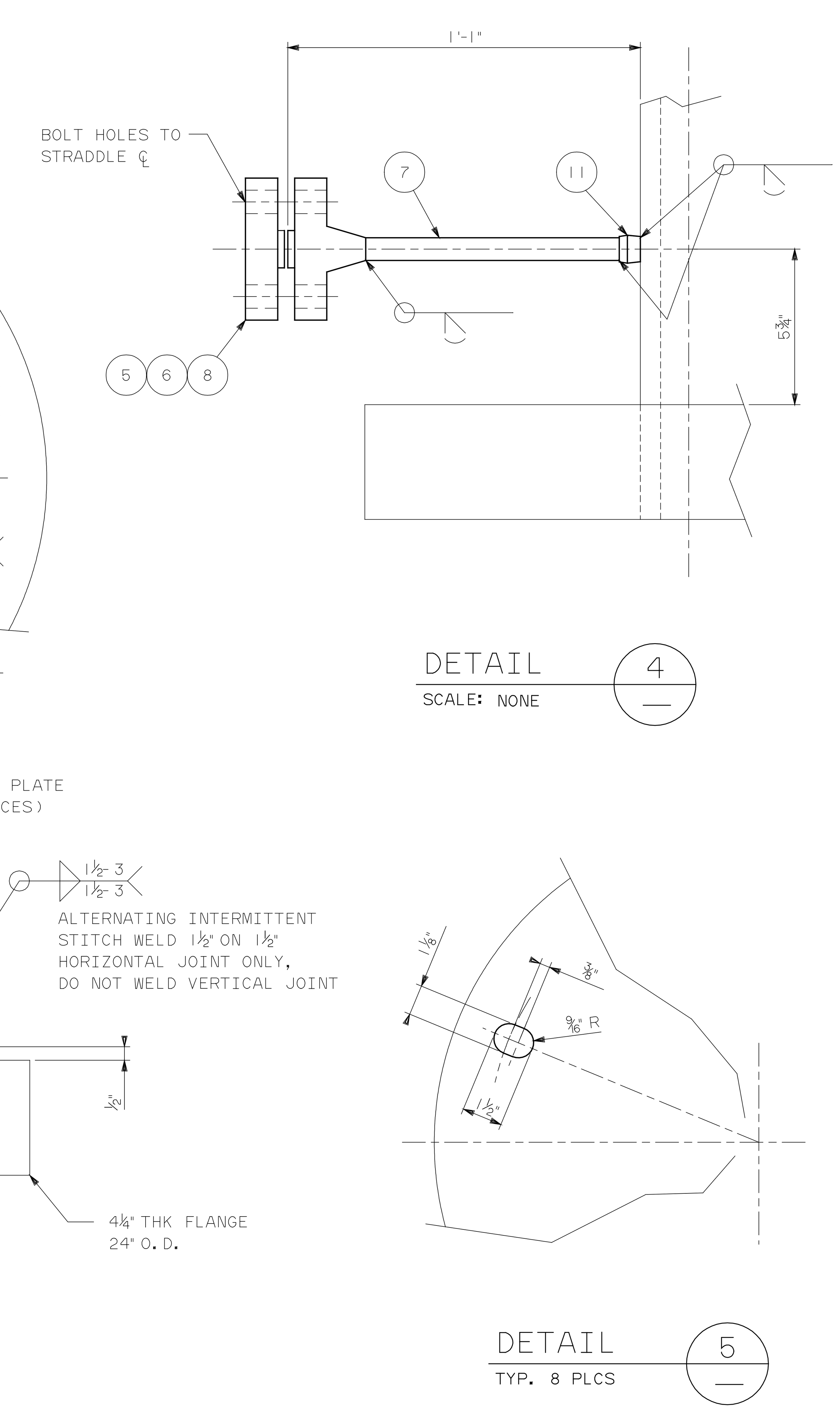


Figure D3: PDU fabrication drawings-3

ITEM	DESCRIPTION	MATERIAL	QTY.	REMARKS
1	2⅞" I.D., 0.75" AW PIPE	INCOLOY 800 HT (UNS N08811)	1	
2	⅜" THK. PLATE	INCOLOY 800 HT (UNS N08811)	4	
3	NUTS AND BOLTS L = 10⅝" *	INCOLOY 800 HT (UNS N08811)	2	FABRICATOR TO VERIFY
4	4¼" PLATE FLANGE 24" O.D.	INCOLOY 800 HT (UNS N08811)	1	
5	½" FLANGE CL2500 WN RF	INCOLOY 800 HT (UNS N08811)	1	
6	½" BLIND FLANGE CL2500 RF	INCOLOY 800 HT (UNS N08811)	1	
7	½" PIPE SCH XXS	INCOLOY 800 HT (UNS N08811)	1	
8	FLEXITALLIC GASKET	INCOLOY 800 HT (UNS N08811)	1	
9	NUTS AND BOLTS L = 1'-0" *	INCOLOY 800 HT (UNS N08811)	8	FABRICATOR TO VERIFY
10	NUTS AND BOLTS L = 1'-0" *	INCOLOY 800 HT (UNS N08811)	6	FABRICATOR TO VERIFY
11	WELDOLET	INCOLOY 800 HT (UNS N08811)	1	

NOTE :
* = APPROXIMATE



GENERAL NOTES

1. ALL MATERIAL TO BE INCOLOY 800HT OR EQUIVQLENT.
2. FABRICATOR SHALL INSPECT AND TEST ALL WELDS AND CONNECTIONS ON THE ASSEMBLY TO ENSURE THAT NO LEAK WILL OCCUR DURING OPERATION.
3. FABRICATOR TO USE INCO 82 FILLER METAL FOR ALL WELDS.
4. FABRICATOR TO SPECIFY WELDOLET FOR ADEQUATE REINFORCEMENT.

REV	DATE	DESCRIPTION	PREP	CKD	APPR	DM/PM
0	10-06-09	ISSUED FOR APPROVAL	EM	XP	KK	EER/EW
A	08-21-09	FOR INFORMATION	EM	XP	KK	EER/EW

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REACTOR DETAILS

SCALE	DRAWING NO.	PAGE	REV
NTS	LA714418 (PROJECT) 000 (UNIT) DW (DOC TYPE) 04 (DISC) 11 (SUBJ) 002 (SER. NO)	1	0

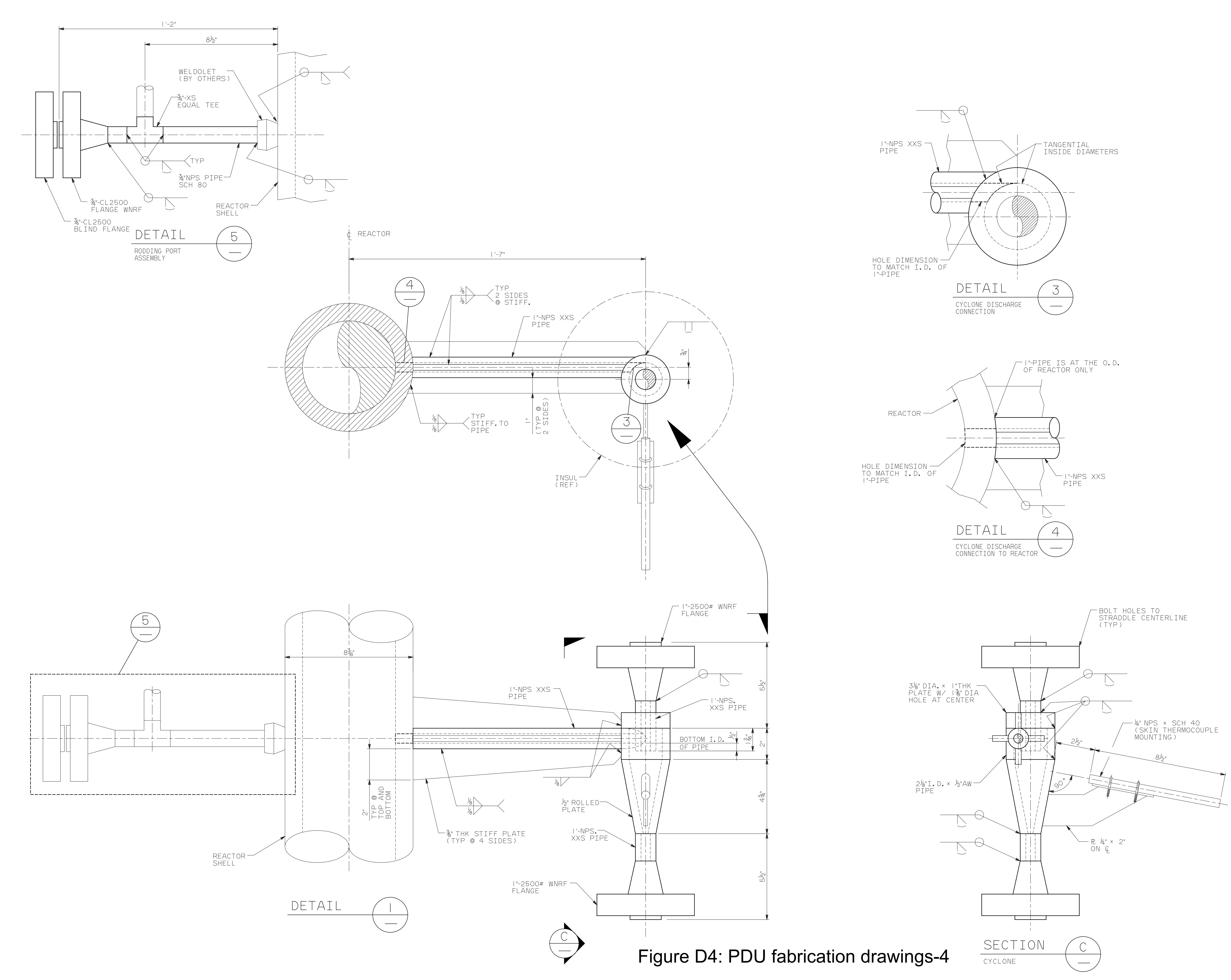

Figure D4: PDU fabrication drawings-4

GENERAL NOTES

1. ALL CONTINUOUS WELDS TO BE GAS TIGHT. ALL BUTT WELDS TO BE FULL PENETRATION.
2. ALL WELDING SHALL BE AS PER ASME IX.
3. ALL MATERIALS SHALL BE INCOLOY 800HT (UNS NO8811).
4. FABRICATOR TO USE INCO82 FILLER METAL ON ALL WELDS.
5. PIPING CONNECTING TO CYCLONE SHOULD NOT IMPOSE ADDITIONAL LOADS ON CYCLONE AND REACTOR.
6. FABRICATOR TO SPECIFY RODDING PORT WELDOLET FOR ADEQUATE REINFORCEMENT.

REV	DATE	DESCRIPTION	PREP	CKD	APPR	DM/PM
0	10-06-09	ISSUED FOR APPROVAL	RCB	XP	KK	EER/EW
A	08-21-09	FOR INFORMATION	RCB	XP	KK	EER/EW

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CYCLONE ASSEMBLY AND DETAILS
PLAN AND ELEVATION

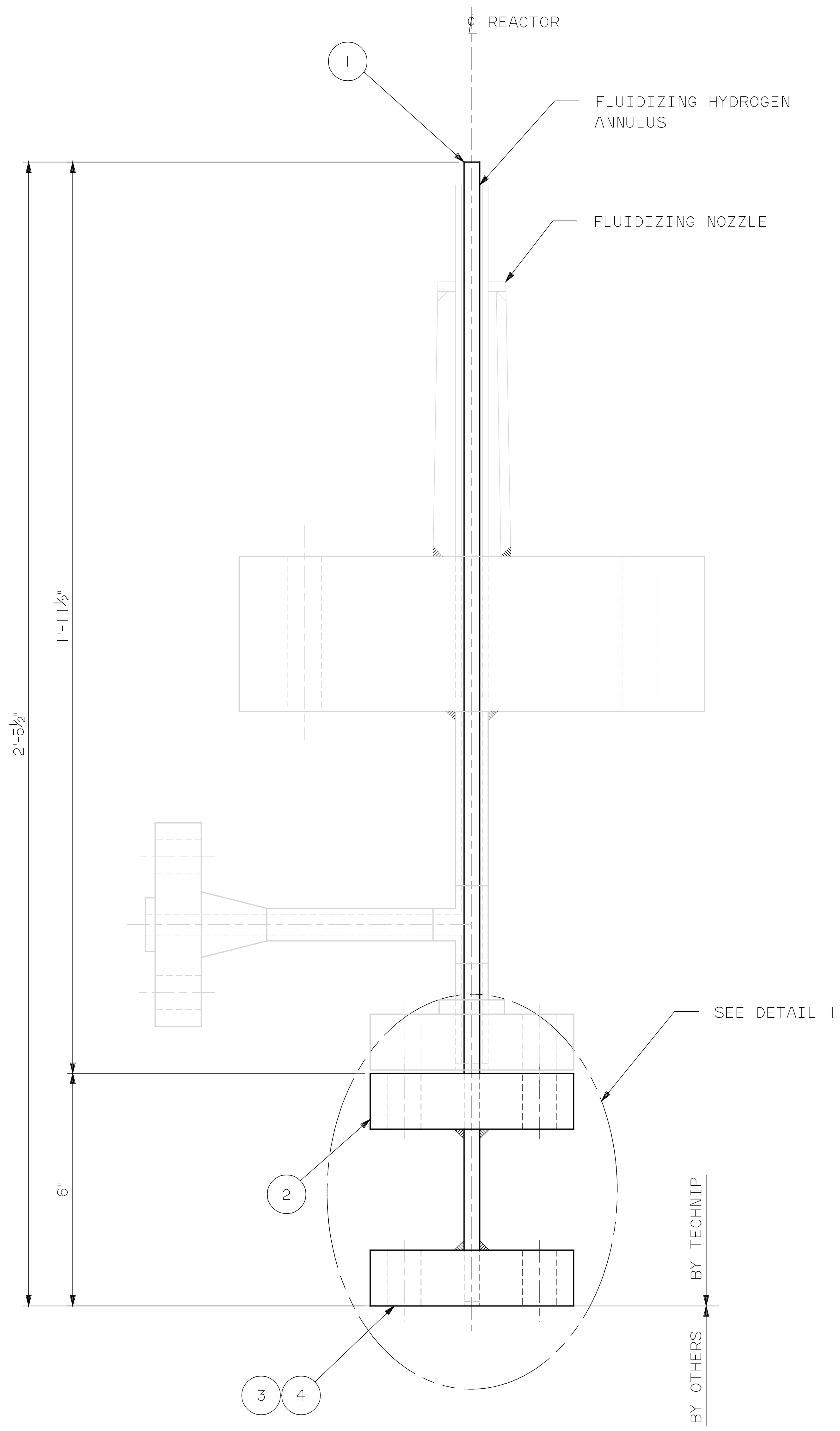
SCALE	DRAWING NO.	PAGE	REV
NTS	LA714418 (PROJECT) 000 (UNIT) DW (DOC TYPE) 08 (DISC) 11 (SUBJ) 001 (SER. NO)	1	0

TD-20-156-0

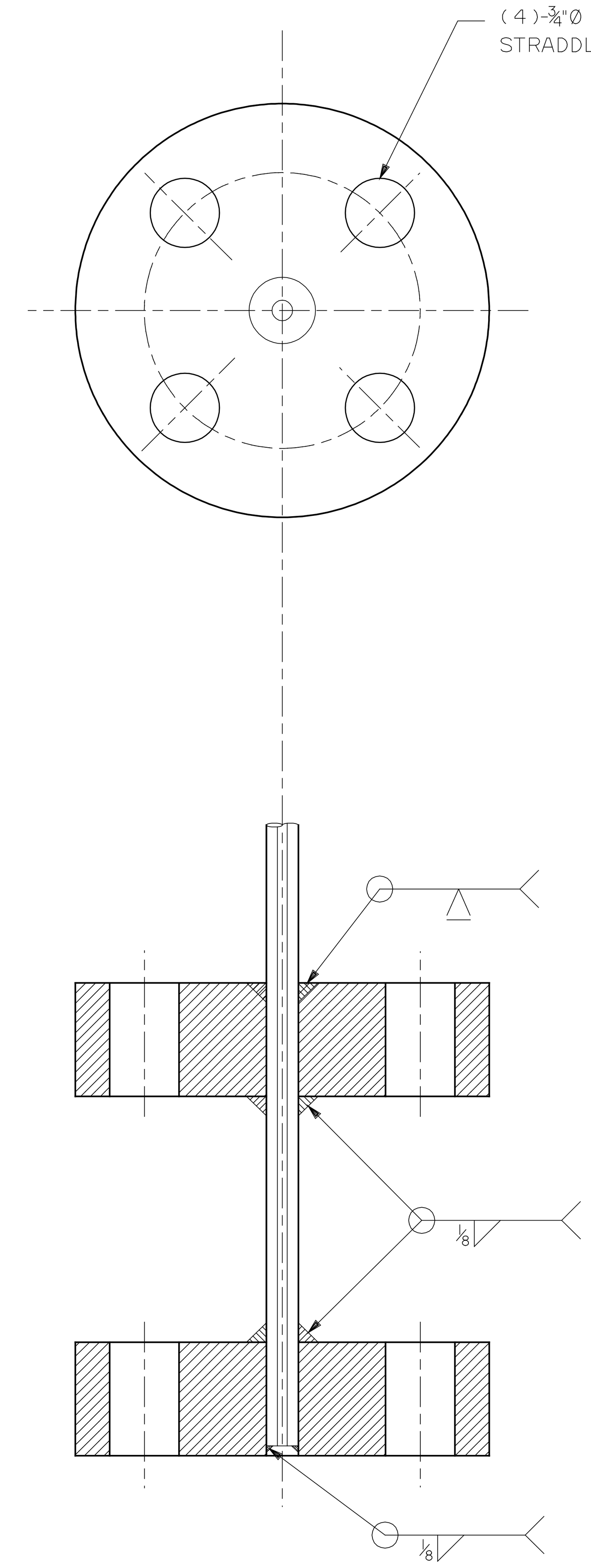
ITEM	DESCRIPTION	MATERIAL	QTY.	REMARKS
1	1/8" SCH80 PIPE	INCOLOY 800HT (UNS N08811)	1	PRIMARY FEED PIPE
2	1/2"-CL2500 BLIND FLANGE DRILLED FOR 1/8" PIPE	INCOLOY 800HT (UNS N08811)	1	
3	1/2"-CL2500 BLIND FLANGE DRILLED FOR 1/8" PIPE	INCOLOY 800HT (UNS N08811)	1	
4	NUTS AND BOLTS	INCOLOY 800HT (UNS N08811)	4	

GENERAL NOTES

1. ALL MATERIAL TO BE INCOLOY 800HT (UNS N08811) OR EQUIVALENT.
2. FABRICATOR SHALL INSPECT AND TEST ALL WELDS AND CONNECTIONS ON THE ASSEMBLY TO ENSURE THAT NO LEAK WILL OCCUR DURING OPERATION.
3. FABRICATOR TO USE INCO 82 FILLER METAL FOR ALL WELDS.



DETAIL 3
SCALE: NONE DW-0411-001



DETAIL 1
SCALE: NONE

Figure D5: PDU fabrication drawings-5

REV	DATE	DESCRIPTION	PREP	CKD	APPR	DM/PM
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A	08-21-09	FOR INFORMATION	EM	XP	KK	EER/EW

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SLURRY FEED
ASSEMBLY AND DETAILS

SCALE	DRAWING NO.	PAGE	REV
NTS	LA714418 (PROJECT) 000 (UNIT) DW (DOC TYPE) 08 (DISC) 39 (SUBJ) 002 (SER. NO)	1	0

TD-20-156-0

GENERAL NOTES

1. ALL CONTINUOUS WELDS TO BE GAS TIGHT. ALL BUTT WELDS TO BE FULL PENETRATION.
2. ALL WELDING SHALL BE AS PER ASME IX.
3. ALL MATERIALS SHALL INCOLOY 800HT (UNS N08811).
4. SOCKOLET SPECIFICATION BY FABRICATOR.

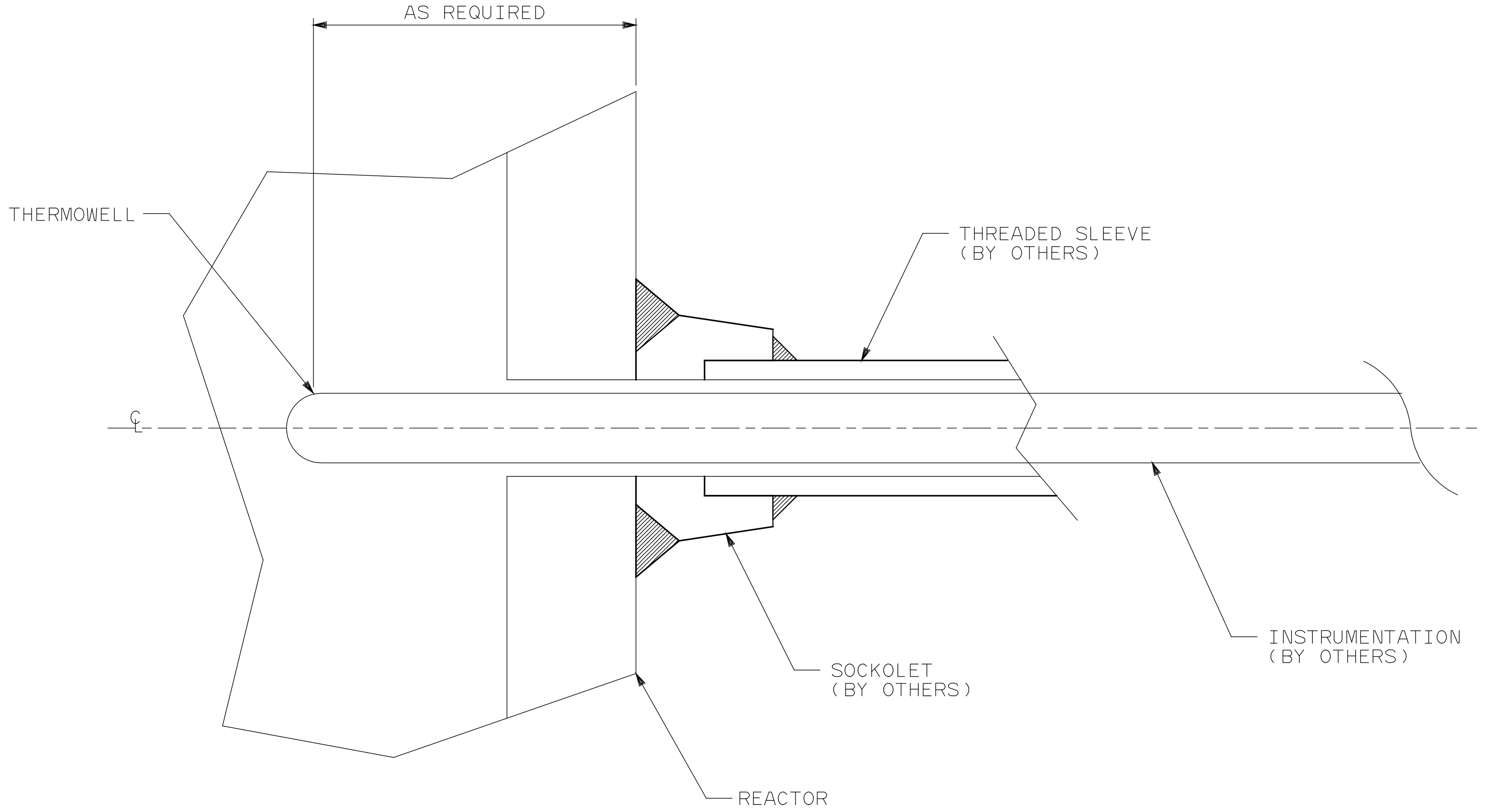

Figure D6: PDU fabrication drawings-6

REV	DATE	DESCRIPTION	PREP	CKD	APPR	DM/PM
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A	08-21-09	FOR INFORMATION	RCB	XP	KK	EER/EW

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RIVERSIDE CALIFORNIA

REACTOR
SAMPLE THERMOCOUPLE ASSEMBLY

SCALE	DRAWING NO.						PAGE	REV
NTS	LA714418 (PROJECT)	000 (UNIT)	DW (DOC TYPE)	08 (DISC)	39 (SUBJ)	003 (SER. NO)	1	0

TD-20-156-0

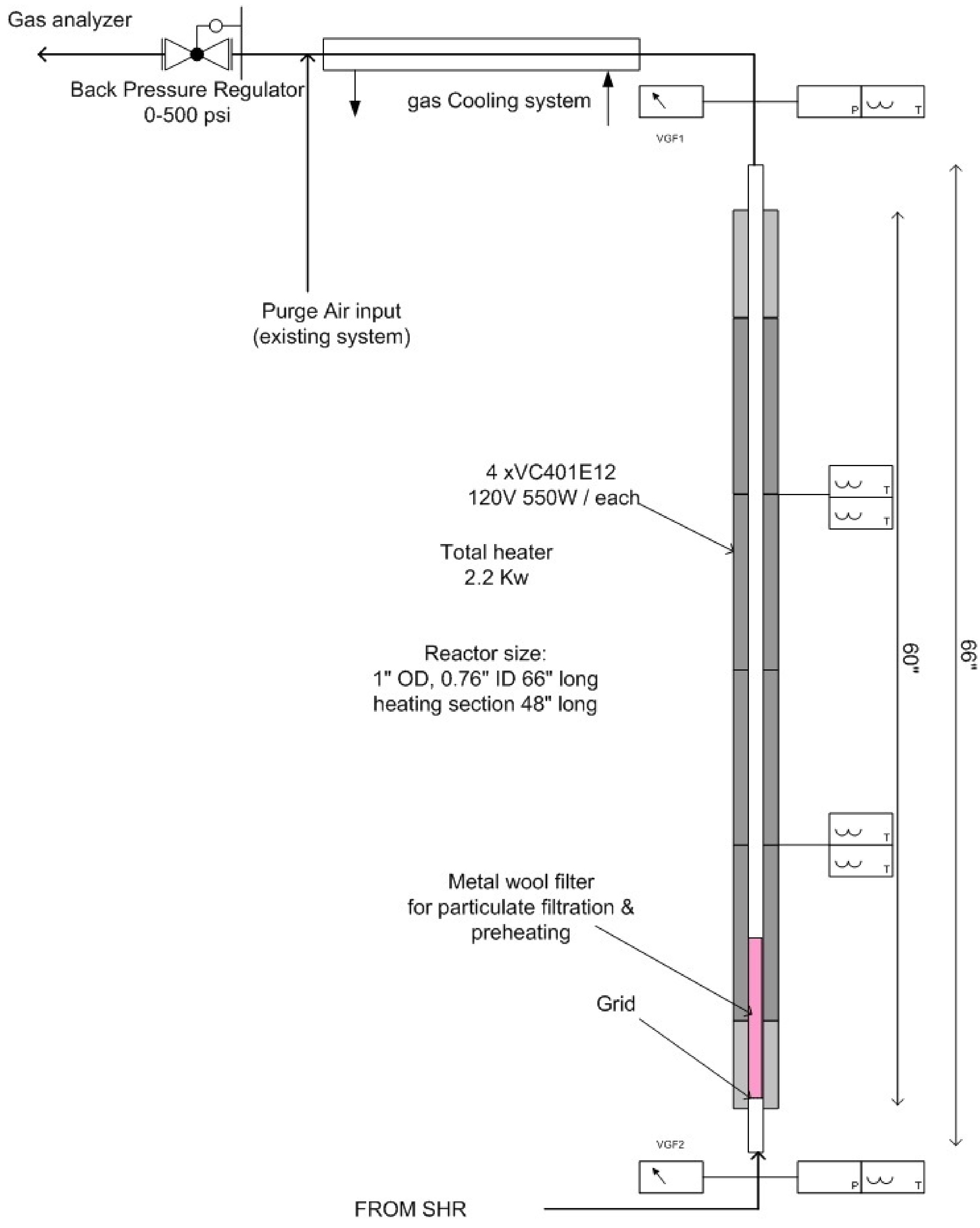


Figure D7: Schematic drawing of SMR reactor

Figure D8: Mock up test setup with sand load

Appendix E:
PDU Operation SOP

Appendix E: PDU Operation SOP

CE-CERT

STANDARD OPERATING PROCEDURE

ISSUED BY: Maintenance and Safety S.O.P. No. 12

SUBJECT: Process Demonstration Unit (**Steam Hydrogasification Reactor)**

APPROVAL: Effective Date: Jan. 23, 2012

Purpose: To maximize the safety of all assigned or visiting personnel within the CE-CERT facility.

Procedure: Start Up

1. Open N_2/H_2 gas cylinders supply valve
2. Open Chiller isolation valve
3. Turn “ON” Chiller pump power switch
4. Turn ON main Exhaust Fan
5. Check & Fill Steam Water pump Supply
6. Check PDU exhaust vent
7. Turn ON PDU Computer
8. Open Labview programs
9. Open Mass Flow Controller to 10slpm of Nitrogen Gas
10. Close Back Pressure Regulator
11. Set the reactor Pressure to 150 psi.
12. Turn Main breaker to ON position
13. Set all heater controllers to 100^{o}C

Note: #4 & #5 heater controllers are slower response than the other 3 controllers. So set it up 50C higher temps.

14. Increase the temperature setting by 100C increments.
15. When WGS8 temperature reach 150^{o}C, then turn ON Steam Pump at 7Hz. Monitor the water level by closing the valve to make sure that the steam pump is pumping water to the reactor.
16. Constantly monitor the pressure, temperature, back pressure regulator, steam pump water level until the reactor reach its the proper operating pressure and temperature.

CE-CERT

STANDARD OPERATING PROCEDURE

ISSUED BY: Maintenance and Safety S.O.P. No. 12

SUBJECT: Process Demonstration Unit (**Steam Hydrogasification Reactor)**

APPROVAL: Effective Date: Jan. 23, 2012

Purpose: To maximize the safety of all assigned or visiting personnel within the CE-CERT facility.

Procedure: Shutdown System

1. Decrease temp. settings #1, #2, #3 controller to 50C below the operating temperature

Note:
- Decrease #4 & #5 controller after the #1, #2, #3 are below 50C from the original settings.
Important - Drain HX every 30 minutes

2. If the reactor temperature are down to 200C then turn OFF Steam pump.
3. Shut OFF Mass Flow meter to zero
4. Depressurize the reactor by slowly turning the Back pressure regulator counterclockwise and monitor the Dry Gas meter speed.
5. Drain HX
6. Shut OFF Exhaust Fan
7. Close Chiller valve
8. Close H2 and N2 Supply tank
9. Close Data Acquisition
10. Switch Heater Breaker to Off Position

Appendix F:
5 TPD Pilot Plant Design

Appendix F: 5 TPD pilot plant design

Preliminary Gasifier Equipment Elevation Sketch
CE-CERT Hydrogasification 5 TPD Pilot

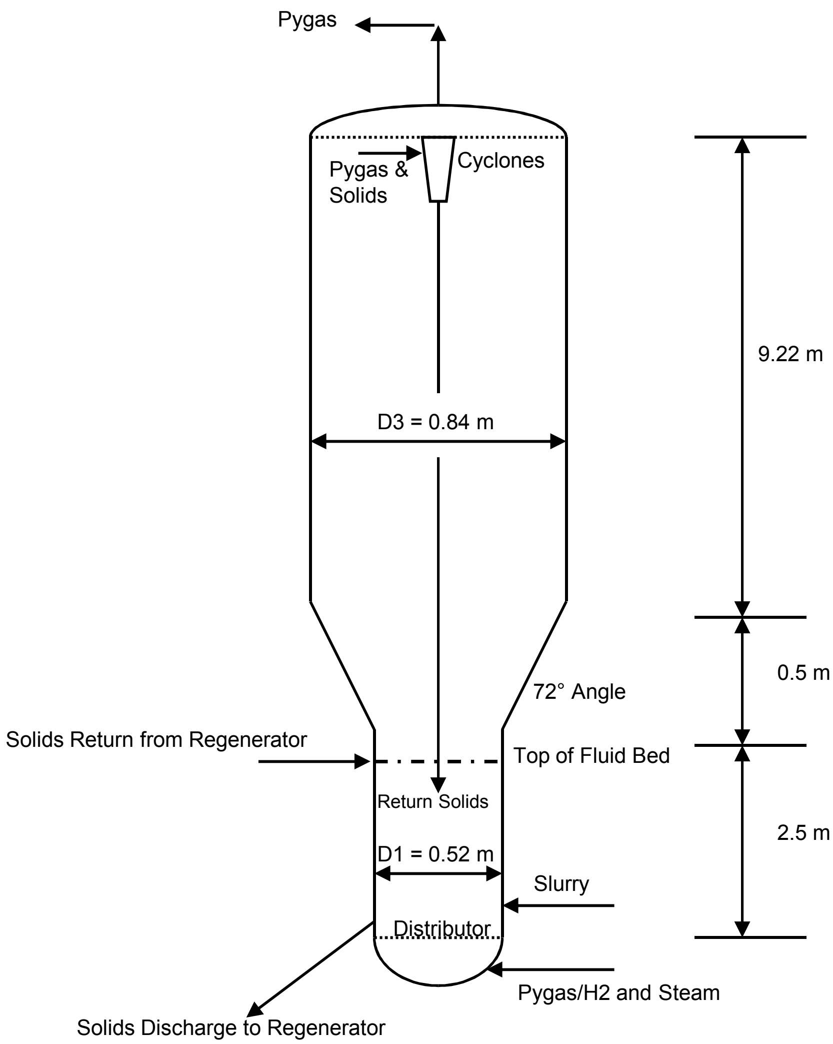
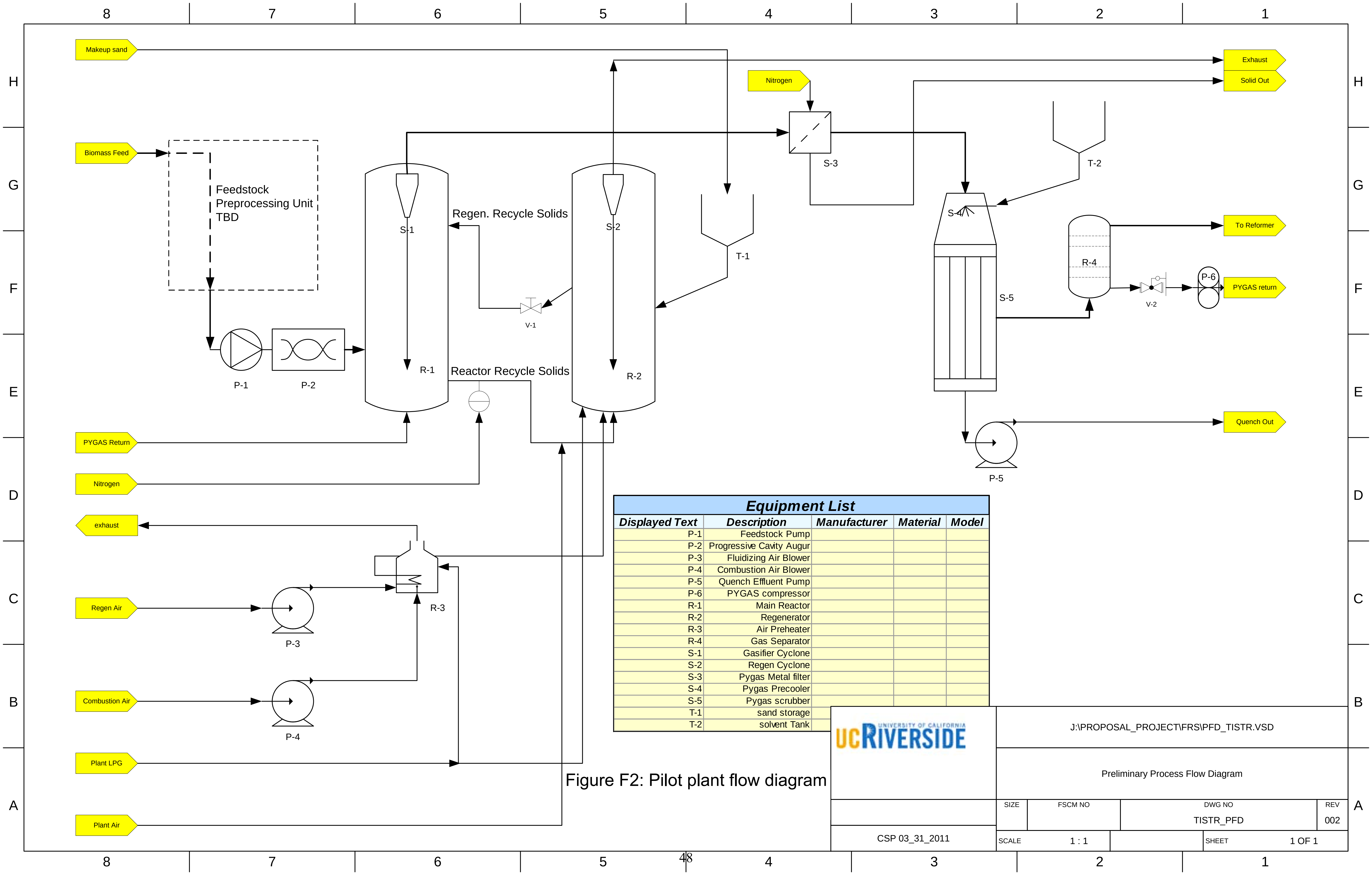


Figure F1: Pilot plant gasifier schematic drawing

850 °C, 400 psig, H2 from Pygas recycle

0.5 m/sec superficial gas velocity directly above gas distributor
0.3 m/sec superficial gas velocity in the freeboard
Transitional angle minimum 60°
Total residence time from distributor to cyclone 35 seconds

Feb. 21 2008, J. Amsden, Technip USA Inc.



Equipment List

Displayed Text	Description	Manufacturer	Material	Model
P-1	Feedstock Pump			
P-2	Progressive Cavity Augur			
P-3	Fluidizing Air Blower			
P-4	Combustion Air Blower			
P-5	Quench Effluent Pump			
P-6	PYGAS compressor			
R-1	Main Reactor			
R-2	Regenerator			
R-3	Air Preheater			
R-4	Gas Separator			
S-1	Gasifier Cyclone			
S-2	Regen Cyclone			
S-3	Pygas Metal filter			
S-4	Pygas Precooler			
S-5	Pygas scrubber			
T-1	sand storage			
T-2	solvent Tank			

Figure F2: Pilot plant flow diagram

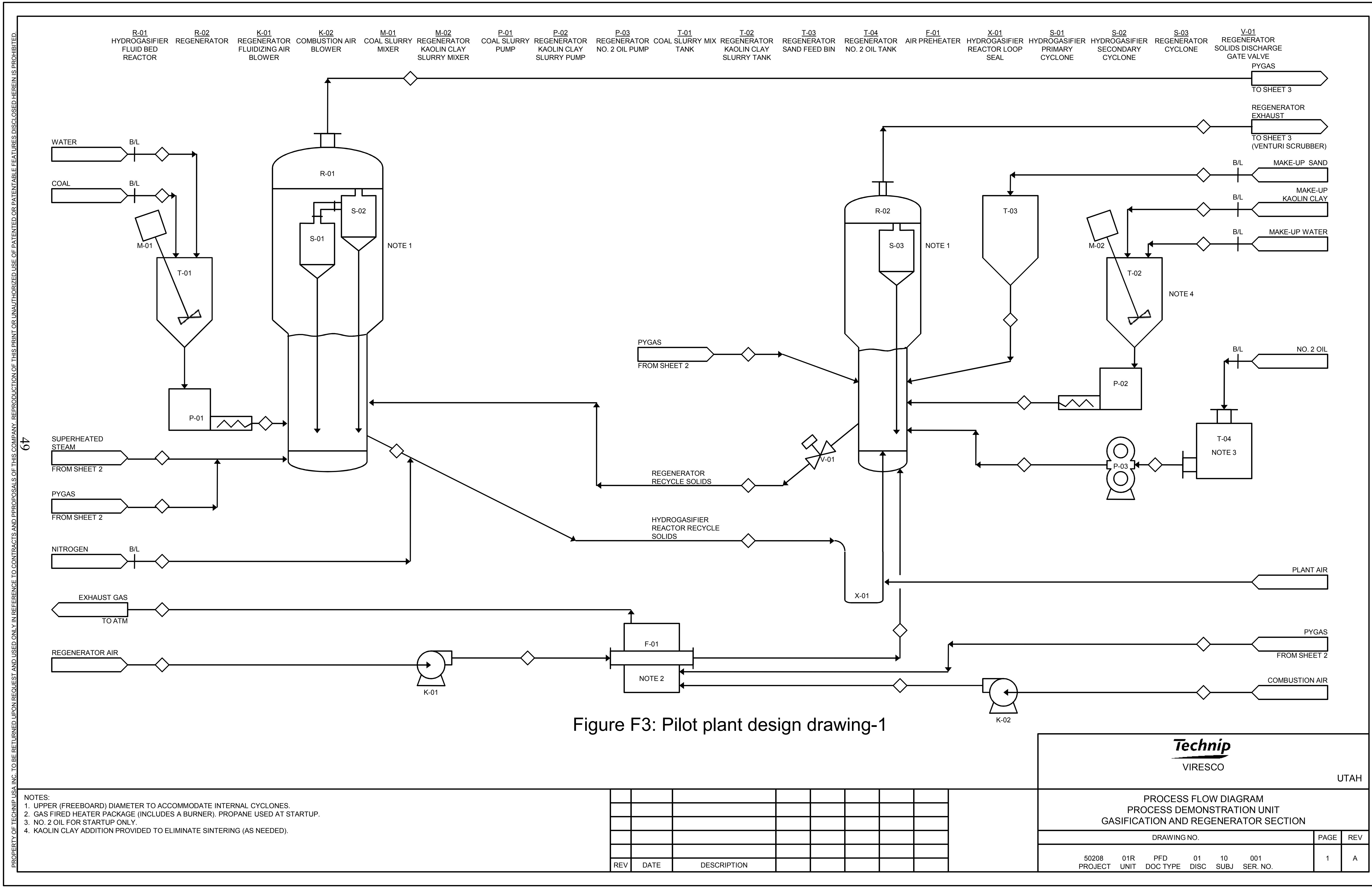


Figure F3: Pilot plant design drawing-1

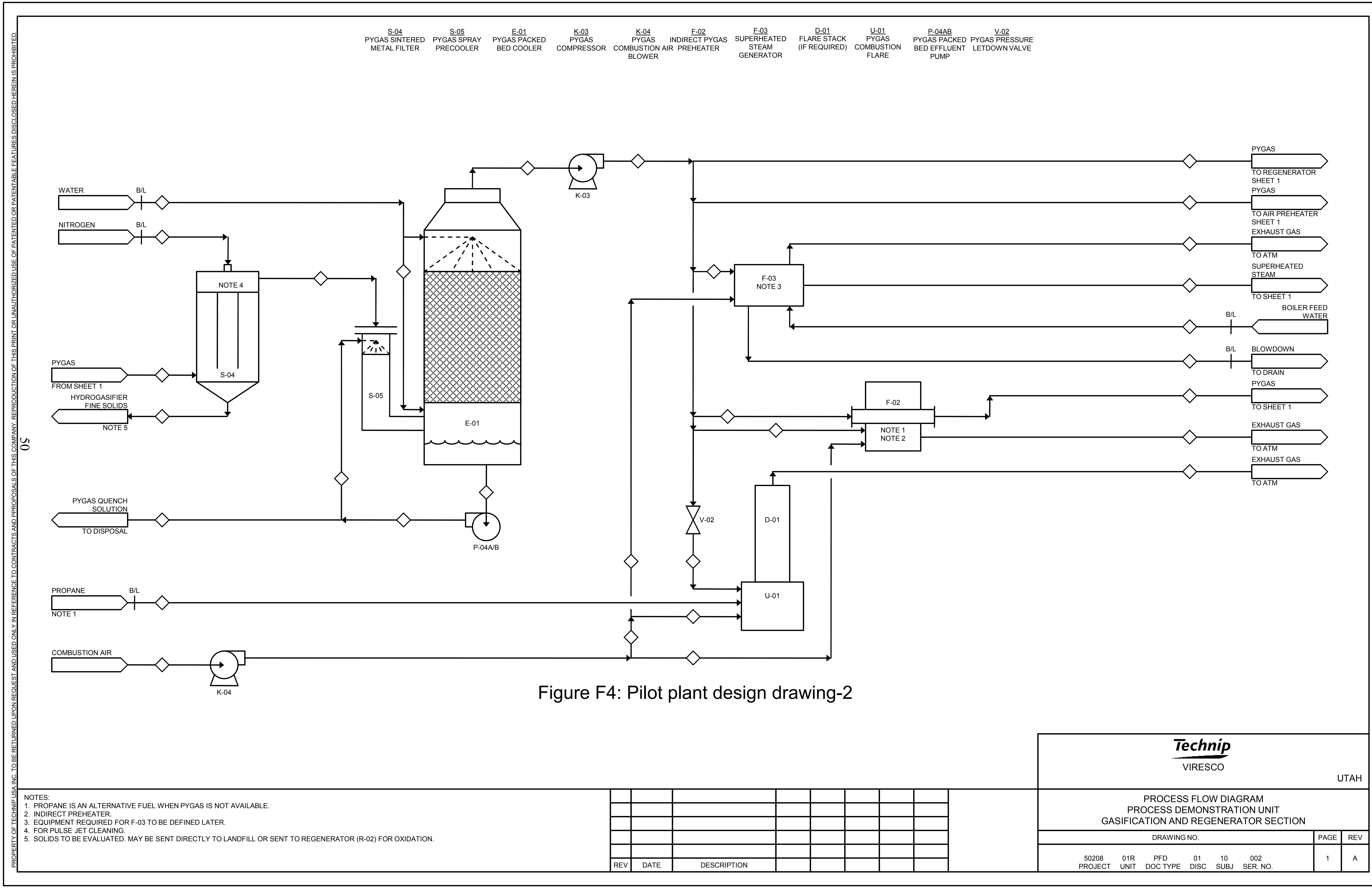


Figure F4: Pilot plant design drawing-2

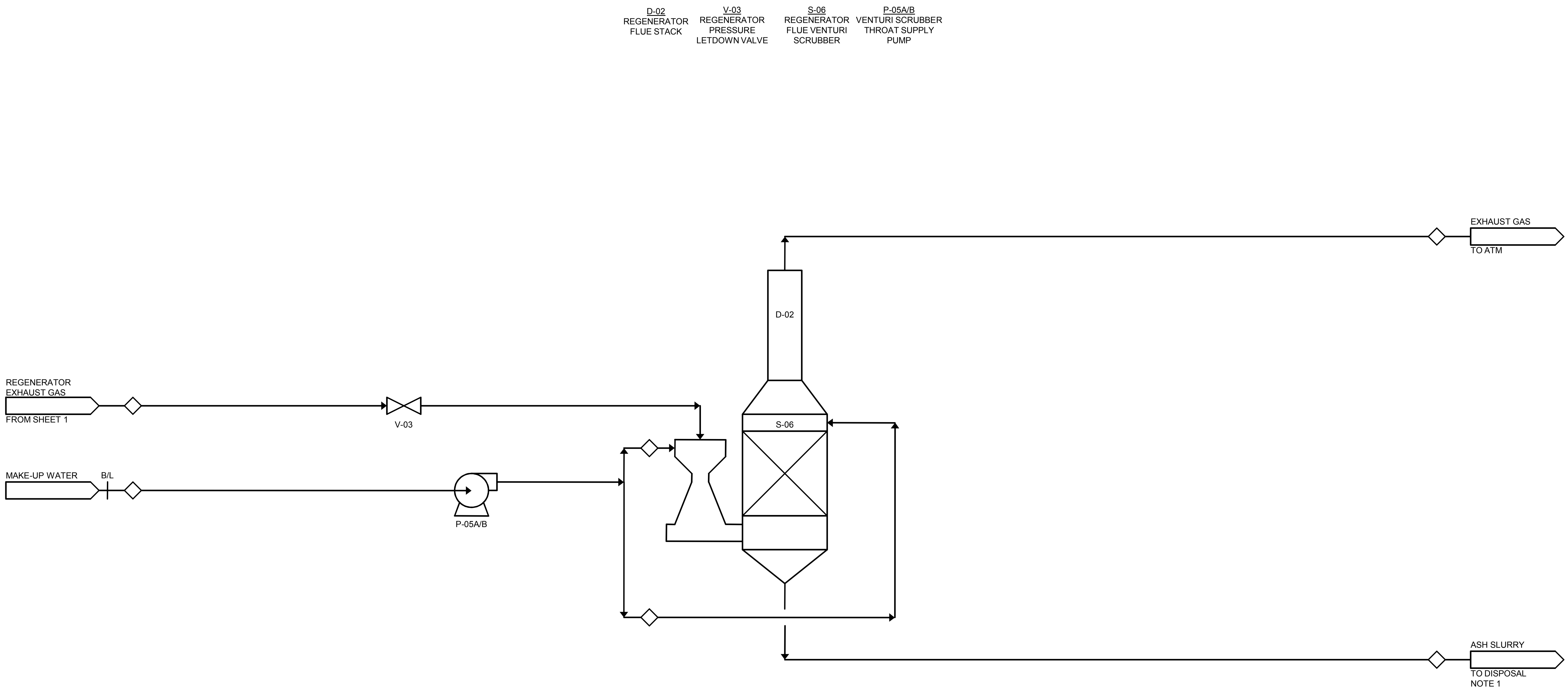


Figure F5: Pilot plant design drawing-3

NOTES:
1. ASH SLURRY TREATMENT AND DISPOSAL TO BE EVALUATED.

REV	DATE	DESCRIPTION

Technip
VIRESCO
UTAH

PROCESS FLOW DIAGRAM
PROCESS DEMONSTRATION UNIT
GASIFICATION AND REGENERATOR SECTION

PROJECT	UNIT	DOC TYPE	DISC	SUBJ	SER. NO.	PAGE	REV
50208	01R	PFD	01	10	003	1	A

DRAWING NO.

Table F1: SPECIFICATION OF
STEAM HYDROGASTIFICATION REACTION (SHR) UNIT (Rev 1.2)

Item	Description	Specification
Site Characteristics	Ambient Pressure	10.9 psia
	Ambient Temperature	30 ~ 37 degree C
	Relative Humidity	60~78%
	Elevation	10 m above sea level
	Emission requirement	N/A
	Equipment location	Indoor
Feedstock Pump	Pump Type	Progressive Cavity
	Pump Electrical Requirement	AC 220 VAC single Phase
	Motor Speed Control	Frequency Control
	Max Slurry Viscosity (@1/100 sec. Shear rate)	1.0 Pascal-Second
	Max Head Pressure	175 psi
Fluidized Bed Reactor (Please state how much gas is produced)	Biomass Feed Rate	5 TPD (@67% moisture) 1.7 TPD (dry basis)
	Biomass Type	Pretreated Slurry (is pre-treatment unit required?)
	Max. Slurry Viscosity (@1/100 sec. Shear rate)	1.0 Pascal-Second
	Nominal Input H2/C molar ratio	1:1
	Operating Temperature	800
	Operating Pressure	150 psi
	Nominal Superficial Gas Velocity	
	@ Bottom of Bed	0.2 m/sec
	@ outlet	0.2 m/sec
	Reactor Height	500 cm
	Reactor ID	10 / 20 cm
	Max. Gas Residence Time	18 second
	Bed Depth	150 cm
	Sand Conveying Medium	Nitrogen
	Sand Particle Size	125 mesh
	Feedstock Particle Size	TBD
	Ash Softening Temperature	TBD
	Ash Fusion Temperature	TBD
	Cyclone Rejection Particle Size	100 um
	Nominal Total Pygas flow rate	4570 kg/day, 1700 Kg per day (dry basis)
Regenerator	Operating Temperature	1000 C
	Operating Pressure	150 psi
	Excess Air for Combustion	25 %

	Combustion Air Inlet temperature	Ambient Temperature
	Aux Fuel	LPG
	Aux Fuel Feed rate	By HMB
	Solid Conveying Medium	Nitrogen
	Bed Depth	1.2 m
	Superficial Gas Velocity	
	@ Bottom of Bed	0.2 m/sec
	@ outlet	0.2 m/sec
	Carbon Extent of Reaction	95%
	Cyclone Rejection Particle Size	100 um
Gas Compressor	Gas Type	Producer Gas
	Max Head Pressure	1500 psi
	Max Gas Rate	12 m3/hr
Instrumentation	Online Analyzers	CH4, CO, CO2 and Total gas Flow
	Online Analyzers Accuracy	+/- 5%
	Control System	PLC base
	HMI Interface	PC base
	Min # of Pressure Monitor Point	5
	Min # of Temp Monitor Point	10

Table F2: Gas cleanup subsystems - Optional
(Not included in the scope of this project at this time.)

Gas Cleanup System-Particle Filtration	Minimum Particle size Rejected	50 um
	Filter Medium	Ceramic
	Minimum Operating Temperature	250 C
	Max Operating Pressure	175 psi
Gas Cleanup System-Tar Cleanup	Operating Type	Solvent Scrubbing
	Maximum output Tar level	10 mg / NM3
	Outlet Temperature	Ambient Temperature
	Max Operating Pressure	175 psi
Gas Cleanup System-Hydrocarbon, Chloride Cleanup	Operating Temperature	Room Temp
	Max Operating Pressure	175 psi
	Sorbent Medium	Activated Charcoal
	Number of Train	1
	Sorbent Life Time (Biomass Feed)	500 hour
	Max Outlet Hydro Carbon level	2 ppmv
	Max Outlet HCl level	2 ppmv
Gas Cleanup System-Sulfur Cleanup	Operating Temperature	Ambient Temperature
	Max Operating Pressure	175 psi
	Sorbent Medium	Zinc Oxide
	Number of Train	1
	Sorbent Life Time (Biomass Feed)	500
	Max Outlet H2S level	2 ppmv

Appendix G:
Preliminary Economic Analysis

Appendix G: Preliminary Economic Analysis

The cost used in this appendix such as plant and capital cost is mainly based on economic analysis made by National Energy Technology Laboratory (NETL) within Department of Energy (DOE). NETL has reviewed the CE-CERT process through a Cooperative Research And Development Agreement (CRADA) by validating the equilibrium model, process flow sheet for F-T (Fischer-Tropsch) liquids production and power generation with IGCC using CE-CERT technology using bituminous coal as feedstock (4000 TPD) in 2008. Although the feedstock used in this case is biosolid and green waste instead of coal, the same number will be used in assessment the cost of the facilities, utilities and chemicals.

The major assumptions used in the economic model are:

Plant Size: 3500 BDT/day

Capital cost: 625.2 Million USD

Feedstock: Biosolid and green waste generated within AQMD

Two year construction & start up

Cost for feedstock: 0 $/ton

Total Labor Costs per year: 1% of the capital cost

Maintenance Cost per year: 2% of capital cost

Operating Cost per year (chemicals, royalties): 2% of capital cost

Loan interest rate: 3%

Inflation rate: 3%

SNG selling price: 6 $/MMBTu

Other costs such as feedstock gathering, delivering, loading/unloading, and storing are not taken into consideration in this case.

Based on the economic model, the production cost of the SNG in a 3500 BDT/day plant using green waste and biosolid as feedstock is 4.39 $/MMBTu with IRR of 16.68%. It should be noted that the feedstock cost and other cost like feedstock delivering cost are not included in the analysis which could be predominate factors that influence the production cost and IRR. From this point of view, the SNG production cost may be more expensive than natural gas. In this case, necessary support and subsidy should be given to make the SNG competitive with natural gas. Detailed economic analysis including plant site location, plant scale, feedstock cost and feedstock delivering cost will be performed in future work.