Report Title

Innovative Instrumentation and Analysis of the Temperature Measurement for High Temperature Gasification

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Abstract

An extensive literature survey on the proposed subject has been conducted in the Center for Advanced Energy Systems and Environmental Control Technologies at Morgan State University. About forty-five related journals and technical reports have been reviewed for the references of the project preparation. Two different types of thermocouples (T-type for the cold model testing, R-type for the hot model testing) have been purchased for the project. The thermocouple assembly for the cold model testing has been designed and fabricated. The cold model of the proposed gasification simulator has been designed and fabricated. The cold model is made of a transparent acrylic tube with 10-inch ID and 20-inch length. This model allows us to observe the phenomena of the gasification process, which may cause dirty and harsh environments around the thermocouples. Two pairs of flanges were made to host the irritating air injection ports, thermocouple assembly, and seal the cold model system. The air injection system is attached to the cold model testing system, which includes an air compressor, an air control valve and the auxiliary tubes. The char coal dust mixtures are used in the cold model to simulate the gasifier environment. The experiment design technique is being carefully implemented along with four (4) different testing parameters; char coal dust weights, irritating air flow rates, irritating air frequency and the ultrasound applications. The sample temperature curves have been obtained from the cold model shakedown testing. The test results are being carefully recorded and analyzed. The testing for ultrasound cleaning application in the cold model will be conducted. The analysis of the test results will be continued using the analysis of variances (ANOVA) and regression analysis methods. The progress of this project has been on schedule.

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1. Introduction

It is well known that gasification offers the cleanest, most efficient method available to produce synthesis gas from low or negative-value carbon-based feed stocks such as coal, petroleum coke, high sulfur fuel oil or materials that would otherwise be disposed as waste. The gas can be used in place of natural gas to generate electricity or as a basic raw material to produce chemicals and liquid fuels. Tomorrow's power fleet likely will be increasingly comprised of advanced plants that gasify coal rather than burning it. Operating the coal gasifier at exactly the right temperature - optimized for both the plant equipment and the type of coal will be a key factor in efficient operation. In addition, optimum efficiency translates directly into low costs of electric power to consumers or low cost liquid fuels and chemicals that can be made from the coal gas. Coal gasification can be used to produce three primary products: low, medium and high BTU gas [1].

The high temperature in gasifiers converts the inorganic materials in the feedstock (such as ash and metals) into a vitrified material resembling coarse sand. Within some feedstocks, valuable metals are concentrated and recovered for reuse. The vitrified material, generally referred to as slag, is inert and has a variety of uses in the construction and building industries.

Gas treatment facilities refine the raw gas using proven commercial technologies that are an integral part of the gasification plant. Trace elements or other impurities are removed from the syngas and are either re-circulated to the gasifier or recovered. Sulfur is recovered either in its elemental form or as sulfuric acid, both marketable commodities.

If the syngas is to be used to produce electricity, it is typically used as a fuel in an integrated gasification combined cycle (IGCC) power generation configuration. IGCC is the cleanest, most efficient means of producing electricity from coal, petroleum residues and other low- or negative-value feed stocks. The combined cycle system has two basic components. The high efficiency gas turbine, widely used in power generation today, burns the clean syngas to produce electricity. Exhaust heat from the gas turbine is recovered to produce steam to power traditional high efficiency steam turbines. The syngas can also be processed using commercially available technologies to produce a wide range of products such as fuels, chemicals, fertilizer or industrial gases. Some facilities have the capability to produce both power and products from the syngas, depending on the plant's configuration as well as site specific technical and market conditions.

All the operating gasifiers are equipped with temperature instrumentation. Normally, the regular temperature measurement techniques such as heat expansion thermometers and regular thermocouples are used in these gasifiers. However, temperature measurement in gasification is always a problem because the current methods are not robust and reliable in the harsh gasifiers environment. Based on the DOE Gasification Database Results Update 2001 [2,3], there are more than 800 gasifiers operating in the United States. Most of them suffer from unreliable temperature measurement, which can trigger false alarms, lower the gas quality and create accidents. Since most of the existing and planned gasifiers are used to or will be used to generate electricity in IGCC, cost rules similar to those used for power plants can be applied to the operation of these gasifiers.

Any feasible instrumentation for temperature measurement in gasifiers will be operated for a long time (at least 150 hours) in an environment, which contains granular carbonaceous material, sticky and/or molten ash and gas containing significant quantities of methane, water vapor, carbon monoxide and hydrogen. Also, low concentrations of alkali metals, hydrogen sulfide, hydrogen chloride and ammonia can be found in the environment.

The objective of this research is to develop innovative instrumentation and analysis for high temperature measurement in gasification using the specialized thermocouple along with two cleaning methods. Basically, ultrasonic dirt peeling and high-pressure oxygen injection cleaning are the two methods proposed to clean the thermocouple tip for accurate and robust measurement. The anti-erosion/corrosion coating sprayed on the thermocouple could make the thermocouple specialized and unique. The proposed instrumentation is believed to be low-cost and reliable. Finally, this research work is expected to reduce a significant amount of the operation/maintenance costs and increase the gas production rate [2,3].

In order to develop the proposed instrumentation successfully, it is essential to design a corresponding cold gasification model to test the proposed instrumentation. The cold model can help to determine some important factors before the hot model tests are scheduled.

2. Design/Fabrication of the Instrumentation

2.1 Design of the Thermocouple Assembly

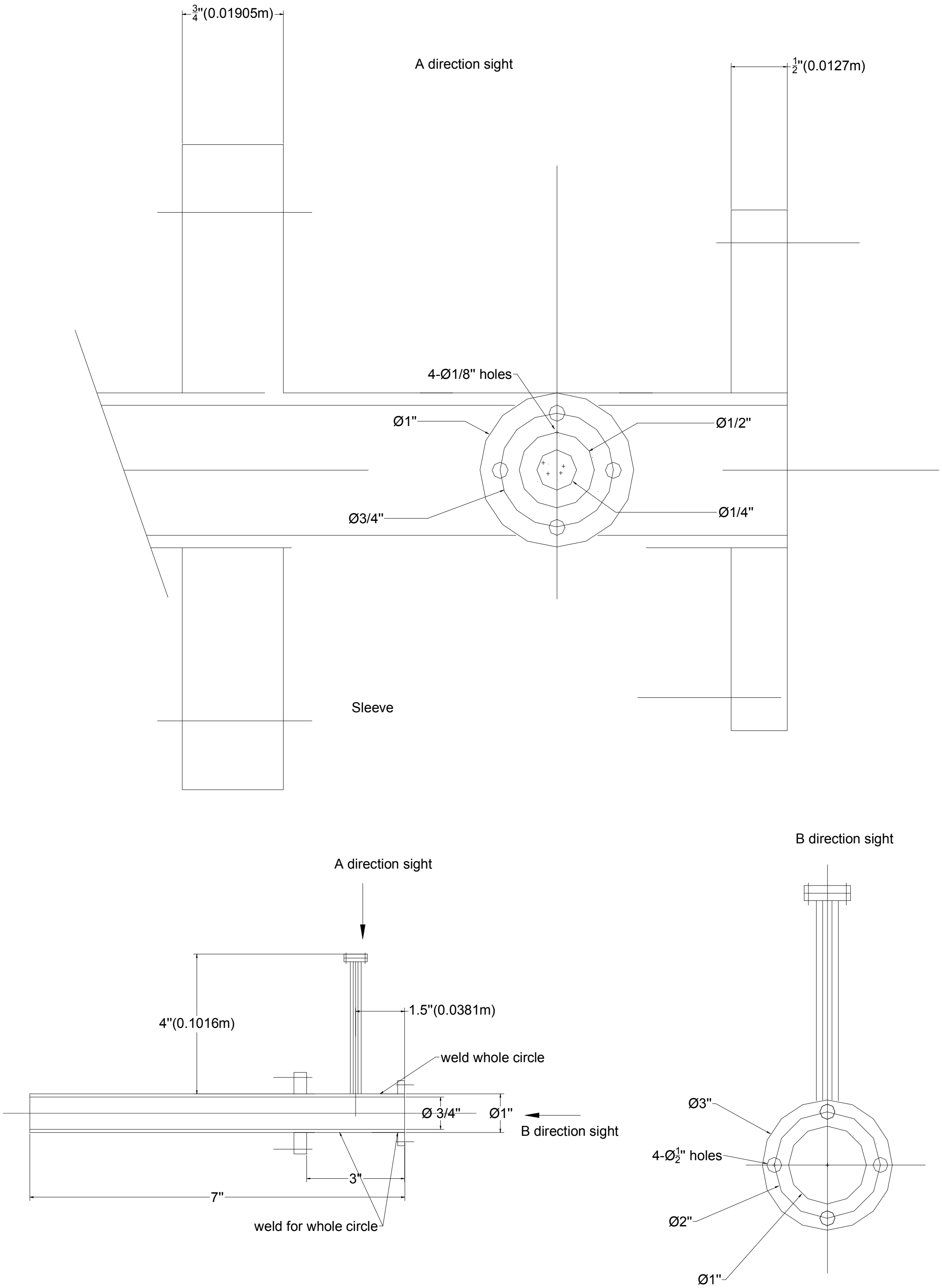
A special sleeve was designed to host the thermocouple, which can allow high-pressure oxygen gas to go through and blow the dirt off the thermocouple tip. The sleeve will be made of a 1-inch stainless steel tube. Two flanges will be welded to the sleeve. The one close to the tip will be used to connect to the gasifier simulator. The other flange will be connected to thermocouple flange, which will be attached to the thermocouple. The detailed design of the thermocouple sleeve is shown in Figure 1.

2.2 Design of the High Pressure Oxygen Injection Cleaning and Ultrasonic Dirt Peeling

The source of the high-pressure oxygen injection will be an 1800-psi oxygen tank with a pressure regulator. The auxiliary piping system for the high-pressure oxygen injection cleaning is under fabrication.

The ultrasonic dirt peeling technique is under design process. The ultrasonic application will be applied to the thermocouple through a path, which is cooled down by cooling water. The ultrasonic dirt peeling application consists of ultrasonic generator, power supply, frequency regulator, etc.

Figure 1 The Detailed Design of the Sleeve for the Thermocouple Assembly



3. Experimental

3.1 Experimental Apparatus and Procedure

The experimental apparatus used in this period were specially designed and fabricated with the accordance to the experimental design method. This method was developed to improve the implementation of total quality control. It is based on the experimental design that provides optimal quality characteristics for a specific objective. Analysis of variances (ANOVA), one of the most important methods in robust design, will be conducted based on the data obtained on both gasifier simulator hot tests and fluidized bed gasifier test. This analysis may validate the data obtained in the gasifier simulator. The ANOVA will also be used to analyze system performance in determining all the factors that have significant effect on the system performance.

The T-type thermocouple is used for cold model testing. A one (1) inch ID PVC tube is used as a sleeve to host the thermocouple. On top part of the sleeve, two ¼-inch holes were drilled to allow the compressed air to pass through. The thermocouple wire is connected to a DPi-32 temperature indicator. A DC power supply unit is used to supply the electric power to the thermocouple assembly. The schematic diagram of the thermocouple assembly is shown in Figure 2.

During this project period, the cold model for the proposed instrumentation was designed and fabricated. The cold model is made of an acrylic tube along with 10-inch ID and 20-inch of height. The tube is sealed with a pair of top flange and a pair of bottom flange. The top flange is designed with twenty (20) vent holes at ¼-inch of diameter. In addition, a one (1) inch hole was made to host the thermocouple assembly. The bottom flange is designed and fabricated with twenty (20) vent holes and four (4) irritating air injection holes. The irritating air injection holes are connected to the controllable air blower. Two cloth filters are installed in both top and bottom flanges. The schematic diagram of the top and bottom flanges is shown in Figures 3 and 4.

Figure 2 The Schematic Diagram of the Thermocouple Assembly for Cold Model Tests

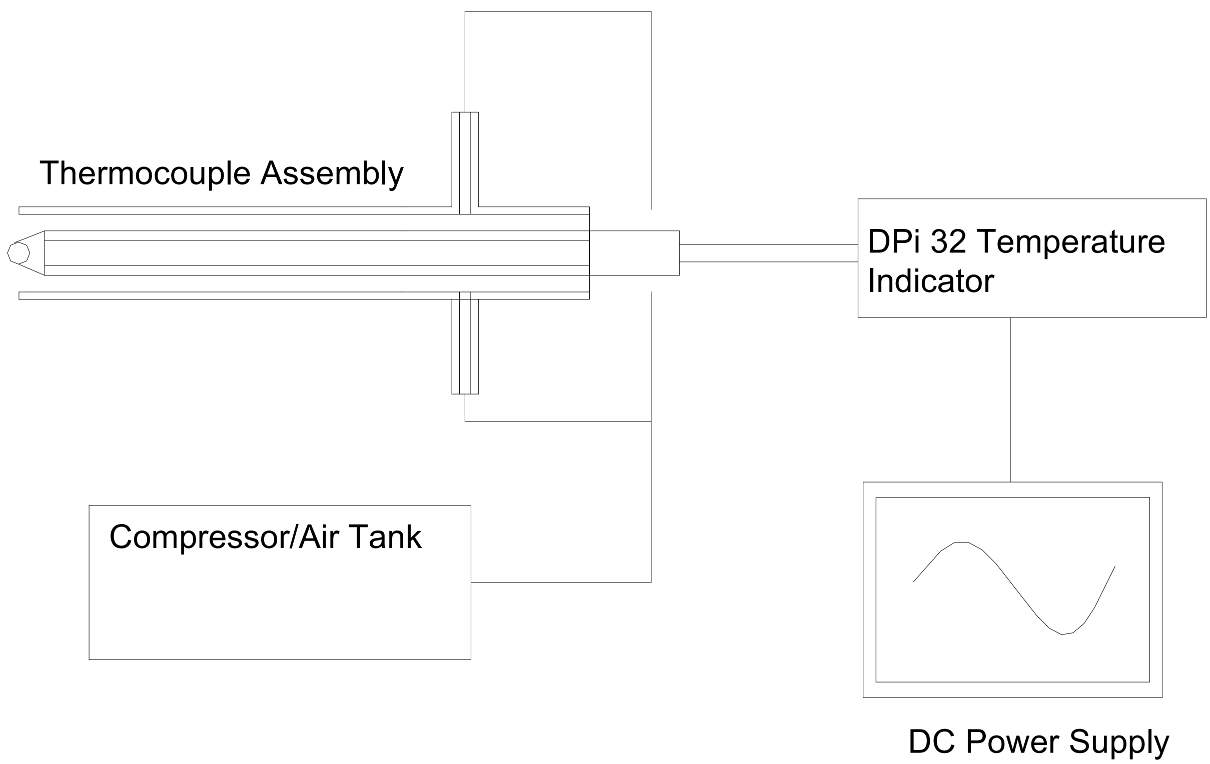
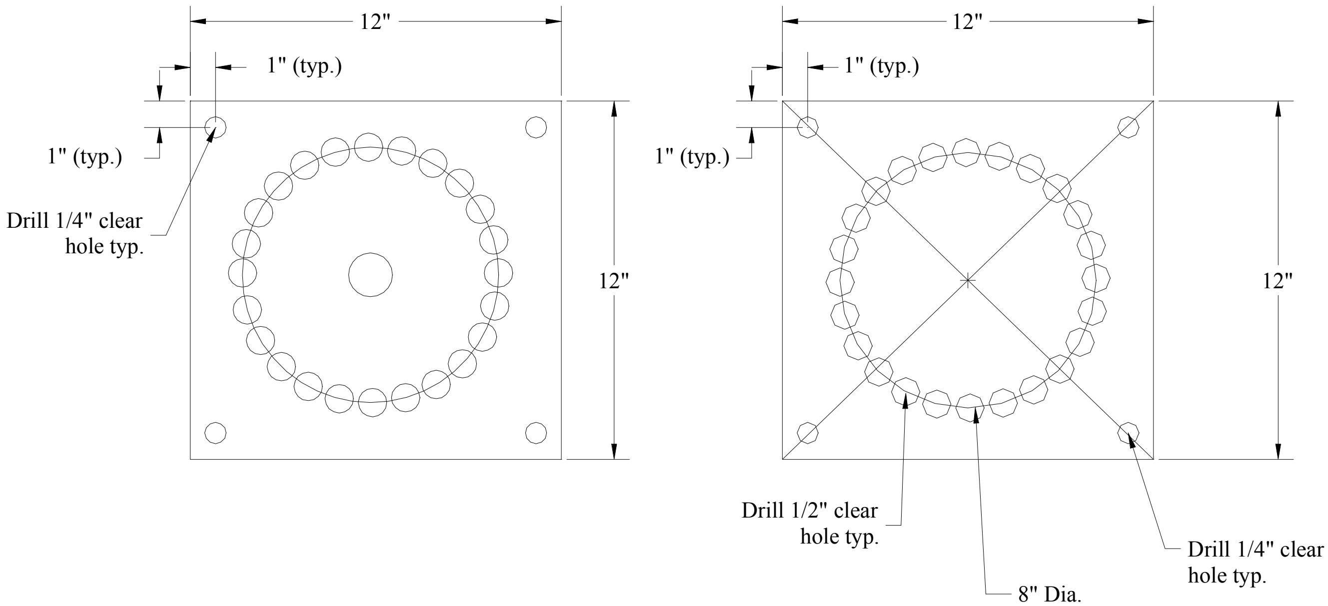


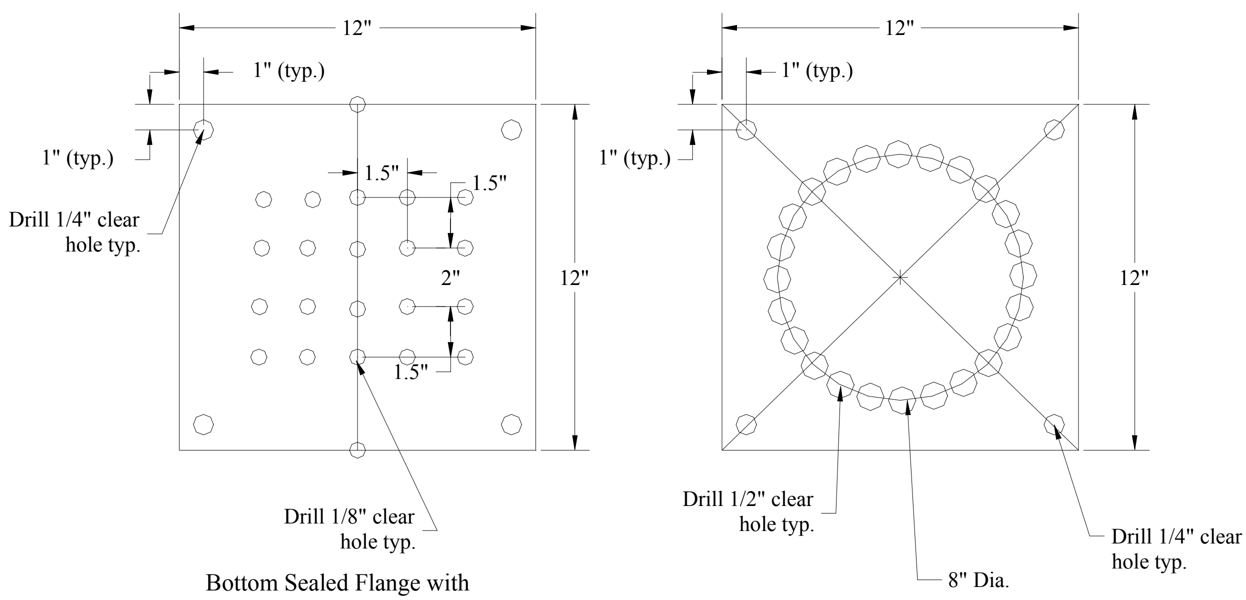
Figure 3 Design of the Top Flange for the Cold Test Model



Top Sealed Flange

Top Openning Flange

Figure 4 Design of the Bottom Flange for the Cold Test Model



Bottom Sealed Flange with Irritation Air Injection Holes

Bottom Openning Flange

3.2 Experimental and Operational Data

The shakedown test of the cold model was conducted at the Center for Advanced Energy Systems & Environmental Control Technologies of Morgan State University. The shakedown tests could determine the sealing performance, air circulation and filter performance for the cold model design. In order to the conduct effective cold model tests, the air leak between each flange is not allowed because of the dirty environment inside the cold model. The air should go through the filter and then vent to the atmosphere. The major experimental and operational data are included in the report. The schematic diagram of the cold model testing facility is shown in Figure 5.

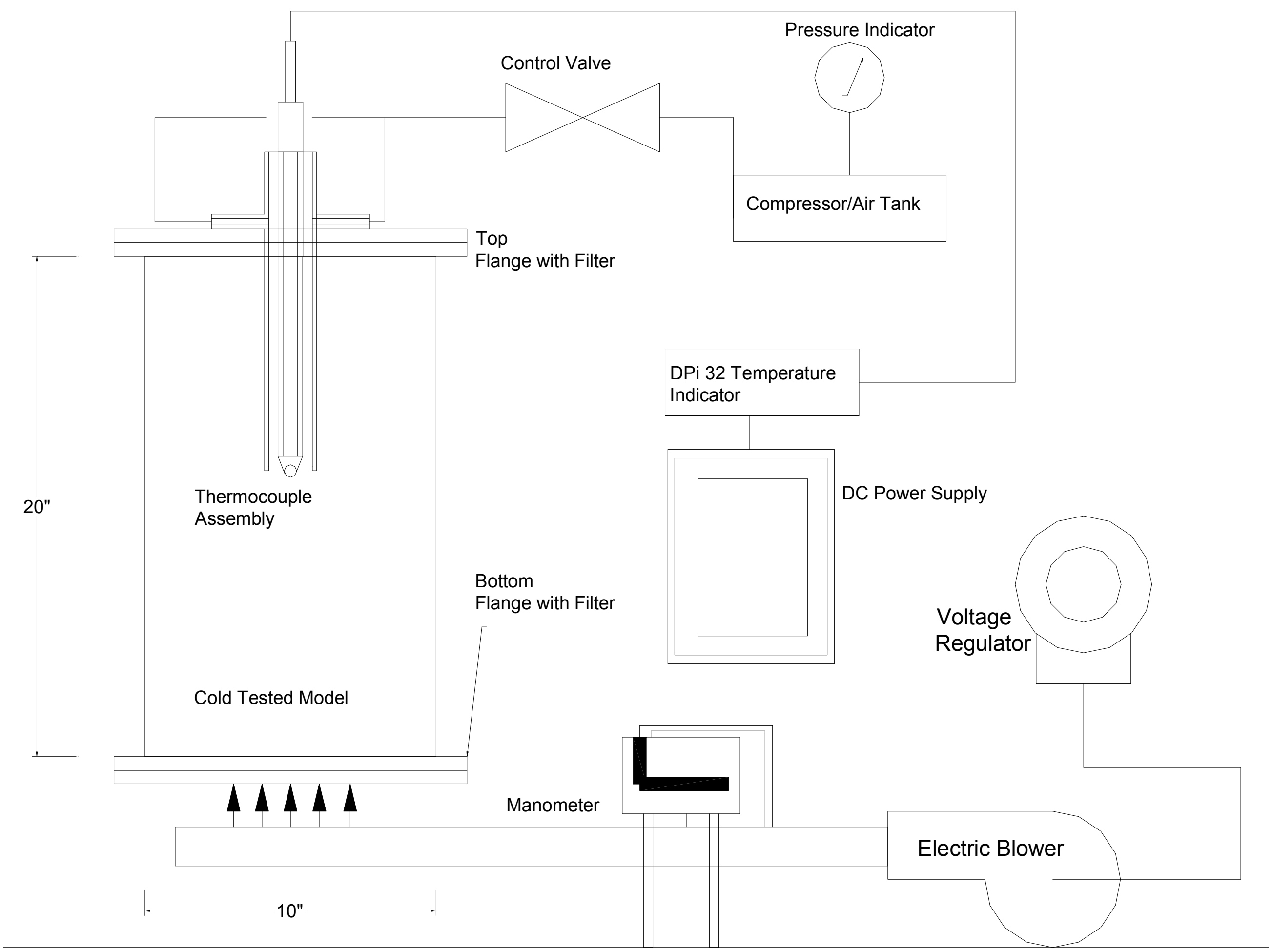


Figure 5 The Schematic Diagram of the Cold Model Testing Facility for Thermocouple Assembly

3.3 Air Leaking Test

Eleven (11) tests were conducted to check the air leak in the cold model system. The voltage regulator was used to control the blower to provide different air flow rates for the cold model. During the tests, the measured parameters were voltage regulator's reading and pressure difference delta P. The air velocity and the air flow rate were the calculated parameters based on the recorded data.

The experiments deign and test data are shown in Table 1 as follows.

Table 1 Sealing Test Parameter Matrix

Experimental No.	Regulator Reading (%)	Delta P (in)	Velocity (m/s)	Flowrate (m3/s)
1	0	0	0	0
2	10	0.005	1.4111	0.0045
3	20	0.011	2.0931	0.0066
4	30	0.02	2.8223	0.0089
5	40	0.05	4.4624	0.0141
6	50	0.1	6.3109	0.01998
7	60	0.16	7.9827	0.02527
8	70	0.23	9.5709	0.03029
9	80	0.3	10.9308	0.0346
10	90	0.37	12.1392	0.03842
11	100	0.42	12.9335	0.04094

The test results are shown in the table 2.

Table 2 Sealing Test Results

Experimental No.	Top Flange Leaking	Bottom Flange Leaking	All Glued Connections
1	No	No	No
2	No	No	No
3	No	No	No
4	No	No	No
5	No	No	No
6	No	No	No
7	No	No	No
8	No	No	No
9	No	No	No
10	No	No	No
11	No	No	No

3.4 Air Circulations and Filter Performance Testing

Similarly, eleven (11) tests were conducted to determine the air circulation and filter performance. In each test, the air flow was following the path which is what we expected; Air blower – cold Model – vent holes – filter – atmosphere.

3.5 Temperature Influence Testing by Electric Motor

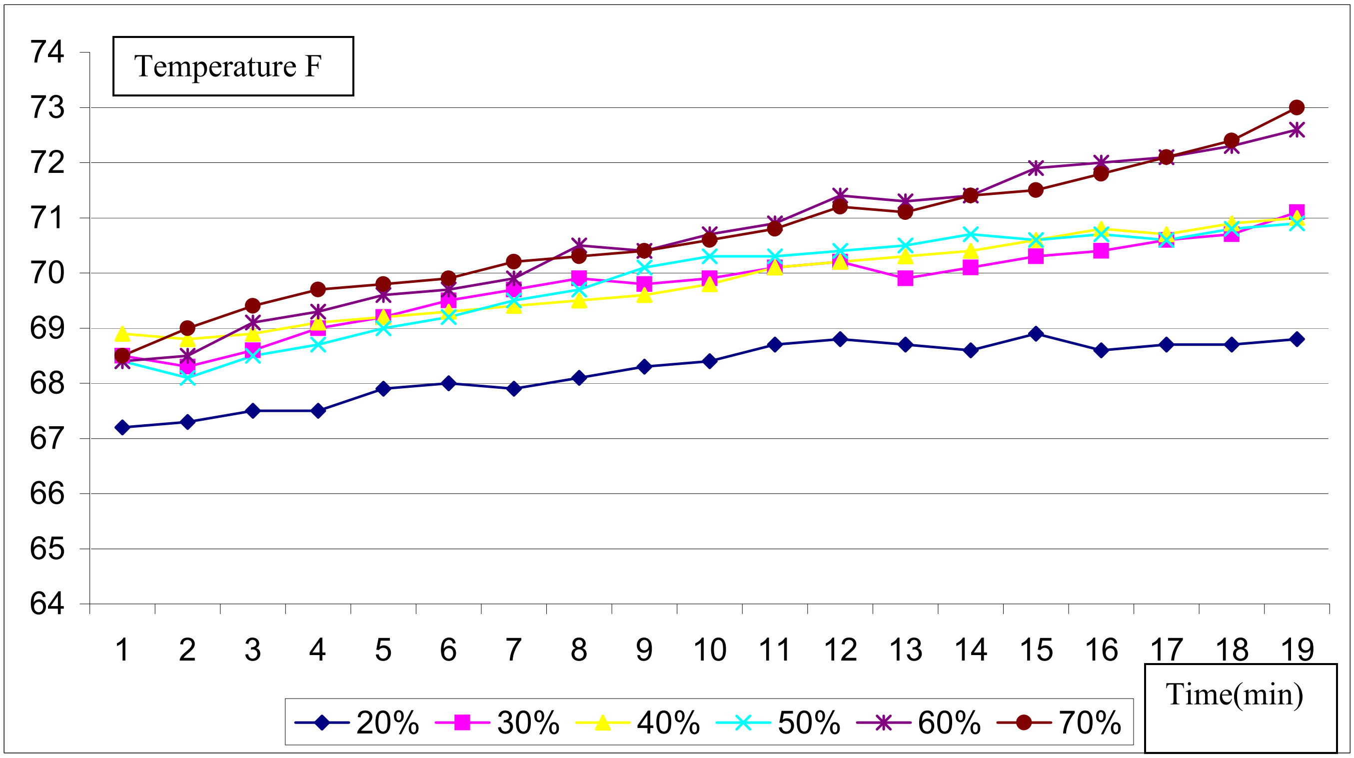
In order to get the basic temperature measurement behavior in the cold model, a series of temperature measurement shall be conducted under an ambient temperature condition before the cold model tests are conducted. Since an electric air blower is used in the cold model testing system, the influence of the electric motor to the temperature inside the cold model shall be evaluated. Six (6) tests were conducted to determine at what test condition the electric motor has the least influence to the temperature inside the cold model. The T-type thermocouple and the DPi-32 temperature indicating system require several minutes of warming up time. Hence, ten (10) minutes warming up time was given for each test at different voltage settings. The time interval between each temperature reading was one (1) minute.

4. Results and Discussion

From the above Tables 1 and 2, no air leak was recorded in the cold model under the cold model testing. The air flow in the cold model operation is also following the path we expected, which is air blower – cold model – vent holes – filter – atmosphere.

From the temperature influence testing by electric motor, temperature in the cold model increased along with the time increasing. The slope increased when voltage percentage increased. The Figure 6 shows the details of the temperature measurements.

Figure 6 Temperature Behaviors in Cold Model at Different Voltage Settings



At 20% voltage, the transient temperature deviated from the other group. At 30%, 40% and 50% voltage, the transient temperature increased at lower slope in comparing with that of 60% and 70% voltage.

Based on the above discussion, the cold model testing parameters can be set in the following settings. All together four (4) parameters are being tested at three (3) different levels. Hence, sixty-four (64) cold model tests will be conducted. Table 3 shows the list of the test parameters and the level design.

Table 3 Test Parameters and the Level Design for Cold Model Tests

Parameter 1		
Irritation air flow rate:		
	Level 1:	0.0141 m3/s
	Level 2:	0.0200 m3/s
	Level 3:	0.0253 m3/s
Parameter 2		
Compressed air injection frequency		
	Level 1:	1/120 hz
	Level 2:	1/60 hz
	Level 3:	1/30 hz
Parameter 3		
Weight of the simulated dust		
	Level 1:	200 grams
	Level 2:	400 grams
	Level 3:	600 grams
Parameter 4		
Ultrasound Application		
	Level 1:	No
	Level 2:	1 device
	Level 3:	2 devices

5. Conclusions

1. The cold model of the gasification simulator has been successfully designed and fabricated.
2. The electric motor of the irritating air blower affected the temperature behaviors in the cold test model.
3. The cold model is ready for the systematic testing on the proposed thermocouple assembly for the gasification environments.
4. The design of the experiments technique is used to the parameter design along with four (4) parameters; char coal dust weights, irritating air flow rates, irritating air frequency and the ultrasound cleaning applications.
5. The analysis of the test results will be continued using analysis of variance (ANOVA) and regression analysis method.

6. Research Continuation

The progress of this project has been on schedule. The systematic tests will be continued in the cold model. The testing for ultrasound cleaning application in the cold model will be conducted. The analysis of test results will be conducted using the analysis of variances (ANOVA) and regression analysis methods.

References

1. Coal Process and Pollution Control, Thomas F. Edgar, Gulf Publish Company, 1983.

2. http://www.fe.doe.gov/coal_power/special_rpts/market_systems/market_sys.shtm.

3. http://www.netl.doe.gov/coalpower.

4. Saliard, S. and S. W. Lee, " Development and Evaluation of Co-generation Capacity at MSU", Proceedings of MSU Science Engineering and Mathematics (SEM) Undergraduate Research symposium, pp. 74-80, July 1999.

5. http://www.clarkson.edu/~microlab/Ultrason.htm.

6. Montgomery, D. C., Design and Analysis of Experiments, 4th Edition, 1997.

7. Liu, Y., G.Chen and S.W. Lee, Factorial Impacts Analysis on Particle Velocity in FBC Cold Model by Laser-based PDPA and Robust Experimental Design, Proceedings of 5th ISSAT International Conference on Reliability and Quality in Design, pp. 156-161, August 13, 1999.

8. DOE Fossil Energy Techline. August 26, 1999.