A Reusable Dust Fuel Cartridge

The Design and Construction of a Dust Feeder Apparatus with Commercial Viability

A Major Qualifying Project, to be submitted to the faculty of
Worcester Polytechnic Institute in partial fulfillment of the requirements for the
Degree of Bachelor of Science for Mechanical Engineering

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Abstract

Coal Dust is used in many metal processing plants to fire the furnaces. On an industrial scale, the burning of coal dust has been shown to be more advantageous than burning chunked coal. However, the burning of coal dust on a smaller scale, such as fuel for residential cooking, has yet to be accomplished. The current project demonstrates a unique strategy to feed dust for such things as residential cooking, and other potential uses. A cylinder that can be filled and refilled is the main feature of the apparatus. Many trial runs will be made with the apparatus which will include three different particle size ranges.

1 Introduction

The study of dust combustion became of paramount importance in wake of the many coal mining disasters occurring across the globe. Learning about, and more importantly controlling the danger that coal processing presents is an ongoing discipline. It is well known that when coal dust is suspended in air, it becomes a very volatile 'cloud' that if exposed to an ignition source can explode violently. Dust explosions are not exclusive to the coal industry; the agricultural industry also has had its share of explosive disasters. In the article "Dust Explosions In The Food Industry", Vahid Ebadat, Ph.D., and the CEO of Chilworth North America, states that the most "powders in the food industry can form explosive dust clouds if the particle size is small and the moisture content is low". Metallic dust is also a very combustible material. In Kunshan in the Jiangsu province of China, an automobile parts factory explosion killed at least 25 people. The cause of the blast was attributed to metallic dust in the air. (http://www.bbc.com/news/world-asia-china-28636056) We are all familiar with the occasional news story of grain silos exploding due to these combinations of factors.

The explosive nature of fine dust has given rise to the study of dust combustibility, not only in order to try to harness the tremendous energy potential that exists in dust, but perhaps more important is to study ways to make these volatile dusts safer for industry. A dust particle has a greater surface to mass ratio than that of say, a chunk of coal, which means a faster more efficient combustion of the dust particle. Important to the study of dust combustibility, is creating an effective technique to mimic a dust cloud's explosive potential as well as metering the flow of the dust cloud for efficient burning and accurate data collection.

The current study at hand seeks to address the challenge of consistently metering coal dust cloud. The major challenge to overcome is the consistent metering of very fine coal dust. Coal dust of particle size of less than 25 microns has proven to be difficult to meter. At very fine particle sizes, dust has a tendency to "clump up", whereas the larger particle sizes will resist clumping. A dust delivery system needs to be able to consistently meter dust particles of different size ranges. This study uses dust sizes of 95-106 microns, 40-53 microns, and 0-25 microns.

2 Background

Coal dust is used to fire the furnaces in the metal processing industry. In order to maximize the flammability of coal dust, a cloud of dust and air is created by introducing very turbulent air. This will give the proper fuel to air ratio to maximize the energy released from the individual dust particles. This also effectively reduces the density of the coal dust, and the mixture will take on some characteristics of a fluid which is critical to its transport and efficient combustion. The use of coal dust as a fuel source for industrial furnaces is beneficial in this application because it instantly ignites, contrary to coal chunks which require time to fully ignite, and this saves time by getting furnaces up and running more quickly.

The study of coal dust has overwhelmingly been concentrated on the phenomenon of coal dust explosions. Also receiving a vast amount of attention is the study of the combustion of coal dust. Burning coal dust as a fuel has some great advantages. As previously mentioned coal dust burns very quickly and efficiently due to its size to mass ratio. Coal is an abundant fuel source that is available throughout many parts of the world. The reputation of coal is that of a dirty fuel source. There is growing research and study with coal, and coal dust specifically, directed towards more efficient and cleaner burning of coal and coal dust.

Of the many studies that looked at the combustion of coal dust, almost all used a closed-system that required loading dust into the dust feeder, and then the system was closed. Then very turbulent air was introduced to the system in order to fluidize the coal dust. Once the dust was delivered and burned the system had no way of replenishment without dismantling of the apparatus. One study used a hopper like device that resembles a funnel. It had a copper tube, with 2 or 3 holes in it to entrain the dust, running up the center of the funnel. This apparatus strategy worked well as did other types of dust feeders. However, very small particle size in the range of 25 microns or less has proven to be difficult to meter accurately.

Another dust injector design incorporates a screw feeder to deliver dust to a heated air flow in a vertical steel tube to be burned at exit. This dust feeder is part of a flame analyzer built by Rockwell. The screw feeder works well with larger micron particle sizes, but is unable to deliver very small particle sized dust at a consistent rate due to the cohesive nature of small particles. Additionally, each particle size range required a different size screw. Another design is the aforementioned dust hopper/funnel entrainment apparatus. Yet another design uses a closed steel cylinder with a fluidized bed of dust. Pressurized methane-air is injected into the cylinder at the bottom and from the top to a jet ring inside the cylinder below the surface of the dust bed to achieve fluidization. Again, the consistent metering of very small particulate dust is not obtained.

Goboshin, Fomenko, and Lee used a dust dispersion method that incorporated a syringe type assembly that was able to produce a “uniform dust flow for a wide range of dust concentrations for duration of up to 4-6 minutes.” The syringe is operated by an electro-mechanical actuator that pushes dust out of the top of the dust chamber where it is mixed with motive air. Dust feeding rate is changed to vary the dust concentration. For this experiment aluminum dust was used. The shape of individual particles of aluminum can be described as spheroid, which differs from the inconsistent shape of a coal dust particle.

Smoot and coworkers used an apparatus that introduced air and coal from one supply line that mixes with Methane from another supply line and then both enter a vibrating chamber at the same time. Inside the chamber is a baffle to help disperse the coal dust then the dust passes through smoothing screens before being burned.

A study by Alexis Belonio of the Central Philippine University has created a stove that uses rice husks as its fuel source.

Alexis Belonio devised a rice husk gas stove for residential cooking. Rice husks are an abundant and inexpensive fuel source, which makes it an attractive economically. What Belonio discovered, was a way to gasify the rice husks through a char process that creates a flammable gas for cooking. Being from the Philippines, Belonio recognized a demand for a stove that used readily available fuel, especially for those people who did not have access to conventional utilities to provide the necessary energy for cooking.

Inspired by the Rice Husk gas stove, and the challenge of metering coal dust of small micron sizes, the current study for this report seeks to construct a device that will meter coal dust of varying sizes to be used as fuel for cooking and possible other applications. The apparatus used for this study incorporates the syringe or piston-cylinder concept of the McGill University apparatus, and additionally, the smoothing screen and the use vibration from the Smoot apparatus.

3 Experimental Set-Up

The Dust Feeder apparatus can be looked at as being comprised of 4 sections. They include the motor or power section, the drive train section, the cylinder and piston section, and the vibrating screen section.

Reusable Dust Fuel Cartridge

Figure 1 the dust cartridge apparatus

(Oriented vertically for illustration purposes)

1 Motor Section

The motor is a rotisserie motor from WONDERMOTOR, the PN01007 Electric Gear Motor 12v Low Speed 50 RPM Gear motor DC. Its rated torque output is 8.5 ft-lb. The motor is connected to the 5/8th inch diameter threaded rod via a shaft coupler that allows for slight misalignments between the motor shaft and the threaded rod shaft. In order to provide linear motion to the piston, the motor must turn counter clockwise, which is only a matter of reversing the wiring connections from the power supply to the motor. Subsequently the plywood carcass of the dust feeder at the motor end of the unit was built to handle the counter forces created by the motor.

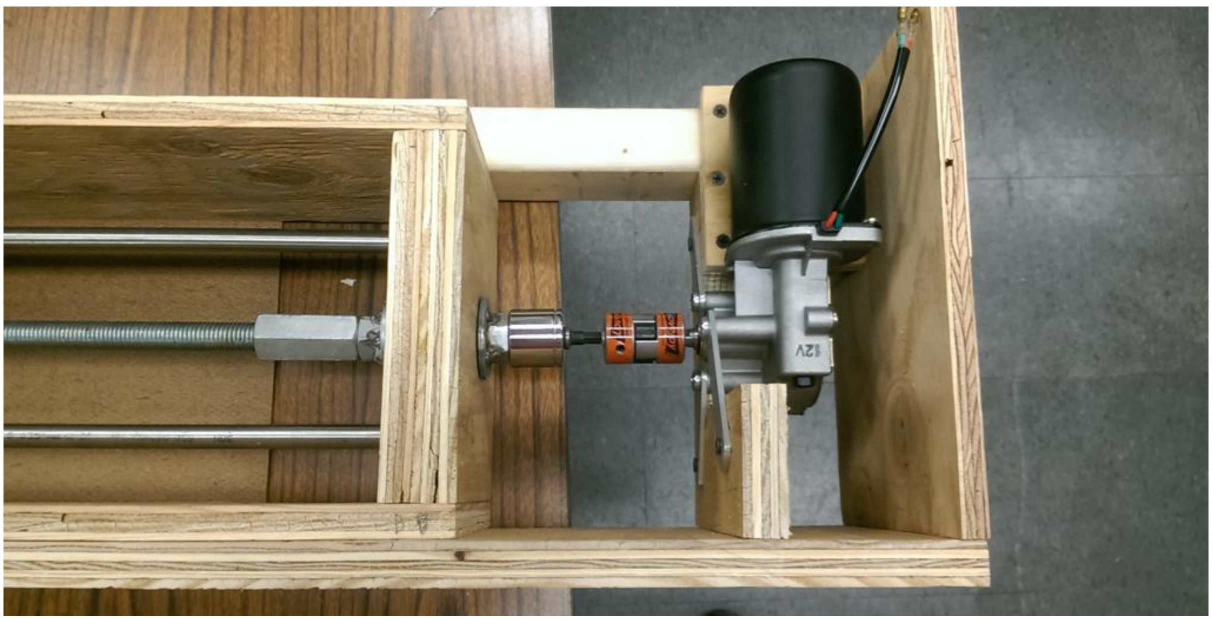

Figure 2 the motor assembly section

1 Drive Train Section

The drive train portion of the Dust Feeder was designed much like a lead screw where rotational motion is translated to linear motion. As the motor turns the threaded shaft, a drive nut travels axially down the threaded shaft. The drive nut is kept from rotating by two outboard shafts and a drive nut outrigger, which allows for the linear travel of the drive nut. The drive nut pushes a hollow tube made of PVC that in turn pushes the piston through the cylinder. The inside diameter of the PVC tube is just big enough to fit over the 5/8th inch threaded shaft.

Figure 3 lead screw type of drive system

2 Piston – Cylinder Section

The piston cylinder portion of the Dust Feeder consists of a clear polycarbonate cylinder and a piston made of PVC pipe, Masonite top and bottom, and Teflon tape wrapped around the Masonite edges to allow for smooth travel inside the cylinder. The choice of clear polycarbonate for the cylinder was twofold; first, being able to see the piston travel inside the cylinder is advantageous, and secondly, the smoothness of the inside of the polycarbonate cylinder will help reduce the force necessary to move the piston in the cylinder. The cylinder was designed to be swapped out with a new fuel packed cylinder when the fuel from the first cylinder has expired. This design will make for a more commercially attractive apparatus. For the present study, the cylinder will just be repacked for each trial with the appropriate size dust particles.

Figure 4 piston and cylinder section

3 Vibrating Screen Section

The vibrating screen section is mounted very close to the outside the top of the cylinder. It is driven by a 12 volt vibrating motor. The screen portion consists of a piece of window screening sandwiched between two PVC rings cut from a pipe. Wrapped around the PVC rings, and making up the stem that the vibrating motor is attached to, is 1/8th inch flexible copper tubing. To secure the tubing around the PVC/screen sandwich is epoxy putty.

Figure 5 vibrating screen assembly

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4 Experimental Procedure

Three coal dust ranges will be studied, 95-106 microns, 45-53 microns, and lastly 0-25 microns. These particle size ranges can be described as fine, medium, and coarse, which will test the device's capability of handling a wide range of dust particle sizes. There will be multiple trials for each dust particle size range. Timed trials of 15 seconds, 30 seconds, and lastly 60 seconds will be conducted. For each timed trial there will be three repetitions in order to determine an average mass flow rate. The average mass flow rate will be charted on a graph versus time for speeds of 7, 10, and 15 rpm.

First, the cylinder is filled with approximately 9 to 10 inches of coal dust. Once filled, the top of the dust in the cylinder is tapped down by hand with force to achieve a tapping density. Tamping down with a large force will result in a large amount of torque required from the motor, especially when packing particle size range of 0-25 microns. This situation was avoided because of the complexity that would accompany a densely packed cylinder. Also, in order to have a bench mark from which to progress from on future work, it was decided to start with a tapped density of coal particles by hand without the use of mechanical forces.

Figure 6 filling with dust Figure 7 ready for test Figure 8 timed trial underway

Figure 6 shows the Dust fuel Cartridge oriented vertically for filling with dust. Figure 7 shows the apparatus prone and ready for timed trials. Figure 8 shows the timed trial underway.

Once the cylinder is prepared with particles the device is laid prone on a bench to conduct the timed trials. The starting procedure is a bit cumbersome due to the separately operated motor, vibrating screen, and stop watch. A small plate is held underneath the vibrating screen. Another plate is used to initially catch the particles as the drive motor and the vibrating motor are started. Once everything appears to working properly the catch plate is pulled away simultaneously with the start of a stopwatch. At the end of the trial time the plate is placed back under the dust falling from the vibrating screen, and this provides the simplest and best method for the start/stop aspect of the apparatus in its current state of completion

5 Results and Discussion

A total of 81 timed trials were conducted. Three ranges of particle size (dust) were tested, these included 0-25 microns, 40-53 microns, and 90-106 microns. These particle sizes were tested over three different speeds of 7 rpm, 10 rpm, and 15 rpm, with three timed intervals of 15 seconds, 30 seconds, and 60 seconds for each speed. Each timed interval included three trials of which the average was taken and converted to g/s to be charted on graphs.

The threaded rod (drive shaft) used for the apparatus has 11 threads per inch which equates to 11 revolutions per inch.   A conversion was done to get the speed in terms of mm/s of linear piston travel. For example:

1 inch/11 rev * 25.4 mm/1 inch * 7 rev/min * 1 min/60 seconds = 0.269 mm/s

This represents a piston speed of 0.269 mm/s at 7 rpm of the drive shaft. Accordingly, for 10 rpm the piston speed is 0.385 mm/s, and for 15 rpm of drive shaft rotation the piston speed is 0.577 mm/s.

6 Timed Trials Mass Flow Rate in g/s

7 rpm

g/s 15 sec.

Trials	1	2	3
0 - 25 µm	0.23	0.231	0.245
40 - 53 µm	0.145	0.116	0.144
90 - 106 µr	0.195	0.209	0.177

g/s 30 sec.

Trials	1	2	3
0 - 25 µm	0.167	0.279	0.223
40 - 53 µm	0.11	0.136	0.139
90 - 106 µr	0.138	0.161	0.166

g/s 60 sec.

Trials	1	2	3
0 - 25 µm	0.189	0.148	0.19
40 - 53 µm	0.144	0.093	0.166
90 - 106 µr	0.161	0.16	0.167

Table 1 Converted to g/s and tabulated for speed of 7 rpm or 0.269 mm/s

10 rpm

g/s 15 sec.

Trials	1	2	3
0 - 25 µm	0.212	0.32	0.318
40 - 53 µm	0.296	0.393	0.315
90 - 106 µr	0.357	0.369	0.386

g/s 30 sec.

Trials	1	2	3
0 - 25 µm	0.185	0.191	0.214
40 - 53 µm	0.293	0.361	0.303
90 - 106 µr	0.347	0.344	0.319

g/s 60 sec.

Trials	1	2	3
0 - 25 µm	0.204	0.21	0.213
40 - 53 µm	0.285	0.32	0.325
90 - 106 µr	0.303	0.312	0.314

Table 2 Converted to g/s and tabulated for speed of 10 rpm or 0.385 mm/s

15 rpm

g/s 15 sec.

Trials	1	2	3
0 - 25 µm	0.254	0.265	0.318
40 - 53 µm	0.453	0.507	0.511
90 - 106 µr	0.432	0.435	0.415

g/s 30 sec.

Trials	1	2	3
0 - 25 µm	0.271	0.296	0.366
40 - 53 µm	0.377	0.411	0.453
90 - 106 µr	0.397	0.449	0.422

g/s 60 sec.

Trials	1	2	3
0 - 25 µm	0.243	0.338	0.323
40 - 53 µm	0.428	0.435	0.412
90 - 106 µr	0.458	0.452	0.478

Table 3 Converted to g/s and tabulated for speed of 15 rpm or 0.577 mm/s

Tables 1, 2 and 3 contain the mass flow rates for all 81 timed trials, over three different speeds. The data collected will be charted on graphs for analysis.

7 Analysis

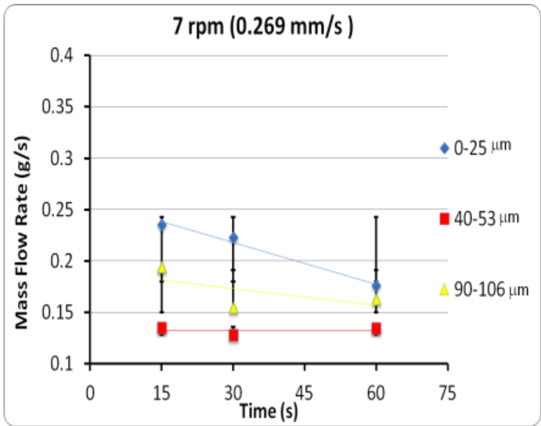


Figure – 9 Average mass flow rates at 7rpm

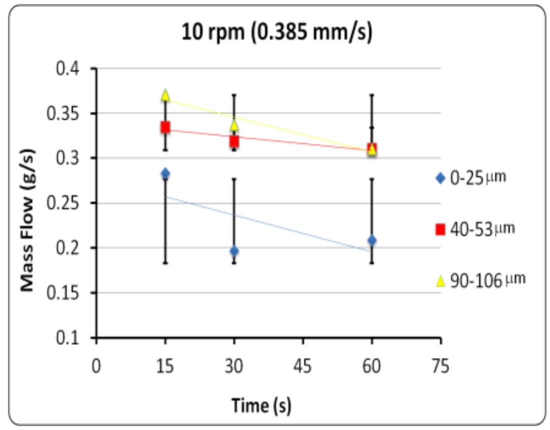


Figure – 10 Average mass flow rates at 10rpm

Figures 9 and 10 are the results of timed trials at 7, and 10 rpm respectively. At both of these speeds there exists some inconsistency in the mass flow rate of particles. In Figure 9 the error bars around the 0-25 micron data points show a wide variability within the data, and at 60 seconds the average mass flow deviates by more than one standard deviation from the mean. In Figure 10, the 0-25 micron size shows even greater variability within the data demonstrated by very wide error bars with the data at 15 seconds falling outside the standard deviation. The best consistency of flow rate is achieved with particle size range of 40-53 microns. Figure 9 shows very narrow error bars for 40-53 microns with an almost perfectly horizontal trajectory. Whereas in Figure 10, the 40-53 average mass flow shows an increase in its variability, but the error bars are narrow relative to the other error bars on the graph. The 90-106 micron size particles show similar performance in Figures 9 and 10 with the data at 15 seconds falling outside one standard deviation for Figure 9, and the data at 60 seconds falling outside one standard deviation for Figure 10.

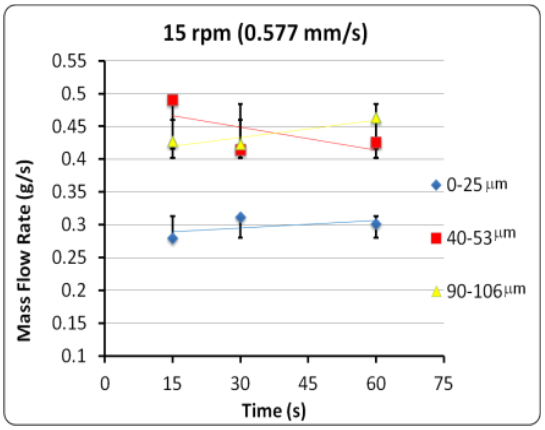


Figure 11 Average mass flow at 15 rpm

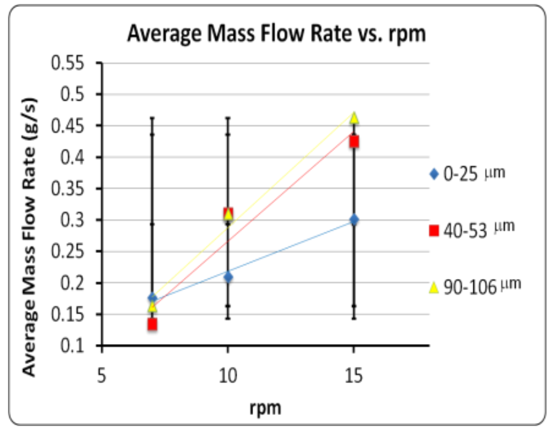


Figure 12 Average mass flow for 60 seconds

The graph in Figure 11 shows that 15 rpm is the critical speed at which the best consistency of mass flow rate for all three particle size ranges is achieved. There is less variability within the data for all three size ranges, evidenced by the data points falling within the standard deviation for each size range.

Figure 12 shows the graph of the average mass flow rate of all three particle sizes for the 60 second timed trials versus the three speeds of 7, 10, and 15 rpm. The particle size ranges of 40-53 microns and 90-106 microns have very similar slopes with a linear progression of mass flow rate. The particle size range 0-25 microns shows linear behavior as well, but as the speed increases the mass flow rate does not keep pace with the other two particle size ranges, which is evidenced by the slope of the 0-25 micron particles. The linear trajectory by all three particle sizes shows that the tapping density was sufficient enough to insure uniform density within the cylinder.

8 Conclusions

The apparatus constructed for this study provides a consistent mass flow rate for particle sizes of 25 to 106 microns, but unable to consistently deliver particle sizes of 0-25 microns. This can be attributed in part by the different characteristics between the particle sizes. The larger particle sizes behave much like a solid, where gravity and inertia rule their movement. The 0-25 micron size particles behave more like a gas and are subject to molecular forces such cohesion of particles, which can be attributed to its lack of consistent mass flow rate.

9 Future Work

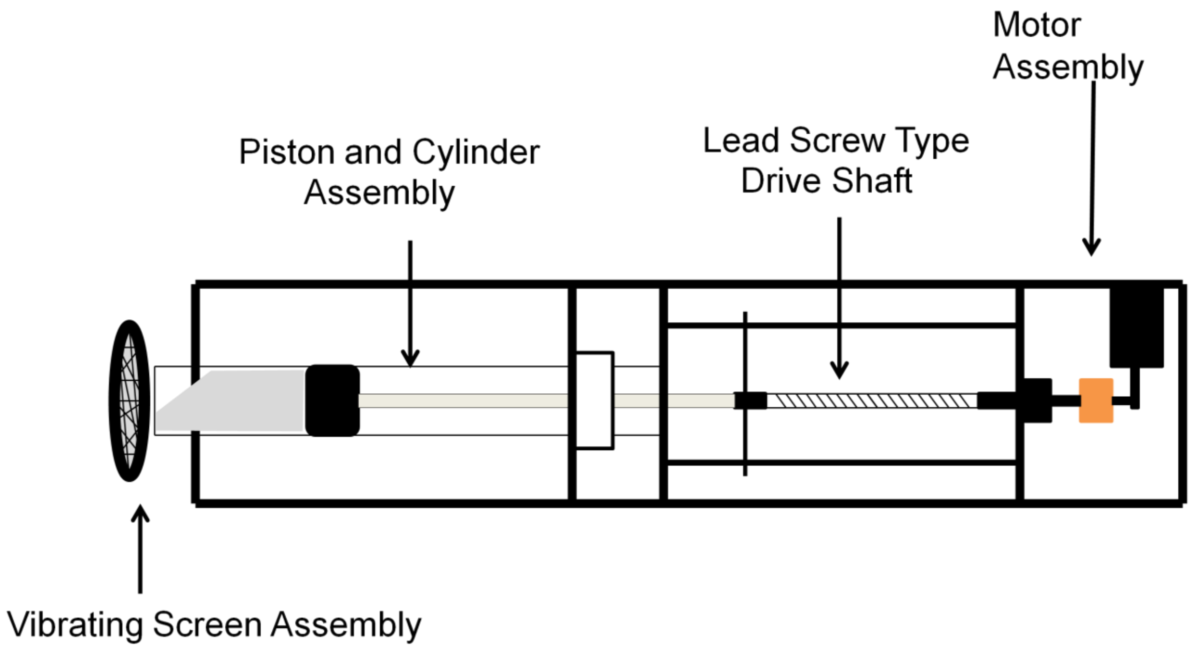
The apparatus as of this study has a length of approximately double the length of the cylinder/cartridge itself. Future work should include the goal of shortening the apparatus to a more reasonable size. Also, a method by which to connect the apparatus to a burner is warranted.

10 References

1. Edbadat, V. (2012, March 21). Dust Explosions In The Food Industry. Retrieved May 11, 2015, from http://www.manufacturing.net/articles/2012/03/dust-explosions-in-the-food-industry
2. Metal dust 'behind deadly China blast' - BBC News. (2014, August 14). Retrieved May 11, 2015, from http://www.bbc.com/news/world-asia-china-28636056
3. Rockwell, S.R., Rangwala, A.S., Fire Safety Journal, 2013. 59: p. 22-29
4. S. Goboshin, I. Fomenko and J. H. S. Lee from the Department of Mechanical Engineering, McGill University, 817 Sherbrooke Street West Montreal, Quebec, H3A 2K6, Canada
5. Smoot, L.D. and Horton M.D.; "Propagation of laminar coal-air flames", Progress in Energy and Combustion Science, P. 235 – 258 (1977)
6. Belonio, A. T. (2005). Rice Husk Gas Stove Handbook. Appropriate Technology Center. Department of Agricultural Engineering and Environmental Management, College of Agriculture, Central Philippine University, Iloilo City, Philippines.

11 Appendix A

Sketch of Dust Fuel Cartridge Apparatus



12 Appendix B

Various Pictures of Dust Fuel Cartridge

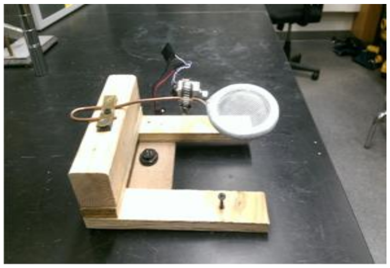


Figure 13 Vibrating Screen Section

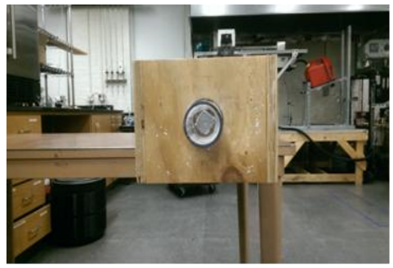


Figure 14 End View into the Cylinder

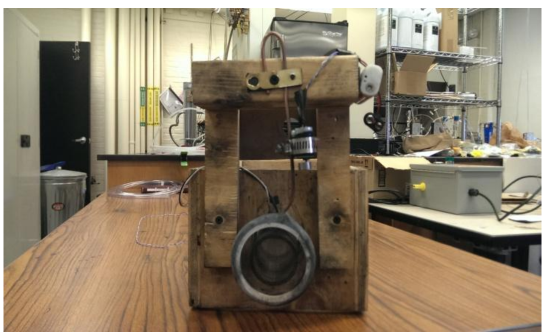


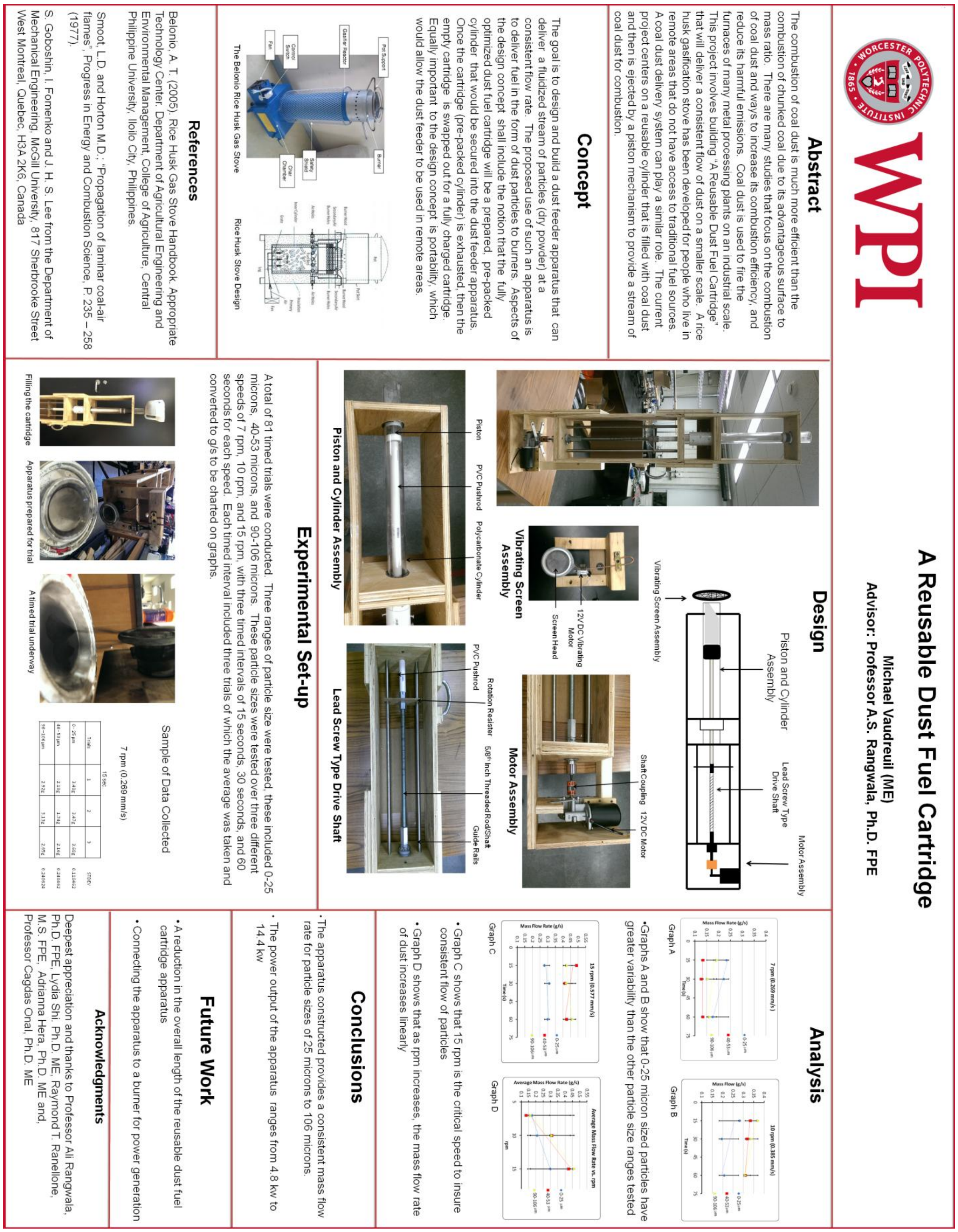
Figure 15 End View with Vibrating Screen

Reusable Dust Fuel Cartridge in Position

Figure 16 Prone

13 Appendix C

Presentation Poster



14 Appendix D

Combustion Laboratory Short Form for Testing

The purpose of this form is to provide a simple way for students to develop an Experimental Plan for short, uncomplicated tests rather than using the Experimental Plan Template. The numbers listed below match the steps in How to Develop an Experimental Plan. You should read that first to learn how to develop a plan and then use the following format to present it.

---

1. Background

   Reason for doing experiment:

   To measure the mass flow rate of dust that is ejected from the dust feeder apparatus.

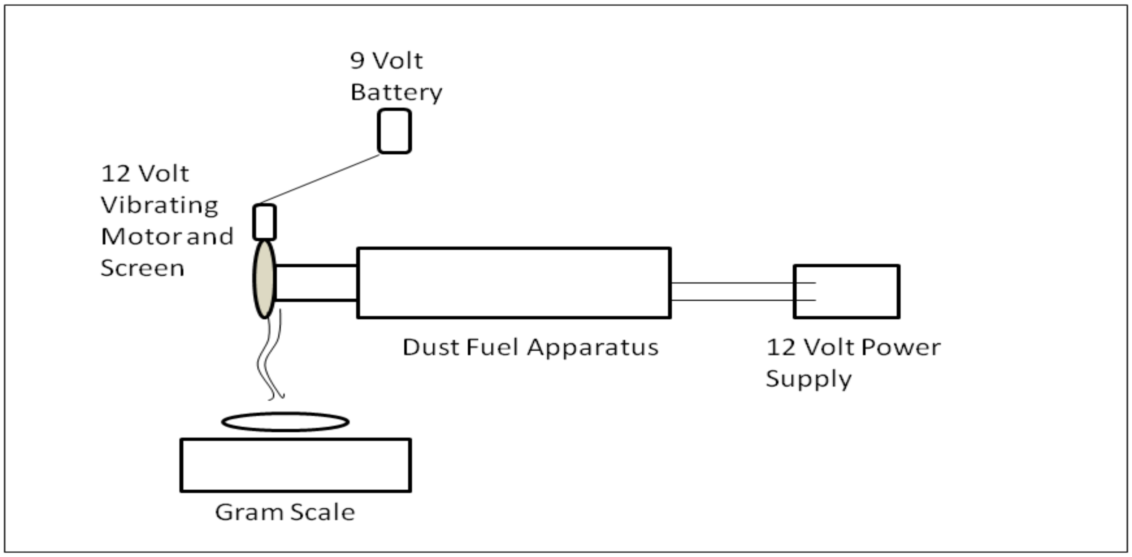
2. Objective

   Data/information you trying to obtain:

   The objective is to determine the consistency of mass flow rate of the dust feeder apparatus by conducting several timed trials over 3 different speeds using 3 different dust particle size ranges.

3. Process flow and instrumentation diagram (PID)

Draw your PID:



4. PID components

List components of PID:

- Laboratory Dual Power Supply
- The Dust Fuel Cartridge
- Laboratory weight scale
- 9 Volt Battery
- 12 Volt Vibrating Motor and Screen

5. Safety issues

List materials and chemicals to be used, required use and hazards:

The primary safety issue is the use and handling of coal dust. Coal dust is poured into the cartridge/cylinder and packed to achieve a tapping density. Care must be taken to prevent the coal dust from becoming airborne and contaminating the lab area.

List Protective Personal Equipment to be worn to protect against those hazards:

A respirator was worn at all times during the use and handling of coal dust throughout the timed trials. Also, safety glasses were worn due to the propensity at which coal dust can become airborne and get into unprotected eyes.

6. Failure possibilities

List failure possibilities of EACH of the PID components and how you will minimize these:

The Dust Fuel Cartridge requires electrical power to the drive motor, and to the vibration motor of the screen assembly. When hooking up the laboratory power supply to the apparatus, I realized that one side of the power supply had failed and would not output electricity. In order to work around this problem, a small 9 volt battery was wired to the vibrating motor of the vibrating screen assembly.

To protect the 12 Volt motor that drives the shaft of the Dust Fuel Cartridge, the power supply was set to output no more than 6 amperes of current. This will prevent the motor from burning out should very high torque levels are encountered.

A failure of the weight scale would require the use of a replacement scale because repair of such a device in the field by an unauthorized technician is not an option.

7. Checklist

Write a checklist which encompasses all your procedures: Include pre-test, test and post-test activities Use additional/separate sheet if needed:

Pre-test:

- Prepare cartridge by filling with coal dust
    - Take off the vibrating screen assembly
    - Place apparatus in vertical position
    - Pour coal dust in cartridge to approximately 8 or 9 inch depth
    - Press the top of the dust with Masonite disk to initially remove excess air
    - Tap the Masonite disk approximately 6 times with finger to a tapped packing density
    - Replace the vibrating screen assembly
    - Lay the Entire Dust Fuel Cartridge horizontally on bench
    - Hook up the 12 volt drive motor to the power supply

Test:

- Powering the Dust Fuel Cartridge
    - Turn on power supply
    - Engage the 9 volt battery to the vibrating screen assembly
- Capturing the ejected dust from the cartridge
    - Allow the system to achieve a steady state of operation
    - Simultaneously pull the capture plate away from the stream of dust and start the stop watch for the timed trial.
    - Dust falls onto another plate during the timed trial
    - Simultaneously put the capture plate under the stream of dust and stop the stop watch
    - Weigh the dust captured on the other plate (Timed Trial amount)
    - Repeat the process until the dust is nearly exhausted in the cartridge
    - Refill the cartridge for more trial runs

Post Test:

- Throughout the experiment care in handling the coal dust was a priority

- Thorough vacuuming of the area following day of testing
- Return coal dust to properly labeled containers
- Return the power supply to its secure location
- Return any hand tools used during the experiment
- Return the apparatus to its secure location

8. Checklist specifics

Plan to inform others of activities:

Informed my advisor of my activities in the lab

Number of people needed to run:

I ran the tests alone to insure as best as possible identical starting and stopping procedures

9. Emergency shutdown

List events that necessitate an immediate shutdown:

The only power equipment requiring a pre determined shut down procedure is the laboratory power supply. Should there be any emergency to contend with, the power supply can be turned off by the power button, or the power supply can be unplugged from its AC electrical source. Should there be a problem with the apparatus itself, the alligator clips to the drive motor can be disengaged very quickly.

10. & 11.   Apparatus checkout

How will you know if all the components work properly?

In order to determine if the components are working properly, it is important to have run the experiment several times as a practice to observe its behavior. The experience from the practice runs of the experiment will help us discern expected behavior from improper behavior.

12. Team review

Explain how all team members will know what is going on:

This is an independent project involving only myself.

13. & 14. Pre-test and test

Explain how you will know the information obtained is valid (i.e., reasonable or makes sense):

The information we are gathering is the mass flow rate of coal dust ejected. The information obtained is valid as long as a steady state of operation of the apparatus is achieved and the behavior of the system does not deviate from the norm.

15. Post-test

List what/how you will clean post-test:

As stated previously, all hand tools will be returned to their proper location, all waste materials are properly disposed of, and the area is completely vacuumed and wiped down. Finally the Dust Fuel Cartridge is secured in its safe location.

15 Appendix E

Results of Timed Trials

7 rpm

15 sec.

Trials	1	2	3	STDEV
0 - 25 µm	3.48	3.47	3.68	0.118462
40 - 53 µm	2.18	1.74	2.16	0.248462
90 - 106 µm	2.92	3.13	2.65	0.240624

30 sec.

Trials	1	2	3	STDEV
0 - 25 µm	5	8.38	6.68	1.69000986
40 - 53 µm	3.29	4.08	4.17	0.48418316
90 - 106 µr	4.13	4.84	4.98	0.45574115

60 sec.

Trials	1	2	3	STDEV
0 - 25 µm	11.36	8.85	11.39	1.457887
40 - 53 µm	8.64	5.55	9.97	2.267649
90 - 106 µr	9.67	9.58	10.04	0.24379

10 rpm

15 sec.

Trials	1	2	3	STDEV
0 - 25 µm	3.18	4.8	4.77	0.926769
40 - 53 µm	4.44	5.9	4.72	0.774855
90 - 106 µm	5.36	5.53	5.79	0.216564

30 sec.

Trials	1	2	3	STDEV
0 - 25 µm	5.54	5.72	6.42	0.46490142
40 - 53 µm	8.78	10.82	9.1	1.09714782
90 - 106 µr	10.42	10.33	9.56	0.47268735

60 sec.

Trials	1	2	3	STDEV
0 - 25 µm	12.22	12.57	12.75	0.269506
40 - 53 µm	17.12	19.18	19.5	1.291666
90 - 106 µr	18.2	18.73	18.86	0.349619

15 rpm

15 sec.

Trials	1	2	3	STDEV
0 - 25 µm	3.81	3.98	4.77	0.512282
40 - 53 µm	6.8	7.6	7.66	0.480139
90 - 106 µm	6.48	6.52	6.22	0.162891

30 sec.

Trials	1	2	3	STDEV
0 - 25 µm	8.13	8.89	10.98	1.47581616
40 - 53 µm	11.32	12.33	13.58	1.1321219
90 - 106 µr	11.91	13.46	12.66	0.7751344

60 sec.

Trials	1	2	3	STDEV
0 - 25 µm	14.58	20.28	19.35	3.05799
40 - 53 µm	25.66	26.08	24.69	0.712905
90 - 106 µr	27.48	27.11	28.7	0.832006

Table 4 Tabulated weights of the coal dust collected for each timed trial

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