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Study of American Wood Pellet Stove Emissions

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STUDY OF AMERICAN WOOD PELLET STOVE EMISSIONS

By

Sergio Gamarra

A Thesis Submitted in Partial Fulfillment of the

Requirements for the Degree of

Master of Science

In

Automotive Engineering Technology

Minnesota State University, Mankato

Mankato, Minnesota

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STUDY OF AMERICAN WOOD PELLET STOVE EMISSIONS

Sergio Gamarra

This thesis has been examined and approved by the following members of the student's committee.

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Dr. Bruce Jones, Advisor

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Dr. Winston Sealy, Committee Member

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Dr. Kuldeep Agarwal, Committee Member

Abstract
STUDY OF AMERICAN WOOD PELLET STOVE EMISSIONS

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Problem: The EPA (Environmental Protection Agency) had not specified emissions performance standards for pellet burning stoves. Instead they were lumped in with cordwood burning stoves. IRETI's decision to pursue this baseline study was guided by Minnesota's concurrent "2025 Energy Action Plan" and the EPA's pellet stove testing method development. Wood pellet fuel, a renewable resource, and the technology developed to utilize it for residential heating should be further studied to examine how together they both stand up to newly developed EPA emissions testing methods. This will establish a benchmark for testing American technology, thus guiding IRETI's efforts of introducing foreign technology to help MN reach the goals set for MN2025.

Methods: Representatives from IRETI worked with several industry representatives and companies in the development of the research program. Commercially available "PFI Premium Standard" wood pellets were chosen as the test fuel. The pellet burning stove used in the study was provided by one of the companies. EPA Method-5G and 28 were followed when deciding which equipment and procedures we would use for our tests as well as the available data analysis calculations and reporting methods.

Conclusions: We were able to equip and develop the lab and produce standard operating procedures to complete the two-hour test burns which included collection

and recording of all the data required by the EPA methods. Our process established consistent burn rates (2.04, 2.11, 2.15 kg/hr.), but the PM samples (4.83, 3.57, 2.44 g/hr) did not seem to follow that consistency. The PM emissions, higher than expected, measured at a weighted average of 4.64 g/hr, falling just outside of the EPA's PM emissions guidelines of a weighted average of 4.5 g/hr. This opened the door to further study the intricacies of wood combustion and the operation of not only the pellet stove, but the effects of the fuel quality, equipment and sensor calibration, and the proper repeatable operation of the emissions equipment.

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Method_5G_PROC-SHEET
Method_28_CALIB-SHEET
Method_28_PROC-SHEET
PM Analysis Data Sheet_5G3
Sampling Data Sheet_5G3

LAB_STARTUP-SHEET_DUAL_5G3
American PM
American GASES
American Temps

Chapter 1: Introduction

Chapter 1.1: Problem Statement

As a member of newly established IRETI (International Renewable Energy Technology Institute) and a graduate student focusing on combustion emissions testing I was asked to develop an EPA certifiable emissions testing lab to be housed in Minnesota State University, Mankato's brand-new Center of Renewable Energy (CORE) lab. IRETI would be the lab where leading renewable energy technology from all over the world could be tested. At the time of testing, Minnesota's "2025 Energy Action Plan" was being worked through legislation, and one of its goals for the state was to utilize 25% renewable resources for energy production by year 2025. At IRETI we joined this initiative by exploring different methods of offsetting our dependability of non-renewable energy sources. At the time, the EPA (Environmental Protection Agency) had not specified emissions performance standards for pellet burning stoves. Instead they were lumped in with cordwood stoves. There were talks that the EPA had begun developing a testing method for wood pellet-fuel burning heating stoves, so at IRETI it was decided this was the perfect opportunity to get ahead of the curve in the field of renewable resources.

IRETI's decision to pursue this baseline study was guided by the concurrent "2025 Energy Action Plan" and the EPA's pellet stove testing method development. Wood pellet fuel, a renewable resource, and the technology developed to utilize it for residential heating should be further studied to examine how together they both stand up to newly developed EPA emissions testing methods. This will establish a benchmark

for American technology, thus guiding IRETI's efforts of introducing foreign technology to help MN reach the goals set for MN2025.

At the time of testing, there were various American pellet fueled heating stove manufacturers offering their products for sale in the US. These manufacturers would soon find themselves in need of EPA certification testing. The problem they were to deal with: can their product pass the soon-to-be developed EPA tests and performance standards? The IRETI team also had questions; can the equipment in the IRETI lab be used to perform these tests? Will the current testing technology and equipment meet future EPA testing requirements? Without EPA certification of their technology American pellet-fuel stove manufacturers could not continue to offer their products to the American marketplace. Pellet fuel is a renewable source of heat energy. If the IRETI lab could help manufacturers of these technologies extract the most energy out of the fuel without increasing pollution, the lab could help MN achieve GOAL 2025 by offsetting the use of non-renewable energy to heat residential homes. (MNDOC).

RENEWABLE ENERGY STANDARD (RES)

2007 Minn. Stat. 216B.1691 requires that the state's electric utilities obtain the following percentages of energy from renewables by the following dates:

Year	utilities	Xcel
2010	7% (goal)	15% req.
2012	12% req.	18% req.
2016	17% req.	25% req.
2020	20% req.	30% req.
2025	25% req.	30% req.

Total 27% renewable electricity by 2025

Status

All electric utilities are on track to meet 2012 goals.
(https://www.revisor.leg.state.mn.us/statutes/?id=216B.1691)

ENERGY POLICY GOALS

2007 Minn. Statute 216C.05 Subd. 2, states it is the energy policy of the state of Minnesota that:

- (1) the per capita use of fossil fuel as an energy input be reduced by 15 percent by the year 2015, through increased reliance on energy efficiency and renewable energy alternatives; and

- (2) 25 percent of the total energy used in the state be derived from renewable energy resources by the year 2025.
(https://www.revisor.leg.state.mn.us/statutes/?id=216C.05)

Table 1: Showing the MNDOC Renewable Energy Standard.

If the IRETI lab could produce certifiable baseline results for the American Technology, IRETI could move forward with comparing the results of stoves manufactured in the United States with those of European countries. Manufacturers in Europe have been developing pellet technology that abides by tougher emissions regulations. Europeans have been utilizing and developing pellet fuel technology for much longer to reduce pollution and their dependency on non-renewable energy.

Chapter 1.2: Method

The premium wood pellets selected for this study were certified by the PFI (Pellet Fuel Industry) standards program (PFI 1) to meet the standards adopted by the EPA. Commercially available wood pellets were chosen as the test fuel. Representatives from IRETI worked with several industry representatives and companies in the development of the research program. The pellet burning stove used in the study was provided by one of the companies. EPA methods 5G and 28 were followed when deciding which equipment and procedures we would use for our tests as well as the available data analysis calculations and reporting methods.

Chapter 1.3: Results

The standard test operation procedure and data recording sheets were developed and completed while reviewing the testing standards. The physical test components, equipment, and test supplies required to support the instrumentation were sourced and set up for use. Connections for the sampling/measuring sensors and equipment were established. Data acquisition devices were configured to record data at the prescribed rates. With the procedures, equipment, data-logging and quality checks in place IRETI was able to perform and complete the preliminary wood burning pellet stove testing using the American stove following Methods 5G and 28. This was the start of our particulate matter emissions database and the groundwork for EPA certification.

Chapter 1.4: Conclusions

The PM (particulate matter EPA Method-5G) samples collected from the burnings with the American stove left us surprised. At first, we did not know what to expect. We were able to complete two-hour test burns which included collection and recording of all the data required by the EPA methods. Our process established consistent burn rates (**2.04**, 2.11, 2.15 kg/hr.), but the PM values (**4.83**, 3.57, 2.44 g/hr.) did not seem to follow that consistency. This opened the door to further study the intricacies of wood combustion and the operation of not only the pellet stove, but the effects of the fuel quality, equipment and sensor calibration, and the proper repeatable operation of the emissions equipment. The preliminary testing was only performed on EPA Method 28 burn rate "Category 4".

A general analysis of the data collected thus far shows the American technology pellet stove is not completely burning the fuel resulting in higher than expected PM emissions. Measured at a weighted average of 4.64 g/hr it falls just outside of the EPA's emissions guidelines of PM emissions of a weighted average of 4.5 g/hr.

This baseline PM emissions data 4.64g/hr converted to the Nordic units of 2.36 g/kg. When compared to the Nordic guideline of 2g/kg for wood burning stoves, was evidence that the European technology was worth looking into. This was evidence that IRETI was moving in the right direction!

Chapter 2: Literature Review

Chapter 2.1: Introduction to Literature Review & Focus

This thesis project was based on testing wood pellet stove emissions. Applicable government standards and peer reviewed articles were reviewed and synthesized to develop laboratory procedures used to conduct and gather data on the emissions-based performance of wood pellet stoves. Information on the following was gathered:

- Technical information on the use and standardization of wood pellet fuels

- The operation of wood pellet fuel burning stoves

- Current testing methods for wood burning stoves

- Laboratory equipment used to measure exhaust emissions based on the EPA requirement to establish burn-rate and measure particulate matter emissions.

The focus of this study was to develop the entire emissions testing process to start the development of a database of pellet stove emissions at IRETI. A pellet stove manufactured in the United States was used to develop the procedures and to measure the performance following existing EPA emissions testing methods. Baseline testing was first step for IRETI at Minnesota State, Mankato in the development of a laboratory that would meet EPA certification requirements. This capability would help MN reach the goals set for MN2025 and open the doors to new technology and development.

Chapter 2.2: Wood Pellet Fuels and Why

As far back as human history is recorded, wood has been used as a renewable source of heat energy. The most common form of firewood, cordwood, is split into manageable pieces, which could be purchased off the side of the road, to be stacked in cords awaiting to be burned in an open fire or a furnace. Compressed wood pellet fuels are a relatively new form of wood fuel, when compared to cordwood. First tried in the 1930's and then re-introduced in the 1970's when the first pellet stove was invented in Washington State by, Dr. Jerry Whitfield (Pahl). The push for new wood heating technology came during the "Oil Embargo" in the 1970's. People sought out alternative fuel sources aside from fossil fuels to solve an economic crisis. (Pahl). As in the 1970's there is a renewed interest in alternative fuels. However, it is due to an environmental crisis caused by a dependency on non-renewable energy (MNDOC). With the health of our environment at stake, many again look to back wood. This statement made in the Wood Pellet Heating Guidebook prepared for the Massachusetts Division of Energy Resources:

"Wood fuels are often referred to as "carbon neutral" This refers to the natural carbon cycle where CO_2 emitted when wood is burned continues to be a part of the overall flux of carbon, while burning fossil fuels releases *new* carbon to the atmosphere that had been locked away underground. Trees capture and store (sequester) carbon. Although the carbon is released when the wood is burned, if harvested and burned at the rate it grows in the forest, no net carbon is released. Thus, burning fossil fuels for space heating increases the net amount of carbon in the atmosphere, while burning wood does not. (DOER)"

The unique characteristics that make wood pellet fuel a better option than split logs are

that it is dry, dense, clean, standard-sized and of predictable performance (PSFS). Its rise

in popularity as a viable source of clean, renewable heat energy has "fired up" the

development of new technology, moved the Federal government to begin including

pellet stoves in their legislation and incentives, therefore it landed right on IRETI's plate.

This was found evident in the popular mechanics article titled, Is Wood the Best

Renewable Fuel for Heating? (Ward)

"A $1500 federal tax credit for high-efficiency wood and pellet stoves—part of the
American Recovery and Reinvestment Act of 2009—expires at the end of 2010. But at
least two pending bills propose to expand and increase the credit up to $6000 to
subsidize the purchase of stoves, biomass boilers and furnaces. Congress is pushing the
passage of its Homestar legislation, a $6 billion incentive program to encourage
residential energy efficiency, which could spur adoption of wood stoves and other
biomass heat sources." (Ward)

The Minnesota Forest Resource Report from 2010 showed that 53% of Minnesota's

sustainable timber yield was being used for industry and fuel use (MNFOREST).

Therefore, there is still room for sustainable growth when considering utilizing this

renewable "carbon neutral" fuel resource.

The Minnesota timber industry can be described as a significantly stocked resource.

However, the market is underutilized. According to Minnesota's 2025 Action Report, the

timber industry needs to be stimulated by new technology and an increase in

investments to make bringing this resource to market a lucrative endeavor to the

landowners. (Action)

The North Eastern United States has used wood as a source of renewable heat energy to offset and reduce their dependability on heating oil. Much can be learned from their experiences. The shift was mentioned in the 2012 article by National Geographic titled High Fuel Costs Spark Increased Use of Wood for Home Heating.

"More than 20 percent of New England households that use heating oil also use wood as a source of heat, said U.S. Energy Information Administration (EIA) analyst Chip Berry. That number is about twice the national rate. New England happens to be the region of the United States that is most dependent on heating oil, which is now by far the most expensive home heating option." (NATGEO)

Chapter 2.3: Classification of Wood Pellet Fuel

When compared to split wood, wood pellets are consistent in size, more energy dense, have strict low moisture content specifications and are graded on % ash content. The consistent size, higher energy density and lower moisture content translate into less transportation costs. In addition, the characteristics described above produce repeatable and measurable results which allow them to be used reliably in automated systems (Ward).

"Pellet fuel offers many advantages over cordwood: It has a moisture content of less than 8 percent, compared to 20 percent or more for seasoned wood and 50 to 60 percent for unseasoned wood. (Btu's are wasted in vaporizing moisture.) Dry pellet fuel is inert and nontoxic. It has an infinite shelf life, and it doesn't harbor bacteria, fungus, bugs or mice. Its energy density rivals that of coal, but it doesn't produce as much ash as either coal or wood. A high surface-to-volume ratio makes pellets combust more like kindling than logs. The pellets' standard size means they can be fed automatically by the

turn of an auger. Once pellets enter the stove's fire pot, airflow is metered to maintain a steady burn. The hopper usually must be refilled daily. Efficient combustion produces particulate emissions levels of around 1 to 3 grams per hour—comparable to oil or gas." (Ward for Popular Mechanics)

Wood pellets can be compared to gasoline (a consistent and standardized fuel) to power a vehicle by carefully regulating the air/fuel mixture to extract the most energy and reduce emissions. The standardized characteristics of pellet fuel can be used to help design the most efficient process for energy extraction and emissions control. The images below showed pellet fuel and the "PFI Quality Mark" listing the grading requirements.

Image 1: Showing the PFI Premium Wood Pellets (DOER).

Image 2: Showing the PFI "Quality Mark" which lists the grade requirements (PFI).

Chapter 2.4: Pyrolysis and Combustion of wood.

The overall process of pyrolysis of wood begins with the removal of all moisture from the solid woody material. In the absence of moisture, the chemical bonds made up of Hydrogen, Carbon, and Oxygen break down. This decomposition requires heat to continue occurring until the bonds begin to react with oxygen and other gases. The highly volatile gases that are formed will reach their flash point and create a visible flame, which is also an exothermic reaction. As the reaction produces more heat, it breaks down more bonds that will react with oxygen to create more heat. This will basically occur until the fuel is all burned up or there isn't enough oxygen or heat to support the reactions. In the image below, there is a temperature gradient showing the highest temperature that can rapidly spike to 1500°C which is just about the melting point of steel.
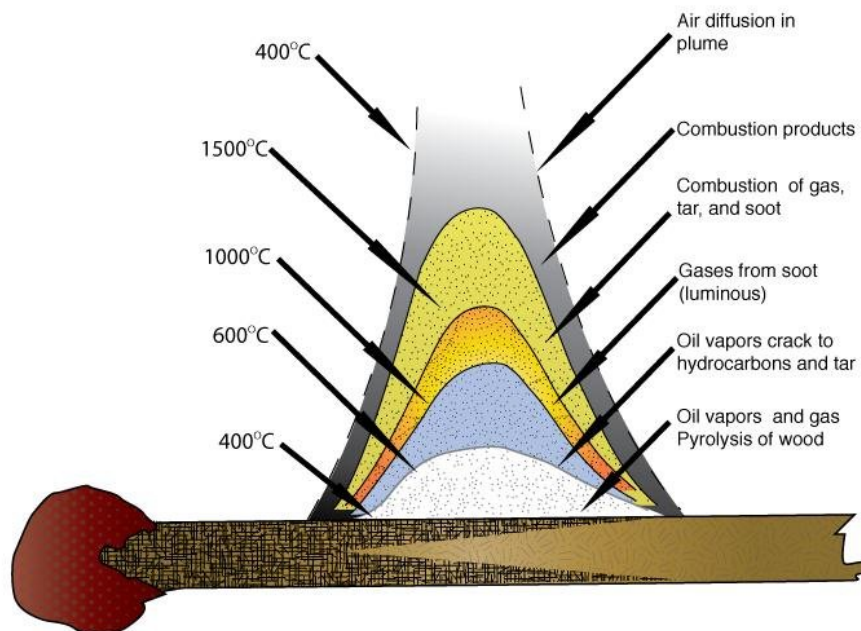
Image 3: Pyrolysis, gasification and combustion in a burning matchstick (Tom Reed)

Chapter 2.5: Thermocouple Sampler

For this test, a thermocouple sampler was to be used to measure the 11 temperatures as stated by the EPA testing guidelines Method-28 and Method 5G. Thermocouples used were the k- type 24 AWG S.S. Shielded, k- type 20 AWG- Fiberglass, and k- type 20 AWG- Teflon. The thermocouples were used to measure temperatures of the multiple surfaces of the pellet stove as well as the PM sampling train (dilution tunnel and filter holders).
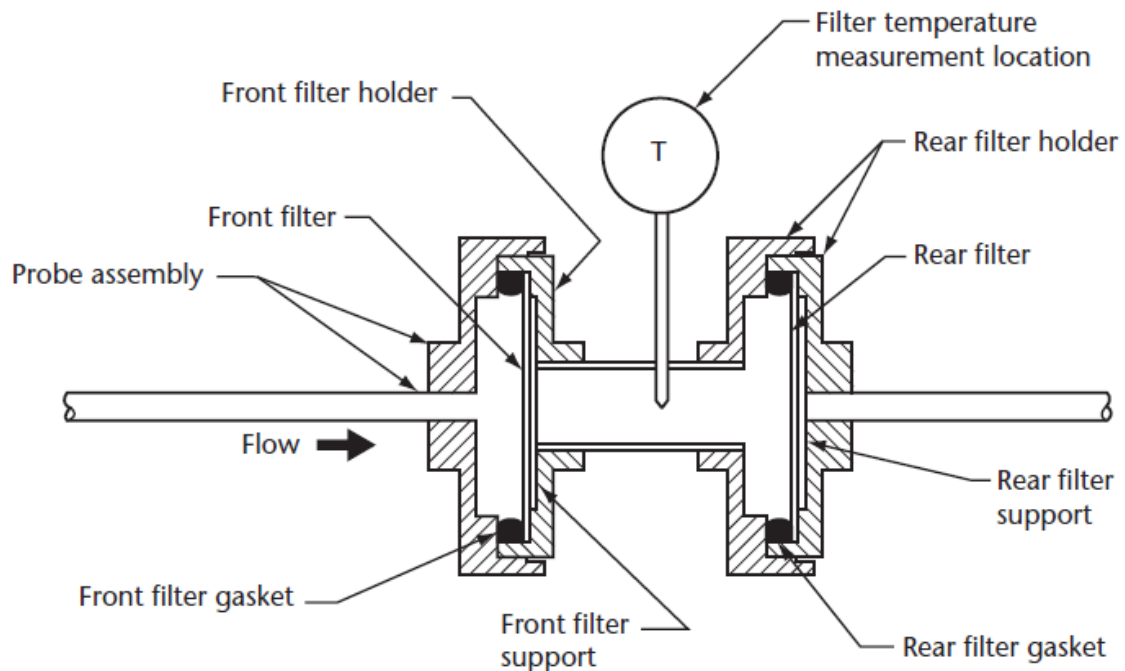
Image 4: Diagram of the PM filter sample holder showing the location of the thermocouple (EPA5G)

The multiple signals needed to be sampled every 10 minutes according to EPA Method 28- Sections 6.4.2 and 8.12.2 (EPA M-28) Calibration required to be done "before the first certification test and semiannually thereafter" (EPA M-28.10.3). Of the 12 thermocouples utilized for sampling, 8 of them were made on site. After welding the ends and connecting them to the DAQ, they were calibrated using a hotplate filled with deionized water and taking readings from the NI-Daq program to condition each signal. After the calibration, they were all ready to be placed throughout the stove and the one could be placed on the ambient temp stand. All temperature data was measured with at National Instruments NI-DAQ interfaced with a computer. Each thermocouple was assigned to a specific channel on the unit to keep track of individual data items.
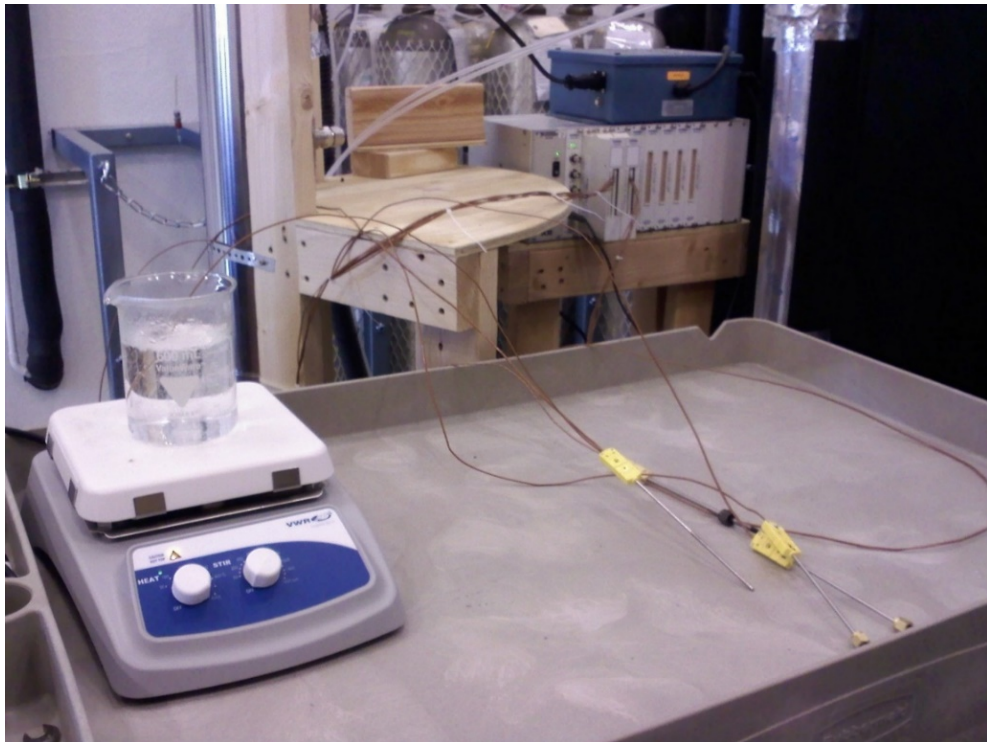
Image 5: Showing the NI-DAQ and the thermo couples being calibrated using a hot plate and deionized water.

Chapter 2.6: PM Sampling Train Application and Operation

EPA Method-28 and 5G both analyze PM emissions. Method-28 was directed at the overall certification and auditing of wood heaters and what to do with the PM data once it was recorded. Method-5G clearly defined how to determine PM emissions utilizing a dilution tunnel and dual filter dry sampling train. Method-5G was used because we had the room in the lab and the ability to set up a dilution tunnel in the lab.

Method-28 requires the use of a more complicated sample stream necessary to determine the percentage of the total exhaust gas flow from the stove. This is necessary to calculate the total amount of PM emitted from the stove when only a small sample of exhaust is sampled. The system requires an impinger bath set-up to remove the water from the test sample. This is necessary because you need to determine the dry exhaust flow rate. A byproduct of combustion is water and impingers, or bubblers, are glass tubes that are held in a water and ice bath container. The hot exhaust stream travels through the impingers and as it does it is cooled. As it cools the water suspended in the air condenses and drops out of the exhaust. At the end of the stream there is little water left in the sample. A picture of the impinger set-up is below.

Image 6: PM sampling train Impinger sample conditioner system.
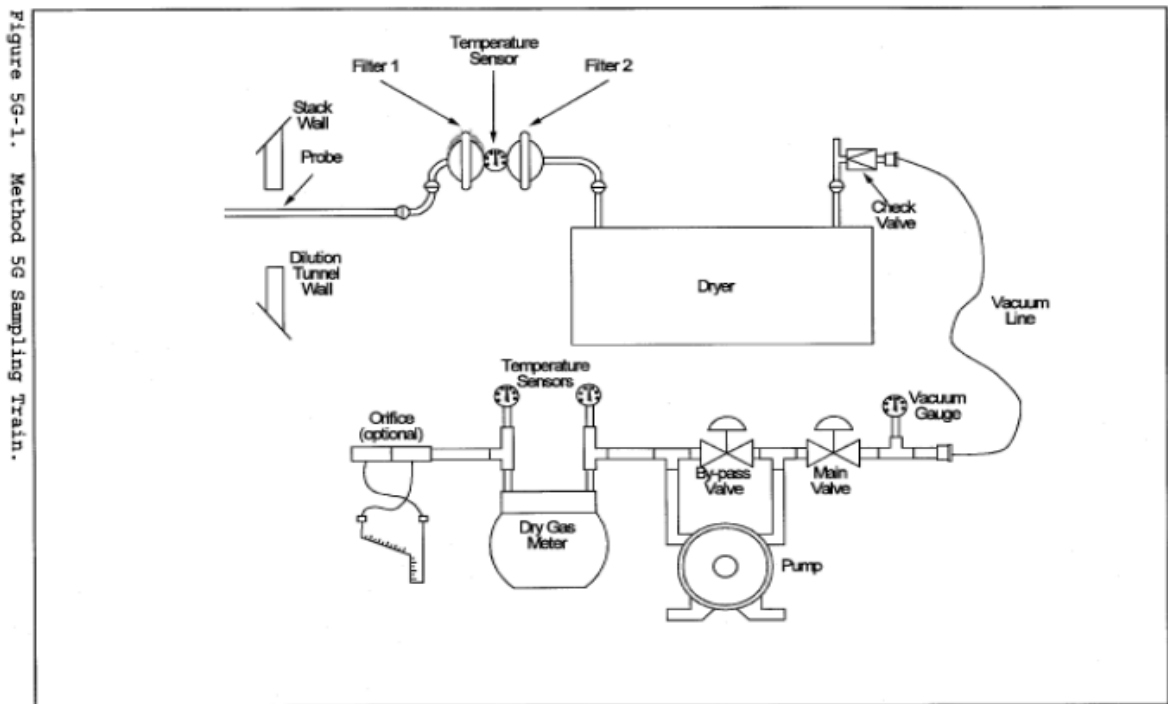
Image__: Single dual-filter dry gas analyzer diagram (EPA5G).

EPA Method-5G was chosen as the sampling procedure because the sample is taken from a simple dilution tunnel. The dilution tunnel was a device that mixed clean air at a known rate with the exhaust emissions gases that exited out of the flue. This method allowed the collection of a cooler sample without the need to pull exhaust gases through an ice bath impinger. The relatively cool sampling temps resulted in less risk of burning the filters. The method allowed sampling by a simpler dry gas analyzer.
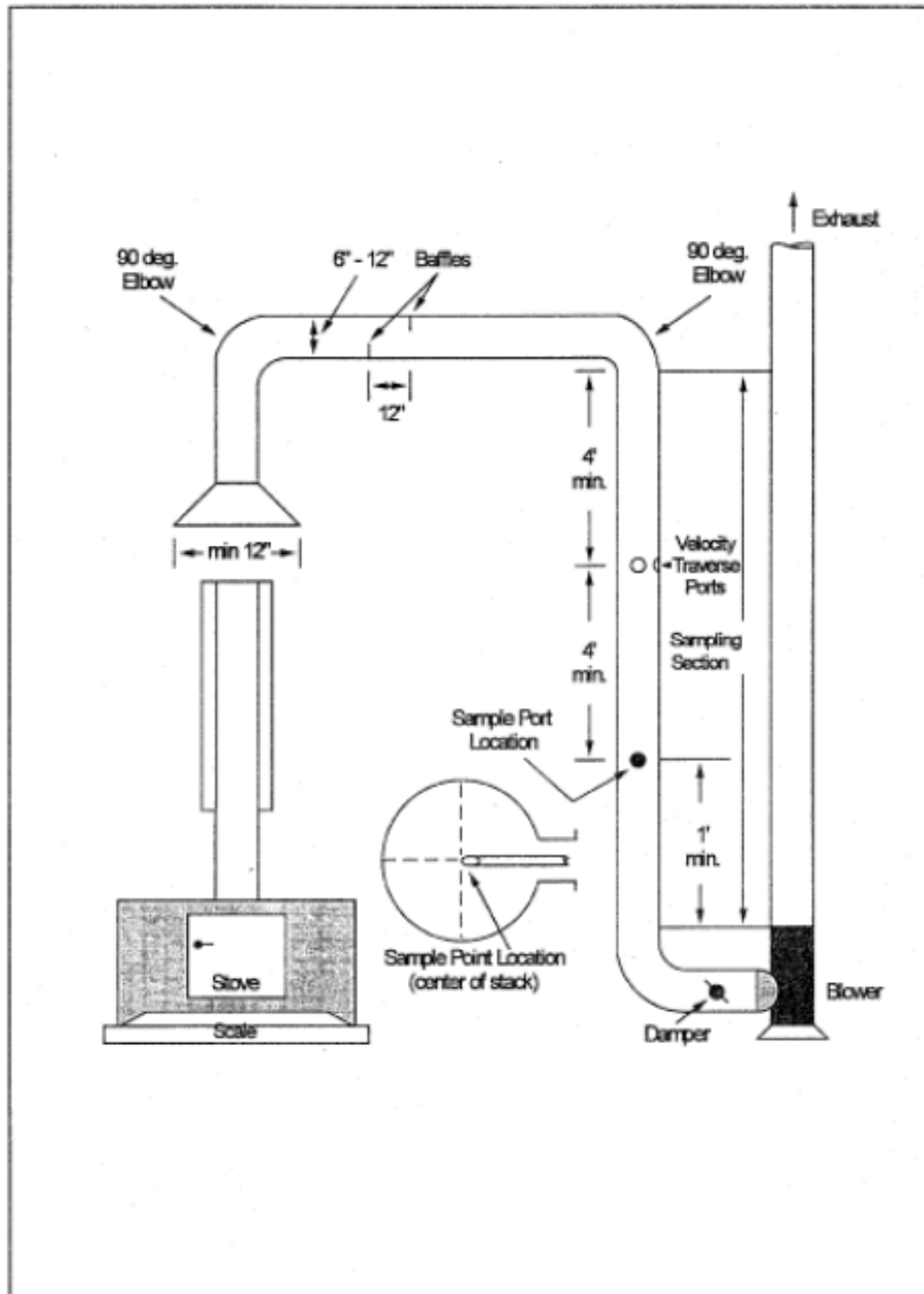
Figure 5G-2. Suggested Construction Details of the Dilution Tunnel.

Image 8: Showing the suggested construction detail of the Method-5G Dilution Tunnel (EPA5G)

For Method-28 a burn rate was determined for the stove based on weight of fuel burned and time elapsed. Method-5G detailed the PM sampling train that draws from a dilution tunnel. In the tunnel we measured various parameters which provided the known flow rate vs sampling rate, so we knew how much PM we captured in the filters over how long of a period at a set flow rate. (EPA M-5G) The methods also described calibration, as well as leak checking the sample train.

Chapter 2.7: Scale Accuracy and Operation

The test procedure required the use of two scales. One was used to determine and monitor the weight of the stove during operation as explained in <u>EPA Method-28.3.2-Weight Monitoring</u>. It was recommended to have a high capacity while being able to output a division size of 0.05kg. The reason for such a large scale was to be able to measure the entire stove including the pellet fuel in the hopper to monitor the weight of fuel consumption to be used for calculation of the burn rate.

Image 9: The 310lb stove was shown her resting upon the scale. The stove boasted a 130lb hopper storage for pellet fuel.

The other scale was used to determine the weights of the desiccator-dried PM sampling

filter discs, holders, and probes before assembly and sampling, then post-sampling of all

the individual components, followed by a 24hr period in the desiccator and a final

weighing as stated by the EPA Method-5G.3.2 Weight Monitoring. This scale had a 60kg

capacity while being able to output a division size of .0001g. The accuracy of the weights

measured in 5G are used to determine the rate of particulate emissions. Ensuring these

measurements were repeatable and accurate is the focus of Method 5G.

Image 10: Showing the analytical scale with covering to reduce draft and moisture
affecting weight of PM sample filter.

Chapter 2.8: Data Analysis and Reporting

Something had to be done with all the data being recording; How would it be analyzed for reporting? For both Method-28 and 5G, Section 12 Data Analysis and Calculation was reserved to include the concise methods for analyzing and calculating the data. The procedures also include prescribed methods for reporting the results as a document.

The XC-260 Source Sampling Console is comprised of plumbing, electrical and thermocouple subsystems that work together to give appropriate control and feedback to the operator.

PLUMBING Subsystem: (X2)

Optional Digital Encoder

00000

Insert Thermocouple

Fine Valve

SK-25 No. 000000001

0000 000

Diaphram Pump

Coarse Valve

Rotometer

DGM-SK-25

Quick Connect
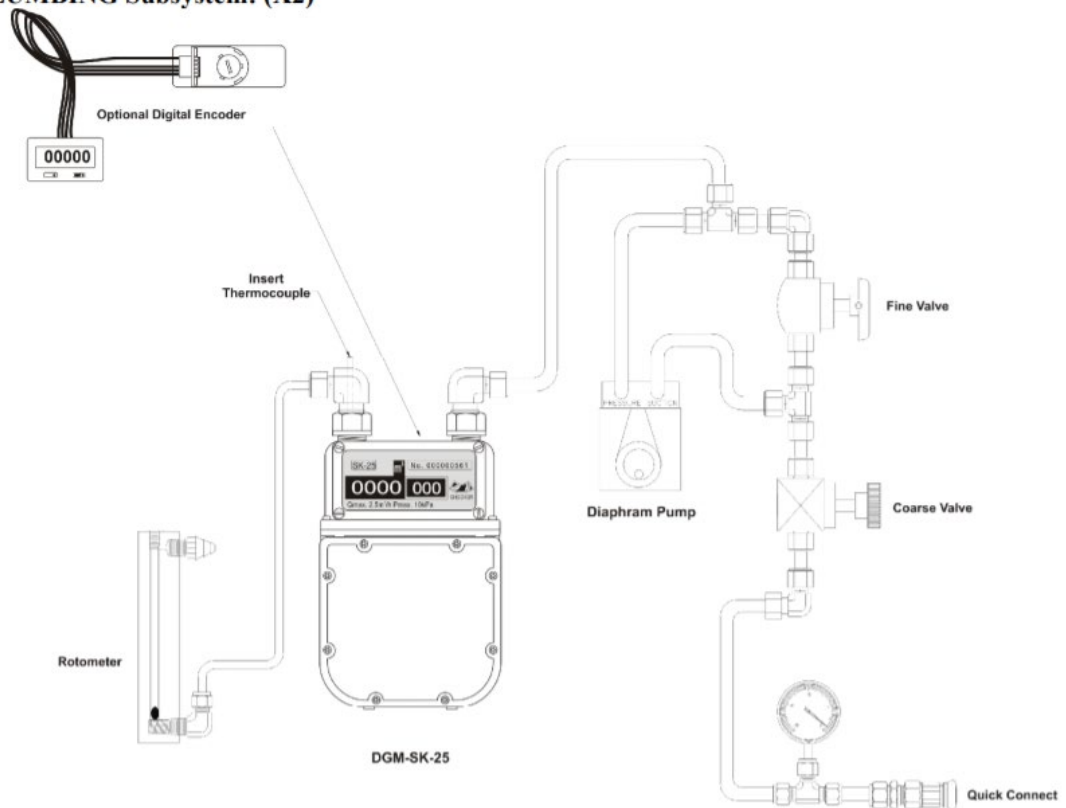
Image 11: Apex Dry gas analyzer. Only showing one of the two dry gas meters.

Chapter 3: Methodology

Chapter 3.1: Introduction

Major focus of this study was to prepare the lab to conduct EPA wood burning stove emissions testing. The specific testing procedures developed were to be used to determine the current state of American pellet fuel, pellet stove technology and how the EPA guidelines work for pellet stove testing.

When designing home heating systems, the fuel to be used must be a consideration in the development of the system. The secondary concern is meeting EPA emissions standards governing how the device will be tested and how it must perform. Thinking globally with the environment in mind, there was also the concern of using the fuel that resulted in being the most environmentally friendly.

The methodology covered the selection of the pellet fuel, the independent lab testing proving the manufacturers claims of the fuel, the selection of testing equipment based on the EPA guidelines, the development of the testing facility, and the standard operation procedures for this specific type of test.

Chapter 3.2: Test Fuel Selection and Testing

Test fuel selection was very important when performing emissions testing. There must have been reasoning behind every choice that was made, including the selection of test fuel. Sampling had to be representative of the fuel that could be used by consumers. As a result, the following information from the Pellet Fuels Institute (PFI) Standard Specifications for Residential/Commercial Densified Fuel. The document outlined the development of the standardized testing procedure for identifying various grades of wood pellet fuels (PFI 11). Determination of these properties was mandatory for determining fuel quality grade (PFI 11). After reviewing this document, it was determined that we wood pellets locally distributed by Menards. The pellets they sold had been testing tested using the PFI standards and graded as "PFI Premium" wood pellet fuel (Image 12). To verify the fuel met PFI standards, MVTL (Minnesota Valley Testing Laboratory) tested samples of the fuel to properly acquire information required to calculate data for EPA reporting. The results are below (Image 13).

TABLE 1 PFI Fuel Grade Requirements

Fuel Property	Residential/Commercial Densified Fuel Standards See Notes 1 - 3		
	PFI Premium	PFI Standard	PFI Utility
Normative Information - Mandatory			
Bulk Density, lb./cubic foot	40.0 - 46.0	38.0 - 46.0	38.0 - 46.0
Diameter, inches	0.230 - 0.285	0.230 - 0.285	0.230 - 0.285
Diameter, mm	5.84 - 7.25	5.84 - 7.25	5.84 - 7.25
Pellet Durability Index	≥ 96.5	≥ 95.0	≥ 95.0
Fines, % (at the mill gate)	≤ 0.50	≤ 1.0	≤ 1.0
Inorganic Ash, %	≤ 1.0	≤ 2.0	≤ 6.0
Length, % greater than 1.50 inches	≤ 1.0	≤ 1.0	≤ 1.0
Moisture, %	≤ 8.0	≤ 10.0	≤ 10.0
Chloride, ppm	≤ 300	≤ 300	≤ 300
Heating Value	NA	NA	NA
Informative Only - Not Mandatory			
Ash Fusion	NA	NA	NA

Image 12: Pellet Fuel Grade Requirements. PFI Premium pellets were used in the study.

MVTL

MINNESOTA VALLEY TESTING LABORATORIES, INC.

1126 N. Front St. ~ New Ulm, MN 56073 ~ 800-782-3557 ~ Fax 507-359-2890
1411 S. 12th St. ~ Bismarck, ND 58502 ~ 800-279-6885 ~ Fax 701-258-9724
51 W. Lincoln Way ~ Nevada, IA 50201 ~ 800-362-0855 ~ Fax 515-382-3885

MEMBER
ACIL

MVTL guarantees the accuracy of the analysis done on the sample submitted for testing. It is not possible for MVTL to guarantee that a test result obtained on a particular sample will be the same on any other sample unless all conditions affecting the sample are the same, including sampling by MVTL. As a mutual protection to clients, the public and ourselves, all reports are submitted as the confidential property of clients, and authorization for publication of statements, conclusions or extracts from or regarding our reports is reserved pending our written approval.

AN EQUAL OPPORTUNITY EMPLOYER

```
Sample Number: 11-F123                        Report Date:  4/26/11

   Sergio Gamarra                             Work Order #: 81-393
   IRETI                                      P.O. #: S. Gamarra
   MNSU - Mankato 109 Center of Renewable Energy   Date Collected:  4/11/11 16:18
   Mankato  MN  56001
                                              Date Received:  4/21/11


Sample Description: Wood
Sample Site: Pellet 1/4"

            * PROXIMATE *                                  * ULTIMATE *
ANALYTE            AS RECEIVED    DRY BASIS     ANALYTE            AS RECEIVED    DRY BASIS
------------------------------------------     ------------------------------------------------
Total Moisture    6.08   wt. %                 Total Moisture    6.08   wt. %
Ash               1.11   wt. %    1.18   wt. % Ash               1.11   wt. %    1.18   wt. %
Volatile Matter   77.01  wt. %    82.00  wt. % Carbon            46.78  wt. %    49.81  wt. %
Fixed Carbon      15.80  wt. %    16.82  wt. % Hydrogen          6.14   wt. %    5.81   wt. %
BTU/lb            7895   BTU/lb   8406   BTU/lb Nitrogen         < 0.2  wt. %    < 0.21 wt. %
Total Sulfur      0.05   wt. %    0.05   wt. % Total Sulfur      0.05   wt. %    0.05   wt. %
                                               Oxygen by Difference  45.72  wt. %  42.93  wt. %

            * SULFUR FORMS *                                * ASH FUSION *
ANALYTE            AS RECEIVED    DRY BASIS     ANALYTE            REDUCING       OXIDIZING
------------------------------------------     ------------------------------------------------
Total Sulfur      0.05   wt. %    0.05   wt. %

        * MINERAL ANALYSIS OF ASH *                        * MISCELLANEOUS *
ANALYTE                           DRY BASIS     ANALYTE            AS RECEIVED    DRY BASIS
------------------------------------------     ------------------------------------------------
```

Image 13: Shows the results of the audit MVTL performed on wood fuel to ensure with the fuel met the standards and we had the required data for use in the Method-28 calculations.

Chapter 3.3: Pellet Fuel Burning Stove Selection and Testing

The test consisted of one American pellet stove. The American stove was donated by a local manufacturer, Hestia. The Hestia HHP2 was a production unit. It was sent out for third-party testing and passed the EPA Method-28 and 5G PM emissions test. We were provided the test results but were asked to refrain from reproducing them or including them in our study.

Preparing the wood pellet stove for testing was outlined in EPA Method-28. It specified the placement on the scale, the location of the thermocouples, what data we needed to gather from the stove, which type of flue pipe needed based on the listed output. The flue pipe had to be placed a specific from the opening of the hood entrance of the dilution tunnel.

The EPA Methods require each lab to develop their own procedures to reflect the operation of the equipment in each lab. The standard procedure sheets developed for the IRETI lab were prepared to seamlessly guide the technician through daily maintenance, equipment start-up, setup, calibration, and operation. The sheets allowed the technician to clearly identify important characteristics pertaining to the interaction of fuel and stove that needed to be recorded. Information gathered from EPA Method-28 combined with custom tailored standard operating sheets guide the technician through each step of the process. Specific steps covered in the procedures include:

- Turning on and calibrating the sampling equipment

- Taking measurements of the lab environmental conditions used in calculation of correction factors

- Preparing the stove for testing

- Starting the test

- Starting the sampling devices

- Recording data

- Ending the test

Chapter 3.4: Emissions Data Collection

The **Study of American Wood Pellet Stove Emissions** was based on collecting data on pellet fuel emissions of an American designed, manufactured, and certified stove. EPA methods, ASTM standards and peer reviewed articles on similar studies had been selected to assist in the literature review and overall study. EPA testing required the selection of a test fuel representative of what consumers would use, knowing which emissions measurement equipment to acquire and implement, adopting the most applicable pellet fuel burning stove testing procedures, and following statistical analysis modeling for data organization and comparison.

The project began with the development of a sound testing procedure. This test procedure covered all the steps in performing an emissions test. The test structure very closely followed the testing procedure recommended by the EPA in their test Method 28- *Certification and Auditing of Wood Heaters*. (EPA28).

Method-28 Section 8.5 Wood Heater Temperature Monitors outlined the locations of where all the thermocouples were installed around the surface of the pellet stove to record the various surface temperatures for each test (EPA28). The signals were controlled and monitored by our National Instruments SCXI 1303 thermocouple sampler and signal conditioner.

The burn-rate data recording was prescribed by EPA Method-28.3.2- Weight Monitoring and was accomplished by mounting the furnace on a digital floor scale that had a 0.05kg resolution. Before the start of the test, additional fuel was added to the hopper to ensure there was enough fuel for the complete test. Once the hopper was full, the test could begin. The scaled was tared and weight was recorded as diminishing from "0" every 10 minutes. The image below showed the HHP2 resting on top of the Mettler Toledo 500kg capacity platform scale.

Image 14: The Hestia HHP2 resting on top of the Mettler-Toledo IND-560 platform scale.

Particulate matter (PM) in exhaust gas emissions was a very important part of the whole picture. Particulate was of great concern because of its direct effects on air quality and human respiratory health, therefore emissions testing required collection of PM data (EPA Method 5G).

Automation was not feasible for collecting PM samples. Instead PM sample collection had to be performed as described in Method-5G. Sampling from the dilution tunnel was pulled in through a probe located inside of the dilution tunnel. This sample was directed over two filters to capture fine PM particles. At this point the samples collected were comprised of both PM and water. Each filter was placed in a desiccant chamber after being removed from the filter holder. After staying in the desiccant chamber for at least

24-hours they were weighed to record the quantity of PM captured by the filter. EPA

method 5G - _Determination of Particulate Matter Emissions from Stationary Sources_

(Dilution Tunnel Sampling Location) was carefully followed for selecting the proper

sampling and measuring equipment along with operating procedures.

Chapter 3.4.1: Exhaust Emissions Measurement Method-28 and 5G

EPA Method-28 and 5G guided the exhaust emissions measurement. They specified

stove operating parameters that required collection procedures to follow when

collecting and recording them as described in EPA Method 28- *Certification and Auditing*

of Wood Heaters. Particulate matter was the primary focus of EPA emissions testing and

reporting. EPA testing Method 28 referred to Method-5G for further detail regarding

Particulate Matter (PM) collection when using a dilution tunnel. PM collection

guidelines and measurement equipment minimum requirements were defined in

Method 5G: *Particulate Equipment*.

The EPA methods guided the decision making for the arrangement of the lab,

construction of the dilution tunnel, selecting the appropriate gas sampling equipment,

fabricating filter holders, quantifying results, and most importantly provided standards

for calibration and quality control.

EPA Method-5G Section 16.2 Dual Sampling Trains was used to validate the decision to

utilize two dual sampling trains. The reasoning behind the choice was the ability to

weigh PM samples in the same room, option to remove the need to weigh in a petri dish

and remove the need to utilize reagents for cleaning the probes and storing and

measuring the reagents. Having chosen the two dual trains added the ability to compare

the two simultaneous samples. This method did add more data but removed the

complexity and chemical handling.

The PM sampling equipment and lab ambient condition measurement devices varied by manufacturers, but all had the accuracy defined by the EPA methods and support also existed when the time came for their calibration. Some of the components were made in-house, including the in-line desiccant sample drier setup and sample probe assembly with the 2" filter disc sample holders (image15). Some of the devices were more complex and required purchase as a complete unit, such as our APEX Instruments XC260 two dual train dry gas analyzer (image 22) and our National Instruments SCXI 1303 thermocouple sampler and signal conditioner.

The dilution tunnel was modeled after the EPA specifications with no variations (image 21), while (image 17) below showed some of the notes taken, overlaying figure 5G-2 from EPA Method-5G, when considering the fabrication of the dilution tunnel. After purchasing the materials, it was erected in the lab. A wooden platform and support structure were built to support the tunnel and the sample probes. Finally, the dilution tunnel was connected to the exhaust plumbing to evacuate the smoke from the lab (image 19).

The PM sampling was performed using two dual 2" filter sampling trains that had the specified stainless-steel probes inserted into the dilution tunnel at 90-degrees of each other. They were connected to the silica filled gas driers before connecting to the APEX XC260 dry gas analyzer. All plumbing was PTFE tubing with stainless steel fittings (image 22). The in-line driers prevented moisture from reaching the dry-gas meters.

To test for ambient conditions the Dry-bulb and Wet-bulb temperatures were measured using a Bacharach sling-psychrometer and the values used to determine Relative Humidity. Air velocity flowing around the stove was measured using a Dwyer Vaneometer. The velocity during testing had to be less than 0.25m/sec. The flue pipe draft measurement was determined using a Dwyer Digital manometer. The proximity of the flue pipe was adjusted until the draft was less than 1.25mmH2O. The dry gas meter on the sampling train was used to measure the leakage results of the pre-test leakage test.

After the testing conditions were met and recorded the technician could move onto preparing the dual train sampling probes. This required utilizing supplies that were stored in the desiccator (image 20). The 2" filters, the holders, the probes and the sealing O-rings needed to be free of moisture before initial weighing. The Ohaus RD60LS scale which had a 60kg capacity while being able to output a division size of .0001g was used to weigh the components. This information was recorded on the PM sample analysis sheet and the sample trains were assembled and ready for insertion into the dilution tunnel.

After all the measurements and adjustments were completed the test was started. The rest of the sampling technology would be gathering data that would be used to calculate the performance and emissions of the wood pellet stove.

During testing, ongoing thermocouple sampling of various surfaces of the stove, flue gas, dilution tunnel, and sampling trains was recorded digitally every 10 minutes. The

diminishing weight of the stove with the fuel in its hopper was recorded manually every 10 minutes.

On the APEX dry gas meter, the important values to record every 10 minutes were:

- Gas meter volume for sample train A and B

- Vacuum for sample train A and B

- Gas Sample Temperatures at the dry gas meter (output by the APEX device)

- Flow rate from the manometers on the dry gas meter.

After the two-hour test, a post-test leak rate was established to ensure the samples were not affect by a sudden leak in the sample train. It was now time to end the computer sampling and remove the filter holders to move them to the desiccator for a 24-hour drying period. After at least 24-hours of drying, the samples were weighed, and the information entered in the remaining fields on our PM data analysis sheet. This concluded the entire sampling test.
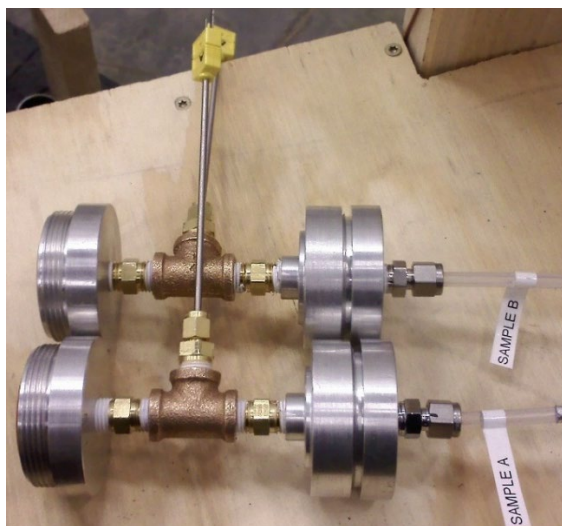
Image 15: Twin dual disc filter holders with Thermocouple temp measurement
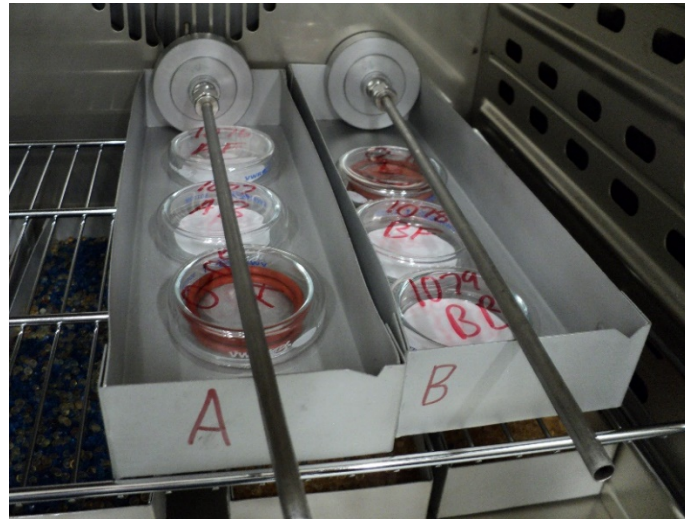
Image 16: Filter holder probes, O-rings, filters, drying out in desiccant oven. Labeled for measurement.
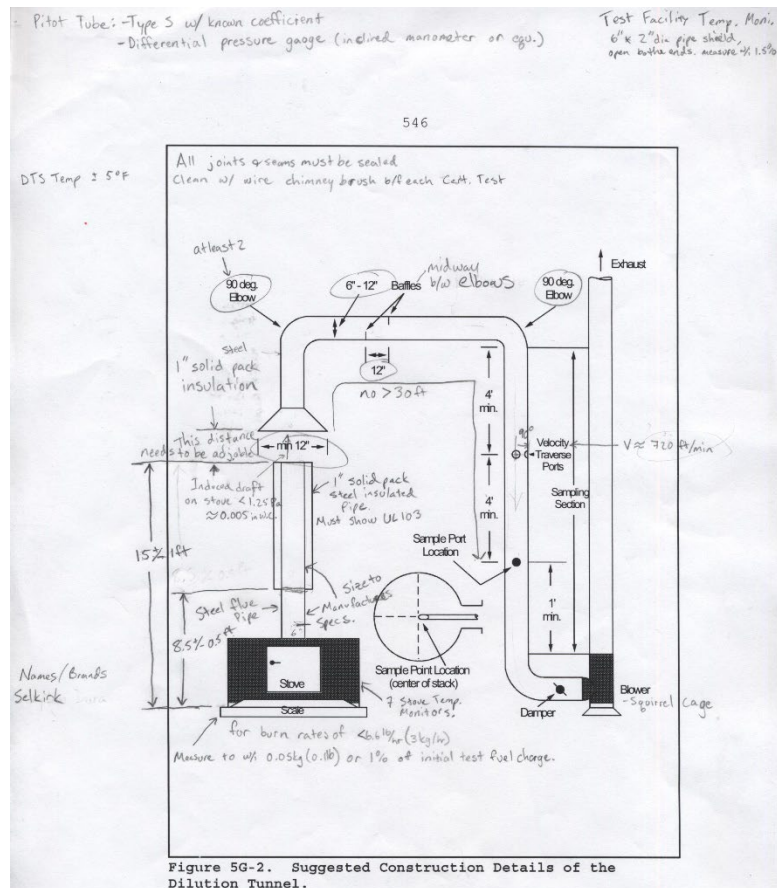
Image 17: Shown is the initial sketching and note taking of the dilution tunnel.

Image 18: Showing the analytical scale with covering to reduce draft and moisture affecting weight of PM sample filter.

Image 19: Showing early stages of entire Method-28 and 5G dilution tunnel and test setup.

Image 20: Showing the Method 5G PM sample train desiccator.
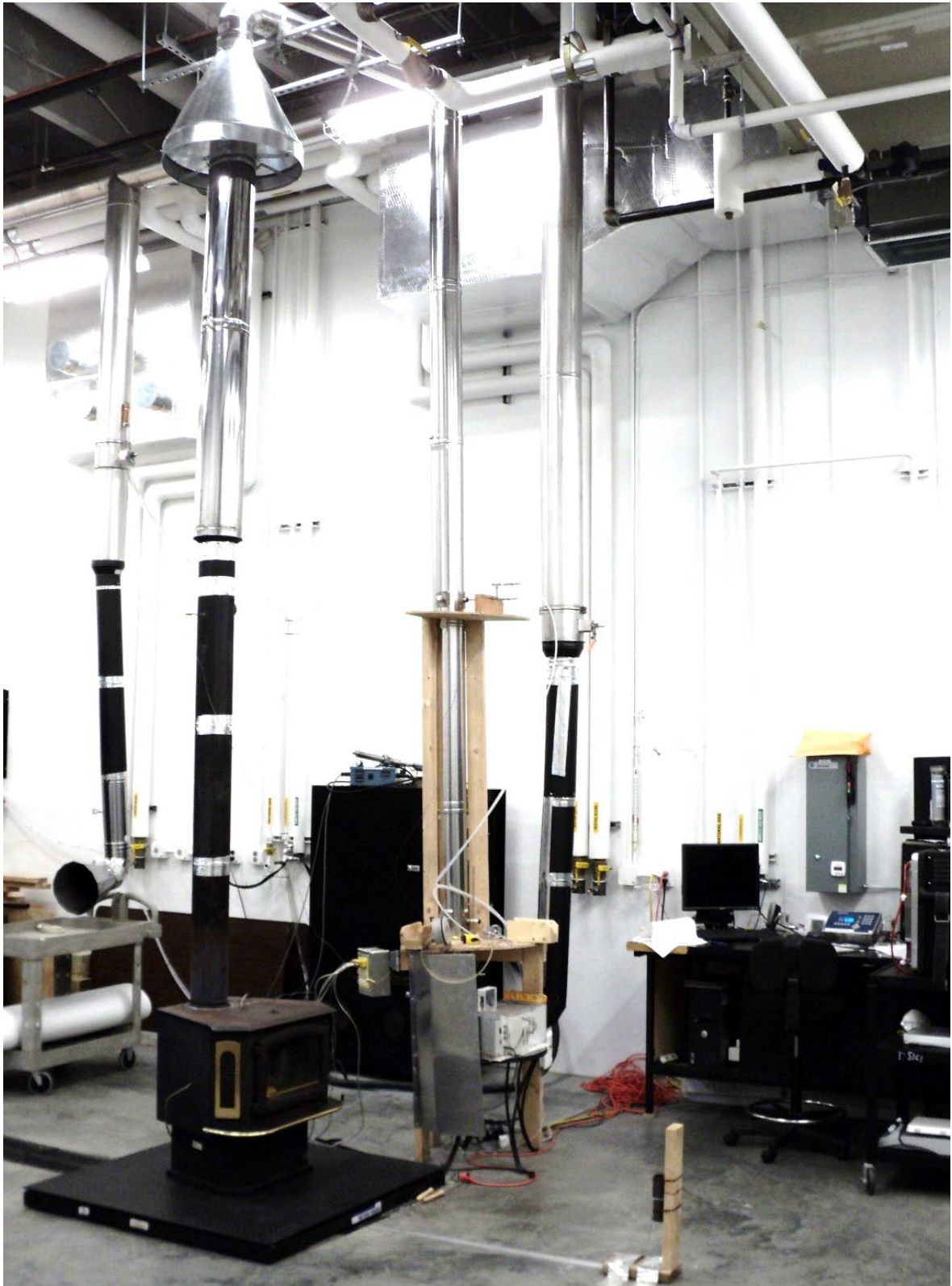
Image 21: Showing the entire Method-28 and 5G dilution tunnel and test setup.

Image 22: Showing the Method 5G APEX XC-260 dry-gas flow analyzer.

Chapter 3.4.2: Data recording sheets

Considering the various components of the emissions test that were all concurrently

producing data, standardized data collection sheets had to be prepared. Luckily most of

the temperature data was being handled by the datalogger. The remaining data had to

be measured, observed and collected by the technician. To reduce operational error,

procedure sheets were prepared that prompted the technician to perform the

measurement observation and offered a methodical location to manually record the

data.

The primary sheet (Appendix) used was the "IRETI CAI FTIR Setup and Operation

Procedure – Dual Test". It contained step by step instruction on preparing the

equipment for testing. Throughout the procedure there were blank spaced

accompanied by their relative unit of measure for the technician to write in the

observed data such as temperature, humidity, draft, air speed, start/stop times, and

stove weights for the length of the test every 10 minutes. Ultimately the data gathered

here was utilized in the calculations sheet.

The second sheet (Appendix) was the "Particulate Sampling Data Sheet_5G". It

contained the table of values that were being displayed by the Apex XC-260 dry gas

analyzer. This table of data was to be updated every 10-minutes for the duration of the

entire 2-hour burn test. "IRETI003P-SCFTEST Test Data" located in the

"IRETI_EPA_M28_Sample_Test_Name" calculations and final report sheet (Appendix).

The third sheet (Appendix) was the "PM Analysis Data Sheet – 5G". It contained the
table of values that needed to be recorded as the technician weighed the desiccated
components of the PM dual filter sample train pre-sampling. The procedure sheet would
remain idle during the burn test. After the sampling and the 24-hour desiccating period,
the technician weighed the desiccated components of the PM dual filter sample train
and record them. The data gathered on this sheet was then entered into "IRETI003P-
SCFTEST PARTICULATE" located in the "IRETI_EPA_M28_Sample_Test_Name"
calculations and final report sheet (Appendix).

Chapter 3.5: Testing levels and Quantity Determination

In the EPA methods there was no randomization required. All tests were performed

independent of each other. The emissions tests were all performed using the store

purchased PFI standard premium wood pellets, because they were approved for

household consumption. Shown below is a table of the tests performed and the

quantities of each. Keep in mind that Method-28 required one test per burn category.

Due to the exploratory nature and lack of stove testing experience, the tests were all

performed at the maximum burn rate category 4.

Table 1 – Particulate Emissions and Burn Rates

Run #	EPA Method 5G, 16 Ave. Emission Rate E_i (g/hr.)	EPA Method 28, 12.5 Burn Rate (Dry-kg/hr.)	EPA Method 28, 8.1.1 Burn Rate Category	EPA Method 5G, 16.2.5 Emissions per Sample Train (g)		
				A	B	% from Ave.
Run 1	2.4419	2.15	Category 4	0.0059	0.0056	2.76%
Run 2	3.5798	2.11	Category 4	0.0069	0.0072	2.41%
Run 3	NA	NA	NA	NA	NA	NA
Run 4	4.8319	2.04	Category 4	0.0107	0.0108	0.59%

Table 2: The results of our three complete tests.

Burn Category Based on Burn Rate

	Category 1	Category 2	Category 3	Category 4
kg/hr.	0.80	1.250	1.900	Maximum burn rate
lb./hr.	< 1.76	1.76 to 2.76	2.76 to 4.19	

Table 3: table to be used to determine burn Category.

Chapter 3.6: "Other Labs" Test Results

As part of the study, results produced by "Other labs" were made available for

comparison purposes. The results helped set up the data collection procedures and

provided verification that the stove was burning as expected and the application of the

EPA test methods was correct. As part of the agreement the results from the other labs

could not be included in this report.

Chapter 3.7: Statistical Analysis and Comparison Utilizing EPA Reporting Method.

The purpose of is the research was to develop a concise testing procedure to collect

exhaust emissions data of commercially available wood pellet fuels along with the

performance of the stove. EPA Method-28 required that the final test result be

calculated using a weighted average that considered the individual burn rate per test

and assigned a weighted value. This boiled the multiple tests into one figure while taking

outliers into account. The data for each burn was to be listed, but the weighted average

is the test grade assigned to the wood burning stove. The weighted average emissions

rate is what is used to determine if the tested stove meets the current wood pellet

standards.

Table 2 – Weighted Average Emissions Rate

Run #	EPA Method 28, 12.1 P_i	EPA Method 28, 12.1 K_i	EPA Method 28, 12.1 $K_i * E_i$	Weighted Average Emissions Rate EPA Method 28, 12.3
	0			
Run 4	0.919	0.926	4.4743394	
Run 2	0.926	0.013	0.0465374	
Run 1	0.932	0.074	0.1807006	E_w = **4.6412 grams/hour**
Run 4	1			

Table 4: Showing assigned weights and final weighted average.

Chapter 4: Results and Experiment Findings

Chapter 4.1: Processing the test results through calculations using Excel Spreadsheets.

At the conclusion of the two-hour burn test and the 24-hour desiccation and weighing of

the PM samples that the data needed to be analyzed. This is where the EPA Method-28

and 5G derived excel spreadsheet was used. The spreadsheet was comprised of various

sheets that all functioned to output the final "IRETI Test Report".

The following spreadsheets required data input:

- **IRETI001F-SCFTEST Fuel**: Data regarding the fuel used.

Customer:	IRETI	Technicians: Sergio Gamarra
Manufacturer:	Hestia	Mark Ryan Fujitake
Model:	HHP2	
Date:	3/3/2011	
Fuel Type:	Hardwood Pellets	
Fuel Grade:	Premium	Certification

Test Fuel Crib Arrangement (Photo or Drawing)

Firebox Volume and Fuel Data

Length:	0.00	inch
Width:	0.00	inch
Accessable Height:	0.000	inch
Total Volume:	0.000	ft^3
Fuel Length(Calc):	0.000	5/6 of Firebox Length Minimum
Load Density*:	7.0 $^+/.$ 0.7	lb/ft^3

*For stove's, use 7.0, for Boilers use 10.0

Calc. Total Fuel Weight:	0.000 or > 0.0 - 0.0	< kgs
Meas. Fuel Weight:	4.600	kg
Moisture Dry:	6.80 > 19 - 25	< M$_{dry}$ %
Moisture Wet:	6.37 > 16 - 20	< M$_{wet}$%

Meas. Fuel Density	0.00 > 401 - 578	< kg/m^3
Meas. Spacer Weight	0.00 kg 0	lbs
Meas. Spacer Moisture	0.00 M$_{dry}$ % 0.000	< M$_{wet}$%
Total Fuel Load	4.600 kg 10.14132	lbs

Piece(2x4,4x4,Spacer)	Height(in)	Width(in)	Length(in)	Volume (ft^3)	Weight(kg)	Moisture Content of Wood M$_{dry}$ %			Average M$_{dry}$%	Temp (°C)
					4.60000	6.80	6.80	6.80	6.80	17.6
					0.00000	0.00	0.00	0.00	0.00	
					0.00000	0.00	0.00	0.00	0.00	
					0.00000	0.00	0.00	0.00	0.00	
					0.00000	0.00	0.00	0.00	0.00	
					0.00000	0.00	0.00	0.00	0.00	

Report | Calculations | **IRETI001F-SCFTEST Fuel** | IRETI003P-SCFTEST Test Data | IRETI004P-SCFTEST Particulate | Velocity Travers

- IRETI003P-SCFTEST Test Data: Data collected from the Dry Gas Meter PM sampling.

Enter All Data from the IRETI100P-SCFTEST Sampling Data Sheet SG into this worksheet

Test Name: 100%WOOD_American_LEVEL_10_2	Dry Bulb	24	???
Stove Make and Model: HHP2	Wet Bulb	13	???
Filter Numbers: A UF: 0 B: 7F: 7	Relative Humidity	26	???
Probe Numbers: A: 00 B: 07	Barometric Pressure (mmHg)	747.5	???
Run Number: 2	Air Velocity	0.15	???

Initial Leak Rate (L/min): A: 0   B: 0
Final Leak Rate (L/min): A: 0   B: 0
Pitot-Tube Coefficient: 99% (Cp)
Tunnel Static Pressure (in. H2O): 0.48
Target Flow Rate: 4   Liters per Minute

Look through the 100. If they are being outside.

Clock Time	Test Run Time (min)	Gas Meter Volume (Liters) A	B	Fuel Weight (kg)	Vacuum (in Hg) A	B	Tunnel Temp. (°C), Ts	Filter Holder Temperature (°C) (Must Be < 32°C) A	B	Gas Sample Temp. @ DGM (°F) Inlet A	Outlet A	Inlet B	Outlet B	Manometer Velocity Head (inH2O) ΔPr	Sample Flow Meters (mmH2O) A	B	Draft (Pa) (Must Be <12.5Pa before test)	PR(a)	PR(b)
AM/PM	-------	A	B		A	B	-------	A	B	Inlet	Outlet	Inlet	Outlet	-------	A	B		PR(a)	PR(b)

START TEST - Turn on Particulate Iso-kinetic Source Sampler. Adjust to around 70 on the Flowmeter scales. Monitor and adjust to achieve 4 Lpm flow. Tare the scale. Insert Test Fuel.

Clock Time	min	A	B	kg	A	B	Ts	A	B	Inlet	Outlet	Inlet	Outlet	ΔPr	A	B	Pa	PR(a)	PR(b)
17:12	0	0	0	4.6	3.0	2.0	50	24	23	77	72	77	73	0.035	79	79	0.75	101.9102223	105.6428582
17:22	10	44	44	4.25	3.0	2.0	51	24	24	71	72	71	74	0.035	75	75	0.75	105.8415046	100.7365945
17:32	20	86	86	3.8	3.0	2.0	51	25	24	71	73	71	75	0.035	72	72	0.75	100.7844539	100.8211569
17:42	30	126	128	3.4	3.0	2.0	53	25	24	71	73	69	70	0.035	70	70	0.75	100.8271569	100.8211569
17:52	40	165	167	3.05	3.0	2.0	53	25	24	71	73	69	70	0.035	70	69	0.75	93.7017960162	93.7017960162
18:02	50	204	207	2.7	3.0	2.0	52	25	23	70	73	69	74	0.035	69	69	0.75	98.4760858033	96.7107746
18:12	60	243	246	2.3	3.0	2.0	52	25	23	71	73	69	74	0.035	69	69	0.75	98.2462608	93.7017960162
18:22	70	282	284	1.9	4.0	2.5	53	25	23	71	73	69	74	0.035	69	69	0.75	98.2301052	91.1240607/3
18:32	80	321	323	1.55	4.0	2.5	53	25	23	70	73	69	74	0.035	69	69	0.75	98.3017035218	93.7017960162
18:42	90	359	361	1.15	5.0	3.0	53	25	23	70	74	69	74	0.035	69	69	0.75	95.7863/4197	93.12460779
18:52	100	398	400	0.75	5.0	3.5	52	25	23	71	74	69	74	0.035	69	69	0.75	98.2316521	93.7017960162
19:02	110	436	438	0.4	5.0	3.5	52	24	23	71	74	69	74	0.035	69	69	0.75	96.71017146	91.2280751517
19:12	120	476	478	0	5.0	4.0	52	24	23	71	74	68	74	0.035	69	68	0.75	100.6730377	95.9480094

Averages																			
Max	120	476	478	4.6	5	4	53	25	24	71	74	69	75	0.035	79	79	0.750	105.843	105.643
Min	0	0	0	0	3	2	50	24	23	70	72	68	73	0.035	69	69	0.750	95.639	91.228

				0			-------							0.0352627659			0.5	PR(a)	PR(b)

- IRETI004P-SCFTEST Particulate: Data from the PM weight analysis.

ST-01 PM Analysis Data Sheet_5G3

100%WOOD_American_LEVEL_10_2

0f,0	B	F7,7	C
0	B	7	C
HHP2			C

Stove Power Level:	10	Total Time (hrs)
Test Start Time:	17:12	
Test End Time:	19:12	2:00
Final Scale Weight(kg):	0	

Calibration Weight (g)

Date -Time	Temp (C)	RH%	O Rings Total Per Pair	Filters Front	Filters Back	Probe	Total Weight	
			0.0000 / *0.00000*	0.0000 / *0.00000*	0.0000 / *0.00000*	0.0000 / *0.00000*	*0.000000*	
3/3/2011	17.6	26						
			0.0000 / *0.00000*	0.1171 / *0.11710*	0.1171 / *0.11710*	109.9090 / *109.90900*	*110.143200*	Before Test
3/5/2011								After Test minus
			0.0000 / *0.00000*	0.1280 / *0.12800*	0.1167 / *0.11670*	109.9044 / *109.90440*	*110.149100*	Total (PM) — *0.005900*
			0.0000 / *0.00000*	0.0000 / *0.00000*	0.0000 / *0.00000*	0.0000 / *0.00000*	*0.000000*	Total (PM)
3/3/2011	17.6	26						After Test minus
			0.0000 / *0.00000*	0.1157 / *0.11570*	0.1175 / *0.11750*	109.9906 / *109.99060*	*110.223800*	Before Test
3/5/2011			0.0000 / *0.00000*	0.1264 / *0.12640*	0.1175 / *0.11750*	109.9855 / *109.98550*	*110.229400*	*0.005600*
			0.0000 / *0.00000*	0.0000 / *0.00000*	0.0000 / *0.00000*	0.0000 / *0.00000*	*0.000000*	Total (PM)
			0.0000 / *0.00000*	0.0000 / *0.00000*	0.0000 / *0.00000*	0.0000 / *0.00000*	*0.000000*	After Test minus / Before Test
			0.0000 / *0.00000*	0.0000 / *0.00000*	0.0000 / *0.00000*	0.0000 / *0.00000*	*0.000000*	Total (PM)
			0.0000 / *0.00000*	0.0000 / *0.00000*	0.0000 / *0.00000*	0.0000 / *0.00000*	*0.000000*	

Report | Calculations | IRETI001F-SCFTEST Fuel | IRETI003P-SCFTEST Test Data | **IRETI004P-SCFTEST Particulate**

- **Velocity Traverse**: Data collected from the dilution tunnel and leak tests.

Blue Values must be entered

Measured Values			Constants			* Clean Pitot Tube		

						Tunnel Velocity Measurements			
						Location	Posi.(in)	Pres.(in H2O)	Vel.m/sec
Tunnel Diameter	6 Inches	0.152400 m	Bws	0.04		C (x)	3	0.05	4.77949105
Tunnel Area	0.19634954 ft^2	0.01824469 m^2	Cp	0.99		X1	0.5	0.04	4.27316451
Tunnel Temperature	52.62 °C	325.77 K	Tstd	293 K		X2	1.5	0.05	4.77949105
Barometric Pressure	29.4 in Hg	747.5 mm Hg	Kp	34.97 Conversion		X3	4.5	0.0475	4.65891809
Tunnel Static Press.	0.4800 in H2O	0.89797 mm Hg	Ms	29 g/g mole		X4	5.5	0.04	4.27316451
Dynamic Pressure	0.0350 in H2O	0.889000 mm H2O	Pstd	760 mm Hg		C (y)	3	0.05	4.77949105
Absolute Average Gas Static Pressure Ps	748.39680 mm Hg					Y1	0.5	0.0375	4.13955753
						Y2	1.5	0.0475	4.65891809
Calculated Tunnel Flow Rate						Y3	4.5	0.05	4.77949105
Tunnel Velocity	3.7886939 m/sec	227 m/min				Y4	5.5	0.0475	4.65891809
Tunnel Flow Rate	3.5257107 dscm/min					Average	TRAV	0.04500000	4.52835342
Within Limits?	FALSE						CENT	0.05000000	4.77949105

4.0%

Fp 0.947364761 Adjustment factor for center of tunnel Pitot tube placement.

Pre-test Leak Check

Pitot Impact Opening	0	3.0 inches H2O Pressure for 15 seconds
Static Pressure Side	0	3.0 inches H2O Suction for 15 seconds

Post-test Leak Check

Pitot Impact Opening	0	3.0 inches H2O Pressure for 15 seconds
Static Pressure Side	0	3.0 inches H2O Suction for 15 seconds

- **Heater Temps**: Data collected from the thermocouples.

												Time to General	Time to seconds	End times
3/3/2011 17:12														
Time Logging Started	17:12:00													
Time Start	17:12:00						Average Start	384.8400906 deg C	0.716667	61,920				
Time End	19:12:00						Average End	378.5280251 deg C	0.716667	61,920				
Total Test Time	2:00:00 Hours/Min					Average Surface Difference			0.8	69,120				
								6.31205482 deg C		9,840.39				

	max	332.77	306.08	309.58	491.59	526.35	24.20	25.68	53.25	254.94	23.99	385.02
	min	304.49	285.65	283.81	458.21	508.39	22.64	22.76	50.93	249.65	16.77	378.12
	average	315.24	296.49	300.59	482.19	516.25	23.69	24.91	52.62	251.86	18.65	382.15

Time	Left	Right	Bottom	Top	Back	Sample B	Sample A	Tunnel	Flue	Ambient	Average Surface Temps
2640.1056	308.1821528	293.40305	307.9154342	488.3512435	526.3485719	22.63589621	22.830322	50.9258695	252.2795777	23.9860903	384.8400906
3240.1296	306.4097428	285.652856	307.2511252	488.3872896	519.5592513	24.12271115	24.90666	51.4344508	251.7171145	21.43561539	381.452053
3840.1536	312.8308989	288.473498	307.3987595	491.0178176	520.4984052	24.15985547	25.239982	51.7613083	250.9969513	18.91699023	384.0438758
4440.1776	312.4621467	304.457216	304.8143168	480.1992592	520.7512422	24.19699851	25.610218	53.031788	252.1296009	18.23942504	384.5368363
5040.2016	304.4886806	300.690343	309.5757042	483.302419	516.4884246	24.04841868	25.684249	53.068073	252.0171119	17.78750537	382.9091143
5640.2256	309.547826	290.920764	306.6974452	478.8639033	515.1153132	23.93697038	25.684249	52.8503513	249.6535822	17.63682871	380.2290503
6240.2496	316.1482173	290.587166	300.6753533	480.1631704	516.4522923	23.7883548	25.536181	52.9592157	252.6544773	17.44845725	380.8052398
6840.2736	314.895311	296.882293	303.484464	491.5941261	518.2226381	23.75119771	25.351067	53.2494861	254.9400515	17.33542077	385.0157665
7440.2976	308.7358621	290.031085	302.9671655	477.925467	516.271629	23.60255666	25.239982	53.1769232	253.5165163	17.18468966	379.1862418
8040.3216	328.2177697	302.389632	295.7167509	489.0721106	509.6933258	23.56539322	25.128887	52.8503513	251.3045547	17.0339406	385.0179179
8640.3456	329.5039746	306.080911	289.2292228	477.1674582	514.5371082	23.37955697	24.980741	52.9591157	250.8544059	16.80778352	383.303735
9240.3696	313.9738233	300.173	283.805927	484.240364	508.3915842	23.37955697	24.832574	52.6688947	252.3170704	16.77008679	378.1169129
9840.3936	332.7732594	304.641764	288.1156609	458.2116016	508.8978397	23.37956997	22.756094	53.1769232	249.803719	21.84859115	378.5280251

The following spreadsheets output data:

- **Calculations**: Fields were all self-populated by the inputs and calculations occurred which output to the "IRETI Test Report" sheet.

	Symbol	Value	Description
1			Designation E2515 – 10 Standard Test Method for Determination of Particulate Matter Emissions Collected by a Dilution Tunnel
3			11. Data Analysis and Calculations
4–6		11.1	Carry out calculations, retaining at least one extra significant figure beyond that of the acquired data. Round off figures after the final calculation. Other forms of the equations may be used as long as they give equivalent results.
8		11.2	*Nomenclature* :
9	A	0.018241469	Cross-sectional area of tunnel m² (ft2).
10	B_{wv}	0.04	Water vapor in the gas stream, proportion by volume (assumed to be 0.02 (2.0%)). (0.04 (4%) Per EPA
11	C_p	0.99	Pitot tube coefficient, dimensionless (assigned a value of 0.99).
12	c_r	0	Concentration of particulate matter room air, dry basis, corrected to standard conditions, g/dscm (gr/dscf) (mg/dscf).
13	$c_{s(a)}$	0.01185050511	Concentration of particulate matter in tunnel gas, dry basis, corrected to standard conditions, g/dscm (gr/dscf) (mg/dscf).
14	$c_{s(b)}$	0.01121381195	Concentration of particulate matter in tunnel gas, dry basis, corrected to standard conditions, g/dscm (gr/dscf) (mg/dscf).
15	$E_{T(a)}$	5.018552253	Total particulate emissions, g.
16	$E_{T(b)}$	4.748920043	Total particulate emissions, g.
17	$E_{(ave)}$	4.883736148	Average particulate emissions, g.
18–20	$E_{(range)}$	4.517455936 to 5.250016359	This is the range in grams which is 7.5% from the average. If the emissions range fall within this, it is a passing test and the data will be white text with a blue background. If the data does not pass, it will be black text with a red backgorund. See 11.7 for details.
22		2.761%	Actual Absolute Difference from the average, Must be Below 7.5%
25			$F_p = \dfrac{V_{strav}}{V_{scent}}$ (1)
27	F_p	0.947364761	Adjustment factor for center of tunnel Pitot tube placement.
30–31	EPA Method 2	12.6	$K_p = $ Pitot Tube Constant, $34.97\ \dfrac{m}{sec}\left[\dfrac{(g/g \cdot mole)(mm\ Hg)}{(K)\ (mm\ water)}\right]^{\frac{1}{2}}$ (2)
33	K'_p	34.97	
35–36	L_a	0.0003	Maximum acceptable leakage rate for either a pretest or post-test leak- check, equal to 0.0003 m³/min (0.010 cfm) or 4 % of the average sampling rate, whichever is less.
37	$L_{p(a)}$	0.000000	Leakage rate observed during the post-test leakcheck, m³/min (cfm).
38	$L_{p(b)}$	0.000000	Leakage rate observed during the post-test leakcheck, m³/min (cfm).
39	$m_{p(a)}$	-4.600	mass of particulate from probe, mg.
40	$m_{p(b)}$	-5.100	mass of particulate from probe, mg.
41	$m_{f(a)}$	10.500	mass of particulate from filters, mg.
42	$m_{f(b)}$	10.700	mass of particulate from filters, mg.
43	m_g	0.000	mass of particulate from filter gaskets, mg.
44	m_r	0	mass of particulate from the filter, filter gasket, and probe assembly from the room air blank filter holder assembly, mg.
45	$m_{n(a)}$	5.9	Total amount of particulate matter collected, mg.
46	$m_{n(b)}$	5.6	Total amount of particulate matter collected, mg.
47	M_d	29	the dilution tunnel dry gas molecular weight (may be assumed to be 29 g/g mole (lb/lb mole).
48	P_{bar}	747.5	Barometric pressure at the sampling site, mm Hg (in. Hg).
49	P_g	12.1920	Static Pressure in the tunnel mm water (in. water).
50	PR		Percent of proportional sampling rate.
51	P_s	748.396797	Absolute average gas static pressure in dilution tunnel, mm Hg (in. Hg).
52		760	Standard absolute pressure 760 mm Hg (29.92 in. Hg).

Report | **Calculations** | IRETI001F-SCFTEST Fuel | IRETI003P-SCFTEST Test Data | IRE

- **IRETI Test Report**: Showed the final data output by all the calculations from the various sheets. It contained the data that was the basis for Chapter 4.2: Individual test results.

See below for sheet in Chapter 4.2.

Chapter 4.2: Individual Test Reports: Burn Rates and PM Emissions from Wood Pellet Fuel Burning American Stove

The results below represented the three burns we achieved. The data was collected, then analyzed individually, followed by inputting them all together for weighted average analysis.

Chapter 4.2.1: Test 1 report

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IRETI Test Report

IRETI001F-MGT-01

Minnesota State University, Mankato

International Renewable Energy Technology Institute (IRETI^{MN})

109 Center of Renewable Energy

Mail Code: RE109

Mankato, Minnesota 56001

IRETI Business Office: 507-389-5414; john.frey@mnsu.edu or jenny.stratton@mnsu.edu

Biogas and Liquid Biofuels Laboratory: 507-389-1970; medea.myhra@mnsu.edu

Solid Combustible Fuels Laboratory: 507-389-5440; mark.sanderson@mnsu.edu

Laboratory used: *Solid Combustible Biomass Lab*

Analysis Report for: *IRETI MN*

109 Center of Renewable Energy, Mankato, MN 56001

Date sampled:	3/3/2011	Date received: -		Date reported: 3/5/2011

Sample ID: 100%WOOD_American_LEVEL_10_2

Enter IRETI NUMBER

Deviations / Environmental Conditions of Sample:
No deviations

Statement about compliant / noncompliant, if applicable:
TEST OF AMERICAN STOVE

ANALYSIS	METHOD	RESULTS		
Filter Max Temp	EPA Method 5G, 2.1	25.68	A deg. C	
		24.20	B deg. C	
Proportional Rate Variation	EPA Method 5G, 12.7	95.64	A - MIN - B	91.23
		110.90	A - MAX - B	105.64
		99.96	A - AVE - B	95.66
Particulate Sample	EPA Method 5G, 16	2.4419	Grams/Hour	
% Diff. Per Sample Train	EPA Method 5G, 16.2.5	2.7605%	Must be < 7.5%	
Room Air Temp	EPA Method 28, 6.12.1	16.77	min. deg. C	
		23.99	max deg. C	
Burn Rate Category	EPA Method 28, 8.1.1	Category 4		
Ave. Surface Temp Diff.	EPA Method 28, 8.14	6.31	deg. C	
Burn Rate	EPA Method 28, 12.5	2.15	kg/hour	

Chapter 4.2.2: Test 2 report (Failed Test)

Four tests were performed, but the second test was interrupted near the end by a power outage, resulting in lost temperature data and a momentary pause in the operation of the dry gas analyzer. This test run was incomplete, therefore, no data presented.

Chapter 4.2.3: Test 3 report

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IRETI^{MN} **IRETI Test Report**   IRETI001F-MGT-01

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IRETI Business Office: 507-389-5414; john.frey@mnsu.edu or jenny.stratton@mnsu.edu
Biogas and Liquid Biofuels Laboratory: 507-389-1970; medea.myhra@mnsu.edu
Solid Combustible Fuels Laboratory: 507-389-5440; mark.sanderson@mnsu.edu

Laboratory used: *Solid Combustible Biomass Lab*

Analysis Report for: *IRETI MN*
109 Center of Renewable Energy, Mankato, MN 56001

Date sampled: 3/16/2011   Date received: -   Date reported: 3/18/2011

Sample ID: 100%WOOD_American_LEVEL_10_3
Enter IRETI NUMBER

Deviations / Environmental Conditions of Sample:
No deviations

Statement about compliant / noncompliant, if applicable:
TEST OF AMERICAN STOVE

ANALYSIS	METHOD	RESULTS		
Filter Max Temp	EPA Method 5G, 2.1	25.46	A deg. C	
		23.60	B deg. C	
Proportional Rate Variation	EPA Method 5G, 12.7	95.16	A - MIN - B	91.41
		106.13	A - MAX - B	102.30
		99.94	A - AVE - B	96.00
Particulate Sample	EPA Method 5G, 16	3.5798	Grams/Hour	
% Diff. Per Sample Train	EPA Method 5G, 16.2.5	2.4132%	Must be < 7.5%	
Room Air Temp	EPA Method 28, 6.12.1	17.34	min. deg. C	
		21.17	max deg. C	
Burn Rate Category	EPA Method 28, 8.1.1	Category 4		
Ave. Surface Temp Diff.	EPA Method 28, 8.14	18.25	deg. C	
Burn Rate	EPA Method 28, 12.5	2.11	kg/hour	

Chapter 4.2.4: Test 4 report

B	C	D	E	F	G	H	I	J	K

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IRETI Test Report

IRETI001F-MGT-01

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Biogas and Liquid Biofuels Laboratory: 507-389-1970; medea.myhra@mnsu.edu

Solid Combustible Fuels Laboratory: 507-389-5440; mark.sanderson@mnsu.edu

Laboratory used: *Solid Combustible Biomass Lab*

Analysis Report for: *IRETI MN*

109 Center of Renewable Energy, Mankato, MN 56001

Date sampled: 3/18/2011   Date received: -   Date reported: 3/20/2011

Sample ID: 100%WOOD_American_LEVEL_10_4

Enter IRETI NUMBER

Deviations / Environmental Conditions of Sample:
No deviations

Statement about compliant / noncompliant, if applicable:
TEST OF AMERICAN STOVE

ANALYSIS	METHOD	RESULTS		
Filter Max Temp	EPA Method 5G, 2.1	25.68	A deg. C	
		23.57	B deg. C	
Proportional Rate Variation	EPA Method 5G, 12.7	94.77	A - MIN - B	90.91
		108.05	A - MAX - B	107.51
		99.93	A - AVE - B	96.43
Particulate Sample	EPA Method 5G, 16	4.8319	Grams/Hour	
% Diff. Per Sample Train	EPA Method 5G, 16.2.5	0.5998%	Must be < 7.5%	
Room Air Temp	EPA Method 28, 6.12.1	20.61	min. deg. C	
		26.68	max deg. C	
Burn Rate Category	EPA Method 28, 8.1.1	Category 4		
Ave. Surface Temp Diff.	EPA Method 28, 8.14	22.56	deg. C	
Burn Rate	EPA Method 28, 12.5	2.04	kg/hour	

Chapter 4.3: Method 28 Final Report

EPA Method 28 included a template for a final report that was to be submitted to the stove manufacturer. The final report was produced utilizing this template. It was a concise document including all the important information regarding and overview of the testing facility, summary and discussion of results, process description, sampling locations, sampling and analytical procedures, quality control and assurance procedures, information on the stove and how it was handled, and any further discussion on the testing. Below is the report shown as images.

HESTIA

HHP 2, NONCATALYTIC

1/17/2011

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Section 1 - Overview

The purpose of this test was for research and development. *Hestia* has retained the International Renewable Energy Technology Institute of Minnesota (IRETI^MN) to perform the aforementioned testing using United Stated Environmental Protection Agency test Methods 5G and 28.

All testing was performed at an elevation of 946 feet above sea level in IRETI^MN's laboratory located at Minnesota State University, Mankato main campus. Our physical address is 109 Center of Renewable Energy, Mankato, MN 56001.

Hestia sent *HHP2 Non-Catalytic* in *January 2011*. It was received by *Sergio Gamarra* of IRETI^MN in *January 2011*.

A total of *4* complete test runs were performed using Method 5G 16.2 with dual sample trains consisting of two filters front and back. The *HHP2 Non-Catalytic's* weighted average particulate emissions rate was able to be calculated. Due to the lack of testing experience and a brand-new testing facility, the stove was set to burn on its highest configuration as described by the manufacturers operating instructions. Four tests were performed, but the third test was interrupted near the end by a power outage, resulting in lost temperature data and a momentary pause in the operation of the dry gas analyzer. This test run was therefore, omitted.

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Section 2 - Summary and Discussion of Results

Table 1 – Particulate Emissions and Burn Rates

Run #	EPA Method 5G, 16 Ave. Emission Rate E_i (g/hr.)	EPA Method 28, 12.5 Burn Rate (Dry-kg/hr.)	EPA Method 28, 8.1.1 Burn Rate Category	EPA Method 5G, 16.2.5 Emissions per Sample Train (g) A	B	% from Ave.
Run 1	2.4419	2.15	Category 4	0.0059	0.0056	2.76%
Run 2	3.5798	2.11	Category 4	0.0069	0.0072	2.41%
Run 3	NA	NA	NA	NA	NA	NA
Run 4	4.8319	2.04	Category 4	0.0107	0.0108	0.59%

Table 2 – Weighted Average Emissions Rate

Run #	EPA Method 28, 12.1 P_i	EPA Method 28, 12.1 K_i	EPA Method 28, 12.1 $K_i * E_i$	Weighted Average Emissions Rate
Run 4	0.919	0.926	4.4743394	EPA Method 28, 12.3 $E_W = \dfrac{\sum_{i=1}^{n}(K_i E_i)}{\sum_{i=1}^{n} K_i}$
Run 2	0.926	0.013	0.0465374	
Run 1	0.932	0.074	0.1807006	
Run 3				E_w = 4.6412 grams/hour

Table 3 – Facility Conditions

Run #	Room Air Temp (°C) Before	After	Barometer Press. (mm. hg.) Before	After	Relative Humidity (%) Before	After	Air Velocity (m/sec) Before	After	Flue Draft (Pa) Pretest	Ave.
Run 1	23.98	21.84	747	747	26	26	0.15	0.15	0.75	0.75
Run 2	18.01	17.49	743	743	36	36	0.15	0.15	1.1	1.1
Run 3										
Run 4	21.21	23.94	757	757	38	38	0.2	0.2	0.4	0.4

Table 4 - Temperatures

Run #	EPA Method 28, 8.14 Average Surface Temp (°C) Before	After	Diff.	EPA Method 5G, 2.1 Filter Max Temp (°C) A	B	EPA Method 28, 6.12.1 Room Air Temp During Test (°C) Min	Max	Catalyst Temp Average (°C) Pre	Post
Run 1	384.4	378.52	5.88	25.68	24.2	16.77	23.99	N/A	N/A
Run 2	370.99	389.24	18.25	25.46	23.6	17.34	21.17	N/A	N/A
Run 3								N/A	N/A
Run 4	392.14	369.57	22.57	25.68	23.57	20.16	26.68	N/A	N/A

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3. Discussion –

Burn rate categories achieved: We chose to operate the stove on High Burn, because we could not make it work on the low settings; there was too much smoke coming out of the stack, and our lack of experience and eagerness to complete a full run drove us to press forward without solving the smoke issue. The different burn rates were not attempted, because we could only get it to work properly in the HI BURN mode allowing us only to analyze the greatest output (burn rate) the stove was capable of.

Test run result selection: We chose the test runs with the most consistent data and closely matching captured PM weights (relative to each pair of filter holders) within 7.0%.

Specific test run problems and solutions: Once stove operation was configured as per manufacturer's recommendations; the stove ran flawlessly after the initial trial and errors of setting the proper feed rate. We were not able to get the stove to operate in the Low Burn mode without too much smoke being produced.

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Section 3 - Process Description

1. Wood heater dimensions – Stove Testing Quote Sheet

2. Firebox Configuration – Pellet Stove

3. Process operation during test:

   a. The feed rate that we found to operate optimally (using manufacturer's printed suggestions) was 10 (upper limit of operating range 1-10)
   b. Followed manufacturers operation procedure once the stove would function without producing too much smoke (based on our opinion).

4. Test fuel: All of the pellet fuel we used was PFI certified wood pellets. They were produced by INDECK energy and were purchased off the shelf as anyone else could. We sent the fuel out to get tested by a third-party test facility and used their analysis results as the data for our calculations. See attached MVTL data sheet. The fuel temperature used for calculations was ambient temperature recorded at the time of the tests, because it was stored in the same area that the stove testing was performed.

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Section 4 - Sampling Locations

Sampling location for analysis of the exhaust gas composition was in the stack 8 feet above the platform scale. The PM sampling was performed in the dilution tunnel at the location designated by EPA Method-5G which was located to the right of the stove.
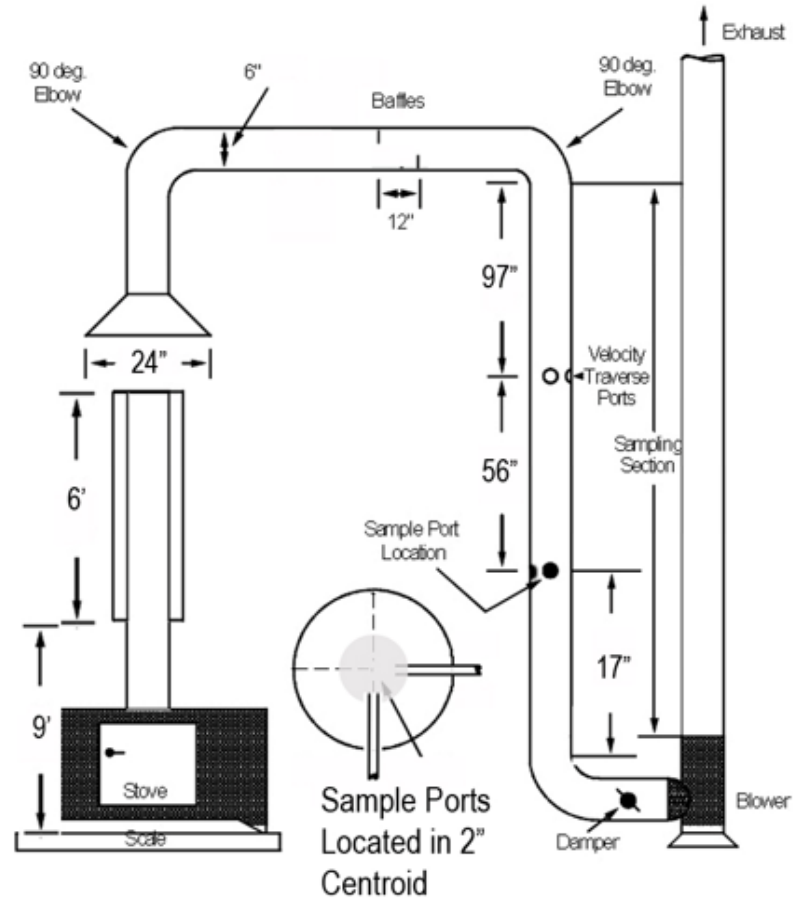
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Section 5 - Sampling and Analytical Procedures

EPA methods 28 and 5G were followed for all testing. For method 5G, 16.2 has been followed using dual sample trains with dual filters.

Sample recovery is done to the specifications in Method 5G, 16.2. This requires desiccating the probe and forward filter holder, both filters and O-rings for a minimum of 24 hours before the test and after the test. All weighing and sample recovery are performed in the same air space; therefore, the capping and transport requirements do not have to be met.

The filters are weighed directly on the scale without the petri dish. All components used for determining particulate weights are weighed 3 times to achieve a constant weight.

All data is entered into spreadsheets to perform calculations. This ensures repeatable, consistent calculations and results.

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Section 6 - Quality Control and Assurance Procedures and Results

1. Calibration procedures and results - certification procedures, sampling and analysis procedures.

Table 4 – Test Method Quality Control Values

Run #	Method 5G 8.5.1 Velocity Traverse Checks				Method 5G, 16.2.1 Filter Velocity (< 150mm/sec) and Leak Checks(<0.160L/min)						Method 5G, 10.2 Volume Metering System			
											Before Test		After Test	
	Pre-Test Pitot Leak Check	Tunnel Flow (dscm /min)	8.5.2 F_P	Post-Test Pitot Leak Check	Initial Leak Rate A (L/min)	Initial Leak Rate B (L/min)	Max Filter Velocity A (mm/sec)	Max Filter Velocity B Max (mm/sec)	Final Leak Rate A (L/min)	Final Leak Rate B (L/min)	A	B	A	B
Run 1	Yes	3.529	0.947	Yes	.000	.000	42.268	42.268	.000	.000	0.0	0.0	476	478
Run 2	Yes	4.215	0.947	Yes	.038	.008	40.347	40.347	.019	.008	0.0	0.0	479	478
Run 3														
Run 4	Yes	3.827	0.947	Yes	.022	.000	41.682	43.069	.030	.008	0.0	0.0	480.23	481.92

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Section7 - Appendices

1. <u>Results and Example Calculations.</u>

    Attach Report Page from the IRETI_SPREADSHEET files

2. <u>Raw Data.</u>

    Attach our raw data if desired

3. <u>Sampling and Analytical Procedures.</u>
    Detailed description of procedures followed by laboratory personnel in conducting the certification test, emphasizing particularly parts of the procedures differing from the methods (e.g., approved alternatives). **Attach our procedure sheet**

4. <u>Calibration Results.</u>
    Summary of all calibrations, checks, and audits pertinent to certification test results with dates. **Attach our calibration sheet**

5. <u>Participants.</u>
    Test personnel, manufacturer representatives, and regulatory observers.
    Sergio Gamarra: Graduate Assistant
    Mark Fujitake: Undergraduate Assistant
    Brad Wyininger: Project Manager
    Mark Sandersen: Project Manager

6. <u>Sampling and Operation Records.</u>
    Copies of uncorrected records of activities not included on raw data sheets (e.g., wood heater door open times and durations).

7. <u>Additional Information.</u>
    Wood heater manufacturer's written instructions for operation during the certification test. **Attach Hestia HHP2 instructions.**

Test Facility Information. Report test facility temperature, air velocity, and humidity information. Included in our procedure sheets and results sheet.

-Pretest Procedure Description. Report all pretest procedures including pretest fuel weight, burn rates, wood heater temperatures, and air supply settings. Included in the IRETI_SPREADSHEET files.

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-Particulate Emission Data. Report a summary of test results for all test runs and the weighted average emission rate. Submit copies of all data sheets and other records collected during the testing. Submit examples of all calculations.

Included in IRETI_SPREADSHEET files are the summary of test results. We calculated a weighted average emissions rate, but it does not bear any weight due to the fact that we did not test in any burn category aside from Category 4. Data sheets should all be stored in the binders. Calculations are part of the IRETI_SPREADSHEET files.

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CHAPTER 5: CONCLUSIONS/ DISCUSSIONS

Chapter 5.1: American Technology

The study was successful in completing PM emissions sampling based on the EPA

Method-28 and 5G standards. The American technology stove was capable of a high

burn rate. It produced PM (EPA5G) samples, collected from the burnings that left us

surprised. At first, we did not know what to expect. We were able to complete two-hour

test burns which included collection and recording all the data required by the EPA

methods. Our process established consistent burn rates (**2.04**, 2.11, 2.15 kg/hr.), but the

PM values (**4.83**, 3.57, 2.44 g/hr.) did not seem to follow that consistency. This was an

eye-opener to the intricacies of wood combustion and the operation of not only the

pellet stove, but the effects of the fuel quality, equipment and sensor calibration, and

the proper repeatable operation of the emissions equipment. The preliminary testing

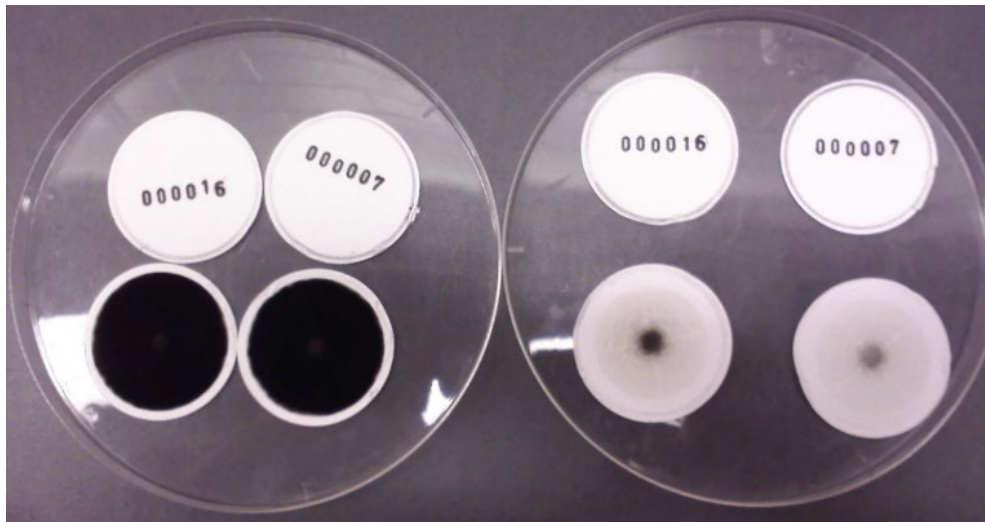was only performed on EPA Method 28 burn rate "Category 4".

Image 23: 2" PM sample filters showing contrast from a high rate burn vs an incomplete

burn.

The truth behind the EPA grading was that the wood pellet stoves, lacking a certification procedure, were being tested and graded as cord-wood stoves, which in 2009 did not have performance standards applied to them (SMOKINGGUN). At this point the standards allowed for high PM emissions, when in all actuality, pellet stoves could burn very clean and not emit excessive PM. A general analysis of the data collected thus far shows the American technology pellet stove is not completely burning the fuel resulting in higher than expected PM emissions. Measured at a weighted average of 4.64 g/hr. This baseline PM emissions data converted to 2.36 g/kg, when compared to the Nordic guideline of 2g/kg for wood burning stoves, was evidence that the European technology was worth looking into. This was evidence that by performing this study and developing a certified test facility and starting this research database, IRETI was moving in the right direction!

Table 1: Summary: Federal and Northeast State Regulations for Biomass Devices

Device Type	Federal	Northeast States
Fireplace	• Exempt from residential wood heater NSPS • EPA voluntary program under development	• No applicable state regulations
Indoor woodstove	• Subject to residential wood heater NSPS • Standard set in 1988 (CAA requires review of standard every 5 years) • EPA working on review	• No applicable state regulations
Pellet stoves	• Loophole in residential wood heater NSPS exempts most units	• No applicable state regulations
Coal and other residential solid fuel stoves	• No applicable federal regulations	• No applicable state regulations
Indoor wood furnace/boiler	• No applicable federal regulations • May participate in EPA OWHH voluntary program	• No applicable state regulations

Table 5: Pay close attention to the summary regarding pellet stoves from June 2009. There was NO NEED to test or even design to meet NSPS (New Source Performance Standards).

Chapter 5.2: Discussion and Conclusion

The overall results of this study proved that the lab could produce repeatable results. The successful development of the testing infrastructure, meeting the documentation requirements, implementing quality control and testing practices, and producing standard operating procedures, calculating spreadsheets, and report sheets all mark the completion of this exploratory testing. Moving forward with more practice using the technology, developing more consistency, fine tuning of the procedures and reducing human error will result in more repeatable results.

The American Technology could burn on high and low. It would be beneficial to try and complete the full-scale test operating at the 4 different burn categories, so that an accurate weighted average could be assigned to the stove.

Compared to the European technology, it can be decided that the American results are less than ideal. The European emissions requirements are stricter. If a stove is CE certified, it essentially means it is more advanced than an American stove. This would be the point where it is determined to further study the European technology!

As noted, the start-up sheets include the instructions for operating an FID (Flame Ionization Detector) and an FTIR (Fourier Transform Infrared Spectroscopy). The goal was to also include emissions analysis data of various combustion emissions gases that are measured in European markets for their more stringent certification. This was the secondary focus on "Getting ahead of the curve". Not only could certification tests be performed, there was the capability to perform research and development.

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(Image) Pyrolysis, gasification and combustion in a burning matchstick (adapted from Tom Reed, http://www.allpowerlabs.com/info/gasification-basics/gasification-explained

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APPENDIX

PROCEDURE SHEETS

Testing Procedure Guidelines and SOP documents:

LAB_STARTUP-SHEET_DUAL_5G3
Method_5G_CALIB-SHEET
Method_5G_PROC-SHEET
Method_28_CALIB-SHEET
Method_28_PROC-SHEET
PM Analysis Data Sheet_5G3
Sampling Data Sheet_5G3

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IRETI CAI FTIR Setup and Operation Procedure - Dual Test

Explanation: This procedure is to be used to guide the user through the process of setting up and operating the testing equipment. You will be preparing all of the equipment in the lab in order to start calibration and testing. This procedure will properly set up the equipment for pellet-stove testing against EPA Method 28 and 5G.

Test Name (1of2): _____

Test Date/Time: _____

Test Description (Span Y/N):

_____

_____

_____

_____

_____

__ 1. Power up the A/C unit in order to maintain laboratory temperature.
__ 2. Power up the Scale
__ 3. Turn on the FID fuel tank.
__ 4. Turn on the N2 gas tank.
__ 5. If the FTIR was purged, while idle, with zero air, turn the 3-way valve on the back of the FTIR bench to the DOWN position for an initial N2 purge of the system before the first real test.
__ 6. Power up the CAI FTIR bench
    - **Power-up time:_____**

__ 7. Power up the CAI laptop
__ 8. Power up the heated sample line controller
__ 9. Allow all 1-hour to stabilize
__ 10. Measure facility conditions and record them.
    - **Temp (DB)_____(WB) _____(RH%)_____Atmospheric Pres.(inHG)_____**

__ 11. Once the laptop is booted up, Open the NOW software and OPUS (Password: OPUS)
__ 12. Check FID for burner temp to be upwards of 250degrees Celsius. If it is not, IGNITE it.

* The best way to ignite the FID flame is to make sure it is getting zero air and FID fuel, hit F8 on the main screen and it should turn right on.

* If FID fails to ignite, check for to see if there is FID fuel flowing and Zero Air flow (3-way valve in back in up position. If it's been sitting for too long, take a 9/16ths wrench and crack open the line marked "FUEL" on the back of the FID and let it bleed out some of the gas.

__ 13. Check Diagnostics for FID and O2 sensors; make sure voltages are not around 9volts.
  - **FID Sample Pressure Sensor Output (in Volts) _____**

__ 14. For the FTIR in OPUS, check the status light in the bottom right corner.

  -Yellow: Might be humidity out of range, but make sure to look and see what is up.

  -Green: all systems GO

  -Red: See what is wrong, if no easy fix, CALL CAI.

__ 15. In OPUS, Click Measure on the toolbar, Click Advanced Measurement, Click Check Signal, Select Spectrum and note the amplitude of the spectrum. *Should be around 7900.
  - **Amplitude:_____**

__ 16. If all diagnostics pass and the system has had 1-hour to warm up and stabilize, Zero the FID using ZERO AIR; wait for it to stabilize before saving the value.
  *This could be done manually on the bench or using the NOW software.

__ 17. After saving a Zero value, go ahead and hook up the line labeled "FID Span" to the Methane bottle.

__ 18. SPAN the FID by choosing the span option and entering the certified bottle value and wait for the value to stabilize before saving the value.
  - **Bottle Value: _____**

__ 19. !!!Make sure if you are using the NOW software to check the standby box before closing the calibration window, if not your zero and span data will not save!!!

__ 20. Zeroing the O2 sensor will be done just as the FID, except it requires a Nitrogen based Zeroing. Turn on the Nitrogen tank and make sure the valve in the front is set on "N2" for nitrogen purging.

__ 21. SPAN will be the same for the O2 detector except the gas will be a known amount of oxygen and it will be SPAN'd through the THC SPAN line. Zero, Span, Standby
  - **Bottle Value: _____**

__ 22. Any changes manually made to the FID or O2 sensor while the NOW software is running must be saved to the NOW program.
  All software and hardware should be ready to start operations.

FTIR Spanning (Can be done once a week)

Date of last SPAN: _____/_____/_____

___ 23. In OPUS, Click Measure on the toolbar, select Control process, select the MNSU process file MNSU_191C_Process1.3, and give the test a name. Click Analyze.
   - **Given Test Name: _____**

___ 24. The cell should be cleared with N2 before each new experiment, so purge for (5-10) minutes.

___ 25. In OPUS click "Measure Reference" while still purging with N2, allowing 5 scans to get a proper reading.
   *A reference must be taken at the start of each experiment

   - **Reference Scan Time: _____**

___ 26. Time to baseline the analyzer and see if it is capturing the gases properly; switch valve in front panel to SPAN.

___ 27. Turn open the Span gas bottles and connect each one at a time allowing 5-10 minutes for the analyzer to stabilize the gas sample. Flow must be @ 10 lpm.
   - **(19.35) SPAN Gas on CO2 (time) _____Analyzer Measured _____%**

   - **(471) SPAN Gas on SO2 (time) _____Analyzer Measured _____ppm**

   - **(48.8) SPAN Gas on CO (time) _____Analyzer Measured _____ppm**

   - **(96.7) SPAN Gas on NO (time) _____Analyzer Measured _____ppm**

   - **(95.8) SPAN Gas on Methane CH4 (time) _____Analyzer Measured _____ppm**

   - **(95.4) SPAN Gas on NOx (time) _____Analyzer Measured _____ppm**

___ 28. As long as all of the values look satisfactory (within 10%), the FTIR is now ready to analyze and record data into the same file.

___ 29. Shut off the SPAN gas bottles and ensure that the cell is being purged with zero air and the valve in the front is set to the 12'oclock (OFF) position to begin sampling.

___ 30. There are no other buttons to click, other than making a note of the flue-gas sampling start time (Which should coincide with the PM test start-up time.)
   - **Start up time: ____:____**

Stove Start-up and Operation (Hestia)

___ 31. Clean ashes and empty ash tray into trash or collect as a sample.
___ 32. Make sure there is fuel in the hopper
___ 33. Turn on the dilution tunnel fan
___ 34. Flip the green toggle switch in the rear of the stove
___ 35. Ensure that the display screen shows "Stove Cold"

36. GO AHEAD and hold the "Start/Shutdown" button
37. Select your burn(comfort) level

    -Burn Level Selected (1-10):_____

    -Stove-on time: _____

    -Flame-on time: _____

38. Ensure stove ignites and starts burning. If not investigate.
39. Allow temperature to stabilize before data recording

FID and O2 logging setup

40. For logging the FID and O2 you must be in the NOW software and click on "Testing" on the toolbar. Then click on bench control utility.
41. Within bench control utility, make sure to click on the Measure option; if not the program will start recording without giving the analyzers a signal to start.
42. Before clicking **Begin test** you can set the rate at which NOW will record to the log file. It is best to set it at a sample rate of every minute.
43. Hit the **Begin test** button and let the analyzer do its job.

Thermocouple Logging Setup

44. Open The Signal Express LabView project called "**IRETI-Hestia**"
45. Turn on the SCXI chassis
46. Make sure computer is linked to SCXI (a pop up will advise you).
47. Click "Run" on the toolbar.
48. Dialogue screen will pop up and display the list of thermocouples to read, check the box labeled "thermocouple."
49. Give the project a name along with the timestamp.

    - Given Name: _____

50. Hit record to start recording at 2 samples per minute.

PM Sampling Setup

51. CLEAN ALL GLASSWARE.
52. Record lab conditions
53. Draft Determination (must be < 1.5)

    - Value measured: _____

54. Ensure that the dilution tunnel hood is capturing all of the smoke output by the stack.

__ 55. Velocity Measurements (Pitot Tube Measurements)

__ 56. Impinger preparation. Mark each one then weigh them with their tops inserted. Fill with the following and take a final weight before setting them upright in the impinger container.

1. Impinger 1: 100 ml of water

2. Impinger 2: 100 ml of water with special top

3. Impinger 3: Empty

4. Impinger 4: 200-300ml of desiccant

Record measurements on "PM Analysis Datasheet"

__ 57. To prepare the particulate filter: Make sure and weigh the paper filters and visually inspect for holes or other issues. Use tweezers to carefully place the front and back filters into the filter holder.
(DO NOT LEAVE OUT for more than two minutes without capping them)

__ 58. Pack crushed ice around the bottles within the impinger container.

__ 59. Slip the water cooling manifold over the sample probe and tighten the ends to seal from water leaks

__ 60. Hook up to the PM sampling controller box, but do not insert the sample probe just yet.

Leak-Check

__ 61. Turn on pump- cover sample probe- Check for vacuum.

__ 62. Once O.K. - Pull cap off first, then shut pump off!!!
IF failure to do this occurs, water will back feed into the filter and entire process must be started over.

- Initial Leak Check Results:_____

Starting a Test

*Means having all systems on-line and being ready to test.

__ 63. **FTIR- OPUS**

__ 64. **FID- NOW**

__ 65. **Thermocouple Recording**

__ 66. **PM Sampling Train**

__ 67. **Data-Recording Sheets**

__ 68. **Timers**

__ 69. **Stove Temp Stabilized (around 45 minutes) * Can check on the data logger. (Level-5 "Back" @ 502C, Level-10 "Back" @ 525C+)**

__ 70. **Tare Scale Time:_____:_____**

__ 71. **Test Start Time:_____:_____(Required Time: 2hrs)**

__ 72. Insert probe into stack up to the 3" line.
__ 73. Once stove is up to temp, start filling out the data sheet called "Particulate Sampling Data Sheet" and turn the pump and timer on.
__ 74. Continuously record data every 10 minutes. This requires adjustment of the flow rate to maintain a flow rate of 15 l/min.
__ 75. Record Scale weights every 10 minutes as well.

Time (10min) Weight (kg)

Start____:____   TARE__

1   ____:____   _____

2   ____:____   _____

3   ____:____   _____

4   ____:____   _____

5   ____:____   _____

6   ____:____   _____

7   ____:____   _____

8   ____:____   _____

9   ____:____   _____

10   ____:____   _____

11   ____:____   _____

END____:____   _____

Sample Recovery

__ 76. Shut off Pump and Timer
__ 77. Remove probe and perform final leak check.
   - **Final Leak Check Results: _____**

__ 78. Disassemble filter holder and quickly start weighing the filters
__ 79. Desiccate the filters, allowing the moisture to be removed from the PM sample.

__ 80. Measure the weight of the impingers to determine how much water was pulled out of the sample stream. Record Data on "Analysis Data Sheet".

__ 81. Calculate on Data on "Analysis Data Sheet".

__ 82. End logging in NOW

__ 83. End logging in OPUS

__ 84. End logging in Signal Express

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Test 2

Test Name (2of2): _____

Test Date/Time: _____

Test Description (SpanY/N):_____

_____

_____

_____

__ 85. Measure facility conditions and record them.
     - Temp (DB)_____(WB) _____(RH%)_____Atmospheric Pres.(inHG)_____

__ 86. All systems should be ready to pick up where Test (1of2) left off.

     FTIR Prep.

__ 87. In OPUS, Click Measure on the toolbar, select Control process, select the MNSU process file MNSU_191C_Process1.3, and give the test a name. Click Analyze.
     - Given Test Name: _____

__ 88. The cell should be cleared with N2 before each new experiment, so purge for (5-10) minutes.

__ 89. In OPUS click "Measure Reference" while still purging with N2, allowing 5 scans to get a proper reading.
        *A reference must be taken at the start of each experiment

- **Reference Scan Time: _____**

__ 90. There are no other buttons to click, other than making a note of the flue-gas sampling start time (Which should coincide with the PM test start-up time.)
- **Start up time: ____:____**

Stove Operation (Hestia)

__ 91. Make sure there is fuel in the hopper
__ 92. If switching burn temp, allow temp to stabilize
__ 93. Select your burn (comfort) level
-**Burn Level Selected (1-10): _____**

-**Stove-on time: _____**

-**Flame-on time: _____**

FID and O2 logging setup

__ 94. For logging the FID and O2 you must be in the NOW software and click on "Testing" on the toolbar. Then click on bench control utility.
__ 95. Within bench control utility, make sure to click on the Measure option; if not the program will start recording without giving the analyzers a signal to start.
__ 96. Before clicking **Begin test** you can set the rate at which NOW will record to the log file. It is best to set it at a sample rate of every minute.
__ 97. Hit the **Begin test** button and let the analyzer do its job.

Thermocouple Logging Setup

__ 98. Click "Run" on the toolbar.
__ 99. Dialogue screen will pop up and display the list of thermocouples to read, check the box labeled "thermocouple."
__ 100. Give the project a name along with the timestamp.
- **Given Name: _____**

__ 101. Hit record to start recording at 2 samples per minute.

PM Sampling Setup

__ 102. CLEAN ALL GLASSWARE.
__ 103. Record lab conditions

__ 104. Ensure that the dilution tunnel hood is capturing all of the smoke output by the stack.

__ 105. Velocity Measurements (Pitot Tube Measurements)

__ 106. Impinger preparation. Mark each one then weigh them with their tops inserted. Fill with the following and take a final weight before setting them upright in the impinger container.

     1. Impinger 1: 100 ml of water

     2. Impinger 2: 100 ml of water with special top

     3. Impinger 3: Empty

     4. Impinger 4: 200-300ml of desiccant

     Record measurements on "PM Analysis Datasheet"

__ 107. To prepare the particulate filter: Make sure and weigh the paper filters and visually inspect for holes or other issues. Use tweezers to carefully place the front and back filters into the filter holder.
(DO NOT LEAVE OUT for more than two minutes without capping them)

__ 108. Pack crushed ice around the bottles within the impinger container.

__ 109. Slip the water cooling manifold over the sample probe and tighten the ends to seal from water leaks

__ 110. Hook up to the PM sampling controller box, but do not insert the sample probe just yet.

Leak-Check

__ 111. Turn on pump- cover sample probe- Check for vacuum.

__ 112. Once O.K. - Pull cap off first, then shut pump off!!!
IF failure to do this occurs, water will back feed into the filter and entire process must be started over.

- **Initial Leak Check Results:** _____

Starting a Test

*Means having all systems on-line and being ready to test.

__ 113. **FTIR- OPUS**
__ 114. **FID- NOW**
__ 115. **Thermocouple Recording**
__ 116. **PM Sampling Train**
__ 117. **Data-Recording Sheets**
__ 118. **Timers**
__ 119. **Stove Temp Stabilized (around 45 minutes) * Can check on the data logger. (Level-5 "Back" @ 502C, Level-10 "Back" @ 525C+)**
__ 120. **Tare Scale Time:____:____**

__ 121. **Test Start Time:____:____(Required Time: 2hrs)**

__ 122. Insert probe into stack up to the 3" line.

__ 123. Once stove is up to temp, start filling out the data sheet called "Particulate Sampling Data Sheet" and turn the pump and timer on.

__ 124. Continuously record data every 10 minutes. This requires adjustment of the flow rate to maintain a flow rate of 15 l/min.

__ 125. Record Scale weights every 10 minutes as well.

Time (10min) Weight (kg)

Start___:___   TARE__

1   ___:___   _____

2   ___:___   _____

3   ___:___   _____

4   ___:___   _____

5   ___:___   _____

6   ___:___   _____

7   ___:___   _____

8   ___:___   _____

9   ___:___   _____

10 ___:___   _____

11 ___:___   _____

END___:___   _____

Sample Recovery

__ 126. Shut off Pump and Timer

__ 127. Remove probe and perform final leak check.
       - Final Leak Check Results: _____

__ 128. Disassemble filter holder and quickly start weighing the filters

__ 129. Desiccate the filters, allowing the moisture to be removed from the PM sample.

__ 130. Measure the weight of the impingers to determine how much water was pulled out of the sample stream. Record Data on "Analysis Data Sheet."

__ 131. Calculate on Data on "Analysis Data Sheet."

__ 132. End logging in NOW

__ 133. End logging in OPUS

__ 134. End logging in Signal Express

TEST & EQUIPMENT SHUT DOWN PROCEDURE

__ 135. Time:_____

__ 136. Final Weight:_____

__ 137. Off and Cool time:_____

__ 138. File relocation

       -OPUS (New folder>Rename>Copy & Paste spectra file and gaslogs into new folder.

       -NOW-FID and O2 data-(Drag into above created folder)

       -Thermocouple log- save log

__ 139. FTIR shut down

  __ 140. Make sure valve on front is returned to N2 purge

  __ 141. Open the N2 tank and purge for 5 minutes

  __ 142. Close N2 tank.

  __ 143. Valve on back is returned to the up position to purge machine with Zero Air.

  __ 144. Check gauge on the front of machine to make sure @ least .5 lpm is flowing.

  __ 145. Shut off CAI computer.

  __ 146. Flip CB1 behind front cover of FTIR to the down "OFF" position.

__ 147. Shut off heated sample line controller box.

__ 148. Wait for "Stove Cold" on stove display (circulation fans will kick "OFF")

  __ 149. Flip off Green switch on back of stove once "Stove Cold" displays.

__ 150. Shut OFF dilution tunnel blower once stove is shut off.

__ 151. Disassemble impingers and dry all beakers.

__ 152. Disconnect Dwyer draft gauge overnight.

END LAB_STARTUP-SHEET_DUAL_5G3

IRETI Pellet Burning Heater Emissions Testing Equipment Calibration Procedure

Explanation: This procedure is to be used to guide the user through the process of calibrating the testing equipment. You will be measuring the values output by the equipment against a known standard and previous calibration. This procedure will properly set up the equipment in accordance to EPA Method 5G.

NOTE: Maintain a laboratory record of all calibrations.

__ 153. -Pitot Tube.
*The Type S pitot tube assembly shall be calibrated according to the procedure outlined in Method 2, Section 10.1, prior to the first certification test and checked semiannually, thereafter. A standard pitot need not be calibrated but shall be inspected and cleaned, if necessary, prior to each certification test.

__ 154. -Volume Metering System.
*Initial and Periodic Calibration. Before its initial use and at least semiannually thereafter, calibrate the volume metering system as described in Method 5, Section 10.3.1, except that the wet test meter with a capacity of 3.0 liters/rev (0.1 ft3/rev) may be used. Other liquid displacement systems accurate to within ±1 percent, may be used as calibration standards.

NOTE: Procedures and equipment specified in Method 5, Section 16.0, for alternative calibration standards, including calibrated dry gas meters and critical orifices, are allowed for calibrating the dry gas meter in the sampling train. A dry gas meter used as a calibration standard shall be recalibrated at least once annually.

__ 155. -Calibration After Use.
*After each certification or audit test (four or more test runs conducted on a wood heater at the four burn rates specified in Method 28), check calibration of the

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metering system by performing three calibration runs at a single, intermediate flow rate as described in Method 5, Section 10.3.2.

NOTE: Procedures and equipment specified in Method 5, Section 16.0, for alternative calibration standards are allowed for the post-test dry gas meter calibration check.

__ 156. -Acceptable Variation in Calibration.
*If the dry gas meter coefficient values obtained before and after a certification test differ by more than 5 percent, the certification test shall either be voided and repeated, or calculations for the certification test shall be performed using whichever meter coefficient value (*i.e.*, before or after) gives the lower value of total sample volume.

-Last Calibration Date_____

__ 157. -Temperature Sensors.
*Use the procedure in Method 2, Section 10.3, to calibrate temperature sensors before the first certification or audit test and at least semiannually, thereafter.

-Last Calibration Date_____

__ 158. -Barometer.
*Calibrate against a mercury barometer before the first certification test and at least semiannually, thereafter. If a mercury barometer is used, no calibration is necessary. Follow the manufacturer's instructions for operation.

-Last Calibration Date_____

__ 159. -Analytical Balance.
*Perform a multipoint calibration (at least five points spanning the operational range) of the analytical balance before the first certification test and semiannually, thereafter. Before each certification test, audit the balance by weighing at least one calibration weight (class F) that corresponds to 50 to 150 percent of the weight of one filter. If the scale cannot reproduce the value of the calibration weight to within 0.1 mg, conduct the multipoint calibration before use.

-Last Calibration Date_____

END METHOD 5G CALIBRATION SHEET

IRETI Pellet Burning Heater Emissions Testing Procedure

Explanation: This procedure is to be used to guide the user through the process of emissions testing. You will be measuring the gaseous and particulate emissions. This procedure will set up the test and verify the emission measurement system's performance in accordance to EPA Method 5G.

8.0 Sample Collection, Preservation, Transport, and Storage.

__ 160. -Clean the dilution tunnel with an appropriately sized wire chimney brush before each certification test.

__ 161. -Draft Determination: Locate the dilution tunnel hood centrally over the wood heater stack exhaust. Operate the dilution tunnel blower at the flow rate to be used during the test run. Measure the draft imposed on the wood heater by the dilution tunnel (*i.e.*, the difference in draft measured with and without the dilution tunnel operating.) Adjust the distance between the top of the wood heater stack exhaust and the dilution tunnel hood so that the dilution tunnel induced draft is less than **1.25 Pa (0.005 in. H2O)**. Have no fire in the wood heater, close the wood heater doors, and open fully the air supply controls during this check and adjustment.

__ 162. -Pretest Ignition : Warm up stove for an hour or until LabView Signal Express shows that the temperature has stabilized.

__ 163. -Smoke Capture.
*During the pretest ignition period, operate the dilution tunnel and visually monitor the wood heater stack exhaust. Operate the wood heater with the doors closed and determine that 100 percent of the exhaust gas is collected by the dilution tunnel hood. If less than 100 percent of the wood heater exhaust gas is collected, adjust the distance between the wood heater stack and the dilution tunnel hood until no visible exhaust gas is escaping. Stop the pretest ignition period, and repeat the draft determination procedure.

__ 164. -Velocity Measurements: During the pretest ignition period, conduct a velocity traverse to identify the point of average velocity. This single point shall be used for measuring velocity during the test run.

__ 165. Velocity Traverse.

-Measure the diameter of the duct at the velocity traverse port location through both ports. Diameter 1:_____ Diameter 2:_____

-Calculate the duct area using the average of the two diameters. Average:_____

 A pretest leak-check of pitot lines as in Method 2, Section 8.1, is recommended. Place the calibrated pitot tube at the centroid of the stack in either of the velocity traverse ports. Adjust the damper or similar device on the blower inlet until the velocity indicated by the pitot is approximately 220 m/min (720 ft/min). Continue to read the velocity and temperature until the velocity has remained constant (less than 5 percent change) for 1 minute. Verify that the flow rate is 4 ± 0.40 dscm/min (140 ± 14 dscf/min); if not, readjust the damper, and repeat the velocity traverse. The moisture may be assumed to be 4 percent (100 percent relative humidity at 85 EF).

__ 166. - Testing Velocity Measurements.
*After obtaining velocity traverse results that meet the flow rate requirements, choose a point of average velocity and place the pitot and temperature sensor at that location in the duct. Alternatively, locate the pitot and the temperature sensor at the duct centroid and calculate a velocity correction factor for the centroidal position. Mount the pitot to ensure no movement during the test run and seal the port holes to prevent any air leakage. Align the pitot opening to be parallel with the duct axis at the measurement point. Check that this condition is maintained during the test run (about 30-minute intervals). Monitor the temperature and velocity during the pretest ignition period to ensure that the proper flow rate is maintained. Make adjustments to the dilution tunnel flow rate as necessary.

__ 167. - Pretest Preparation.

__ 168. - Fill the first and second impinger with 100 ml of water. Weigh and record their initial mass to the nearest 0.5 g.

__ 169. 8.1.1 Place 200 to 300 g of silica gel in each of several air-tight containers. Weigh each container, including silica gel, to the nearest 0.5 g, and record this weight. As an alternative, the silica gel need not be preweighed, but may be weighed directly in its impinger or sampling holder just prior to train assembly.

__ 170. 8.1.2 Check filters visually against light for irregularities, flaws, or pinhole leaks. Label filters of the proper diameter on the back side near the edge using numbering machine ink. As an alternative, label the shipping containers (glass or polyethylene petri dishes), and keep each filter in its identified container at all times except during sampling.

__ 171. 8.1.3 Desiccate the filters at 20 ± 5.6 EC (68 ± 10 EF) and ambient pressure for at least 24 hours. Weigh each filter (or filter and shipping container) at intervals of at least 6 hours to a constant weight (*i.e.*, #0.5 mg change from previous weighing). Record results to the nearest 0.1 mg. During each weighing, the period for which the filter is exposed to the laboratory atmosphere shall be less than 2 minutes. Alternatively (unless otherwise specified by the Administrator), the filters may be oven dried at 105 EC (220 EF) for 2 to 3 hours, desiccated for 2 hours, and weighed. Procedures other than those described, which account for relative humidity effects, may be used, subject to the approval of the Administrator.

*During preparation and assembly of the sampling train, keep all openings where contamination can occur covered until just prior to assembly or until sampling is about to begin. Using a tweezer or clean disposable surgical gloves, place one labeled (identified) and weighed filter in each of the filter holders. Be sure that each filter is properly centered and that the gasket is properly placed so as to prevent the sample gas stream from circumventing the filter. Check each filter for tears after assembly is completed. Mark the probe with heat resistant tape or by some other method to denote the proper distance into the stack or duct. Set up the train as shown in Figure 5G-1.

__ 172. -Leak-Check Procedures.
*That portion of the sampling train from the pump to the orifice meter shall be leak-checked prior to initial use and after each certification or audit test.. Use the procedure described in Method 5, Section 8.4.1.

__ 173. *Pretest Leak-Check. A pretest leak-check of the sampling train is recommended, but not required. If the pretest leak check is conducted, the procedures outlined in

Method 5, Section 8.4.2 should be used. A vacuum of 130 mm Hg (5 in. Hg) may be used instead of 380 mm Hg (15 in. Hg).

__ 174. *Post-Test Leak-Check. A leak-check of the sampling train is mandatory at the conclusion of each test run. The leak-check shall be performed in accordance with the procedures outlined in Method 5, Section 8.4.2. A vacuum of 130 mm Hg (5 in. Hg) or the highest vacuum measured during the test run, whichever is greater, may be used instead of 380 mm Hg (15 in. Hg).

__ 175. -Preliminary Determinations.
*Determine the pressure, temperature and the average velocity of the tunnel gases as in Section 8.5. Moisture content of diluted tunnel gases is assumed to be 4 percent for making flow rate calculations.

__ 176. -Sampling Train Operation.
*Position the probe inlet at the stack centroid, and block off the openings around the probe and porthole to prevent unrepresentative dilution of the gas stream. Be careful not to bump the probe into the stack wall when removing or inserting the probe through the porthole; this minimizes the chance of extracting deposited material.

__ 177. *Begin sampling at the start of the test run (once warmed up). During the test run, maintain a sample flow rate proportional to the dilution tunnel flow rate (within 10 percent of the initial proportionality ratio) and a filter holder temperature of no greater than 32 EC (90 EF). The initial sample flow rate shall be approximately 0.015 m3/min (0.5 cfm).

__ 178. *For each test run, record the data required on a data sheet such as the one shown in Figure 5G-3. Be sure to record the initial dry gas meter reading. Record the dry gas meter readings at the beginning and end of each sampling time increment and when sampling is halted. Take other readings as indicated on Figure 5G-3 at least once each 10 minutes during the test run. Since the manometer level and zero may drift because of vibrations and temperature changes, make periodic checks during the test run.

__ 179. *During the test run, make periodic adjustments to keep the temperature between (or upstream of) the filters at the proper level. Do not change sampling trains during the test run.

__ 180. *At the end of the test run, turn off the coarse adjust valve, remove the probe from the stack, turn off the pump, record the final dry gas meter reading, and conduct a post-test leak-check, as outlined in Section 8.8.2. Also, leak-check the pitot lines as described in Method 2, Section 8.1; the lines must pass this leak-check in order to validate the velocity head data.

Final Dry Gas Meter Reading:_____

Post Test Leak Check:_____

Leak Check Pitot Line:_____

Leak Check Pitot Line:_____

__ 181. **-Calculation of Proportional Sampling Rate.**
*Calculate percent proportionality (see Section 12.7) to determine whether the run was valid or another test run should be made.

__ 182. **-Sample Recovery.**
*Same as Method 5, Section 8.7,with the exception of the following: 8.12.1 An acetone blank volume of about 50-ml or more may be used.

__ 183. *Treat the samples as follows:
*Container Nos. 1 and 1A. Treat the two filters according to the procedures outlined in Method 5, Section 8.7.6.1. The filters may be stored either in a single container or in separate containers. Use the sum of the filter tare weights to determine the sample mass collected.

*Container No. 2. Taking care to see that dust on the outside of the probe or other exterior surfaces does not get into the sample, quantitatively recover particulate matter or any condensate from the probe and filter holders by washing and brushing these components with acetone and placing the wash in a labeled glass container. At least three cycles of brushing and rinsing are required.

__ 184. *Between sampling runs, keep brushes clean and protected from contamination.
__ 185. *After all acetone washings and particulate matter have been collected in the sample containers, tighten the lids on the sample containers so that the acetone will not leak out when transferred to the laboratory weighing area. Mark the height of the fluid levels to determine whether leakage occurs during transport. Label the containers clearly to identify contents.

END METHOD 5G PROCEDURE SHEET

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IRETI Pellet Burning Heater Emissions Testing Equipment Calibration Procedure

Explanation: This procedure is to be used to guide the user through the process of calibrating the testing equipment. You will be measuring the values output by the equipment against a known standard. This procedure will properly set up the equipment in accordance to EPA Method 28.

__ *1. 10.0 Calibration and Standardizations.*

__ 2. **Note:** Same as Section 10.0 of either Method 5G or Method 5H, with the addition of the following:

__ 3. -Platform Scale.
__ 4. *Perform a multi-point calibration (at least five points spanning the operational range) of the platform scale before its initial use. The scale manufacturer's calibration results are sufficient for this purpose. Before each certification test, audit the scale with the wood heater in place by weighing at least one calibration weight (Class F) that corresponds to between 20 percent and 80 percent of the expected test fuel charge weight. If the scale cannot reproduce the value of the calibration weight within 0.05 kg (0.1 lb) or 1 percent of the expected test fuel charge weight, whichever is greater, recalibrate the scale before use with at least five calibration weights spanning the operational range of the scale.

__ 5. -Balance (optional).
__ 6. *Calibrate as described in Section 10.1.

__ 7. -Temperature Monitor.
__ 8. *Calibrate as in Method 2, Section 4.3, before the first certification test and semiannually thereafter.

__ 9. -Moisture Meter.

__ 10. *Calibrate as per the manufacturer's instructions before each certification test.

__ 11. -Anemometer.
__ 12. *Calibrate the anemometer as specified by the manufacturer's instructions before the first certification test and semiannually thereafter.

__ 13. -Barometer.
__ 14. *Calibrate against a mercury barometer before the first certification test and semiannually thereafter.

__ 15. -Draft Gauge.
__ 16. *Calibrate as per the manufacturer's instructions; a liquid manometer does not require calibration.

__ 17. -Humidity Gauge.
__ 18. *Calibrate as per the manufacturer's instructions before the first certification test and semiannually thereafter.

END METHOD 28 CALIBRATION SHEET

:
:
:
:
:
:
:
:
P a g e | 95

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IRETI Pellet Burning Heater Emissions Testing Procedure

Explanation: This procedure is to be used to guide the user through the process of emissions testing. You will be measuring the gaseous and particulate emissions. This procedure will set up the test and verify the emission measurement system's performance in accordance to EPA Method 28.

*Certification testing requirements and procedures for pellet burning wood heaters are identical to those for other wood heaters, with the following exceptions:

*Test Fuel Properties. The test fuel shall be all wood pellets with a moisture content no greater than 20 percent on a wet basis (25 percent on a dry basis). Determine the wood moisture content with either ASTM D 2016-74 or 83, (Method A), ASTM D 4444-92, or ASTM D 4442-84 or 92 (all noted ASTM standards are incorporated by reference - see §60.17).

__ 1. -Test Fuel Charge Specifications.
__ 2. *The test fuel charge size shall be as per the manufacturer's written instructions for maintaining the desired burn rate.

__ 3. -Wood Heater Firebox Volume.
__ 4. *The firebox volume need not be measured or determined for establishing the test fuel charge size. The firebox dimensions and other heater specifications needed to identify the heater for certification purposes shall be reported.

__ 5. -Heater Installation.
__ 6. *Arrange the heater with the fuel supply hopper on the platform scale as described in
__ 7. Section 8.6.1

__ 8. -Pretest Ignition.

__ 9. *Start a fire in the heater as directed by the manufacturer's written instructions, and adjust the heater controls to achieve the desired burn rate. Operate the heater at the desired burn rate for at least 1hour before the start of the test run.

__ 10. -Test Run.

__ 11. *Complete a test run in each burn rate category as follows:

__ 12. *Test Run Start. When the wood heater has operated for at least 1 hour at the desired burn rate, add fuel to the supply hopper as necessary to complete the test run, record the weight of the fuel in the supply hopper (the wood heater weight), and start the test run. Add no additional fuel to the hopper during the test run. Record all the wood heater surface temperatures, the initial sampling method measurement values, the time at the start of the test, and begin the emission sampling. Make no adjustments to the wood heater air supply or wood supply rate during the test run.

__ 13. -Data Recording.

__ 14. *Record the fuel (wood heater) weight data, wood heater temperature and operational data, and emission sampling data as described in Section 8.12.2.

__ 15. -Test Run Completion.

__ 16. *Continue emission sampling and wood heater operation for 2 hours. At the end of the test run, stop the particulate sampling, and record the final fuel weight, the run time, and all final measurement values, including all wood heater individual surface temperatures.

__ 17. -Calculations.

__ 18. *Determine the burn rate using the difference between the initial and final fuel (wood heater) weights and the procedures described in Section 12.4. Complete the other calculations as described in Section 12.0.

END Method 28 PROC-SHEET

Test Name (RUN #): _____

Filter Numbers: A _____ B _____

Probe Numbers: A _____ B _____

Stove Make and Model: _____

Stove Power Level:

Test Start Time:

Test End Time:

Final Scale Weight:

Components		Date -Time	Temp(C)-RH%	Weight (mg)						
				Filters		O-rings				
				Front	Back	Front	Back	Probe	Total (PM)	
A	(Before)	/ / - :								
	(After)	/ / - :								
B	(Before)	/ / - :								
	(After)	/ / - :								

Notes: _____

_____

_____

END PM Analysis Data Sheet_5G3

Test Name: _____

Stove Make and Model: _____

Filter Numbers: A _____ B _____

Run Number: _____

Pitot-Tube Coefficient: ___99%___ (Cp)

Room Temperature: _____ (°C)

Barometric Pressure: _____ (mmHg)

Draft or Static Pressure: _____ (mm H$_2$O)

Clock Time	Test Run Time (min)	Gas Meter Volume (Liters)		Vacuum (in Hg)		Tunnel Temp. (°C), T$_s$	Filter Holder Temperature (°C)		Gas Sample Temp. @ DGM (°C)				Ma Velo (in
		A	B	A	B	--------	A	B	Inlet	Outlet	Inlet	Outlet	--------
									A		B		
AM/PM	--------												
:	00												
:	10												
:	20												
:	30												
:	40												
:	50												
:	1:00												
:	1:10												
:	1:20												
:	1:30												
:	1:40												
:	1:50												
:	2:00												
END	Total												
	Average												

(Initial / Final / Meas / Targe)

END Sampling Data Sheet 5G3

EXAMPLES OF RAW DATA SHEETS

LAB_STARTUP-SHEET_DUAL_5G3
American PM
American GASES
American Temps

IRETI CAI FTIR Setup and Operation Procedure - Dual Test

Explanation: This procedure is to be used to guide the user through the process of setting up and operating the testing equipment. You will be preparing all of the equipment in the lab in order to start calibration and testing. This procedure will properly set up the equipment for pellet-stove testing against EPA Method 28 and 5G.

Test Name (1of2): _100% Wood_ Fingers_ level 10_3/3/11_

Test Date/Time: _3/3/11 11:00_

Test Description (Span Y/N): _New Aluminum Filter Holders are Great_
Sucess! Span was off on O₂
_by 3 %_

___ 1. Power up the Scale
___ 2. Turn on the FID fuel tank.
___ 3. Turn on the N2 gas tank.
___ 4. If the FTIR was purged, while idle, with zero air, turn the 3-way valve on the back of the FTIR bench to the DOWN position for an initial N2 purge of the system before the first real test.
___ 5. Power up the CAI FTIR bench
    - **Power-up time:** _11:00_
___ 6. Power up the CAI laptop
___ 7. Power up the heated sample line controller
___ 8. Allow all 1-hour to stabilize
___ 9. Measure facility conditions and record them.
    - **Temp (DB)** _A_ **(WB)** _3_ **(RH%)** _41_ **Atmospheric Pres.(mmHg)** _749_
___ 10. Once the laptop is booted up, Open the NOW software and OPUS (Password: OPUS)
___ 11. Check FID for burner temp to be upwards of 250degrees Celsius. If it is not, IGNITE it.
    * The best way to ignite the FID flame is to make sure it is getting zero air and FID fuel, hit F8 on the main screen and it should turn right on.
    * If FID fails to ignite, check for to see if there is FID fuel flowing and Zero Air flow (3-way valve in back in up position. If it's been sitting for too long, take a 9/16ths wrench and crack open the line marked "FUEL" on the back of the FID and let it bleed out some of the gas.
___ 12. Check Diagnostics for FID and O2 sensors; make sure voltages are not around 9volts.
    - **FID Sample Pressure Sensor Output (in Volts)** _2.51_
___ 13. For the FTIR in OPUS, check the status light in the bottom right corner.
        -Yellow: Might be humidity out of range, but make sure to look and see what is up.
        -Green: all systems GO
        -Red: See what is wrong, if no easy fix, CALL CAI.
___ 14. In OPUS, Click Measure on the toolbar, Click Advanced Measurement, Click Check Signal, Select Spectrum and note the amplitude of the spectrum. *Should be around 7900.
    - **Amplitude:** _101_

___ 15. If all diagnostics pass and the system has had 1-hour to warm up and stabilize, Zero the FID using ZERO AIR; wait for it to stabilize before saving the value.

      *This could be done manually on the bench or using the NOW software.

___ 16. After saving a Zero value, go ahead and hook up the line labeled THC Span to the Methane bottle.

___ 17. SPAN the FID by choosing the span option and entering the certified bottle value and wait for the value to stabilize before saving the value.
- **Bottle Value:** ___ 95.8 ___

___ 18. !!!Make sure if you are using the NOW software to check the standby box before closing the calibration window, if not your zero and span data will not save!!!

___ 19. Zeroing the O2 sensor will be done just as the FID, except it requires a Nitrogen based Zeroing.
    Turn on the Nitrogen tank and make sure the valve in the front is set on "N2" for nitrogen purging.

___ 20. SPAN will be the same for the O2 detector except the gas will be a known amount of oxygen and it will be SPAN'd through the THC SPAN line. Zero, Span, Standby
- **Bottle Value:** ___ 24.01% ___

___ 21. Any changes manually made to the FID or O2 sensor while the NOW software is running must be saved to the NOW program.

    All software and hardware should be ready to start operations.

FTIR Spanning (Can be done once a week)
    Date of last SPAN: 05 / 03 / 11

___ 22. In OPUS, Click Measure on the toolbar, select Control process, select the MNSU process file MNSU_191C_Process1.3, and give the test a name. Click Analyze (Actually level 10)
- **Given Test Name:** ___ 100% Need Fingers level 5-3/4 11

___ 23. The cell should be cleared with N2 before each new experiment, so purge for (5-10) minutes.

___ 24. In OPUS click "Measure Reference" while still purging with N2, allowing 5 scans to get a proper reading.
    *A reference must be taken at the start of each experiment
- **Reference Scan Time:** 12-13

___ 25. Time to baseline the analyzer and see if it is capturing the gases properly; switch valve in front panel to SPAN.

___ 26. Turn open the Span gas bottles and connect each one at a time allowing 5-10 minutes for the analyzer to stabilize the gas sample. Flow must be @ 10 lpm.
- **(19.35) SPAN Gas on CO2 (time)** 12:17 **Analyzer Measured** 19.336 %
- **(471) SPAN Gas on SO2 (time)** 12:21 **Analyzer Measured** 467.6 ppm
- **(48.8) SPAN Gas on CO (time)** 12:25 **Analyzer Measured** 47.28 ppm
- **(96.7) SPAN Gas on NO (time)** 12:29 **Analyzer Measured** 96.825 ppm
- **(95.8) SPAN Gas on Methane CH4 (time)** 12:35 **Analyzer Measured** 96.57 ppm
- **(95.4) SPAN Gas on NOx (time)** 12:40 **Analyzer Measured** 94.57 ppm

___ 27. As long as all of the values look satisfactory (within 10%), the FTIR is now ready to analyze and record data into the same file.

___ 28. Shut off the SPAN gas bottles and ensure that the cell is being purged with zero air and the valve in the front is set to the 12'oclock (OFF) position to begin sampling.

___ 29. There are no other buttons to click, other than making a note of the flue-gas sampling start time (Which should coincide with the PM test start-up time.)
- **Start up time:** 1 :44

Stove Start-up and Operation (Hestia)
___ 30. Draft Determination (must be < 1.25)
- **Value measured:** ___ 75

_31. Pre-test Air Velocity Determination (must be <0.25m/sec)
- **Value measured:** _2 m/sec_
_32. Clean ashes and empty ash tray into trash or collect as a sample.
_33. Make sure there is fuel in the hopper
_34. Flip the green toggle switch in the rear of the stove
_35. Ensure that the display screen shows "Stove Cold"
_36. GO AHEAD and hold the "Start/Shutdown" button
_37. Select your burn(comfort) level
-**Burn Level Selected (1-10):** _5_
-**Stove-on time:** _10:54_
-**Flame-on time:** _11:01_
_38. Ensure stove ignites and starts burning. If not investigate.
_39. Allow temperature to stabilize before data recording

FID and O2 logging setup
_40. For logging the FID and O2 you must be in the NOW software and click on "Testing" on the toolbar. Then click on bench control utility.
_41. Within bench control utility, make sure to click on the Measure option; if not the program will start recording without giving the analyzers a signal to start.
_42. Before clicking **Begin test** you can set the rate at which NOW will record to the log file. It is best to set it at a sample rate of every minute.
_43. Hit the **Begin test** button and let the analyzer do its job.

Thermocouple Logging Setup
_44. Open The Signal Express LabView project called "**IRETI-Hestia**"
_45. Turn on the SCXI chassis
_46. Make sure computer is linked to SCXI (a pop up will advise you).
_47. Click "Run" on the toolbar.
_48. Dialogue screen will pop up and display the list of thermocouples to read, check the box labeled "thermocouple."
_49. Give the project a name along with the timestamp.
- **Given Name:** _100% Wood — Fingers level_10- 3/4/11_
_50. Hit record to start recording at 2 samples per minute.

PM Sampling Setup (must be done once everything else is ready)
_51. Ensure that the dilution tunnel hood is capturing all of the smoke output by the stack.
_52. Make sure manometer is level and zeroed out.
_53. Open a <u>Dilution Tunnel Flow</u> spreadsheet located on the Desktop>Procedure_Testing folder.
_54. Save in the <u>Test Data</u> file in the Documents folder and assign the current test name.
Name given: _100 Wood — Fingers level_10-3/3/11_
_55. Velocity Traverse (Pitot Tube & Manometer) *Record and Calculate in spreadsheet.
*Must be around **220 m/min at centroid!**
*Monitor for a minute
*Perform Velocity Traverse
*Calculate the total gas flow rate = 4 +/- 0.40 dscm/min; if not, adjust and repeat
_56. Using the Apex PM sampling box, set the flow rate to 4 lpm by resetting timers and flipping on pump and timers simultaneously. (Tip: try to achieve 2 lpm in 30 seconds)
- Adjust the flow meters accordingly.

Filter Numbers?

57. To prepare the particulate filters*: Number the filters, near the edge. Visually inspect for holes or other issues.
   *Must be desiccated for 24 hrs before use.
✓ 58. To prepare the probes rinse with acetone to clean and remove moisture before desiccating.
✓ 59. Weigh filters and probes. PM
   *Record measurements on "Analysis Data Sheet"
✓ 60. Carefully assemble the probes with filter to the mid-section of the sample train.
   TIGHTEN VERY LIGHTLY*
✓ 61. Quickly bring the remaining filter to the test location to finish assembling the rear half of the sample train.
   (DO NOT LEAVE OUT for more than two minutes without capping)

Leak-Check
62. Turn on pump- cover sample probes- Check for vacuum.
   -Ball on flow meter should drop to 0 (meaning no flow).
   - Initial Leak Check Results: 0.004, 0.000
      A   B

What's our allowable rate?
.161 lpm

Starting a Test
   *Means having all systems on-line and being ready to test.
✓ 63. FTIR- OPUS
✓ 64. FID- NOW
✓ 65. Thermocouple Recording
✓ 66. PM Sampling Trains
   - Insert probes; be careful not to bump probes into the stack wall as it could extract sediment along the lining of the stack wall.
   (Make sure during the test filter holder temperature remains under 90°C)

✓ 67. Data-Recording Sheets
✓ 68. Timers
✓ 69. Stove Temp Stabilized (around 45 minutes) * Can check on the data logger. (Level-5 "Back" @ 502C, Level-10 "Back" @ 525C+)
70. Insert probes into the dilution tunnel up to the marked 3" line.

Check team PS

71. Once stove is up to temp, start filling out the data sheet called "Particulate Sampling Data Sheet" and turn the pump and timer on.
✓ 72. Tare Scale Time: 1:44
✓ 73. Test Start Time: 1:44 (Required Time: 2hrs)
✓ 74. Continuously record data every 10 minutes. This requires adjustment of the flow rate to maintain a flow rate of 4 l/min.
✓ 75. Record Scale weights every 10 minutes as well.

Time (10min)	Weight (kg)
Start 1:44	TARE
1 1:54	-.35
2 2:04	-.75
3 2:14	-1.00
4 2:24	-1.40
5 2:34	-1.75
6 2:44	-2.15
7 2:54	1.20

1.55
-2.2

added 3.75
weighed @ 2:44 to 1.50

8	3:04		.85
9	3:14		.5
10	3:24		.15
11	3:34		-.25
END	3:44		-.60

Sample Recovery

76. Shut off Pumps and Timers
77. Remove probes and perform final leak checks.
   - Final Leak Check Results: .008 B.000
78. Separate probe and mid-section from rear portion of filter holder and collect the rear filter in a Petri dish. Bring everything to the weighing station.
79. Disassemble mid-section from probe, remove front filter.
80. ~~Quickly start weighing all of the components, minus the mid-section~~ Dessicate + weigh 24hrs later
81. ~~Record Data on "Analysis Data Sheet"~~
82. End logging in NOW
83. End logging in OPUS
84. End logging in Signal Express
85. Desiccate the filters for 24hrs, allowing the moisture to be removed from the PM sample.
86. Record Data on "Analysis Data Sheet".
87. Calculate data on "Analysis Data Sheet"

Test 2

Test Name (2of2): 100% Wood Fingers _ level _ 10 _ 2 _
Test Date/Time: 3/3/11 4:16pm
Test Description (Span Y/N):_____

_____
_____

88. Measure facility conditions and record them
   - Temp (DB) 74 (WB) 13 (RH%) #26% Atmospheric Pres.(mmHg) 748
89. All systems should be ready to pick up where Test (1of2) left off.

FTIR Prep.
90. In OPUS, Click Measure on the toolbar, select Control process, select the MNSU process file MNSU_191C_Process1.3, and give the test a name. Click Analyze.
   - Given Test Name: 100 WOOD Fingers _LEVEL _ 10 _ 2 _
91. The cell should be cleared with N2 before each new experiment, so purge for (5-10) minutes.
92. In OPUS click "Measure Reference" while still purging with N2, allowing 5 scans to get a proper reading.

*A reference must be taken at the start of each experiment
Reference Scan Time: __4:25__

93. There are no other buttons to click, other than making a note of the flue-gas sampling start time (Which should coincide with the PM test start-up time.)
    - Start-up time: _____

Stove Operation (Hestia)
94. Make sure there is fuel in the hopper
95. If switching burn temp, allow temp to stabilize
96. Select your burn (comfort) level
    -**Burn Level Selected (1-10):** __10__
    -**Stove-on time:** _____
    -**Flame-on time:** _____

FID and O2 logging setup
97. For logging the FID and O2 you must be in the NOW software and click on "Testing" on the toolbar. Then click on bench control utility.
98. Within bench control utility, make sure to click on the Measure option; if not the program will start recording without giving the analyzers a signal to start.
99. Before clicking **Begin test** you can set the rate at which NOW will record to the log file. It is best to set it at a sample rate of every minute.
100. Hit the **Begin test** button and let the analyzer do its job.

Thermocouple Logging Setup
101. Click "Run" on the toolbar.
102. Dialogue screen will pop up and display the list of thermocouples to read, check the box labeled "thermocouple."
103. Give the project a name along with the timestamp.
    - **Given Name:** __#DO Wood Fingers Level W_2__
104. Hit record to start recording at 2 samples per minute.

PM Sampling Setup (must be done once everything else is ready)
105. Ensure that the dilution tunnel hood is capturing all of the smoke output by the stack.
106. Make sure manometer is level and zeroed out.
107. Open a Dilution Tunnel Flow spreadsheet located on the Desktop>Procedure_Testing folder.
108. Save in the Test Data file in the Documents folder and assign the current test name.
    Name given: __DTF_ lon Wood –Fingers_ Level 10_2__
109. Velocity Traverse (Pitot Tube & Manometer) *Record and Calculate in spreadsheet.
    *Must be around **220 m/min at centroid!**
    *Monitor for a minute
    *Perform Velocity Traverse
    *Calculate the total gas flow rate = 4 +/- 0.40 dscm/min; if not, adjust and repeat
110. Using the Apex PM sampling box, set the flow rate to 4 lpm by resetting timers and flipping on pump and timers simultaneously. (Tip: try to achieve 2 lpm in 30 seconds)
    - Adjust the flow meters accordingly.
111. To prepare the particulate filters*: Number the filters, near the edge. Visually inspect for holes or other issues.

*Must be desiccated for 24 hrs before use.
112. To prepare the probes rinse with acetone to clean and remove moisture before desiccating.
113. Weigh filters and probes.
   *Record measurements on "Analysis Data Sheet"
114. Carefully assemble the probes with filter to the mid-section of the sample train.
   TIGHTEN VERY TIGHTLY
115. Quickly bring the remaining filter to the test location to finish assembling the rear half of the sample train.
   (DO NOT LEAVE OUT for more than two minutes without capping)

Leak-Check
116. Turn on pump- cover sample probes- Check for vacuum.
   -Ball on flow meter should drop to 0 (meaning no flow).
   - **Initial Leak Check Results:** _A0, B0_

Starting a Test
   *Means having all systems on-line and being ready to test.
117. **FTIR- OPUS**
118. **FID- NOW**
119. **Thermocouple Recording**
120. **PM Sampling Trains**
   - Insert probes; be careful not to bump probes into the stack wall as it could extract sediment along the lining of the stack wall.
   (Make sure during the test filter holder temperature remains under 90°C)
121. **Data-Recording Sheets**
122. **Timers**
123. **Stove Temp Stabilized (around 45 minutes) * Can check on the data logger. (Level-5 "Back" @ 502C, Level-10 "Back" @ 525C+)**
124. Insert probes into the dilution tunnel up to the marked 3" line.
125. Once stove is up to temp, start filling out the data sheet called "Particulate Sampling Data Sheet" and turn the pump and timer on.
126. **Tare Scale Time:** _5 : 12_
127. **Test Start Time:** _5 : 12_ **(Required Time: 2hrs)**
128. Continuously record data every 10 minutes. This requires adjustment of the flow rate to maintain a flow rate of 4 l/min.
129. Record Scale weights every 10 minutes as well.

Time (10min)	Weight (kg)
Start _5 : 12_	TARE
1 _5 : 22_	-.40
2 _5 : 32_	-.75
3 _5 : 42_	-1.15
4 _5 : 52_	-1.55
5 _6 : 02_	-1.90
6 _6 : 12_	-2.30
7 _6 : 22_	-2.70
8 _6 : 32_	-3.05
9 _6 : 42_	-3.40
10 _6 : 52_	-3.80

11 _7:02_   _-4.25_
END _7:12_   _-4.6_

Sample Recovery
130. Shut off Pumps and Timers
131. Remove probes and perform final leak checks.
   - **Final Leak Check Results:** _0.00_   _0.00_
132. Separate probe and mid-section from rear portion of filter holder and collect the rear filter in a Petri dish. Bring everything to the weighing station.
133. Disassemble mid-section from probe, remove front filter.
134. Quickly start weighing all of the components, minus the mid-section
135. Record Data on "Analysis Data Sheet"
136. Post-test Air Velocity Determination (must be <0.25m/sec)
   - **Value measured:** _.15_
137. End logging in NOW
138. End logging in OPUS
139. End logging in Signal Express
140. Desiccate the filters for 24hrs, allowing the moisture to be removed from the PM sample.
141. Record Data on "Analysis Data Sheet".
142. Calculate data on "Analysis Data Sheet"

TEST & EQUIPMENT SHUT DOWN PROCEDURE
143. Time: _7:23pm_
144. Final Weight: _4.9_
145. Off and Cool time: _7:40_
146. File relocation
   -OPUS (New folder>Rename>Copy & Paste spectra file and gaslogs into new folder)
   -NOW-FID and O2 data-(Drag into above created folder)
   -Thermocouple log- save log
147. FTIR shut down
148. Make sure valve on front is returned to N2 purge
149. Open the N2 tank and purge for 5 minutes
150. Close N2 tank.
151. Valve on back is returned to the up position to purge machine with Zero Air.
152. Check gauge on the front of machine to make sure @ least .5 lpm is flowing.
153. Shut off CAI computer.
154. Flip CB1 behind front cover of FTIR to the down "OFF" position.
155. Shut off heated sample line controller box.
156. Wait for "Stove Cold" on stove display (circulation fans will kick "OFF")
157. Flip off Green switch on back of stove once "Stove Cold" displays.
158. Disconnect Dwyer draft gauge overnight.

Particulate Sampling Data Sheet – 5G3

Test 1

Date: 3/3/11 - 1:39
Technician: MRF-SAG
A- C

Test Name: 100% Wood Fibers Wood 3/3/11

Field	Value
Stove Make and Model:	MH? I
Filter Numbers:	4F - 4, V gF
Run Number:	1
Pitot-Tube Coefficient:	99% (Cp)
Room Temperature:	21 (°C)
Barometric Pressure:	749 (mmHg)
Draft or Static Pressure:	4.8 (mm H₂O)
Initial Leak Rate:	.004 , .000 (m³/min)
Final Leak Rate:	.001 , .000 (m³/min)
Measured or Assumed Moisture:	4 (%)
Target Flow Rate = 4 lpm	

Clock Time	Test Run Time (min)	Gas Meter Volume (Liters)		Vacuum (in Hg)		Tunnel Temp. (°C), Tₛ	Filter Holder Temperature (°C)			Gas Sample Temp. @ DGM (°F)				Manometer Velocity Head (inH₂O), ΔPₛ	Sample Flow Meters (mmH₂O)	
AM/PM		A	B	A	B		A	B	Inlet	A Outlet		B Inlet	B Outlet		A	B
1:44	00	0	0	-2.5	-2	----	49	21	71	71	72	73	35.35	60	60	60
1:54	10	38.97	38.975	-2.5	-1	50	22	21	71	71	74	.035	60	60	60	
2:04	20	76.9	77.08	-2.5	-1	50	25	22	72	71	72	75	.035	60	60	60
2:14	30	116	116	-2.5	-1	50.4	24	23	73	73	72	76	.035	60	60	60
2:24	40	150	150	-2.5	-1	50.6	24	23	73	74	78	35	.035	60	60	60
2:34	50	182	183	-2.5	-1	50	24	23	73	75	78	77	.035	60	60	60
2:44	1:00	217	219	-2.5	-1	50	24	23	73	75	72	77	.035	60	60	60
2:54	1:10	253	255	-2.5	-1	50	24	23	73	76	78	78	.035	60	60	60
3:04	1:20	291	291	-5	-1	50	24	23	76	76	72	78	.035	60	60	60
3:14	1:30	331	330	-5	-2.5	49	24	24	76	76	23	27	.035	60	60	60
3:24	1:40	370	371	-5	-2.5	49	24	24	76	76	73	27	.035	60	60	60
3:34	1:50	410	412	-5	-2.5	50	24	24	76	76	76	78	.035	60	60	60
3:44	2:00	449	451	-5	-2.5	50	23	25	73	72	72	78	.035	60	60	60
END																
Total																
Average																

PM Analysis Data Sheet – 5G3

Date: 3/3/11 - 1:40
Technician: SAG

Test Name (RUN #): 100% wood - Fingers Level (6 - 3/3/11)
Filter Numbers: A _4 F 4_ B _8 F, 8._
Probe Numbers: A _04_ B _08_
Stove Make and Model: _HHPC_

Stove Power Level: 10
Test Start Time: 1:44 pm
Test End Time: 9:44 pm
Final Scale Weight: _____

Test 1

Components		Date-Time	Temp(C)-RH%	Weight (mg)					
				Filters .0001		O-rings			Total (PM)
				Front	Back	Front	Back	Probe .0001	.0119
A	(Before)	3/3/11 - 1:29	.0119	.1164	.1161	1.7164		109.8485	.0119 + .0001 + .0001
	(After)	/ / - :	0.1283	.1162	1.7733		109.8434		— .0001 = — .0088
B	(Before)	3/3/11 - 1:39	.1172	.1163	1.7794		110.1058		.0119 + .0001 + .0001
	(After)	/ / - :	.1279	.1165	1.7756	1.7191	110.1045		.0119

Notes: _____

Particulate Sampling Data Sheet – 5G3

Test 2

Date: 2/5/11 - 4:52
Technician: SAG

Test Name: 100 wksat Finger Level 10 L
Stove Make and Model: HHP2
Filter Numbers: A QF, Q,   B QF, Q,
Run Number: 2

Pitot-Tube Coefficient: 99% (Cp)
Room Temperature: 24 (°C)
Barometric Pressure: 7475 (mmHg)
Draft or Static Pressure: .48 (mm H₂O)

Initial Leak Rate: A 0.00 B 0.00 (m³/min)
Final Leak Rate: A 0.000 B 0.000 (m³/min)
Measured or Assumed Moisture: 4 (%)
Target Flow Rate = 4 lpm

Clock Time	Test Run Time (min)	Gas Meter Volume (Liters)		Vacuum (in Hg)		Tunnel Temp. (°C), T_s	Filter Holder Temperature (°C)		Gas Sample Temp. @ DGM				Manometer Velocity Head (inH₂O), ΔP_s	Sample Flow Meters (mmH₂O)	
AM/PM		A	B	A	B		A	B	A Inlet	A Outlet	B Inlet	B Outlet		A	B
5:12	00	0	0	2B-3		50	24	23	71	72	71	73	.035	79	79
5:22	10	44	44	3	2	51	24	24	72	71	71	74	.035	75	75
5:32	20	86	86	3	2	51	25	24	71	73	71	75	.035	72	72
5:42	30	126	128	3	2	52	25	24	71	73	69	74	.035	70	70
5:52	40	165	167	3	2	53	25	24	71	74	69	74	.035	69	69
6:02	50	204	207	3	2	52	25	23	70	74	69	74	.035	69	69
6:12	1:00	243	246	4	2	52	25	23	71	74	69	74	.035	69	69
6:22	1:10	282	284	4	25	53	25	23	71	74	69	74	.035	69	69
6:32	1:20	321	323	25	25	53	25	23	70	74	69	74	.035	69	69
6:42	1:30	359	361	3	3	63	25	23	70	71	69	74	.035	69	69
6:52	1:40	398	400	5	3	52	25	23	76	74	69	74	.035	69	69
7:02	1:50	436	438	5	35	52	24	23	71	74	69	74	.035	69	69
7:12	2:00	476	478	5	4	52	24	23	71	74	69	74	.035	69	69
END									7084	7053	7146	7173			
Total		476	478												
Average															

Edited By: SAG
March 3, 2011

PM Analysis Data Sheet – 5G3

Test 2

Date: 3/3/11 4:33
Technician: SAG

Test Name (RUN #): 100 wood Emgers Level 10, 2
Filter Numbers: A OF1Q, B F7,7,
Probe Numbers: A OO B O7
Stove Make and Model: HHP2

Stove Power Level: LO
Test Start Time: 5:12
Test End Time: 7:16
Final Scale Weight: - 4.65

Components		Date-Time	Temp(C)- RH%	Filters– .0O11 Front	Back	O-rings Front	Back	Probe .0O46	Total (PM)
A	(Before)	3/3/11 - :	.0101	0.1171	.1171	1.7594	1.7572	109.909	.0051 ₂
	(After)	/ / - :		0.1280	.1167	1.7494	1.7531	109.9874	+.0109 +(.0544)+(-.6539) +(.0041)+(-.0046) -.0019
B	(Before)	3/3/11 - :		0.1157	.1175	1.7537	1.7529	109.9906	+.0107 +(0)+(-.013) +(-.0041)+(-.0051)
	(After)	/ / - :		0.1264	.1175	1.7340	1.7488	109.9655	-0.0015
			.010 ⁻		0		-.0051	.0056	

Notes: