Impacts of Diluting Ethanol on Alcohol Stove Emissions and Efficiencies

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I. Objectives

Wood and charcoal are common sources of fuel used for personal cooking in developing countries. However, these sources are inefficient and can have significant health risks. A push for cleaner burning fuels, such as ethanol, is occurring, but creates market and cost challenges. To ease this cost burden, ethanol diluted with water is considered as an alternative to distilled ethanol. However, diluted ethanol could reduce the combustion efficiency, lowering its viability as an alternative cooking fuel. This study will use a simple alcohol stove to compare the impacts of diluent on emissions and efficiencies. It is expected that increasing diluent will result in reduced emissions and minimal change in cooking efficiencies. These measurements will be determined according to the standard Water Boiling Test protocol with a Portable Emissions Measurement System (PEMS), and the data collected from this experiment will be compared to the literature.

An alcohol cookstove will be used to burn an ethanol-water dilution. The mass percent of ethanol in the fuel mixture will be varied from 95%, 90%, 85%, 80%, and 75%. The experimental approach will test for fuel burn efficiency and stove efficiency of the diluted ethanol fuel. A standardized water boiling test, enabling the comparison of a wide variety of stoves, will be implemented to measure the efficiency of the stove. This test will compare the energy adsorbed by water within a pot to the energy released by the fuel. A gas analyzer will examine the CO and CO_2 contents. A stagnation style flow meter will measure the exhaust flow. By using the exhaust flow and CO and CO_2 content a fuel burn efficiency can be calculated. A detailed outline and sketch of the experiment and equations used can be found in appendix A The CO emissions of the burn is a health concern since the stoves will be used within an enclosed environment. In addition, the efficiency of the stove will determine if dilution of the fuel is a feasible alternative to pure ethanol enabling a more cost effective source of cleaner energy.

II. Calibration and Measurements

In order to apply the water boiling test and gather data, measurements of the mass of the fuel and temperature of the water are required. The equations of interest and the corresponding error analysis can be found in appendix A and B. Omega type-k thermocouples and a Ohaus Scout scale will be used and calibrated. The PEMS will be used for measuring the CO and CO_2 emissions. The PEMS is calibrated every 6 months by Aprovecho Research Center and is outside of the scope for this experiment, so we will not be calibrating the PEMS. However, the PEMS samples the emissions from the exhaust flow, and thus the flow velocity needs to be known. A Nailor Industries 36FMS is used to measure the flow and requires calibration. The flow-meter is a 4-point stagnation pitot tube that measures pressure drop in the system. This pressure drop is measured using an Omega PCL-1b. The Omega PCL-1b is a module that is calibrated by the manufacture who provides certificate of calibration and thus will not be calibrated. Details and specifications of each instrument can be found in appendix D.

Calibration of type-k thermocouples was performed using a 2 point method, achieved using an ice bath and a boiling bath. The modules used during calibration were a SCXI 1303 for the cold-junction, a SCXI 1102 amplifier and module, a SCXI 1000 chassis for signal conditioning, and a PCI-6023E module to convert the analog signal to digital. The connection chart found in appendix C has been included to help understand the required modules. The software reading the temperature measurements was National Instruments Laboratory Virtual Instrument Engineering Workbench (LabVIEW™). This software has calibration properties for each channel; the results of these calibrations are shown in appendix H. The maximum and minimum tolerances were taken for the ice and boiling baths resulting in ranges for low and high of -0.402 to 0.136 °C and 98.45 to 99.1 °C. Caution will be used to ensure that the thermocouples do not touch the bottom of the pot, as this could skew the temperature measurements.

Precision weights were used in calibration of the scales. For calibration of scales and balances, the American Society for Testing and Materials (ASTM) International [1] recommends that the precision weights used have a tolerance that is factor smaller than the readability of the scale. For example if a scale reads to 1 gram, the precision weights are required to have a tolerance of 0.1–0.9 grams at most. The scale used for this experiment has a readability limit of 1 gram, and the weights used had precision on the order of $\pm$ 0.001 grams, satisfying

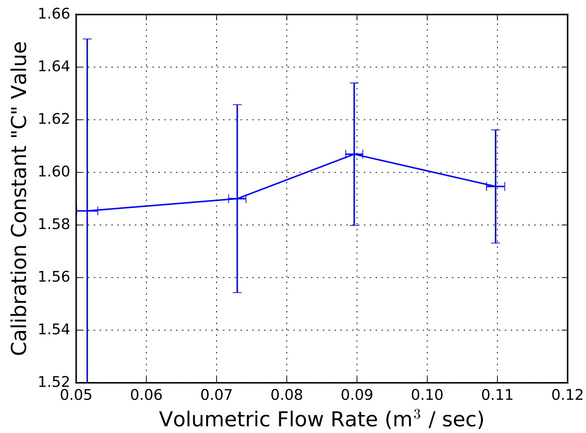


Fig. 1. Calibration curve for the FMS36 flow-meter

ASTM's recommendation. Images of the calibration can be found in appendix H. Using this calibration method ensures that the largest source of error is the instrumentation error in the scale.

The flow-meter was calibrated by creating a velocity profile using a pitot tube, see appendix D. The average of the velocity profile measurements for 4 different volumetric flow rates were compared to the volumetric flow rate calculated from an equation provided by the manufacturer of the flow-meter, found in figure 1 and provided as follows:

$$u = 215\sqrt{\Delta P} \tag{1}$$

in which u is the volumetric flow rate and ΔP is the differential pressure across the flow-meter. The calibration was applied to this equation by multiplying by a calibration constant C, which was determined as follows:

$$C = \frac{v_{Pitot}A}{215\sqrt{\Delta P}} \tag{2}$$

in which v_{Pitot} is the average velocity through the duct determined using the pitot tube and A is the measured cross sectional area of the duct. The calibration constant was found to be approximately 1.6 with a relative uncertainty of approximately 4%, as seen in figure 1.

The uncertainty of the experiment was revised using values obtained during the calibration procedure. The uncertainty of the thermal efficiency improved from approximately 5% to 4% due to the newer selection of calibrated thermocouples that have a smaller tolerance than previously expected (+/- 1.0°C versus +/- 2.2°C). The uncertainty of the CO production increased from approximately 6% to 7% due to the introduction of uncertainty associated with the calibration of the flow-meter.

III. Conclusion

Lessons were learned in calibrating the required measurement devices. One noteworthy lesson became readily apparent while attempting to calibrate the flow-meter. Two methods were identified for the calibration of the flow-meter, which is a Nailor device. The first method identified required the Nailor device to be duct taped to makeshift piping attached to the positive displacement dry-test meter, but this method proved to be troublesome. The 4 inch NPS duct which the Nailor device was attached had to be necked down to 0.5 inch tubing using available materials. Leaks in the connections between the Nailor device and the piping as well as the connections to the tubing caused large differences between the volumetric flow rates measured by the Nailor and the dry-test meter (the relative uncertainty of CO production increased to values greater than 400%). To overcome this challenge, we used a hand-held pitot tube to calibrate the Nailor, building a velocity profile at the exit of the tube. Using this measurement and measurements of its cross sectional area, we were able to calibrate the Nailor flow-meter while minimizing the increase in uncertainty of the CO production to an acceptable degree (uncertainty of 7% from its previous value of 6%). This small increase in uncertainty resulting from additional measurements bolsters our confidence in moving forward with the experiment.

Acknowledgment

The authors would like to extend special thanks to Dr. Nordica MacCarty and the Aprovecho Research Center for their continued support and guidance throughout this project.

References

[1] ASTM-E617. Standard specification for laboratory weights and precision mass standards. Book of Standards, 14, 2013.

[2] Robert van der Plas and H. S. Mukunda. The water boiling test version 4.1.2, January 2009.

[3] Nordica MacCarty, Dean Still, and Damon Ogle. Fuel use and emissions performance of fifty cooking stoves in the laboratory and related benchmarks of performance. Energy for Sustainable Development, 14(3):161–171, 2010.

Appendix

A. Experimental Design and Analysis

1) Summary of Objectives: An alcohol cookstove will be used to burn an ethanol-water dilution. The fuel will vary the mass percent of ethanol to 95%, 90%, 85%, 80%, and 75%. The experimental approach will test for fuel burn efficiency and stove efficiency of the diluted ethanol fuel. A standardized water boiling test, enabling the comparison of a wide variety of stoves, will be implemented to measure the efficiency of the stove. This test will compare the energy adsorbed by water within a pot to the energy released by the fuel. A gas analyzer will examine the CO and CO_2 contents. A stagnation style flow meter will measure the exhaust flow. By using the exhaust flow and CO and CO_2 content a fuel burn efficiency can be calculated. The CO emissions of the burn is a health concern since the stoves will be used within an enclosed environment. In addition, the efficiency of the stove will determine if dilution of the fuel is a feasible alternative to pure ethanol enabling a more cost effective source of cleaner energy.

2) Experimental Design: For a complete understanding of the experimental design and set up, reference the flow chart found below in parts 4) and 5). A simple personal cookstove will be constructed from aluminum beverage cans. The stove construction will feature a small fuel reservoir central to the stove axis, and will have a vaporization chamber on the sides of the stove, surrounding the reservoir. Small holes, acting as jets, will be punched or drilled near the top of the vaporization chamber for fuel vapors to escape.

Fuel concentrations will be mixed in batches (see appendix F. A container will be placed on a scale , and the scale will be tared. The desired water will be added to the scale, and then the calculated ethanol will will be added to the water. The water is added first because ethanol has a lower vaporization temperature. The mixed fuels will be stored in sealed containers until used.

A Pitot tube type flow meter (Nailor Industires Inc. Model: 36FMS) will measure the flow in the exhaust duct work. A differential pressure transducer (Omega PCL-1B) will measure the difference between the stagnation pressure and the static pressure. Prior to installing the flow meter, a dry test meter will be used for calibration of the meter. A thermocouple will be installed at the inside the duct to obtain the exhaust temperature.

The Portable Emissions Measurement System (PEMS), developed by the Aprovecho Research Center, will measure the constituents of the exhaust. PEMS will monitor and record emission levels, including CO and CO_2 in real time via a data acquisition system connected through a software interface. These concentrations will be used to help calculate fuel burn efficiency.

A pot with a known mass and material will be suspended above the stove. Five hundred grams of room-temperature water will be poured into the pot. The pot will be placed on a continuous reading scale during the duration of the test. Two type-k thermocouples will be placed in the water to measure temperature raise during the burn.

The empty cookstove will be placed on a calibrated scale and its mass will be recorded. A measured volume of diluted ethanol fuel will be poured into the cookstove. The mass of the fuel will be measured. The measuring of the fuel will be preformed immediately prior to ignition in to order to reduce evaporation.

The instruments will begin to take readings 10 minutes prior to testing to ensure the sensors have steady conditions. The fuel is ignited from the reservoir. A few minutes are needed to preheat the stove prior to the jets igniting. The time taken until the jets ignite will be measured. Two thermocouples will be within the cookstove to measure the fuel temperature and the pressure chamber temperature.

The stove will be left to burn until all of the fuel is expended and the flame extinguishes. The weight of the pot and the remaining water will be measured immediately after the flame extinguishes, and the apparatus will be allowed to cool to room temperature.

The experiment will be repeated for five times at each ethanol concentration.

3) Data Analysis: The collected data will be used to determine the fuel burn efficiency and stove efficiency for each concentration of ethanol. The stove will be calculated using the following equation:

$$h_c = \frac{\Delta E_{H_2O,heat} + \Delta E_{H_2O,evap}}{E_{released}} \tag{3}$$

where h_c is the thermal efficiency, $\Delta E_{H_2O,heat}$ is the change in energy of the water in the pot, $\Delta E_{H_2O,evap}$ is the energy spent evaporating water, and $E_{released}$ is the energy released by the stove [2].

The energy released by the stove will be determined by multiplying the mass of the ethanol solution by the calorific value of the solution, 26.8 MJ/kg. Note that the water in the solution will not add to the energy released, and therefore the mass used in this calculation will vary based on the concentration, even if the same volume is used each repetition of the experiment.

The heat energy in the pot will be calculated using the data from the thermocouples in the pot using the specific heat equation:

$$\Delta E_{H_2O,heat} = m_{water} c_p \Delta T \tag{4}$$

where m_{water} is the mass of the water remaining in the pot at the end of the test, c_p is the specific heat of the water, and ΔT is the change in temperature in the water between when the fuel was ignited and when the flame was extinguished. The mass and specific heat of the pot will be taken into consideration as necessary.

The energy spent evaporating the water will be calculated using the loss of mass of the water in the pot plus the mass of water lost in the ethanol solution using the equation for the latent heat of vaporization:

$$\Delta E_{H_2O,evap} = m_{evap} h_v \tag{5}$$

where m_{evap} is the mass of the water evaporated due to boiling and h_v is the latent heat of vaporization of water.

The time for the water to reach boil will be measured using data from the thermocouples in the pot. This time will be the time measured between ignition of the fuel and when the temperature plot reaches a plateau around 100°C.

The fuel burn efficiency will be based on how much of the carbon is released as CO. The CO content will be determined from the measured particulate count from the PENS, the volumetric flow rate, and temperature of the exhaust.

The percentage of carbon in the ethanol fuel that will be consumed in the production of CO will be calculated using the following equation:

$$\epsilon = \frac{n_{CO}}{2n_{ethanol}} \tag{6}$$

where n_{CO} is the number of molecules of CO produced and $n_{ethanol}$ is the number of ethanol molecules in the fuel. n_{CO} will be calculated using the following equation:

$$n_{CO} = \frac{N_A P_{static} C_{CO} V}{R T_{ambient}} \tag{7}$$

where N_A is Avogadro's constant, P_{static} is the static pressure in the fume hood exhaust, C_{CO} is the average concentration of CO measured by the PEMS in parts per million over the course of the experiment, $T_{ambient}$ is the ambient temperature, and V is the volume of air that passes through the fume hood over the course of the experiment. V will in turn be calculated by multiplying the volumetric flow rate through the fume hood exhaust, *u*, by the burn time in seconds. The volumetric flow rate through the fume hood exhaust in units of cubic feet per minute will be found using the following equation:

$$u = 215\sqrt{\Delta P} \tag{8}$$

in which ΔP is the differential pressure across the pitot tube flow meter in inches of units of water. This equation for the volumetric flow rate was provided by the manufacturer of the pitot tube flow meter, and will be calibrated prior to collecting experimental data.

The number of ethanol molecules in the fuel will be found using the following equation:

$$n_{ethanol} = \frac{N_A m_{fuel} C_x}{M_{ethanol}} \tag{9}$$

where m_{fuel} is the mass of the fuel added to the stove, C_x is the ethanol concentration of the solution, and $M_{ethanol}$ is the molar mass of ethanol.

The data obtained for each solution concentration will be compared to determine if any trends exist. Additionally, the data will be compared to results from literature to verify all conclusions.

4) Experiment Set Up: Below is a schematic of the experiment

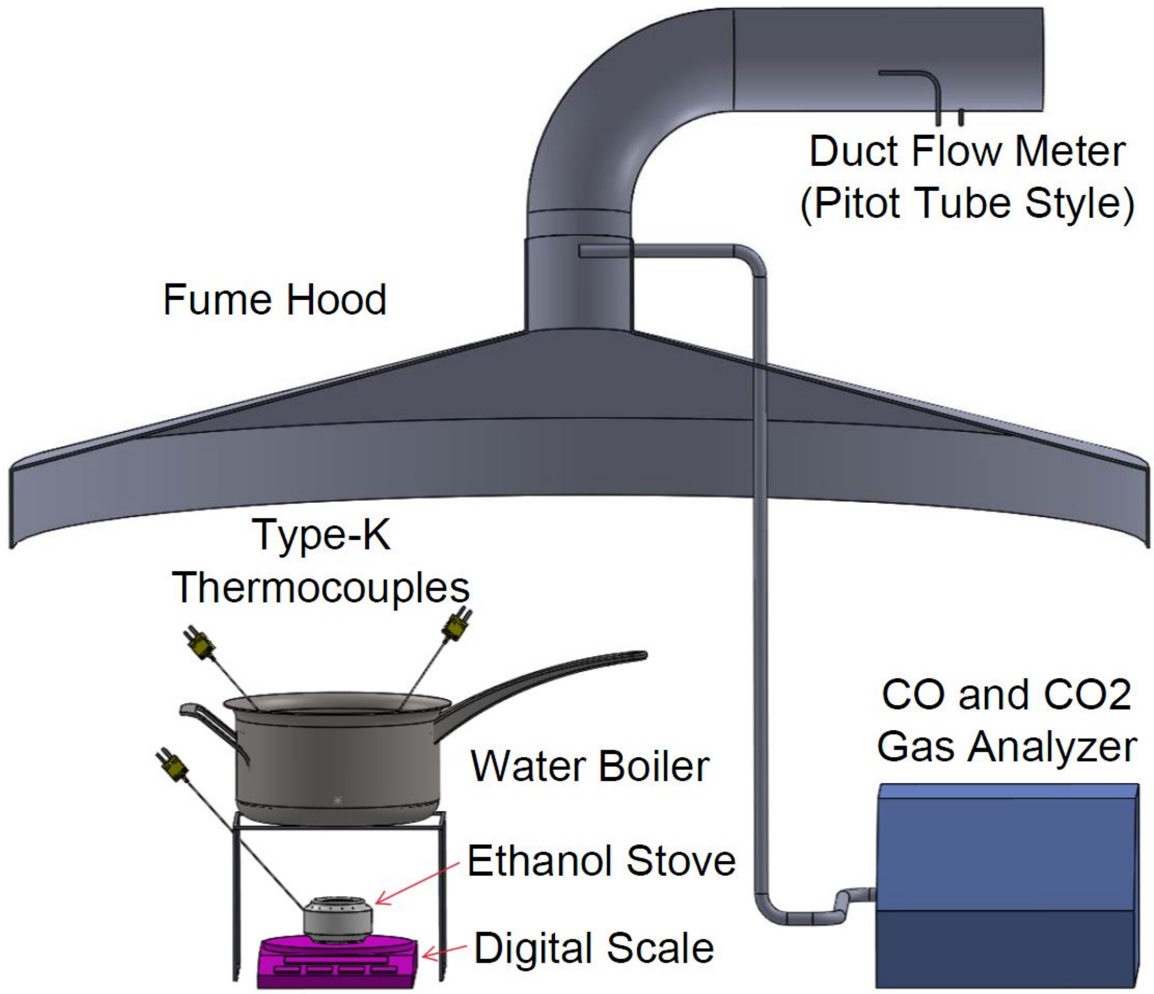
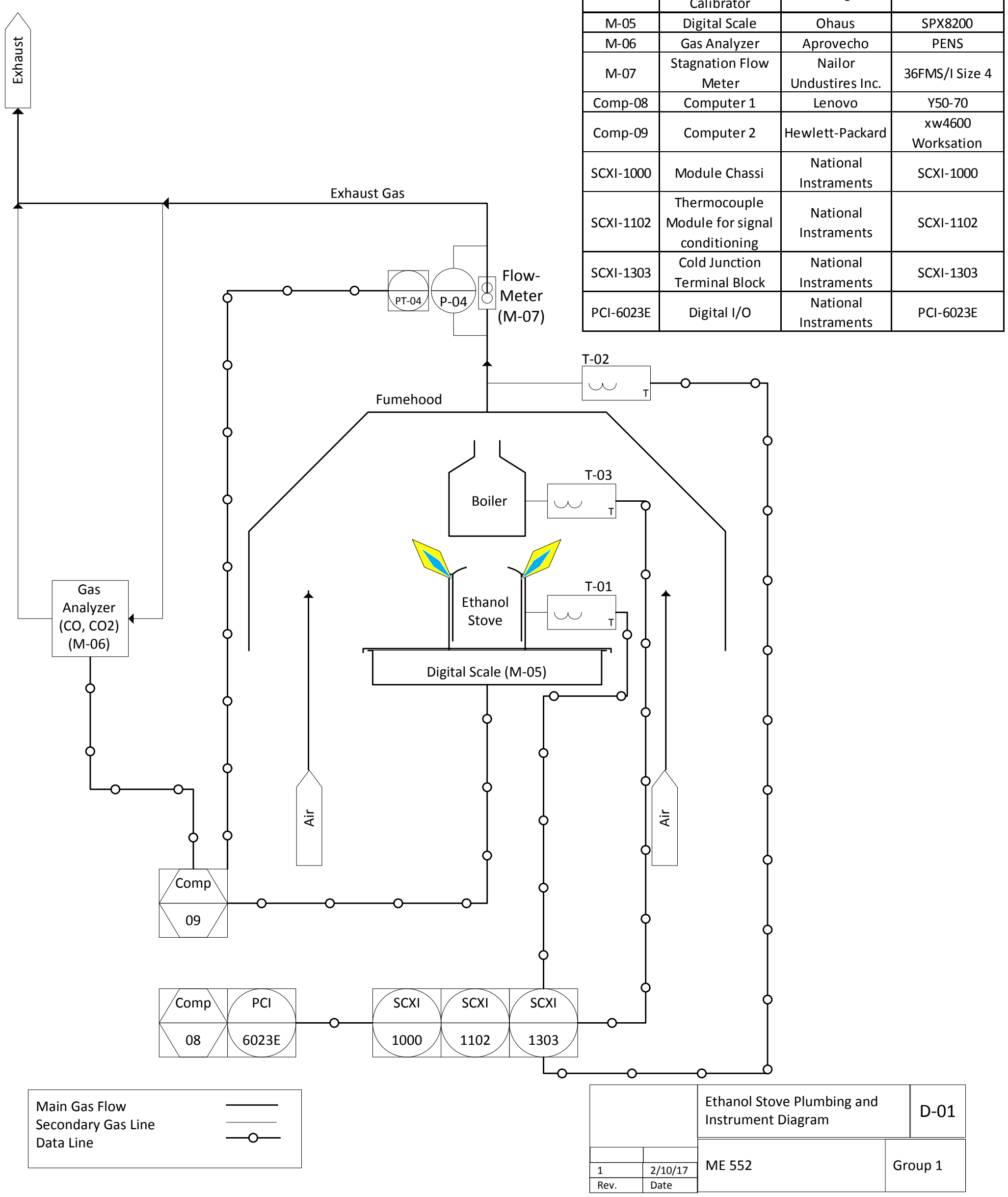


Fig. 2. CAD model of the the experimental set up

5) Experiment Flow Chart: below is a chart depicting the experimental setup

Equipment Call-out	Mesurement Device	Manufacture	Part Number
T-01 T-02 T-03	Type-k Thermocouple	Omega	KQXL-116E-12
P-04	0-10 inches of Water Column Pressure Guage	Omega	PCL-MA-10WC
PT-04	Pressure Calibrator	Omega	PCL-1B
M-05	Digital Scale	Ohaus	SPX8200
M-06	Gas Analyzer	Aprovecho	PENS
M-07	Stagnation Flow Meter	Nailor Undustires Inc.	36FMS/I Size 4
Comp-08	Computer 1	Lenovo	Y50-70
Comp-09	Computer 2	Hewlett-Packard	xw4600 Worksation
SCXI-1000	Module Chassi	National Instraments	SCXI-1000
SCXI-1102	Thermocouple Module for signal conditioning	National Instraments	SCXI-1102
SCXI-1303	Cold Junction Terminal Block	National Instraments	SCXI-1303
PCI-6023E	Digital I/O	National Instraments	PCI-6023E



B. Uncertainty Design Analysis

An uncertainty analysis of the thermal efficiency was performed using the equipment tolerances found in appendix D1, preliminary test information from a test run at the Aprovecho Research Center, review of literature, and engineering judgement. The analysis was performed using the Kline McClintock method and was implemented in Python with the code included in appendix G.

A relative uncertainty of 20% or better for both the thermal efficiency and the CO production percentage is proposed as a target for the measurements in this experiment. This target value is reasonable for cook stove applications because it has been shown that variability between tests of the same stove at the same laboratory can vary between 5% and 25% [3].

The uncertainty analysis concluded that the thermal efficiency can be expected to have a relative uncertainty of approximately 4.2%. This value is improved from the previous estimates of uncertainty in the experiment because of the use of more precisely calibrated thermocouples. The majority of measurements used to calculate the thermal efficiency are measurements of mass, and consequentially the relative uncertainty is most impacted by the accuracy of the scale. To illustrate the effect of improving the accuracy of the scale, the Python code was modified to determine the uncertainty of a scale with 10 times greater accuracy (0.1 gram versus 1 gram). The modified code demonstrated that the uncertainty would be reduced by approximately 60% with the more accurate scale. An uncertainty tree of the thermal efficiency can be found in figure 3 below.

Although the accuracy of the scale had the greatest impact on the uncertainty of the thermal efficiency, the uncertainty was also notably impacted by the accuracy of the thermocouples used. Using thermocouples with 10 times greater accuracy (0.1°C verus 1.0°C) lessened the relative uncertainty by approximately 9%.

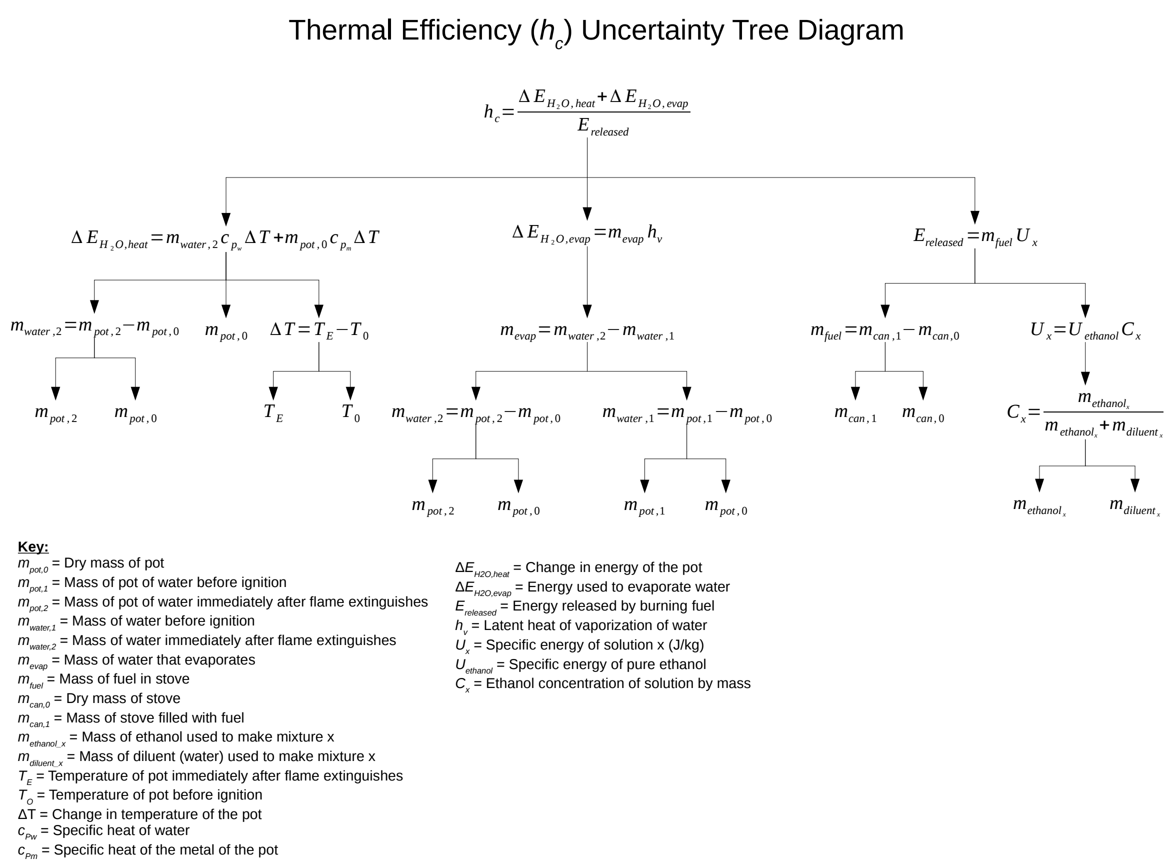
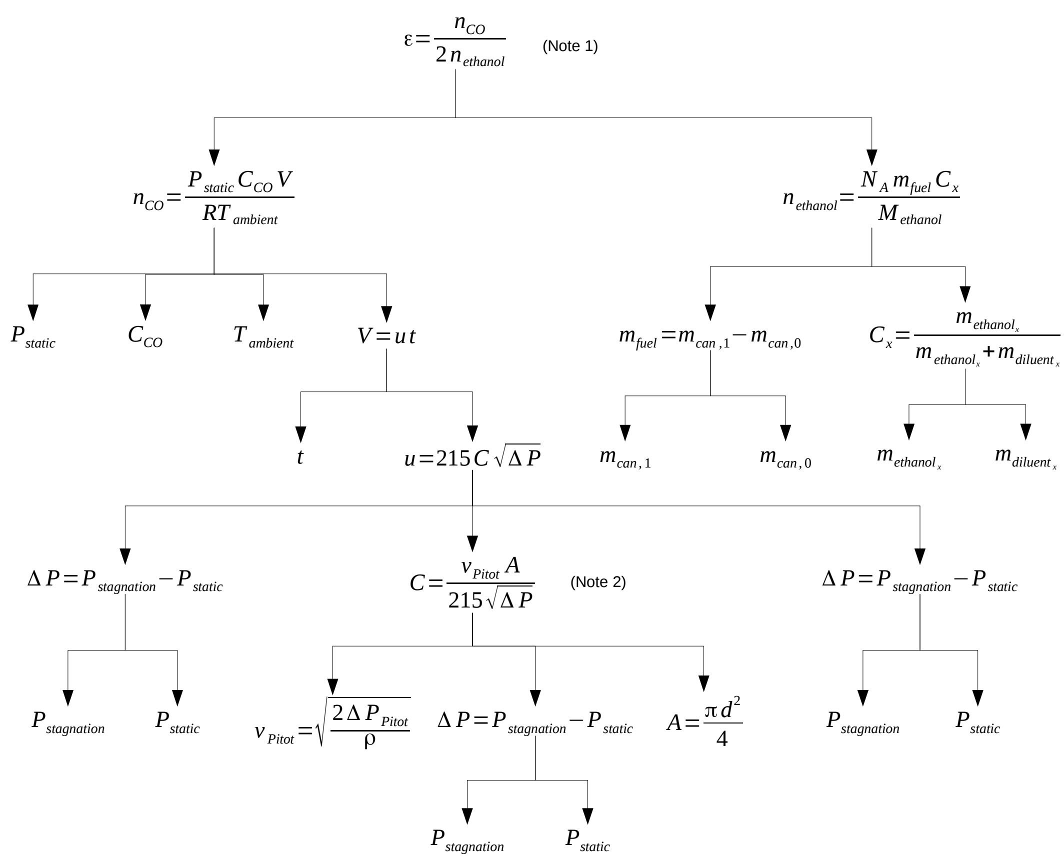


Fig. 3.

The uncertainty analysis concluded that the CO production percentage can be expected to have a relative uncertainty of approximately 7%. The greatest source of uncertainty for the CO production percentage was the CO sensor of the PEMS. Although the 0.5 ppm accuracy of the unit is highly sensitive for most applications, the CO production rate from the stove is very small, therefore the relative error is very large. Improving the accuracy of the CO detector by a factor of 10 would reduce the relative uncertaincy by approximately 33%. Improvements in pressure, temperature, or mass measurements were found to have a smaller impact on the uncertainty. Figure 4 below depicts an uncertainty tree of the CO production percentage.

CO Production Percentage (ε) Uncertainty Tree Diagram



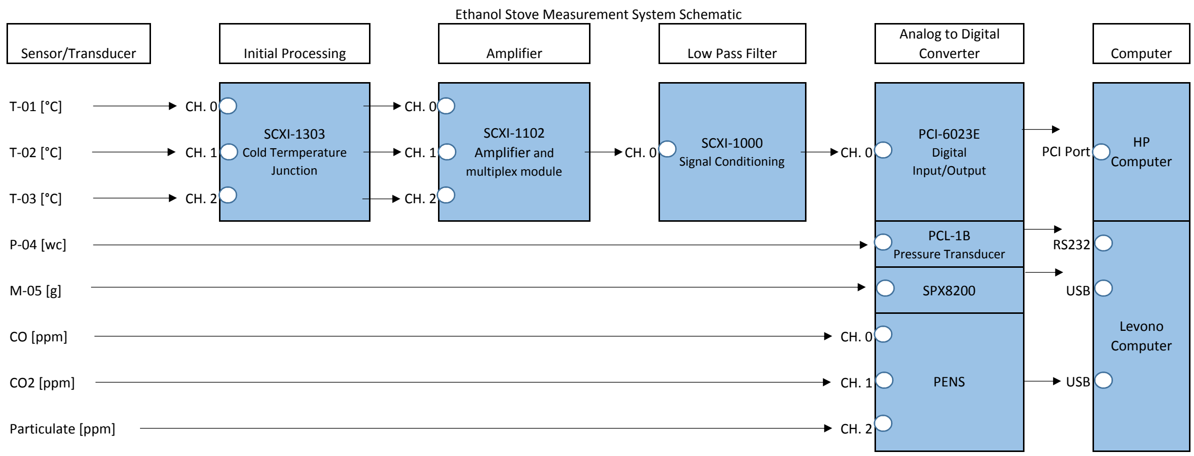
Notes:
1) There are 2 carbon atoms in each ethanol molecule
2) The formula for volumetric flow rate through the sampling tube was provided from the manufacturer and is in units of cubic feet per minute and inches of water.

Key:

n_{CO} = Number of molecules of CO released in test
$n_{ethanol}$ = Number of molecules of ethanol in test
m_{fuel} = Mass of fuel in stove
$m_{can,0}$ = Dry mass of stove
$m_{can,1}$ = Mass of stove filled with fuel
$m_{ethanol\_x}$ = Mass of ethanol used to make mixture x
$m_{diluent\_x}$ = Mass of diluent (water) used to make mixture x
$M_{ethanol}$ = Molar mass of ethanol (46.06844 g/mol)
N_A = Avogadro's number
R = Universal gas constant
C_x = Ethanol concentration of solution by mass
C_{CO} = CO concentration of exhaust gas (ppm)
$T_{ambient}$ = Ambient temperature
P_{static} = Ambient temperature
$P_{stagnation}$ = Ambient temperature
ΔP = Change in pressure across the sampling tube
ΔP_{Pitot} = Change in pressure across Pitot tube
t = Total burn time
V = Total volume of air passed through hood during test
C = calibration constant of sampling tube
d = Diameter of sampling tube
ρ = Density of ambient air
u = Volumetric flow rate of air passed through hood during test

Fig. 4.

C. DAQ Setup



Ethanol Stove Measurement System Schematic
Sensor/Transducer
Initial Processing
Amplifier
Low Pass Filter
Analog to Digital Converter
Computer
T-01 [°C]
T-02 [°C]
T-03 [°C]
P-04 [wc]
M-05 [g]
CO [ppm]
CO2 [ppm]
Particulate [ppm]
CH. 0
CH. 1
CH. 2
SCXI-1303
Cold Termperature Junction
SCXI-1102
Amplifier and multiplex module
SCXI-1000
Signal Conditioning
PCI-6023E
Digital Input/Output
PCL-1B
Pressure Transducer
SPX8200
PENS
PCI Port
RS232
USB
HP Computer
Levono Computer

D. Instruments

1) Instrument Error List: table I lists the necessary instruments for the experiment. The table lists the item, the item model and the manufacturers instrument tolerance. The instruments listed in the table are described in more detail in this section of the appendix.

TABLE I. MEASUREMENT EQUIPMENT USED

Instrument	Model	Tolerance	Tolerance (Alternative)
Thermocouples	Super OMEGACLAD XL KQXL-116E-12	+/- 1.0C	+/- 0.75%
Scale	OHAUS Scout SPX8200	+/- 1 g	
Calipers	Tritan	+/- 0.5 mm	
Differential Pressure Transducer	OMEGA PCL-1B	0.006% of span	
Sampling Tube	Nailor Industries Inc. Model 36FMS Measuring Station	N/A (Will be calibrated)	
Stopwatch	N/A	+/- 0.01 sec	
CO Sensor	Alphasense CO-AF Carbon Monoxide Sensor	+/- 0.5 ppm	
CO_2 Sensor	SainSmart MH-Z14 Sensor Module for Arduino	+/- 50 ppm	
Pitot Tube	N/A	N/A (Will be calibrated)	

2) Particle Emissions Measurement System: This section contains some of the images and notes on the PEMS.

Fig. 5. PEMS case

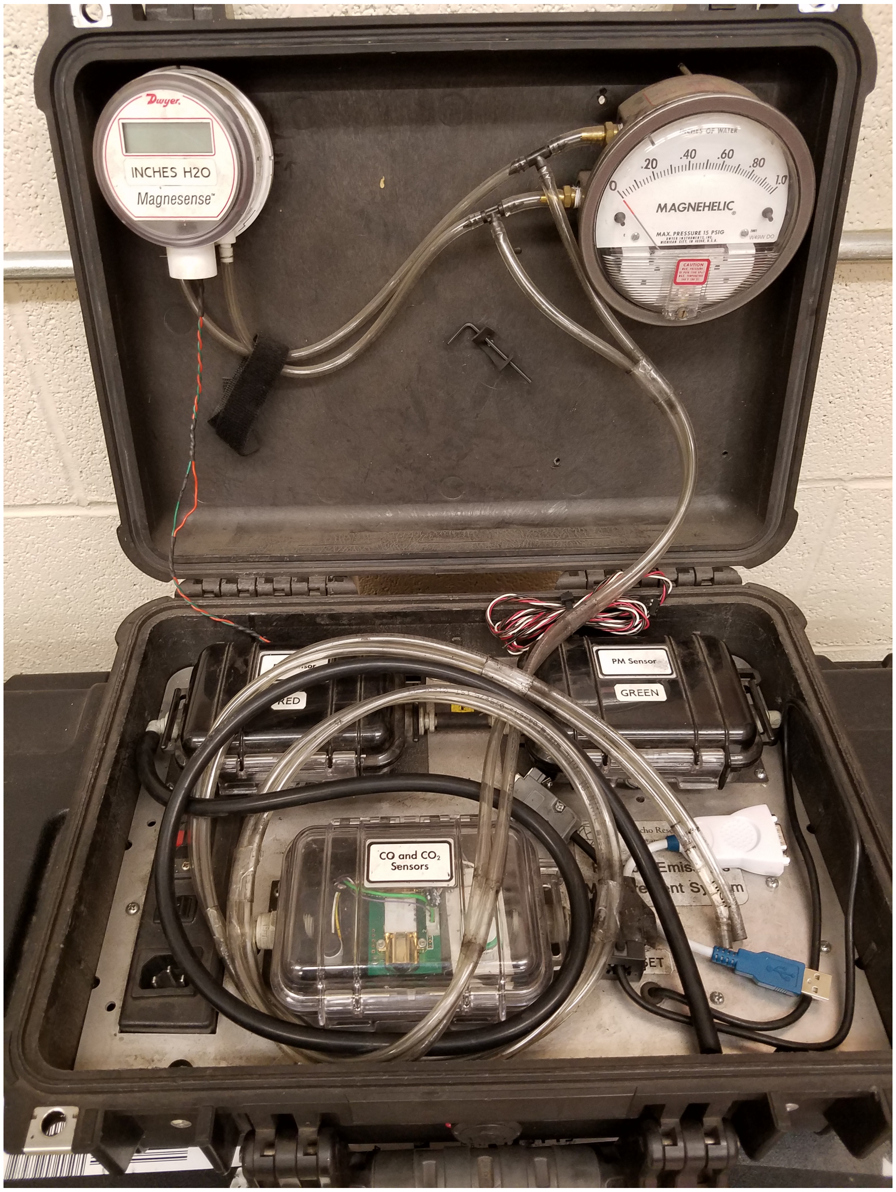


Fig. 6.   PEMS case open

Instructions for Use of the Portable Emissions Monitoring System (PEMS)

For PEMS #2022 and Newer

Aprovecho Research Center

Updated November 28, 2012

Aprovecho Research Center
Advanced Studies in Appropriate Technology Laboratory
79093 Highway 99, PO Box 1175
Cottage Grove, Oregon 97424 USA
541-767-0287
www.aprovecho.org

1. Purpose of the PEMS

The purpose of the PEMS is to quantify reductions in health-harming emissions from cooking stoves by collecting, measuring, and analyzing emissions of CO_2, CO, and PM. Collecting emissions is essential for quantifying the total amount of pollution released without the effects of ventilation and dilution within the air of a kitchen. The combustion efficiency of the stove can be understood by investigating the reported measures such as emissions per task completed (specific emissions) and emissions per kilo of fuel burned (emission factors).

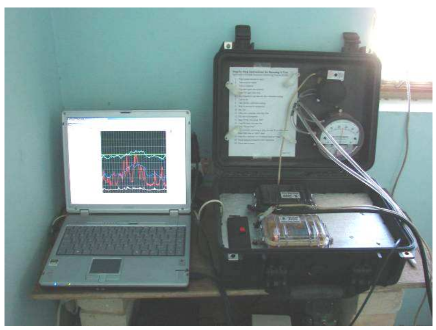


Photo 1: PEMS sensor box and computer

Photo 2: PEMS hood in use

Photo 3: PEMS sensor box, laptop, and hood in cases

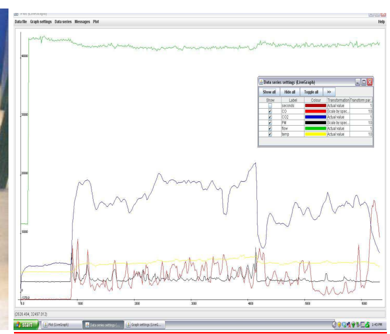


Photo 4: Live graphical readout

2. Uses of the System

2.1 Lab-Based WBT

The WBT is used to optimize stoves in the laboratory. The same fuel, pot, and tending practices are used in every test to eliminate those variables in order to focus on the stove

3) Omega PCL-1b: This section includes the PCL-1b catalog information.

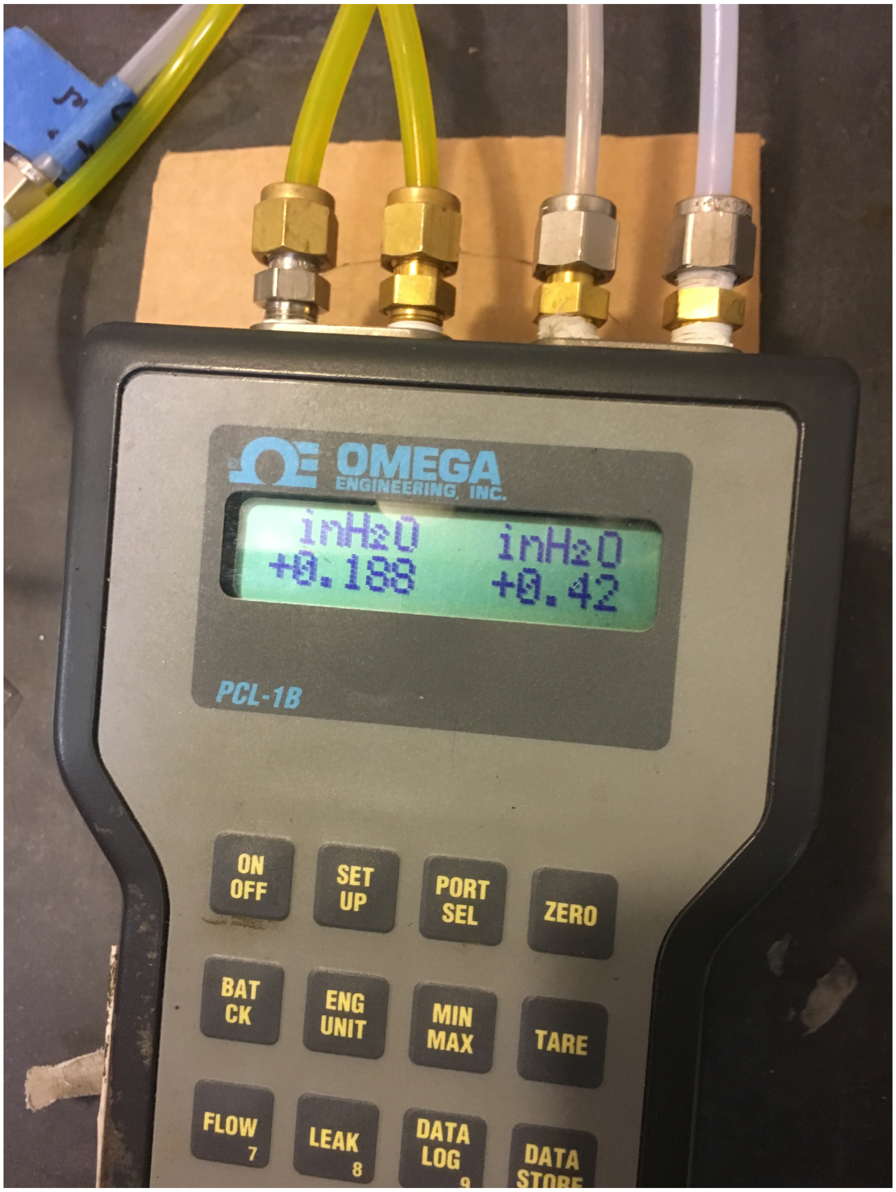


Fig. 7. PCL-1b transducer in use for calibration of flow meter

HANDHELD PRESSURE CALIBRATORS
WITH INTERCHANGEABLE INPUT MODULES

PCL-1B Series

1 YEAR WARRANTY NIST Standard

PCL-1B, with 2 plug-in modules, PCL-MB-030G, and PCL-MB-3KG,

- **Plug-In Pressure Modules Cover Ranges from 0.25 inH2O to 7500 psi**
- **Dual Display Shows Applied Pressure and Transducer Output Simultaneously**
- **Accurate to ±0.06% Full Scale**
- **Measures Pressure, Temperature, Voltage, Current, Flow, and Leak Rate**

The OMEGA® PCL-1B pressure calibrators are full featured handheld instruments that can measure pressure, temperature, flow, vacuum, leak, current, voltage, and change of state for switch testing—virtually all pressure measurement and test functions that an application would require.

A complete PCL-1B system consists of a base unit and 1 or 2 plug-in modules. Pressure modules are available in full scale ranges between 0.25 inH2O and 7500 psi and in gage, vacuum, absolute, differential, and compound pressure types. Three temperature modules are available, for thermocouple (J, K, T, E, R, S, B, and N calibrations), and RTDs (Pt100, Ni120 and Cu120 or Pt1000 types).

When installed in the base unit, these quick-select modules not only afford unparalleled measurement flexibility; they also help protect the pressure sensor from damage. Modules can be switched in just seconds, without tools. In addition to its keypad features (see diagram on next page), the base unit can link to a computer, data acquisition system, or dumb terminal via a standard RS232 connection.

The PCL-1B can accept two removable PCL-M pressure modules, modules sold separately, Visit us online.

Shown smaller than actual size.

4) Nailor Industry 36FMS: The Nailor Industry 36FMS flow-meter was given to us to use by Aprovecho Research Center. This device is a 4-pt pitot tube system that averages between the points. A pressure difference is then read by Omega's PC-1b pressure transducer.

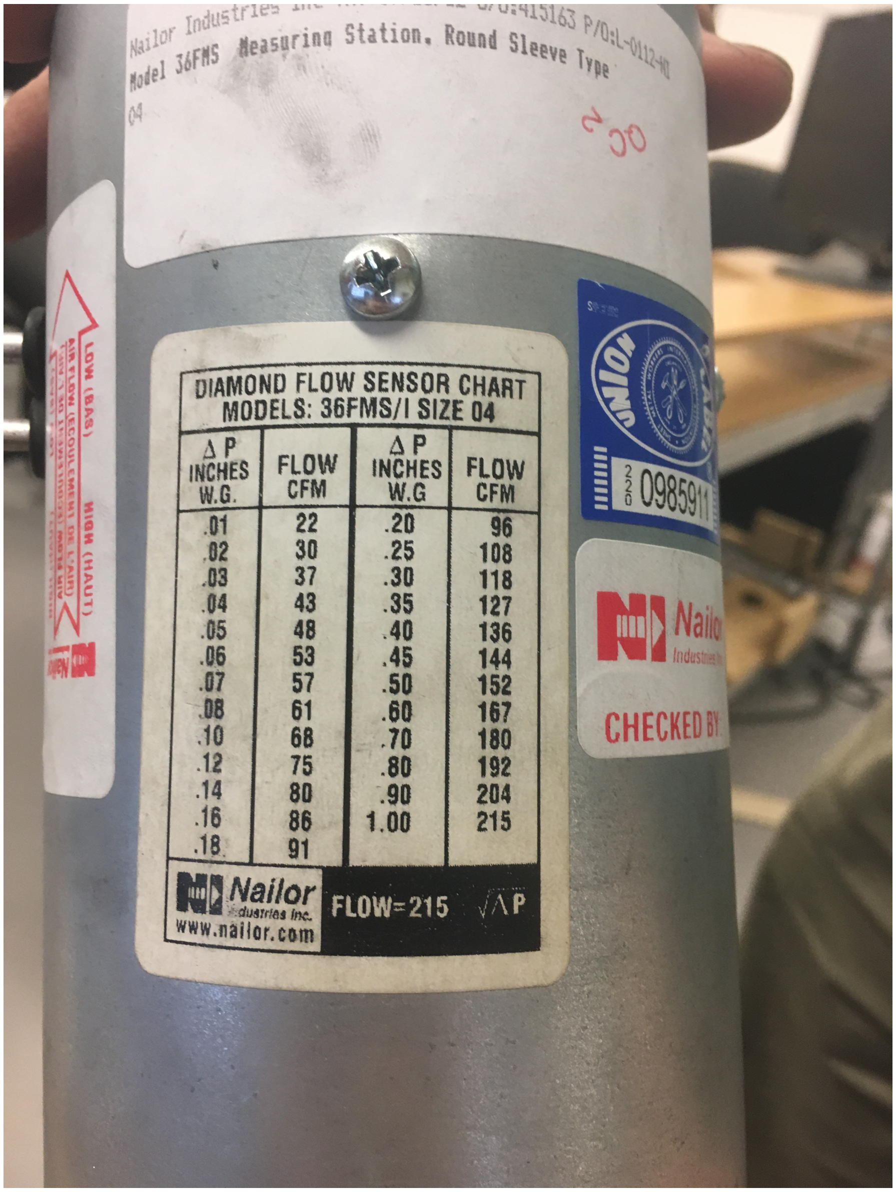


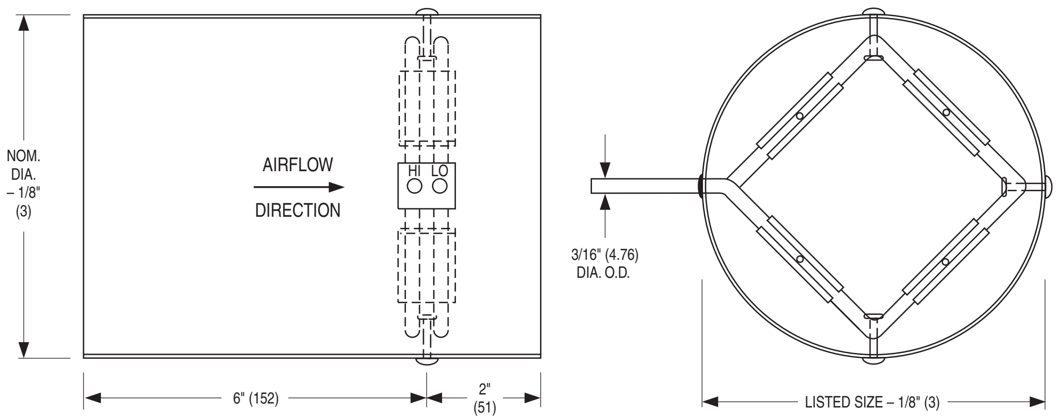
Fig. 8. Nailor series calibration curve printed on the device.

Nailor Industries Inc.

FLOW MEASURING STATION

ROUND DUCT • SLEEVE TYPE

MODEL: 36FMS



DESCRIPTION:

The Model 36FMS Flow Measuring Station is a multi-point averaging airflow sensor. It has been designed to provide accurate sensing by sampling air velocities in the four quadrants of a round duct. The differential pressure flow sensor provides an averaged reading at an amplification of approximately 2.5 times the velocity pressure, dependent upon nominal size.

FEATURES:

- Available to suit nominal round ductwork sizes from 4" (102) to 18" (457) diameter.
- All metal construction - no combustible materials in the air stream.
- Amplifies velocity pressure approximately 2.5 times to give a wide range of useful output signal vs. flow.
- Compact size allows easy installation in existing ductwork.
- Sensor design minimizes pressure drop and regenerated noise.
- Label provided on each unit gives airflow vs. signal differential pressure for direct reading of airflow.
- Multi-point sensing gives an accurate output signal with a maximum deviation of only ± 5% with a hard 90 degree elbow, provided a straight inlet condition with a minimum length of two equivalent duct diameters is provided.

Unit Size	Recommended Airflow Range	
	cfm	l/s
4	0 – 200	0 – 94
5	0 – 315	0 – 149
6	0 – 450	0 – 212
7	0 – 630	0 – 297
8	0 – 860	0 – 406
9	0 – 1185	0 – 559
10	0 – 1400	0 – 661
12	0 – 1980	0 – 934
14	0 – 2795	0 – 1319
16	0 – 3650	0 – 1722
18	0 – 4800	0 – 2266

SPECIFICATIONS:

Materials: Sensor – aluminum.
Body – 22 ga. (0.85) galvanized steel.
Media: Air or other common inert gases.
Standard Tubing: 1/4" (6.35) O.D. x 0.04" (1.0) wall FR tubing (by others).

OPTIONS:

❑ Special Features.
Specify: ________________________

SCHEDULE TYPE:				
PROJECT:	Dimensions are in inches (mm).			
ENGINEER:	DATE	B SERIES	SUPERSEDES	DRAWING NO.
CONTRACTOR:	8 - 20 - 08	FMS	7 - 23 - 03	36FMS-1

5) Ohaus Scout scale: Images and product details of the Ohaus Scout scale can be found below.

Fig. 9. ohaus scale with two 200 gram ohaus precision weights

Scout®

Portable Balances

Setting New Standards in Laboratory & Industrial Weighing— The Next Generation of Scout Balances

Ideal for laboratory and industrial applications, the OHAUS Scout comes in a slim, stackable design with large backlit LCD. Features include superior overload protection, multiple weighing units and application modes. Geared for high performance in your facility with fast stabilization time and high resolution weighing results, these portable balances set a new standard in laboratory and industrial weighing.

Standard Features Include:

- **Bright Backlit LCD & 4 Button Control Enable Efficient Operation and Ease of Use**
  Combined with a simplified 4 button operation, the Scout's large backlit display increases readability in low light working conditions, and is easier to view from a distance.
- **Bolstered by Superior Overload Protection and Impact-Resistant Pan Support**
  Integrated superior overload protection and impact-resistant pan support safeguard against shock and overloading the balance in rugged and demanding environments.
- **Better Performance and Higher Capacities Widen the Range of Weighing Applications**
  Stabilization time as fast as 1 sec and advanced weighing technology, lead to improved productivity in your facility. Increased capacity unlocks a wider range of weighing applications.

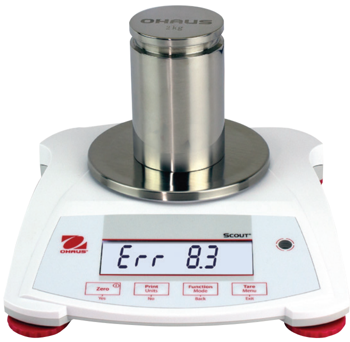
Scout® Portable Balances

Improved Experience with Backlit Display and 4 Button Operation

Poor lighting environment is not an issue with the Scout. The large, bright backlit LCD display improves readability in conditions where lighting is poor, and makes it easy to see the results from a distance. 4 clearly marked buttons remove complexity, and guide you quickly and easily through setup, unit of measure changes, calibration and more.

Durability Guaranteed with Superior Protective Features

The Scout equipped with superior overload protection rated at 10 times the capacity of the balance, high strength stainless steel pan, impact-resistant pan support and integrated transportation/storage lock, delivers the same durable quality that you expect from OHAUS products. To complement our signature durability, we've designed the Scout to be stackable when utilizing the optional stacking and storage cover, which also protects the balance when not in use.



Most Versatile Portable Balance in its Class

With the Scout, it's all about accuracy, efficiency and possibilities! Stabilization time as fast as 1 sec means increased productivity in any facility or lab. With improved resolution, you can count on extremely precise and repeatable weighing results. Additionally, the increased capacity of the Scout gives you more flexibility in your weighing applications.

Draftshield Model Available

Scout's ingenious draftshield (1mg models only) was designed with an easy to remove top cover piece. This serves as a wind protection ring which keeps the weighing surface stable in rough environments, while maintaining weighing speed.

Built-in Application Modes

- **Weighing**—Determines the weight of items on the pan in the selected unit of measure.
- **Parts Counting**—Counts the number of pieces on the pan using a uniform weight.
- **Percent Weighing**—Measures the weight of a sample displayed as a percentage of a pre-established reference weight.
- **Check Weighing**—Compares the weight of a sample against target limits.
- **Totalization**—Measures cumulative weight of multiple items. Cumulative total may exceed balance capacity.
- **Display Hold**—Manually holds the last stable weight or the first highest stable weighing value on the display.

Draftshield
Protects the sample from external influences, increasing the speed and repeatability of measurements

Connectivity
Expanded connectivity options including RS232, USB Host, USB Device, Ethernet and Bluetooth®

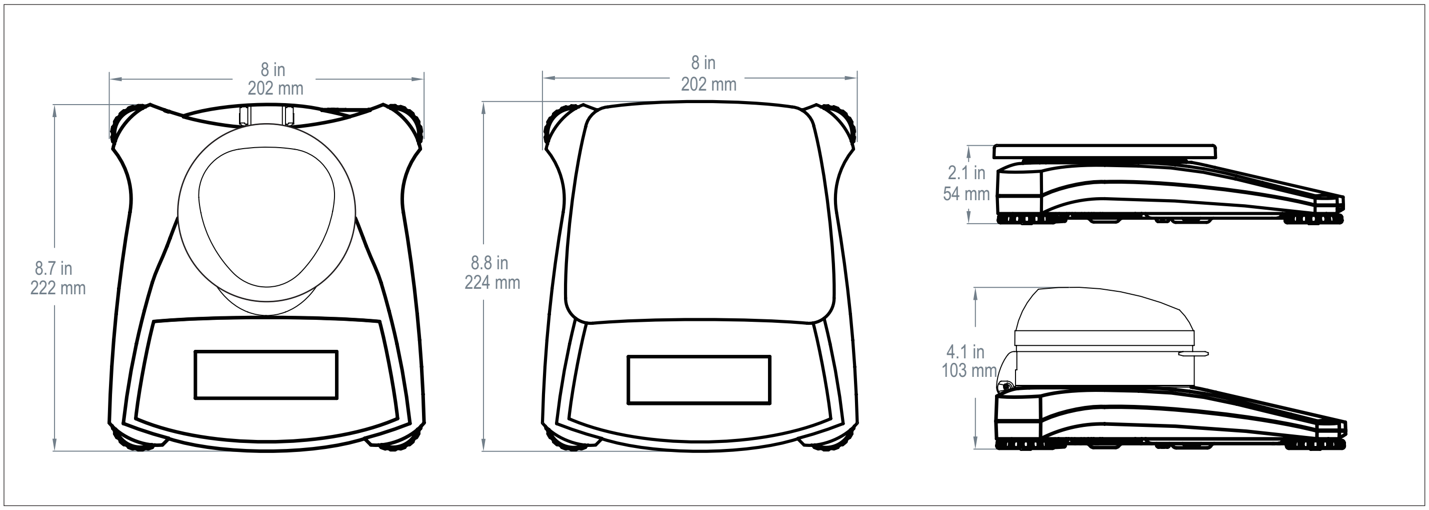
Weigh Below Hook
The integral weigh below hook on the bottom of the Scout allows for density determination or specific gravity calculations

Security Slot
Integrated security slot prevents theft

Lockswitch
The Scout can be locked into a specific configuration using the lockswitch

Large Backlit LCD Display
High contrast LCD Display displays weight and application data clearly, even in poor lighting conditions

Outline Dimensions



Scout® Portable Balances

Model	SPX123	SPX223	SPX222	SPX422	SPX622	SPX1202	SPX2202	SPX421	SPX621	SPX2201	SPX6201	SPX8200
Capacity (g)	120	220	220	420	620	1200	2200	420	620	2200	6200	8200
Readability (g)	0.001	0.001	0.01	0.01	0.01	0.01	0.01	0.1	0.1	0.1	0.1	1
Repeatability (Std. Dev.) (g)	0.002	0.002	0.01	0.01	0.01	0.02	0.02	0.1	0.1	0.1	0.1	1
Linearity (g)	0.003	0.003	0.01	0.01	0.02	0.03	0.03	0.1	0.1	0.1	0.2	1
Capacity × Readability (kg)	N/A	N/A	N/A	N/A	N/A	1.2 × 0.00001	2.2 × 0.00001	N/A	N/A	2.2 × 0.0001	6.2 × 0.0001	8.2 × 0.001
Capacity × Readability (lb)	N/A	N/A	N/A	N/A	1.36690 × 0.00005	2.64555 × 0.00005	4.85020 × 0.00005	N/A	1.3670 × 0.0005	4.8500 × 0.0005	13.6685 × 0.0005	18.080 × 0.005
Span Calibration Mass*	100 g	200 g	200 g	200 g	300 g	1 kg	2 kg	200 g	300 g	2 kg	5 kg	8 kg
Linearity Calibration Mass*	50, 100 g	100, 200 g	100, 200 g	200, 400 g	300, 600 g	500g, 1 kg	1 kg, 2 kg	200, 400 g	300, 600 g	1 kg, 2 kg	3 kg, 5 kg	4 kg, 8 kg
Stabilization Time (s)	1.5	1.5	1	1	1	1.5	1.5	1	1	1	1	1
Construction	ABS housing & stainless steel pan											
Draftshield	Yes		No									
Calibration	User-selectable external span or linearity calibration/Digital with external weight											
Tare Range	Full capacity by subtraction											
Weighing Units	g, kg, ct, N, oz, ozt, dwt, lb, lb:oz, grn											
Application Modes	Weighing, Parts Counting, Percent Weighing, Check Weighing, Totalization, Display Hold											
Power Requirement	AC adapter (included) or 4 AA batteries (not included)											
Typical Battery Life (Hours)	80		120	80				120			80	120
Communication	RS232, USB Host, USB Device, Ethernet or Bluetooth® (available as an accessory)											
Display Type	Liquid crystal display (LCD) with backlight											
Display Size	0.78 in/20 mm digits											
Overload Capacity	10 times rated capacity											
Operating Temperature Range	50°F / 10°C to 104°F / 40°C at 10% to 85% relative humidity, non-condensing											
Storage Conditions	-20°C (-4°F) to 55°C (131°F) at 10% to 90% relative humidity, non-condensing											
Pan Size (W × D)	Ø3.7in/ 93 mm		Ø4.7in/ 120 mm			6.7 × 5.5 in/ 170 × 140 mm		Ø4.7 in/ 120 mm	6.7 × 5.5 in/ 170 × 140 mm			
Balance Dimensions (W × D × H)	8 × 8.7 × 4.1 in/ 202 × 222 × 103 mm		8 × 8.8 × 2.1 in/ 202 × 224 × 54 mm									
Shipping Dimensions (W × D × H)	11.8 × 9.8 × 5.1 in/ 300 × 250 × 129 mm		11.8 × 9.8 × 3.4 in / 300 × 250 × 86 mm									
Net Weight	1 kg											
Shipping Weight	1.5 kg											

* Calibration weights are included with models up to 620g capacity.

Other Standard Features and Equipment

Transportation lock, stainless steel pan, menu & calibration lockout switch, slip-resistant and adjustable feet, leveling bubble, mechanical and software overload/underload protection, stability indicator, auto tare, low battery indicator, auto shut-off, user selectable printing options, user selectable communication settings

Compliance

- **Product Safety:** IEC/EN 61010-1; CAN/CSA C22.2 No. 61010-1; UL Std. No. 61010-1
- **Electromagnetic Compatibility: IEC/EN 61326-1 Class B; FCC Part 15 Class B; Industry Canada ICES-003 Class B**

Accessories

RS232 Interface Kit 30268982
USB Host Interface Kit 30268983
USB Device Interface Kit.......................30268984
Bluetooth Interface Kit 30268985
Ethernet Interface Kit..........................30268986
Stacking & Storage Cover (6 pcs) 30268987
Stacking & Storage Cover (1 pc) 30268988
Printer, Impact, SF40A, AM 30064203
Auxiliary Display Kit..........................30269019
Security Device................................80850043
Top Loading Kit for Density Determination....30269020
Carrying Case 30269021
In-use Cover...................................30269022

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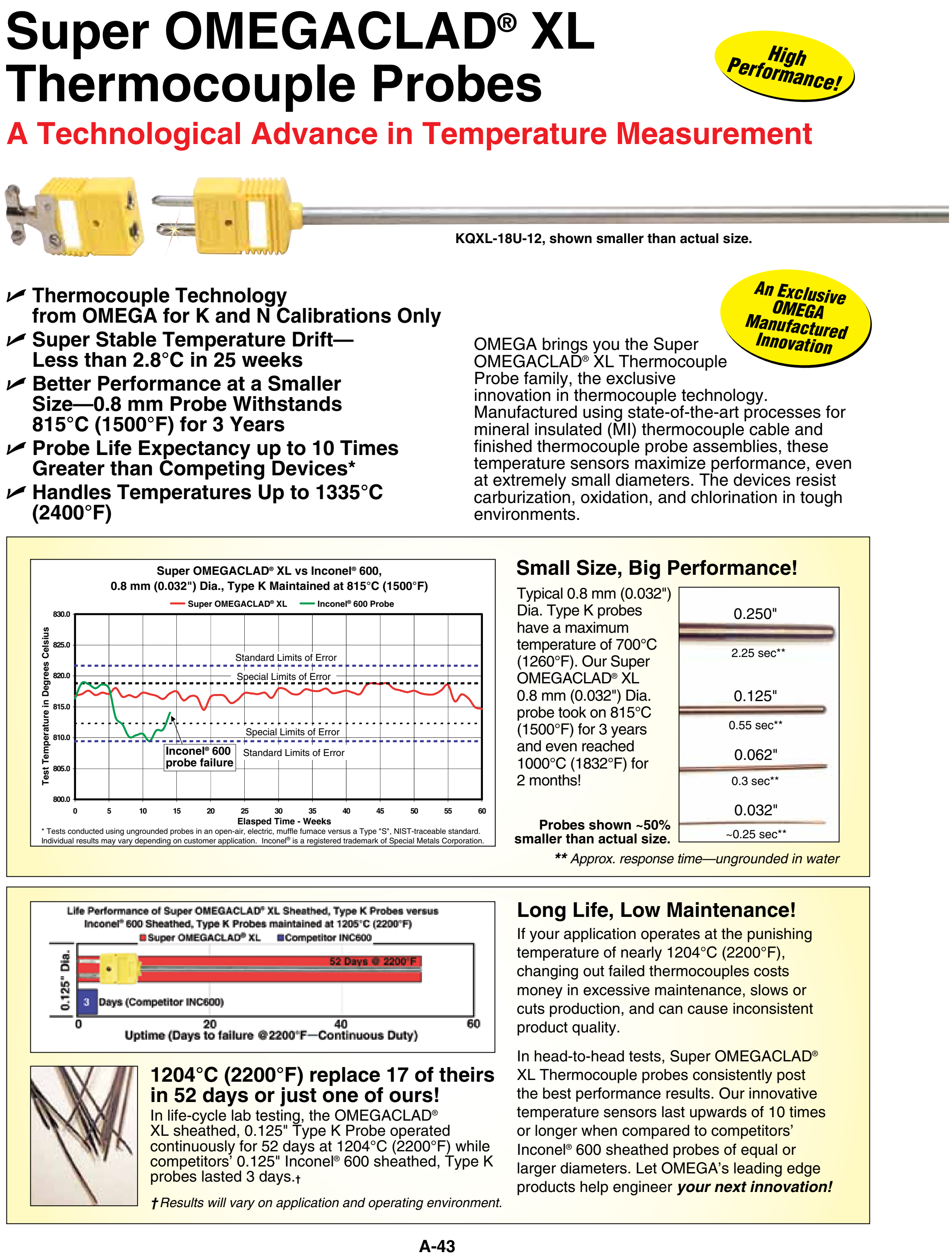
www.ohaus.com

With offices throughout Europe, Asia and Latin America

***ISO 9001:2008**
Registered Quality Management System

OHAUS®

6) Omega Type-K Thermocouples: the first information page on the thermocouples can be found below



Super OMEGACLAD® XL Thermocouple Probes

High Performance!

A Technological Advance in Temperature Measurement

KQXL-18U-12, shown smaller than actual size.

- **Thermocouple Technology from OMEGA for K and N Calibrations Only**
- **Super Stable Temperature Drift—Less than 2.8°C in 25 weeks**
- **Better Performance at a Smaller Size—0.8 mm Probe Withstands 815°C (1500°F) for 3 Years**
- **Probe Life Expectancy up to 10 Times Greater than Competing Devices***
- **Handles Temperatures Up to 1335°C (2400°F)**

An Exclusive OMEGA Manufactured Innovation

OMEGA brings you the Super OMEGACLAD® XL Thermocouple Probe family, the exclusive innovation in thermocouple technology. Manufactured using state-of-the-art processes for mineral insulated (MI) thermocouple cable and finished thermocouple probe assemblies, these temperature sensors maximize performance, even at extremely small diameters. The devices resist carburization, oxidation, and chlorination in tough environments.

* Tests conducted using ungrounded probes in an open-air, electric, muffle furnace versus a Type "S", NIST-traceable standard. Individual results may vary depending on customer application. Inconel® is a registered trademark of Special Metals Corporation.

Small Size, Big Performance!

Typical 0.8 mm (0.032") Dia. Type K probes have a maximum temperature of 700°C (1260°F). Our Super OMEGACLAD® XL 0.8 mm (0.032") Dia. probe took on 815°C (1500°F) for 3 years and even reached 1000°C (1832°F) for 2 months!

Probes shown ~50% smaller than actual size.

*** Approx. response time—ungrounded in water*

1204°C (2200°F) replace 17 of theirs in 52 days or just one of ours!

In life-cycle lab testing, the OMEGACLAD® XL sheathed, 0.125" Type K Probe operated continuously for 52 days at 1204°C (2200°F) while competitors' 0.125" Inconel® 600 sheathed, Type K probes lasted 3 days.†

† Results will vary on application and operating environment.

Long Life, Low Maintenance!

If your application operates at the punishing temperature of nearly 1204°C (2200°F), changing out failed thermocouples costs money in excessive maintenance, slows or cuts production, and can cause inconsistent product quality.

In head-to-head tests, Super OMEGACLAD® XL Thermocouple probes consistently post the best performance results. Our innovative temperature sensors last upwards of 10 times or longer when compared to competitors' Inconel® 600 sheathed probes of equal or larger diameters. Let OMEGA's leading edge products help engineer ***your next innovation!***

A-43

Fig. 10. Omega thermocouples

E. Operating Procedures

	Task	Description
1	Start up fume hood	Start up the fume hood and ensure that air is flowing through the ducts
2	Set flow rate	Set the flow rate and record value for data processing
3	Start up emissions software	open up the emissions software package and check to see if it is gathering data.
4	Zero CO and CO2	Run for 10 minutes prior to ignition step to get an average ppm in the abient air for a zero,
5	Measure Ambient Temperature	Measure the Ambient temperature for reference value
6	Tare scale to pot	Tare scale to wieght of the pot used to boil water
7	Wiegh water	poor the water into the pot and wiegh it till the scale stops oscillating in values, Record the value
8	Tare scale to stove	Tare scale to wieght of the stove that will contain the fuel
9	Wiegh fuel	Poor fuel into stove till it reaches the first lip. then wiegh the stove with the fuel till the scale stops oscilating. record value
10	Ignite fuel	Using a long lighter, ignite the fuel. When a visible flame sets up remove lighter.
11	Start timer	Begin timing burn.
12	Stop	Stop the timer when all fuel is consumed and the flame visible goes out. Record time
13	Export data file	Export the data file to be used in data processing.

F. Mixing Procedures

We will be diluting the ethanol by percent weight

1) Calculate percent weight of water and measure and weigh accordingly.
2) Weigh desired quantity of ethanol.
3) Once the ethanol weight is within +/- one percent of desired weight mix with the water and pour into a nonreactive container(plastic bottle is sufficient).
4) Seal the container and label it with the calculated weight percentage and that state clearly that the contents are fuel and flammable.
5) for clean up place all fuels in the flammables storage cabinet.

G. Code

```
#!/usr/bin/env python3
# -*- coding: utf-8 -*-
"""
Created on Thu Feb  2 10:10:13 2017

This program uses the uncertainties package in Python to automatically
calculate and propagate the uncertainties in the equations for the ME 552
Winter 2017 Group 1 project.  The method used to propagate the uncertainties is
the Kline McClintock method.

@author: andrewalferman
"""

# Import the required packages
import pylab as pyl
import uncertainties as unc
import scipy.constants as const
import numpy as np # BE CAREFUL WITH NUMPY, UNC DOESN'T SUPPORT IT

"""
The following parameters are for experiment 1.  This program is not configured
to run automatically and solve every set of data simultaneously, so the numbers
below must be manually updated for each of the different measurements.

Also note that all values will be in meters, Pa, seconds, kg, etc.
"""

# Define the universal constants
R = 8.3145 # J/mol*K
R_air = 287.058 # J/kg*K, specific gas constant of air
NA = const.Avogadro
hv = 2258000. # J/kg # Heat of vaporization, assumed to be constant
cpw = 4186. # J/kg # Specific heat of water at ambient temperature
cpm = 490. # J/kg*K
Uethanol = 26400000. # J/kg # Energy in ethanol
Methanol = 0.04607 # kg/mol # Density of ethanol

# Conversion factors for handy dandy use later, if needed
intom = 0.0254 # Inches to meters
psitopa = 6894.76 # psi to Pascals
psioffset = 14.7 # psig to psia
cftocm = 0.0283168 # cubic feet to cubic meters
inwtopa = 248.84 # Inches of water to Pascals
cfmtocms = 0.000471947 # Cubic feet per minute to cubic meters per second
mbartopa = 100. # Millibars to Pascals
mmtom = .001 # Millimenters to meters
degftometric = 9/5 # Convert F to C or K, not including absolute scale

# Put all the equipment tolerances in here because it's the cool thing to do
thermocouples = 1.0 # Degrees C, but could be 0.75% reading
thermometer = 0.2 * degftometric # Degrees F
barometer = 1. # Millibar
caliper = 0.5 # Millimeters
scale1 = 0.001 # 1 gram accuracy
pressscale = 10. # 10 inches H2O
pressscale2 = 200 # 200 inches H2O
press = 0.0006 * pressscale
press2 = .0006 * pressscale2
stopwatch = 0.01 # Photograph the stopwatch to achieve this
CO = 0.5 # parts per million
```

```
CO2 = 50 # parts per million, may be 5% of reading though

# Add in all of the measured masses
# All units will be in kg
mcan0 = unc.ufloat(0.010, scale1) # Similar to values found at Aprovecho
mcan1 = unc.ufloat(0.050, scale1) # Similar to values found at Aprovecho
methanol = unc.ufloat(0.95, scale1) # Assuming 95% concentration
mdiluent = unc.ufloat(0.050, scale1) # Assuming 95% concentration
mpot0 = unc.ufloat(0.5, scale1) # Assuming the pot will weigh around 0.5 kg
mpot1 = unc.ufloat(1.0, scale1) # Assuming 0.5 kg / 0.5 L water added
mpot2 = unc.ufloat(0.995, scale1) # Assuming we lose 5g of water due to boiling

# Add in the pressure measurements of the sampling tube
# Will be input and output in inches of water
deltaP = unc.ufloat(0.1028, press) # Measured value during calbibration
deltaPpitot = unc.ufloat(0.11, press) # Measured value during calbibration

# Absolute pressure in Pascals
Pabsolute = unc.ufloat(1017.6666666, barometer) * mbartopa

# Add in the CO and CO2 readings
COppm = unc.ufloat(10., CO)
CO2ppm = unc.ufloat(200., CO2)

# Add in burn time, in seconds
burntime = unc.ufloat(15.*60., stopwatch) # Assuming that it will burn 15 min

# Add in the temperature measurements
# Input and output in Kelvin
T0 = unc.ufloat(295.98, thermocouples) # Measured value during calibration
Tambient = unc.ufloat(295.17, thermometer) # Measured value during calibration
TE = unc.ufloat(373.15, thermocouples) # Assuming boiling point at sea level

# Inner diameter of sampling tube
d = unc.ufloat(98.625, caliper) * mmtom # ID of sampling tube in meters

# Plug in each of the equations and solve.  The bottom of the tree is computed
# first in order to allow computation of the higher level tolerances.
A = 0.25 * np.pi * d**2
rho_air = Pabsolute / (R_air * Tambient)
mwater1 = mpot1 - mpot0
mwater2 = mpot2 - mpot0
mevap = mwater1 - mwater2
mfuel = mcan1 - mcan0
Cx = methanol / (methanol + mdiluent)
Ux = Uethanol * Cx
Ereleased = mfuel * Ux
EH2Oevap = mevap * hv
deltaT = TE - T0
vpitot = ((2*(deltaPpitot*inwtopa))/rho_air)**0.5
Vdottube = (215.*(deltaP**0.5)) * cfmtocms
C = (vpitot * A) / Vdottube
Vdot = Vdottube * C
V = Vdot * burntime
COpartial = Pabsolute * COppm / 1.e6
CO2partial = Pabsolute * CO2ppm / 1.e6
nco = (NA * COpartial * V) / (R * Tambient)
nco2 = (NA * CO2partial * V) / (R * Tambient)
nethanol = NA * mfuel * Cx / Methanol
EH2Oheat = mwater2*cpw*deltaT + mpot0*cpm*deltaT
hc = (EH2Oheat + EH2Oevap) / Ereleased
epsilon = nco / (2 * nethanol)
```

```
print('————————————————————————————')
print('THERMAL EFFICIENCY (h_c)')
print('Nominal value: {:.2f}%'.format(hc.n * 100.))
print('Relative uncertainty: +/- {:.2f}%'.format((hc.s / hc.n) *100.))
print('————————————————————————————')
print('CO PRODUCTION')
print('Nominal value: {:.2f}%'.format(epsilon.n * 100.))
print('Relative uncertainty: +/- {:.2f}%'.format(
        (epsilon.s / epsilon.n) *100.))

lw = 1
fs = 14
pyl.figure(0, figsize=(6,4.5), dpi=600)
pyl.xlabel('Volumetric Flow Rate (m$^3$ / sec)', fontsize=fs)
pyl.ylabel('Calibration Constant "C" Value', fontsize=fs)
pyl.grid(True)
pyl.errorbar([i.n for i in Vlist], [j.n for j in Clist], xerr=[k.s for k in Vlist],
             yerr=[l.s for l in Clist], linewidth=lw)
pyl.savefig('CalibrationConstantCurve.pdf')
```

- Code Output:
  - THERMAL EFFICIENCY (h_c)
  - Nominal value: 18.95%
  - Relative uncertainty: +/- 4.24%
- CO Production
  - Nominal value: 1.17%
  - Relative uncertainty: +/- 6.78%

H. Images

Fig. 11. Prototype stove used in preliminary test

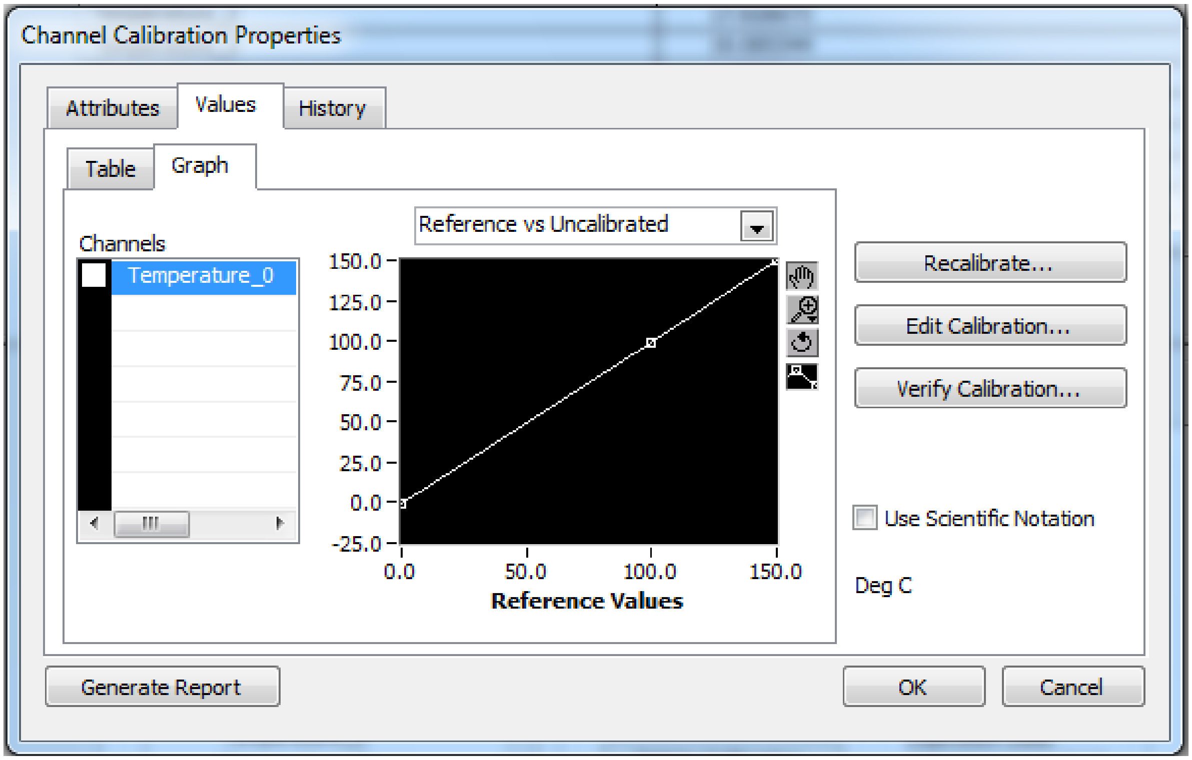


Fig. 12. 2 point calibration curve using a 0.0C° ice bath and a 100C°.

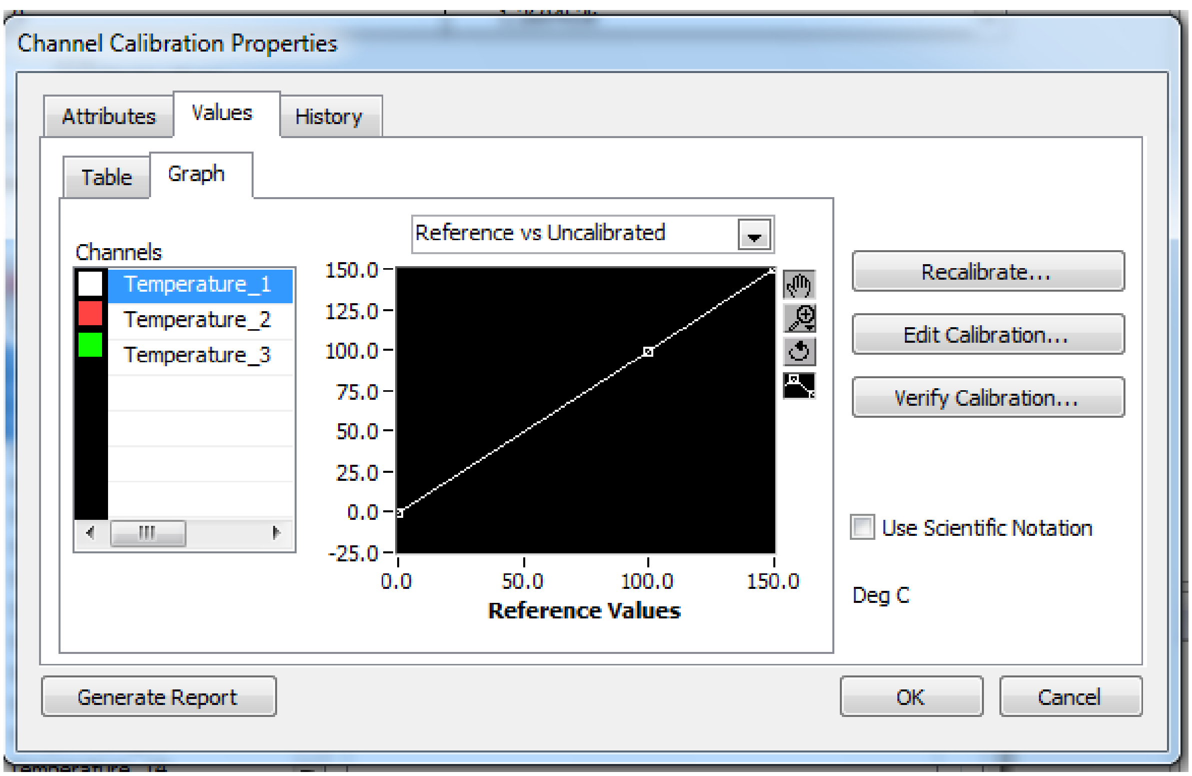


Fig. 13. 2 point calibration curve using a 0.0C° ice bath and a 100C°.

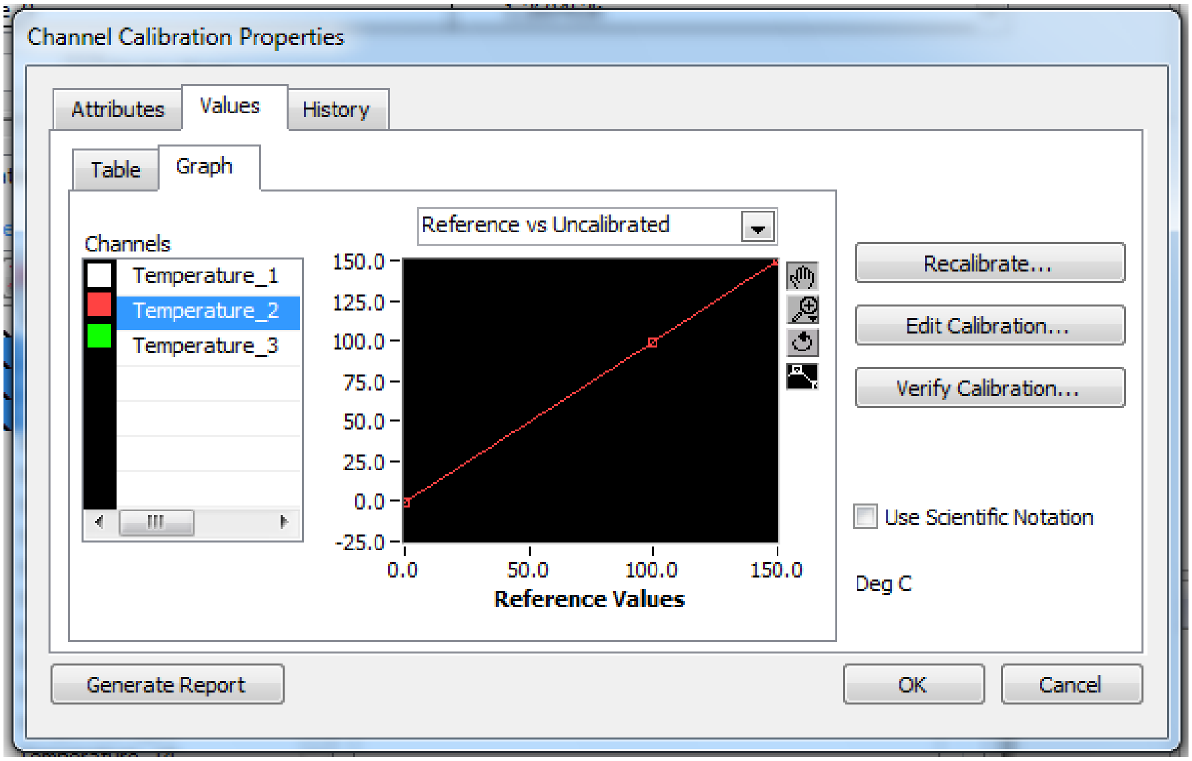


Fig. 14. 2 point calibration curve using a $0.0C^{\circ}$ ice bath and a $100C^{\circ}$.

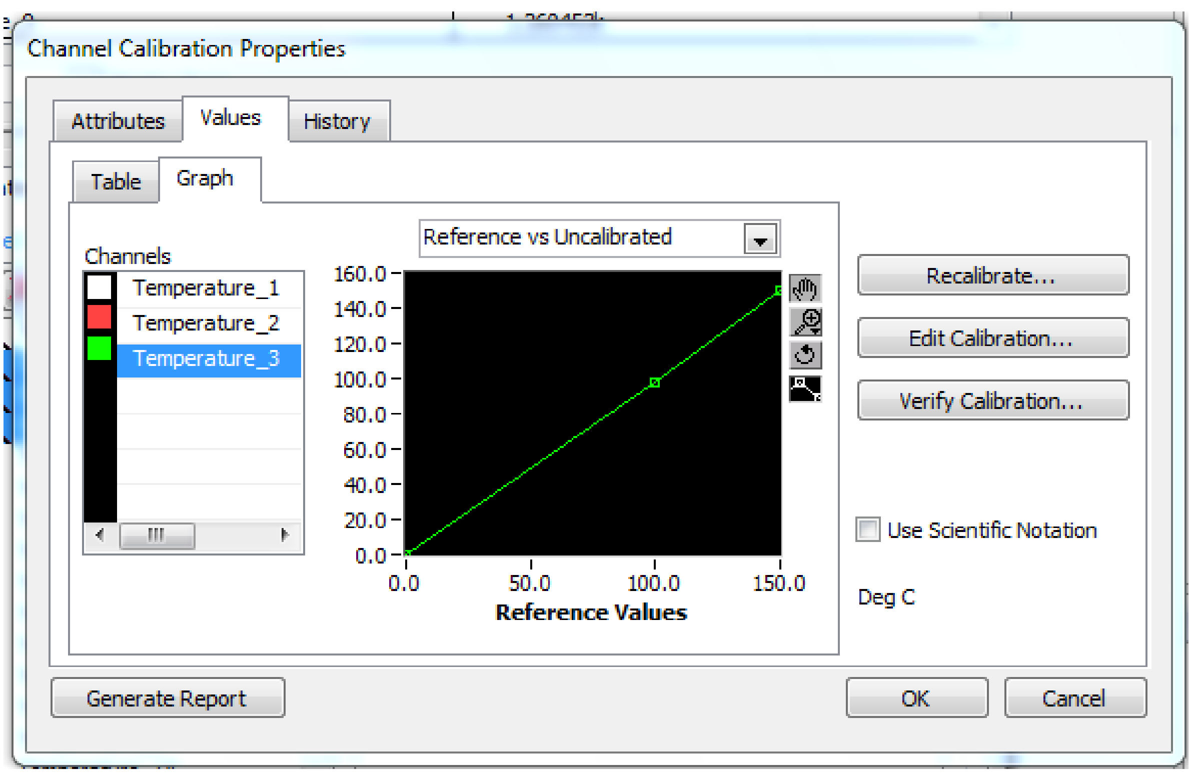


Fig. 15. 2 point calibration curve using a $0.0C^{\circ}$ ice bath and a $100C^{\circ}$.