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Residential Wood Combustion Technology Review
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Abstract

A review of the current states-of-the-art of residential wood combustion (RWC) was conducted. The key environmental parameter of concern was the air emission of particles. The technological status of all major RWC categories was reviewed. These were cordwood stoves, fireplaces, masonry heaters, pellet stoves, and wood-fired central heating furnaces. Advances in technology achieved since the mid-1980's were the primary focus. These study objectives were accomplished by reviewing the published literature and by interviewing nationally recognized RWC experts.

The key findings of the review included: (1) The NSPS certification procedure only qualitatively predicts the level of emissions from wood heaters under actual use in homes, (2) Wood stove durability varies with model and a method to assess the durability problem is controversial, (3) Nationally the overwhelming majority of RWC air emissions are from non-certified devices (primarily from older non-certified woodstoves), (4) New technology appliances and fuels can reduce emissions significantly, (5) The ISO and EPA NSPS test procedures are quite dissimilar and data generated by the two procedures would not be comparable, and, (6) The effect of wood moisture and wood type on particulate emission appears to be real but to be less than an order of magnitude.

Appendix C

Solid Fuel Committee of the Hearth Products Association (HPA) Comments on Review Topics

Table of Contents

Attendees to Solid Fuel Technical Committee Meeting

1. Dan Henry, Vice President, Aladdin Steel Products
2. Bill Sendelback, President & CEO, Breckwell
3. David Johnson, DSJ Technical Services
4. Prasad Deshmukh, Electronic Engineer, Duraflame
5. Thao Huynh, Chemist One, Duraflame
6. Paul Lynch, New Business Dev. Manager, Duraflame
7. Lohit Tutupalli, Research Scientist, Duraflame

- Dennis Jaasma, President, EECI
- Jim Kovacs, Mgr. Engineering R & D, FPI
- Ken Maitland, Director of Engineering, FMI
- Walter Moberg, President, Firespaces
- John Crouch, Director of Government Relations, HPA
- Michael Van Buren, Technical Director, HPA
- Denny Kingery, Product Engineer, Heatilator
- Wayne Terpstra, Vice President of Technical Services, Heatilator
- Rick Curkeet, Chief Engineer, Intertek Testing Services
- Ben Myren, President, Myren Consulting
- James E. Houck, Vice President, OMNI
- David McClure, Vice President, OMNI
- Paul Tiegs, President, OMNI
- John Francisty, R &D Manager, Pacific Energy
- Jerry Whitfield, President, Pyro Industries
- Eric Dufour, Director of R & D, Security Chimneys
- Tim French, Mgr. of Eng. Wood Products & Drafting, Superior Fireplace
- Steven Plass, Product Manager, Superior Fireplace
- Erkki Jarvinen, Technical Director, Tulikivi
- Bill Bradberry, President of Sales, Vestal Mfg.

Hearth Products Association Solid Fuel Technical Committee Meeting
Friday January 9, 1998

Review of questions from OMNI Laboratories
Residential Wood Combustion Technology Review
EPA Purchase Order no. 7C-R285-NASX

1. *State-of-the-art of woodstove combustion and emission control technologies.*

1. l Are in-home emission reductions as compared to conventional stoves shown in Table 1 for catalytic and non-catalytic certified stoves reasonable?

Dr. Houck explained that the values in Table 1 are from in-situ studies, they are not laboratory test results. Dr. Houck reviewed data taken from the mid 1980's through 1996.

Dr. Houck explained that some of these numbers are best guess. The greatest uncertainty is with the conventional stoves - this data is optimistic. Rick Curkeet thought the emissions for conventional stoves are actually much worse. There was a question of how many of the convention stoves used in-situ had been developed to meet the Oregon standard. This would imply that the conventional stoves used for in-situ studies had improved emissions compared to those stoves that did not meet the Oregon standard.

The EPA data is based on 30 conventional stoves. A vote was taken in the room as to whether 18.5 g/kg was too low, the consensus was that it was too low. Rick Curkeet suggested that a range of 20-200 g/kg be used. Everyone agreed. Dr. Houck told the group that EPA wanted a specific number. All attendees agreed that there was not just one specific number. The comparison was made of fuel economy with different vehicles. It would depend on the vehicle and how it was driven.

Dan Henry mentioned that he had seen some EPA approved appliances tested with densified fuels that had very low emissions, below 1 g/hr and that should be reflected in this table.

1.2 Are efficiencies shown in Table 2 for catalytic and non-catalytic certified stoves reasonable?

Rick Curkeet stated that the efficiencies of conventional stoves range from 20 to 50% efficient. The efficiencies for non-catalytic stoves go by EPA default efficiencies, which takes away the motivation to improve the efficiencies of non-catalytic stoves. There are two different types of non-catalytics, those that pass Washington State standards and those that do not.

Conventional, catalytic and non-catalytic stoves go by default numbers for efficiencies, whereas

pellet, masonry and densified fuel are calculated. 68% efficiency is more accurate than 63% for non-catalytic stoves. The default efficiency for pellet stoves is 78%.

The group agreed that single numbers are misleading; a range of efficiencies should be used for each type of stove. Erkki, from Tulikivi questioned the efficiencies of the masonry heaters; use patterns have to be considered.

There were concems on the efficiencies given to conventional stoves however, it is difficult to prove or disprove this number without additional in-situ data.

1.3 Can catalyst technology for use in woodstoves be fundamentally improved?

Yes, microprocessors could be added to stoves to monitor and control the stove, preheating of the catalyst could be done with propane or electric resistance heat. However, EPA's current standards are design restrictive and do not allow these types of improvements. In addition, catalytic stoves have lost their market share over the last four years, in part due to their initial cost. Any modification to the stove that would drive up the cost of the stoves would probably end sales of these stoves altogether.

1.4 Is the use of manufactured fuel (densified and wax logs) a credible emission reduction strategy? See Tables 1 & 2.

The committee does not look at this as an emission reduction strategy, but rather as a technological possibility. Yes, manufactured logs are an option for cleaning up woodstove emissions, both conventional and EPA approved. Whether or not they are a credible strategy would depend on the EPA State Implementation Plan.

1.5 For non-catalytic stoves the heat retention adjustment with refractory material of various densities can reduce particulate emissions. How big an effect can this have?

Refractory materials and the type chosen can make a difference with light off in the first five minutes of a test burn. This can make the difference between a 5g/hr run and a 25g/hr run. This is fundamental, but very stove specific. There are other design characteristics that also make just as much of a difference. These types of "tricks" to make a stove perform better in an EPA emissions test may or may not make a difference on how stoves perform in the field. No one at the meeting had seen conclusive data to prove or disprove this correlation. There was general agreement that for some stoves, this can have a very large effect, both in the lab and in the field.

1.6 Approximately one half of the particulate emissions occur during the kindling phase for non-catalytic woodstoves and more than half for catalytic woodstoves. Are there improvements in technology that can mitigate this problem? Can specially designed high BTU wax logs be used to achieve a fast start and reduce kindling phase emissions?

Dan Henry told the group how EPA and Aladdin Steel were working on a system with very stable secondary combustion. The system used a gas pilot light. Dan wanted to certify the stove using the pilot light. At first EPA approved this and later revoked it stating the appliance had to be tested without the pilot light running because this would be considered a dual fuel. The system was considered dual fuel and therefore could not be certified. An in-situ study was done in Spokane and Dennis Jaasma was going to perform an in-situ study in Virginia prior to EPA revoking this concept.

There have been similar other products. Ben Myren told of a product that used an electric combustion enhancement and emissions reduction technology that also was rejected by EPA.

High Btu wax logs can be used to achieve a fast start and therefore lower emissions of woodstoves, however EPA would probably consider this a dual fuel system.

> *1.7 Should masonry heaters with tight fitting doors and draft control be classified as a wood stove and be subject to some type of certification even though most weigh more than 800 kg?*

Walter Moberg stated there are advantages for masonry heaters to be listed and tested to EPA standards, however the industry suffers because there is no fair way to do this at the present time under the existing standard. Erkki stated that those masonry heaters that are not built on site should have some type of certification, but masonry heaters should not be tested the same way a woodstove is tested. There was agreement that masonry heaters need to be certified, but not as woodstoves, but rather to their own masonry heater standard.

> *1.8 Are the emissions and efficiencies for masonry heaters, based on in- home tests, shown in Tables 1 and 2 reasonable?*

The thought was these numbers given are generally fair values, although efficiencies are difficult to measure.

> *1.9 The OMNI staff feels the emissions per unit of heat delivered (e.g., lb/MBTU or g/MJ) is a more appropriate way to rank the performance of wood burning appliances than emission factors (lb/ton or g/kg) or emission rates (g/hr). Comments?*

Dan Henry brought up the point that to go from g/hr to g/kg would mean re-educating the public and the state and local regulators. Historically, the industry initially wanted g/kg but the environmental community wanted g/hr. Neither g/hr nor g/kg motivates manufacturers to increase efficiencies.

> *1.10 Default efficiency values are used for woodstoves. This, coupled with the fact that emission factors or rates (not g/MJ) are used to rank woodstoves, does not provide an incentive for manufacturers to increase the efficiency of their stoves. -Comments? Should*

the efficiency test method as described (FR v. 55, n 1611 p. 33925, Aug. 20,1990) be required to be used and the results listed?

Rick Curkeet commented that almost all EPA approved stoves have higher efficiencies than the EPA default efficiency. Grams/hr and efficiency are two separate parts of the equation. If woodstove manufacturers also were required to test for efficiency, this would drive up the cost of testing stoves.

Grams/MJ vs. g/hr - g/hr makes an appliance that stores heat (such as a masonry heater) look bad. Another thing to consider is that g/MJ should take into account transmission losses, for instance, if the unit is outside the house.

Jerry Whitfield stated that if you were to go to a g/MJ measurement, there would be more regulation, due to the fact that g/MJ is very difficult to define.

1.11 Have certified stove design and performance improved since the first certified stoves? If so, how?

Yes - John Francisty pointed out that the stoves today are more durable, and more user friendly. Proof of this is the longer warranty periods on the stoves today. Manufacturers are more confident in the durability of their stoves.

2. State-of-the-art of fireplace emission control technology.

2.1 Are the emission factors and efficiencies for the in-home use of fireplaces and inserts shown in Tables 3 and 4 reasonable?

EPA standards all look at emissions on a mass per mass source basis.

Use patterns are critical and the purpose for an appliance is also critical. Are you talking about a heater such as a stove or a fireplace that is used for aesthetics?

Grams/MJ should not be used to measure emissions from a fireplace. The problem is what do you do about the products in between a heater and a fireplace such as masonry heaters? There may in fact need to be three different test methods.

Grams/kg may be the best way to test an appliance, but regulators wanted g/hr because they wanted emissions based on time. The thought of the group was that no-burn-days covers incidents such as the example given of fireplaces being used at Christmas time. Dr. Houck mentioned that 28% of cordwood is burned in fireplaces and 7% of those are used as a primary source of heat according to studies in the Southeastern U.S.

It was also mentioned when looking at fireplaces, glass doors can make a difference in efficiency

of 30-40%.

2.2 There appear to be only a few practical design or technology options for fireplaces that will potentially mitigate particulate emissions. - What designs and technologies are available? What retrofit options are there?

Walter Moberg mentioned that there have got to be options that have not been explored. Fireplaces are significantly under developed from an emissions standpoint. Glass doors in themselves can lower emissions.

2.3 The use of wax fire logs reduces emissions over the use of cordwood. Can the formulation of wax logs be changed to produce even fewer emissions?

Duraflame log representatives informed the committee that there are ways of lowering emissions from wood/wax logs that are being explored by some manufacturers.

2.4 What are the distinctions between a masonry fireplace and a masonry heater?

The big differences between fireplaces and heaters are the hearth opening size, heating ability and efficiency. Masonry heaters have smaller openings, more heating ability, and higher efficiencies, but it is a matter of drawing a line in efficiencies to separate the two. Colorado has a masonry heater standard.

2.5 As with woodstoves, the OMNI staff believe that the mass of emissions per unit of heat delivered is a better way to rank the performance of fireplaces than emission factors or emission rates.

See question 1.10

3. State-of-the-art of wood-fired central heating furnace emission control technology.

3.1 According to a Department of Energy survey, out of the 20.4 million households that used a wood burning appliance in 1993, less than 0.3 million used a wood burning furnace as their primary source of heat. Are there enough wood-fired central heating furnaces in use to merit their closer evaluation? How many commercially available models are there? Are there emissions data for them? Should they be certified?

Rick Curkeet pointed out that the lack of EPA regulations on wood fired central boilers has killed R&D on central heating furnaces. Outdoor furnaces could potentially give the wood burning industry a black eye. It is however a viable technology and is used in Europe. More automation could be developed.

There is a need for a separate central furnace standard as opposed to a modified woodstove

standard. The Canadian standard CSA B415 committee started a furnace standard but sales of the product did not warrant it, so it was never finished. CanMet did some work on this.

CSA B415 is a consensus standard, which allows for modifications, unlike the EPA standard, which has no method of modification or industry participation once it is set up.

4. State-of-the-art of Pellet-fired woodstove technology.

4.1 Are the emissions and efficiencies for the in-home use ofpellet stoves shown in Tables 1 and 2 reasonable'?

Table 1 information comes from Klamath Falls and Medford, as well as estimates by OMNI staff.

Jerry Whitfield stated that comparing particulate from cordwood and pellet stoves is apples and oranges. From pellet stoves, larger particles are being captured instead of smaller ones that are more of a health risk. There are no data that show this at the present time. Pellet burning in the field is more controllable and definable. For this reason pellet stoves should not be tested by the same method as a cordwood stove.

4.2 The 35:1 air-to-fuel ratio cut-off for certification has produced two classes of pellet stoves - those that are certified and those that are not. The latter class may have models that are less efficient and have higher emissions than the former. Should the regulations be amended to close the loophole and discourage the practice of intentionally designing models with a higher air-to-fuel ratio to avoid certification?

Jerry Whitfield stated that it is not necessarily true that "The latter class may have models that are less efficient and have higher emissions than the former". Dan Henry stated that it is very difficult to meet or exceed the 35:1 ratio.

4.3 Have pellet stove design and performance improved since the first models were introduced? If so, how?

Yes, they have improved, but we are on the brink of a third generation of stoves that could be just as clean as gas or oil.

5. *Ramifications of ISO.*

5.1 The International Organization for Standardization (ISO) has a technical committee for developing emissions, efficiency and safety test standards for wood-fired residential heaters and fireplaces. (See Table 5 for comparison of the draft ISO Method 13336 with EPA Methods 28, 5G and 5H.) Do you feel that the EPA methods should be replaced with or be made comparable to an international standard?

It was the feeling of the group that the ISO standard has very little relevance at this time. It is

being used mainly in New Zealand and Australia. The group felt that the Canadian standard CSA B415 should be looked at more closely. The question is, should the U.S. get involved in the ISO standard so that it is a standard that the U.S. can agree with? At the present time manufacturers have very little interest in dedicating any resources to this effort.

6. Correspondence between in-home and laboratory emission test results.

6.1 How accurately do certification tests predict in-home performance?

We don't know what the correlation is if any. Dan Henry stated that it is unlikely that a lab test would mirror in-home performance given the fuel alone used in the lab is different from cordwood. The original purpose of the test was to rank stoves given a standard test procedure. Also, given that the accuracy of the lab test is plus or minus 20% makes it difficult.

Ben Myren brought up the Klamath Falls study where the cleanest lab stove was the cleanest stove in the field. The same held true for the dirtiest stove in the lab. The EPA test protocol may be very accurate at predicting relative field performance.

It was also brought up that the EPA test should not designate a low burn, but allow the manufacturer to choose a low burn rate for its appliance.

6.2 How would you design research testing in the laboratory to simulate in-home use?

This would be very difficult due to the variations in use patterns and fuel types in the field.

7. EPA Method 28 strengths and weaknesses.

7.1 Method 28 is in part an "art ". Fuel loading density, fuel moisture, fuel characteristics (old vs. new growth, grain spacing, wood density) and coal bed conditioning can be adjusted within the specification range of the method to influence results. In your experience what things have the most effect on particulate emissions? How much influence can they have?

There are many little things that affect emissions during a test burn and they vary with every stove.

John Francisty stated that this industry has spent literally millions of dollars trying to get their appliances to reach a 1 kg/hr burn rate, which is unnecessary. There does not need to be a certain low burn rate. The low burn rate has the largest impact on the emissions of the stove.

Everyone agreed that the low burn rate and the high burn rate were critical in the test procedure and the two middle burn rates were academic.

7.2 Burn rate weighting is based on very limited data and the cities from where the data

were obtained are not very representative of wood use nationwide (see Table 6). How can the weighting scheme be improved to be more representative of the nation as a whole?

Don't use 1 kg/hr as an artificial minimum burn rate requirement.

Plus the EPA rule is design restrictive. An example of this is in the late 1980's EPA stopped regulating wood burning furnaces and R&D stopped almost immediately.

Historically, we ended up with a test method using conventional lumber because there was a database using conventional lumber. The 1 kg/hr low burn rate was imposed because regulators thought the industry would be getting away with something if an artificial low burn weren't imposed. As a note, there was an ASTM standard at the time that was repeatable and reliable.

The question was asked if question 7 is irrelevant. Dr. Dennis Jaasma pointed out that most stoves in the field burned at the low burn rate category. However, burn rates with cordwood vary more than that of dimensional lumber. Users know that to get a longer burn, you use a larger piece of wood.

It was also mentioned that the industry is not making or selling many woodstoves and that everything discussed is going to cost a lot of money for the industry to comply with. This should be considered with any possible change made to the present test methods.

Ben Myren pointed out that with the new air quality standards, improvements would need to be made.

7.3 The equationfor the calculation ofthe air-to-fuel ratio in Method 28A is in error. The error produces a small but significant difference in the calculated air-to-fuel ratio. Should the Method be corrected or should it be left as a "predictor" of the air-to-fuel ratio?

Dr. Jim Houck pointed out that the calculation is flawed due to the volume occupied by hydrocarbon gas being considered a constant. What this error does is have a negative effect on stove efficiencies as well as measured air-to-fuel ratios. Stoves have to be well over the 35:1 ratio to actually meet the exemption.

CSA B415 gives a solid basis for calculating efficiencies.

It was brought up that there should be only one test if the tests do not give the same answers.

7.4 The assumed molefraction of hydrocarbons (Y_{HC}) is defined as a constant in the air-to-fuel ratio calculations in Method28A. The mole fraction of hydrocarbons in the vapor phase will vary significantly with fuel and combustion conditions. Should hydrocarbon

vapors (more appropriately, organic compound vapors) be measured as part of the Method?

The committee as a whole had no strong opinion on this issue.

8. EPA Methods 5G and 5H correlation.

8.1 The comparison data to demonstrate the correlation between 5G and 5H are limited. Should the correlation between the two Methods be re-evaluated?

No, just eliminate Method 5H. There should not be two methods in one standard that do not produce identical results. One method should be eliminated. The perception is that 5H gives lower results even though theoretically it should give a higher result.

The correlation between the two methods has never been tested, but they do not converge to zero, as they should with the correction. There is also a problem at higher burn rates.

8.2 It is the general perception that Method 5H produces lower numbers than 5G. Method 5G is less costly and more precise than 5H. - Comments? - Should there be just one sampling method?

There should be one Method 5G, however the correction multiplier in 5G that is supposed to make 5G and 5H equal would have to be removed.

8.3 The same points regarding flow rate calculations (air-to-fuel ratio) and hydrocarbons as made for Method 28A are applicable to Method 5H. -- Comments?

They are wrong and should be changed. This is a modification of Method 5.

8.4 The precision of EPA's basic Method 5 is estimated as being about 20%. Almost one quarter of the 214 stoves listed as certified by the EPA as of 8/12/97 are within 20% of their respective (catalytic or noncatalytic) emission limits. -Comments?

How many of the 214 are still being sold? The safety factor is already built into the Phase II appliances by dropping Phase I from 9 g/hr to 7.5 g/hr.

8.5 Based on practical experience with the 5G and 5H, how can they be improved?

There are many improvements that are needed. An example of this are the calibration requirements. The test methods are also very susceptible to barometric pressure, especially at the low burn rate.
Correct 5G and 5H so that the results match or get rid of 5H and get rid of the correction factor

on 5G. This may mean changing the pass/fail number. 5G was designed for variable flow rates, which better represents wood stoves.

9. Performance deterioration of EPA-certified woodstoves in the field.

9.1 It is the opinion of many in the woodstove industry that catalysts last only five years and that a stove designed for a catalyst operated without a functioning catalyst can produce as much emissions as a conventional stove. -Comments?

The thought was that the life of the catalyst was dependent upon the operator as well as the stove design so it is very difficult to say. Also the emissions from a catalytic stove without a functioning catalyst are very much a function of the stove design.

9.2 Field studies in Glens Falls, NY, Medford, OR, Klamath Falls, OR, and Crested Butte, CO, showed that emissions from some catalytic stoves became appreciably worse even after only two to three years of use. Inspection of stoves in Glens Falls showed that catalyst deterioration and leaky bypass systems were responsible. Have improvements been made in the design of catalytic stoves to minimize these problems? Is it reasonable to require homeowner training on the proper use of catalytic stoves and/or to incorporate into their costs an inspection and catalyst replacement program?

The Glens Falls stoves were "cooked" by overdrafting chimneys. Woodstoves are the only type of residential heating appliance that do not have some type of overdraft protection. This needs to be changed.

Education of consumers would be helpful, but how would this be done? Would you require a stove owner to be licensed? This is not reasonable.

10. Stress test pros and cons.

10.1 A short-term laboratory woodstove durability testing protocol was developed to predict the long-term durability of stoves under conditions characteristic of in-home use (see EPA-600/R-94-193). It was concluded in that study that damage occurs during those occasional times when a woodstove is operated in the home at exceptionally high temperatures. The laboratory stress test was designed to operate a woodstove at very high temperatures over a one to two week period to predict long-term durability under in-home use. Is this a reasonable approach?

One manufacturer mentioned that his stove failed the stress test even though they have had very little problems with them in the field. This would indicate that the test was much too severe.

10.2 Should a stress test be made part of the certification process?

The feeling was that a stress test should not be made a part of the certification test.

11. Feasibility of developing separate emission factors for dry and wet wood and for soft-wood and hardwood species classes.

> *11.1 Optimum wood moisture for low particulate emissions seems to be in the 18% to 20% range. Are you aware of any data that will allow the impact of wood moisture to be isolated from other variables? Could it be different for wood from different tree species?*

No one present knew of any data that were not already available to OMNI.

> *11.2 Wood from different tree species clearly burns differently. The chemical makeup and density of wood from different tree species is different. For example wood from coniferous trees has more resin than wood from deciduous trees. It is believed that particulate emission factors will be different for wood from different tree species. If this is true different parts of the country may have different emissions factors for residential wood combustion. Are you aware of any data that document different emission factors for wood from different tree species?*

The committee generally agreed that testing with different wood species made more sense than at four burn rates on the same species.

12. Routine maintenance.

> *12.1 Would routine maintenance of stoves once they were in a home reduce particulate emissions? Would this be more relevant for catalytic stoves than noncatalytic stoves? Would this be relevant for pellet stoves with electronic and moving parts?*

The committee agreed that routine maintenance was very relevant and that training of chimney sweeps, who perform much of the routine maintenance, is important.

> *12.2 Should the homeowner be provided with a maintenance manual or a training course at the time of purchase? Should a maintenance program be part of the purchase price particularly for catalytic stoves?*

Homeowners are provided with maintenance instructions at the time of purchase. A maintenance program for catalytic stoves would likely make these stoves even less popular in the market than they already are.

> *12.3 What would the key elements of routine maintenance be?*

This varies from model to model, and is covered in each individual owner's manual.