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**OIL HEAT VENT ANALYSIS PROGRAM (OHVAP)
USERS MANUAL AND ENGINEERING REPORT**

R. F. KRAJEWSKI

NOVEMBER 1996

Prepared for:
Office of Building Technologies,
State and Community Programs
Building Equipment Division
U.S. Department of Energy
Washington, DC 20585

MASTER

Energy Efficiency and Conservation Division

DEPARTMENT OF APPLIED SCIENCE

**BROOKHAVEN NATIONAL LABORATORY
UPTON, LONG ISLAND, NEW YORK 11973**

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Under Contract No. DE-AC02-76CH00016

Energy Efficiency and Conservation Division
Brookhaven National Laboratory
Upton, N.Y. 11973

Abstract

Oil-fired heating appliances have traditionally used conventional chimney venting systems. In more recent times, masonry chimneys have given way to fabricated metal chimneys which have had the advantage of lower installed cost. Even more recently, there has been an effort by the industry to apply power venting technology to oil-fired appliances. These changes in venting technology have been accompanied by ever improving appliance efficiencies. The successful application of these modern, high efficiency oil-fired appliances depends upon the safe and cost effective integration of the heating appliance and the vent system. Unfortunately, due to the complexity inherent in such issues as heat loss, condensation and corrosion the available manual calculations provide only a steady state rather than transient analysis. In addition, these methods are exceedingly cumbersome. While computerized methods have been developed, for the most part they are usually these same steady state calculations placed into a spreadsheet or BASIC program.

To address the problems inherent to steady state computations, an effort was made to determine the general availability of transient analysis design tools and it was decided that another simulation specifically geared towards the needs of the oil heat industry would have to be developed. The computer simulation that resulted is the Oil Heat Vent Analysis Program (OHVAP).

As the name implies, OHVAP analyzes a vent system, it will not design one. Given a particular geometry, firing rate, and a some other data the program will report the gas and wall temperatures, static pressures, and condensate amounts throughout the vent system. Whether or not these reported values indicate that the vent system provides acceptable performance is left to the user's discretion. The program will report what is happening, not whether any one event is good or bad.

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Introduction

Oil-fired heating appliances have traditionally used conventional chimney venting systems. In more recent times, masonry chimneys have given way to fabricated metal chimneys which have had the advantage of lower installed cost. Even more recently, there has been an effort by the industry to apply power venting technology to oil-fired appliances. These changes in venting technology have been accompanied by ever improving appliance efficiencies. The successful application of these modern, high efficiency oil-fired appliances depends upon the safe and cost effective integration of the heating appliance and the vent system. Unfortunately, due to the complexity inherent in such issues as heat loss, condensation and corrosion the available manual calculations provide only a steady state rather than transient analysis. In addition, these methods are exceedingly cumbersome. While computerized methods have been developed, for the most part they are usually these same steady state calculations placed into a spreadsheet or BASIC program.

To address the problems inherent to steady state computations, an effort was made to determine the general availability of transient analysis design tools for the oil heat industry. Several computer simulations (VENT II developed by the Gas Research Institute and FLUESIM developed by the Canada Mortgage and Housing Corporation) are available, but all were judged inadequate for some or all of the below reasons:

- Only gas fired appliances were modeled
- Sulfuric acid condensation was not addressed
- Vent design was secondary to building and appliance modeling

What is OHVAP?

To address the limitations present in VENT II and FLUESIM it was decided that another simulation specifically geared towards the needs of the oil heat industry would have to be developed. The computer simulation that resulted is the Oil Heat Vent Analysis Program (OHVAP). The program:

- Provides transient heat transfer analysis
- Determines water and sulfuric acid condensation
- Models barometric damper operation
- Can use custom fuel compositions
- Simulates postpurge and prepurge operation
- Can handle a variety of vent configurations including conventional chimney, sidewall vents, and sealed combustion systems
- Records results in a LOTUS™ version 1.0 spreadsheet (*.wk1)

As the name implies, OHVAP analyzes a vent system, it will not design one. Given a particular geometry, firing rate, and a some other data the program will report the gas and wall temperatures, static pressures, and condensate amounts throughout the vent system. Whether or not these reported values indicate that the vent system provides acceptable performance is left to the user's discretion. The program will report what is happening, not whether any one event is good or bad. The reason that a spreadsheet format was chosen for the data output was to enable the program's user to analyze the results using the capabilities available in most spreadsheets.

Who should use OHVAP?

The program should be used by someone who has engineering knowledge of how oil fired venting systems are supposed to work. The relationship between gas temperatures and available static pressures at a minimum should be understood as should the effects of gas and wall temperatures upon condensation.

What is needed to use OHVAP?

The computer hardware and software required to run the OHVAP computer model is as follows:

- A 386 based IBM PC or compatible with math coprocessor (486DX or Pentium preferred) - At this writing 486DX operation is recommended; Pentium operation is flawed and is being resolved; *See Appendix G, Section G-3.7 for more information.*
- 4 MB of ram
- A DOS or Windows based spreadsheet capable of importing LOTUS™ version 1.0 (*.wk1) formatted files
- ASCII file editor (DOS' edit.exe or Windows notepad) for editing *.TTP files

The information the program will require from the user is:

- The geometry of the vent system
- The materials used within the vent system
- Firing rate
- Excess air setting (or CO₂ levels)
- Fuel composition
- Barometric damper setting or damper curve (if applicable)
- Fan curve for draft fan (if applicable)
- Temperature and humidity for indoor and outdoor air
- Post and prepurge durations (if applicable)

How to use this report

This report is organized into three sections. Section I is the User's Manual which describes how to work with the program, Section II is the Engineering Report which details how the program works, and Section III consists of the conclusions and appendices.

Section I consists of two chapters. Chapter 1 provides a reference for every screen that a user will see as a vent case is entered into the program. Each screen corresponds to one of the menu choices and is described in order that they appear. Chapter 2 provides the new user with a tutorial on entering case file information into the program and reading the results in the spreadsheet. In general, the reader is advised to be familiar with the information provided in this section before moving on to Section II.

Section II also consists of two chapters. Chapter 3 takes a "high altitude" approach and provides a general overview to the basic organizational structure of the program. The program's flowchart is provided and discussed at a cursory level. Chapter 4 then burrows further into the heart of the OHVAP model. It describes the engineering basis for the calculations that OHVAP performs as it conducts the analysis from heat transfer to pressure drop.

In Section II the conclusion of this report provides insight into those areas of the model that we feel could be enhanced or better defined. Possible experimental work that would be beneficial to the validation of the model is also discussed. The last portion of Section III, contains six appendices that cover information ranging from OHVAP's internal file formats to a description of how OHVAP was actually used at Brookhaven National Laboratory to develop a set of venting tables to assist the oil heat industry.

Appendices A & B provide direct support for the OHVAP model. Appendix A provides a graph showing the relationship between the amount of excess combustion air and the levels of carbon dioxide and oxygen found in the flue gas. Appendix B describes the properties of the various materials that OHVAP will recognize in building a vent system.

Appendices C through E describe the internal file formats that OHVAP uses to store case information and to transfer that information from the data entry portion of the program to the engineering module.

Appendix F describes how OHVAP was used to develop a set of chimney relining tables for the oil heat industry. Appendix G contains review and reference information.

Section I: User's Manual

Chapter 1: Menu Reference

This section will provide a guided tour of the OHVAP menu screens. Each screen will be described below. It is arranged in the order that the menus will appear on the screen from left to right.

Figure 1: Initial Startup Screen

Getting Started

Change to the directory where you have installed OHVAP (C:\OHVAP if you accepted the defaults) and start the program by typing **ohvapv3**. Your screen will look like Figure 1.

The **menu bar** contains the top level menus that will then call up the various screens that will be described below. The **background** serves as a backdrop upon which the various dialog boxes will appear. Clicking the mouse on the Alt-X located on the status bar will exit the program. If you don't have a mouse, pressing the Alt-x key combination will serve the same purpose. Pressing the F10 key will enable you to use the arrow keys to move around the menu bar. To pull down any of the menus directly, the shortcut key combination is the first letter in the menu title and the Alt key. Thus

Alt-F will pull down the File menu. In many of the screens there will be two buttons that can be pressed OK and CANCEL. The OK button (and the Enter key) will save the choices that were made on that screen and then exit the screen. The CANCEL button (and the ESC key) will exit the screen without saving any changes.. Thus if you wish to change the liner material from steel to clay you would have to be sure to press the OK button rather than the Cancel.

Figure 2: File Menu

File Menu

To pull down the File Menu (Figure 2) left click the mouse on the word **File** on the menu bar or press the **Alt-F** key combination. The file menu lets you create new case files, open saved files, save changed ones, and exit the entire program.

New: The New command clears out all values and options that may have been set in this current session. These values are then set back to the initial defaults.

Load: The Load command displays a file selection dialog box for you to select a previously saved case file. The screen (Figure 3) contains an input line where you may type in the name of the file that you wish to load or a filter (such as *.VAP) to restrict the list of files shown.

Figure 3: Load File Dialog

Figure 4: Save As Dialog

To select a file to load either type the name in the **File Name** input line or click the file with the mouse. Pressing the OK button (or the Enter key) will then load the file. Pressing CANCEL (or the ESC key) exits from the dialog without loading a file.

Save: The SAVE command saves the current case file under the same name, overwriting any other file in the current directory with the new information. If the file does not yet have a name this command is equivalent to SAVE AS.

Save As: This menu choice lets you save the current case file under a different name, or in a different directory. Selecting the SAVE AS menu choice reveals a dialog box (Figure 4) similar to the LOAD CASE screen. Type the new name of the case in the File Name input line, or select one of the files listed and press the OK button. The case file will then be written to disk. If you selected a file that already existed, the new information will replace the old.

Change Directory: The File|Change Directory command calls up a screen (Figure 5) that lets you specify a drive and directory to make current. The current directory is

Figure 5: Change Directory Dialog

where OHVAP will load and store case files. You can either type the new path on the input line or you can select the directory with the mouse. Pressing the OK button then

sets the new directory and exits the dialog box. Pressing the Chdir button sets the new directory and displays the subdirectory tree off of the new directory. If you wish to undo your current actions, pressing Revert will change you back to your initial directory.

Exit: File|Exit exits the OHVAP menu shell. If you have made changes to a case file and have not saved them they will be lost.

Figure 6: Geometry Menu

Geometry Menu

Pressing Alt-G or clicking the mouse on Geometry will pop up the Geometry menu (Figure 6). This is where all of the physical characteristics of the vent system are assigned. Materials, damper characteristics, and draft inducers are all examples of items that may be changed from this menu.

Segment Definition: The Segment Definition screen is shown in Figure 7. Segments are the basic building blocks of any vent system. Within each user defined Segment the, materials, shape, location, angle (position), size, and type are all constant. Thus if a vent connector was 10 feet long and the first 5 feet were insulated while the other half was not the connector would have to be divided into two distinct segments. Figure 7 shows all of the information that must be unique to each segment

File		Geometry		Combustion		Other		Run		Help	
[*]						Segment Definition					
Segment Number				Type							
(*) 1	() 16	() Not Defined		() Std. 90 deg. Elbow							
() 2	() 17	(*) Straight		() Short Radius Elbow							
() 3	() 18	() T Section (Flow in Run)		() Long Radius Elbow							
() 4	() 19	() T Section (Flow in Side)		() Flow Damper							
() 5	() 20	() Std. 45 deg. Elbow		() Custom							
() 6	() 21										
() 7	() 22	Shape		Number of Elements:		1					
() 8	() 23	(*) Circular		Segment Length (ft):		1					
() 9	() 24	() Rectangular		Angle (+/- 90 deg):		90					
() 10	() 25	() Lined		Inside Diameter (in):		6					
() 11	() 26			Size of Side A (in):		NA					
() 12	() 27			Size of Side B (in):		NA					
() 13	() 28	Location		Damper Angle (0-60 deg):		NA					
() 14	() 29	(*) Indoors									
() 15	() 30	() Outdoors									
				Custom K Factor:		NA					
				OK		Cancel					

Alt-X Exit

Figure 7: Segment Definition Screen

with the exception of materials selection. In essence, what you will be doing on this screen is building the entire vent system segment by segment from the appliance to the vent exit.

Segment Number: Segment numbers start at 1 and go to a program maximum of 30. Segment 1 is located adjacent to the appliance and the count then increases from there towards the exit of the vent. Selecting a segment number from this list will show all of the currently assigned values for that segment.

Type: Type defines the basic flow and heat transfer properties of the segment. Selecting any type other than straight limits you to one element (see below) per segment. Information on the pressure drop, heat transfer, and size of each of the segments can be found in *Section II: Engineering Report*. If none of the other segment types supply the correct flow characteristics that you desire, selecting CUSTOM will allow you to set the pressure loss factor (see below).

Shape: Shape selects the overall crosssectional shape of the segment. If Circular is chosen then all layers of material are set as concentric circles. Conventional stovepipe is an example of a circular shape. Rectangular assumes that the segment crosssection forms a rectangle or square. If the shape of a segment is set to lined OHVAP then fixes the

geometry of the segment by assuming that the inner material layers of the segment are circular and that the outer layers are square. If the actual vent being modeled is not square then it will have to be "converted" into a square for modeling purposes (see *Section II: Engineering Report*). See *Appendix G, Section G-3.6 for clay tile liner sizes and shapes*.

Location: Is the segment located indoors or outdoors? The location defines the temperatures that the segment is exposed to and determines the initial gas and wall temperatures.

Number of Elements: Elements are user defined subdivisions of Segments and are the physical basis for all of the heat transfer and pressure drop calculations that OHVAP performs. Thus, if the segment type selected is Straight then you have control over how many elements make up the segment. If any other type of segment is defined, then this option will be set to NA and there will only be one element defined for that segment. While the menu will let you type over the NA, anything that is placed here will be ignored. The number of elements defined within the system has a direct effect upon both the accuracy of the simulation and the speed with which the program runs. The more elements defined, the greater the accuracy but the longer the program will have to run. In general, an elemental spacing of approximately one element per foot of segment length will provide sufficient accuracy at an acceptable speed.

Segment Length: As in **Number of Elements** (above) if a segment type other than Straight is selected this option will be set to NA. For any other type of segment the length is dependent upon the segment diameter (see *Section II: Engineering Report*).

Figure 8: Segment Angle with the Horizontal

Angle: This is the angle that the segment makes with the horizontal. A horizontal segment has an angle of 0° and a vertical segment has an angle of 90° . (Figure 8)

Figure 9: Rectangular Segment Sides

Inside Diameter: In a circular segment this is the internal (flue gas side) diameter of the segment. In a lined segment this is the internal diameter of the liner. For a rectangular segment this is NA.

Size of Side A: In a rectangular segment (Figure 9) this is the size of the longest side on the inner (flue gas) side. In a lined segment this size is taken by OHVAP as the size of all four sides on the gas side of the segment. Note that in a lined segment this side **MUST** be set larger than the sum of the internal diameter of the liner and twice the thickness of the all the liner materials. So if the liner has an internal diameter of six inches and the liner is two inches thick overall, this value must be set larger than ten inches. That is; $(6 + 2(2) = 10)$.

Size of Side B: In a rectangular segment (Figure 9) this is the size of the shorter side on the gas side. In a lined segment this value is ignored.

Damper Angle: The angle set by an internal flow damper relative to the direction of flow. If any segment type other than flow damper is selected this will be NA. A setting of 0° indicates that the damper is wide open. The maximum setting is 60° as the damper can never be fully closed (at least as far as OHVAP is concerned).

File Geometry Combustion Other Run Help					
Layer Specification					
Segment Number			Layer Material		
☒ 1	☐ 7	☐ 13	☐ 19	☐ 25	☐ Not Defined
☐ 2	☐ 8	☐ 14	☐ 20	☐ 26	☐ Air (Convective Gap)
☐ 3	☐ 9	☐ 15	☐ 21	☐ 27	☐ Aluminum
☐ 4	☐ 10	☐ 16	☐ 22	☐ 28	☐ Clay Tile
☐ 5	☐ 11	☐ 17	☐ 23	☐ 29	☐ Concrete
☐ 6	☐ 12	☐ 18	☐ 24	☐ 30	☐ Glass: Pyrex Type
Layer Number			☐ Masonry Brick		
☒ 1	☐ 3	☐ 5	☐ 7	☐ 9	☐ Mineral Fiber: Blanket <400 F
☐ 2	☐ 4	☐ 6	☐ 8	☐ 10	☐ Mineral Fiber: Blanket <1000 F
Layer Thickness (inches):			☐ Mineral Fiber: Blanket <1200 F		
Enter "T" if this is a transition layer			☐ Pearlite: Loose Fill <1400 F		
			☐ Plastic (PVC)		
			☒ Steel: Galvanized		
			☐ Steel: Mild (1% Carbon)		
			☐ Steel: Stainless		
			☐ Steel: SS Flex		
			☐ Vermiculite: Loose Fill <1400 F		
			☐ Custom 1		
			☐ Custom 2		
<input type="button" value="OK"/> <input type="button" value="Cancel"/>					
Alt-X Exit					

Figure 10: Layer Specifications Screen

Custom K Factor: If the segment type is set to custom then you can set the pressure loss factor for the segment at this point. For more information of the "K" factor and its relationship with the pressure drop calculations see *Section II: Engineering Report*.

Layer Specifications: The Layer Specifications screen is shown in Figure 10. This is where the remaining segment information is entered.

Segment Number: This is the number of the segment whose materials you wish to specify. Segment number 1 is at the appliance exit and the count increases from there towards the vent system exit.

Layer Number: The number of the layer whose materials you wish to set. Layer number one is on the inner (flue gas) side of the segment and the count increases the further out from the gas you go. There is a maximum number of ten layers allowed per segment.

Layer Material: The actual material that any given layer is made of. Properties for each of the materials are listed in *Appendix B: Material Properties*. If none of the materials listed have the properties that you require there are choices devoted to two custom materials. The properties for these custom materials may be set by going to the OTHER|Edit Custom Materials screen.

File Geometry Combustion Other Run Help									
Barometric Damper Specification									
Element Number									
☐ None	☐ 9	☐ 18	☐ 27	☐ 36	☐ 45	Nominal Size (inches)			
☐ 1	☐ 10	☐ 19	☐ 28	☐ 37	☐ 46	☐ 4	☐ 7		
☒ 2	☐ 11	☐ 20	☐ 29	☐ 38	☐ 47	☐ 5	☐ 8		
☐ 3	☐ 12	☐ 21	☐ 30	☐ 39	☐ 48	☒ 6	☐ Custom		
☐ 4	☐ 13	☐ 22	☐ 31	☐ 40	☐ 49	Draft Setting			
☐ 5	☐ 14	☐ 23	☐ 32	☐ 41	☐ 50	☐ Low			
☐ 6	☐ 15	☐ 24	☐ 33	☐ 42		☒ Medium			
☐ 7	☐ 16	☐ 25	☐ 34	☐ 43		☐ High			
☐ 8	☐ 17	☐ 26	☐ 35	☐ 44					
Custom Damper Curve									
Dilution Air (scfm) = $A + B \cdot X + C \cdot X^2 + D \cdot X^3 + E \cdot X^4$ where X = Draft (in wc)									
A: <input type="text" value="0"/>			D: <input type="text" value="0"/>			OK		Cancel	
B: <input type="text" value="0"/>			E: <input type="text" value="0"/>						
C: <input type="text" value="0"/>									
Alt-X Exit									

Figure 11: Barometric Damper Specifications Screen

Layer Thickness: The thickness of the given layer. If the segment is defined as a lined type then the layer that lies between the circular liner and the square portion of the segment is referred to as the transition layer. For example if the segment has three layers; a steel liner, the air gap around the steel, and clay tile, layer one would be set to be the steel liner with whatever thickness it may have. Layer two would be the air gap and its thickness would be set to 'T'; and layer three would be the clay tile with whatever thickness the tile may have. The designation 'T' tells OHVAP that the effective thickness is to be determined by OHVAP.

Barometric Damper: Barometric damper options are set from the screen depicted in Figure 11.

Element Number: The element that contains the barometric damper. If there is no barometric damper present within the system then this should be set to None. All of the other options will then be ignored. Be aware that the damper location is independent of any other choices that may be made. What segment type or shape is selected is immaterial to the damper, regardless of physical reality. Thus a barometric damper could be located by OHVAP inside the base of a chimney surrounded by 12 inches of concrete. The program simply needs to know where the dilution air will enter into the vent system.

File Geometry Combustion Other Run Help

[■] Draft Inducer

Pressure (in wc)= A + BX + CX^2 + DX^3 + EX^4
X= Gas flow (scfm)

Element Number					Coefficients
(*) None	() 11	() 22	() 33	() 44	A: 0
() 1	() 12	() 23	() 34	() 45	B: 0
() 2	() 13	() 24	() 35	() 46	C: 0
() 3	() 14	() 25	() 36	() 47	D: 0
() 4	() 15	() 26	() 37	() 48	E: 0
() 5	() 16	() 27	() 38	() 49	
() 6	() 17	() 28	() 39	() 50	
() 7	() 18	() 29	() 40		
() 8	() 19	() 30	() 41		
() 9	() 20	() 31	() 42		
() 10	() 21	() 32	() 43		

OK Cancel

Alt-X Exit

Figure 12: Draft Inducer Fan Specification Screen

It should also be noted that regardless of whether the damper is located indoors or outdoors the dilution air is at the indoor conditions.

Nominal Size: This refers to the diameter of the maximum damper opening. The dilution flow that results from damper sizes ranging from 4 through 8 inches in diameter are based upon test results obtained at Brookhaven National Laboratory (see *Section II: Engineering Report*). If the required size is not listed either choose the closest size or select Custom which will require you to enter a curve fit of the dilution flow vs. available draft at the damper (see below). See *Appendix G, Section G-3.3 for more information on curve fits*.

Draft Setting: This refers to the position of the counter weight. Choose whether you wish to have low, medium, or high draft available at the appliance. For the effect that this setting has upon dilution see *Section II: Engineering Report*. If the Custom damper size was chosen then this entry will be ignored and the curve defined by the coefficients will prevail.

A,B,C,D,E,F: These are the coefficients for the equation of dilution flow vs available draft for the Custom damper size. See *Appendix G, Sections G-3.3 and G3.5 for information on coefficients for dilution for draft control and chimney leakage*.

Draft Inducer: The screen shown in Figure 12 is where options for a draft fan will be set. See Appendix G, Section G-3.4 for information on draft inducers.

Element Number: The element that contains the draft fan. If there is no fan present within the system then this should be set to None. All of the other options will then be ignored. Be aware that the fan location is independent of any other choices that may be made. What segment type or shape is selected is immaterial to the fan, regardless of physical reality. Thus a fan could be located by OHVAP inside the base of a chimney surrounded by 12 inches of concrete. The program simply needs to know where the pressure change attributed to the fan should be applied.

A,B,C,D,E: These are the coefficients for the fan curve shown on the screen. The curve relates the pressure generated by the draft fan as a function of the gas flow passing

Figure 13: Combustion Menu Screen

through the fan. This information should be available from the fan manufacturer. If only a rough estimate is available of the pressure that the fan generates, then a constant pressure change should be assigned by setting the value of A and setting B through E to values of 0. This will yield a constant pressure change (the value set in A) across the element that holds the fan. See Appendix G, Section G-3.4 for information on coefficients.

Figure 14: Air Settings Screen

Combustion Menu

Selecting Combustion from the menu bar calls up the Combustion menu (Figure 13). All of the variables related to the burner and appliance are set using this menu including such things as firing rate, fuel composition, and air temperatures.

Air Settings: The air settings screen is shown in Figure 14.

Indoor Air Temperature: The temperature segments located indoors are exposed to. This is also the temperature of any dilution air that enters the system.

Indoor Relative Humidity: Determines that amount of water vapor present in the indoor air.

Outdoor Air Temperature: Temperature that any segments located outdoors are exposed to.

Outdoor Relative Humidity: Determines the amount of water vapor present in the outdoor air.

Figure 15: Burner Settings Screen

Outside Pressure: Determines the static pressure at the vent exit. This may be varied to simulate the effects of wind at the vent exit. It is important to note that this represents a deviation from actual atmospheric pressure, as the units are in gauge pressure, not absolute pressure.

Burner Settings: The Burner Settings screen (Figure 15) allows you to control all of the factors that are associated with the burner itself.

Firing Rate: This is the nominal rate at which the burner will use fuel. If the firing rate is desired is not listed then Custom should be selected.

Custom Firing Rate: If the firing rate selected is Custom then this box will contain the firing rate used. If any of the predefined firing rates are selected then the contents of this box will be ignored.

Excess Air: The amount of air that enters the burner in excess of that which is required for complete combustion. If needed, *Appendix A* contains a graph showing the relationship between the excess air and the CO₂ or O₂ level in the of the flue gasses. The value should be entered as a percentage (20%=20 not 0.20).

Off Cycle Burner Flow Factor: This is a multiplying factor for the amount of air that flows through the burner and appliance during the off-cycle. This field allows you to tailor the off-cycle flow to agree with a testing standard or to model a specific piece of equipment. The default value for this field is 1.0. If you wish to model the “standard” AFUE test procedure, the ratio of off-cycle flow vs on-cycle flow must be 0.40. Experience gained in the development of the Chimney Relining Tables (see *Appendix F*) has shown that for a firing rate of 1.0 gph a value of 1.33 will yield approximately 0.4 for the off-cycle vs. on-cycle flow ratio. This value will be different for different firing rates and you will have to experiment to obtain the off-cycle flow that you wish. If you wish to customize the off cycle burner flow, the procedure is as follows. First, determine the desired ratio of off-cycle mass flow to on-cycle mass flow. Then let OHVAP perform a run with this option set at the default value of 1.0. Calculate the off-cycle mass flow to on-cycle mass flow ratio that resulted in the run. Divide the desired ratio by this new

Fuel Composition	
Specific Gravity:	0.865
Carbon wt. %	87.3
Hydrogen wt. %	12.5
Sulfur wt. %	0.2
Water wt. %	0
Oxygen wt. %	0
Nitrogen wt. %	0
Non-Combustible wt. %	0
<input type="button" value="OK"/> <input type="button" value="Cancel"/>	

Alt-X Exit

Figure 16: Fuel Composition Screen

calculated ratio. The result is the new Off Cycle Burner Flow Factor that should be used. This field should never be set equal to 0 or to any negative number. See *Appendix G, Section G-3.1 for initial guidance on burner flow factors.*

Combustion Air Source: Defines the properties of the combustion air and off-cycle flow in terms of temperature and relative humidity. These properties are dependent upon the settings found on the screen for **Combustion|Air Settings**.

Figure 17: Time-Temperature Profile Dialog

Fuel Composition: The fuel composition screen (Figure 16) is where you may customize the composition of the fuel used in the burner. The default values are those listed in the *North American Combustion Handbook* for No. 2 fuel oil. The values should be entered as percentages (20%=20).

Time-Temperature Profile: The time temperature profile is a temperature history of the flue gasses as they exit the appliance over one complete firing cycle. The data file containing the time-temperature profile is selected from the screen shown in Figure 17. By entering *.TTP on the input line a list of the available data files will be displayed. Select the file you wish. Ten files are provided with OHVAP; a boiler group (identified as blr***.ttp) and a furnace group (identified as furn***.ttp). The operating cycle for each of the appliances is an approximation of the AFUE Test Procedure. For the boiler, the burner-on period and burner-off period is 10 and 33 minutes respectively. For the furnace the same periods are 4 and 13 minutes respectively. These files are offered as guides with end-of-burn appliance exit gas temperatures of 275, 345, 420, 495, and 575° F. These temperatures are approximations of appliance steady-state efficiencies of 88, 86, 84, 82, and 80% respectively at a combustion CO₂ level of 12% based on the stack-loss method. If you wish to model a specific appliance then you can either edit the information in one of these files or to create a new TTP file with the temperatures that you desire. See *Appendix C: Time Temperature Profile Data Files* for information on the TTP file format.

Figure 18: Other Menu Screen

Figure 19: Cycle Time Settings Dialog

Other Menu

The Other menu (Figure 18) serves as a catch all for the remaining information that OHVAP needs to function properly.

Cycle Time Settings: This screen (Figure 19) is where you set the parameters which affect the number of burner cycles (warm up/cool down periods) and the time step the program will use.

Number of Cycles: The number of repetitive warm-up/cool-down cycles to which the flue gas vent system is exposed. Since the vent components and gasses always start each simulation at ambient temperatures, the first three cycles should be viewed as conditioning cycles, with the fourth cycle representing a “typical” cycle. If you wish to simulate a worst case/cold start then the first or second cycle should suffice.

Cycle Duration: The time over which a complete warm-up/cool-down cycle occurs.

Burner On Period: The length of time within a cycle that the burner is actually running and using fuel.

Time Step: The length of time that the program uses as it “walks” through the vent system. Longer time steps yield faster run times but less accurate results as the program moves through each cycle with fewer calculations. Shorter time steps yield more accurate results but take longer as the program will require more calculations. In general a ten second time step will produce adequate speed and results.

Figure 20: Edit Custom Materials Screen

Edit Custom Materials: This screen (Figure 20) is where you enter the properties for the custom materials that are listed on the Geometry|Layer Specifications menu. These properties are stored with each case file as it is saved. If you do not use the custom materials option from the Layer Specifications screen then these values are ignored. For a listing of the materials properties predefined within OHVAP see *Appendix B: Material Properties*.

Heat Transfer: Modifications to how OHVAP determines heat transfer may be selected from this screen (Figure 21). Disregard the settings shown in Figure 21. See the modifiers shown below.

Film Coefficient Modifiers: These are direct modifiers for the equations that OHVAP uses to determine the convective film coefficient for the given location. The current setting for these modifiers has the default value 1.0 with the following exceptions:

Air Side (vert. indoors): 0.5, Air Side (hor. indoors): 0.5

Air Side Radiation Off: When this option is selected radiation cooling from the outer surface of the vent to the ambient air will not be factored into the heat transfer calculations.

Air Gap Radiation Off: When this option is checked convection will be the only heat transfer mechanism to operate across air gaps. The gap will then provide a perfect radiant barrier.

Condensation Off: This will disable condensation within the program. It is the effective equivalent of stating that the flue gasses do not contain water or sulfuric acid.

File Geometry Combustion Other Run Help

Heat Transfer Parameters

Film Coefficient Modifiers		Heat Transfer Options	
Gas Side (indoors):	2	☒ Air Side Radiation Off	
Gas Side (outdoors):	1	☒ Air Gap Radiation Off	
Air Side (vert. indoors):	.5	☒ Condensation Off	
Air Side (hor. indoors):	.5		
Air Side (vert. outdoors):	1		
Air Side (hor. outdoors):	1		
Air Gap (indoors):	2		
Air Gap (outdoors):	2		

OK

Cancel

Alt-X Exit

Figure 21: Heat Transfer Options Screen

Output: The Output screen (Figure 22) controls how OHVAP prints out the results of the analysis. These output files are created in a LOTUS™ 123 version 1 format. These

Figure 22: Output File Options Screen

files can only contain 8000 rows and each time OHVAP prints one row is used. Printing many cycles over a short print interval can thus fill up the output file very quickly. Keeping the sheer size of the file to less than 1000 rows of data will also speed up the analysis of the results.

Initial Print Cycle: The point in time when OHVAP starts to print the results to the output files. Printing then continues from the beginning of this cycle until the end of the program run. Setting this value to 1 will print out the results from every cycle in the current run (up to the maximum of 8000 lines of data).

Print Interval: Time spacing between each print out.

File Contents: Defines the information present within the output files. These files are automatically named to conform to case file name. Thus if the case file name is boiler.vap the output file would be named boiler.wk1. In the case where both output file types are selected the filename will have the last two letters replaced with a -1 or -2. To account for this it may be easier to limit the base file name to six characters and to

always make the last two letters of the file name be XX. Thus boiler.vap would become boilerxx.vap and the output files would become boiler-1.wk1 and boiler-2.wk1.

File Organization: File organization defines the arrangement of the information within the output files. Selecting variable will keep all of the individual output values together (gas temperatures followed by liner temperatures followed by pressures, etc.). Selecting element will arrange the information by element (the gas temperature, liner temperature and static pressure for element one will all come before element two starts). For more information on this see *Appendix E: Output File Formats*.

Figure 23: Purge Options Screen

Pre/Post Purge: The settings for using a prepurge or postpurge are controlled from the screen seen in Figure 23.

Enable: The default value is no prepurge and no postpurge. By selecting one or both of these options you are turning on the given feature.

Purge Control: If one or both of the purges is enabled this selection determines which piece of equipment (if applicable) controls the flow. If burner is selected then the blower in the burner provides the air flow, while if a draft fan is in control it provides the flow.

In either case, the amount of air that flows through the burner is fixed as the amount of

Figure 24: Run Menu Screen

air that enters the burner when it is running normally (required combustion air + excess air).

Pre-Purge Duration: How long the prepurge will run prior to burner ignition.

Post-Purge Duration: How long the postpurge will run after burner shutdown.

Run Menu

Selecting the Run Menu (Figure 24) to begin the analysis of the vent system will pop up the dialog box shown in Figure 25.

Run Case: Selecting this option will convert the case file currently in memory into a file which will be transferred to the engineering analysis portion of the program. The engineering module will then run and analyze the vent system.

Generate Temporary Files: By selecting this option, OHVAP will generate the temporary files that would be passed to the engineering module but will NOT run the analysis. The files will be stored under the names Casename.tmp and Casename.ttp,

Figure 25: Run Dialog

where **CASENAME** is the name of the current case file. To get the engineering module to then run this case you would rename or copy the files to **vap.tmp** and **vap.ttp** respectively and place them in the same directory as the engineering module **vapengv3.exe**. Then just run the engineering program. This feature thus enables you to run the simulation in batch mode by creating a series of temporary files and then having MSDOS batch commands handle the renaming and running of the model.

Chapter 2: Tutorial

The Vent System

This chapter will present a short tutorial on the use of OHVAP to analyze venting systems. It is recommended that you be sitting at a computer running OHVAP as you go through this chapter. The first step that you should take is to develop a sketch or diagram of the vent system. OHVAP does **not** do this for you. It must be done by hand. **Figure 26** is a detailed example of what can be done, although a much simpler sketch will suffice to hold and store the information regarding the vent system configuration. The diagram will serve as a reference for setting up the input files and in evaluating the information contained in the output files. The relationship between segments and elements can be seen in **Figure 26** as well.

For example, in the figure, the first section of the chimney connector, a 1 foot long piece of single wall galvanized pipe, is shown as both Segment 1 and Element 1. The next two single wall components, a Tee and an Elbow are defaulted within the program as Segment/Elements 2 and 3 respectively. Segment 4 contains three Elements (4, 5, and 6) each of which is 1 foot long. This resolves the basic single wall chimney connector reference information.

The next component is a Tee which by default is a segment containing only one element (Segment 5 and Element 7). This component is more complicated than the previous in that it contains multiple layers of materials. Reference notes should be made at this point, regarding the physical and material attributes of the

Figure 26 A typical oil fired venting system.

building components abutting the chimney.

The balance of the vent system consists of a single major component, the chimney. In the case illustrated in Figure 26, the chimney above the connector penetration is multi-layered and is constructed of masonry with an air gap and an inner rectangular clay tile liner. This particular chimney is defined to be in conformance with the requirements of NFPA 211. Other non-conforming chimney constructions may be defined at the user's option. In this case, this component is resolved as Segment (6) and contains Elements 8 through 32.

Other information that is needed by the program includes:

Heating Appliance: The firing rate and excess air settings (or CO₂ levels in the flue gas) of the burner and the time temperature profile for the appliance.

Chimney Connector: The diameter and material thickness must be noted for each segment of the connector. If the connector is made up of multi-layer components (such as double walled L-Vent), the inside diameter must be noted together with the thickness(s) of each of the successive layer(s).

Draft Control: The element containing the draft control and it's diameter must be noted.

Masonry Chimney: The entry of the chimney connector occurs at the base of the masonry chimney. This Segment/Element is unique in the sense that must be approximated by the use of an existing component shape; a Tee, which is multi-layered. If the chimney is interior to the building, then layers of the chimney base are defined, in large part, to simulate the balance of the masonry chimney above. If the masonry chimney is located exterior to the building, the chimney base layers are defined, in large part, to simulate the foundation penetration.

In either case, the Masonry Chimney above the base Tee is defined as an essentially free standing structure with a rectangular clay liner, an air gap, and a surrounding structure made of brick or masonry block. The assumption of a free standing structure permits a conservative approximation of the actual heat loss from the chimney to it's surroundings based on one dimensional heat transfer. The actual heat loss occurs in three dimensions; horizontally, laterally, and longitudinally.

Preparing the Case Files

Once the program starts, all of the options will be set to an initial default value. You can now start entering the case information by moving through the **Geometry** menu. Selecting **Segment Definition** will allow you to enter a nearly complete definition of the entire vent system. It should be noted that any field which does not apply to a given segment type will have NA as the default setting. While OHVAP will let you change these entries, any changes will be ignored.

Referring to **Figure 26**, enter the following information for the first segment: Segment Number = 1, Type = Straight, Shape = Circular, and Location = Indoors, Number of Elements = 1, Segment Length (ft.) = 1, Angle = 90 (vertical), and Inside Diameter (in.) = 6. Since the Shape is circular, the sizes of Side A and Side B are not applicable (NA).

For the second segment; Segment Number = 2, Type = Tee Section (Flow on Run), Shape = Circular, Location = Indoors, Angle = 90 (vertical, *orientation is ignored*), Inside Diameter (in.) = 6. *See Appendix G, Section G-3.2 for explanation.* Another approximation for Segment Number 2 could be: Type = Straight, Shape = Circular, Location = Indoors, Number of Elements = 1, Segment Length (ft.) = 1.5, Angle = 90 (vertical), Inside Diameter (in.) = 6.

For the third; Segment Number = 3, Type = Std. 90 Deg Elbow, Shape = Circular, Location = Indoors, Angle = 90 (vertical, *orientation is ignored*), Inside Diameter (in.) = 6. *See Appendix G, Section G-3.2 for explanation.*

For the fourth segment; Segment Number = 4, Type = Straight, Shape = Circular, Location = Indoors, Number of Elements = 3, Segment Length (ft.) = 3, Angle = 0 (horizontal), Inside Diameter (in.) = 6. Note that although the segment count is 4, the element count is now 6 due to the multi-element nature of Segment 4.

The connector penetration into the base of the chimney forms segment five, which, for purposes of this illustration, is located on the exterior wall of the building. Due to the limited geometries built into OHVAP this segment's construction will have to be approximated. For this example, the approximation will be: Segment Number = 5, Type = Tee Section (Flow in Side), Shape = Circular, Location = Outdoors (Exterior chimney), Angle = 90 (vertical, *orientation is ignored*), Inside Diameter (in.) = 6. Note that the segment count is 5 and the element count is 7. *See Appendix G, Section G-3.2 for explanation.*

Another (not used here) approximation could be; Segment Number = 5, Type = Tee Section (Flow in Side), Shape = Rectangular, Location = Outdoors (Exterior chimney), Angle = 90 (vertical, *orientation is ignored, see Appendix G as above*), Side A = 6.75, Side B = 6.75. Here, Side A and Side B are set to match the inside measurements of a standard 8 X 8 clay chimney liner. The segment and element count would still be 5 and 7 at this point. *See Appendix G, Section G-3.6 for clay tile sizes.*

For the last segment, a 25 foot masonry chimney, enter the following; Segment Number = 6, Type = Straight, Shape = Rectangular, Location = Outdoors, Number of Elements = 25, Segment Length (ft.) = 25, Angle = 90 (vertical), Side A = 6.75, Side B = 6.75. Note that although the segment count is 6, the element count is now 32 due to the multi-element nature of Segment 6.

Once you're satisfied with the selections, a mouse click on the OK button will accept the selections. The screen will then revert to the initial startup screen.

The Input File, although not yet complete, should be saved at this point. Frequent saving of the file, particularly after long periods of numeric entry, can prevent the loss of input information and wasted time. The user should click on **File** and then click on **Save As**. Type the file name EXAMPXX.VAP on the input line. Pressing the OK button will then save the current file.

Upon completion of the save operation the initial screen will be displayed. Now select **Geometry|Layer Materials** menu to enter materials used within the vent system. This screen permits a complete definition of the layers in Segment 1 through Segment 4. In this illustrative case the entire chimney connector is single wall (.019 inches thick) galvanized steel material.

By using the mouse and keyboard enter the following values; Segment Number = 1, Layer Number = 1 (single wall), Layer Thickness (inches) = .019, Layer Material = Steel: Galvanized. Each successive segment of the chimney connector (Segments 2 through 4) is subsequently identified using the same values for Layer Number, Layer Thickness, and Layer Material entered for Segment 1.

Segment 5, the chimney connector penetration, is a special case and can only be approximated. For this illustration we will assume the first configuration, described earlier, and assume a circular cross section matching the circular section of Segment 4. As a further assumption, the chimney base Tee is made up of three layers. These layers, starting from the innermost are; galvanized steel (.019 inches thick), refractory clay tile (.625 inches thick), and foundation concrete (12 inches thick).

The following values can now be entered for Segment 5; Layer Number = 1, Layer Thickness (inches) = .019, Layer Material = Steel: Galvanized. Next; Layer Number = 2, Layer Thickness (inches) = .625 (*See Appendix G, Section 3.6 to estimate wall thicknesses*), Layer Material = Clay Tile. Next; Layer Number = 3, Layer Thickness (inches) = 12, Layer Material = Concrete.

For the chimney itself enter the following: Segment 6; Layer Number = 1, Layer Thickness (inches) = .625 (*See Appendix G as above*), Layer Material = Clay Tile. Next; Layer Number = 2, Layer Thickness (inches) = .5; Layer Material = Air (Convective Gap); and last Layer Number = 2, Layer Thickness (inches) = 4, Layer Material = Masonry Brick.

Select **Geometry|Barometric Damper**. Referring to **Figure 26**, determine the Element Number containing the barometric damper, it's Nominal Size (inches), and the Draft Setting corresponding to the counter-weight position for Low, Medium, and High. The following values can be entered; Element Number = 2, Nominal Size (inches) = 6, Draft Setting = Medium. The Custom box has not been selected and so nothing under the Custom Damper Curve entries is applied.

Since there is no draft inducer present select **Geometry|Draft Inducer** to ensure that one is not defined. This would be a good time to Save the case file.

From the initial screen, you can now move on by selecting the **Combustion** menu. The Combustion menu screen gives access to Air Settings, Burner Settings, Fuel Composition, and Time-Temperature Profile.

Select **Air Settings**. From here you can select Indoor Air Temperature (F), Indoor Relative Humidity (%), Outdoor Air Temperature (F), Outdoor Relative Humidity (%), and Outside Pressure (in.WC, gauge). For now we'll accept the defaults by pressing the OK button.

Click on **Combustion|Burner Settings**. From here enter the following information: Firing Rate=1.0 gph, Excess Air= 20%, Combustion Air Source= Indoor and an Off Cycle Flow Factor of 1.33.

The Off -Cycle Burner Flow Factor (OBFF) is normally defaulted as 1. Because of experience with use of the OHVAP program, the value shown is 1.33 for a firing rate of 1.0 gph. This value of 1.33 will provide an Average Burner "Off " Period Flow/Average Burner "On"Period Flow ratio at the appliance of about 0.4 which is in agreement with estimates contained and used in the AFUE Test Standard. You should

experiment to find the appropriate value to use for each case. This can be done by first using the default value of 1.0 for the OBFF and then calculating the above ratio under these operating conditions. A multiplier correction to the OBFF is formed by dividing 0.4 by the calculated ratio. Another run using the corrected OBFF is all that is required to bring in values close to 0.4 for the ratio. *See Appendix G, Section G-3.1 for default values of the OBFF.*

Selecting **Combustion|Fuel Composition** will allow you to change the fuel composition. For this example we will accept the default.

The next step is to select a Time-Temperature Profile. From the dialog box select BOIL345.TTP to simulate a boiler. As discussed earlier, five files each are provided with OHVAP; a boiler group (identified as boil***.ttp) and a furnace group (identified as furn***.ttp). These files can be displayed by typing *.ttp in the File Name box and pressing Enter/Return on the computer keyboard. The operating cycle for each of the appliances is an approximation of the applicable AFUE Test Procedure. For the boiler, the burner-on period and burner-off period is 10 and 33 minutes respectively. For the furnace the same periods are 4 and 13 minutes respectively. These files are offered as guides with end-of-burn appliance exit gas temperatures of 275, 345, 420, 495, and 575° F. These temperatures are approximations of appliance steady-state efficiencies of 88, 86, 84, 82, and 80% respectively at a combustion CO₂ level of 12% based on the stack-loss method.

Moving on to the **Other|Cycle Time Settings** menu, we want to simulate a normal operating cycle. Thus enter Number of Cycles to Run = 4; Since we chose a boiler Time-Temperature Profile we need to ensure that a full boiler cycle is what runs. Therefore enter Cycle Duration (min.) = 43 and Burner On Period (min.) = 10. We can accept the default Time Step of ten seconds.

Selecting **Other|Heat Transfer** allows you to customize the effect of the various heat transfer mechanisms. Keeping the default values of 1 for the film modifiers should suffice for design conditions. If you are modeling a specific system these numbers can be changed to have the program match the temperatures and pressures from a real system. Laboratory tests have indicated that the following film modifiers work well for a conventional masonry system: Gas Side (indoors), = 1, Gas Side (outdoors) = 1, Air Side (vert. indoors) = .5, Air Side (hor. indoors) = .5, Air Side (vert. outdoors) = 1, Air Side (hor. outdoors) = 1, Air Gap (indoors) = 1, and Air Gap (outdoors) = 1. For this and most other cases you will run, the heat transfer options can be set to these conditions.

Selecting the **Other|Output** menu will let you choose how much information to print out. For this illustration use the following the following: Initial Print Cycle = 4, Print Interval (sec.) = 10, File Contents = Both File 1 and File 2, and File Organization = Variable.

For now we will assume that the appliance doesn't use a prepurge or postpurge. Select **Other|Pre/Post Purge** to ensure that neither one of these features is enabled.

The Input File is now complete and should be saved at this point. Selecting **RUN** will display the Run Analysis dialog. Selecting **Run Case** will then run the engineering

```
Output file 1= 86S25D-1.wk1
Output file 2= 86S25D-2.wk1
Cycle= 4
Time= 2588
Segment= 6
Element= 32
Piter= 0
Fiter= 1

Papp= 0.02718 in. wc. draft      Tgas(app)= 87.0 deg. F
Pexit= -0.00023 in wc. draft    Tgas(exit)= 66.1 deg. F
Tliner(exit)= 59.3 deg. F

Program Ended

D:\OHVAPU3\861025>
```

Figure 27 Screen display when OHVAP has completed a run

analysis for the vent system we just entered.

Running the Program

When the program is running the screen will look similar to Figure 27 (with the exception of the "Program Ended" statement). The display will contain information about the currently running file. Among the items displayed during the run time will be; the Output File Number (s) and Filename (s), the Cycle being run, the Time (seconds), the current Segment and Element being analyzed, the current number of Pressure

iterations (Piter), and the current number of Flow iterations (Fiter). In addition, the following calculated system operating parameters are displayed; the draft pressure at the appliance (Papp), the residual draft pressure at the vent system exit (Pexit), the gas temperature at the appliance (Tgas (app)), the gas temperature at the vent system exit (Tgas (exit)), and the vent system inner wall temperature at the exit (Tliner (exit)). At the completion of the computer run an audible warble will sound and a Program Ended will be displayed together with a DOS screen cursor. The results of the run will be stored in the two spreadsheets EXAMP-1.wk1 and EXAMP-2.wk1.

The completion of a run with OHVAP results in the creation of one or two LOTUS™ *.WK1 files. While these files are not considered large in terms of storage, a hard-copy print out of each file would occupy several pages.

The format used by OHVAP for the first part of each output file is arranged in column form. The first eight columns are the same regardless of what output options are selected. The columns after column 8 will vary depending upon whether the file organization selected was by Element or by Variable, and according to how many elements are defined within the system. The first eight columns are as follows:

<u>COLUMN</u>	<u>DESCRIPTION</u>
1	(Cycle) Cycle number
2	(Time) Elapsed time in seconds
3	(Tapp) Flue gas temperature at the appliance (F)
4	(Papp) Flue gas pressure at the appliance (in. H ₂ O)
5	(QB) Flow through burner (SCFM)
6	(QD) Flow through draft control (SCFM)
7	(Backflow) Reverse flow in last element (SCFM)
8	BLANK

If the output files are created by Variable they will have the following appearance starting with column 9:

<u>COLUMN</u>	<u>DESCRIPTION (ELEMENT 1....ELEMENT i)</u>
	<u>File-1</u>
Tgout1....Tgouti	Flue gas exit temperature (°F)
Blank	
Tl1....Tli	Flue gas side surface temperature of liner (°F)
Blank	
Ps1....Psi	Static pressure (in. H ₂ O)

File-2

Tlair1....Tlairi	Air-gap side surface temperature of liner (°F)
Blank	
Acid1....Acidi	Acid condensation (lbs)
Blank	
Water1....Wateri	Water condensation (lbs)

If the output files are created by Element they will have the following appearance starting with column 9 -

<u>COLUMN</u>	<u>DESCRIPTION (VARIABLE 1....VARIABLE i)</u>
---------------	---

File-1

Tgout1	Flue gas exit temperature for element 1 (°F)
Tl1	Flue gas side surface temp. for element 1 (°F)
Ps1	Static pressure for element 1 (in. H ₂ O)
Blank	
.	.
.	.
Tgouti	Flue gas exit temperature for element i (°F)
Tli	Flue gas side surface temp. for element i (°F)
Psi	Static pressure for element i (in. H ₂ O)
Blank	

File-2

Tlair1	Air-gap side surface temp. for element 1 (°F)
Acid1	Acid condensation for element 1 (lbs)
Water1	Water condensation for element 1 (lbs)
Blank	
.	.
.	.
Tlairi	Air-gap side surface temp. for element i (°F)
Acidi	Acid condensation for element i (lbs)
Wateri	Water condensation for element i (lbs)

Troubleshooting

If an error message is displayed or the program ceases to run for any reason then the first place to check for errors is the input file. Reload the case and check all of the

values. Unfortunately, no error checking is performed in the data entry portion of the program. If layers are defined with a thickness of 0 (or less) inches, or if segments are defined with a negative length the program has no way of catching these errors until it tries to perform the analysis, at which point it will just crash with little to no warning.

Section II: Engineering Report

Chapter 3: Program Overview

This chapter will describe the internal operations of the OHVAP engineering module. A flow chart of the engineering module is presented in **Figure 28**. The discussion that follows will step through this flow chart and will examine the details and algorithms behind each of the steps. The engineering theories and assumptions made in these algorithms are more fully described in *Chapter 4: Engineering Background*. As you read through this chapter it is recommended that you keep referring to the OHVAP Flow-Chart shown in **Figure 28** since the steps involved in the analysis get quite involved.

The flow model used within the OHVAP engineering module is based upon the concept of plug flow; gasses enter into the vent system as discreet **GAS PLUGS** that do not interact with each other. Each plug consists of the amount of gas that would enter the system over the course of one time step. Thus if the flow was 60 cfm and the time step was 10 seconds, each plug would be 10 ft³. These plugs enter the system at element 1 and proceed downstream to the exit of the system, each new plug that enters pushing the others ahead of it. Each plug within the program carries with it such information as temperature and static pressure at the beginning and ending of each plug, where the plug starts and ends within the system, whether or not the plug has passed a dilution device and if it has been diluted.

In analyzing a vent system OHVAP performs an iteration procedure that starts at the flue collar of the appliance in the first element and continues through every element in the system. When the flue gasses first enter element one, heat transfer, pressure drop, and condensation across the element are determined. The gasses then pass into element 2 and the calculations are then performed for this element. This continues with OHVAP walking through the vent system element by element until it's finished with the current gas plug. OHVAP then moves on to the next plug and resumes the element by element stepping through the system. It continues this until the exit is reached. Since the exit of the vent is open to the atmosphere, the static pressure at the exit plane of the last element must be equal to atmospheric. If this is not the case, then the pressure back at the appliance is adjusted and the entire process starts over with the new pressure. This continues until the exit pressure converges on atmospheric.

OHVAP Flow-Chart

When OHVAP leaves the menu/data entry portion of the program (described in *Section I: User's Manual*) and enters the engineering module, the first step that OHVAP takes is to **INITIALIZE** the **SYSTEM VARIABLES** including such things as:

Figure 28: OHVAP FLOW CHART

1) Setting system temperatures and gas compositions:

Before the program starts the analysis, the entire vent system is set to a "cold start" condition. This refers to the fact that all the gas and wall temperatures are set equal to the ambient temperatures where each element is located. Thus an element located in a 65°F basement would have all of the gas and wall temperatures associated with that element set at 65 degrees. The gas compositions are likewise set to the ambient. Thus elements located indoors will contain indoor air, and elements located outdoors will contain outdoor air.

2) Determine event timing:

Determine when, during the course of the firing cycle a pre or post purge would start, when the burner would light off, and when the burner would shut down.

3) Calculate gas flows:

In order to speed processing time, the program calculates as much information as possible before any iteration loops begin. Among these precalculated variables are the gas compositions for the combustion products and for any purge flows that might occur.

4) Create output files:

This step in the program merely creates the output files and sets up the column titles for future use. Depending upon what the programs user has selected as output options, OHVAP will print the results of the analysis into one or two data files. These files are compatible with the LOTUS™ 123 version 1 spreadsheet program. This format was chosen primarily because every commercial spreadsheet and graphics package on the market can read these files. Thus additional analysis and graphics routines did not have to be developed within OHVAP.

In step two, **Start Time Loop**, the program starts the counter for the number of cycles and begins to keep track of how far within the current cycle the program is. The other main task of this portion of the program is to make a backup copy of the previous time step's results. Since OHVAP is an iterative process, this becomes necessary when the program has to "refine" the appliance operating pressure. This backup is then used to restore the vent temperatures and gas compositions for each iteration.

Step three, **SET TIME FLAGS**, is where OHVAP determines whether or not the burner is on, if there is a purge operation, or if the system is just operating under natural leakage flows. These flags are then used to determine the temperature, mass, and composition of the entering gas plugs and to ascertain whether or not a downstream draft fan is operating.

CREATE NEW GASPLUG, is actually the first step in the iterative process. At this stage a new plug is created. The temperature of this plug is determined from the Time-Temperature Profile that the user has selected. Its composition and volume are determined by whether or not the burner is running, purging, or just leaking. If the burner is just leaking, then the volume of the flow is directly dependent upon the static pressure at the appliance, otherwise the precalculated flow is used instead.

BEGIN PLUG LOOP and **BEGIN ELEMENT LOOP** just start the internal count of where the program is within the vent system. It is at this point that OHVAP starts to step through the vent system.

Once the two loops are entered, the first thing OHVAP has to do is **DETERMINE the STARTING ELEMENT of the CURRENT PLUG**. This sets the initial (pre heat transfer) temperature of the gasses within the plug. If the plug loop was just started, then OHVAP is working on the first plug and so its initial temperature will be the one determined by the Time-Temperature Profile. If the program has moved past the first plug then the process is more complicated. The program now has to determine whether or not the plug is beginning in a portion of the vent system that it "occupied" in the previous time step. If it is, then the plug's initial temperature is set to the temperature calculated at this point in the system during the previous time step. If the plug has moved further downstream in the system than the area it previously controlled, then the plug's starting temperature is set to the temperature of its leading edge from last time step. If the plug had been pushed past a barometric damper and the proper flag was set, the plug is then diluted. This diluted temperature then becomes the initial starting temperature of the gas plug.

If the plug begins in the middle of an element then a "pseudo element" is created out of the current real element. This fabricated element consists of nothing more than a subdivision of the actual element consisting of the distance from the start of the plug to the end of the element. If the total volume of the plug will not fill up even this smaller space, then the pseudo element will become the size of the plug itself.

OHVAP then checks to see if the current plug is actually in the **BAROMETRIC DAMPER**. If this is the case control of the program passes into the **DAMPER ROUTINE**. The pressure at the entrance to the damper element determines the flow of dilution air. This dilution air is then proportionally divided (on a mass basis) among

Figure 29: Plug AB is split into undiluted Plug A and diluted plug B.

all of the plugs that moved past the damper during this time step (Figure 29) and the flags within each gas plug are set to trigger dilution when those plugs come up for analysis in turn. The plug that enters the damper is then split into two separate plugs corresponding to the portions of the current plug upstream of the damper and the portion that actually enters the damper. The plug upstream of the damper remains undiluted until it passes the damper next time step. The plug currently in the damper then is mixed with its portion of the dilution air and a new composition and temperature is arrived at.

Once the plug has been diluted (if necessary) OHVAP enters the **HEAT**

TRANSFER LOOP (Figure 30).

This loop determines how much condensation occurs, what the gas temperatures leaving each element will be, what the average wall temperatures are, and what flow rates the vent system sees. It proceeds as follows:

1) Estimate the mass of gas "leaving" the current element:

OHVAP determines gas flows on a mass basis; thus within the program almost all references to velocity and flow rate are actually mass flow rates. In conducting the analysis, OHVAP takes the amount of gas that enters an element and subtracts out the amount of gas that is required to fill the element. Thus if 10 ft³ of gas enters an element with an internal volume of 1 ft³ approximately 9 ft³ of gas will exit. This will vary due to the density change associated with the cooling of the gas. The initial estimate for the flow leaving the element will be this 9 ft³.

2) Calculate Heat Transfer Parameters from Gas Flow Estimates: From the flow estimates arrived at in the previous step, the program then determines the various factors that affect heat transfer and condensation (convective coefficient, gas diffusivity, density, viscosity, etc).

3) Condensation/Evaporation:

From these parameters, the program then determines how much (if any) mass transfer is occurring between the gas and the liner surface. This routine is also the primary

Figure 30 Heat Transfer Loop

weakness of the OHVAP simulation, as the condensation algorithms (described in the next section) are inherently **steady state** calculations and have been attached onto the true transient heat transfer algorithms. The heat given to (lost by) the surface of the liner is then immediately factored into the liner and gas temperatures.

4) Generate Heat Transfer Equation Matrix:

At this point the heat transfer routine starts to step through each node in the element, from the gas to the outer wall of the chimney. It determines the coefficients for the equations of heat transfer going into and out of each node. These coefficients then generate a system of equations which must be solved simultaneously.

5) Solve Matrix

6) Recalculate Gas Flows:

From the new temperatures recalculate the average density of the gas within the element. From this density, determine the gas flow leaving the element. If it agrees with the initial estimates then the heat transfer is assumed to have converged and the program exits the heat transfer loop. If the flows don't agree, the new flows are used. This process continues until the flows converge.

Once the heat transfer loop is completed, OHVAP calculates the **PRESSURE DROP** across the current element. This takes into account the temperature change, any changes in elevation, whether or not a draft fan is located in the element, frictional losses, and whether or not the plug has gone through an entire element or only a portion of one. This is the last elemental calculation that OHVAP performs. If the analysis is not finished with the current element because the plug ended halfway through the element (and thus all calculations were performed on a pseudo element) then OHVAP steps along to the **NEXT PLUG**.

When the program is completed with the current real element it then determine if this was the last element in the vent system. If not, then the program steps along to the **NEXT ELEMENT** and the process continues. If it was the last element in the system then OHVAP compares the static pressure at the exit of the last element (P_{exit}) with atmospheric (P_{atm}). If they are equal, OHVAP writes the temperatures, pressures, etc. to the output files and then proceeds on to the next time step. If the pressures have not converged, then OHVAP makes a new estimate of the pressure at the appliance and restarts the loop.

Chapter 4: Engineering Background

Vent System Construction

There are three key concepts that OHVAP uses in evaluating the performance of a venting system. These concepts: **segment**, **element**, and **node**, are all used within the program to model the physical construction of the vent. As has already been stated, OHVAP views the entire vent system as a series of discrete sections called segments. A segment is a component of the vent system whose physical and material properties are constant. These are such properties as shape, materials, orientation, location, etc. Whenever any one of these properties changes, a new segment has to be defined. Each segment is then subdivided into a number of elements. It is within each element that heat transfer and pressure drop calculations are performed.

Depending upon the type and shape of the segment in which an element finds itself, its length will either be set by the user or a function of the segment's diameter (or the average of the two sides A&B if rectangular).

Table 4-1: Segment Length vs Segment Diameter			
Segment Type	Length (round or lined)	Number of Elements	Length (rectangular)
Straight	User defined	User Defined	User Defined
T-straight	$3*D$	1	$3*(A+B)/2$
T-flow in side	$2.5*D$	1	$2.5*(A+B)/2$
Std. 45° elbow	$(2+\pi/4)*D$	1	$(2+\pi/4)*(A+B)/2$
Std. 90° elbow	$(2+2\pi/4)*D$	1	$(2+2\pi/4)*(A+B)/2$
Short radius 90° elbow	$(2+1.5\pi/4)*D$	1	$(2+1.5\pi/4)*(A+B)/2$
Long radius 90° elbow	$(2+3\pi/4)*D$	1	$(2+3\pi/4)*(A+B)/2$
Flow Damper	$2*D$	1	$2*(A+B)/2$
Custom	$2*D$	1	$2*(A+B)/2$

Each segment can consist of up to ten different layers of materials. These layers are arranged such that layer 1 is on the flue gas side of the segment, and layer ten is on the outside of the segment. The number of layers that a segment has determines how many **NODES** are created. Nodes are the subdivisions through the walls of the vent system that form the basis for the heat transfer calculations. Each node "carries" with it the various properties that are needed for heat transfer, such as density, specific heat,

surface area, thermal conductivity, etc. The node layouts are shown as Figure 31 for circular segments, Figure 32 for rectangular, and Figure 33 for lined .

Figure 31: Node layout for a 2 layer circular segment.

Figure 32: Node layout for a 2 layer rectangular node

Figure 33: Node layout for a 3 layer lined segment.

Gas Flows

Gasses enter into the vent system from only three locations: the burner, the barometric damper, and the vent terminus. The burner provides flows of either combustion products or air during the entire burner cycle. If there is a barometric damper installed in the system, then it will provide flows of dilution air during the entire cycle, and the vent terminus will provide an entrance to outside air only if the stack gasses shrink due to temperature changes to the point where they fail to completely fill the vent system.

Burner Flow

There are several key assumptions regarding the burner's role in the vent system. First, it is assumed that the burner is always providing a flow of gasses. Within OHVAP it is impossible to completely seal the burner against off-cycle flow. The second assumption is that all of the fuel would be completely burned. Third, the burner is assumed to provide a constant amount of air so long as the blower is operating. Fourth

and last, that all of the water and sulfuric acid passes out of the heat exchanger and into the vent system. The heat exchanger is assumed to be perfectly clean and that it will always stay that way. The composition and volume of the gas entering the vent system

Figure 34: Determination of On-Cycle gas composition

is dependent upon such factors as the composition of the incoming air, burner operation, burner settings, and the time-temperature profile.

If the burner is running normally (fuel is being burned) then a material balance is performed about the appliance using the composition of the fuel and combustion air to determine the combustion products (Figure 34). The amounts of fuel and air used are set by the program user from the menu program. The percentage of the fuel sulfur that is converted into sulfuric acid (H₂SO₄) is based upon work performed at Brookhaven National Laboratory, which has yielded the following relationship: where a=excess air percentage (50%=50)

$$\% \text{ conversion} = 3.7558 \times 10^{-4} + 1.2986 \times 10^{-2} * a + 3.07357 \times 10^{-4} * a^2 - 3.24899 \times 10^{-6} * a^3$$

Figure 35: Determination of Off-Cycle gas composition

If the burner isn't running at all (Figure 35) the amount of air entering the system is determined by using a modified orifice flow equation. Where P =pressure in combustion chamber (inches of water column) then:

$$BurnerFlow(scfm)=2.370\sqrt{100*\bar{P}}+(70*P)$$

If the burner is operating as part of a purge cycle then the amount of air entering the appliance is fixed as the amount required for complete combustion plus excess air. Thus if 30 cfm of air are required when the fuel is burning, then 30 cfm will enter the burner during a purge cycle.

Figure 36: Dilution air flow for a nominal 4 inch damper

Damper Flow

The barometric damper, like the burner, provides an entry into the vent system. Dilution air may enter, but no combustion products may exit the system at this point. The amount air flowing into the vent system through a barometric damper is determined in one of three ways by OHVAP; by directly looking up the flow off the flow curves for damper sizes of 4 (Figure 36), 6 (Figure 37), and 8 inches (Figure 38), by averaging

Figure 37: Dilution air flow for a nominal 6 inch damper

Figure 38: Dilution air flow for a nominal 8 inch damper

these curves for the intermediate sizes of 5 and 7 inches, or (best) by using a custom curve provided by the program's user at run time. Once the volume of the dilution flow has been determined, then the two gas streams are mixed and the new temperature and composition of the combustion products is determined by performing a material/energy balance. See Appendix G, Section G-3.3 for custom dilution curve coefficients.

Backflow

There may come a point during the burner cycle that the gasses flowing through the vent system are cooled to the point where they actually shrink below the level of the vent terminus. When this happens OHVAP makes up for the "lost" volume by backfilling the vent system with outside air. Due to the assumptions made for the burner and barometric damper given above, there can never be a spillage of combustion products from the vent system into the house.

Gas Properties

There are two principle gas streams whose properties need to be evaluated within OHVAP: air and combustion products. In both cases, these streams are mixtures of different gasses. Air is made up of Nitrogen, Oxygen, and Water. The combustion products consist of Nitrogen, Oxygen, Water, Carbon Dioxide, Sulfur Dioxide, and Sulfuric Acid. Being mixtures, the basic properties are determined by using a mass or mole weighted average of the pure component properties. The sole exception to this is

the gas density, where the perfect gas law is used instead. Strictly speaking, taking a molar average will not properly determine the viscosity or thermal conductivity or a gaseous mixture. However, for OHVAP's purposes the simple molar average provided acceptable results while saving large amounts of computer processing time.

Flow Model

The flow model used within the OHVAP engineering module is based upon the concept of plug flow; gasses enter into the vent system as discrete plugs that do not interact with each other. Each plug consists of the amount of gas that would enter the system over the course of one time step. Thus if the flow was 60 cfm and the time step was 10 seconds each plug would be 10 ft³. These plugs enter the system at element 1 and proceed downstream to the exit of the system, each new plug that enters pushing the

Figure 39: An extreme example of gas being “left behind” by a plug as it passes through an element. (A) Before heat transfer; (B) After heat transfer

others ahead of it. The basic operation is as follows:

The static pressure at the appliance is set at some initial value, usually the result

of the last time step's iteration. The gas then enters the system as a discrete plug. The temperature change for the plug is calculated as it passes through the first element. The pressure drop for the gas is then determined. From the temperature of the gas its density is calculated, and this is used to determine how much gas "remains behind" in the first element. Figure 39 shows an extreme example of this; as the gas in the figure passes through the element it is cooled to the point where its density has doubled. The (now cooler and denser) excess gas then enters the second element and the process repeats itself. This process continues until the vent exit is reached. Since the pressure at the exit plane of the vent must be atmospheric pressure, the comparison is made and the pressure at the beginning of the system is adjusted accordingly. The entire sequence then repeats itself with the new entrance pressure as the starting point. This may or may not have an effect upon the gas flows (both off cycle burner flows and dilution air are pressure sensitive) and the process will continue until the exit pressure equals atmospheric pressure.

Figure 40: A gas plug being split at the barometric damper. As yet, there has been no dilution; plug 2 has merely been split into two separate plugs (2& 3)

Figure 41: Barometric damper operation

Barometric Damper

If there is a barometric damper present, the plug that first enters the damper element is split into two plugs; one plug upstream of the damper for the gasses that haven't yet entered the damper (and so will not be diluted this time step), and another plug that has its upstream edge at the left boundary of the damper element (Figure 40).

The amount of dilution air entering is then determined from the static pressure present at the upstream edge of the damper element. This air is then divided proportionally among all of the plugs that were moved past the damper in this time step (Figure 41). The dilution air is then mixed with the plug in the damper, and then the heat transfer and pressure drop calculations are performed on this plug. As each plug downstream of the damper comes up for analysis in turn, if there is unmixed dilution air being carried along with it, this air is mixed with the plug after its initial temperature is determined. Heat transfer and pressure drop calculations are then done as normal.

Pressure Drop

The pressure differential across an element is determined from the overall energy equation for a fluid:

$$\Delta P = \frac{\rho_g (V_1^2 - V_2^2)}{2g_c} + \Delta h (\rho_g - \rho_a) + M + \rho_g \Delta P_f$$

where:

- P = pressure in psfa
- ρ_g = gas density in lbm/ft³
- ρ_a = ambient air density in lbm/ft³
- V_1 = gas velocity at the start of the element in ft/s
- V_2 = gas velocity at the exit of the element in ft/s
- Δh = change in height across the element
- M = pressure added by a fan (draft booster or inducer) psfa
- ΔP_f = frictional pressure loss (feet of fluid)
- g_c = 32.174 (ft·lbm/s²·lbf)

The temperatures used to calculate the velocities in the kinetic energy term are those determined after heat transfer has been performed. The frictional losses are calculated from the following equation:

$$\Delta P_f = K \left(\frac{V_{avg}^2}{2g} \right)$$

with K being determined from Table 4-2. If the segment shape is rectangular then the diameter used in the table is the hydraulic diameter ($D_H = 1.30 \cdot (AB)^{0.625} / (A+B)^{0.250}$).

Table 4-2: Friction Loss "K" Factors			
Standard 90° Elbow	K=0.70	T: Flow In Side	K=1.50
Short Radius 90° Elbow	K=0.90	T: Flow in Run	K=0.40
Long Radius 90 ° Elbow	K=0.40	Straight Segment	$K=4 \cdot F_f \cdot (L/D)$
Standard 45° Elbow	K=0.350	U Bend	K=1.60
Sudden Expansion	$K=(1-d^2/D^2)^2$	Sudden Contraction	$K=0.5 \cdot (1-D^2/d^2)$

D=larger diameter; d=smaller diameter; L=element length; F_f = Fanning Friction Factor

Friction Factor

In evaluating the pressure drop through a straight segment the function for the friction loss factor requires the **Fanning Friction Factor**. This value is dependent upon a number of factors: pipe wall roughness, pipe diameter, and Reynold's number.

Below a Reynold's number of 2100, the flow of gasses through the vent is laminar. For laminar flow the friction factor evaluates to

$$F_f = \frac{16}{Re} \quad Re < 2100$$

When the Reynold's Number is greater than 2100 but less than 3500 the fluid is in the transition range. The equation for this regime is :

$$\frac{1}{\sqrt{F_f}} = 4 \log \frac{D}{e} + 2.28 - 4 \log \left(4.67 \cdot \frac{D/e}{Re \sqrt{F_f}} + 1 \right)$$

where:

- F_f = Fanning friction factor
- D= Diameter or Equivalent Diameter of pipe
- e= Specific roughness
- Re= Reynold's Number

Since the Fanning friction factor lies on both sides of the equation, iteration is required to solve the equation.

When the gas has Reynold's numbers greater than 3500, OHVAP considers the flow to be fully turbulent. For this flow regime the equation for the friction factor is:

$$\frac{1}{\sqrt{F_f}} = -3.6 * \log \left[\frac{6.9}{Re} + \left(\frac{e}{3.7 * D} \right)^{10/9} \right]$$

where the symbols have the same meanings as before.

Heat Transfer

Heat transfer within a vent system is the result of four different processes: conduction, convection, radiation, and mass transfer (condensation). Heat is transferred from the flue gasses to the vent wall by a combination of convection and mass transfer. Within the wall of the vent conduction, convection and radiation all come into play; and heat is transferred from the wall to the ambient air by a combination of radiation and convection.

If a control volume is taken to represent some node p within the vent wall, as depicted in Figure 42, then an energy balance can be taken for the entire volume. Assuming that no heat is generated internally to the volume (as would happen if a chemical reaction was taking place) the only way for energy to enter the volume is by crossing the faces (left, right, top, bottom, inside the page, and outside the page). The

Figure 42: Control volume around node P

energy balance thus yields:

$$Q_{lp} + Q_{rp} + Q_{tp} + Q_{bp} + Q_{ip} + Q_{op} = \text{heat accumulation in node p}$$

where Q = heat flow from the given face to node p

OHVAP uses this approach to develop a one dimensional finite difference algorithm to determine the gas and wall temperatures of the vent system. In developing a finite difference algorithm there are two choices for the basic format. An **explicit** approach uses the temperatures of the surrounding nodes (l, r, t, b, I, and o) at the current time (t) to determine the temperatures at a future time (t+ Δt) for node p. An **implicit** approach uses the temperatures of the surrounding nodes that exist at the future time (t+ Δt) to determine the future temperatures of node p. The advantage of using the explicit approach is that the system of equations that develop are relatively easy to solve. The disadvantage is that there is very tight linkage between the time step and node size. The smaller the time step used, the larger the nodes must be. The relationship between node size and time step is the Fourier number ($k\Delta t/\rho C_p \Delta x^2$) which must be less than or equal to 0.25 in order for the equation set to remain stable. In an implicit approach there is no such restriction. There are however, two disadvantages to using the implicit approach. One is that the equations must all be solved simultaneously; and the other is round off error. Solving the equations simultaneously becomes trivial using a computer and round off error only becomes a factor for very large (more than 100 nodes) equation sets. Since the node layout within OHVAP is fixed at 2*(# of layers+1) and there are a maximum of 10 layers there can only be 23 equations (including the gas temperature) at most. Thus for OHVAP the advantage of improved stability easily won out over a simpler calculation.

Modifying the above equation into a one dimensional form (where heat flow is assumed to go from "left" to "right") then yields

$$Q_{lp} + Q_{rp} = \text{heat accumulation in node P}$$

When this one dimensional form is then cast into an implicit finite difference format you get:

$$K_{lp} A_{lp} (T_l - T_p) + K_{rp} A_{rp} (T_r - T_p) = \frac{m C_p}{\Delta t} (T_p - T_p^*)$$

where:

- K = heat transfer coefficient
- T_l = temperature of node l at time $t + \Delta t$
- T_p = temperature of node p at time $t + \Delta t$
- T_r = temperature of node r at time $t + \Delta t$
- T_p^* = temperature of node p at time t
- m = mass of node p
- C_p = heat capacity of node p
- A = Surface area between node l and node p

This can be further manipulated to

$$(K_{lp}A_{lp})T_l - (K_{lp}A_{lp})T_p + (K_{rp}A_{rp})T_r - (K_{rp}A_{rp})T_p = \left(\frac{mC_p}{\Delta t}\right)T_p - \left(\frac{mC_p}{\Delta t}\right)T_p^*$$

which becomes

$$(K_{lp}A_{lp})T_l - [(K_{lp}A_{lp}) + (K_{rp}A_{rp}) + \left(\frac{mC_p}{\Delta t}\right)]T_p + (K_{rp}A_{rp})T_r = -\left(\frac{mC_p}{\Delta t}\right)T_p^*$$

Thus the temperature of every node p at time $t + \Delta t$ is dependent upon its current temperature and the future temperatures of the nodes adjacent to it. This equation is then used for every node in each element, until a system of equations is built. This system results in a matrix which can then be solved for the gas and wall temperatures within each element.

The value of K , the heat transfer coefficient, is dependent upon which type (or types) of heat transfer are occurring. If conduction is the means by which heat is transferred from one node to another then $K = k/L$, where k is the thermal conductivity of the material between the nodes and L is the distance between the nodes. If convection then K is the film coefficient. If radiation is occurring then a radiation coefficient is determined and K will be the sum of the convective and radiative coefficients.

Convection

The rate at which heat is transferred by convection is determined primarily by whether or not the gas flow is forced or natural. Natural convection occurs when the gas

motion is driven solely by temperature differences between the gas and a surface. Density differences between the gas adjacent to the surface and the gas in the bulk fluid provide the force needed to establish flow near the surface. Within a vent system natural convection occurs within an air gap, and from the walls to the ambient air. Forced convection occurs when there is some other (usually mechanical) means of moving the gas past the surface. Gasses flowing through a chimney because of draft fall into this latter category, as they are driven by the buoyancy forces that arise from the density differences between the flue gasses inside the vent and the ambient air outside the vent; **not** because of temperature differences between the gas and the liner.

Natural Convection

The convective coefficient for natural convection is heavily dependent upon the geometry of the system. If the orientation of the element in question is not vertical or horizontal but at some other angle then an average value is used. The general equation for natural convective heat transfer is:

$$h = (\text{FCM}) \times (k/L) \times (\text{GrPr})^m$$

where:

FCM = Film Coefficient Modifier (entered by the user in the OHVAP menu)

k = Thermal Conductivity of the gas film

L = Length of the convection cell

Gr = Grashof Number ($L^3 \rho^2 g \beta \Delta T / \mu^2$)

Pr = Prandtl Number ($C_p \mu / k$)

a, m = geometry constants

The geometry constants (a & m) are dependent upon where the convection is occurring. If the film coefficient is being evaluated for the outer surface of the vent then OHVAP assumes that the convection is equivalent to that which would be found near a flat plate at the same temperature. If the film coefficient is being evaluated for an air gap, then the program assumes that the gap is in the form of a rectangular enclosure at the same temperature.

Note: In Tables 4-3 through 4-6: $Y = \text{Gr} \times \text{Pr}$; $B = D/L$; $C = Y \times B^3$.

Table 4-3: Geometry Constants for a Vertical Plate		
$Y < 1.0 \times 10^4$	$a = 1.36$	$m = 0.20$
$Y > 1.0 \times 10^9$	$a = 0.130$	$m = 1/3$
$1.0 \times 10^4 \leq Y \leq 1.0 \times 10^9$	$a = 0.590$	$m = 1/4$

Table 4-4: Geometry Constants for a Horizontal Plate		
$Y > 1.0 \times 10^9$	$a = 0.130$	$m = 1/3$
$Y > 1.0 \times 10^4$	$a = 0.530$	$m = 1/4$
$Y > 1$	$a = 1.090$	$m = 0.20$
$Y > 0.001$	$a = 1.090$	$m = 0.10$
$Y > 1.0 \times 10^{-5}$	$a = 0.710$	$m = 1/25$
$Y \leq 1.0 \times 10^{-5}$	$a = 0.490$	$m = 0$

Table 4-5: Geometry Constants for a Vertical Air Gap		
$Y = Gr * Pr$	$B = D/L$	$C = Y * B^3$
$C < 2.0 \times 10^5$	$a = 0.20 * B^{(-5/36)}$	$m = 1/4$
$C \geq 2.0 \times 10^5$	$a = 0.0710 * B^{1/9}$	$m = 1/3$

Table 4-6: Geometry Constants for a Horizontal Air Gap		
$Y = Gr * Pr$	$B = D/L$	$C = Y * B^3$
$C < 3.0 \times 10^5$	$a = 0.210 * B^{(-1/4)}$	$m = 1/4$
$C \geq 3.0 \times 10^5$	$a = 0.0750$	$m = 1/3$

Forced Convection

The manner in which the forced convective coefficient is calculated depends upon whether the gas flow is laminar or turbulent. Laminar flow occurs at Reynold's numbers below 2100 and turbulent flow at values greater than 2100. Note that Reynold's

numbers between 2100 and 3500 are considered the transition region. However whether the gas flow is laminar or turbulent, *McAdams* has shown that the equation used within OHVAP for turbulent flow will provide acceptable results. Thus the equation for laminar flow is:

$$h = (FCM) * \left[1.860 * \left(\frac{k}{L} \right) * \left(N_{Re} N_{Pr} \frac{D}{L} \right)^{1/3} \right]$$

and for turbulent flow

$$h = (FCM) * \left[0.5 * F_f * C_p * G * N_{Pr}^{-2/3} \right]$$

where:

FCM= Film Coefficient Modifier (entered by the user in the OHVAP menu)

k= thermal conductivity

L= length of the gas flow path

D= diameter of vent pipe

N_{Re} = Reynold's Number (DG/μ)

N_{Pr} = Prandtl Number ($C_p \mu/k$)

F_f = Fanning friction factor

C_p = heat capacity

G= mass flow rate per unit area

Radiation

OHVAP calculates radiation effects when the current node is either an air gap or the outer surface of the vent. These effects are determined by calculating a radiation coefficient that is roughly equivalent to the standard convective film coefficient. This coefficient is then added to the convective film coefficient to arrive at an overall film coefficient. The equation used to determine h_r is given below. For simplicity the emissivity of the surfaces are assumed to be unity.

$$h_r = 0.1730 * \frac{\left(\frac{T_1}{100} \right)^4 - \left(\frac{T_2}{100} \right)^4}{T_1 - T_2}$$

where:

- $h_r =$ radiation film coefficient
- $T_1 =$ temperature of the first surface
- $T_2 =$ temperature of the second surface or ambient air

Special Case: Gas Temperature

With heat transfer proceeding from left to right, the flue gas is always assumed to be on the "left". Thus when the gas is "node P" there is no node to the left. Furthermore, from the gas' point of view, the wall temperature remains at a constant value for the entire time step. To take this into account, the gas temperature exiting an element is determined by using from the log mean temperature difference. Thus

$$mC_p(T_1 - T_2) = hA * \frac{(T_1 - T_w) - (T_2 - T_w)}{\ln \frac{T_1 - T_w}{T_2 - T_w}}$$

where

- $m =$ mass flow of flue gas
- $C_p =$ heat capacity of the flue gas
- $h =$ convective film coefficient
- $A =$ surface area
- $T_1 =$ temperature of gas entering the element at time $t + \Delta t$
- $T_2 =$ temperature of gas exiting the element at time $t + \Delta t$
- $T_w =$ wall temperature at time $t + \Delta t$

This can be algebraically manipulated to become

$$T_2 = T_w + (T_1 - T_w)e^{-\left(\frac{hA}{mC_p}\right)}$$

Building the Matrix

A simple element is depicted in **Figure 43**. The gas is flowing on the left side of a single wall, with the given node layout:

- T_{g1} = gas temperature entering the element at time $t + \Delta t$
- T_{g2} = gas temperature exiting the element at time $t + \Delta t$
- T_g = average gas temperature within the element at time $t + \Delta t$
- T_1 = surface temperature at time $t + \Delta t$
- T_2 = centerline temperature of wall at time $t + \Delta t$
- T_3 = outer surface temperature at time $t + \Delta t$
- T_{amb} = ambient air temperature (constant)

Figure 43: A simple element from a 1 layer segment

Since the finite difference approach uses average temperatures, the average gas temperature calculated from the matrix is $T_{avg} = 0.5 * (T_1 + T_2)$. Thus the equation in the heat transfer matrix to determine the gas temperature looks like

$$T_g - 0.5 * \left(1 - e^{-\frac{hA_g}{mCp}}\right) * T_1 = 0.5 * \left(1 + e^{-\frac{hA_g}{mCp}}\right) * T_g^*$$

where

- $T_g =$ average gas temperature at time $t + \Delta t$
- $T_g^* =$ average gas temperature at time t
- $T_l =$ average wall temperature at time $t + \Delta t$
- $m =$ mass flow of flue gas
- $C_p =$ heat capacity of the flue gas
- $h =$ convective film coefficient
- $A =$ surface area

For the inner surface of the liner the equation would be

$$hA_g T_g - \left[hA_g + \frac{kA_l}{L} + \frac{mC_p}{\Delta t} \right] T_l + \frac{kA_l}{L} T_2 = -\frac{mC_p}{\Delta t} T_l^*$$

For the middle of the liner the equation would be

$$\frac{kA_l}{L_l} T_l - \left[\frac{kA_l}{L_l} + \frac{k_r A_r}{L_r} + \frac{mC_p}{\Delta t} \right] T_2 + \frac{k_r A_r}{L_r} T_3 = \frac{mC_p}{\Delta t} T_2^*$$

For the outer surface of the liner the equation would be

$$\frac{k_r A_r}{L_r} T_2 - \left[\frac{k_r A_r}{L_r} + h_a A_o + \frac{mC_p}{\Delta t} \right] T_3 + h_a A_o T_{amb} = -\frac{mC_p}{\Delta t} T_3^*$$

The completed heat transfer matrix would look as follows:

$$\begin{bmatrix} 1 & -(\frac{1}{2})(1-e^{\frac{hA_g}{mCp}}) & 0 & 0 & (\frac{1}{2})(1-e^{\frac{hA_g}{mCp}}) \\ hA_g & -(hA_g + \frac{kA_l}{L} + \frac{mCp}{\Delta t}) & \frac{kA_l}{L} & 0 & \frac{mCp}{\Delta t} * T_1^* \\ 0 & \frac{kA_l}{L} & -(\frac{kA_l}{L} + \frac{kA_r}{L} + \frac{mCp}{\Delta t}) & \frac{kA_r}{L} & \frac{mCp}{\Delta t} * T_1^* \\ 0 & 0 & \frac{kA_r}{L} & -(\frac{kA_r}{L} + hA_o + \frac{mCp}{\Delta t}) & \frac{mCp}{\Delta t} * T_1^* - hA_o T_{amb} \end{bmatrix}$$

which is then solved using Gaussian elimination.

Mass Transfer

The mass transfer calculations performed by OHVAP determine how much water or sulfuric acid condenses from the flue gasses or evaporates off the liner in any given time step. There are two central assumptions made within OHVAP regarding mass transfer :

- 1) All acid that condenses will immediately react with the surface and so will never evaporate
- 2) Steady state calculations are used

The procedure generally follows that outlined by *Kern* for condensing from a mixture of vapor and noncondensable gas. The calculation is identical for both water and sulfuric acid and proceeds as follows:

- 1) Determine the partial pressure of the condensible vapor in the gas
- 2) Estimate the partial pressure of the vapor at the wall
- 3) Calculate the log-mean pressure difference between the bulk gas and wall
- 4) Calculate the diffusion coefficient for the vapor through the gas
- 5) Determine the molar rate of condensation
- 6) Convert the molar rate into actual mass condensed.

If the vapor pressure of the water at the wall is greater than the partial pressure of the water vapor in the bulk gas then the condensate will evaporate off the wall and reenter the gas stream.

Mass transfer has a marked effect upon the rates of heat transfer through the wall. If water and acid are condensing from the gas, then the wall will absorb a greater amount of heat which will then be wicked away into the wall. Within OHVAP as the water and acid reach the wall the heat that they deposit is immediately used to raise the temperature of the liner surface. This increased temperature is then used as the basis for all of the calculations in the heat transfer matrix. Similarly, when water evaporates from the surface, all of the latent heat required is removed from the wall, thus lowering its temperature. The water vapor is now mixed with the flue gasses chilling them. Heat transfer calculations are then performed based upon these new cooler temperatures.

Chapter 5: Conclusion

The OHVAP program is a tool designed to help the user (system designer) to determine whether or not a given flue gas venting system serving a single oil-fired appliance is properly configured. The proper configuration will be evident in terms of capacity (available draft at the appliance) and inner wall temperature (to minimize acid/water condensation).

Given the characteristics of the vent (geometry) and heating appliance (time/temperature profiles), the program will report the temperature, static pressure, and condensation history throughout the entire vent system. From this information the system designer should be able to determine how the given system will work in the field.

Validation of OHVAP has been limited to temperature comparisons between predicted and measured experimental results obtained in the laboratory. These comparisons show good correlation between the predicted draft, flue-gas, and inner wall temperatures in both the connector and chimney configurations used in the laboratory.

Discussions with the oil-heat industry have resulted in supportive test results in terms of measured temperature of the flue-gas and inner walls. Despite the agreement in terms of temperature there is still an industry-wide open question of the actual physical mechanism of acid/water condensation and corrosion. This has to do specifically with the clay tile liner used in typical masonry chimneys conforming to NFPA 211. While many masonry chimneys exhibit long life serving oil-fired appliances, there are specific cases of heavy condensation and severe damage within the chimney.

Future Programming Work

OHVAP goes beyond the limitations that currently prevent the other transient vent analysis programs that are available from satisfying the needs of the oil heat industry. However there are other limitations within OHVAP. It is hoped that at some point in the future these limitations will be addressed. They can be prioritized as follows:

- 1) Enhance the condensation model to provide a fully dynamic transient analysis of the water and sulfuric acid condensation within the vent system. Currently OHVAP uses a steady state condensation model that is attached to the transient heat transfer model.
- 2) Build the proper error checking into the menu module. As stated earlier, the

program provides no error checking at all. If there is an error in the information fed into the program the only way that it will be revealed is by the program crashing to a halt.

- 3) Support multiple appliance systems. The current version of OHVAP will currently handle a vent system that is designed for one appliance. While OHVAP was being developed, many questions arrived from the industry regarding multiple appliance systems. While this condition can be "forced" in the model by combining the appliances into one larger appliance, this does not truly answer the need, especially for non-synchronized operation or appliances that may be located at different elevations.
- 4) Refine the flow model to allow finer divisions within the gas plugs. Currently gas plugs may occupy more than one element within the system. To achieve greater accuracy, a greater number of gas plugs would better simulate the continuum of flue-gas in the system.
- 5) Convert the heat transfer routines from a one dimensional to a two dimensional form. This will allow the program to more realistically account for the fact that many conventional chimney systems are sheltered along one wall from outside ambient conditions. It will also allow a lined chimney system to have the round liner within a rectangular chimney. Currently, the rectangular chimney is chopped into a square to allow the nodes to fall into place. A two-dimensional heat transfer model would allow the walls to be modeled directly, without conversion.
- 6) Increase the flexibility of the printing functions. OHVAP currently limits the user to reporting on six variables over a maximum of fifty elements. Furthermore, this output is limited to two files. These limitations were built into the model purposely to conform to the LOTUS™ version 1 spreadsheet format. By allowing other file formats, there is no reason to limit the output choices to six variables or even fifty elements. The newer WINDOWS™-based spreadsheets can handle much greater amounts of data than the older LOTUS standard.

Future Experimental Work

During the development of the OHVAP program, there was a constant dialog with the oil heating industry. As a result of this interaction, there was enough feedback that there is great confidence in the temperature results calculated by the program. Unfortunately, there is almost no information available regarding the amount or type of

condensation that is present within a venting system. While the temperature data that does exist does provide some confidence in the condensation model, actual experimental data would be even more valuable.

Along these lines, the best possible way to accumulate the necessary data would be to build a fully instrumented chimney. By operating under laboratory conditions, this would allow a detailed validation of every facet of the OHVAP model. Unfortunately, current research priorities and severe limitations in available federal funds under BNL's Oil Heat R&D program as sponsored by the U.S. DOE have precluded any further work in the foreseeable future. BNL is hopeful that private sector funding might allow this work to continue at some point in the future.

Appendices

Appendix A: The Relationship Between Excess Air and CO₂ & O₂ Levels

The following graph shows the relationship between the excess air setting for the burner and the levels of oxygen and carbon dioxide found in the flue gasses. To use the graph, the level of oxygen or carbon dioxide is found on the left hand axis. Look across the graph to the appropriate curve and then down to the horizontal axis. This will reveal the excess air level that should be used within OHVAP.

Appendix B: Material Properties

Table B-1: Material Properties				
Material	Roughness (ft)	Heat Capacity (Btu/(lbm °F))	Density (lbm/ft ³)	Thermal Conductivity (Btu/(hr ft ² °F/ft))
Aluminum	0.0001	0.214	171	128
Clay Tile	0.01	0.220	100	0.28
Concrete	0.004	0.156	144	0.54
Glass	0.000005	0.2	139	0.59
Masonry Brick	0.01	0.2	123	0.4
Mineral Fiber T<400°F	NA	0.16	3	0.03
Mineral Fiber T<1000°F	NA	0.17	6	0.027
Mineral Fiber T<1200°F	NA	0.17	12	0.028
Pearlite	NA	0.32	7.5	0.04
PVC	0.000005	0.2	86	0.1
Steel, Galvanized	0.0005	0.12	489	26.2
Steel, Mild	0.0004	0.12	489	26.2
Steel, Stainless	0.0003	0.11	488	10
Steel, Stainless Flex	0.007	0.11	488	10
Vermiculite	NA	0.32	6	0.047

Note: Where the entry for the specific roughness of the material is “NA” OHVAP will not allow that material to be used as the first layer in the vent.

Appendix C: Time Temperature Profile File Format

The time temperature profile of the combustion products as they leave the burner is stored in ASCII files denoted as *filename.ttp*. The format for these files is relatively straight forward. **Figure C-1** shows a sample of a TTP file. The first line consists of only one number: the number of entries in the file. The remainder of the file consists of the time (in minutes) followed by the temperature (°F) of the gas exiting the appliance at that time. There is no real limit to the number of temperatures that can be used, so long as they describe the entire temperature cycle that is to be modeled. In **Figure C-1** there are a total of 24 entries that describe a 43 minute cycle that starts at a temperature of 89°F and ends at 87°F. The cycle then starts again at 89 °F. As OHVAP steps through time, the program interpolates between the temperatures listed in this file.

To properly measure a complete cycle requires a TTP file of at least six data points: three before the peak temperature, the peak temperature itself, and two after the peak. In general though, anywhere between 20 and 30 temperatures should more than suffice. There should be more data points during times of rapid change (such as burner warm up) than in times of slower change (the last 15 minutes of a typical 43 minute boiler cycle).

```
24
0.00, 89.00
0.50, 227.00
1.00, 298.00
1.50, 316.00
2.00, 324.00
2.50, 329.00
3.00, 334.00
5.00, 342.00
7.00, 343.00
10.00, 345.00
10.25, 305.00
11.00, 217.00
11.50, 179.00
12.00, 157.00
12.50, 144.00
13.00, 136.00
13.50, 130.00
14.00, 124.00
16.00, 119.00
18.00, 108.00
20.00, 97.00
25.00, 92.00
35.00, 88.00
43.00, 87.00
```

Figure C-1: Sample TTP File

Appendix D: OHVAP Case File Formats

Figure D-1 contains a sample of an OHVAP case file (*CASEFILE.VAP*). This is typical of what is saved to disk when you have completed creating or editing a case file. The format is as follows:

TTP file

Total number of Segments defined

Segment information (1 segment/line):

Segment # - 1

Segment type code

Segment shape code

Segment location code

Number of elements

Segment length

Segment angle

Segment internal diameter

Size of Side A

Size of Side B

Damper angle

Custom K factor

Total number of layers in the system

Layer information (1 layer/line):

Segment sort key

Layer sort key

Segment # - 1

Layer Material Code

Layer Thickness

Barometric Damper: (one line)

Element

Damper size code

Damper setting code

Coefficients A thru E

Burner Information: (one line)

Firing rate code

Value for Custom Rate

Excess air setting

Off-cycle flow factor

Combustion air source code

Fuel composition information: (one line)

BOIL345.TTP

6

0 1 0 0 1 1 90 6 NA NA NA NA

1 2 0 0 NA NA 90 6 NA NA NA NA

2 5 0 0 NA NA 90 6 NA NA NA NA

3 1 0 0 9 9 0 6 NA NA NA NA

4 3 0 1 NA NA 90 6 NA NA NA NA

5 1 2 1 20 40 90 8 10 10 NA NA

12

0 0 0 0 12 .019

1 0 1 0 12 .019

2 0 2 0 12 .019

3 0 3 0 12 .019

4 0 4 0 12 .019

4 1 4 1 3 .625

4 2 4 2 4 12

5 0 5 0 15 .019

5 1 5 1 1 T

5 2 5 2 3 .625

5 3 5 3 1 .5

5 4 5 4 6 4

2 2 1 0 0 0 0

9 3.3 28.4 1.31 0

0.865 87.3 12.5 0.2 0 0 0 0

2 1 .5 .5 1 1 2 2 0

0 0 0 0 0 0

4 0 2 0

0 0 0 0

60 50 42 50 0

4 43 10 1

0 0 0 0

0 0 0 0

Figure D-1: Sample OHVAP case file
(*CASEFILE.VAP*)

Specific gravity
Carbon weight percent
Hydrogen weight percent
Sulfur weight percent
Water weight percent
Oxygen weight percent
Nitrogen weight percent
Ash weight percent
Heat transfer options: (one line)
Film coefficient modifier: indoor gas side
Film coefficient modifier: outdoor gas side
Film coefficient modifier: indoor air side (vertical)
Film coefficient modifier: indoor air side (horizontal)
Film coefficient modifier: outdoor air side (vertical)
Film coefficient modifier: outdoor air side (horizontal)
Film coefficient modifier: indoor air gap
Film coefficient modifier: outdoor air gap
Code for Heat transfer options selected
Draft inducer fan data: (one line)
Element
Fan curve coefficients A thru E
Output options: (one line)
Initial print cycle
Code for print time step
Code for output file contents selection
Code for output file organization selection
Purge options: (one line)
Code for pre/post purge enable
Code for purge controller
Prepurge duration
Postpurge duration
Air settings: (one line)
Indoor air temperature
Indoor relative humidity
Outdoor air temperature
Outdoor relative humidity
Outside air pressure at vent terminus
Time settings: (one line)
Number of cycles
Duration of each cycle

Duration of the burner "on" period
Time step code
Custom materials information: (one material per line)
Density
Specific roughness
Heat capacity
Thermal conductivity
End of file

Appendix E: OHVAP Temporary File Formats

Figure E-1 contains a sample of the temporary files that OHVAP generates. OHVAP uses these files to pass information from the menu/data entry portion of the program to the engineering module when **Run|Run Case** is selected from the menu. This information is also created when the user selects **Run|Generate Temporary Files** from the menu. By selecting this option, the case file is converted into this temporary file format using the names *CASEFILE.TMP* and *CASEFILE.TTP*. By copying these files to the names *VAP.TMP* and *VAP.TTP*, the users can then run the engineering module without going through the menu screens. This is especially useful if batch operation is desired. By creating a series of these temporary files, a DOS batch file can then copy the files into *VAP.TMP* and *VAP.TTP* and then run the engineering module (*vapengv3.exe*). The batch file can then repeat this process for every case to be run.

The file format is as follows:

The case filename

NUMBER of segments defined (only 1 segment in the figure to save space)

Segment information: (one line)

Segment type code

Shape code

Number of nodes through the wall of the segment

Location code

Segment angle

Segment internal diameter or equivalent diameter if rectangular

Change in elevation across each element

Actual length of each element

Cross sectional flow area

Specific roughness of layer 1

Custom K factor

The next eight lines contain the nodal information for each segment; one property/line

```
SAMPLEXX.VAP
1
12 1 3 1 1.570796 0.5 1 1 0.19635
0.0005 3.688203e-37
1.570796 1.573283 1.578258
1.573283 1.578258 1.580745
0 0.000396 0.000396
0.000396 0.000396 0
0 0.036543 0.036659
0.036543 0.036659 0
0 26.200001 26.200001
26.200001 26.200001 0
33
0 1 2 3 3 3 3 3 3 3 3 4 5 5 5 5 5 5
5 5 5 5 5 5 5 5 5 5 5 5 5
2 2 1 0 0 0 0 0
0 0 0 0 0 0
0.865 0.873 0.125 0.002 0 0 0 0
60 50
42 50 0
2 1 .5 .5 1 1 2 2 0
3.3 0.284 1.31 1
10 4 4 1 2580 2 0
0 600 0 0 0 0 0
```

Figure E-1: Sample *.TMP file

Surface area of the left face of each node
 Surface area of the right face of each node
 Distance from the left face of the node to the nodal point
 Distance from the right face of the node to the nodal point
 Thermal mass of the left portion of each node
 Thermal mass of the right portion of each node
 Thermal conductivity of the material on the left of each node
 Thermal conductivity of the material on the right of each node
 The total number of elements that are defined within the vent system
 Which segment each element is located in (one line)
 Barometric damper properties: (one line)
 Damper element
 Damper size
 Damper setting
 Custom damper coefficients (A thru E)
 Draft inducer fan properties: (one line)
 Fan element
 Fan curve coefficients (A thru E)
 Fuel Composition: (one line)
 Specific gravity
 Carbon weight percent
 Hydrogen weight percent
 Oxygen weight percent
 Nitrogen weight percent
 Ash (noncombustible) weight percent
 Indoor air conditions: (one line)
 Temperature
 Relative humidity x 100
 Outside air pressure deviation from atmospheric
 Heat transfer options: (one line)
 Film coefficient modifier: indoor gas side
 Film coefficient modifier: outdoor gas side
 Film coefficient modifier: indoor air side (vertical)
 Film coefficient modifier: indoor air side (horizontal)
 Film coefficient modifier: outdoor air side (vertical)
 Film coefficient modifier: outdoor air side (horizontal)
 Film coefficient modifier: indoor air gap
 Film coefficient modifier: outdoor air gap
 Code for Heat transfer options selected
 Burner settings: (one line)

Firing rate
Excess air
Off cycle flow factor
Combustion air source
Time settings: (one line)
Time step
Number of cycles to run
Initial print cycle
Printing delay
Duration of each complete cycle
Output options: (one the same line as the Time settings)
Code for which file(s) to print out
File organization
Cycle "events" information
Time the burner starts
Time the burner stops
Time the prepurge starts
Time the prepurge stops
Time the postpurge starts
Code for which device controls the purge operation
End of file

Appendix F: Development of the Proposed Chimney Relining Tables

This appendix describes the development of the lined masonry chimney venting tables from the output of the Oil Heat Vent Analysis Program (OHVAP).

The preparation of the input files for OHVAP included the following general geometric configuration information:

(1) Masonry chimneys constructed in accordance with NFPA 211; ie, a clay tile inner liner surrounded by a 0.5 inch air gap, all enclosed with 4 inches of masonry brick. For the cases used in vent table preparation the clay tile was assumed to be standard 8 inch square tile with interior dimensions of 6.75 by 6.75 inches. The chimney heights used in the evaluation were 10, 15, 20, and 25 feet above the breeching.

(2) The connectors are nominally defined as 4, 6, 8 and 10 feet of total straight length. In fact, the single wall (.019 thick) galvanized steel connectors consist of a 1 foot vertical straight section into a standard "tee" containing a barometric draft control. The exit of the "tee" enters a standard 90° elbow which connects to horizontal straight section. This straight section connects to the breech opening in the masonry chimney. For the connectors, two horizontal lengths, 3 and 9 feet, were analyzed and the results for the intermediate lengths were interpolated.

(3) Where additional chimney liners were applied, these consist of 6, 5, and 4 inch diameter smooth stainless pipe with a .019 inch thick wall. The connector, over its entire length, as well as the diameter of the barometric draft control, is held consistent with the diameter of the applied liner. The chimney liners are assumed to be uninsulated (air gap unfilled) and positioned concentric with the inner clay tile of the masonry chimney.

Twelve firing rates were evaluated. These were 0.25, 0.4, 0.5, 0.65, 0.75, 0.85, 1.0, 1.25, 1.5, 1.75, 2.0, and 2.25 gallons per hour. The appliance efficiencies (steady-state) were 80%, 82%, 84%, 86%, and 88%. At a flue gas CO₂ level of 12% the respective flue gas temperatures at the above steady-state efficiencies were 575, 495, 420, 345, and 275° F. Standard boiler time-temperature profiles were used to simulate the appliance cyclic operation with a 10 minute burner "on" period and a 33 minute burner "off" period. Each case run consisted of four cycles with the first three used to condition the vent system and the fourth to store the results of the computations in the output files.

Output File Description

The completion of a run with OHVAP results in the creation of one or two Lotus™ *.WK1 files. While these files are not considered large in terms of storage, a hard-copy print out of each file would occupy several pages. For this reason, only portions of the output files will be replicated as example figures herein.

The format used by OHVAP for the first part of each output file is arranged in column form as follows:

<u>COLUMN</u>	<u>DESCRIPTION</u>
1	(Cycle) Cycle number
2	(Time) Elapsed time in seconds
3	(Tapp) Flue gas temperature at the appliance (F)
4	(Papp) Flue gas pressure at the appliance (in. H ₂ O)
5	(QB) Flow through burner (SCFM)
6	(QD) Flow through draft control (SCFM)
7	(Backflow) Reverse flow in last element (SCFM)
8	BLANK

Depending on the selection for output, whether by Variable or by Element, and the number of elements used, the following arrangement of columns will be recorded starting with column 9:

If the output files are created by Variable they will have the following appearance starting with column 9 -

<u>COLUMN</u>	<u>DESCRIPTION (ELEMENT 1....ELEMENT i)</u>
<u>File-1</u>	
Tgout1....Tgouti	Flue gas exit temperature (F)
Tl1....Tli	Flue gas side surface temperature of liner (F)
Ps1....Psi	Static pressure (in. H ₂ O)
<u>File-2</u>	
Tlair1....Tlairi	Air-gap side surface temperature of liner (F)
Acid1....Acidi	Acid condensation (lbs)
Water1....Wateri	Water condensation (lbs)

If the output files are created by Element they will have the following appearance starting with column 9 -

<u>COLUMN</u>	<u>DESCRIPTION (VARIABLE 1....VARIABLE i)</u>
<u>File-1</u>	
Tgout1	Flue gas exit temperature for element 1 (F)
Tl1	Flue gas side surface temp. for element 1 (F)
Ps1	Static pressure for element 1 (in. H ₂ O)
BLANK	
.	.
.	.
Tgouti	Flue gas exit temperature for element i (F)
Tli	Flue gas side surface temp. for element i (F)
Psi	Static pressure for element i (in. H ₂ O)
BLANK	
<u>File-2</u>	
Tlair1	Air-gap side surface temp. for element 1 (F)
Acid1	Acid condensation for element 1 (lbs)
Water1	Water condensation for element 1 (lbs)
BLANK	
.	.
.	.
Tlairi	Air-gap side surface temp. for element i (F)
Acidi	Acid condensation for element i (lbs)
Wateri	Water condensation for element i (lbs)
BLANK	

Table Generation

The files used to evaluate the cases needed to establish the venting tables were of the form defined by Variable and only File-1 was used. The criteria used in evaluating acceptability for all cases were based on the vent conditions occurring at the end of the burner "on" period. The acceptable vent system will have:

- (1) a static pressure at the appliance is less than or equal to -0.03 inches of water.
- (2) The inner surface temperature at the exit of the chimney is greater than or

equal to 95° F.

The approach taken in generating the venting tables utilized a spreadsheet application, in this case Quattro Pro™. This permitted the evaluation of the static pressure at the appliance and the inner surface temperature at the chimney exit at the end of the burner “on” period. This soon proved to be a tedious activity since the results of 1920 computer runs had to be individually evaluated. A portion of a typical output file is shown in Figure F-1.

CYCLE	TIME	TAPP.	PAPP.	QB	QD	Backflow		Tgout1	Tgout2	Tgout3
	(sec)	(F)	(in wc)	(scfm)	(scfm)	(scfm)		(F)	(F)	(F)
4	0	89.0	-0.019	29.44	5.96	0.00		87.9	84.5	84.1
4	10	135.0	-0.028	29.44	11.16	0.00		130.7	115.6	111.5
4	20	181.0	-0.039	29.44	18.26	0.00		173.5	141.0	134.2
4	30	227.0	-0.047	29.44	24.43	0.00		216.3	162.6	153.6
4	40	250.7	-0.052	29.44	28.05	0.00		238.7	172.4	162.8
4	50	274.3	-0.056	29.44	31.21	0.00		260.9	182.8	172.3
4	60	298.0	-0.060	29.44	34.16	0.00		283.0	192.2	180.9
4	70	304.0	-0.061	29.44	35.42	0.00		288.8	193.7	182.6
4	80	310.0	-0.063	29.44	36.97	0.00		294.6	195.0	184.0
4	90	316.0	-0.064	29.44	37.51	0.00		300.2	198.3	186.9
4	100	318.7	-0.065	29.44	38.60	0.00		302.8	199.8	188.4
4	110	321.3	-0.065	29.44	39.19	0.00		305.3	199.4	188.1
4	120	324.0	-0.065	29.44	39.19	0.00		308.0	201.3	190.1
4	130	325.7	-0.066	29.44	39.61	0.00		309.9	202.7	191.9
4	140	327.3	-0.066	29.44	39.61	0.00		311.9	204.2	193.6
4	150	329.0	-0.067	29.44	40.45	0.00		313.8	205.6	195.2
4	160	330.7	-0.067	29.44	40.87	0.00		315.7	204.6	194.7
4	170	332.3	-0.067	29.44	40.83	0.00		317.5	205.8	196.1
4	180	334.0	-0.068	29.44	41.37	0.00		319.4	207.0	197.4
4	190	334.7	-0.068	29.44	41.37	0.00		320.2	207.7	198.2

Figure F-1: Typical OHVAP output file. This file extends further than what is shown in this figure; to column DB (No.107) to the right and downward to row 261.

The solution to this problem was the creation of two spreadsheet template forms, each of which was directed at one of the two nominal connector lengths used in the simulation; 4 and 10 feet long and each with a 25 foot chimney. The nominal 4 foot long connector and chimney system contains 32 elements while the nominal 10 foot long connector system and chimney contains 38 elements. Each template (Figure F-2) would contain information on the average flue-gas mass flow ratio, appliance and chimney base pressures, and temperatures for the gas and wall at the ends of the connector and chimney exit.

The first step in the general procedure used to create the template is to open one of the output files within the spreadsheet application. The values for static pressure at the appliance and inner surface temperature at the chimney exit, among others, is copied

In the second step the spreadsheet is then rendered completely devoid of cell values, with headings retained. The now empty spreadsheet is then saved with a name which defines the template. At the time of the save the mouse cursor must be located at the first cell of the spreadsheet.

In the third step, combining of each output file in turn into this template will render the static pressure and temperature values immediately available along with the appropriate graphs for reference. An example of the combined spreadsheet is shown in Figure F-3.

The fourth step in the procedure involves the preparation of a spreadsheet to perform a linear interpolation of the appliance static pressure and the inner surface temperature at the chimney exit for the intermediate nominal connector lengths of 6 and

CALCULATION TABLE 86% BASE CASE					25 foot chimney			
CHIM.H	DRAFF				TEMPERATUR			
CONN.L	4	6	8	10	4	6	8	10
GPH	FT	FT	FT	FT	FT	FT	FT	FT
0.2	0.049	0.04816	0.04673	0.045	49.7	49.6234	49.4669	49.3
0.4	0.055	0.05413	0.0524	0.050	54.0	53.6870	53.3340	52.9
0.5	0.058	0.05680	0.05490	0.05	57.1	56.5772	55.9845	55.3
0.6	0.062	0.06033	0.0585	0.056	61.6	60.9639	60.3079	59.6
0.7	0.063	0.06153	0.0597	0.05	64.5	63.857	63.124	62.3
0.8	0.064	0.06273	0.0609	0.059	67.4	66.670	65.871	65.0
1	0.065	0.06390	0.06200	0.060	71.9	70.9842	70.0385	69.0
1.2	0.065	0.06380	0.06190	0.0	77.5	77.017	76.484	75.9
1.5	0.064	0.06293	0.06097	0.05	83.1	82.2775	81.4250	80.5
1.7	0.062	0.06086	0.05883	0.056	88.3	87.4442	86.5384	85.6
2	0.059	0.05760	0.05550	0.053	93.2	92.2643	91.2886	90.3
2.2	0.056	0.05410	0.05190	0.049	97.7	96.7643	95.7786	94.7

Figure F-4: Base case masonry chimney with no metal liner

8 feet. An entry form is made for each of the vent system configurations and firing rates under evaluation. Once this spreadsheet is prepared, all that is necessary is that the appropriate calculated values for the nominal 4 and 10 foot connectors be entered. The spreadsheet then automatically calculates and displays the respective values for the intermediate nominal connector lengths. Examples of these interpolation spreadsheets are shown in Figures F-4 and F-5.

The fifth and final step is to scan each of the interpolation spreadsheets and pick out the firing rate ranges that satisfy the acceptability criteria for the chimney height,

lateral (nominal connector) length, and liner diameter.

Included on these next pages are the chimney relining tables. This is the latest revision to the text submitted by BNL to the National Fire Protection Association for inclusion in the latest revision of NFPA Standard 31: Installation of Oil Burning Equipment.

"B" CASES								
CHIM.H	DRAFF				TEMPERATU			
CONN.L	4	6	8	10	4	6	8	10
GPH	FT	FT	FT	FT	FT	FT	FT	FT
0.2	0.054	0.05283	0.0513	0.049	64.4	62.9281	61.446	59.9
0.4	0.061	0.05950	0.05790	0.056	73.3	72.68	72.01	71.3
0.5	0.064	0.06293	0.0612	0.059	76.1	76.126	76.093	76.0
0.6	0.06	0.06630	0.06460	0.062	83.6	82.8707	82.1314	81.3
0.7	0.06	0.06723	0.0654	0.063	87.0	86.2973	85.5847	84.8
0.8	0.0	0.06816	0.06633	0.064	89.9	89.2773	88.5847	87.8
1	0.071	0.06926	0.06743	0.065	94	93.2973	92.5947	91.8
1.2	0.071	0.06913	0.06717	0.065	98.9	98.4205	97.9110	97.
1.5	0.070	0.06800	0.06590	0.063	102.8	102.48	102.13	101.7
1.7	0.067	0.06520	0.06330	0.061	106.	105.85	105.51	105.1
2	0.064	0.06196	0.05973	0.057	108.9	108.653	108.337	108.0
2.2	0.059	0.05730	0.05520	0.053	111.2	111.046	110.813	110.5

Figure F-5: Interpolation for the "B" cases which define a 6 inch metal liner positioned inside the existing clay tile liner in the masonry chimney.

Relining Masonry Chimneys

F-1 A tile lined masonry chimney serving an oil-fired appliance should comply with applicable building codes such as NFPA Standard 211, Section 3-2, Construction of Masonry Chimneys. An additional listed metal chimney liner may be needed to reduce transient low draft during start-up and acid/water condensation during cyclic operation. This is particularly true for high-mass masonry chimneys serving oil-fired appliances producing relatively low flue-gas temperature.

F-2 For masonry chimneys, local experience may indicate how well the construction has withstood the lower temperatures produced by a modern oil-fired appliance. Evidence of potential or existing chimney damage should be determined by visual examination of the chimney and liner. Exterior indicators such as missing or loose mortar/bricks, white deposits (efflorescence) on brickwork, a leaning chimney or water stains on interior building walls should be investigated further. Interior chimney examination with a mirror (or video camera) can reveal damaged or missing liner material. The detailed characteristics of a properly constructed masonry chimney, on which to base the inspection on, are included in NFPA Standard 211 (1992), Chapter 3. The liner must be continuous, properly aligned, intact, and must extend beyond the top of the chimney. The chimney should also have a clean-out at the base. Any debris collected in the chimney base, drop-leg or connector should be removed and examined for content and source of debris. If any doubt exists regarding the condition of the chimney, examination by an experienced professional is strongly recommended and any problems must be corrected.

F-3 The physical condition and suitability of an existing chimney must be checked before the installation of a new oil-fired appliance or the upgrade (new burner or reduced firing rate) of an existing appliance. The chimney should be inspected and, if needed, cleaned.

F-4 The current practice in existing residential oil-fired appliances is to reduce the firing rate, often to levels of 1 gallon per hour or less, for energy conservation purposes. Older oil-fired appliances are being replaced with new models having efficiencies significantly higher than 80%. The resulting reduction in flue gas temperatures will increase the potential for water and acid condensation in the inventory of masonry chimneys serving these appliances.

F-5 Residential sized heating appliances sold in the U.S. are required to be tested in accordance with the Annual Fuel Utilization Efficiency (AFUE) Test Procedure. This procedure is based on ASHRAE Standard 103-1982. In 1987, the National Appliance

Energy Conservation Act (NAECA) was passed into Federal Law by Congress. This law requires that, starting January 1, 1992, for input less than 300,000 Btuh, all boilers and furnaces must have an AFUE of at least 80 percent and 78 percent respectively. Many available oil-fired boilers and furnaces already exceeded these minimum requirements with AFUE values of 82 to 86 percent.

Modern heating appliances meeting these new requirements are being installed as replacements for older systems as well as in new construction. In the replacement of existing older systems, the venting system, largely masonry chimneys, might be oversized and in poor repair. The operational flue-gas temperatures for modern mid- and high-efficiency systems range from 300°F up to about 500°F at the outlet of the unit. These low flue-gas temperatures may be further reduced before reaching the chimney because of heat loss from the connector through dilution when a draft regulator is used. In either case, the resulting available flue-gas temperatures are frequently either insufficient to sustain adequate draft in an older, oversized masonry chimney or permits condensate to form on cold connector and chimney liner walls.

F-6 After installation of a new oil-fired appliance or upgrade, if no chimney modifications were required at the time of installation, the condition of the chimney must be re-checked after three months and after six months of normal heating appliance operation to verify that the chimney is still in good condition and suitable for continued use. If any doubt exists regarding the condition of the chimney, examination by an experienced professional is again highly recommended and any problems must be corrected.

F-7 Results of a computational analysis by Strasser using the Oil Heat Vent Analysis Program (OHVAP), Version 1.0 ^[1] to analyze a series of masonry chimney venting systems indicates that current applications of modern oil-fired heating appliances may have some difficulty in terms of the formation of acid/water condensation within the chimney during winter operation. OHVAP is a transient simulation program written specifically for oil-fired equipment. The simulation uses algorithms modeling flue-gas composition, system pressure, draft control dilution ^[2,3], system gas-flow, and heat transfer in vent systems serving oil-fired appliances.

These results have been translated into fuel input firing rate (gallons per hour) recommendations in the use of metal liner systems for remediation of troublesome masonry chimney vent systems. The results are shown in the accompanying tables. These tables show appliance steady state efficiency, chimney height and nominal connector length. See section F-9 for specific examples of the proposed application of these tables.

F-8 The issue of water condensation in masonry chimneys has been documented as are the issues of damage to masonry, mortar and liners in chimneys often due to improper construction.^[4,5]

F-9 In interpreting the OHVAP simulation results to develop the recommendations, two criteria for successful system performance are applied at the end of the appliance burner "on" period. These criteria are:

- 1) A minimum available winter-time draft at the appliance of about - 0.03 inches of water column.
- 2) A minimum chimney liner surface temperature at the top of the chimney of about 95° F (water dew point of diluted flue gas).

The tables are derived (by simulation) on the basis of 12% CO₂ but the recommendations are valid for CO₂ levels between 10% and 14%. In addition, a listed insulation system is assumed to surround the metal liner within the chimney. Slightly lower liner temperatures can be expected if no insulation is applied in practice. Field experience and confined efforts in verification analysis using the OHVAP simulation model confirm that liners without insulation are acceptable in most cases with the exception of very marginal conditions.

F-10 The relined exterior chimney venting tables are included in this Appendix. In order to use the tables, the user must first determine the approximate steady-state efficiency of the appliance being vented. This approximation can be made using one of three methods for a specific appliance. These are; 1) the Flue Loss method, 2) the Heating Capacity method and 3) the Annual Fuel Utilization Efficiency (AFUE) method.

F-10.1 The Flue Loss method involves the adjustment of the appliance burner for a satisfactory maximum flue gas CO₂ level (minimum excess combustion air) and a trace to No. 1 smoke (Bacharach scale) after a minimum of 10 minutes of operation. The flue gas temperature is then measured at the appliance exit and the value is used to select the table or tables for use in obtaining the recommended vent size and firing rate. If the measured temperature falls between two tables, examine the recommendations contained in the tables above and below that of the measured temperature. When all measurements are completed the appliance burner adjustments should be checked and readjusted if needed to conform with CO₂ and smoke level settings as indicated in the equipment manufacturer's specifications.

F-10.2 The Heating Capacity method involves dividing the appliance heating capacity

(usually given in 1000's of Btu per hour) by the input rate (converted to 1000's of Btu per hour) multiplied by 100. This result will provide an approximate steady-state efficiency value for selecting the table or tables used in obtaining the recommended vent size and firing rate.

F-10.3 The AFUE method involves the determination of the AFUE for the appliance at hand. The AFUE for a particular model of the appliance can be obtained from published annual listings (GAMA, Hydronics Institute) or promotional material provided by the appliance manufacturer. An estimate of the steady-state efficiency can be obtained by adding 1.0 percentage point to the AFUE value of a hydronic boiler and 2.0 percentage points to the AFUE value of a warm air furnace. This steady-state efficiency value can then be used in selecting the table or tables used in determining the recommended vent size and firing rate.

F-10.4 The following three working examples serve to illustrate the required procedures for evaluating the recommendations offered in the table.

F-10.4.1 As a first example, assume that an appliance firing 1.0 GPH has an efficiency determined by the AFUE method to be 88 percent (AFUE=87 percent + 1.0 percent = 88 percent). The total length of the connector is 7 feet, and the chimney is 20 feet high. Locating the proper table, it is determined that the chimney is listed, but the connector length is not, therefore the user must interpolate between the table entries for connectors of 6 and 8 feet long. Looking in the 6 foot connector row it can be seen that only a 5 inch liner will suffice; 6 inches being rated only for higher firing rates of 1.25-2.25 GPH and 4 inches being rated only for a lower firing rate range of 0.65-0.85 GPH. In the 8 foot connector row only a 5 inch liner will do, as the 6 inch liner and the 4 inch liner are the same as above. In this case the liner size selection is very clear, a 5 inch liner is the indicated choice since both values that bracket the specific characteristics of the working example match.

F-10.4.2 As a second example, assume that applying the Flue Loss method resulted in a measured flue gas temperature of 523° F after burner adjustment. The firing rate for the appliance is 1.0 GPH. In addition, the total straight connector length is 7 feet into a 22 foot chimney. Note that some of the parameters of the system are not precisely located among the tables. The method that we will employ here is to bracket the system parameters to evaluate an appropriate recommendation. Using a connector/chimney combination of 6/20 at 495° F and 575° F at 1.0 GPH, the recommendations allow for a 4, 5, or 6 inch diameter metal liner. Similarly, for a connector/chimney combination of 8/25 at 495° F and 575° F at 1.0 GPH the same three liner sizes are allowed. In this instance, the choice is clear in that any of the three metal liner sizes would be

satisfactory. If the firing rate had been 1.25 GPH, however, the metal liner size choices would have been restricted to 5 and 6 inches due to the high end limit of 1.0 GPH defined under the connector/chimney size of 8/25 at 495° F. On the other hand, if the firing rate had been 0.5 GPH the metal liner choices would have been restricted to 4 and 5 inches due to the low end limit of 0.65 GPH defined under the same connector/chimney combination and flue gas temperature.

F-10.4.3 As the third example, assume that applying the Heating Capacity method resulted in an estimated steady-state efficiency of 87 percent with a firing rate of 0.85 GPH. In this case, suppose a 4 foot connector is used between the appliance and the chimney which stands 25 feet above the breech. In the table for a steady-state efficiency of 88 percent, the 4 and 5 inch metal liners are shown as satisfactory. In the table for a steady-state efficiency of 86 percent, the 4, 5 and 6 inch metal liners are satisfactory. Based on average values for firing rates between the two tables, the 4 and 5 inch liners should be satisfactory for a steady-state efficiency of 87 percent. In any case, an adjustment of firing rate, an increase of draft, or an increase in the excess combustion air would help serve to bring the system out of any marginal performance condition.

F-11 In some cases, the relining system performance does not meet either the minimum appliance draft or the minimum liner temperature criteria regardless of treatment. These are shown as "NR" meaning they are not recommended for simple relined chimney venting. In these cases an improvement in system performance can be achieved by using a listed alternative venting system. These alternatives include, but are not limited to, a power-vent (where draft is insufficient) or an insulated factory-built metal chimney (where liner wall temperatures are too low).

F-12 REFERENCES

- [1] Strasser, J. et al. 1994 "Oil-Heat Vent Analysis Program" (OHVAP), Under development and evaluation.
- [2] Krajewski, R. F. 1994 "Development of Oil Heat Venting Tables", Oil Heat Technology Conference and Workshop, No. 94-15.
- [3] Butcher, T. et al. 1990 "Chimney Related Energy Losses in Oil-Fired Heating Systems: Configuration Effects and Venting Alternatives", BNL-46021.
- [4] Gorden, E. et al. 1990 "Masonry Chimney Inspection and Relining", AGAL Unpublished Topical Report.

- [5] Kam, V. P. et al. 1991 "Masonry Chimneys and Liners", AGAL Draft Topical Report.

Figure F-6: Recommended Metal Liner Size for Retrofitting Clay Tile-Lined Masonry Chimneys versus Fuel Oil Firing Rates, gallons per hour. To Be Used When Field Inspection Indicates Relining is Required.

Base Case: Exterior Residential Clay Tile-Lined Masonry Chimney Complying with NFPA 211, Standard for Chimneys, Fireplaces, Vents, and Solid Fuel-Burning Appliances, subsections 3-2.2 through 3-2.7.

Table F-7(a)
Steady State Efficiency=88%
(12 percent CO₂, 275 Deg.F Gross)

Height Ft.	Lateral Ft.	Liner 6 in.	Liner 5 in.	Liner 4 in.
10	4	0.75-1.25	0.5-0.85	NR
	6	0.75-1.25	0.5-0.85	NR
	8	0.85-1.0	0.5-0.65	NR
	10	0.85-1.0	0.65	NR
15	4	0.85-2.0	0.65-1.25	0.4-0.65
	6	1.0-2.0	0.65-1.25	0.5
	8	1.0-1.75	0.65-1.25	0.5
	10	1.0-1.75	0.65-1.0	NR
20	4	1.25-2.25	0.65-1.5	0.5-0.75
	6	1.25-2.25	0.75-1.5	0.65-0.85
	8	1.25-2.25	0.75-1.5	0.65-0.85
	10	1.25-2.25	0.75-1.5	0.65-0.85
25	4	1.25-2.25	0.85-1.75	0.65-0.85
	6	1.25-2.25	0.85-1.75	0.65-0.85
	8	1.25-2.25	0.85-1.75	0.65-0.85
	10	1.25-2.25	0.85-1.75	0.65-0.85

NR = Not Recommended

Table F-7(b)
Steady State Efficiency=86%
(12 percent CO₂, 345 Deg.F Gross)

Height Ft.	Lateral Ft.	Liner 6 in.	Liner 5 in.	Liner 4 in.
10	4	0.65-1.5	0.4-1.0	0.4-0.5
	6	0.65-1.5	0.4-1.0	0.4
	8	0.65-1.5	0.4-1.0	0.4
	10	0.65-1.5	0.4-1.0	NR
15	4	0.65-2.25	0.4-1.5	0.4-0.85
	6	0.65-2.25	0.5-1.5	0.4-0.75
	8	0.65-2.25	0.5-1.5	0.4-0.65
	10	0.75-2.25	0.5-1.5	0.4-0.65
20	4	0.75-2.25	0.5-1.75	0.4-1.0
	6	0.85-2.25	0.65-1.75	0.4-0.85
	8	0.85-2.25	0.65-1.75	0.4-0.85
	10	0.85-2.25	0.65-1.75	0.4-0.85
25	4	0.85-2.25	0.65-2.0	0.4-1.0
	6	0.85-2.25	0.65-2.0	0.5-1.0
	8	0.85-2.25	0.65-2.0	0.5-1.0
	10	1.0-2.25	0.65-2.0	0.5-1.0

NR = Not Recommended

Table F-7(c)
Steady State Efficiency=84%
(12 percent CO₂, 420 Deg.F Gross)

Height Ft.	Lateral Ft.	Liner 6 in.	Liner 5 in.	Liner 4 in.
10	4	0.4-2.0	0.25-1.25	0.25-0.65
	6	0.4-2.0	0.25-1.25	0.25-0.65
	8	0.4-1.75	0.4-1.25	0.25-0.5
	10	0.5-1.75	0.5-1.0	0.25-0.5
15	4	0.5-2.25	0.4-1.75	0.25-0.85
	6	0.5-2.25	0.4-1.5	0.25-0.85
	8	0.65-2.25	0.4-1.5	0.25-0.85
	10	0.65-2.25	0.4-1.5	0.4-0.85
20	4	0.65-2.25	0.4-2.0	0.25-1.0
	6	0.65-2.25	0.4-2.0	0.4-1.0
	8	0.65-2.25	0.4-1.75	0.4-1.0
	10	0.65-2.25	0.4-1.75	0.4-1.0
25	4	0.65-2.25	0.4-2.25	0.4-1.0
	6	0.65-2.25	0.5-2.25	0.4-1.0
	8	0.65-2.35	0.5-2.0	0.4-1.0
	10	0.75-2.25	0.5-2.0	0.4-1.0

NR = Not Recommended

Table F-7(d)
Steady State Efficiency=82%
(12 percent CO₂, 495 Deg.F Gross)

Height Ft.	Lateral Ft.	Liner 6 in.	Liner 5 in.	Liner 4 in.
10	4	0.4-2.25	0.25-1.25	0.25-0.75
	6	0.4-2.0	0.25-1.25	0.25-0.65
	8	0.4-2.0	0.25-1.25	0.25-0.65
	10	0.4-2.0	0.25-1.25	0.25-0.65
15	4	0.4-2.25	0.25-1.75	0.25-1.0
	6	0.4-2.25	0.25-1.75	0.25-0.85
	8	0.4-2.25	0.25-1.75	0.25-0.85
	10	0.4-2.25	0.25-1.75	0.25-0.85
20	4	0.5-2.25	0.4-2.0	0.25-1.0
	6	0.5-2.25	0.4-2.0	0.25-1.0
	8	0.5-2.25	0.4-2.0	0.25-1.0
	10	0.5-2.25	0.4-2.0	0.25-1.0
25	4	0.5-2.25	0.4-2.25	0.25-1.25
	6	0.65-2.25	0.4-2.25	0.25-1.25
	8	0.65-2.25	0.4-2.25	0.4-1.0
	10	0.65-2.25	0.4-2.25	0.4-1.0

NR = Not Recommended

Table F-7(e)
Steady State Efficiency=80%
(12 percent CO₂, 575 Deg.F Gross)

Height Ft.	Lateral Ft.	Liner 6 in.	Liner 5 in.	Liner 4 in.
10	4	0.25-2.25	0.25-1.5	0.25-0.85
	6	0.25-2.25	0.25-1.5	0.25-0.75
	8	0.25-2.0	0.25-1.25	0.25-0.75
	10	0.25-2.0	0.25-1.25	0.25-0.75
15	4	0.4-2.25	0.25-1.75	0.25-1.0
	6	0.4-2.25	0.25-1.75	0.25-1.0
	8	0.4-2.25	0.25-1.75	0.25-1.0
	10	0.4-2.25	0.25-1.75	0.25-0.85
20	4	0.4-2.25	0.25-2.0	0.25-1.25
	6	0.4-2.25	0.25-2.0	0.25-1.0
	8	0.4-2.25	0.25-2.0	0.25-1.0
	10	0.4-2.25	0.4-2.0	0.25-1.0
25	4	0.4-2.25	0.4-2.25	0.25-1.25
	6	0.4-2.25	0.4-2.25	0.25-1.25
	8	0.5-2.25	0.4-2.25	0.25-1.25
	10	0.5-2.25	0.4-2.25	0.25-1.25

NR = Not Recommended

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Appendix G - Addendum Issues

G-1 Technical Committee for Liquid Fuel Burning Equipment - NFPA 31

Because of the early scheduling required for the revision cycle of NFPA 31, the results of OHVAP Version 1.0 (1993-94) were incorporated in the document for the 1997 publication of NFPA 31. It should be noted that Version 1.0 did not take into account radiative heat loss from the vent system exterior nor water/acid condensation within the vent system. OHVAP Version 3.0 corrects these shortcomings.

Version 3.0 was completed in late 1995, too late for the current revision cycle of NFPA 31 1997. While the recommendations contained within NFPA 31 1997 address only masonry chimney relining and chimney heights to 25 feet, it is expected that a more aggressive set of recommendations, using OHVAP Version 3.0, will be incorporated in NFPA 31 2000.

G-2 Oil Heat Conference and Workshop - 1996

Several issues related to recommendations developed through the application of OHVAP were presented during Workshop held at the conference. In summary, with no particular priority, these were:

- 1) The limitation of chimney height (currently 25 feet), tile flue liners (currently 8" x 8"), and firing rate (currently 2.25 gph) should be expanded.
- 2) Common venting of appliances should be an option to be evaluated by OHVAP.
- 3) Metal chimneys and power venting recommendations should be addressed.
- 4) The effects of additional connector elbows, chimney offsets, altitude, and less than ideal chimneys should be examined.
- 5) The applicability of the existing tables to furnaces and "new" integrated systems should be addressed.
- 6) Examine the effects of draft control dilution air relative to "whole house" energy conservation and chimney "drying".

G-3 Review of the Computer Program (OHVAP Version 3.0) and Final Report

The Oil Heat Vent Analysis Program (OHVAP Version 3.0) and the text of this report were evaluated in BETA testing during the summer of 1996. The results of this review and other industry inputs are presented in this Addendum.

G-3.1 Burner "off" Period Flow Factor

This section addresses information provided for the user to select an appropriate value of burner "off" period flow factor. As currently presented, the program requires an initial run with the flow factor set at the default value of 1.0. A subsequent evaluation of the burner "off" to burner "on" flow ratio would permit the user to "correct" the flow factor to achieve the 0.4 value set by the AFUE Procedure.

As an approach to improving the first cut the following alternate values of flow factors are offered for a base masonry chimney configuration. The base system is defined here as one which serves an appliance with a steady state efficiency of 86%. It has the following geometric configuration, ambient temperatures, and operating conditions:

- 1) The connector is 6" inches in diameter and consists of:
 - a) a vertical rise of 2.5 feet containing a barometric draft control
 - b) an elbow which feeds a 9 foot horizontal lateral to a chimney
- 2) The exterior masonry chimney is 25 feet tall and contains a clay tile lining
- 3) The firing rates are 0.25, 0.4, 0.5, 0.65, 0.75, 0.85, 1.0, 1.25, 1.5, 1.75, 2.0, and 2.25 gallons per hour with an excess-air of 28.4% (12% CO₂). The system is operated with a 10 minute burner "on" period and a 33 minute burner "off" period for a total cyclic period of 43 minutes.
- 4) Basement and outdoor temperatures of 60° and 42° F respectively

The user should understand that the base flow factors offered in the following table are starting points and that variations in the venting system, as specified by the user, from the default system, as specified herein, will effect the final calculated results. These variations may require the user to fall back on the original iterative procedure.

Burner Flow Factor Values

Firing Rate Gph	Burner Flow Factor (Base Sys.)	Burner Flow Factor	Burner Flow Factor	Burner Flow Factor	Burner Flow Factor
0.25	0.37				
0.4	0.57				
0.5	0.69				
0.65	0.88				
0.75	1.02				
0.85	1.14				
1.0	1.33				
1.25	1.65				
1.5	1.97				
1.75	2.29				
2.0	2.59				
2.25	2.92				

The user is encouraged to use the blank cells in the table to record for future reference any other flow factor values that may apply to configurations different from the base chimney system.

G-3.2 Elevation Effects in Vent Fittings

As an indirect result of the review process, a problem has been identified related to calculation of the elevation effects within elbows, tees, and special fittings. In its original format the program permits the user to select the orientation of these fittings. In the 90° position (vertical) these fittings are incorrectly credited for elevation in that total axial lengths are applied whereas only the vertical fraction of the axial length is valid. This error results in an over-estimation of the flue gas buoyancy effect for these fittings as they are used throughout the vent system. There is no simple way to correct the code other than to completely eliminate elevation (buoyancy) effects for these fittings. This revision is now in place in Version 3.0 of the program. It should be noted

that other axial length effects such as flow friction and heat transfer are retained as before.

This program revision (OHVAP Version 3.0) will result in an under-estimation of the system buoyancy effects and lower appliance draft estimates. Buoyancy effects have a greater effect on system behavior closer to the appliance ie; buoyancy effects through given elevation differences are greater where the flue gas is hotter.

In it's present form, Version 3.0 offers some remediation of the elevation problem. This amounts to the substitution of an additional straight length in the vertical direction to account for buoyancy effects. For example, where a tee is to be mounted vertically to accommodate a barometric dilution control, the substitution of a straight piece of pipe of equivalent length (height) may suffice. Dilution flow insertion will require selection of an element within the substituted straight piece for the barometric draft control. A similar approach may be applied to vertical elbows positioned in series or following a straight section. Errors in calculated fiction loss and heat transfer must be balanced against the potential error in buoyancy effect when using this technique.

G-3.3 Dilution Flow for Draft Control

The measured flow through a nominal 6 inch diameter barometric draft control is illustrated in Figure 37. A fourth order polynomial curve fit for the medium dilution flow through the control has the following form:

$$\text{FLOW(SCFM)} = A + B(P_{\text{DFT}}) + C(P_{\text{DFT}})^2 - D(P_{\text{DFT}})^3 + E(P_{\text{DFT}})^4$$

Where the coefficients are:

$$A = 0.0118$$

$$B = 82.4$$

$$C = 15402$$

$$D = -114388$$

$$E = 241873$$

$$(P_{\text{DFT}}) = \text{Draft pressure (Inches of W.C.) in the control}$$

A series of multipliers were developed using flow coefficients defined in a paper (No. 1428) authored by Nottage, Locklin, and Huebscher for the American Society of Heating and Ventilating Engineers (ASHVE) titled "Barometric Draft-Control Analysis". Using these flow coefficients and the polynomial curve fit of the BNL test data gathered for a 6" diameter draft control, similar curves were scaled for dampers ranging from 4" to 30" in diameter. The following table contains the multipliers and scaled polynomial

coefficients. These coefficients may be used in the menu shown in Figure 11 where a "Custom" damper is described.

Barometric Draft Control Coefficients - (Control set at medium dilution flow)

Draft Control Dia. (in.)	Mult.	Coeff. "A"	Coeff. "B"	Coeff. "C"	Coeff. "D"	Coeff. "E"
4	0.444	0.005	36.6	6838	-50788	107392
5	0.694	0.008	57.2	10689	-79385	167860
6	1.0	0.012	82.4	15402	-114388	241873
7	1.36	0.016	112.1	20947	-155568	328947
8	1.78	0.021	146.7	27416	-203611	430534
9	2.25	0.027	185.4	34655	-257373	544214
10	2.78	0.033	229.1	42818	-317999	672407
12	4.0	0.047	329.6	61608	-457552	967492
14	5.44	0.064	448.3	83787	-622271	1315789
16	7.11	0.084	585.9	109508	-813299	1719717
18	9.0	0.1062	741.6	138618	-1029492	2176857
20	11.11	0.131	915.5	171116	-1270851	2687209
22	13.44	0.159	1107.5	207003	-1537375	3250773
26	18.78	0.222	1547.5	289250	-2148207	4542375
30	25.0	0.295	2060	385050	-2859700	6046825

Again, the user is encouraged to use the blank cells in the table to record for future reference any other draft control flow values that may apply to configurations different from those presented here.

G-3.4 Draft Inducer Fans

Draft inducer fan curves were developed from a polynomial fit of the fan curve presented in Appendix A, Figure A-2.1 of the "Guidelines for the Design and Application of Oil-Fired Venting Systems", BNL Informal Report No. 49582 dated September 1993. The fan curves should be applicable up to 2.25 gallons per hour firing rate. The scaled coefficients are provided in the following table for the original fan curve and fans with sequentially reduced pressures.

Draft Inducer Fan Coefficients

Pressure versus Flow(0)	Mult.	Coeff. "A"	Coeff. "B"	Coeff. "C"	Coeff. "D"	Coeff. "E"
1.35 in. of Water	1.0	1.3514	-18.3252 E-3	5.768 E-4	-9.695 E-6	3.8174 E-8
0.675 in.	0.5	0.6757	-9.1626 E-3	2.884 E-4	-4.8475 E-6	1.9087 E-8
0.338 in.	0.25	0.3379	-4.5813 E-3	1.442 E-4	-2.42375 E-6	0.9435 E-8
0.169 in.	0.125	0.169	-2.2907 E-3	0.721 E-4	-1.21188 E-6	0.47718 E-8

G-3.5 Chimney Leakage (Air Infiltration)

The issue of chimney leakage is presented here, not as a directly applicable feature within OHVAP, but rather as an approach to addressing the realistic performance of chimneys. The difficulties with the simulation are:

- 1) OHVAP Version 3.0 currently permits only one source of dilution air into the flue gases; that being a single draft control located in an element of the vent system.
- 2) The single source of the dilution air and it's properties are always taken as that of the location of the appliance and not from the immediate surrounding location of the chimney.
- 3) The model of leakage flow across the chimney wall is based on data for elevator shaft construction using clay block.

4) Simulation of a chimney leakage requires the user to a) assume that leakage flow enters with normal draft control dilution at or near the chimney base or b) assume that no draft control dilution is present and that dilution is solely based on chimney leakage.

In any case the simulation approach is only a crude approximation. This is due to the dilution air in source properties (indoors) and that only a single point of entry is currently permitted by OHVAP.

The flow is based on data presented in Chapter 23 of the 1993 ASHRAE Fundamentals Handbook. The data is shown among a series of curves for various construction materials. Curve No. 6 represents the leakage flow across clay tile block in CFM per square foot as a function of pressure difference in inches of water. A curve fit of this leakage flow is:

$$\text{Shaft Wall Leakage Flow} = 0.5(P_{\text{DFT}}) + 3.8(P_{\text{DFT}})^{0.5} \quad (1)$$

Where: P_{DFT} is taken as the draft pressure difference (outside to inside) across the chimney wall (brick, air gap, tile liner) to the flue gas.

Since the overall leakage should represent the elemental leakage along the height of the chimney, P_{DFT} is taken as the average draft that exists in the chimney. In addition, the average draft is assumed to vary linearly along the height of the chimney from a maximum at the bottom to zero at the top. So the average draft is taken as:

$$P_{\text{AVERAGE DFT}} = P_{\text{DFT}}/2 \quad (2)$$

and

$$\text{Incremental Chimney Leakage Flow} = 0.5(P_{\text{DFT}}/2) + 3.8(P_{\text{DFT}}/2)^{0.5} \quad (3)$$

or

$$\text{Incremental Chimney Leakage Flow} = 0.25(P_{\text{DFT}}) + 2.69(P_{\text{DFT}})^{0.5} \quad (4)$$

Remember that the above equation represents the leakage flow per square foot of clay liner. This is taken as the interior area of the clay liner under examination and will vary with case depending on it's size, shape and height. For example, assuming a nominal 8 X 8 inch clay tile liner in a chimney 25 feet tall:

$$\text{Internal Area per foot of chimney} = (4)(6.75'')(12'')/(144) = 2.25 \text{ Ft}^2/\text{Ft}$$

and

$$\text{Total Internal Area} = (2.25)(25) = 56.25 \quad (5)$$

Multiplying equation (4) by equation (5) we get

$$\text{Overall Chimney Leakage Flow} = 14.06(P_{\text{DFT}}) + 151.31(P_{\text{DFT}})^{0.5} \quad (6)$$

Where, referencing the OHVAP Barometric Draft Control menu:

$$\text{Coefficient "B"} = 14.06$$

$$\text{Coefficient "F"} = 151.31$$

One point of entry for leakage flow can be taken as near the base of the chimney as possible as possible such as in the last element of the connector or within the base itself. Here the flow can be combined together with the dilution flow of a draft control.

The above coefficients can be added to the appropriate coefficients defining a custom draft control located at or near the chimney base or used by themselves in the chimney base where no draft control is considered. The user is referred to the next section for clay tile shapes and sizes.

G-3.6 Minimum Stack and Vent Sizes

This information is an extraction from Tables 3 and 4 of the Sixth Edition, June 1989, of the Testing and Rating Standard for Heating Boilers as published by the Hydronics Institute. The tables have been augmented to include the equivalent Hydraulic Diameter (round wetted cross section) for the rectangular tile liners.

Minimum Stack Dimensions for Oil-Fired Natural Draft Boilers - Rectangular

Maximum Burner Capacity (Gallons per Hour)	Nominal Liner Dimensions (Inches)	Inside Dimensions of Liner (Inches)	Equivalent Hydraulic Diameter (Inches)
2.1	8 X 8	6.75 X 6.75	7.38
3.5	8 X 12	6.5 X 10.5	8.97
5.3	12 X 12	9.75 X 9.75	10.66
7.7	12 X 16	9.5 X 13.5	12.33
11.5	16 X 16	13.25 X 13.25	14.48
15	16 X 20	13 X 17	16.21
21	20 X 20	16.75 X 16.75	18.31
26	20 X 24	16.5 X 20.5	20.07
33	24 X 24	20.25 X 20.25	22.14
41	24 X 28	20.25 X 24.25	24.19
52	28 X 28	24.25 X 24.25	26.5
59	30 X 30	25.5 X 25.5	27.88
76	30 X 36	25.5 X 31.5	30.94
100	36 X 36	31.5 X 31.5	34.43

**Minimum Stack Dimensions for Oil-Fired
Natural Draft Boilers - Round**

Maximum Burner Capacity (Gallons per Hour)	Inside Diameter of Liner (Inches)
1.3	6
1.8	7
2.5	8
4.5	10
5.6	11
7	12
12	15
19	18
28	21
40	24
53	27
69	30
88	33
109	36

**Recommended Minimum Vent Sizes for
Mechanical Draft Oil-Fired Boilers**

Gross Output or DOE Heating Capacity - (MBh)	Minimum Vent Diameter (Inches)
Up to 132	4
133 - 198	5
199 - 324	6
325 - 504	7
505 - 648	8
649 - 792	9
793 - 1260	10
1261 - 1800	12
1801 - 2700	14
2701 - 3350	16
3351 - 4400	18
4401 - 6000	20
6001 - 7350	22
7351 - 8800	24
8801 - 11700	27
11700 - 18000	30

G-3.7 Pentium Processors

A major problem has been identified with the application of Version 3.0 on Pentium computers. It has been found that OHVAPV3.EXE, the input menu portion of the OHVAP program, will not run to completion on some Pentium computers. The problem appears in the RUN portion of the menu program and seems to be related to

writing the CASEFILE.TMP, CASEFILE.TTP, VAP.TMP, and VAP.TTP files to the memory or hard disk. As a result, the handing off of these files for use by the VAPENG3.EXE, the engineering portion of the program, is interrupted and in some cases, the computer is locked up and must be rebooted.

The problem does not exist with 486DX computers. A "work around" approach has been investigated and has proven successful. The first step is to prepare a "batch" of the CASEFILE.TMP and CASEFILE.TTP files on a 486DX computer. This can be done directly from the RUN menu portion of the OHVAP3.EXE program. A batch file is then prepared which copies each CASEFILE.TMP and CASEFILE.TTP in turn to the VAP.TMP and VAP.TTP and follows with a call for the execution of VAPENG3.EXE. The format for the batch file (for example; RUNCASE.BAT) is as follows:

```
copy CASE1.TMP VAP.TMP
copy CASE1.TTP VAP.TTP
VAPENG3
copy CASE2.TMP VAP.TMP
copy CASE2.TTP VAP.TTP
VAPENG3
.
.
.
copy CASEn.TMP VAP.TMP
copy CASEn.TTP VAP.TTP
VAPENG3
```

A copy of each CASEFILE.TMP and CASEFILE.TTP together with the batch file RUNCASE.BAT can then be installed in a directory containing VAPENG3.EXE on the Pentium system. The invocation of RUNCASE at the prompt will run each case in turn at the higher calculational speed of the Pentium system. The approach is not as clumsy as it may seem if a number of cases are run at the same time. This was, in fact, the approach used to generate vent table results for NFPA 31 on a 486DX system.

An evaluation of this problem and the approach to its correction are underway at the present time.

G-3.8 Other Open Issues

The current planning activities include some improvements to OHVAP and its application to address some of the above issues. These include:

1) An implementation of a “simple” masonry chimney air leakage into the flue gas to address part of items 4 and 6 above.

2) The expansion of the recommendations for NFPA 31 2000 to address items 1, 3, 4, and 5 above.

For the near term, however, because of their extensive impact on OHVAP code, the consideration of some issues remain deferred. These issues include:

- a) Transient condensation of water/acid in the flue gas
- b) Correction of effective elevation calculations to permit “hot” flue gas buoyancy effects for vertical elbows, tees, and special fittings
- c) Correction of the calculation to permit ambient temperatures below 0°F and accounting for the heat transfer effects of condensate freezing in the vent system
- d) Common venting and “rigorous” elemental leakage into the flue gas