LFL or LEL Control for the Ovens*

*** LEL - Lower Explosion Limit, LFL - Lower Flammability Limit.**

Prepared for California Energy Commission (CEC)

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Executive Summary

Process heating applications that involve flammable solvent removal consume large amounts of energy to maintain solvent concentrations within safe lower flammable limits (LFL) or lower Explosion limits (LEL) in the exhaust air. National Fire Protection Association (NFPA) guidelines require that significant amounts of exhaust air be removed to maintain a safe solvent concentration. The NFPA safety ventilation requirements are significantly lower when LFL monitoring equipment is used compared to the absence of such equipment. This lowers the process energy requirement due to reduced ventilation requirements (Reference 1).

Flammable solvents used in industrial production processes are typically evaporated within industrial ovens. The elevated oven temperatures evaporate solvent vapors more quickly and allow for faster production. Because the vapors are flammable, the exhaust air is discharged (along with the heat) to prevent the accumulation of the vapors in the oven. As the solvent evaporation rate increases, it is necessary to maintain higher ventilation rates to reduce the solvent vapor concentration levels below the respective LFL.

Using LFL monitoring equipment can reduce energy consumed during solvent removal. The equipment continuously tracks the solvent concentration and can be used to adjust or control the rate of ventilation air based on real needs, thereby maintaining a safe ratio throughout the process. LFL monitoring equipment can employ several technologies including catalytic systems, infrared sensors, ionization systems, and combustion sensors. LFL monitoring equipment has self-check functions and uses a calibrated test gas for periodic self-calibration. Because the vaporization process depends on the intake and exhaust air, linking the LFL controller to an adjustable speed drive on the exhaust system fan can improve process efficiency even further (damper adjustments can also be used).

This LFL control calculator tool can be used to estimate annual energy savings and the associated money (US dollars) savings, and reductions in CO_2 emissions through monitoring and/or control of LFL in an oven. The user is required to measure operational LFL levels and use it as current value. Savings resulting from increasing the LFL concentration in the oven through the use of reliable and proven LFL monitoring equipment can be calculated by entering the allowable LFL limit for a given solvent.

The primary objective of this calculator is to identify energy savings potential in industrial heating operations to make a go / no go decision on further detailed engineering and economics analysis. The user is required to give data for several operating parameters that can be measured or estimated from normal operating conditions using available records. All data should be collected at average unit operating conditions.

This calculator estimates the annual expected energy savings in terms of million British thermal units per year (MMBtu/year) by using the given cost of fuel for the industrial application and the number of operating hours per year. This calculator also gives the reduction of CO_2 emissions that result from the combustion of natural gas. The results from this calculator should be considered preliminary and a starting point for more detailed technical and economic analysis and is expected to be within plus or minus 5 percent of actual results.

Note to the user of this calculator tool

Use of this tool requires knowledge of combustion and operation of heating systems such as a furnace, oven, heater, boiler, kiln, dryer etc. The user is referred to several training programs and references quoted at the end of his document for further information on the available resources for getting trainings that would provide additional knowledge for the subject matters discussed in this document.

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1. Description of the subject area

This work paper describes a calculator tool that will allow a user to estimate annual energy (fuel) savings, reductions in CO_2 emissions, and energy cost savings ($/year) of implementing Lower Flammability Limit (LFL) or Lower Explosion Limit (LEL) monitoring and control systems in an oven where flammable solvent vapors are present during process heating operation. Such systems are used in industries such as metal finishing, coating, plastics, rubber parts, and food processing.

National Fire Protection Association (NFPA) guidelines require that concentration of flammable vapors present in drying ovens must be maintained below 25% of the LFL for the type of solvent vapors or flammable gases if LFL levels are not monitored. This mandates that ventilation (or make-up) air be used to dilute flammable vapors. The introduction of ventilation air into the oven occurs due to negative oven pressure and is often uncontrolled. In some cases, a separate air blower is used to supply specified amount of air for either make up air or for combustion of fuel in the burners. This air has to be heated to the exhaust air temperature and can account for a large percentage (in some cases as high as 75%) of the total heat required for the oven.

Installing LFL monitoring equipment allows the LFL limit to be raised from 25% to as high as 50% of the LFL per NFPA guidelines. This allows for a reduction in the exhaust gas that is required to be removed from the unit. Hence, use of LFL monitoring equipment can help reduce the energy used for ventilation or make up air and improve the efficiency of the oven.

This LFL control calculator tool can be used to estimate annual energy savings and the associated money (US dollars) savings, and reductions in CO_2 emissions through monitoring and/or control of LFL in an oven. The estimated annual expected energy savings are in terms of million British thermal units per year (MMBtu/year). It also estimates the energy cost reduction by using the given cost of fuel for the oven and the number of operating hours per year. The user is required to measure the current LFL levels for use with the tool. Savings resulting from using a higher LFL level through the use of reliable and proven LFL monitoring equipment can be calculated by entering the allowable LFL limit for a given solvent.

The focus of this tool is on the reduction of natural gas consumption used for industrial processes by controlling LFL levels or the amount of ventilation air used by the ovens. Several methods are available to accomplish this goal.

Use a LFL probe to monitor LFL in the oven – This method allows for the monitoring of LFLs within an oven and/or its exhaust air. Most probe designs combine an indicator for LFL levels and an output signal that can be used for remote displays and for integration with additional control technologies to meet desired LFL levels. The user is advised to discuss their specific application with their supplier and oven manufacturer before making a final decision. Probes can be obtained from several suppliers.

Control or reduction of ventilation – makeup air – This method involves controlling ventilation or makeup air for the oven to meet the required LFL requirements. The degree of control over the amount of makeup air depends on the oven heating system and the process itself. The oven supplier should be contacted to determine the best strategy that would allow finer control over makeup air to meet the desired LFL levels. Possible methods of control include, but are not limited to:

- Control over the speed of the induced draft (ID) fan located on the exhaust stack

- Oven pressure controls to reduce air leakage into the oven
- Control over the openings at the inlet and outlet of the oven
- Customized methods specific to the particular process design

Control of Make Up Air – This method limits the amount of uncontrolled makeup air through seal leaks and provides the required amount of makeup air to meet the LFL requirements.

Below is a brief summary of important calculation parameters:

LFL or LEL reading for the exhaust air – This parameter is measured inside the oven or within the exhaust stack. A LFL probe should be used to obtain this reading. If a probe is not available, it is necessary to go through calculations to determine the LFL level. This is performed using solvent evaporation rates, rate of natural gas consumption, and measurements of the contents and flow rates of the unit's flue gases. The desired LFL level is required before and after implementation of the efficiency measure.

Exhaust air (flue gas) temperature – The temperature of the exhaust gas exiting the oven before and after implementation of the efficiency measure.

Oxygen content of exhaust air from the oven – The percentage of oxygen in the exhaust air (measured on a dry basis) before and after implementation of the energy efficiency measure.

Combustion air temperature – The temperature of the combustion air (which is the air mixed with fuel in the burner) before and after implementation of the energy efficiency measure.

Fuel consumption or current firing rate per hour (MM Btu/hour) – The estimated hourly average consumption of natural gas (or other type of fuel) of the equipment's combustion system. This value should be based on the most recent 12-month period of natural gas consumption (MM Btu/year) and number of hours for the heating system.

Number of operating hours (hours/year) – The number of hours for which the equipment is operated. This should be based on the most recent 12-month period of natural gas consumption.

Cost of fuel - The average historical fuel cost ($/MM Btu) and, if possible, future projected cost based on contracts with the energy supplier.

2. Impact of LFL control on energy savings and CO2 emissions

Controlling LFL levels within an oven where solvent vapors or other flammable gases are present can result in both energy savings and CO2 emission reduction. All commonly used fossil fuels (such as natural gas) when combusted result in the formation of CO_2. The reduction in CO_2 emissions is directly proportional to the reduction in natural gas use.

The actual savings in energy consumption and the associated costs vary according to several operating parameters. These include:

- Current and future (modified conditions) values of LFL as measured in the exhaust air for the oven
- Fuel energy content
- Type of solvent(s) that would result in presence of flammable vapors in the oven (this determines amount of ventilation air required for the oven at a given LFL level)

- Average firing rate (energy consumption per hour) Amount of excess air used for the burners
- Number of operating hours per year
- Temperature of exhaust air leaving the oven
- Average temperature of the combustion and excess air entering the heating system.
- Cost of fuel in terms of $/MMBtu

The energy savings can vary from 10% for well run ovens to as high as 40% in case where the ovens have little monitoring and operational control of LFL levels. The exact value of savings (expressed as US dollars per MMBtu) can be estimated by using this calculator.

Energy savings resulting from an efficiency project directly correlate to CO2 savings. According to U.S. Environmental Protection Agency (EPA) estimates (Reference 5), the combustion of natural gas used in USA produces 116.39 lbs. of CO_2 per MM Btu heat input. For convenience, most calculations use 117 lbs. CO_2 emission per MM Btu heat input from natural gas. If the natural gas composition is available, it is advisable to carry out detailed combustion calculations to estimate value that is more accurate for the CO_2 produced by the combustion of natural gas. Reduction in CO_2 emissions is calculated by using the value of reduction in energy (fuel) used for the furnace.

3. Discussion on the technical approach and the calculations

Obtaining greater control of LFL concentrations in drying ovens will result in energy savings while maintaining the desired safety and productivity of the oven. The annual energy savings is the difference between the annual energy use by the baseline system and the annual energy use by the oven after steps are taken to control of LFL in exhaust air. In all cases involving LFL level control, it is essential to measure value of LFL level before and after implementation of LFL level controls. LFL levels within the exhaust air can be measured using a LFL probe or through detailed calculations that require superior knowledge of the equipment and process. In most cases, the detail calculations are difficult and unreliable.

For the operation of driers involving flammable solvent emissions, there is a required amount of air or inert gas or combustion products (all referred to as air in the following discussion) to maintain a specified safe operating conditions within the equipment (varying depending on the solvent). A table given in the NFPA publication “NFPA 68 Standard for Ovens and Furnaces” gives the required amount of dilution air per gallon of the solvent (completely evaporated). This table can be used to determine the amount of air required to achieve the desired LFL level in an oven or, alternatively, to determine the amount of air mixed with solvents for a given level of LFL.

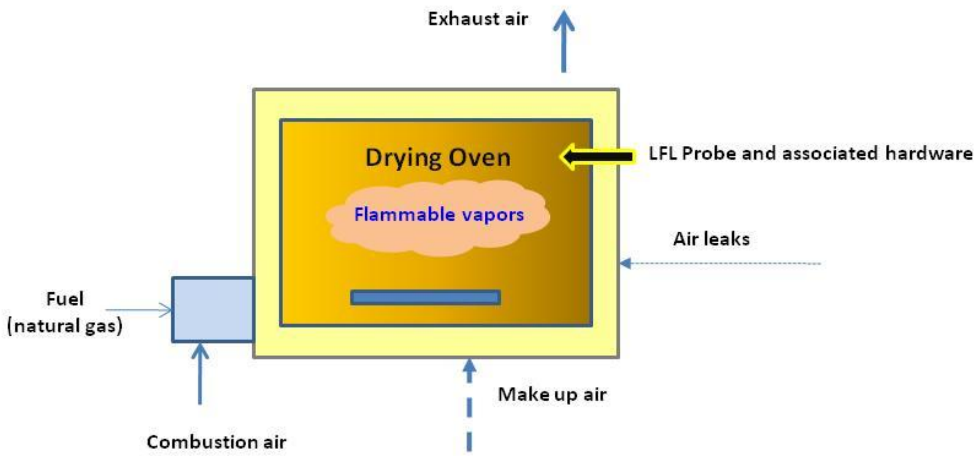

Exhibit 1: Typical drying oven schematic

Energy savings resulting from the use of LFL monitoring and control equipment is due to reduction in mass flow (volumes of air) used to maintain safe operating conditions in the oven. The total mass flow of exhaust air includes the mass of combustion products from the burners, mass flow of solvent vapors present in the exhaust air, and make up air that comes from various sources (such as seal leaks). The mass flow rate of combustion products may change from current conditions due to a reduction in the amount of heat required for the ventilation air. Using the concept of available heat, explained later, is used to allow for reduction in burner heat input. Hence, it is only necessary to calculate reduction in ventilation airflow (make-up air) that is directly related to the final LFL value.

To calculate energy savings, this calculator requires:

- Measurement or an estimate of current and expected (proposed) values of LFL levels for the solvent(s) used in the oven
- Calculations for air flow reductions correlating to the change in LFL levels
- Temperature of the combustion and exhaust air
- Oxygen (O_2) content of exhaust air at current operating conditions
- Burner operating information including items such as the current fuel use and excess air used for the burners

This information is used to calculate total volume (equivalent mass flow) of exhaust air and corresponding flow rate for the ventilation air at current operating conditions. User input for the expected LFL value is used to calculate reduction in ventilation airflow and the corresponding reduction in required fuel input.

In the following calculations the reduction in air or exhaust air flow is defined as ΔM_a or ΔV_{sa}.

$$\Delta H_e = \Delta M_a * C_{pma} * \Delta T_e \text{ or}$$

$$\Delta H_e = \Delta V_{sa} * C_{pva} * \Delta T_e$$

Where

ΔH_e = Change in heat content of exhaust air (Btu/hr)

ΔM_a = Change in mass flow rate (lbs/hr) of air calculated based on change in LFL value.

C_{pma} = Specific heat of exhaust air in terms of Btu/(lb. ^{O}F)

ΔV_{sa} = Change in volume flow rate [Standard cubic feet (SCF)/hr.] of air calculated based on change in LFL value.

C_{pva} = Specific heat of exhaust air in terms of Btu/(scf. ^{O}F)

ΔT_e = Increase or change in temperature of exhaust air (^{O}F)

Reduction in the heat requirement (ΔH_e) for the air is used to calculate the actual reduction in burner heat input for the oven. This calculation requires knowledge of the available heat (often known as combustion efficiency) of the burners used in the oven.

The term "available heat" is defined as difference in heat input and the heat content of exhaust air leaving the furnace system. It is usually expressed as percentage (%) and represents the amount of heat remaining within an oven as a fraction of the heat input to the oven.

The following symbols are used in the equations below:

H_f = Oven or furnace heat demand (Btu/hr)

H_{av} = Available heat (Btu/hr)

H_{in} = Heat input in the oven (Btu/hr)

H_{ex} = Heat content of exhaust air leaving the heating system or oven (Btu/hr)

Avht(%) = Percent available heat

The total heat input is defined as $H_{in} = H_f + H_{ex}$

$$H_{av} = H_{in} - H_{ex}.$$

$$H_{ex} = H_{in} - H_f$$

$$H_{av} = H_f$$

Available heat expressed as a percentage is used as a good indication of performance of a heating system and it is given as

$$Avht(\%) = 100\% * H_f / H_{in}$$

Therefore

H_{in} = 100%* H_f / Avht(%)   (Note that this value is still is expressed as Btu/hr.)

The oven or heat demand includes the amount of heat required to raise temperature of the ventilation air as reflected in change in heat contained in the exhaust air. This can be used to calculate reduction in the burner heat input or heat required for the oven.

The energy savings (H_{saving}) would be equal to change in exhaust air heat content divided by the available heat for the burner combustion products.

H_{saving} = ΔH_e / Avht(%)

Avht(%),depends on the following variables:

- Fuel composition
- Exhaust gas temperature
- Combustion air temperature
- Percent oxygen (dry) in the combustion products for the burners.

Available heat can be calculated by using combustion calculations for a given fuel. For this excess air calculator tool, the calculations use a typical natural gas composition as found in California.

The natural gas composition used for calculations in this tool is given below. Note that the user gives the composition in the column marked “By Volume”. If the values in column “By Volume” do not add up to 100% the program will adjust the percentages under column “Adjusted by Volume” to add up to 100% by changing the value of each component % proportionately. In most cases, the total under column “By Volume” is not equal to 100% due to rounding error.

For this calculator, the “higher heating value” or “gross heating value” for the fuel is used. The higher or gross heating value for natural gas with the composition shown in Exhibit 2 is 1,020 Btu per standard cubic foot (scf). The heating value of natural gas varies from 970 Btu/scf to as high as 1,200 Btu/scf. However, in many situations 1,000 Btu/scf is considered a good approximation. Minor changes in the heating value have very little effect on the savings achieved with changes (usually reduction) in excess air.

It is recognized that natural gas composition may vary somewhat during the year or from location to location. However, a series of calculations shows that the variation in natural gas composition has very small effect on the available heat as a percentage of the heating value. Hence, available heat changes are within a narrow range and the error for this value is relatively small and within plus or minus 5%. Thus, we advise users of this calculator that the accuracy of its estimates will be in the same range of variation, i.e. plus or minus 5%. A separate calculator is available to calculate the exact value of available heat when the fuel composition is known or when the natural gas composition is significantly different from that stated in Exhibit 2.

Further discussion on available heat and the effect of fuel composition is discussed in references 1 and 2.

Fuel Gas Analysis (See note below)		
Gas composition	**By volume**	**Adjusted by volume**
CH_4	**94.10%**	**94.241%**
C_2H_6	**2.40%**	**2.404%**
N_2 and other inert	**1.41%**	**1.412%**
H_2	**0.03%**	**0.030%**
C_3H_8	**0.49%**	**0.491%**
C_4H_{10} + C_nH_{2n}	**0.29%**	**0.290%**
H_2O	**0.00%**	**0.000%**
CO	**0.42%**	**0.421%**
CO_2	**0.71%**	**0.711%**
SO_2	**0.00%**	**0.000%**
O_2	**0.00%**	**0.000%**
Total of fuel components	**99.85%**	**100.000%**
Difference	**0.15%**	**0.00%**
Note: The fuel gas composition is in volume %. The higher hydrocarbons in fuel are treated as same as C_4H_{10} and all other inert gases are treated as N_2.		

Exhibit 2: Composition of natural gas used for calculations.

We define H_{annual} as the annual energy savings in Btu/year. Then

Annual savings can be expressed in terms of Btu/year, Therms/year or millionBtu/year (MMBtu/year) by using the appropriate equations given below.

(Dividing by 1,000,000 is necessary if H_{annual} is measured in Btu/hr instead of MMBtu/hr)

The CO_2 savings can be calculated by using the fuel combustion calculations or by using the EPA guidelines for CO_2 generation calculations. Reference 5 gives details of US EPA guidelines.

4. Instruction on use of the calculator

The following list summarizes the user inputs that are required. The user should collect this information before using this calculator tool.

- Company name, plant location and address
- Customer name and contact information
- Heating equipment description (where the energy-saving measure is applied)
- Equipment type (furnace, oven, kiln, heater, boiler)
- Equipment use (e.g., textile drying, aluminum melting, food processing)

Note: The preceding information may be optional for the web-based calculators due to users' concerns about privacy.

- LFL reading – current reading or value (%)
- Current firing rate (Btu/hr)
- Excess air used for the burners (%)
- Temperature of exhaust air or flue gases (^{O}F)
- Combustion air temperature (^{O}F).
- Ambient air temperature (^{O}F).
- Oxygen (% O2) in exhaust air or flue gas (%, dry basis)
- SCF air required per gallon of solvent (scf) from the table given as Appendix 1
- New suggested value for LFL or LEL (%)
- Fuel (energy cost) in terms of $ per MMBtu
- Number of operating hours per year

The calculator gives following results:

- Available heat for the burners (%)

- Estimated makeup air or air leaks (scfh)
- Heat used in the oven (Btu/hr)
- Total volume of exhaust air (scfh)
- Gallons of solvents used per hour
- New volume of exhaust air required (scfh)
- Reduction in exhaust air volume (scfh)
- Net heat savings (Btu/hr)
- Total or gross heat savings (Btu/hr)
- Annual fuel cost savings ($/year)
- Reduction in CO2 emissions (tons/year)

Note that the CO_2 savings are based on natural gas as the fuel for the heating equipment. A correction factor must be applied if any other fuel is used.

The LFL control calculator requires the following input parameters describing the heating process in order to estimate the savings. Exhibit 3 shows the user information screen and Exhibit 4 shows the calculator screen.

Exhibit 4 shows the required data for the calculator. The calculator cells are color coded. The white cells are used for data input by the user while the colored (yellow and light blue or green) cells are protected and give results of the calculations. The user is not allowed change numbers shown in the colored cells.

The first section requires information about the user, equipment, and process.

Monitor and Control Lower Explosive or Flammability Limit (Calculator of LEL or LFL Control for the Ovens)					
1	Company name	ABC Corporation			
2	Plant name or designation	LA Plant			
3	Plant address	12345 Main Street, Gabriel, CA 90878			
4	Contact name	Bob Smith			
5	Contact address	54321 First Street, North Warren, CA 90878			
6	Contact phone number and e-mail	Phone:	916-756-9923	E-mail:	b.smith@abccorp.com
7	Date (format mm/date/year)	May 12, 2010			
Heating equipment description (where the energy saving measure is applied)					
8	Equipment type (e.g. furnace, oven, kiln, heater, boiler)	Paint drying oven			
9	Equipment use (e.g., textile drying, aluminum melting)	Continuous coil coating line			
10	Other comments if any	The oven does not have any type of LEL or LFL monitoring system at this time.			

Exhibit 3: Required information for the calculator user

Line 1 – Name of the company.

Line 2 – Name or known designation such as "main plant" or "secondary plant" if applicable.

Line 3 – Plant address.

Line 4 – Contact name for the plant – This individual is main contact and is responsible for collecting and providing the required information.

Line 5 – Address for the contact person.

Line 6 – Contact phone number and e-mail to be used for all future communications.

Line 7 – Date when the calculations are carried out.

Line 8 – Type of heating equipment – This can be an oven, furnace, boiler, heater, etc. This is the heating equipment where data is collected and the given energy saving measure is to be applied.

Line 9 – Process or function for which the heating equipment is used – This can be name of the process such as drying, melting, water heating, etc.

Line 10 – Any additional information that can be useful in application of the results –The second section of the calculator is used for collecting the necessary data and reporting the estimated savings.

Line 11 – LFL reading – current reading or value – Give measured or estimated value of LFL in percentages. *The most accurate values can be obtained by using an LFL measuring instrument.* In case where such an instrument is not available, it may be possible to get approximate value of the LFL level by using volume of exhaust air measured by using a Pitot tube or other similar flow measuring device with temperature corrections and the quantity of solvent or flammable liquid vaporized in the oven. This will be an approximate and perhaps higher in value.

Line 12 – Current average hourly fuel consumption (MM Btu/hr) – This is the value of current fuel consumption or burner heat input expressed in MMBtu/hour. This should be an average value based on measurements of fuel use over a period of time or at "average" operating conditions. It is possible to get this value if the fuel consumption data is available for a certain period of time (monthly, annually etc.) for the furnace being considered. Note that the meter data, if used to calculate the fuel use, must be corrected for the pressure and temperature at the meter and the heat input should be calculated using the heating value of the fuel. For the most commonly used or average-quality natural gas in California, a heating value of 1020 per standard cubic foot (scf) will be a good approximation.

Line 13 – Excess air used for burners (%) – This is obtained by measuring air and fuel (natural gas) flow for the burners. Note that the O_2 reading for the exhaust air is NOT a good indication of the burner excess air. If it is not possible to get flow readings use a value suggested by the oven supplier or by the burner supplier. If no further information is available, use 10% excess air as a default number. In most low temperature ovens with exhaust air temperature in the range of 300 deg/ F. to 600 deg. F. this would give tolerable (plus or minus) error.

LEL or LFL Control for the Ovens			
	Items	**Values**	**Comments - Suggestions**
11	LEL reading - current reading or value	5.1%	Measured value using probe.
12	Current *average hourly* fuel consumption (MM Btu/hr)	6.00	
13	Excess air used for burners % *	10	Default can be 10%
14	Temperature of flue gases (°F)	450	
15	Combustion air temperature (°F)	80	
16	Ambient temperature (°F)	70	
17	Available heat for burners (%)	81%	
18	% O2 in exhaust air or flue gases	17.0	Dry basis
19	Estimated makeup air or air leaks (scfh)	230,447	
20	SCF air at LEL per gallon of solvent	2,885	See table or use default value 2,500 as approximation
21	Heat used in the oven/dryer (Btu/hr) - estimated	3,784,376	
22	Total volume of exhaust air (scfh)	291,529	
23	Gallons of solvent used (per hour)	5.1	Estimated based on given data for LEL etc.
24	New suggested value for LEL or LFL (%)	40	
25	New volume of exhaust air required - estimated	36,806	
26	Reduction in exhaust volume (scfh)	254,724	
27	**Net heat savings (Btu/hr)**	**1,884,956**	
28	Total or gross heat savings @ burner tip (Btu/hr)	2,323,944	
29	Fuel cost ($/Million Btu)	$ 6.00	
30	Operating hours (hours per year)	7,200	
31	**Annual fuel cost savings ($/year)**	**$ 100,394**	
32	**CO2 savings (tons/year)**	**$ 979**	
33	**Annual fuel savings (MM Btu/year)**	**13,572**	

* Note: This is NOT excess air in exhaust or stack gases. It represents how the burners are adjusted for air-fuel ratio. In many cases the users are advised to adjust burners for 10% to 20% excess air (2% to 4% Oxygen) in combustion products.

Exhibit 4: Example of calculator inputs and results

Line 14 – Temperature of flue gases (deg. F.) – Give the exhaust air or flue gas temperature measured as close to the exit of the oven as possible. The temperature should be taken when the oven is operating at normal ("average") operating conditions. Readings taken at non-average production or operating conditions can give unreliable results. Exhaust gases should not be mixed with cold air at the point where the temperature is measured for the measurement to be valid. Care should be taken to locate the thermocouple or temperature measurement sensor in the middle of the stack or area from where the flue gases are discharged. Measuring the temperature at the top of the stack or very close to the wall of the discharge duct can give erroneous reading. In almost all cases, the flue gas temperature does not change by any significant value with the use of preheated combustion air or make up air, since the oven zone temperatures are controlled to meet the required process conditions.

Line 15 – Combustion air temperature (^{O}F.) – The measured value of the temperature of combustion air entering the burners. In many cases, it is not possible to get the exact air temperature at the burner, and it is common to use the temperature of air entering the combustion air blower or the ambient temperature around the air blower. For a case where preheated combustion air is used it is necessary to use combustion air temperature at the burner or at the exit of the air preheating equipment such as a recuperator, regenerator or regenerative burners.

Line 16 – Ambient temperature (^{O}F) – The ambient temperature at or near location of the oven.

Line 17 – Available heat for burners (%)– This is a calculated value based on the data given above. The calculation uses the "Available Heat" tool developed as part of this tool set and assumes natural gas as fuel. The natural gas composition used for this calculation is same as that given in Exhibit 4 above.

Line 18 – % O2 in exhaust air or flue gases – obtained from flue gas analysis using commonly available combustion or flue gas analyzers. These analyzers give the flue gas analysis on dry basis. The sample for the gas analysis should be taken when the furnace is operating at normal operating conditions. Readings taken at non-average production or operating conditions can give unreliable results. It is necessary to make sure that the flue gases are NOT mixed with cold air before the gas is measured. Care should be taken to locate the sampling probe in the middle of the stack or area from where the flue gases are discharged. Collecting the sample at the top of the stack or very close to the wall of the discharge duct can give erroneous reading. It is also necessary to make sure that there is no air leakage through the sampling port when the sampling probe is inserted in the stack or sampling location.

Line 19 – Estimated make up air or air leaks (scfh) – This is calculated using available information on the O_2 content of exhaust air or flue gas, burner heat input, heat input data for the excess air and combustion air temperature at the current operating conditions.

Line 20 – SCF air required at LFL per gallon of solvent – This value can be obtained from the solvent properties data given as Appendix 1. The user selects the solvent or flammable liquid vapors used for the process and then the corresponding value of standard cu. ft. of air required at LEL or LFL condition. If the solvent or flammable vapors are a mixture of several materials then it is necessary to get an average value based on the mass fraction of each liquid and corresponding value of LFL.

For example if there are two liquids with mass fraction of x% and y% and their corresponding volumes for the LFL values are V_{ax} and V_{ay} then the average volume will be equal to:

The value V_{av} (scf/gallon) is used as input for this cell.

In this case x% + y% = 100%

It is not necessary to know the exact value of gallons of solvents present or used in the oven since this will be calculated later in this calculator (Line 23).

Line 21 – Heat used in the oven (Btu/hr) – This is a calculated value and it represents heat used in the oven for all other heat loads (such as heating the material and liquids being processed, wall loss, and other losses). It is calculated by deducting heat used in exhaust air from the burner heat input. It is assumed that the heat load remains constant when the ventilation air is changed.

Line 22 – Total volume of exhaust air (scfh) – This term is calculated using burner heat input, excess air used for burners, and ventilation air volume calculated above. This represents current volume of exhaust air discharged from the oven.

Line 23 – Gallons of solvent used (per hour) – This value is calculated using exhaust gas volume (Line 22), measured value of LEL (Line 11) and SCF air at LFL per gallon of the solvent (Line 20).

Line 24 – New suggested value of LFL or LEL (%) – The user is required to give this value. For cases where the LFL is continuously monitored, this value can approach but not exceed 50% of the LFL. The energy savings are based on this value and in many cases the user may want to be conservative and may select lower than 50% as a starting point.

Line 25 – Estimated new volume of exhaust air required (scfh) – This is a calculated value based on gallons of solvent used (Line 23), new suggested value of LFL (Line 24) and the required air volume at the solvent LFL (Line 20.

Line 26 – Reduction in exhaust air volume (scfh) – This is a calculated value based on the current exhaust gas volume (Line 22) and new volume of exhaust air (Line 25).

Line 27 – Net heat savings (Btu/hr) – This is a calculated value based on reduction in exhaust air volume, average specific heat exhaust air and temperature of flue gases or exhaust air.

Line 28 – Total or gross heat savings @ burner tip (Btu/hr) – This is the value calculated using net heat savings and available heat for the burner combustion or combustion efficiency.

Line 29 – Fuel cost ($/MM Btu) – The user gives cost of fuel expressed in terms of $/MM Btu. The cost should include all charges related to use of fuel at "the burner tip". This value can be obtained directly from monthly or annual gas bills. It is often stated as a line item on the bill. If the bill does not specifically mention the gas cost then it is necessary to calculate average cost of fuel by using values of total fuel cost and annual fuel used.

If necessary, contact the fuel (natural gas) supplier or distributor for more information.

Line 30 – Number of operating hours (per year) – This represents annual operating hours at the average firing conditions given above.

Line 31 – Annual fuel cost savings ($/year) – This is the difference between cost of energy (heat input) used per year with the current operating conditions and cost after implementation LFL monitoring and control system for the oven.

Line 32 – Reduction in CO_2 emissions (tons/year) – These savings are calculated based on annual fuel savings, assuming the fuel used is natural gas. The savings are in Short (US) tons, not in Metric tons.

Line 33 – Annual fuel savings (MM Btu/year) – This is the total about of energy saved over the course of one year.

5. References and Resources

1. Hans L. Melgaard, "Substantial Energy Savings are Often Realized by Monitoring Process Oven Exhausts," *Plant Engineering*, November 1980

2. *North American Combustion Handbook*, Third Edition, 1986. Published by North American Mfg. Company, Cleveland, OH.

3. *Combustion Technology Manual*, Fifth Edition, 1994. Published by Industrial Heating Equipment Association, Cincinnati, OH.

4. *Improving Process Heating System Performance: A Sourcebook for Industry*, U.S. Department of Energy and Industrial Heating Equipment Association. Available online at

   http://www1.eere.energy.gov/industry/bestpractices/pdfs/process_heating_sourcebook2.pdf

5. *Unit Conversions, Emission Factors and Other Reference Data*, published by the U.S. EPA, November 2004. Available online at http://www.epa.gov/cpd/pdf/brochure.pdf

6. *Tip sheets and Technical Briefs*, published by The U.S. Department of Energy. Available online at

   http://www1.eere.energy.gov/industry/utilities/steam_tools.html

7. Training opportunities for process heating technology

- The U. S. Department of Energy (DOE), Energy Efficiency and Renewable Energy (EERE) Office of Industrial Technologies (ITP) web site. http://www1.eere.energy.gov/industry/
- Sempra Energy – Southern California Gas Company web site. www.socalgas.com
- California Energy Commission web site

  www.energy.ca.gov

Appendix 1

Data for commonly used solvents

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Solvent Name	Molecular Weight	Flash Point °F	Auto-ignition °F	LEL % by Volume	UEL % by Volume	Specific Gravity Water =1	Vapor Density Air = 1	Boiling Point °F	lb per Gal	scf Vapor per gal	scf Vapor perlb	scf Air at LEL per gal
Acetone	58	-4	869	2.5	12.8	0.79	2	133	6.58	43.9	6.67	**1712**
n-Amyl Acetate	130	60	680	1.1	7.5	0.88	4.5	300	7.33	21.8	2.98	**1961**
sec-Amyl Acetate	130	89		1	7.5	0.88	4.5	249	7.33	21.8	2.98	**2159**
Amyl Alcohol	88	91	572	1.2 at 212°F	10.0 at 212°F	0.82	3	280	6.83	30	4.4	**2472**
Benzene	78	12	928	1.2	7.8	0.88	2.8	176	7.33	35	4.78	**2885**
Benzine	Mix	0	550	1.1	5.9	0.64	2.5		5.33	28.5	5.35	**2566**
n-Butyl Acetate	116	72	797	1.7	7.6	0.88	4	260	7.33	24.4	3.34	**1413**
n-Butyl Alcohol	74	98	650	1.4	11.2	0.81	2.6	243	6.75	35.3	5.23	**2484**
sec-Butyl Alcohol	74	75	761	1.7 at 212°F	9.8 at 212°F	0.81	2.6	201	6.75	35.3	5.23	**2039**
Butyl Cellosolve	118	148	472	1.1 at 200°F	12.7 at 275°F	0.9	4.1	340	7.5	24.6	3.28	**2209**
Butyl Propionate	130	90	799			0.88	4.5	295	7.33	21.8	2.98	
Camphor	152	150	871	0.6	3.5	0.99	5.2	399	8.24	21.1	2.55	**3489**
Carbon Disulfide	76	-22	194	1.3	50	1.26	2.6	115	10.49	53.4	5.09	**4056**
Cellosolve	90	110	455	1.7 at 200°F	15.6 at 200°F	0.93	3	275	7.75	34.6	4.46	**1998**
Cellosolve Acetate	132	124	715	1.7	13	0.98	4.7	313	8.16	23.1	2.84	**1338**
Chlorobenzene	113	82	1099	1.3	9.6	1.11	3.9	270	9.24	31.6	3.42	**2403**
Corn Oil	Mix	490	740			0.9			7.5			
Cottonseed Oil	Mix	486	650			0.9			7.5			
m-Cresol or p-Cresol	108	187	1038	1.1 at 302°F		1.03	3.7	395	8.58	30.7	3.58	**2763**
Cyclohexane	84	-4	473	1.3	8	0.78	2.9	179	6.5	29.9	4.61	**2271**
Cycloheanone	98	111	788	1.1 at 302°F	9.4	0.95	3.4	313	7.91	31.2	3.95	**2808**
p-Cymene	134	117	817	0.7 at 212°F	5.6	0.86	4.6	349	7.16	20.7	2.93	**2933**
Dibutyl Phthalate	278	315	757	0.5 at 456°F		1.04	9.6	644	8.66	12.1	1.41	**2399**
o-Dichlorobenzene	147	151	1198	2.2	9.2	1.31	5.1	356	10.91	28.7	2.67	**1276**
Diethyl Ketone	86	55	842	1.6		0.81	3	217	6.75	30.3	4.56	**1866**
n-Dimethyl Formamide	73	136	833	2.2 at 212°F	15.2	0.94	2.5	307	7.83	41.5	5.37	**1844**
p-Dioxane	88	54	356	2	22	1.03	3	214	8.58	37.7	4.45	**1848**
Ethyl Acetate	88	24	800	2	11.5	0.9	3	171	7.5	33	4.45	**1615**
Ethyl Alcohol	46	55	685	3.3	19	0.79	1.6	173	6.58	55.3	8.52	**1621**
Ethylbenzene	106	59	810	0.8	6.7	0.87	3.7	277	7.25	26.4	3.7	**3279**
Ethyl Ether	74	-49	356	1.9	36	0.71	2.6	95	5.91	30.9	5.3	**1596**

Appendix 1

Data for commonly used solvents

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Solvent Name	Molecular Weight	Flash Point °F	Auto-ignition °F	LEL % by Volume	UEL % by Volume	Specific Gravity Water =1	Vapor Density Air = 1	Boiling Point °F	lb per Gal	scf Vapor per gal	scf Vapor perlb	scf Air at LEL per gal
Ethyl Lactate	118	115	752	1.5 at 212°F		1.04	4.1	309	8.66	28.4	3.32	**1865**
Ethyl Methyl Ether	60	-35	374	2	10.1	0.7	2.1	51	5.8	37.6	6.53	**1842**
Ethyl Propionate	102	54	824	1.9	11	0.89	3.5	210	7.4	28.1	3.84	**1452**
Ethylene Dicholride	99	56	775	6.2	16	1.3	3.4	183	10.8	42.3	3.96	**640**
Gasoline	Mix	-45	536	1.4	7.6	0.8	3.0- 4.0		6.7	29.7	4.46	**2094**
n-Heptane	100	25	399	1	6.7	0.68	3.5	209	5.7	21.9	3.92	**2169**
n-Hexane	86	-7	427	1.1	7.5	0.66	3	156	5.5	24.7	4.56	**2223**
Kerosene (Fuel Oil #1)	Mix	100- 162	410	0.7	5	0.83			6.9			
Linseed Oil - Raw	Mix	432	650			0.93		600	7.7			
Magiesol 47	203	215	428	0.5		0.8	7	464	6.7	12.7	1.91	**2527**
Magisol 52	236	265	428	0.5		0.81	8.2	518	6.7	11.1	1.64	**2201**
Methyl Acetate	74	14	850	3.1	16	0.93	2.8	140	7.7	37	5.3	**1157**
Methyl Alcohol	32	52	725	6	36	0.79	1.1	147	6.6	79.5	12.25	**1246**
Methyl Carbitol	120	205	465	1.4	22.7	1.01	4.1	389	8.4	27.2	3.27	**1945**
Methyl Cellosolve	76	102	545	1.8	14	0.96	2.6	255	8	40.7	5.16	**2220**
Methyl Celloosolve Acetate	118	111		1.7	8.2	1.01	4.1	292	8.4	27.6	3.32	**1595**
Methyl Ethyl Ketone	72	16	759	1.4 at 200°F	11.4 at 200°F	0.8	2.5	176	6.7	35.8	5.44	**2521**
Methyl Lactate	104	121	725	2.2 at 212°F		1.1	3.6	293	9.2	34.1	3.77	**1515**
Mineral Spirites #10	Mix	104	473	1.8 at 212°F	6	0.8	3.9	300	6.7	22.9	3.43	**2836**
Naphtha (VM&P Regular)	Mix	28	450	0.9	5.9			203-320				
Naphthalene	128	174	979	0.9		1.1	4.4	424	9.2	27.7	3.06	**3049**
Nitrobenzene	123	190	900	1.8 at 200°F		1.25	4.3	412	10.4	32.7	3.19	**1786**
Nitroethane	75	82	778	3.4		1.04	2.6	237	8.7	44.7	5.23	**1269**
Nirtromethane	61	95	785	7.3		1.13	2.1	214	9.4	59.7	6.43	**758**
Nitropropane-1	89	96	789	2.2		1	3.1	268	8.3	36.2	4.4	**1609**
Nitropropane-2	89	75	802	2.6	11	0.99	3.1	248	8.2	35.8	4.4	**1343**
Paraffin Oil	Mix	444				0.83- 0.91						
Peanut Oil	Mix	540	833			0.9			7.5			
Perchloroethylene	166	None	None	None		1.62	5.8	250	13.5	31.1	2.36	
Petroleum Ether	Mix	<0	550	1.1	5.9	0.66	2.5		5.5	29.4	5.35	**2646**
Propyl Acetate	102	55	842	1.7 at 100°F	8	0.89	3.5	215	7.4	38.1	3.84	**1626**
n-Propyl Alcohol	60	74	775	2.2	13.7	0.8	2.1	207	6.7	43	6.53	**1910**
i-propyl Alcohol	60	53	750	2	12.7 at 200°F	0.78	2.1	181	6.5	41.9	6.53	**2052**
n-pPropyl Ether	102	70	370	1.3	7	0.75	3.5	194	6.2	23.7	3.84	**1798**
Pryridine	79	68	900	1.8	12.4	0.98	2.7	239	8.2	40	4.96	**2180**
Rosin Oil	Mix	266	648			1		680	8.3			
Soy Bean Oil	Mix	540	833			0.9			7.5			
Tetrahydrofuran	72	6	610	2	11.8	0.89	2.5	151	7.4	39.8	5.44	**1952**
Toluene	92	40	896	1.1	7.1	0.87	3.1	231	7.2	31.1	4.26	**2800**
Turpentine	136	95	488	0.8		0.87	4.7	300	7.2	20.6	2.88	**2556**
Vinyl Acetate	86	18	756	2.6	13.4	0.93	3	161	7.7	34.8	4.56	**1305**
o-Xylene	106	88	867	0.9	6.7	0.88	3.7	292	7.3	26.7	3.7	**2945**