PDHonline Course M312 (4 PDH)

Fire Dynamics Series: Estimating Fire Flame Height and Radiant Heat Flux From Fire

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CHAPTER 4. ESTIMATING WALL FIRE FLAME HEIGHT, LINE FIRE FLAME HEIGHT AGAINST THE WALL, AND CORNER FIRE FLAME HEIGHT

4.1 Objectives

This chapter has the following objectives:

- Identify the three regions of a diffusion flame.
- Explain how corners and walls affect flames.
- Define relevant terms, including persistent flame region, intermittent flame region, flame height, and flame extension.

4.2 Introduction

If a fire is located close to a wall or a corner (i.e., formed by the intersection of two walls), the resulting restriction on free air entrainment will have a significant effect on fire growth and spread. The primary impact of walls and corners is to reduce the amount of entrained air available to the flame or plume. This lengthens flames and causes the temperature in a plume to be higher at a given elevation than it would be in the open. Remember that the expression for estimating flame height given in Chapter 3 assumes that the fire source is located away from the walls and corners.

When a diffusion flame develops and is in contact with the wall, its structure can be subdivided into three regions, which are commonly identified as the persistent flame region, the intermittent flame region, and the buoyant plume region. As the plume rises to the ceiling, its direction changes from vertical (upward) to horizontal. Until the point where the flow changes direction, the plume is primarily driven by buoyancy. Thereafter, the plume is driven by its residual momentum and becomes a jet, which is referred to as the "ceiling jet."

The flame heats the wall material with which it comes in contact. The heat flux to the wall is a function of location and is highest in the persistent flame region. The flame height depends on the amount of air entrained which, in turn, is proportional to the fuel heat release rate. On occasions, it may also be necessary to calculate the flame projections against a wall from the spill of flammable liquid in a trench or flames emerging from a burning electrical cabinet.

4.3 Flame Height Correlations for Walls Fires, Line Fires, and Corner Fires

In a wall flame, the wall-side heat flux appears to be governed by the flame radiation, while the heat flux in the far field is primarily attributable to convection. This implies that flame height can be a scaling factor representing the distribution of wall heat transfer. Using the analogy of unconfined fires, the flame height is expected to depend only on the gross heat release rate of the fuel. The terms "flame height" and "flame extension" designate the lengths of flame in the vertical and horizontal directions, respectively. A wall flame generated from a fire located against a wall can only entrain air from half of its perimeter. Thus, wall flame can be considered to be geometrically half of an axisymmetric flame and its mass flow rate, in turn, is half of that from an axisymmetric flame.

A flame generated from a fire located in a corner of a compartment (typically where the intersecting walls form a 90° angle) is referred to as corner flame. Corner fires are more severe than wall fires because of the radiative heat exchange between the two burning walls. However, the physical phenomena controlling fire growth in corner and wall scenarios are very similar, if not identical.

4.3.1 Wall Fire Flame Height Correlation

Delichatsios (1984) reported by Budnick, Evans, and Nelson (1997) developed a simple correlation of flame height for elongated fire based on experimental data. Figure 4-1 depicts the configuration used in developing the correlation for wall flame height. In the following correlation, the flame height is based on the rate of HRR per unit length of the fire:

$$H_{f(Wall)} = 0.034\dot{Q}'^{\frac{2}{3}} \qquad (4\text{-}1)$$

Where:

$H_{f(Wall)}$ = wall flame height (m)
0.034 = entrainment coefficient
$\dot{Q}'$ = HRR per unit length of the fire (kW/m)

The above correlation can be used to determine the length of the flame against the wall and to estimate radiative heat transfer to objects in the enclosure.

4.3.2 Line Fire Flame Height Correlation

Delichatsios (1984) reported by Budnick et. al., (1997) also developed a flame height correlation for line fires against a wall. Like the wall fire flame height correlation, this correlation is based on experimental data. The geometry for this case is shown in Figure 4-2. Delichatsios' correlation is expressed by the following equation based on the rate of HRR per unit length of the fire:

$$H_{f(Wall,Line)} = 0.017\dot{Q}'^{\frac{2}{3}} \qquad (4\text{-}2)$$

Where:

$H_{f(Wall, Line)}$ = line fire flame height (m)
0.017 = entrainment coefficient
$\dot{Q}'$ = HRR per unit length of the fire (kW/m)

The above correlation can be used to determine the length of the flame against the wall from a line fire source and can be used to estimate radiative heat transfer to objects in the enclosure.

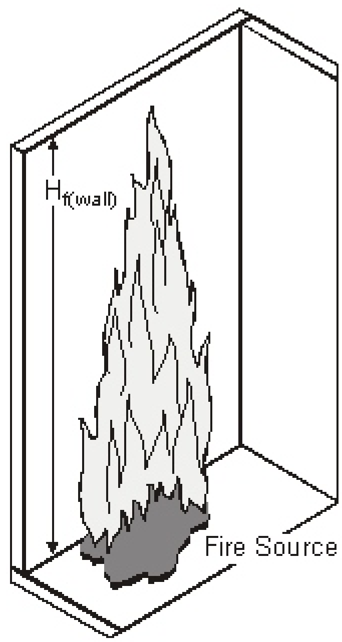

Figure 4-1 Wall Fire Flame Configuration

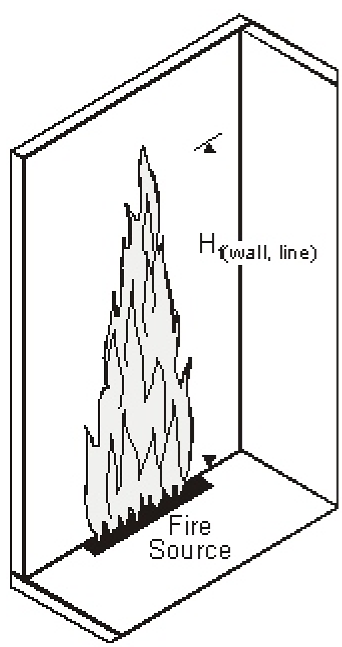

Figure 4-2 Line Fire Flame Against a Wall

4.3.3 Corner Fire Flame Height Correlation

A corner fire may be modeled using a pool fire and specifying the center coordinates as the apex of the corner. At the start of the fire, a diffusion flame develops and makes contact with the walls. As flames spread along the intersection of wall and ceiling, they eventually reach another corner. With a noncombustible ceiling, flames also spread downward. By contrast, with a combustible wall, the heat transfer between two walls in contact with the fire source results in a much more rapid fire spread. Figure 4-3 depicts the configuration used in developing the corner flame height correlation from experimental data. Hasemi and Tokunaga (1983 and 1984) suggest the following expression, based on the correlation of an extensive number of fire tests:

$$H_{f(Corner)} = 0.075\dot{Q}^{\frac{3}{5}} \qquad (4\text{-}3)$$

Where:

$H_{f(Corner)}$ = corner fire flame height (m)
0.075 = entrainment coefficient
$\dot{Q}$ = HRR of the fire (kW)

The above correlation can be used to determine the length of the flame against the intersection of two walls and to estimate radiative heat transfer to objects in the enclosure.

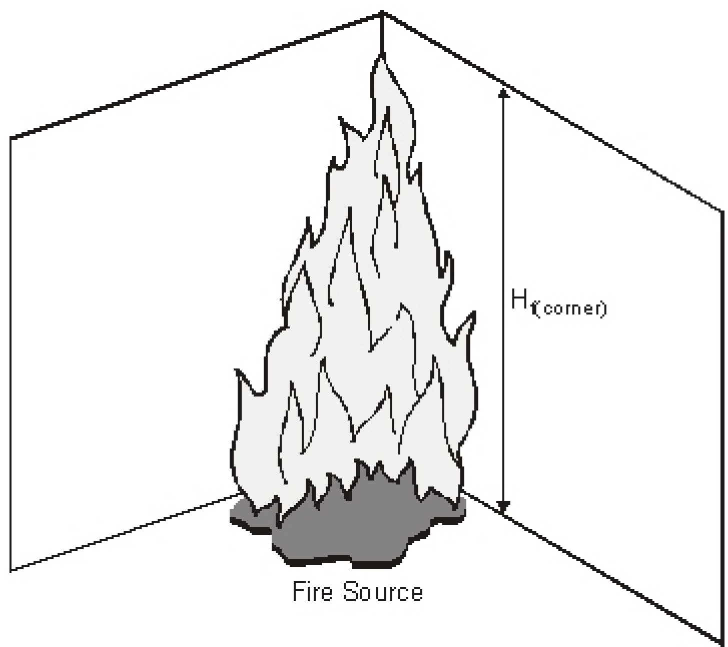

Figure 4-3 Corner Fire Flame Configuration

4.4 Assumptions and Limitations

The methods discussed in this chapter are subject to several assumptions and limitations:

(1) This method includes correlations for flame height for liquid fire.

(2) The size of the fire (flame height) depends on the length of the fire.

(3) This correlation is developed for two-dimensional sources.The turbulent diffusion flames produced by fires burning at or near a wall configuration of a compartment affect the spread of the fire.

(4) Air is entrained only from one side during the combustion process.

4.5 Required Input for Spreadsheet Calculations

The user must obtain the following information to use the spreadsheet:

(1) fuel type (material)
(2) fuel spill volume (gallons)
(3) fuel spill area (ft^2)

4.6 Cautions

(1) Use the appropriate spreadsheet (04_Flame_Height_Calculations.xls) on the CD-ROM for wall fire flame height, line fire flame height, and corner fire flame height calculations.

(2) Use the page that best represents the fire configuration.

(3) Make sure to enter the input parameters in the correct units.

4.7 Summary

This chapter describes methods of calculating the height of a flame and its buoyant gases when the fire source is near a wall or a corner. These fire scenarios are often used as idealized representatives of situations of much greater complexity. The correlations presented were obtained from laboratory scale fires providing local measurements of gas temperature and velocity both below and above the flame tips, as well as measurements of visual flame length.

4.8 References

Budnick, E.K., D.D. Evans, and H.E. Nelson, "Simple Fire Growth Calculations," Section 11 Chapter 10, *NFPA Fire Protection Handbook*, 18th Edition, National Fire Protection Association, Quincy, Massachusetts, 1997.

Delichatsios, M.A., "Flame Heights of Turbulent Wall Fire with Significant Flame Radiation," *Combustion Science and Technology*, Volume 39, pp. 195–214, 1984.

Hasemi Y., and T.Tokunaga, "Modeling of Turbulent Diffusion Flames and Fire Plumes for the Analysis of Fire Growth," Proceedings of the 21st National Heat Transfer Conference, American Society of Mechanical Engineers (ASME), 1983.

Hasemi Y., and T.Tokunaga, "Some Experimental Aspects of Turbulent Diffusion Flames and Buoyant Plumes from Fire Sources Against a Wall and in Corner of Walls," *Combustion Science and Technology*, Volume 40, pp. 1–17, 1984.

4.9 Problems

Example Problem 4.9-1

Problem Statement

A pool fire scenario arises from a breach (leak or rupture) in an oil-filled transformer. This event allows the fuel contents of the transformer to spill 2 gallons along a wall with an area of 9 ft^2. A cable tray is located 8 ft above the fire. Calculate the wall flame height of the fire and determine whether the flame will impinge upon the cable tray.

Solution

Purpose:
(1) Calculate the wall flame height.
(2) Determine whether the flame will impinge upon the cable tray.

Assumptions:
(1) Air is entrained only from one side during the combustion process.
(2) The fire is located at or near a wall configuration of a compartment that affects the spread of the fire.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:

(a) 04_Flame_Height_Calculations.xls (click on *Wall_Flame _Height*)

FDTs Input Parameters:

-Fuel spill volume (V) = 2 gallons
-Fuel Spill Area or Dike Area (A_{dike}) = 9.0 ft^2
-Select Fuel Type: **Transformer Oil, Hydrocarbon**

Results*

Fuel	Wall Fire Flame Height ($H_{f(Wall)}$) m (ft)	Cable Tray Impingement
Transformer Oil, Hydrocarbon	3.0 (10.0)	Yes

*see spreadsheet on next page

Spreadsheet Calculations

FDT^s: 04_Flame_Height_Calculations.xls (click on Wall_Flame _Height)

CHAPTER 4. ESTIMATING WALL FIRE FLAME HEIGHT

Version 1805.0

The following calculations estimate the wall fire flame height.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Fuel Selected.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s).
The chapter in the NUREG should be read before an analysis is made.

INPUT PARAMETERS

Fuel Spill Volume (V)	2.00	gallons	0.0076 m^3
Fuel Spill Area or Dike Area (A_{dike})	9.00	ft^2	0.836 m^2
Mass Burning Rate of Fuel ($\dot{m}''$)	0.039	kg/m^2-sec	
Effective Heat of Combustion of Fuel ($\Delta H_{c,eff}$)	46000	kJ/kg	
Empirical Constant ($k\beta$)	0.7	m^{-1}	

Calculate

THERMAL PROPERTIES FOR

BURNING RATE DATA FOR LIQUID HYDROCARBON FUELS

Fuel	Mass Burning Rate $\dot{m}''$ (kg/m^2-sec)	Heat of Combustion $\Delta H_{c,eff}$ (kJ/kg)	Empirical Constant $k\beta$ (m^{-1})
Methanol	0.017	20,000	100
Ethanol	0.015	26,800	100
Butane	0.078	45,700	2.7
Benzene	0.085	40,100	2.7
Hexane	0.074	44,700	1.9
Heptane	0.101	44,600	1.1
Xylene	0.09	40,800	1.4
Acetone	0.041	25,800	1.9
Dioxane	0.018	26,200	5.4
Diethy Ether	0.085	34,200	0.7
Benzene	0.048	44,700	3.6
Gasoline	0.055	43,700	2.1
Kerosene	0.039	43,200	3.5
Diesel	0.045	44,400	2.1
JP-4	0.051	43,500	3.6
JP-5	0.054	43,000	1.6
Transformer Oil, Hydrocarbon	0.039	46,000	0.7
561 Silicon Transformer Fluid	0.005	28,100	100
Fuel Oil, Heavy	0.035	39,700	1.7
Crude Oil	0.034	42,600	2.8
Lube Oil	0.039	46,000	0.7
User Specified Value	Enter Value	Enter Value	Enter Value

Reference: *SFPE Handbook of Fire Protection Engineering, 3rd Edition, Page 3-26.*

Select Fuel Type

Transformer Oil, Hydrocarbon

Scroll to desired fuel type then Click on selection

Heat Release Rate Calculation

Reference: SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002, Page 3-26.

$Q = m''\Delta H_{c,eff}(1 - e^{-k\beta D})\, A_{dike}$

Where Q = pool fire heat release rate (kW)

m'' = mass burning rate of fuel per unit surface area (kg/m^2-sec)

$\Delta H_{c,eff}$ = effective heat of combustion of fuel (kJ/kg)

$A = A_{dike}$ = surface area of pool fire (area involved in vaporization) (m^2)

$k\beta$ = empirical constant (m^{-1})

D = diameter of pool fire (diameter involved in vaporization, circular pool is assumed) (m)

(Liquids with relatively high flash point, like transformer oil require localized heating to achieve ignition)

Pool Fire Diameter Calculation

$A_{dike} = \pi D^2/4$

$D = \sqrt{(4A_{dike}/\pi)}$

Where A_{dike} = surface area of pool fire (m^2)

D = pool fire diamter (m)

D = 1.032 m

Heat Release Rate Calculation

$Q = m''\Delta H_{c,eff}(1-e^{-k\beta D})\, A_{dike}$

Q = 771.52 kW 731.26 Btu/sec

Heat Release Rate Per Unit Length of Fire Calculation

$Q' = Q/L$

Where Q' = heat release rate per unit length (kW/m)

Q = fire heat release rate of the fire (kW)

L = length of the fire source (m)

Fire Source Length Calculation

$L \times W = A_{dike}$

L x W = 0.836 m^2

L = 0.914 m

$Q' = Q/L$

Q' = 843.75 kW/m

ESTIMATING WALL FIRE FLAME HEIGHT

Reference: NFPA Fire Protection Handbook, 19th Edition, 2003, Page 3-134.

$H_{(wall)} = 0.034\, Q'^{2/3}$

Where $H_{(wall)}$ = wall fire flame height (m)

Q' = rate of heat release per unit length of the fire (kW/m)

$H_{(wall)} = 0.034\, Q'^{2/3}$

$H_{(wall)}$ =	3.04 m	9.96 ft	Answer

NOTE

The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002, and NFPA Fire Protection Handbook, 19th Edition, 2003. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation, and should only be interpreted by an informed user.

Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations.

Any questions, comments, concerns, and suggestions, or to report an error(s) in the spreadsheet, please send an email to nxi@nrc.gov or mxs3@nrc.gov.

Example Problem 4.9-2

Problem Statement

A pool fire scenario arises from a transient combustible liquid spill. This event allows the fuel contents of a 15 gallon can to form along a wall with an area of 30 ft^2. A cable tray is located 12 ft above the fire. Determine the line wall fire flame height and whether the flame will impinge upon the cable tray if the spilled liquids are (a) diesel, (b) acetone, and (c) methanol.

Solution

Purpose:

(1) Calculate the line wall fire flame height using three transient combustibles.

(2) Determine whether the flame will impinge upon the cable tray in each case.

Assumptions:

(1) Air is entrained only from one side during the combustion process.

(2) The fire is located at or near a wall configuration of a compartment that affects the spread of the fire.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:

(a) 04_Flame_Height_Calculations.xls (click on *Wall_Line_Flame _Height*)

FDT^s Input Parameters:

-Fuel spill volume (V) = 15 gallons
-Fuel Spill Area or Dike Area (A_{dike}) = 30.0 ft^2
-Select Fuel Type: Diesel, Acetone, and Methanol

Results*

Fuel	Wall Line Fire Height ($H_{f(Wall\ Line)}$) m (ft)	Cable Tray Impingement
Diesel	3.8 (12.3)	Yes
Acetone	2.44(8.0)	No
Methanol	1.2 (3.8)	No

*See spreadsheets on next page

Spreadsheet Calculations

FDT[s]: 04_Flame_Height_Calculations.xls (click on Wall_Line_Flame _Height)

(a) Diesel

CHAPTER 4. ESTIMATING LINE FIRE FLAME HEIGHT AGAINST THE WALL

Version 1805.0

The following calculations estimate the line fire flame height against the wall.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Fuel Selected.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s).
The chapter in the NUREG should be read before an analysis is made.

INPUT PARAMETERS

Fuel Spill Volume (V)	15.00	gallons	0.0568 m^3
Fuel Spill Area or Dike Area (A_{dike})	30.00	ft^2	2.787 m^2
Mass Burning Rate of Fuel (m")	0.045	kg/m^2-sec	
Effective Heat of Combustion of Fuel ($\Delta H_{c,eff}$)	44400	kJ/kg	
Empirical Constant (kβ)	2.1	m^{-1}	

Calculate

THERMAL PROPERTIES FOR

BURNING RATE DATA FOR LIQUID HYDROCARBON FUELS

Fuel	Mass Burning Rate m" (kg/m^2-sec)	Heat of Combustion $\Delta H_{c,eff}$ (kJ/kg)	Empirical Constant kβ (m^{-1})
Methanol	0.017	20,000	100
Ethanol	0.015	26,800	100
Butane	0.078	45,700	2.7
Benzene	0.085	40,100	2.7
Hexane	0.074	44,700	1.9
Heptane	0.101	44,600	1.1
Xylene	0.09	40,800	1.4
Acetone	0.041	25,800	1.9
Dioxane	0.018	26,200	5.4
Diethy Ether	0.085	34,200	0.7
Benzene	0.048	44,700	3.6
Gasoline	0.055	43,700	2.1
Kerosene	0.039	43,200	3.5
Diesel	0.045	44,400	2.1
JP-4	0.051	43,500	3.6
JP-5	0.054	43,000	1.6
Transformer Oil, Hydrocarbon	0.039	46,000	0.7
561 Silicon Transformer Fluid	0.005	28,100	100
Fuel Oil, Heavy	0.035	39,700	1.7
Crude Oil	0.034	42,600	2.8
Lube Oil	0.039	46,000	0.7
User Specified Value	Enter Value	Enter Value	Enter Value

Select Fuel Type: Diesel

Scroll to desired fuel type then Click on selection

Reference: *SFPE Handbook of Fire Protection Engineering*, 3rd Edition, Page 3-26.

Heat Release Rate Calculation

Reference: SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002, Page 3-26.

$Q = m''\Delta H_{c,eff} (1 - e^{-k\beta D}) A_f$

Where
- Q = pool fire heat release rate (kW)
- m'' = mass burning rate of fuel per unit surface area (kg/m^2-sec)
- $\Delta H_{c,eff}$ = effective heat of combustion of fuel (kJ/kg)
- $A_f = A_{dike}$ = surface area of pool fire (area involved in vaporization) (m^2)
- $k\beta$ = empirical constant (m^{-1})
- D = diameter of pool fire (diameter involved in vaporization, circular pool is assumed) (m)

(Liquids with relatively high flash point, like transformer oil require localized heating to achieve ignition)

Pool Fire Diameter Calculation

$A_{dike} = \pi D^2/4$

$D = \sqrt{(4A_{dike}/\pi)}$

Where
- A_{dike} = surface area of pool fire (m^2)
- D = pool fire diameter (m)

$D =$ 1.884 m

Heat Release Rate Calculation

$Q = m''\Delta H_{c,eff} (1 - e^{-k\beta D}) A_{dike}$

$Q =$ 5462.02 kW 5177.01 Btu/sec

Heat Release Rate Per Unit Length of Fire Calculation

$Q' = Q/L$

Where
- Q' = heat release rate per unit length (kW/m)
- Q = fire heat release rate of the fire (kW)
- L = length of the fire source (m)

Fire Source Length Calculation

$L \times W = A_{dike}$

$L \times W =$ 2.787 m^2

$L =$ 1.669 m

$Q' = Q/L$

$Q' =$ 3271.73 kW/m

ESTIMATING LINE WALL FIRE FLAME HEIGHT

Reference: NFPA Fire Protection Handbook, 19th Edition, 2003, Page 3-134.

$H_{f(wall\ line)} = 0.017\ Q'^{2/3}$

Where
- $H_{f(wall\ line)}$ = wall fire flame height (m)
- Q' = rate of heat release per unit length of the fire (kW/m)

$H_{f(wall\ line)} = 0.017\ Q'^{2/3}$

$H_{f(wall\ line)} =$ 3.75 m 12.29 ft **Answer**

NOTE

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FDT[s]: 04_Flame_Height_Calculations.xls (click on Wall_Line_Flame _Height)

(b) Acetone

CHAPTER 4. ESTIMATING LINE FIRE FLAME HEIGHT AGAINST THE WALL

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The following calculations estimate the line fire flame height against the wall.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Fuel Selected.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s).
The chapter in the NUREG should be read before an analysis is made.

INPUT PARAMETERS

Fuel Spill Volume (V)	15.00	gallons	0.0568 m^3
Fuel Spill Area or Dike Area (A_{dike})	30.00	ft^2	2.787 m^2
Mass Burning Rate of Fuel (m")	0.041	kg/m^2-sec	
Effective Heat of Combustion of Fuel ($\Delta H_{c,eff}$)	25800	kJ/kg	
Empirical Constant (kβ)	1.9	m^{-1}	

Calculate

THERMAL PROPERTIES FOR

BURNING RATE DATA FOR LIQUID HYDROCARBON FUELS

Fuel	Mass Burning Rate m" (kg/m^2-sec)	Heat of Combustion $\Delta H_{c,eff}$ (kJ/kg)	Empirical Constant kβ (m^{-1})
Methanol	0.017	20,000	100
Ethanol	0.015	26,800	100
Butane	0.078	45,700	2.7
Benzene	0.085	40,100	2.7
Hexane	0.074	44,700	1.9
Heptane	0.101	44,600	1.1
Xylene	0.09	40,800	1.4
Acetone	0.041	25,800	1.9
Dioxane	0.018	26,200	5.4
Diethy Ether	0.085	34,200	0.7
Benzene	0.048	44,700	3.6
Gasoline	0.055	43,700	2.1
Kerosene	0.039	43,200	3.5
Diesel	0.045	44,400	2.1
JP-4	0.051	43,500	3.6
JP-5	0.054	43,000	1.6
Transformer Oil, Hydrocarbon	0.039	46,000	0.7
561 Silicon Transformer Fluid	0.005	28,100	100
Fuel Oil, Heavy	0.035	39,700	1.7
Crude Oil	0.034	42,600	2.8
Lube Oil	0.039	46,000	0.7
User Specified Value	Enter Value	Enter Value	Enter Value

Reference: *SFPE Handbook of Fire Protection Engineering*, 3rd Edition, Page 3-26.

Select Fuel Type

Acetone

Scroll to desired fuel type

Click on selection

Heat Release Rate Calculation

Reference: *SFPE Handbook of Fire Protection Engineering, 3[rd] Edition, 2002, Page 3-26.*

$Q = \dot{m}''\Delta H_{c,eff} (1 - e^{-k\beta D}) A_f$

Where Q = pool fire heat release rate (kW)

$\dot{m}''$ = mass burning rate of fuel per unit surface area (kg/m^2-sec)

$\Delta H_{c,eff}$ = effective heat of combustion of fuel (kJ/kg)

$A_f = A_{dike}$ = surface area of pool fire (area involved in vaporization) (m^2)

$k\beta$ = empirical constant (m^{-1})

D = diameter of pool fire (diameter involved in vaporization, circular pool is assumed) (m)

(Liquids with relatively high flash point, like transformer oil require localized heating to achieve ignition)

Pool Fire Diameter Calculation

$A_{dike} = \pi D^2/4$

$D = \sqrt{(4A_{dike}/\pi)}$

Where A_{dike} = surface area of pool fire (m^2)

D = pool fire diameter (m)

D = 1.884 m

Heat Release Rate Calculation

$Q = \dot{m}''\Delta H_{c,eff} (1 - e^{-k\beta D}) A_{dike}$

Q = 2865.94 kW 2716.39 Btu/sec

Heat Release Rate Per Unit Length of Fire Calculation

$Q' = Q/L$

Where Q' = heat release rate per unit length (kW/m)

Q = fire heat release rate of the fire (kW)

L = length of the fire source (m)

Fire Source Length Calculation

$L \times W = A_{dike}$

L x W = 2.787 m^2

L = 1.669 m

$Q' = Q/L$

Q' = 1716.69 kW/m

ESTIMATING LINE WALL FIRE FLAME HEIGHT

Reference: *NFPA Fire Protection Handbook, 19[th] Edition, 2003, Page 3-134.*

$H_{f(wall\ line)} = 0.017\ Q'^{2/3}$

Where $H_{f(wall\ line)}$ = wall fire flame height (m)

Q' = rate of heat release per unit length of the fire (kW/m)

$H_{f(wall\ line)} = 0.017\ Q'^{2/3}$

$H_{f(wall\ line)}$ =	2.44 m	8.00 ft	Answer

NOTE

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UNITED STATES NUCLEAR REGULATORY COMMISSION

FDT[s]: 04_Flame_Height_Calculations.xls (click on Wall_Line_Flame _Height)

(c) Methanol

CHAPTER 4. ESTIMATING LINE FIRE FLAME HEIGHT AGAINST THE WALL

Version 1805.0

The following calculations estimate the line fire flame height against the wall.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Fuel Selected.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s).
The chapter in the NUREG should be read before an analysis is made.

INPUT PARAMETERS

Fuel Spill Volume (V)	15.00	gallons	0.0568 m^3
Fuel Spill Area or Dike Area (A_{dike})	30.00	ft^2	2.787 m^2
Mass Burning Rate of Fuel (m")	0.017	kg/m^2-sec	
Effective Heat of Combustion of Fuel ($\Delta H_{c,eff}$)	20000	kJ/kg	
Empirical Constant (kβ)	100	m^{-1}	

Calculate

THERMAL PROPERTIES FOR

BURNING RATE DATA FOR LIQUID HYDROCARBON FUELS

Fuel	Mass Burning Rate m" (kg/m^2-sec)	Heat of Combustion $\Delta H_{c,eff}$ (kJ/kg)	Empirical Constant kβ (m^{-1})
Methanol	0.017	20,000	100
Ethanol	0.015	26,800	100
Butane	0.078	45,700	2.7
Benzene	0.085	40,100	2.7
Hexane	0.074	44,700	1.9
Heptane	0.101	44,600	1.1
Xylene	0.09	40,800	1.4
Acetone	0.041	25,800	1.9
Dioxane	0.018	26,200	5.4
Diethy Ether	0.085	34,200	0.7
Benzene	0.048	44,700	3.6
Gasoline	0.055	43,700	2.1
Kerosene	0.039	43,200	3.5
Diesel	0.045	44,400	2.1
JP-4	0.051	43,500	3.6
JP-5	0.054	43,000	1.6
Transformer Oil, Hydrocarbon	0.039	46,000	0.7
561 Silicon Transformer Fluid	0.005	28,100	100
Fuel Oil, Heavy	0.035	39,700	1.7
Crude Oil	0.034	42,600	2.8
Lube Oil	0.039	46,000	0.7
User Specified Value	Enter Value	Enter Value	Enter Value

Reference: *SFPE Handbook of Fire Protection Engineering, 3rd Edition, Page 3-26.*

Select Fuel Type

Methanol

Scroll to desired fuel type then Click on selection

Heat Release Rate Calculation

Reference: SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002, Page 3-26.

$Q = m''\Delta H_{c,eff} (1 - e^{-k\beta D}) A_f$

Where
- Q = pool fire heat release rate (kW)
- m'' = mass burning rate of fuel per unit surface area (kg/m²-sec)
- $\Delta H_{c,eff}$ = effective heat of combustion of fuel (kJ/kg)
- $A_f = A_{dike}$ = surface area of pool fire (area involved in vaporization) (m²)
- $k\beta$ = empirical constant (m⁻¹)
- D = diameter of pool fire (diameter involved in vaporization, circular pool is assumed) (m)
  (Liquids with relatively high flash point, like transformer oil require localized heating to achieve ignition)

Pool Fire Diameter Calculation

$A_{dike} = \pi D^2/4$

$D = \sqrt{(4A_{dike}/\pi)}$

Where
- A_{dike} = surface area of pool fire (m²)
- D = pool fire diameter (m)

D = 1.884 m

Heat Release Rate Calculation

$Q = m''\Delta H_{c,eff} (1 - e^{-k\beta D}) A_{dike}$

Q = 947.61 kW 898.16 Btu/sec

Heat Release Rate Per Unit Length of Fire Calculation

$Q' = Q/L$

Where
- Q' = heat release rate per unit length (kW/m)
- Q = fire heat release rate of the fire (kW)
- L = length of the fire source (m)

Fire Source Length Calculation

$L \times W = A_{dike}$

L x W = 2.787 m²

L = 1.669 m

$Q' = Q/L$

Q' = 567.62 kW/m

ESTIMATING LINE WALL FIRE FLAME HEIGHT

Reference: NFPA Fire Protection Handbook, 19th Edition, 2003, Page 3-134.

$H_{f(wall\ line)} = 0.017\ Q'^{2/3}$

Where
- $H_{f(wall\ line)}$ = wall fire flame height (m)
- Q' = rate of heat release per unit length of the fire (kW/m)

$H_{f(wall\ line)} = 0.017\ Q'^{2/3}$

$H_{f(wall\ line)}$ =	1.17 m	3.82 ft	Answer

NOTE

The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002, and NFPA Fire Protection Handbook, 19th Edition, 2003. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation, and should only be interpreted by an informed user.
Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations.
Any questions, comments, concerns, and suggestions, or to report an error(s) in the spreadsheets, please send an email to nxi@nrc.gov or mxs3@nrc.gov.

Example Problem 4.9-3

Problem Statement

A pool fire scenario arises from a rupture in a diesel generator fuel line. This event allows diesel fuel to spill 1.5 gallons along the corner of walls with an area of 10 ft^2. An unprotected junction box is located 12 ft above the fire. Determine whether the flame will impinge upon the junction box.

Solution

Purpose:

(1) Calculate the line wall fire flame height.
(2) Determine whether the flame will impinge upon the junction box.

Assumptions:

(1) Air is entrained only from one side during the combustion process.
(2) The fire is located at or near a wall configuration of a compartment that affects the spread of the fire.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:

(a) 04_Flame_Height_Calculations.xls (click on *Corner_Flame _Height*)

FDTs Input Parameters:

-Fuel spill volume (V) = 1.5 gallons
-Fuel Spill Area or Dike Area (A_{dike}) = 10 ft^2
-Select Fuel Type: **Diesel**

Results*

Fuel	Corner Fire Flame Height ($H_{f(Corner)}$) m (ft)	Junction Box Impingement
Diesel	6.4 (21.1)	Yes

*see spreadsheet on next page

Spreadsheet Calculations

FDT[s]: 04_Flame_Height_Calculations.xls (click on Corner_Flame _Height)

CHAPTER 4. ESTIMATING CORNER FIRE FLAME HEIGHT

Version 1805.0

The following calculations estimate the corner fire flame height.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Fuel Selected.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s).
The chapter in the NUREG should be read before an analysis is made.

INPUT PARAMETERS

Parameter	Value	Unit	Converted
Fuel Spill Volume (V)	1.50	gallons	0.0057 m^3
Fuel Spill Area or Dike Area (A_{dike})	10.00	ft^2	0.929 m^2
Mass Burning Rate of Fuel (m'')	0.045	kg/m^2-sec	
Effective Heat of Combustion of Fuel ($\Delta H_{c,eff}$)	44400	kJ/kg	
Empirical Constant ($k\beta$)	2.1	m^{-1}	

Calculate

THERMAL PROPERTIES FOR

BURNING RATE DATA FOR LIQUID HYDROCARBON FUELS

Fuel	Mass Burning Rate m'' (kg/m^2-sec)	Heat of Combustion $\Delta H_{c,eff}$ (kJ/kg)	Empirical Constant $k\beta$ (m^{-1})
Methanol	0.017	20,000	100
Ethanol	0.015	26,800	100
Butane	0.078	45,700	2.7
Benzene	0.085	40,100	2.7
Hexane	0.074	44,700	1.9
Heptane	0.101	44,600	1.1
Xylene	0.09	40,800	1.4
Acetone	0.041	25,800	1.9
Dioxane	0.018	26,200	5.4
Diethy Ether	0.085	34,200	0.7
Benzene	0.048	44,700	3.6
Gasoline	0.055	43,700	2.1
Kerosene	0.039	43,200	3.5
Diesel	0.045	44,400	2.1
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Transformer Oil, Hydrocarbon	0.039	46,000	0.7
561 Silicon Transformer Fluid	0.005	28,100	100
Fuel Oil, Heavy	0.035	39,700	1.7
Crude Oil	0.034	42,600	2.8
Lube Oil	0.039	46,000	0.7
User Specified Value	Enter Value	Enter Value	Enter Value

Reference: *SFPE Handbook of Fire Protection Engineering*, 3rd Edition, Page 3-26.

Select Fuel Type

Diesel

Scroll to desired fuel type then Click on selection

Heat Release Rate Calculation

Reference: *SFPE Handbook of Fire Protection Engineering*, 3rd *Edition, 2002, Page 3-25.*

$Q = m''\Delta H_{c,eff}(1 - e^{-k\beta D})\, A_f$

Where Q = pool fire heat release rate (kW)

m'' = mass burning rate of fuel per unit surface area (kg/m^2-sec)

$\Delta H_{c,eff}$ = effective heat of combustion of fuel (kJ/kg)

$A_f = A_{dike}$ = surface area of pool fire (area involved in vaporization) (m^2)

$k\beta$ = empirical constant (m^{-1})

D = diameter of pool fire (diameter involved in vaporization, circular pool is assumed) (m)

(Liquids with relatively high flash point, like transformer oil require localized heating to achieve ignition)

Pool Fire Diameter Calculation

$A_{dike} = \pi D^2/4$

$D = \sqrt{(4A_{dike}/\pi)}$

Where A_{dike} = surface area of pool fire (m^2)

D = pool fire diamter (m)

D = **1.088** m

Heat Release Rate Calculation

$Q = m''\Delta H_{c,eff}(1 - e^{-k\beta D})\, A_{dike}$

Q = **1667.09** kW **1580.10** Btu/sec

ESTIMATING CORNER FIRE FLAME HEIGHT

Reference: *Hesemi and Tokunaga, "Modeling of Turbulent Diffusion Flames and Fire Plumes for the Analysis of Fire Growth," Growth," Proceeding of the 21st National Heat Transfer Conference, American Society of Mechanical Engineers (ASME), 1983.*

$H_{f(corner)} = 0.075\, Q^{3/5}$

Where Q = heat release rate of the fire (kW)

$H_{f(corner)} = 0.075\, Q^{3/5}$

$H_{f(corner)}$ =	**6.43 m**	**21.10 ft**	**Answer**

NOTE

The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002 and Hesemi and Tokunage, 1983.

Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation, and should only be interpreted by an informed user.

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