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 $90^{\circ}$ 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:

$$
\begin{equation*}
\mathrm{H}_{\mathrm{f} \text { (Wall })}=0.034 \dot{Q}^{r^{\frac{2}{3}}} \tag{4-1}
\end{equation*}
$$

Where:

$$
\begin{aligned}
& \mathrm{H}_{\mathrm{f}(\text { Wall })}=\text { wall flame height }(\mathrm{m}) \\
& 0.034=\text { entrainment coefficient } \\
& \dot{\mathrm{Q}}^{\prime}=\mathrm{HRR} \text { per unit length of the fire }(\mathrm{kW} / \mathrm{m})
\end{aligned}
$$

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:

$$
\begin{equation*}
\mathrm{H}_{\mathrm{f}(\text { Wall, Line })}=0.017 \dot{\mathrm{Q}}^{r^{\frac{2}{3}}} \tag{4-2}
\end{equation*}
$$

Where:
$\mathrm{H}_{\mathrm{f}(\text { Wall, Line })}=$ line fire flame height (m)
0.017 = entrainment coefficient
$\dot{\mathrm{Q}}^{\prime}=\mathrm{HRR}$ 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:

$$
\begin{equation*}
H_{f(\text { Comer })}=0.075 \dot{Q}^{\frac{3}{5}} \tag{4-3}
\end{equation*}
$$

Where:
$\mathrm{H}_{\mathrm{f}(\mathrm{Correr})}=$ corner fire flame height ( m )
0.075 = entrainment coefficient
$\dot{Q}=H R R$ 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 $\left(\mathrm{ft}^{2}\right)$

### 4.6 Cautions

(1) Use the appropriate spreadsheet (04_Flame_Height_Calculations.xIs) 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, $18^{\text {th }}$ 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 $21^{\text {st }}$ 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 $9 \mathrm{ft}^{2}$. 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 ${ }^{\text {s }}$ ) Information:
Use the following $\mathrm{FDT}^{\mathrm{s}}$ :
(a) 04_Flame_Height_Calculations.xls (click on Wall_Flame_Height)

FDTs Input Parameters:
-Fuel spill volume $(\mathrm{V})=2$ gallons
-Fuel Spill Area or Dike Area $\left(A_{\text {dike }}\right)=9.0 \mathrm{ft}^{2}$
-Select Fuel Type: Transformer Oil, Hydrocarbon

## Results*

| Fuel | Wall Fire Flame Height $\left(\mathrm{H}_{\mathrm{f}(\text { Wall })}\right)$ <br> $\mathrm{m}(\mathrm{ft})$ | Cable Tray <br> Impingement |
| :--- | :--- | :--- |
| Transformer Oil, <br> Hydrocarbon | $3.0(10.0)$ | Yes |

[^0]
## Spreadsheet Calculations

FDTs ${ }^{\text {s }} 04$ _Flame_Height_Calculations.xls (click on Wall_Flame _Height)

## CHAPTER 4. ESTIMATING WALL FIRE FLAME HEIGHT

## Version 18050

The tollow lig cala katbors estlo ate the wall fre name be bit
Parameters In YELLOW CELL S are Entered by the User.
Parameteri In GREEN CELLS are Automatically selected from the DROP DOWN MENU tor the Ruel selected.


The claptrit the NUREG stonklbe radbetore at analys $t$ made.

## INPUT PARAMETERS

FteISpill volume ( $($ )
FtelspillArea or DkeArea ( $A_{\text {ds }}$ )
Mass Euring Rate of Fiel (in)
Etectwe Heat of Combustbi orfiel ( $\Delta \mathrm{H}_{\mathrm{cm}}$ )
Empricalconstart (i/ $\beta$ )

| 2.00 | galbus | $0.076 \mathrm{~m}^{2}$ |
| ---: | :--- | :--- |
| $9 . .00$ | tt | $0836 \mathrm{~m}^{2}$ |

Calculate
THERMAL PROPERTIES FOR
BURHIMG RATE DATA FOR LIQUID HYDROCARBOH FUELS

| Fiel | Mass binlig Rat $\mathrm{m}^{\prime}$ ( $\mathrm{kg} \mathrm{m}^{2}-\mathrm{sec}$ ) | $\begin{array}{\|l} \text { Heator com bistiol } \\ \left.\Delta \mathrm{H}_{\text {caf }} \text { (.J. } \mathrm{Jgg}\right) \end{array}$ | EnplitalColstat $k \beta\left(m^{-1}\right)$ | Select Fuel Type <br> Tranatomar Cll. Hidocarber ${ }^{-}$ |
| :---: | :---: | :---: | :---: | :---: |
| Me tranol | 0.017 | 20,000 | 100 | Serdl to de slred fuel type then |
| Etranol | 0.015 | 26,800 | 100 | Click on selection |
| 8 tare | 0.078 | 45,700 | 2.7 |  |
| Berze ne | 0.085 | 40,100 | 2.7 |  |
| Hexare | 0.074 | 44,700 | 1.9 |  |
| Heptae | 0.101 | 44,500 | 1.1 |  |
| xylare | 0.09 | 40,800 | 1.4 |  |
| Ace tre | 0.041 | 25,800 | 1.9 |  |
| Dbxate | 0.018 | 26,200 | 5.4 |  |
| Detty Etrer | 0.085 | 34,200 | 0.7 |  |
| berzere | 0.048 | 44,700 | 3.6 |  |
| Gatolle | 0.055 | 43,700 | 2.1 |  |
| Kerosere | 0.039 | 43,200 | 3.5 |  |
| Desel | 0.045 | 44,400 | 2.1 |  |
| JP-4 | 0.051 | 43,500 | 3.6 |  |
| JP-5 | 0.054 | 43,000 | 1.6 |  |
| Trastomer Oll, Hydrocatbor | 0.039 | 46,000 | 0.7 |  |
| 561 Silvor Trastomer Fhkd | 0.005 | 28,100 | 100 |  |
| Fretoll, Heavy | 0.035 | 39,700 | 1.7 |  |
| Cride oll | 0.034 | 42,600 | 2.8 |  |
| Libe oll | 0.039 | 46,000 | 0.7 |  |
|  | Eiter Valte | Eitr IValte | Eter Valre |  |



## NOTE

The above calculations are based on principles developed in the SFPE Handbook of Fire
Protection Engineering. $3^{\text {nd }}$ Edition, 2002, and NF PAFre Frotection Handbook, 19 Edition, 2000.
Calculations are based on centain assumptions and have inherent imitations. The results of such calculations mayor maynd have reasonable predictive capabilities or a given stuation, and stould conlybe interpreted byan informed user.
Athough each calculation in the spreadshet has been verived with the resuts of hand calculation. there is no absolute guarantee of the acouracy ofthese calculations.
Any questions, corrments, concems, and suggestions, or to report an ermer's) in the spreadsheet,
please send an email to nxi@ne govormxs3 @enregov.


## 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 $30 \mathrm{ft}^{2}$. 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 ${ }^{\text {s }}$ ) Information:
Use the following $\mathrm{FDT}^{\text {s }}$ :
(a) 04_Flame_Height_Calculations.xls (click on Wall_Line_Flame _Height)

FDT ${ }^{\text {s }}$ Input Parameters:
-Fuel spill volume $(\mathrm{V})=15$ gallons
-Fuel Spill Area or Dike Area $\left(A_{\text {dike }}\right)=30.0 \mathrm{ft}^{2}$
-Select Fuel Type: Diesel, Acetone, and Methanol

## Results*

| Fuel | Wall Line Fire Height $\left(\mathrm{H}_{\mathrm{f}(\text { Wall Line })}\right)$ <br> $\mathrm{m}(\mathrm{ft})$ | Cable Tray <br> Impingement |
| :--- | :--- | :--- |
| Diesel | $3.8(12.3)$ | Yes |
| Acetone | $2.44(8.0)$ | No |
| Methanol | $1.2(3.8)$ | No |

[^1]Spreadsheet Calculations
FDTs: 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 Enteredbythe User.
Parameters in GREEN CELLS are Rutomatically Selected from the DROP DOWN M ENU for the Fuel Selected.
Al subsequent out ut values are calculated bythe spreadsheet and based on values specified in the input
parameters. This spreadstreet 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) | 1500 galbss | $0.0568 \mathrm{~m}^{3}$ |
| :---: | :---: | :---: |
| Fuel Spill Area or Dike Area ( $\mathrm{A}_{\text {sun }}$ ) | 3000 tt | $2.787 \mathrm{~m}^{2}$ |
| Mass Buming Pate of Fuel ( m ') | $0045 \mathrm{~kg} / \mathrm{m}^{2} \mathrm{fec}$ |  |
| Effective Heat of Combustion of Fuel ( $4 \mathrm{H}_{\text {cull }}$ ) | $44400 \mathrm{~kJ} . \mathrm{kg}$ |  |
| Empirical Constant (k $\beta$ ) | 2.1 m |  |

## Calculate

THERMAL PROPERTIES FOR
BURNING RATE DATA FOR LIQUID HY DROCARBON FUELS

| Fuel | Mass Buming Pate m ( $\mathrm{kg} / \mathrm{m}^{2}-\mathrm{sec}$ ) | Heat of Combustion $\stackrel{4}{ } \mathrm{H}_{\mathrm{can}}(\mathrm{k} \cdot / \mathrm{kg})$ | Empirical Constant $\mathrm{k} \beta\left(\mathrm{m}^{-1}\right)$ | Select Fuel Type <br>  |
| :---: | :---: | :---: | :---: | :---: |
| Methanol | 0017 | 20000 | 100 | Scroll to desired fuel type then |
| Ethanol | 0015 | 26800 | 100 | Click on selection |
| Butane | 0078 | 45,700 | 2.7 |  |
| Benzene | 0085 | 40,100 | 2.7 |  |
| Hexane | 0074 | 44,700 | 1.9 |  |
| Heptane | 0.101 | 44,600 | 1.1 |  |
| X y | 009 | 40800 | 1.4 |  |
| Acetone | 0041 | 25.800 | 1.9 |  |
| Dioxane | 0018 | 26.200 | 5.4 |  |
| Diethy Eher | 0085 | 34.200 | 0.7 |  |
| Benzene | 0048 | 44,700 | 3.6 |  |
| Gasoline | 0055 | 43,700 | 2.1 |  |
| Kerosene | 0039 | 43,200 | 3.5 |  |
| Diesel | 0045 | 44,400 | 2.1 |  |
| JP-4 | 0051 | 43500 | 3.6 |  |
| JP-5 | 0054 | 43000 | 1.6 |  |
| Transtormer Oil, Hydrocarton | 0039 | 46000 | 0.7 |  |
| 561 Silicon Transformer Fuid | 0005 | 28.100 | 100 |  |
| Fuel Oil, Heavy | 0035 | 39,700 | 1.7 |  |
| Crude Oil | 0034 | 42.600 | 28 |  |
| Lube Oil | 0039 | 46000 |  |  |
| User Speciled Value | Enter Value | Enter Value | Enter Value |  |

```
Heat Release Rate Calculation
    Petrerce:SFPEHivctook of R/ve Porection Exibeetrys 3'd Ection 2002, Puge 3-25.
    Q =m*\DeltaH
    Where }Q\mathrm{ -pooltle leat releace nt (kW)
    m* = mass bunligg ne ofthelpermits urtace area (kgin - &ec)
    \DeltaH
```



```
            k\beta= empircalconstant (m)
```



```
                                    Lkjiks with re katle vilgl thsi polit, lke tanstommer
                                    oll require bcalted leatigg b achleve ggritos)
    Pool Rre Clameter Calculaton
    A cive= = D 
    D=V (LA Astu/h)
    Where }\quad\mp@subsup{A}{\mathrm{ tha }}{}=\mathrm{ surtace area ot pooltre (m)
        D = poolfire damer (m)
    D= 1.884
        m
    Heat Release Rate Calculation
    Q =m"\DeltaH
    Q = 5452.02 kW 5177.01 Btusec
Heat Release Rate Per UnIt Lengthof Flre Calculation
    Q'=Q/L
    Where \quadQ'=leatelease rat perintlength (aW/m)
        Q = Tle leat revase ne ofthe fire (W)
        L = length of the fle sonme (m)
    Rre source Length Calculation
    LxW= A mun
    LxW= 2.787 m
    L= 1.669 m
    Q'=Q/L 
```

ESTIMATING LINE WALL FIRE FLAME HEIGHT
Pêerence:NFPAF/e Pratationtivithook, in Eation 2003 Page 3-134
$\mathrm{H}_{\text {swal } \operatorname{lng}}=0.017 \mathrm{Q}^{.2 \mathrm{al}}$
Where $\quad H_{\text {(inal ind }}=$ wall fire thame le gitt (in)
$Q^{\prime}=$ rat of leat pease pernitlestu of the fire kWin)
$\mathrm{H}^{-}=0.017 \mathrm{Q}^{\prime}$

| $\mathrm{H}_{\text {(ival lime) }}=$ | 3.75 m | 12.29 tt | Mnswer |
| :---: | :---: | :---: | :---: |

## NOTE

The above calculatons are based on pricples deve loped 1 the SFPE Handbook of Fire
 Catilatons are based on certal assmptbus and lave intere it im lations. The res itt of
 shonkivbe tepreedby an in med isem.
 there s so abs oltt graratee of the accu koy of these calcu tatbss.
Anyquestbis, comment, concens, andsiggestons, or beportan errors) the spreadsteet,



FDTs ${ }^{\text {s }}$ 04_Flame_Height_Calculations.xls (click on Wall_Line_Flame _Height)
(b) Acetone

## CHAPTER 4. ESTIMATING LINE FIRE FLAME HEIGHT AGAINST THE WALL

## Version 1805.0

The following calculations estimate the line fire flame height agairst the wall.
Parameters in YELL OW 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)
> Fuel Spill Asea or Dike Area ( $A_{d k e}$ )
> Mass Burning Rate of Fuel (m')
> Effective H eat of C ombustion of Fuel ( $\left.\Delta \mathrm{H}_{c, n n)}\right)$
> Empirical Corstant (k $\beta$ )

| 15.00 | gallons <br> $\mathrm{ft}^{\text {t }}$ <br> $\mathrm{kg}_{\mathrm{m}}{ }^{2}$-sec <br> k.alkg | $0.0568 \mathrm{~m}^{3}$ |
| :---: | :---: | :---: |
| 30.00 |  | $2.787 \mathrm{~m}^{2}$ |
| 0.041 |  |  |
| 25800 |  |  |
| 1.9 |  |  |

Calculate
THERMAL PROPERTIE S FOR
BURNING RATE DATA FOR LIQUID HYDROCARBON FUELS

| Fuel | Mass Burning Rate $\mathrm{m}^{\prime \prime}\left(\mathrm{k} \mathrm{g}^{\prime} \mathrm{m}^{2} \cdot \mathrm{sec}\right)$ | Heat of Combustion $\Delta \mathrm{H}_{\mathrm{c}, \mathrm{er}}(\mathrm{kJ} / \mathrm{kg})$ | Empirical Constant $\mathrm{k} \beta\left(\mathrm{m}^{-1}\right)$ | Select Fuel Type <br> Acetore |
| :---: | :---: | :---: | :---: | :---: |
| Methanol | 0.017 | 20,000 | 100 | Scrollto desired fuel typ' |
| Ethanol | 0.015 | 26.800 | 100 | Click on selection |
| 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 |  |
| Diocane | 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 | 48,000 | 0.7 |  |
| 561 Silicon Transformer Fluid | 0.005 | 28,100 | 100 |  |
| Fuel Oil, Heany | 0.035 | 39,700 | 1.7 |  |
| Crude Oil | 0.034 | 42,600 | 2.8 |  |
| Lube Dil | $0.039$ | $48,000$ | $0.7$ |  |
| User Specified Value | Enter Value | Enter Value | Enter Value |  |

```
Heat Release Rate Calculation
    Petrerce:SFPEHivctook of R/ve Porection Exibeetrys 3'd Ection 2002, Puge 3-25.
    Q =m*\DeltaH
    Where }Q\mathrm{ -pooltle leat releace nt (kW)
    m" = mass buning net ofthelpermits urtace area (kgin - &ec)
    \DeltaH
```



```
            k\beta= empircalconstant (m)
```




```
                                    oll require bcalted leatigg b achleve ggritos)
    Pool Rre Clameter Calculaton
    A cive= = D 
    D=V (LA Astu/h)
```



```
        D = poolfire damer (m)
    D= 1.884
        m
    Heat Release Rate Calculation
    Q =m"\DeltaH
    Q = 2865.94 kW 27 16.39 B tuec
Heat Release Rate Per UnIt Lengthof Flre Calculation
    Q'=Q/L
    Where \quadQ'=leatrepase rat perintergu(kW/m)
        Q = Tle leat revase ne ofthe fire (W)
        L= felgth of the fire sovrce (m)
    Rre Source Length Calculation
    LxW= A mun
    LxW= 2.787 m
    L= 1.669 m
    lol
```

ESTIMATING LINE WALL FIRE FLAME HEIGHT
Pêerence:NFPAF/e Pratationtivithook, in Eation 2003 Page 3-134
$\mathrm{H}_{\text {vad } \operatorname{lng})}=0.017 \mathrm{Q}^{.2 \mathrm{a}}$
Where $\quad H_{\text {(inal ind }}=$ wall fire thame le gitt (in)
$Q^{\prime}=$ rat of leat pease pertitlentu orthe nre kWm.
$\mathrm{H}^{2}=0.017 \mathrm{Q}^{\prime}$

| $\mathrm{H}_{\text {(ival lime }}=$ | 2.44 m | 8.00 tt |
| :--- | :--- | :--- |

## NOTE

The above calculatons are based on pricples deve loped 1 the SFPE Handbook of Fire
 Cabilatons are basedon certaln assmptbis and lave intere it limitatons. The res ite of
 shoukd ontbelteredby litomed iser.
 there $k$ so abs oltteguarante of the accu koy of these calcu latbis.
Anyquestbis, comment, concens, andsiggestons, orb reportal error(s) the spreadsleet, please send an emall bixuirggov ormxs3euregov.


FDT ${ }^{\text {s }}$ : 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 bythe User.
Parameters in GREEN CE LLS are Rutomatically Selectedfrom the DROP DOWN MENU for the Fuel Selected.
Al subsequent output values are calculated bythe spreadsheet and based on values specified in the input
parameters. This spreadstheet is protected and secure to a void 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) | 1500 galbas | $0.0588 \mathrm{~m}^{3}$ |
| :---: | :---: | :---: |
| Fuel Spill Area or Dike Area ( $\mathrm{A}_{\text {din }}$ ) | $3000 \pi$ | $2.787 \mathrm{~m}^{2}$ |
| Mass Burning Fate of Fuel (m') | $0017 \mathrm{~kg} / \mathrm{m}^{2}+$ ec |  |
| Effective Heat of Combustion of Fuel ( $4 \mathrm{H}_{\text {cut }}$ ) | 20000 kJ kg |  |
| Empirical Constant (k) | 100 m |  |

Calculate
THERMAL PROPERTIES FOR
BURNING RATE DATA FOR LIQUID HY DROCARBON FUELS

| Fuel | Mass Buming Fate m " $\left(\mathrm{kg} / \mathrm{m}^{2}-\mathrm{sec}\right)$ | Heat of Combustion $\stackrel{4}{4} \mathrm{H}_{\mathrm{can}}(\mathrm{k} \cdot / \mathrm{kg})$ | Empirical Constant $\mathrm{k} \beta\left(\mathrm{m}^{-1}\right)$ | Select Fued Type <br> Me thanol |
| :---: | :---: | :---: | :---: | :---: |
| Methanol | 0017 | 20000 | 100 | Scroll to desired fuel type then |
| Etranol | 0015 | 26800 | 100 | Click on selection |
| Butane | 0078 | 45,700 | 2.7 |  |
| Benzene | 0085 | 40,100 | 2.7 |  |
| Hexane | 0074 | 44,700 | 1.9 |  |
| Heptane | 0.101 | 44,600 | 1.1 |  |
| x ylene | 009 | 40.800 | 1.4 |  |
| Acetone | 0041 | 25800 | 19 |  |
| Dioxane | 0018 | 26,200 | 5.4 |  |
| Diethy Ether | 0085 | 34,200 | 0.7 |  |
| Benzene | 0048 | 44,700 | 3.6 |  |
| Gasoline | 0055 | 43,700 | 2.1 |  |
| Kerosene | 0039 | 43.200 | 3.5 |  |
| Diesel | 0045 | 44,400 | 2.1 |  |
| JP-4 | 0051 | 43500 | 3.8 |  |
| JP-5 | 0054 | 43000 | 1.6 |  |
| Transtormer Oil, Hydrocarbon | 0039 | 46.000 | 0.7 |  |
| 561 Silicon Transformer Fluid | 0005 | 28,100 | 100 |  |
| Fuel Oil, Heawy | 0035 | 39,700 | 1.7 |  |
| Crude Oil | 0034 | 42.600 | 28 |  |
| Lube Oil User Specired Value | O 0339 Enter Value | 46000 Enter Value | $0.7$ |  |

## Heat Release Rate Calculation


$Q=m m^{*} \Delta H_{\text {cat }}\left(1-e^{* \phi}\right) A_{c}$
Where $\quad Q$-pooltie leat releate ate kW)

$\Delta \mathrm{H}_{\mathrm{g}}=$ ettectre leat of combistbi oftrel (kJ kg)
$A_{1}=A_{\text {dw }}=s$ intace area of pool tire erea involed in vaporteaton) $\left(n^{2}\right)$
$k \beta=$ empircalconstant $\left(\mathrm{m}^{-}\right)$
 Lkikls with re katue wink thas polit ike tanstomer oll requ lre bcallued leatig to acheve kgithor)
Pool Rre Diameter Calculaton
$A_{\text {diel }}=\pi D^{2} / 4$
$D=V\left(4 A_{\text {dus }} / n\right)$
Where $\quad A_{\text {dise }}=$ surtace areaot pool fire $\left(\mathrm{m}^{2}\right)$
D = pooltire damer (n)
$D=\quad 1.884$
m
Heat Release Rate Calculation

$Q=\quad 947.61 \mathrm{~kW}$
898.16 Btakec

Heat Release Rate Per UnIt Length of Fire Calculation
$Q^{\prime}=Q / L$
Where $\quad Q^{\prime}=$ leat elease rat perintiengtu (kW/m)
$Q=$ tie leat release ne of the fire ( $W$ )
$\mathrm{L}=\mathrm{k} \mathbf{1} \mathrm{g} \mathrm{g} \mathrm{h}$ of the fire source (m)

Rre source Length Calculation
$\mathrm{L} \times \mathrm{W}=\mathrm{A}_{\mathrm{san}}$
$\mathrm{L} \times \mathrm{W}=\quad 2.787 \mathrm{~m}^{2}$
$\mathrm{L}=\quad 1.669 \mathrm{~m}$
$\begin{array}{ll}Q^{\prime}=Q / L & \\ Q^{\prime}= & 567.62 \mathrm{~kW} / \mathrm{m}\end{array}$

ESTIMATING LINE WALL FIRE FLAME HEIGHT
Peierence:NPPAF/e Practionihivtiook, $9^{n}$ Eation 2003 Page 3-134
$\mathrm{H}_{\text {swal } \operatorname{lng}}=0.017 \mathrm{Q}^{.2 a}$
Where $\quad H_{\text {(ual inm }}=$ wall fire thame le gitt (in)
$Q^{\prime}=$ rat of leat e lease pernitestu of the fire $k W h \mathrm{~m}$
$\mathrm{H}_{\text {inad inmil }}=0.017 \mathrm{Q}^{\prime}$


## NOTE

The above calculathos are based on princples deve bped the SFPE Handbook of Fire
 Catilatbis are based on certal assimptbis and lave intere it im lations. The res itt of
 shonkivbe tepreedby an in med isem.
 there $k$ absolite grarante of the accu koy of these calcu lations.
Anyquestbis, comment, concens, andsiggestons, orb reportan errors) the spreadsteet, please se ud an emall $u x$ uenrgov ormxs3eurcgov.


## 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 $10 \mathrm{ft}^{2}$. 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 $\mathrm{FDT}^{\text {s }}$ :
(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 $\left(\mathrm{A}_{\text {dike }}\right)=10 \mathrm{ft}^{2}$ -Select Fuel Type: Diesel

## Results*

| Fuel | Corner Fire Flame Height $\left(\mathrm{H}_{\mathrm{f}(\text { Corner })}\right)$ <br> $\mathrm{m}(\mathrm{ft})$ | Junction Box <br> Impingement |
| :--- | :--- | :--- |
| Diesel | $6.4(21.1)$ | Yes |

*see spreadsheet on next page

## Spreadsheet Calculations

FDTs ${ }^{\text {s }} 04$ _Flame_Height_Calculations.xls (click on Corner_Flame _Height)

CHAPTER 4. ESTIMATING CORNER FIRE FLAME HEIGHT
Version 1805.0
The tollowing cakitators estim ate the coner fire tiame le kit
Param eters in YELLOWCELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically selected tom to DROP DOWN MENU for the Fuel selected.


The claptill the NUREG s torkibe read be tore at anal/sk is made.

## INPUT PARAMETERS

| FielSpilvohme (V) | 1.50 | galbes | 0.0051 m |
| :---: | :---: | :---: | :---: |
| Fielspllarea or Dke Area ( $A_{\text {dsw }}$ ) | 10.00 | t | $0.929 \mathrm{~m}^{2}$ |
| Hass Einlig Rat of Fiel (n) | 0.045 | $\mathrm{kgm}^{2}-\mathrm{sec}$ |  |
| Etectlve Heatotcombistor of Fiel ( $\Delta \mathrm{H}_{\text {cul }}$ ) | 44400 | kJkg |  |
| Emplricalconstant ( $\beta$ ) | 2.1 |  |  |

Calculate


## Heat Release $R$ ate Calculation

Reference: SFPE Herolbook of Fire Protection Engineering, $3^{\text {nf }}$ Edition, 2002, Page 3-25.
$Q=m " \Delta H_{c, R \pi}\left(1-e^{+F D}\right) A_{T}$
Where $\quad Q=$ pool fire heat release rate ( kN )
$m^{\prime \prime}=\mathrm{mass}$ burning rate of fuel per unit surface area ( $\mathrm{kg} \mathrm{m}^{2}{ }^{2}$-sec)
$4 H_{c, R} \pi=$ effective heat of combustion of fuel ( $\mathrm{kJ} / \mathrm{kg}$ )
$A_{t}=A_{\text {dke }}=$ surface area of pool fire (area involved in vaporization) $\left(\mathrm{m}^{2}\right)$
$\mathrm{k} \beta=$ empirical constant $\left(\mathrm{m}^{-1}\right)$
$D=$ 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
$A_{\text {dke }}=\pi D^{2 / 4}$
$D=V\left(4 A_{\text {dke }} / \pi\right)$
Where $\quad A_{d k e}=$ surface area of pool fire $\left(m^{2}\right)$
$D=$ pool fire diamter (m)
$D=1.088 \quad m$
Heat Release Rate Calculation
$Q=m " H_{c, R \pi}\left(1-e^{+5}\right) A_{\text {dke }}$
$\mathrm{Q}=\quad 1667.09 \mathrm{~kW} \quad 1580.10$ Etuisec

## ESTIMATING CORNER FIRE FLAME HEIGHT

Reference: Hesemi and' Tohmaga, 'Modeling of Tubulent Difiusion Rames and' Fre Plumes fr the Aralysis of Five Growh,"
Growth,' Procee ding of the $21^{\text {th }}$ 伯tonal Heat Transter Comerence. Ame rican Society of Mechanical Engineers (ASME), 1983.
$\mathrm{H}_{\text {toone! }}=0.075 \mathrm{Q}^{35}$
Where $\quad Q=$ heat release rate of the fire ( KN )
$\mathrm{H}_{\text {thoner) }}=0.075 \mathrm{Q}^{30}$
$\mathrm{H}_{\text {ticaner })}=\quad 6.43 \mathrm{~m} \quad 21.10 \mathrm{ft}$

## NOTE

The above calculations are based on principles developed in the SFPE Handbook of Fire Protedion Engineering, $3^{\text {El }}$ Edition, 2002 and Hesemi and T okunage, 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 in formed 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 the se calculations.
Any questions, comments, concerns, and suggestions, or to report an error(s) in the spreadsheet, please send an email to $n \times i\left(\begin{array}{l}\text { nrc.gov or } m \times 33 @ n r c . g o v . ~\end{array}\right.$



[^0]:    *see spreadsheet on next page

[^1]:    *See spreadsheets on next page

