Texas Commission On Environmental Quality

INTEROFFICE MEMORANDUM

To: APD Technical Staff Date: September 10, 2004

From: Dom Ruggeri, P.E., Team Leader
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Subject: Technical Basis for Flare Parameters

This memo provides the technical basis for default and derived flare stack parameters used in screening and refined modeling demonstrations. Please refer questions to Keith Zimmermann or Karianne Kurth.

Background.

Because of the design and operation of a flare, it is difficult to obtain the necessary input parameters for atmospheric dispersion modeling. A large open flame radiates a significant portion of the heat of combustion associated with a flaring gas stream. The buoyancy of the combustion gases will be related to the remaining sensible heat of the flare gases. The modeling strategy developed in the late 1970's focused on two methods to determine the buoyancy flux component, F, of plume rise. One method uses a traditional point source type characterization with user-provided stack diameter, exit temperature, diameter, and exit gas velocity to determine the value of F. In this method, the heat release of the flared gas is used to derive an equivalent stack diameter while the temperature and velocity are fixed. This method must be used with the Environmental Protection Agency (EPA) Industrial Source Complex (ISC3) model since there are no specific input options for a flare. The second method was developed for the flare source type characterization. In this method, the user provides the heat release from the flare and the model internally uses a fixed temperature and velocity to calculate the effective diameter. Either method can be used with the SCREEN3 program.

Method 1. Derivation of Equivalent Stack Parameter.

In this method, developed by the Texas Air Control Board (TACB) and the EPA in the late 1970's and early 1980's, stack parameters are derived such that a buoyancy flux parameter calculated by the model will be equivalent to the actual buoyancy flux of the flare's combustion gases. The buoyancy flux parameter equation, used by the ISC3 and SCREEN3 models to calculate plume rise (Δh), requires four variables: stack temperature (T), ambient temperature (T_a), stack gas velocity (v), and stack diameter (d) (Equation 1). Another form of the buoyancy flux equation that is not programmed into the models requires only the heat (assumed to be all sensible) of the stack gases to calculate buoyancy flux (Equation 2). If the heat of the stack gases is known and if three of the four variables are fixed, then the remaining variable in Equation 1 can be found. In Method 1, the stack temperature, ambient temperature, and stack exit velocity are fixed. Therefore, the equivalent stack diameter for a flare can be found by taking the two buoyancy flux equations and solving for diameter, d (Briggs, 1969):

$$F = (gvd^2 / 4) \ [(T - T_a) / T] \qquad (1)$$

$$F = (3.7 \times 10^{-5}) \ q_n \qquad (2)$$

Where:

F = buoyancy flux (m^4/s^3)
g = acceleration due to gravity (m/s^2)
v = stack gas exit velocity (m/s)
d = stack diameter (m)
T = stack temperature (K)
T_a = ambient temperature (K)
q_n = net heat release (sensible heat) (cal/s)

In order to determine an equivalent stack diameter, set the two equations equally to each other. To solve for diameter, hold all other variables in the first equation constant.

$$(3.7 \times 10^{-5})\ q_n = (gvd^2 / 4)\ [(T - T_a) / T] \qquad (3)$$

A default value of T = 1273 K is a reasonable value to use for the exit temperature of the flare. Based on a typical range of ambient temperatures in Texas, T_a could vary between approximately 0 ˚C and 40 ˚C (273 K and 313 K) (TACB, 1979).

In order to avoid stack-tip downwash, use $v \geq 1.5u$ (Briggs, 1969), where u = wind speed (m/s). Since Texas rarely has continuous wind speeds greater than 30 miles per hour (mph), set u = 30 mph. Solve to get v = 45 mph, or 20.12 m/s. Set v = 20 m/s as a reasonable substitute variable for the exit velocity.

The TCEQ method to determine an equivalent stack diameter uses the following default values: v = 20 m/s, T = 1273 K, and let T_a = 308 K (35˚C). The ambient temperature is chosen to provide a reasonable, conservative estimate of plume rise. When holding all other variables in Equation 1 constant, the difference between buoyancy flux component values calculated for T_a = 0 ˚C and T_a = 40 ˚C is 4 percent (TACB, 1979). The value for q_n is determined from the gross heat release (total heat of combustion of gases going to the flare) using the following formula (Tan, 1967):

$$q_n = q\ (1 - 0.048\ \sqrt{(MW)}) \qquad (4)$$

Where:

q_n = net heat release (sensible heat) (cal/s)
q = gross heat release (cal/s)
MW = mean molecular weight of stream going to the flare (g/gmole).

Now, solving Equation 3:

$$(3.7 \times 10^{-5})\ q_n = [(9.8)(20)d^2 / 4]\ [(1273 - 308) / 1273] \qquad (5)$$

The result is:

$$q_n = (1003906)\ d^2 \qquad (6)$$

Solve for d and get:

$$d = 10^{-3}\ (q_n)^{½} \qquad (7)$$

The default values for velocity, temperature, and diameter are used by the model to calculate the amount of plume rise (Δh) above the flare's flame tip. The effective plume height (H_e), that is, the height of the centerline of the plume above the ground, is the flare height plus the calculated amount of plume rise (Δh) using the velocity, temperature, and diameter defined in this method. In the TCEQ method, no additional plume height is considered for the length of the flame.

$$H_e = H_s + \Delta h \qquad (8)$$

Where:

H_s = physical height of the flare (m)
Δh = plume rise above the top of the flare (m)

In summary, the relationship between the stack diameter and the heat release is based on reasonably assumed parameters for the conditions of a flare. It may be appropriate to deviate from the conservative TCEQ parameters for real-world, episodic events. *If a deviation is made from the parameters assumed in the TCEQ method, then one must derive a new relationship between stack diameter and heat release.* For example, using Equation 7 to determine diameter while using a velocity other than 20 m/s would result in errors in the modeling results. This method is referenced in the User's Guide to the Texas Climatological Model (Aug. 1980), App. C and the User's Guide to the Texas Episodic Model (Oct. 1979), App. E.

Method 2: Direct Input of Flare Parameters to SCREEN3.

The EPA SCREEN3 version contains an option for the direct input of flare parameters. The screening model requires only the height of the flare (m), the emission rate (g/s), and the total (gross) heat release of the flare. The program code within the SCREEN3 program assumes stack parameters as defined below in the method developed by EPA.

The EPA method used in SCREEN3 to determine an equivalent stack diameter uses net heat release determined by the following equation:

$$q_n = (0.45)\ \ q \qquad (9)$$

Where:

q = gross heat release from the flare (cal/s) input by the user
q_n = net heat release from the flare (cal/s)

Equation 9 is documented in the SCREEN3 User's guide. Experimental data provided support for EPA's assumption that 55 percent of the gross heat released from the flare is radiative and only the remaining 45 percent of the gross heat released is sensible and remains available for plume rise (Leahey, 1984).

The following default values are internally used in the SCREEN3 program: $v = 20$ m/s, $T = 1273$ K, and $T_a = 293$ K, or 20 °C (SCREEN3 User's Guide). Equation 3 can be solved using these values to obtain Equation 10 below. Equation 10 is similar to Equation 7, TCEQ's method for determining stack diameter.

$$d = 9.88 \times 10^{-4} (q_n)^{½} \qquad (10)$$

Where:

q_n = net heat release (cal/s) as defined in Equation 9

The EPA SCREEN3 model uses these values for velocity, temperature, and diameter to calculate the amount of plume rise (Δh) above the flare's flame tip.

The physical release height of the flare is adjusted in the EPA method by adding the calculated length of the flame to the height of the top of the flare structure, using the formula:

$$H_a = H_s + [(4.56 \times 10^{-3}) (q^{0.478})] \qquad (11)$$

Where:

H_a = Adjusted flare height (m)
H_s = Physical flare height (m)
q = gross heat release (cal/s) input by the user

This formula is from an American Petroleum Institute (API) publication providing a plot of flame length vs. heat release and is summarized in Fundamentals of Stack Gas Dispersion (Beychok, 1979). The above equation is then derived from the API publication's simple assumption that the flare tilts at 45 degrees. The flame length is added to the physical flare height to obtain the adjusted flare height. This equation also is referenced in the SCREEN3 FORTRAN source code within the file named SCREEN3A.FOR.

The effective plume height (H_e), that is, the centerline of the plume above the ground, is the adjusted flare height summed with the calculated amount of plume rise (Δh) using the velocity, temperature, and diameter defined in this method.

$$H_e = H_a + \Delta h \qquad (12)$$

The effective plume height (H_e) is the height the model uses for the centerline of the Gaussian distribution of concentration. A greater effective stack height will result in lower ground level concentrations. Adding a flame length to the height of the flare results in a greater effective stack height which will produce a less conservative ground level concentration.

Summary

The two methods for modeling flares are comparable. In the original TCEQ method development, the net heat released from the flare is calculated based on the mean molecular weight of the stream going to the flare. This approach tends to result in approximately 50-75 percent of the gross heat released from the flare contributing to plume rise. No addition to the plume height is considered for the length of the flame. In addition, the TCEQ method assumes a conservative ambient temperature of 308 degrees K.

In the EPA method, the radiant heat from the flare is always assumed to be 55 percent of the gross heat release, regardless of what gas stream is going to the flare. This approach leaves only 45 percent of the gross heat release of the flare available for plume rise. This would result in a reduced amount of plume rise. This is somewhat offset by the EPA assumption that the release height of the flare should be adjusted by adding a value representing the length of a flame tilted at 45 degrees. In addition, the EPA method assumes an ambient temperature of 293 K.

The ISC3 model does not have an option for the direct input of the gross heat release from a flare. A set of pseudo-stack parameters must be calculated in order to use the ISC3 model to estimate downwind concentrations from a flare. For consistency, we prefer that the TCEQ method be used to determine stack parameters for screening modeling as well. However, it may be appropriate to deviate from the conservative TCEQ parameters in order to obtain representative concentrations for real-world, episodic events.

References

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