

Technical Note

Inverse Square Law - Flame

1998-1022 Rev 1 12/18

Purpose:

Applying the Inverse Square Law to Flame Detection Applications

Inverse Square Law - Overview

Definition of the Inverse Square Law:

The principle in physics that the effect of certain forces on an object varies by the inverse square of the distance between the object and the source of the force. The magnitude of light, sound, and gravity obey this law, as do other quantities. For example, an object placed three feet away from a light source will receive only one ninth ($1/3^2$, the inverse of 3 squared) as much illumination as an object placed one foot from the light.

inverse-square law. (n.d.). The American Heritage® Science Dictionary. Retrieved January 8, 2018 from Dictionary.com website <http://www.dictionary.com/browse/inverse-square--law>

The application is much the same for Electro-Optical Flame Detectors, in that the 'light source' is a Fire and the 'object' is a Flame Detector. However, since fire is a random and chaotic phenomenon of combustion, and not a constant steady source, the application of the inverse square law is an approximation, even though the formula for its calculation is precise.

Graphic view:

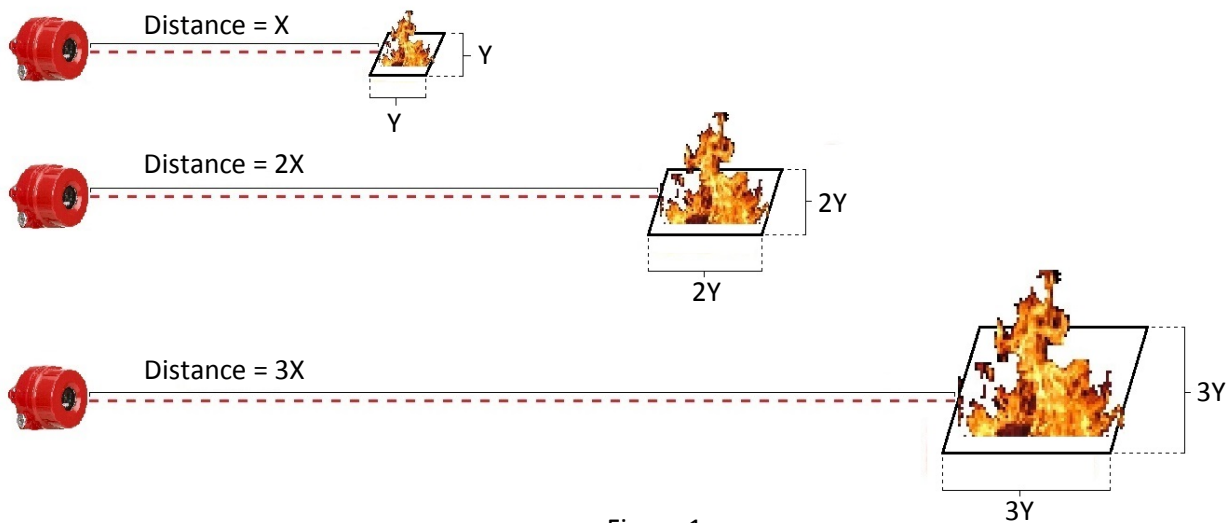


Figure 1

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The topmost Flame Detector in Figure 1 will alarm to the 1st Fire at a distance of X. The area (or size) of the 1st Fire is Y². We need to understand the *distance coefficient* to calculate the new fire sizes for the other cases. The *distance coefficient* is new distance divided by the original or reference distance. The reference distance in the Figure 1 is X and the new distances are 2X and 3X, respectively. In the middle case $2X \div X = 2$, so the distance coefficient for the second fire is 2. We multiply the sides of the pan of the original fire by this distance coefficient to obtain our new fire size (the product of 2Y and 2Y is 4Y²). We calculate the third case using the same method: $3X \div X = 3$, so the distance coefficient for the third fire is 3. We multiply the sides of the pan of the original fire by this distance coefficient to obtain our new fire size (the product of 3Y and 3Y is 9Y²).

The Inverse Square Law for magnitude of light (radiant energy from a Fire) is typically expressed using a square pan Fire, which is optimal for fuels that are in a liquid state at ambient temperatures.

This is fine for square pan Fires. What about other Fires shapes?

For non-square rectangular pan fires, apply the distance coefficient to both non-equal sides of the rectangular pan.

EXAMPLE:

Fire Size = 2 ft. X 3 ft.

Detection Distance = 40 ft.

We want to see this fire at 80 feet.

The distance coefficient is $80 \div 40$ or 2

The new fire size will need to be 4 ft. by 6 ft.

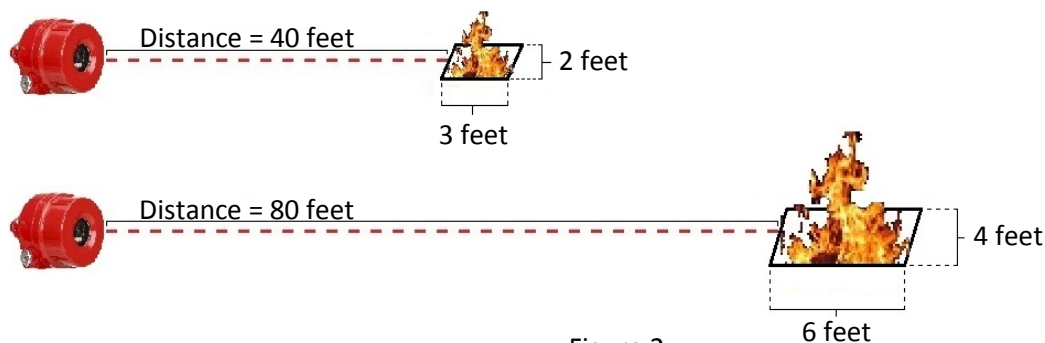


Figure 2

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Sometimes, fires from liquid flammable fuels are tested using a round pan instead of a square or a rectangular pan. For round pan fires, apply the distance coefficient to the diameter of the pan.

EXAMPLE:

Fire Size = 4 inch diameter

Detection Distance = 10 ft.

We want to see this fire at 30 feet.

The distance coefficient is $30 \div 10$ or 3

The new pan diameter will need to be 12 inches.

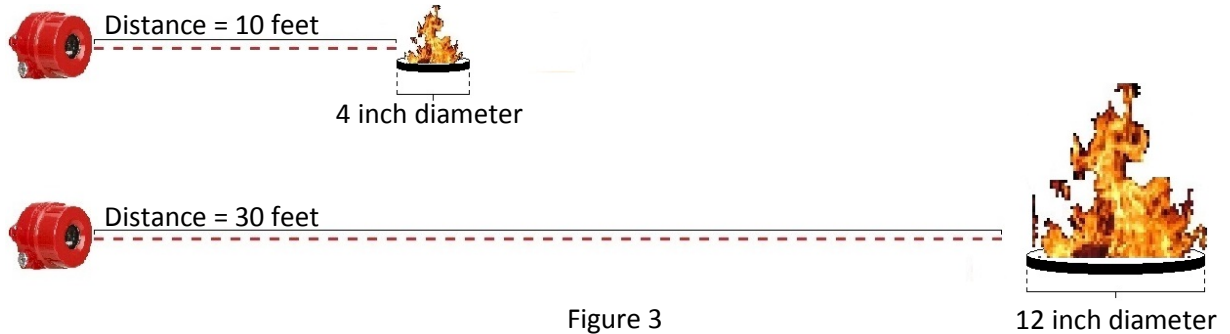


Figure 3

12 inch diameter

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For a Plume Fire, such as with Silane, Hydrogen, Methane, and other fuels that are in a gaseous state at ambient temperatures, the application of the distance coefficient is applied differently. Gaseous Fires that Honeywell defines are typically $\frac{3}{8}$ inch width by 32 inches high or in some cases 48 inches high. Usually, the new Plume Fire will need to have the same width. In other words, the new Plume fire will need to have a $\frac{3}{8}$ inch width also, and only the fire height will change. To accomplish this, the square of the distance coefficient should be applied to the Fire Height.

EXAMPLE:

Fire Size = $\frac{3}{8}$ inch X 32 inches

Detection Distance = 50 ft.

We want to see this fire at 75 feet.

The distance coefficient is $75 \div 50$ or 1.5

The new fire height will need to be 32 inches X (1.5^2) or 72 inches.

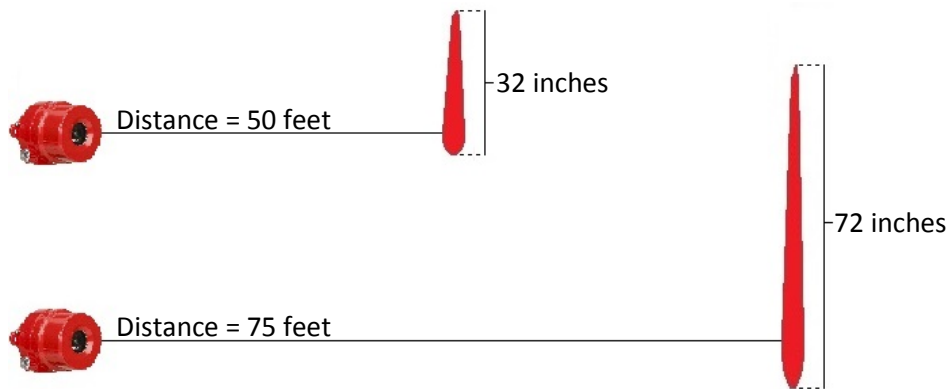


Figure 4

One of the problems with Plume Fires is that the flame shape is irregular and has a rapid expanse near the bottom, tapering up slowly as the flame reaches the peak of its height (see Figure 5), and is therefore not exactly $\frac{3}{8}$ X 32 or $\frac{3}{8}$ X 48.

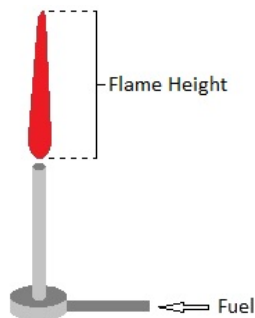


Figure 5

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Conversions

We may want to convert one fire shape to the equivalent of another fire shape, to provide an accurate comparison. One manufacturer may use a square pan fire and another a round pan fire, for example. Here are some steps to convert the Fire Shapes previously discussed in this document to a square pan fire, and vice versa.

Square to other fire shapes:

1. Calculate the area of a square pan fire by squaring the length of a side.
2. Divide the area of the square pan fire by:
 - a. For rectangular pan fires, divide by a given side of the rectangular pan to find the length of the other side of the rectangular pan.
 - b. For round pan fires, divide by π (approximately 3.141592654); take the square root of this result and multiply by two (2) to obtain the approximate diameter of an equivalent round pan fire.
 - c. For plume fires, divide by $\frac{3}{8}$ or 0.375 to obtain the approximate height of an equivalent plume fire.

Rectangle to other fire shapes:

1. Calculate the area by multiplying two non-equal sides of a rectangular pan fire.
2. Divide the area of the rectangular pan fire by:
 - a. For square pan fires, do not divide, take the square root of the rectangular pan fire area to determine the length of each side of an equivalent square pan fire.
 - b. For round pan fires, divide by π (approximately 3.141592654); take the square root of this result and multiply by two (2) to obtain the approximate diameter of an equivalent round pan fire.
 - c. For plume fires, divide by $\frac{3}{8}$ or 0.375 to obtain the approximate height of an equivalent plume fire.

Round to other fire shapes:

1. Calculate the approximate area of a round pan fire using πr^2 to calculate, where ' π ' is approximately 3.141592654 and ' r ' is the radius of the pan.
2. Divide the area of the round pan fire by:
 - a. For square pan fires, do not divide, take the square root of the round pan fire area to determine the approximate length of each side of an equivalent square pan fire.
 - b. For rectangular pan fires, divide by a given side of the rectangular pan to find the approximate length of the other side of the rectangular pan.
 - c. For plume fires, divide by $\frac{3}{8}$ or 0.375 to obtain the approximate height of an equivalent plume fire.

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Plume to other fire shapes:

1. Calculate the approximate area of a plume fire by multiply $\frac{3}{8}$ or 0.375 by the height of a plume fire.
2. Divide the approximate area of a plume fire by:
 - a. For square pan fires, do not divide, take the square root of the round pan fire area to determine the approximate length of each side of an equivalent square pan fire.
 - b. For rectangular pan fires, divide by a given side of the rectangular pan to find the approximate length of the other side of the rectangular pan.
 - c. For round pan fires, divide by π (approximately 3.141592654); take the square root of this result and multiply by two (2) to obtain the approximate diameter of an equivalent round pan fire.

There are many other factors that will affect the actual detection distance. Here is a partial list of factors:

- Sunny, cloudy, partially cloudy
- Position of the Sun and the Detector facing
- Fog, mist, steam, rain
- Aspirated dirt, dust, and other debris
- Cleanliness of the optics
- Cleanliness of the application
- Reflected energy

Nevertheless, applying the inverse square law to a pan fire or a plume fire will always yield an approximate result.

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