A Look at Gas Infrared Heaters

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Gas infrared emitters are used in a range of process applications, including paint and powder curing, paper and coating drying, and heat setting. Here's a look at the basics behind this heater type.

The mission of a gas infrared emitter, or heater, is to convert the chemical energy in a fuel gas such as natural gas to thermal radiation to perform useful work in a range of industrial operations. Some of the typical applications for gas infrared emitters include:

- Drying paper and coatings on paper.
- Drying heat-set ink.
- Heating flooring products.
- Drying and heat-setting textiles.
- Curing coatings on carpet backs.
- Glass annealing.
- Paint drying.
- Flowing and curing powder coatings.

The process starts when the fuel gas is mixed with air and delivered to the emitter. What happens next makes the difference between excellent or poor radiant performance, but first, the basics.

The Basics

Gas infrared emitters are used to dry and cure coatings on paper and other web-based products.

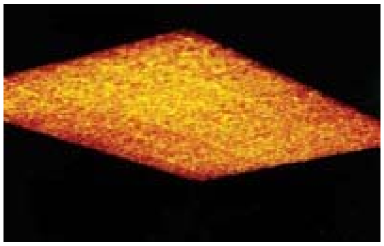
A simplified formula for the stoichiometric (ideal fuel gas/air ratio) combustion of methane (natural gas typically is more than 90 percent methane) and air is:

$CH_4 + 2\ O_2 + 7.52\ N_2$ --> $CO_2 + 2\ H_2O + 7.52\ N_2$ + trace elements + heat

Most combustion processes require some excess air due to imperfect mixing and rapid combustion. In addition, excess air minimizes carbon monoxide emissions and ensures the fuel is completely consumed. A natural gas flame has a low infrared emittance and a low mass. The energy emitted in the form of infrared by a natural gas flame is reported to be less than 5 percent of the gross energy content of the flame.1 This means the hot products of combustion (CO_2, H_2O and N_2) must transfer a portion of their sensible energy to heat the infrared emitter by forced convective heating. Raising the emitter's temperature causes it to emit useful quantities of infrared.

Simple Infrared Emitter Demonstration

Infrared heat flux principles can be demonstrated with an ordinary wood kitchen match. Caution should be used to prevent injury if trying this demonstration. Strike a common wood kitchen match and hold it vertically with the flame at the top. When the chemical flareup subsides and just the wood is burning, a finger can be held within about 0.1875" to the side (not the top) of the flame with no danger of burning because the flame emits little infrared. However, as the flame burns down the stalk, the hot gas molecules from the flame, rising by natural convection, transfer enough of their energy to the matchtip to cause the tip to glow red and emit infrared. Now, the finger must be moved away to prevent burning. As the flame continues burning down the stalk, the rising hot gas molecules diffuse into the surrounding air at the matchtip location so they no longer heat the tip sufficiently, and the tip stops glowing.



Operating at full rated power, this Embedded Combustion radiant emitter reportedly has 98.7 percent radiant area per unit area.

This simple demonstration teaches that:

- A flame must transfer its energy to a gas infrared emitter by convection to produce useful quantities of infrared.
- The flame and emitter must be positioned correctly to obtain the best heat transfer results.

Non-sooty gas flames, by themselves, emit very little infrared.

Heat Transfer Modes

Heat transfer from fluid molecule to fluid molecule or from fluid molecule to a solid surface, on the molecular scale, is achieved either by convection or electromagnetic waves (that is, infrared). The match demonstration showed that a flame has a poor infrared emittance, so heat transfer from a flame is mostly by convection, not infrared. The effectiveness, or rate of convective heat transfer between gases and surfaces, increases proportionally as you increase one or more of the following:

- Contact surface area.
- Temperature differential (delta T) between the hotter gases and the colder surface.
- Contact time.
- The convection coefficient, which is a function of the geometry, gas velocities and gas properties.

To maximize the conversion to radiation efficiency and to reduce the formation of NOX, an infrared emitter must limit the actual combustion temperature and minimize the temperature differential (delta T) between the emitter and the products of combustion being exhausted. The reason for this is quite simple: The higher the temperature of the gaseous products of combustion (exhaust) leaving the emitter, the greater the heat content of these gases. The total heat content of the exhaust gases leaving the emitter, and all other losses, must be subtracted from the gross heat input to the emitter to get the maximum amount of energy remaining to heat the emitter to produce infrared. The energy remaining to heat the emitter after subtracting the exhaust energy and other losses often is called available heat.2

A large internal surface area and more contact time between the hot combustion gases and the emitter structure improve the convective energy transfer, reducing the temperature difference (delta T) between the emitter and the exhausted combustion products. Thermal NO_X increases exponentially with temperature. Above about 2,000^{o}F (1,093^{o}C), it is generally the predominant mechanism for forming NOX in the combustion process.3

Additionally, for maximum gas infrared emitter performance, the emitter's emittance should be as high as possible. An emitter's emittance is defined as the actual infrared output of a real emitter compared to that of a theoretical black body emitter operating at the same temperature. A perfect black body emitter has an emittance of 1.0 (100 percent) and emits the maximum possible infrared at any given temperature over all wavelengths.3 Actual emitters emit infrared at a percentage less than 100 percent. Black body ratings indicate infrared output, so the higher an emitter's emittance, the higher its infrared output at a given temperature.

Another important infrared emitter design criteria is to maximize the actual radiant area per emitter overall area. This is accomplished first by the emitter material and emitter structure design and second by minimizing frames, clips, holes, gaps and other non-radiating or lower temperature-radiating items from the emitter face.

References

- 1. B. Ji and C.E. Baukal, "Spectral Radiation Properties of Oxygen-Enhanced/Natural Gas Flame Radiation," *Proceedings of the 1998 International Gas Research Conference,* 8-11 November 1998, San Diego, Dan Dolenc (ed.), Vol. 5, p. 422-433, 1998.
- 2. C.E. Baukal, *Heat Transfer in Industrial Combustion*, CRC Press, Boca Raton, Fla., 2000.
- 3. U.S. Environmental Protection Agency, "Nitrogen Oxide Control for Stationary Combustion Sources," U.S. EPA report EPA/625/5-86/020, 1986.
- 4. R. Siegel and J.R. Howell, *Thermal Radiation Heat Transfer*, 4th Edition, Taylor & Francis, New York, 2001.

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