Direct-Fired Vapor for Concrete Curing

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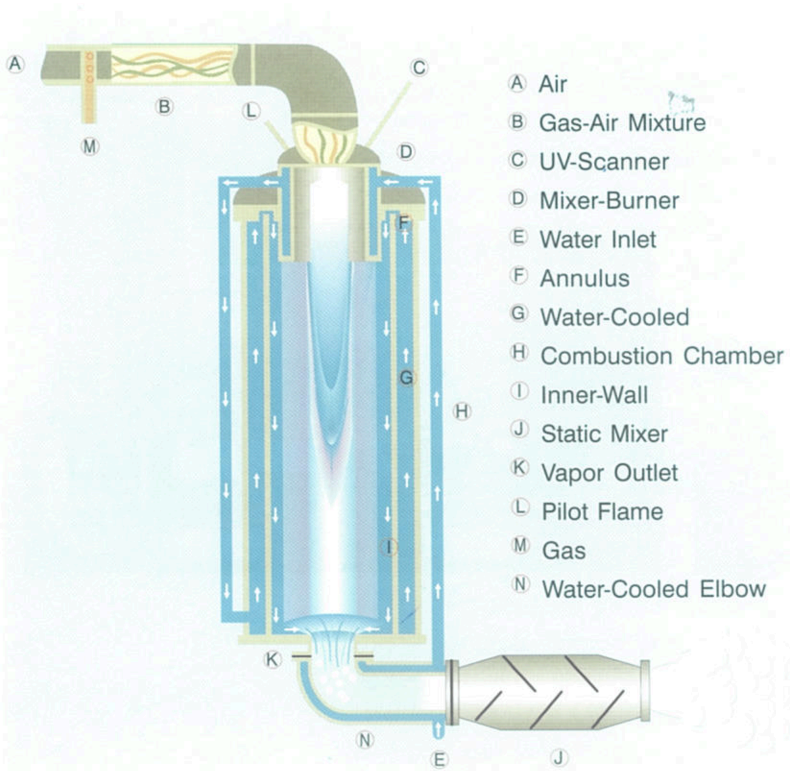
Vapor is used in the precast concrete industry for the accelerated curing of precast concrete products including concrete pipe, prestressed structural concrete, concrete block, ornamental concrete, cast stone and assorted precast concrete products.

Vapor provides the necessary heat and moisture to accelerate the curing process vis a via the hydration process, providing quicker production times and a reduction in the amount and/or type of cement. Since the introduction of direct-fired vapor and its many benefits, more and more concrete producers are using direct-fired vapor to accelerate the curing of concrete in their operations.

Fig.1



Production of Direct-Fired Vapor

Figure 1 is a schematic representation of the direct-fired vapor generation process. In the system shown in Figure 1, air and fuel (natural gas or propane) are introduced into a pre-mix burner where they mix together as they travel toward the combustion chamber. The air is supplied under pressure from a positive displacement blower. The fuel is also supplied under pressure, either directly from the customer's gas line, or through some type of pressure boosting system.

Once the air/fuel mixture reaches the combustion chamber, a temporary pilot is used to ignite the mixture and the resulting flame burns down through the center of the combustion chamber. On this particular unit, water is metered through the burner to cool it, and then flows into the combustion chamber where it flows over and down the inner wall. Upon reaching the bottom plate of the chamber, the water is directed to the smaller exhaust opening where it is vaporized into vapor by the hot products of combustion (which are at a temperature of 1092°C [2000°F] or more) as they are forced to exit through the same opening. Upon exiting the chamber, the products may then flow through a static mixer which helps to insure a more homogenous mixture of water vapor and the products of combustion which are N_2, CO_2, some excess O_2 and generally a small amount of CO and NOx. This resulting mixture of vapor

and flue gases is referred to as direct-fired vapor. The products of combustion present in the direct-fired vapor are the same ones found in any conventional gas fired oven in your home.
Once the process is initiated, the pilot can be turned off, and as long as the proper amounts of air, fuel and water are supplied, vapor is produced. The equipment is rated in millions of BTU's per hour rather than boiler horsepower (1 boiler horsepower = 33.479 BTU/hr= 9,8 kW/hr). Fig. 2 shows a single speed VaporMite vapor generator.

Vapor Temperature Control

Unlike a conventional boiler which must conform to the steam curve, a direct-fired vapor generator can produce either saturated or superheated vapor at low vapor pressures. This is accomplished by controlling the amount of water that is introduced into the combustion chamber and thus into the products of combustion. For a given burner output, as more water is introduced into the process, the vapor/flue gas temperature drops. As less water is allowed to enter the process, this temperature rises. Consequently, a direct-fired system can produce either saturated or superheated vapor without affecting the steam pressure (operating pressure) or the total energy output of the unit.
Table I shows the amount of water present in 1.0 MMBTU's (300 kW) of direct-fired vapor based on 20 % excess air in the initial air/fuel mixture. On this chart, the total amount of water present in the vapor is greater than the amount of water added to the combustion chamber by the amount of water vapor formed in the combustion process. As mentioned earlier, the vapor temperature is determined by the amount of water added to the combustion products and is not, in general, dependent on the vapor pressure. Thus, all of these vapor temperatures are available to a direct-fired unit at any vapor pressure between 0 and 700 mbar (0 and 10 psig) at sea level.

Fig. 2

Table I.

Amount of water present in direct-fired vapor at various vapor temperatures for a 1.0 MMBTU/hr (300 kW/hr) direct-fired vapor generator

Vapor Temperature °C	Vapor Temperature °F	Kilograms of Water Added to Combustion Products*	Pounds of Water Added to Combustion Products*	Total Kilograms of Water in Vapor*	Total Pounds of Water in Vapor*
104.34	220	356.01	784.88	398.68	878.95
109.89	230	353.95	780.34	396.62	874.41
115.44	240	351.91	775.83	394.58	869.9
120.99	250	349.91	771.42	392.57	865.48
126.54	260	347.95	767.11	390.62	861.18
132.09	270	346.04	762.9	388.71	856.97
137.64	280	344.18	758.8	386.85	852.87
143.19	290	342.37	754.79	385.03	848.86
148.74	300	340.59	750.87	383.26	844.94
154.29	310	338.89	747.12	381.56	841.19
159.84	320	337.19	743.39	379.86	837.46
165.39	330	335.57	739.82	378.24	833.89
170.94	340	334.03	736.41	376.7	830.48
176.49	350	332.52	733.08	375.19	827.15
182.04	360	331.08	729.91	373.75	823.98
187.59	370	329.68	726.82	372.35	820.89
193.14	380	328.34	723.88	371.01	817.95
198.69	390	327.08	721.09	369.75	815.16
204.24	400	325.85	718.39	368.52	812.46
209.79	410	324.77	716.01	367.44	810.08
215.34	420	323.7	713.65	366.37	807.72
220.89	430	322.73	711.5	365.4	805.57
226.44	440	321.82	709.49	364.49	803.56

* Based on Unit Output of 1.0 MMBTU (300 Kw/h)
* Incoming Air, Water and Fuel Temperature Assumed at 15,5°C (60° F)
* Based on 20 % Excess Air in the Air/Fuel Mixture

Vapor Pressure and Dew Point of Direct-Fired Vapor

In general, the vapor pressure in a direct-fired system is determined by several factors such as the size and length of distribution piping, the amount of vapor flowing through the piping, and by the restrictions created by any valves, elbows, tees, or other fittings in the piping network. Since the steam temperature does not depend on the pressure, it is not necessary to maintain any specific pressure within the piping in order to achieve a particular vapor temperature.

In most cases, it is desirable to keep the vapor pressure as low as possible due to several factors. First, the lower the pressure the less danger there is of someone being burned due to a leak. Also, the air and fuel supplied to the burner must be at a pressure somewhat greater than the vapor pressure in order for the unit to operate. As the pressure rises for any particular vapor output rate, more motor horsepower is required in order to drive the air blower and more fuel pressure is required.

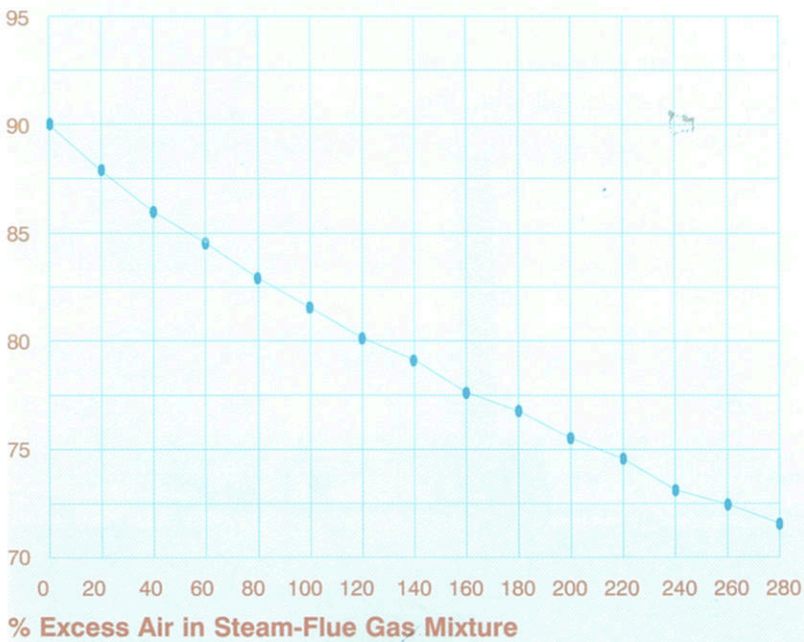
While the pressure does not affect the vapor temperature of direct-fired vapor, it does affect the "dew point" of the vapor/flue gas mixture. The "dew point" is the temperature at which the vapor starts to condense out of the products of combustion. Since most of the heat is carried in the vapor and not in the non-condensible flue gases, it is not the actual steam temperature but rather the "dew point" of the steam that determines the maximum temperature to which a product can efficiently be heated using direct-fired vapor.

For conventional boiler steam at sea level and atmospheric pressure, the dew point is about 100°C (212°F). Thus under atmospheric conditions, (1 bar_{abs} [14.69 psia] atmospheric pressure), the maximum achievable product temperature with a conventional boiler is 100°C (212°F). If a higher temperature is required, the product must be heated under pressure with the required pressure being determined from the steam curve. For example, if a product must be heated to 121°C (250°F) at sea level with boiler steam, the steam must be allowed to condense under a pressure of 2,09 bar_{abs} (29.82 psia [absolute pressure]). It must be remembered that it is the absolute pressure and not simply the gauge pressure that determines the temperature at which the steam will condense since the atmospheric pressure changes with changes in elevation. As the atmospheric pressure drops, the maximum attainable temperature under atmospheric conditions drops and more pressure is required to reach the same final temperature. At an elevation of 914 meters (3000 feet) above sea level, the atmospheric pressure has dropped to about 0,925 bar_{abs} (13.16 psia) and the boiler steam must be condensed under a pressure of at least 1,188 bar (16.9 psig) (2,09 bar_{abs} - 0,925 bar_{abs} [29.82 psia - 13.16 psia]) in order to achieve a product temperature of 121°C (250°F) or 105 mbar (1.5 psig) (1,03 bar_{abs} - 0,925 bar_{abs} [14.69 psia - 13.16 psia]) to achieve a temperature of 100°C (212° F).

The dew point of direct-fired vapor is determined by the vapor temperature the amount of excess air in the vapor/flue gas mixture, and by the pressure at which the vapor is condensed. Thus a change in elevation affects the dew point of direct-fired vapor in much the same way as it affects the dew point of conventional boiler steam. The particular vapor temperature affects the actual dew point by only about

1,64°C (3°F) for any particular elevation and pressure with a higher vapor temperature tending to lower the dew point.
The amount of excess air in the vapor is one of the most important factors affecting the dew point of direct-fired vapor. Figure 3 shows the dew point of the vapor versus the percent of excess air in the combustion process. As the chart shows, even with no excess air, the dew point of the vapor is about 89,4°C (193°F) at sea level and atmospheric pressure. This is caused by the fact that the other combustion products such as N_2, CO_2, etc. help to dilute the vapor and thus lower the dew point. In general, the direct-fired vapor generator operates with a maximum of 20 - 25 % excess air which correlates to a dew point of about 87,7°C (190°F). Thus, with a direct-fired system operating at sea level, the maximum achievable product temperature under atmospheric conditions would be about 87,7°C (190°F). If it is desired to heat the product to a higher temperature, say 93,24°C (200°F), this can be accomplished by pressurizing the conditioning vessel or heat exchanger and allowing the vapor to condense under pressure. For a product temperature of 93,24°C (200°F) under the conditions listed above, the vapor would need to be condensed under a pressure of at least 1,314 bar_{abs} (18.69 psia [4.0 psig]) at sea level.
Most direct-fired vapor generators are designed for producing low pressure (< 1,05 bar [< 15 psig]) vapor. Therefore, the maximum attainable temperature will be limited to the dew point at the maximum vapor pressure the unit can produce. Some manufacturers do make special, high pressure units for use in applications requiring higher temperatures.

Fig. 3
Dew Point of Directed-Fired Steam vs. % Excess Air at Sea Level



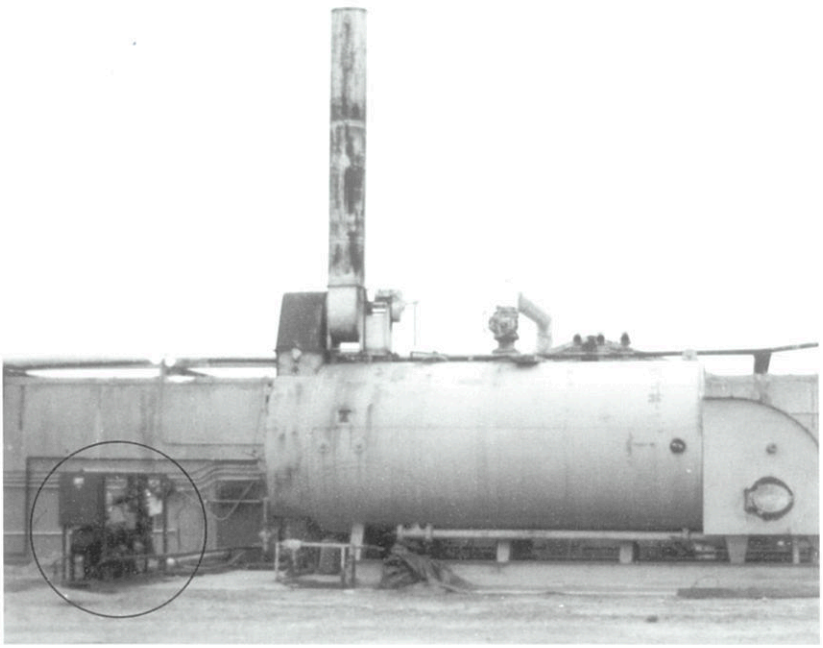
- Based on a steam temperature of 104° C (220° F)
- 21° C (70° F) incoming air and natural gas
- 37,7° C (100° F) temperature rise-boiler

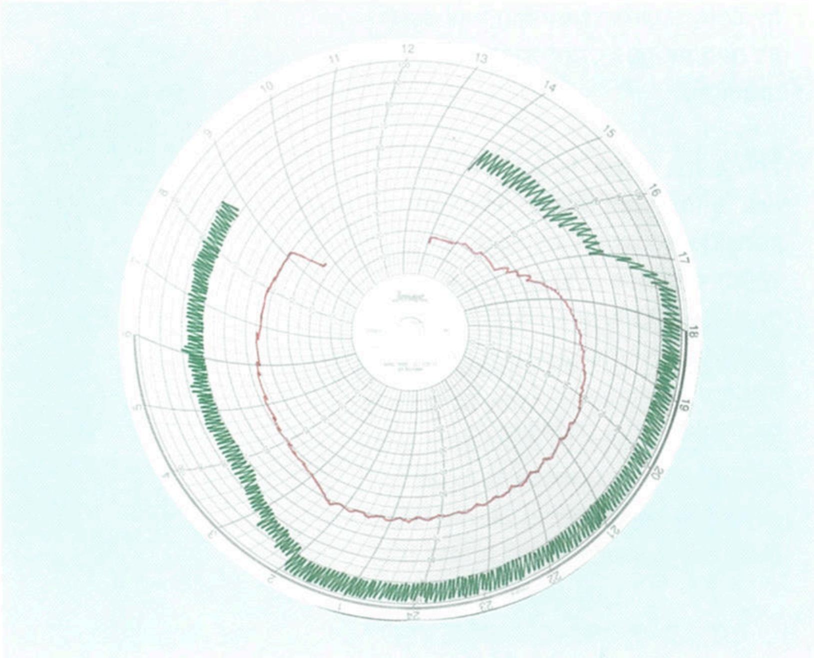
The Direct-Fired Accelerated Concrete Curing Systems

When a hydrocarbon fuel such as natural gas or propane is burned, one of the products of combustion will be water which is present in the form of superheated vapor. If the temperature of the combustion products drops low enough, the water vapor (steam) formed in the combustion process starts to condense. The temperature at which this occurs is called the "dew point". As the products of combustion are cooled further below the dew point, more and more water will be condensed. Any water that is condensed will give off an amount of heat known as the heat of vaporization. The heat of vaporization for water at sea level is about 970 BTU/lb (0,127 kW/kg). That means that for every pound of water that can be condensed out of the products of combust-

ion, 970 BTU's (0,127 kW/kg) will be recovered. If the water remains in the vapor state (as in the boiler stack or a car's exhaust), this energy is lost.
All hydrocarbon fuels have both a high and a low heating value. The low heating value is the amount of heat that the fuel can provide if all of the water formed in the combustion process remains in the vapor state. The high heating value is the amount of heat the fuel can supply if all of the water formed in the combustion process is condensed. For natural gas, the high heating value is 11 % greater than the low heating value. For propane, the high heating value is 9 % greater.
In a conventional boiler system, the stack temperature is purposely kept well above the dew point of the combustion products. This is done for two reasons. First, the water formed in the combustion process is typically very acidic and will quickly corrode the boiler stack and other parts if allowed to condense. Second, if the water is allowed to condense, it can run back into the burner and causes combustion problems. Since the temperature of the combustion products is kept above the dew point, the maximum achievable efficiency is governed by the low heating value of the fuel.
In order to operate economically, a direct-fired vapor generating system must be able to take advantage of a portion of the high heating value of the fuel. In order to accomplish this, the vapor/fuel gas mixture must be cooled to a low enough temperature to condense not only the water added to the combustion products to produce the vapor, but also condense a portion of the water formed in the combustion process. The most efficient means of doing this in a batch flow process such as concrete curing is with direct contact atmospheric vapor.

In operation, the freshly cast concrete product is surrounded by an enclosure such as a kiln, insulated vinyl tent or insulated vinyl curing cover. This enclosure should provide for the reduction of heat loss through the membrane as well as through openings to the outer atmosphere to increase the energy efficency of the curing operation. Within the enclosure is a vapor distribution system that may be either a simple hose or a pipe with varying sized distribution holes to provide for even heat throughout even a 200 m long concrete product. Once the enclosure is in place, the curing cycle, following the





prescribed industry standards, is ready to commence.
The curing system may be operated manually or through the use of an automatic controller that measures temperature and time. Manually, the system is operated by a supervisor who measures the temperature of the concrete and, based on this reading, turns the vapor generator on-off. After the prescribed number of hours the vapor generator is turned off and the curing enclosure removed to provide access to a fully cured ready to be stored concrete product.
Manual operation requires the prescence of a supervisor to make sure that the concrete follows the prescribed curing cycle. Automatically, the supervisor places a temperature probe under the enclosure, near the concrete product. The vapor generator is placed in the automatic mode and the curing controller is turned on. At this point the supervisor may leave and not return until the curing cycle is completed. The temperature probe measures the concrete temperature and sends this information to the curing controller, which compares the measured temperature with the required temperature. Based on this comparison the curing controller turns the vapor generator on-off until the curing cycle is complete. At this time the enclosure may be removed and the concrete product is ready for handling.

Advantages and Disadvantages of a Directed-Fired Vapor Generator

There are many items to consider when installing any type of vapor process system. The intent here is to list some of the major advantages and disadvantages associated with a direct-fired vapor generating system. The major advantages of a direct-fired system are as follows:

- Since the direct-fired vapor generator is a low pressure device, most boiler codes and restrictions do not apply, and a full-time operator may not be required for the unit.

- They take up much less floor space than a conventional boiler of comparable output.

- For operations such as concrete curing, the direct-fired system is 40 - 60 % more efficient than a conventional boiler system due to lower radiant heat losses, reduced stack losses, no idling cost or long warm-up period, and the ability of this type of system to utilize a portion of the high heating value of the fuel.

- Water treatment costs are lower than for a boiler system.

- Insurance rates are generally lower due to the low pressure operation of these units.
- Maintenance costs are typically

lower than those for a conventional boiler which must be retubed every few years.

- Since they operate only when vapor is required, the total amount of emissions produced by a direct-fired system is approximately 40 - 60 % less than that produced by a boiler.

While there are many advantages associated with the use of direct-fired vapor, there are also some disadantages. Some of the disadvantages are:

- The minimum amount of vapor that can be supplied to the process is limited by the turn-down of the burner. In a boiler system, the minimum amount of steam that can be supplied is limited only by the capabilities of the process steam valve. However, this is not a concern for most concrete curing processes.

- A direct-fired vapor generator requires larger distribution piping than a conventional boiler of a comparable output. Consequently, it is not typically possible to simply replace an existing boiler with a direct-fired system without making some distribution piping changes. Sometimes, however, this possibility does exist.

- Existing shell and tube heaters and steam heaters for building heat will not operate off of the direct-fired vapor generator in most cases. A small steam boiler is usually required for any processes such as these.

- Most direct-fired systems will not allow for the burning of diesel or other liquid fuels. Since the vapor is generally in direct contact with the product being heated, a clean burning fuel such as natural gas or propane is required.

- The items listed here are only a few of the pros and cons to be considered when installing any vapor process system. Each must be carefully evaluated in order to determine which type of system is best suited for a particular plant or process.

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