

RESIDENTIAL GAS FURNACE HEAT EXCHANGER TESTING

By: Douglas De Werth P.E.

INTRODUCTION

Gas furnaces have earned a reputation for safe, reliable performance. Steps have been taken in designing these furnaces to prevent flue products from leaking into the home environment. However, in those situations where a heat exchanger has become excessively cracked or corroded, it is possible for some undesirable flue gas to leak into the circulating air system. For most furnace types, excluding those with power burners, such leakage can occur only for short, intermittent portions of the operating cycle. Leakage can occur in furnaces with power burners whenever the burner is on, because the flue gases are generally at a higher pressure than the circulating air side of the heat exchanger. If left uncorrected, defective heat exchangers can become a hazard and affect the comfort and well being of the building's occupants.

Currently there are several procedures in use to detect leakage from a heat exchanger; for example, visual examination, smoke bombs, odor tracing and salt spray, as well as commercially available kits such as Leak-Seek (lithium citrate traced through the heat exchanger). The effectiveness of these methods has been evaluated. Some have undesirable side effects, such as accelerated heat exchanger corrosion caused by salt spray. Other test methods are overly sensitive. It is important that the test method is not so severe that it detects minute, inconsequential openings, since this could induce a homeowner to replace a sound furnace unnecessarily.

Some of these methods are partially successful, but the results of most either are suspect and/or have undesirable side effects. In an effort to obtain a better technique, the Gas Appliance Manufacturer's Association (GAMA) initiated a research project in 1980 which was continued with support from the Gas Research Institute (GRI).

The research program involved:

- review and evaluation of all existing leak detection methods,
- determination of normal furnace operating conditions from the standpoint of pressure differences across the heat exchanger, and
- development and field testing of an acceptable, improved test procedure.

An accurate and reliable heat exchanger leak detection method has been developed. This method was field tested by seven utilities during the 1982-83 heating season.

REVIEW OF EXISTING LEAK DETECTION PROCEDURES

Gas equipment servicemen use a variety of procedures in attempts to identify potentially dangerous leaks in furnace heat exchangers. The procedures are used in response to service calls for:

- odors

- fluttering burner flames
- suspected cracked heat exchanger
- sooted heat exchanger
- routine service

Thirteen different procedures were identified after surveying utility companies. Many of these methods do not give reliable results, thus two different methods are often used by a serviceman at the job site. Some of the methods are also corrosive to the heat exchanger and metal parts of the furnace. Other methods are performed under unrealistic conditions (such as increased pressure in the heat exchanger); some can result in an unsafe or unpleasant environment; some are so sensitive that they indicate leakage even in new heat exchangers.

One of the most common methods used is a visual inspection of the heat exchanger with a mirror and a strong light. The serviceman must then make a value judgment as to whether any cracks or holes he finds are large enough to warrant replacement of the furnace. Generally any fault is reason for recommending that the home owner obtain a second opinion of the need for replacement of the heat exchanger.

The use of smoke bombs is the second most common practice. With the flue outlet and burner access opening blocked, a smoke bomb or candle is ignited in the heat exchanger. Observations for smoke are then made in the circulating air side of the heat exchanger. When the bomb is activated, a positive pressure is created inside the heat exchanger, forcing the smoke out of even very small cracks. This makes the test very sensitive. Precautions are also needed with this method so the smoke does not get into the house where it may stain certain paints fabrics and tiles.

An air analysis test may be used in addition to the smoke test. This test detects combustion products in the circulating air stream as an indirect indication of heat exchanger cracks. If high readings are obtained, there is no doubt that the heat exchanger has a crack or fault. With slight increases a more thorough examination of the heat exchanger may be required. The drawbacks of this method are that it is complicated and time consuming to perform, and the detection device is expensive.

Odorants, such as sulfur candles and oil of wintergreen have been used for detecting leaks. A small quantity of the odorant is introduced into the combustion side of the heat exchanger; the hot air registers in the house are then checked for the characteristic odor. Any odor in the circulating air would indicate a heat exchanger leak. With the sulfur candle this test can be quite reliable, but very unpleasant smelling. The wintergreen is more pleasant but the odor clings to the servicemen's hands and clothes, making the test unreliable.

Another test procedure is to release a small amount of carbon monoxide (CO) in the hot heat exchanger and then check for high concentrations of CO in the circulating air stream. The detector needed for this method is expensive and the use of CO is dangerous.

Refrigerant has been used as a tracer gas with a halogen leak detector. Refrigerant vapor is released in the combustion side of the heat exchanger and if the halogen detector senses halogens in the circulating air stream, a leak is present. A problem with this method is that phosgene gas (a deadly poison) can be generated if the refrigerant passes through a flame. Additionally, refrigerant is heavier than air.

A spray can of fluorescent solution is marketed which is sprayed onto a heat exchanger with a suspected leak and penetrates even the finest crack. The crack is then detected using an ultraviolet light; however, the heat exchanger must be accessible for close examination of all surfaces.

The American National Standards for Gas-Fired Central Furnaces (Z21.47-1978) outlines a test method using a fuming or smoking material such as titanium tetrachloride. The material is introduced into the combustion chamber, and if combustion products are discharged through door cracks or other openings, their presence will be revealed by observing the smoke. A drawback to this method is that titanium tetrachloride is very corrosive.

Another widely used procedure involves spraying a sodium salt solution into the burner flames and checking the circulating air stream with a propane torch for the presence of sodium ions. If the blue flame of the torch turns yellow, this indicates the presence of sodium ions and a leak. As the solution is sprayed into the burner flame, visual inspection of the heat exchanger surface below the burner port level is needed. If a solution of sodium chloride (table salt) is used, corrosion of the heat exchanger can be accelerated. Sodium bicarbonate salt solutions, on the other hand, are non-corrosive. The drawbacks to the sodium ion tracing method are that dust in the air can be mistaken for the sodium ion and acceptable leakage's may be detected, since the test is very sensitive.

A procedure similar to sodium ion tracing is to trace for lithium ions. A halide leak detector flame is used that turns red in the presence of lithium ions. A lithium citrate salt solution is sprayed into the flame. A distinctive red/purple flame indicates lithium ions. The drawback of this procedure is that, like the sodium ion trace procedure, it is very sensitive and will identify acceptable leakage.

All of these methods have some undesirable drawbacks. The ideal method for detecting the leakage of flue gases into the circulating air stream would not be harmful to the furnace components or the home environment would be performed under realistic operating conditions, and would not detect small amounts of acceptable leakage.

DEVELOPMENT OF THE IMPROVED THREE - STEP METHOD

FURNACE HEAT EXCHANGER PRESSURE MEASUREMENTS

The preceding covered the results of a survey aimed at identifying procedures for determining flue gas leakage into the circulating air stream. One drawback cited for some tests, for example the smoke bomb test, was that it was performed under unrealistic furnace operating conditions. This test causes higher than normal pressures in the furnace heat exchanger. The pressure drop across the furnace heat exchanger surface has a significant effect on the tendency of flue gases to pass from one side of the exchanger to the other. Only if the flue gas side is more positive than the circulating air side will there be a tendency for flue gases to leak into the circulating air through any cracks or corrosion holes in the heat exchanger.

In order to determine the actual operating pressure inside and outside of the heat exchanger, measurements were made with four furnaces with typical heat exchangers. Two of the furnaces were equipped with atmospheric burners, one with an induced draft system, and the fourth with a power burner. Flue gas pressure taps were attached at two inch intervals up the side of the heat exchanger from the burner port to the flue outlet. Circulating air taps were located adjacent to the flue gas taps. Pressure measurements were taken with and without the circulating air blower in operation. The results showed that with atmospheric burners the average pressure on the flue gas side with the burners operating is about 0.02 inch water column (WC). The average pressure on the circulating air side of the heat exchanger is 0.3 inches WC when the blower is operating. Thus the air side of the heat exchanger is more positive than the flue gas side when the circulating blower is on. If there were a hole, leakage would be from the air side to the flue gas side. When the blower is off the air side pressure is less positive than the flue gas side and leakage would occur from the flue gas side to the air side. This condition exists only during the short heat up period before the blower comes on.

An induced draft system has a negative pressure of about 0.2 inch WC or less on the flue gas side of the heat exchanger at all times. The flue products are drawn through the combustion chamber causing the flue gas side always to be under a negative pressure. A positive pressure on the air side of the heat exchanger, caused by the circulating air blower, further insures that the flue gases stay in the combustion chamber.

With a power burner system the flue gas side of the heat exchanger must have a positive pressure of as much as 0.4 inch WC. Thus, the pressure on the flue gas side is more positive than the air side, whether the circulating air blower is on or off. The only exception is the top of the heat exchanger where the circulating air blower would impinge directly on the heat exchanger. The air side pressure would be more positive than the flue gas side at those points. If there were a hole or crack, flue gases would leak into the circulating air stream at all times, except if the hole or crack was located at the top of the heat exchanger.

To summarize: In a furnace with atmospheric burners, flue gases could only leak into the circulating air system through a hole or crack during the time the blower was not operating. Induced draft furnaces would not allow any leakage through the heat exchanger as they operate under a negative pressure. A power burner system is more critical in that the flue gas side of the heat exchanger is always more positive than the circulating air side when the furnace is operating. Thus, if there were a hole or crack, flue gases could leak into the circulating air stream.

THIS ANALYSIS OF FLUE GAS LEAKAGE BASED ON THE PRESSURE DIFFERENCE ACROSS THE HEAT EXCHANGER IS TRUE FOR RELATIVELY SMALL HOLES. FOR HEAT EXCHANGERS WITH LARGE PERFORATIONS, FLUE GASES MAY LEAK REGARDLESS OF THE PRESSURE DIFFERENTIAL. Large perforations would be detected by a thorough visual observation of the heat exchanger or by the flame pattern. No further test procedure would then be needed.

A method for detecting flue gas leakage through a furnace heat exchanger should not be administered at a pressure higher than what is found under normal operating conditions. Doing so would detect minuscule leaks allowed by the ANSI Standards, because it is almost impossible to construct a hermetically sealed heat exchanger. Even continuous welding used to construct clamshell type systems may result in pin holes along the weld. These pin holes may leak a very small amount of flue gas that would be insignificant from the standpoint of indoor air pollution. Any method developed for detecting leakage through a furnace heat exchanger should not be so sensitive that it detects the leakage from those small pin holes.

MINIMUM HOLE SIZE ALLOWABLE

Since it is almost impossible to construct a heat exchanger that is entirely air tight, any test method developed to detect flue gas leakage needs to have quantitative aspects. It would not be desirable to identify as unacceptable any heat exchanger leakage that meets the requirement for heat exchanger joints according to the American National Standards. The standards for Gravity and Fan Type Direct Vent Wall Furnaces (Z21.44-1981), and for Direct Vent Central Furnaces (Z21.64- 1978), requirement for tight joints in heat exchangers is met if the combustion chamber-vent section does not leak more than 2% of the flue gases.

MAXIMUM LEAKAGE ALLOWED

After conservatively determining that the minimum hole size representing an unacceptable condition was a 1/8 inch diameter hole, it was necessary to select the maximum CO concentration to be allowed in the flue gases leaking through the 1/8 inch hole. A 100% safety factor was used on the maximum 400 ppm air-free CO allowed by the American National Standards for Furnaces, Z21.47- 1983. Thus, 200 ppm air-free CO was used as the reference for detection.

THE THREE - STEP METHOD FOR DETECTING UNACCEPTABLE FLUE GAS LEAKAGE FROM FURNACE HEAT EXCHANGERS

EQUIPMENT NEEDED:

- Combustible Gas Detector, properly calibrated. (64 ppm methane equivalent for the specific instrument used in the field test).
- Tracer gas mixture of 14.3 percent methane in nitrogen. This mixture is available from specialty gas distributors and should be obtained in a cylinder size that can easily be carried by a service person.
- Single stage regulator/flowmeter (0-30 cfh) that can be adapted to fit the specialty gas cylinder.
- Stainless steel tubing for injection probe, 1/4 inch I.D., of appropriate length.
- Calibration gas for gas detector - (200 ppm CO in nitrogen was used in the field test.)

Before leaving for service calls each day, the calibration and battery strength of the combustible gas detector should be checked.

In the following text, the term "repair" is intended only to mean the tightening of fasteners such as sheet metal screws, etc., or gasket replacement.

STEP 1

The first step is a visual examination of the heat exchanger. Clean any loose particles that may be built up on visible surfaces of the heat exchanger. Make this examination utilizing a mirror and a strong flashlight by inspecting the internal sections for signs of split seams, open cracks and severe deterioration. Examine joints between flue gas passages of the heat exchanger and other parts of the furnace. If construction is such that a portion of the heat exchanger or radiator is in the cold air return compartment, special care should be given when examining these parts.

Access for visual inspection of the heat exchanger is frequently limited by evaporator coils, etc., therefore a removable inspection plate, access panel or heat register on the plenum would be helpful to visually examine the exchanger from the air side of the heat exchanger. Any visible crack or hole in the heat exchanger is a reason for requiring replacement of the heat exchanger.

STEP 2

The next step is to ignite the pilot and main burner and observe the flame pattern before and after the blower is turned on. Observe the flame pattern for floating flames and flame roll-out or any flame distortion. These observations indicate a possible split seam, open crack, severe deterioration of the heat exchanger or mechanical separation of the heat exchanger from the jacket. Disturbance of the flame by the blower is a reason for requiring repair or replacement of the heat exchanger.

STEP 3

In preparation for conducting the CH₄ tracer procedure of the method an access to the air side of the system is needed. Use a warm air register in the plenum of the furnace or open a suitable size hole in the plenum about 3 inches from the top of the heat exchanger. If it is not possible to achieve 3 inches, any opening as close to the heat exchanger as possible will be acceptable; however, more time must be allowed for a reaction. If there are air conditioning cooling coils, the hole should be on the heat exchanger side of the coils, if possible. If not, drill the hole as close to the top of the coil as possible. In the case of downflow furnaces, the blower compartment should be accessible; and, for horizontal furnaces, both the blower compartment or warm air outlet will be used depending on the duct configuration.

With the access opening prepared carry out the following procedure:

1. Allow the furnace to operate at least 5 minutes, and then quickly conduct the rest of the procedure while the heat exchanger is warm.
2. Check the vent connector for any blockage.
3. Turn off the main burner and pilot and the power supply to the unit.
4. Insert the gas detector probe into the selected access opening in the plenum and null out any background disturbance.
5. Place the injector probe for the tracer gas in the bottom of a heat exchanger section. Adjust the flow rate of the tracer gas to seven (7) cubic feet per hour (cfh). Maintain this flow rate through the balance of the test. For multiple section heat exchangers do one section at a time.
6. As the heat exchanger is flooded move the gas detector probe to cover the top of the heat exchanger section for at least 2 minutes.

7. If an unacceptable leak is present the calibrated indicator light will go on during the 2 minute period:
 - If the tick rate increases during the probing period, but the light does not go on, there is no unacceptable leak. But it may be desirable to further investigate if the tick rate increase is substantial.
 - If the light goes on, the leakage rate is unacceptable and the source of the leak should be investigated by further probing. This is a reason for requiring repair or replacement of the heat exchanger.
8. Repeat above procedure (Nos. 5 through 7) with remaining heat exchanger sections.
9. Any access openings made in the furnace plenum to conduct the test must be closed or sealed.
10. If no reason for corrective action is indicated, relight the pilot and turn the furnace back to its ready condition in accord with the manufacturer's rating plate or instructions. Seal the hole in the plenum with a small piece of sheet metal.

NOTES ON EQUIPMENT AND PROCEDURE

TRACER GAS

A mixture of 14.3 percent methane in nitrogen is used as the tracer gas because this mix cannot be diluted with air to obtain a combustible mixture. The United States Department of Interior Bulletin 279, "Limits of Inflammability of Gases and Vapors", shows that any mixture less than 14.3 percent methane in nitrogen never forms an explosive mixture.

Industrial gas cylinder distribution companies can supply the tracer gas mixture in a cylinder size that servicemen can easily carry into a house.

FLOW METER AND REGULATOR

A single stage flow meter (0-30 cubic feet per hour)/regulator combination was used on the tracer gas cylinder. This allows the flow of the tracer gas to be adjusted to a rate similar to what would be seen in actual furnace operation. About seven cfm of tracer gas is proper for a typical sectional furnace. A length of Tygon tubing carries the gas from the regulator to the injection probe, which is a piece of 1/4inch diameter stainless steel tubing approximately twelve inches long.

COMBUSTIBLE GAS DETECTOR

A combustible gas detector that can be calibrated to emit a signal when the maximum leakage rate of the tracer gas is detected, must be used. The instrument used in this study had a series of lights and an alarm which indicated different levels of combustible gases. The initial "SLIGHT" light and the "ALARM" could be adjusted separately to respond to any selected combustible gas concentrations. A flexible probe 18 inches long allowed detection across most of the top of the heat exchanger.

TRACING TECHNIQUE

The tracer gas must be injected below the burner(s)) in order to detect any heat exchanger holes or cracks at, above or below the burner port level. The rate of injection can be adjusted to develop a flow through the heat exchanger similar to what might occur during actual operation of the burner. The method is conducted close to the actual pressure conditions established through the laboratory pressure measurements made on the four different furnace heat exchangers.

After a flow of the tracer gas has been established, the calibrated gas detector is used to determine whether any of the tracer gas has leaked into the circulating air side of the heat exchanger. Access to the air side of the heat exchanger is obtained through the plenum. If a warm air register is provided it can be removed, or a small hole can be cut in the plenum. The probe of the combustible gas detector is moved across the area about three inches above the heat exchanger. An unacceptable leak is indicated if the calibrated indicator light goes on within one to two minutes. If the probe cannot be held close to the heat exchanger because of an air conditioning coil, a longer response time will be needed.

FIELD TEST OF PROCEDURE

The developed method was field tested by seven utility companies during the 1982-83 heating season. Each utility was asked to perform their normally used detection procedure followed by the new Three-Step Method. Seventy-two reports were received from the utilities. Fifty-two times the furnaces were dismantled and the heat exchanger examined for cracks or holes to verify the result of the tests conducted. The new Three-Step Method found cracks or holes in eight cases where the company's normally used procedure did not indicate a leak. In five other cases the servicemen were able to use the gas detector to trace leaks from the outlet seals or draft hoods. This would not have been possible using the technique(s) normally used by the utilities to check the condition of a furnace heat exchanger.

Two of the utilities altered the injection probe (1/4 inch diameter stainless steel tubing, 12 inches long). One drilled small holes down the length of the probe while the other curved the end of the probe upward. Both of these modifications, designed to direct the tracer gas vertically upward, caused an upward jet action that bypassed cracks and holes visually seen on the side of the heat exchanger. Laboratory results during the development of the test method showed that the tracer gas injection probe should be directed to the bottom of the heat exchanger and the gas allowed to rise and slowly fill the heat exchanger.

Overall, the seven utility companies participating in the field test felt that the new Three-Step Method was accurate and reliable, and that the method was easy to perform and could be accomplished in less than one hour.

CONCLUSIONS AND RECOMMENDATIONS

The Three-Step Method for determining unacceptable leakage from furnace heat exchangers is an improved procedure which offers reliable and accurate results. The Gas Appliance Manufacturers Association has recommended that the Three-Step Procedure become an Appendix to the National Fuel Gas Code; this is to be considered by the Z223 Advisory Panel on Equipment Installation.

There are, however, two situations in which the tracer gas step of this method may not fully perform its functions. First, heat exchanger holes which develop at or below the burner port level may not be detected by tracing the combustible gas in a plane within 3 inches of the top of the exchanger. Holes at that location should be detected by the visual step of the procedure. Secondly, if the furnace incorporates an air conditioning system it may not be possible to probe within 3 inches of the heat exchanger because of the A-coil. The tracer gas step will work; however, the response time will be longer when it is necessary to probe downstream of A-coils. Refrigerant gas leaking from the A-coil may interfere with the tracer gas step. Both of these situations should be investigated further.