

# Fossil fuel heating equipment

## principles and troubleshooting techniques

### Application Note

This application note was written to provide you with an understanding of the basic principles of fossil fuel heating systems and how to troubleshoot these systems using thermometers, digital multimeters (DMMs), clamp meters, pressure/vacuum modules and other accessories. Heat pumps and forced air electric heat furnaces are discussed in other application notes available from Fluke.

### Heating systems principles

Forced-air heat is generated at a central furnace and is then distributed and delivered to the conditioned space via a duct system. A properly designed heating system will generate quiet, filtered, and comfortable air into the conditioned zone. Modern systems have been recently designed that will also filter the air electronically, modulate airflow as zone temperatures change, and bring in fresh outside air based on occupied time.

There are three types of fossil fuel heating systems predominantly available on the market today. These include natural gas, liquefied petroleum (LP) and fuel oil forced-air furnaces.

### Fossil fuel forced-air heating

Forced-air fossil fuel furnaces are factory manufactured, packaged heating units that include:

- A combustion chamber designed for gas or oil

- A heat exchanger
- A flue gas exhaust chamber
- A forced air circulating fan and,
- A controller section.

Newer units often include a secondary heat exchanger to increase efficiency and an auxiliary fan for combustion gases. Since the newer units substantially cool the combustion gases, removing water vapor from the combustion gases, they often are called condensing high-efficiency furnaces. Additionally, they will have plastic flue gas piping instead of older more traditional metal flue pipe since the gas temperatures are much lower than less efficient older units.

Older standard gas furnaces were 65 % to 78 % efficient,

while newer high efficiency furnaces are 78 % to 85 % efficient when used with induced draft fans. Modern condensing furnaces, however, are 90-95 % efficient.

Modern fossil fuel furnaces also come equipped with electronic controls for ignition, fan speed control, electronic thermostats, and safety controls. The typical operating pressure of the natural gas furnaces at the burner is 3.5 inches of water column.

Natural gas is predominantly used as the preferred fuel in larger cities and communities where main gas lines are available. Fuel oil and Liquid Petroleum (LP) heating furnaces are more popular in rural communities.



DMM with microamps capability testing the flame rectification circuit.

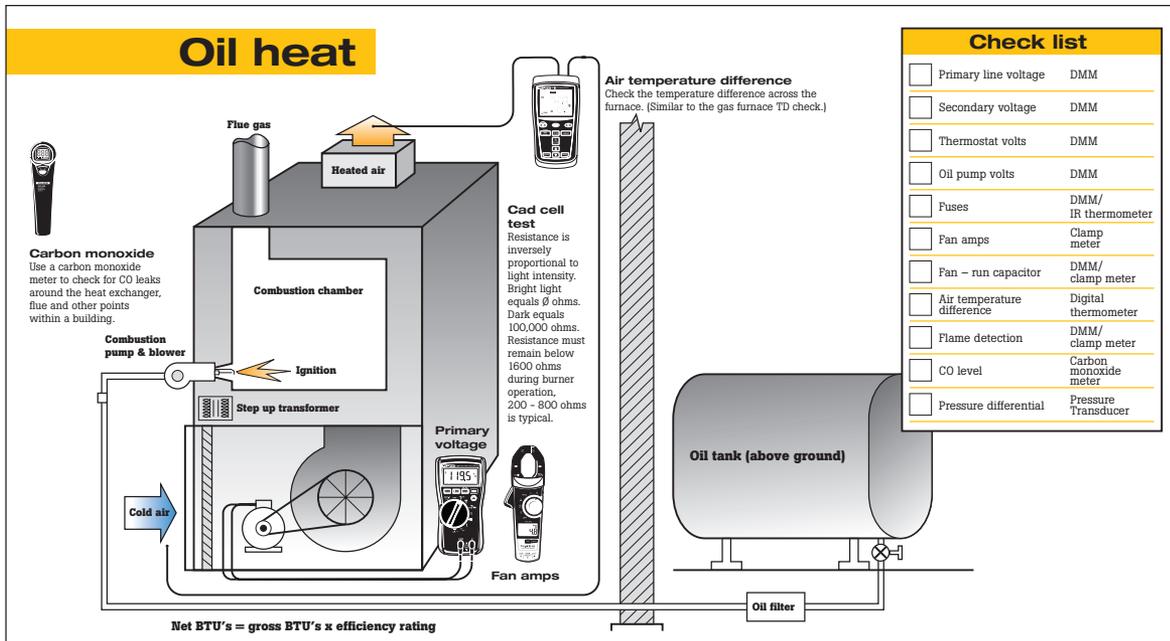


Figure 1. Key measurement points on an oil system.

Fuel oil (diesel) furnaces are similar to gas furnaces except that the fuel must be pumped and atomized within the furnace combustion chamber, since it is provided to the customer in the liquid state. Plus, the atomized oil must be ignited with high voltage electrodes.

The components within LP heating furnaces are almost identical to traditional natural gas furnaces, except the operating pressure of the gas at the burner is typically 9 to 11 inches of water column.

The temperature of the zone is determined by controlling the combustion process as needed in order to transition heat into the conditioned space. This often requires a pre-purge, purge, ignition sequence, flame proof and verification, combustion cycle, and post-purge upon completion.

### Troubleshooting fossil fuel forced-air heating furnaces

When troubleshooting the fossil fuel forced-air furnace, it is important to break the unit down into three basic components:

- The thermostat control system
- The ignition control sequence
- The fan control system

### Testing the thermostat control system

The thermostat control system on any furnace follows a basic design. It is comprised of two wires; a red wire for 24 volt ac power, and a white wire for the main heat control signal back to the furnace. When cooling is controlled from the same thermostat, then a green wire for fan control and a yellow wire for condensing unit control will also be present. Heating and cooling switching is based on temperature changes. Independent fan operation between heating or cooling cycles is controlled by a manual switch. Some equipment has more than one stage of heating or cooling. In these cases, there will be a W1 output for first stage heat, a W2 output for second stage heat, a Y1 output for first stage cooling, a Y2 output for second stage cooling. Second stage outputs may alternately be controlled by electronic timers rather than a temperature sensitive switch.

When troubleshooting the thermostat, it is important to first verify that 24 volt ac power is available at the transformer secondary and at the thermostat.



Checking current with a clamp meter.

Once this is verified, then you should use a digital multimeter (DMM) or an HVAC clamp meter to check for voltage at the white wire coming from the thermostat. If power is available at the transformer, but not at the outlet of the thermostat, then the problem is with the thermostat. If the power signal is available at the white wire at the outlet of the thermostat, but is not powering up the heating primary control, check for an open safety switch or loose connection at the primary control. The primary control may be a gas valve on a standing pilot furnace, an ignition control on a hot surface or spark ignition gas furnace, a sequencer on an electric furnace, or an oil burner primary control.

### Testing the fan control system

Like the thermostat, the fan control system, which automatically turns on the fan, is simple and straightforward. Traditional furnace fan controls used a temperature reactant bimetal probe in the plenum to control a fan switch. These controls had a Fan-ON and a Fan-OFF temperature setting. Some even had a self contained heater to act as a Fan-ON timer by adding heat to the bimetal probe. This heater paralleled the burner control signal to start the timing. Most modern furnaces have migrated to electronic fan timers that start and stop the fan at pre-set or adjustable timings after the combustion process has begun or ended. Both methods of fan control rely on establishing and maintaining the combustion process before they will start the fan. To troubleshoot the fan plenum control system, first verify that the plenum combustion chamber is getting hot. If it is not hot, check the main gas valve and combustion controls. If it is hot and the fan is not

running, check the condition of the fan motor. It is possible it has failed due to seized bearings. While the power is off, check to see if the fan spins easily. Check the combustion fan control to make sure it isn't stuck open and preventing the fan from running. This can be done with a DMM or multifunction clamp meter. The combustion fan is called a Combustion Air Blower on a 90 percent (Category IV) furnace and is called a Combustion Air Inducer on an 80 percent (Category I) furnace. All furnaces that use a combustion fan must establish that a minimum air volume exists before an ignition sequence is allowed. This is normally accomplished with a pressure differential switch. Use a volt meter to determine if the pressure switch is closing after the combustion fan reaches full speed. If the switch does not close, use a pressure transducer to measure the pressure differential. If the pressure differential is greater than the listed "make" pressure, then the switch is faulty. If the pressure differential is less than the "Make" pressure, then there is a problem within the furnace or in the vent system.

If the circulating fan is running and you want to determine if it is set at the proper speed, then you need to check the temperature difference across the combustion heat exchanger. This requires measuring the return air temperature and the discharge air temperature. These temperatures can be checked by using a digital recording thermometer to log the temperatures. The normal temperature difference is about 40 °F to 70 °F. Note, this will vary depending upon the equipment manufacturer's design of the heat exchanger surface, so be sure to look at the manufacturer's specifications within the unit for acceptable temperature difference variations.



Testing voltage with a multi-function clamp meter.

### Testing the flame verification control system

Checking the flame verification control system is required as part of the troubleshooting process when a flame will not stay lit on a gas or oil furnace. Fuel oil heating furnaces use several types of flame verification systems. Older gas furnaces use a thermocouple with a millivolt signal to verify flame presence. Newer, more efficient gas systems utilize various electronic flame verification systems. Oil furnaces use a cad cell with a resistance output to the controllers. Some manufacturers have also tried using a temperature actuated switch mechanism. This article will only address the most popular flame verification systems including the thermocouple, flame rod system, and cad cell system.

**To test the unloaded condition of the thermocouple** you simply measure the output signal of the thermocouple with a DMM or clamp meter. This is accomplished by unscrewing the thermocouple from the gas valve and attaching the leads from your DMM or clamp meter to the positive and negative polarities of the thermocouple. Normal unloaded output signals of the thermocouple when heat is applied to the tip is 20 millivolts to 30 millivolts. The thermocouple should be tested under load. For this test, a thermocouple adapter must be placed in series between the gas valve and the thermocouple. This allows the loaded millivolts to be tested. A good thermocouple in a good flame location should be at least 8-12 millivolts. The drop out point of the safety solenoid in the gas valve is usually about 4 millivolts.

**Testing the flame rod.**

(See Figures 2 and 3.) Most of today's light commercial and residential gas burner controls utilize a flame rod to confirm the presence of the flame. Here's how it works: The ignition control sends out a voltage to the flame rod. The flame itself serves as a partial diode rectifier between the flame rod and the ground. Without a flame, the circuit is open and there is no current. However, the presence of a flame will allow a few microamps of dc current to flow. The acceptable microamp reading varies from one manufacturer to another. Expected microamp values vary widely between controls. The drop out microamps may be as low as 0.16 microamps, or upwards of 18 microamps and higher.

**The test procedure itself is simple.**

1. Shut off the furnace and locate the single wire between the controller and the flame rod. Typically, the wire is terminated at the control panel or the flame rod with standard spade connectors.

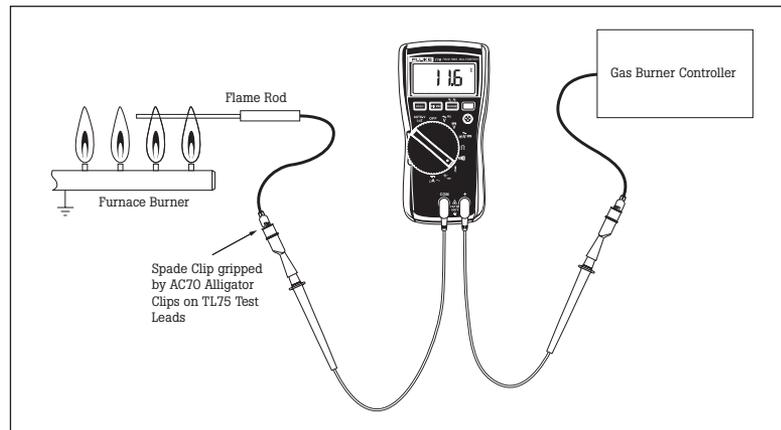


Figure 2. With this setup, either an HVAC DMM or an HVAC clamp meter can be used.

2. Break the spade connection and place the test leads from a DMM or clamp meter that measures microamps in series into the circuit. Having alligator clips for the test leads will make the connection much easier.
3. Turn on the meter and set it in the dc microamp ( $\mu\text{A}$ ) mode. Restore power to the furnace (follow furnace manufacturer's instructions for safe operation) and set the furnace to call for heat.
4. Once the burner or pilot ignites, check your meter reading. Refer to the furnace troubleshooting instructions to determine how to proceed with this result. Typically, a low or zero microamp reading may indicate several potential problems including:
  - a. The flame sensor is not close enough to the flame.
  - b. Carbon build-up on the rod is limiting current flow (clean flame rod with steel wool).
  - c. The flame rod is shorted to ground.
  - d. Continuity is not present between the control module and the flame rod (use a DMM or clamp meter with continuity function to check).
  - e. The control module is bad and needs to be replaced. Verify using the equipment manufacturer's manual.



Checking the 24 V ac supply voltage.

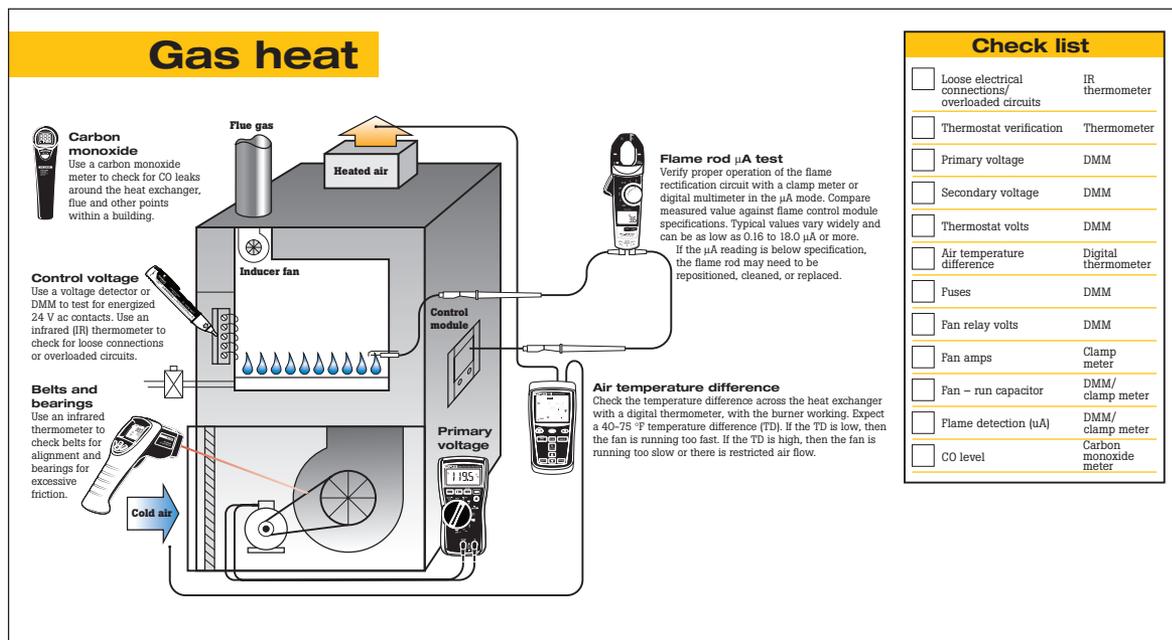


Figure 3. Key measurements on a gas system.

### Testing the cad cell.

Most of today's light commercial and residential oil burner controls utilize a cad cell to confirm the presence of the flame. These systems work in the following manner:

1. On a call for heat, the primary control starts the pump motor and energizes a high voltage transformer to create an ignition spark.
2. The igniters start the combustion process. The flame light serves as the energy source which powers the cad cell.
3. As light increases, the resistance goes down. As the resistance goes down, the controller verifies the flame condition and continues to allow the oil pump to operate. If the oil pump fails or oil pressure is lost, the cad cell sends a much higher resistance to the control and the oil pump shuts off on a manual reset. Without a flame, the circuit opens up and there is no oil pump pressure delivered to the combustion chamber.

To test the cad cell shut off the furnace and locate the two wires which run from the cad cell to the controller. Typically, the wires are terminated at the primary control "F" "F" terminals. Connect an ohmmeter to the cad cell leads. After flame is established, the "F" "F" terminals must be jumpered to maintain ignition. This allows for an unhurried reading of the cad cell resistance.

1. Start the oil burner.
2. After ignition, jumper the "F" "F" terminals on the primary control.
3. Read the resistance across the cad cell.

The resistance must be well below the drop-out resistance of 1600 ohms. This will typically be between 200-800 ohms. Dirt or soot on the face of the cad cell will block light from the burner and cause a higher than expected resistance. A higher than expected resistance will also occur if the cad cell is misaligned so it cannot properly see the flame.

With the burner off, make sure the cad cell is clean and properly aligned so it can see the flame. Use a drop light to check the cad cell. With the light on, the resistance should drop toward zero. With the light off (and the ambient area dark), the resistance should increase toward 100,000 ohms. Make sure there is a good connection between the cad cell pins and the cad cell socket. If the burner is located in an area of bright ambient light, the cad cell may be getting a "false light" reading of 800 ohms or less. The oil primary control will not allow the burner to start if light is sensed when the burner should be off. Having alligator clips for the test leads will make the connection much easier. Turn on the DMM and set the meter in the ohms mode. Read the resistance with the cad cell exposed to the light within the mechanical space. If the light is not bright enough, shine your flashlight into the surface of the cad cell. As the light is increased, the resistance goes down toward zero ohms.

Next cover the cad cell with a piece of black electrical tape. The resistance should go up to approximately 100,000 ohms. If the cad cell does not respond to a change in light intensity, it has gone bad and needs to be replaced. If the resistance does vary between zero and 100,000 ohms as light is added or removed, it is probably operating properly, and you need to look for other problems within the furnace control circuit.

## Test points on fossil fuel furnaces

### I. Low voltage

- Thermostat, continuity and low amps at heat anticipator (1 to .2)
- Gas valve – 24 volts ac
- Safeties-limits, air pressure, temperature
- Flame proof thermocouple mV, flame rod – microamps

### II. High voltage on oil furnaces

- 120 V ac, 5000 V dc to 12,000 V dc ignition

### III. Gas supply

- Natural gas: 7 inches w.c. supply pressure and 3.5 inches w.c. manifold pressure (typical)
- LP gas: 11 inches w.c. supply pressure and 8-10 inches w.c. manifold pressure (typical)

### IV. Combustion gases

- CO<sub>2</sub> or O<sub>2</sub> are a measure of excess air
- CO is a measure of the quality of combustion

### V. Temperature

- CO<sub>2</sub> (or O<sub>2</sub>) along with vent temperature is a measure of combustion efficiency  
Standard older furnaces – 450 °F  
Mid efficiency furnaces – 350 °F  
High efficient furnaces 90 % and up, very cool, uses PVC piping
- Temperature difference across heat exchanger – indication of proper air flow will be between 40 °F to 70 °F. **Note:** This will vary depending upon the equipment manufacturer's design of the heat exchanger surface.

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Printed in U.S.A. 6/2006 2434064 A-EN-N Rev B