

**Explosion Hazards During  
Fuel Transition in Combustion Equipment**

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### **Abstract**

Combustion equipment capable of burning both gaseous and/or liquid fuels allows facilities to transition between various fuels based on the relative availability and price of the fuels. Explosion hazards, however, exist when transitioning from one fuel to another fuel in this equipment during normal operation. This paper describes a recent explosion in a single burner, positive pressure, thermal fluid heater.

The explosion occurred while transitioning the combustion fuel from natural gas to #6 fuel oil. During the transition the amount of combustion air was not sufficient to accommodate the addition of the #6 fuel oil resulting in an unstable, pulsating flame. The flame instability resulted in a partial or total extinction of the flame, followed shortly thereafter by a re-ignition of the unburned fuel/air mixture. The subsequent re-ignition created an overpressure that blew out the convection section of the heater. This paper reviews the several lessons that can be learned from this incident in order to prevent future incidents, including a review of guidelines and standards applicable to similar combustion equipment that outline control strategies for safely transitioning between fuels.

### **1. Background**

This paper describes a recent investigation performed by Exponent, where an explosion occurred in a thermal fluid heater during a transition from natural gas to #6 fuel oil. The details of the incident are discussed in the first section, along with a review of guidelines and standards applicable to similar combustion equipment. In the second section, a detailed analysis of the incident is provided which includes operator procedures, process data recorded and the most likely scenario for the incident. The paper will conclude with lessons learned and recommendations to prevent similar incident from occurring.

#### **1.1 Incident**

Exponent Failure Analysis Associates (Exponent) was asked to investigate the explosion that occurred in a thermal fluid heater at 2:00 pm on the day of the incident. The explosion occurred while transitioning the combustion fuel from natural gas to #6 fuel oil. The incident heater was a vertical-cylindrical process heater with a radiant section that was approximately 43 feet in height followed by a 12-foot convective section (see Figure 1). The thermal fluid heater had a BTU

input of 54.0 mmbtu/hr, and was fired by a single burner capable of firing either natural gas or #6 fuel oil. The burner can simultaneously fire both fuels during a transfer from natural gas to #6 fuel oil. Under normal operation, the stack has a slight positive pressure (0.2" w.c.). The damage was mostly limited to the convective section, which ruptured due to an overpressure inside the heater as shown in Figure 2.

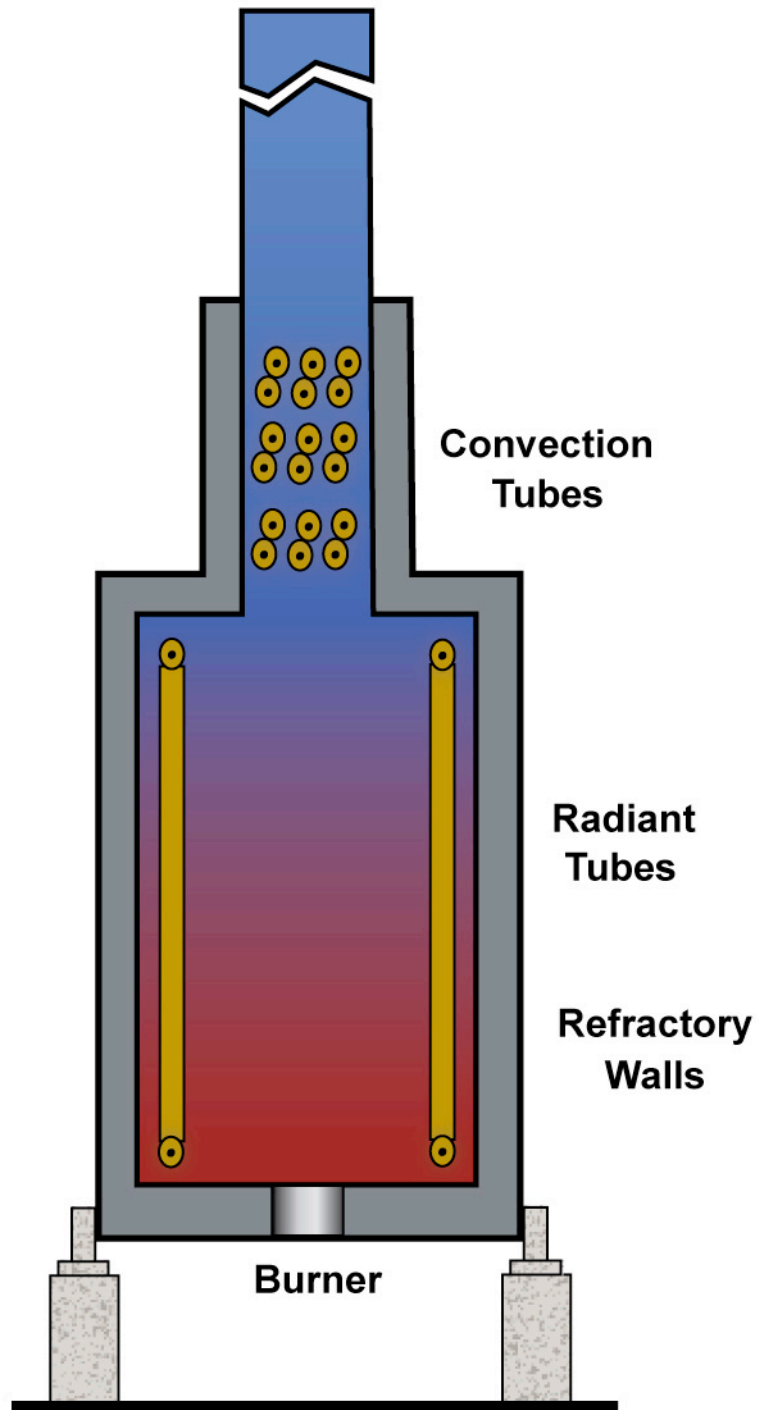


Figure 1: Vertical Cylindrical Process Heater



**Figure 2: Ruptured Convection Section**

At this facility, the fuel in the burner was transitioned manually from natural gas to #6 fuel oil. The process data for the thermal fluid heater around the time of the incident were recorded on strip charts and included: combustion-air flow rate, natural-gas flow rate, #6 fuel-oil flow rate, recirculation fuel-oil flow rate, percent oxygen in the flue gas, stack temperature and thermal-fluid flow rate, pressure and outlet temperature. A limited temporal sampling of data was also recorded on the Distributed Control System (DCS) for the thermal fluid heater, but this data does not include the combustion-air flow rate.

## **1.2 Codes and Standards**

Thermal fluid heaters are not currently covered by an NFPA standard and are specifically excluded in the scope of NFPA 85 “Boiler and Combustion Systems Hazards Code”.<sup>1</sup> However, guidance provided in Chapter 5 of NFPA 85 and in Factory Mutual Data Sheet (FM DS) 6-4 on single burner boilers that are capable of simultaneously firing natural gas and oil is helpful. Section 5.7.4.2 “Subsequent Fuel Light-Off — Oil” specifically addresses guidelines associated with a manual transition from natural gas to oil. A brief review of section 5.7.4.2 from NFPA 85 will be given next. The reader is referred to NFPA 85 (2004) section 5.7.4.2 for the actual text.

The general procedure for transitioning manually from natural gas to fuel oil as outlined by NFPA 85 includes the following steps: (1) ensure all controls are in the manual position, (2) reduce the control for the gas-firing rate to the light-off position, (3) place the oil control to the light-off position and (4) place the fuel transfer into combination oil/gas mode. Manual shutoff valves, capable of adjusting the firing rate, shall be provided at the burner downstream of the safety shutoff valves for both natural gas and fuel oil. Once all of the oil safety interlocks are

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<sup>1</sup> Currently an NFPA working group is developing a proposed standard for thermal fluid heaters.

satisfied, the fuel transfer is performed using the manual gas and oil valves mentioned above and not by the using control valves that are normally used to adjust firing rate. The procedure entails slowly opening the manual oil valve to light the oil flame from the gas flame. Once the oil flame is lit, the oil-firing rate is slowly increased while simultaneously lowering the gas-firing rate, trying to maintain a constant heat input of the combined fuel flow to the burner.

This procedure continues until the manual oil valve is fully open and the manual gas valve is completely closed. During transition, excess air should be maintained at all times by continuously monitoring the air-to-fuel ratio, oxygen indicator or opacity indicator. Also the airflow must be maintained at a constant rate.

## 2. Analysis

### 2.1 *Typical Transfer Procedure at the Facility*

The procedure employed at the facility for transitioning from natural gas to #6 fuel oil at the time of the incident is summarized as follows. All controls were set to “manual” and the fuel transfer was set to combination gas/oil. Guidelines at the facility instructed operators to lower the gas-firing rate to the low-fire position during fuel transfer. These guidelines were based on the burner manufacturer’s specifications. However, operators indicated that it was not possible to lower the gas-firing rate to the low-fire position due to loss of flame during the transition. Therefore, the gas-firing rate needed to be maintained at a typical gas-firing rate just prior to transfer. The oil-firing rate was set to a minimum level to maintain a stable oil flame. The manual oil valve was opened and the oil flame was established. The transfer was performed at the control valves by lowering the gas-firing rate and gradually increasing the oil-firing rate to maintain a stable flame.

### 2.2 *Strip Chart and DCS data*

The data recorded on the DCS can be seen in Figure 3, while Figure 4 shows the time shifted data obtained from the strip charts. The time coordinate indicated on the original strip charts is generally not the same as the actual time of day and can differ from one strip chart to another. Furthermore, the time shift between pens is approximately 5 minutes. The data in Figure 4 was compiled by matching the time coordinate for the natural gas flow rate so that the changes in the natural gas flow rate profile on the strip charts matched those recorded on the DCS. Next, the time coordinate for combustion air flow rate and the #6 fuel flow rate were shifted relative to the natural gas flow rate by adding 5 minutes and subtracting 5 minutes, respectively. A time shift similar to the natural gas flow rate was also performed for the percent excess oxygen.

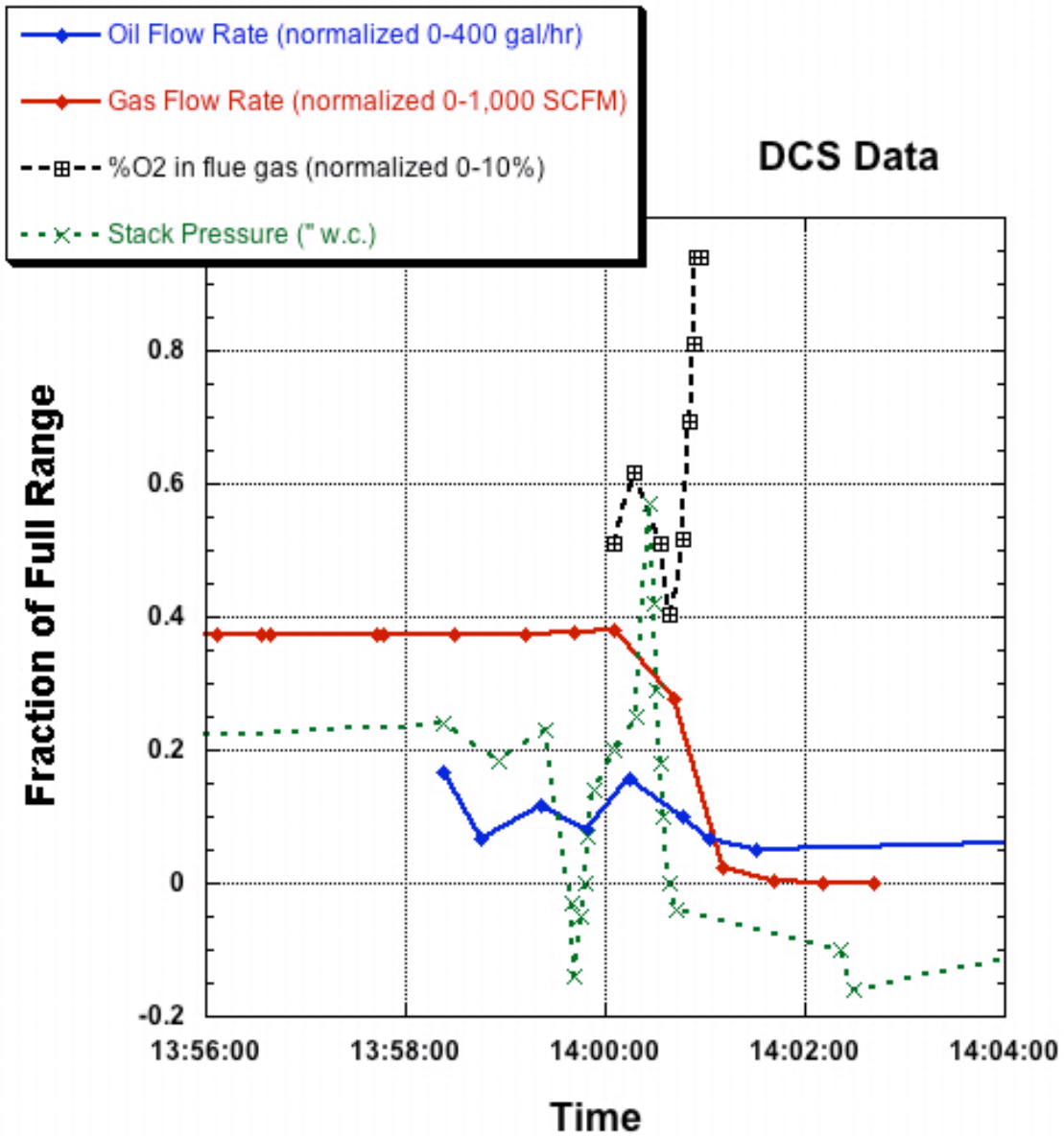
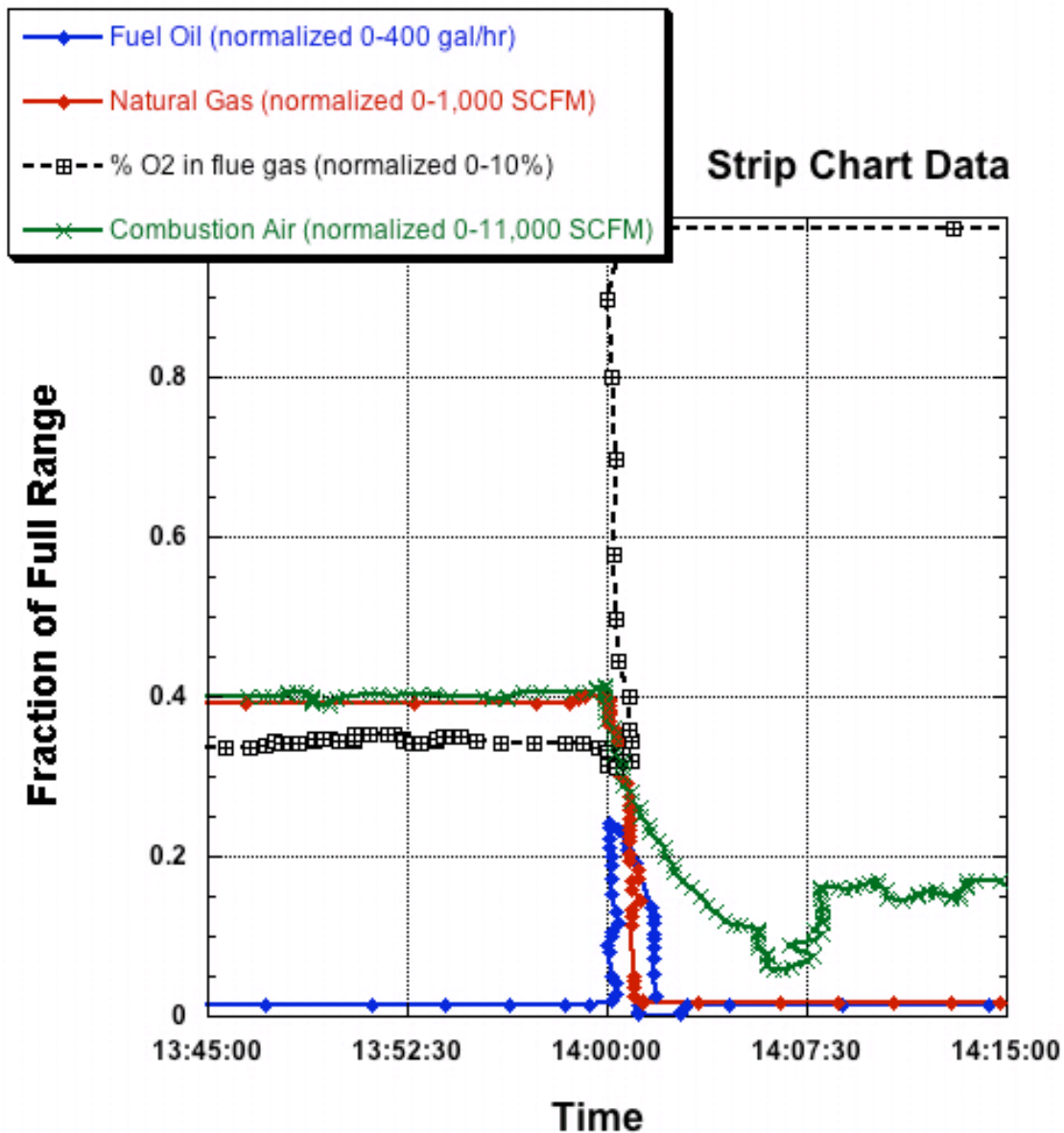


Figure 3: Process Data Recorded on the DCS System



**Figure 4: Process Data Recorded on the Strip Charts**

Moments before 14:00, the recorded natural gas and air flow rates were approximately 372 SCFM and 4400 SCFM respectively, while the %O<sub>2</sub> in the flue gas was recorded on the strip charts to be around 3.4%. Sometime just after 14:00, #6 fuel oil was introduced to the burner. The maximum flow rate of #6 fuel oil recorded after 14:00 by the DCS and the strip charts was approximately 1.04 gal/min (62.4 gal/hr) and 1.6 gal/min (96.9 gal/hr), respectively. The required air for ideal or stoichiometric combustion (i.e. the amount of air required to burn all the fuel and have 0% excess O<sub>2</sub> in the flue gas) at the moment when #6 fuel oil was introduced and both fuels were burning in the burner can be seen in Table 1.

**Table 1: Required Combustion Air**

Data Source	Natural Gas (SCFM)	#6 Fuel Oil (gal/min)	Air (SCFM)	Required Air (SCFM)
DCS	372	1.04	4400	5100
Strip Chart	372	1.6	4400	5900

The supplied combustion air was not sufficient for complete combustion of both fuels after the #6 fuel oil was added. Why then did the %O<sub>2</sub> in the flue gas not drop off to zero? Based on the process data, the %O<sub>2</sub> in the flue gas started to decrease and then rose sharply after the addition of the #6 fuel oil, while the stack pressure was initially positive and then became negative. Testing of the other process heaters at the facility showed that there was a significant time delay (on the order of 30-60 seconds) between the addition of the #6 fuel oil and the moment the %O<sub>2</sub> in the flue gas dropped off during a transition from natural to fuel oil. This explains why the %O<sub>2</sub> in the flue gas did not drop off to zero on the time scale associated with this incident.

### 2.3 Scenario

The most likely scenario is the amount of combustion air was not sufficient to accommodate the addition of the #6 fuel oil and resulted in an unstable, pulsating flame. The flame instability resulted in a partial or total extinction of the flame, followed shortly thereafter by a re-ignition of the unburned fuel/air mixture. The subsequent re-ignition created an overpressure that blew out the convection section.

## 3. Corrective Actions

The procedure employed at the facility for fuel transition from natural gas to fuel oil differed from that outlined in NFPA 85 in four areas: (1) the gas-firing rate could not be reduced to the low fire position for fuel transfer, (2) the manual transfer occurred at the control valves and not at the manual valves, (3) the heat input for both fuels was not maintained at a nearly constant level and (4) excess air was not maintained at all times. The two major areas that were addressed at the facility after the incident involved reducing the gas-firing rate to the low-fire position and maintaining excess air at all time during fuel transition.

The burner manufacturer was contacted to address problems associated with fuel transition while the gas-firing rate was in the low-fire position. Loss of flame was a common problem associated with fuel transitions below 40% gas-firing rate. The goal was to minimize the amount of fuel required during transition, hence minimize the risk associated with transfer. Once the minimum in the gas-firing rate was determined for a stable fuel transition, the issue of excess air could be addressed.

Knowing the firing rates of both the natural gas and #6 fuel oil during transition, the facility established a protocol that calculated the amount of combustion air needed such that %O<sub>2</sub> in the flue gases was approximately 5%. The combustion air was maintained at this level throughout

the fuel transition. After completion of the transfer, the combustion air was adjusted to the appropriate set point for the given fuel oil rate.

#### **4. Conclusions**

Burning in a fuel rich environment can have undesirable effects and should be avoided. These effects include: flame instabilities resulting in an unsteady/pulsating type combustion in the chamber, and incomplete combustion resulting in the formation of CO and other unburned hydrocarbons. Therefore, facilities should always maintain excess air during fuel transitions. One way to ensure excess air is by employing procedures similar to those outlined in NFPA 85 for automated transfers. For example, for transitions from natural gas to fuel oil this would include: (1) ensure the natural gas is set to the light-off position, (2) ensure the position of the control valve for the fuel oil is set to the light-off position, (3) gradually increase the combustion air to a preset value corresponding to the addition input of the fuel oil, (4) establish oil flow to the burner, (5) establish a stable oil flame, (6) shutoff the natural gas and (7) remove the excess combustion air.

It is expected that these issues will be addressed in a future NFPA standard.