Comparison of Fiber Optic and Thermocouple Temperature Measurement in a Catalyst Tube Reactor

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ABSTRACT

Measuring the temperature profile at various radial locations along the length of a catalyst tube in an ethylene oxide (EO) reactor provides vital information for the safe and efficient operation of the reactor. This paper will present the results of a test of a thirty-two (32) channel fiber optic temperature measurement system in an EO reactor.

INTRODUCTION

In November, 2002, a thirty-two (32) channel fiber optic temperature measurement system was tested in a forty-two (42) foot high ethylene oxide (EO) tube reactor to demonstrate its suitability for use in industrial applications.

The sensors provided discrete measurement points along the length of the reactor. Monitoring the temperature along the length of the reactor provided the reactor operator with vital information for the safe and efficient operation of the reactor including:

- Detection of hot spots that could compromise the integrity of the reactor
- Improved prediction of the end of life for the catalyst in the reactor.

Conventional multipoint thermocouple probes are considered unsatisfactory for use in temperature measurement of small diameter catalyst tubes for the following reasons:

- The large cross-section of thermocouple probes adversely affects the flow and heat transfer dynamics of the catalyst reaction in the small diameter tubes.
- Because of the size, fewer than ten discrete measurement points can be included in a typical thermocouple probes.
- The life of conventional thermocouple probes is often less than six months.

The multipoint fiber optic temperature sensing system tested in this application overcomes these shortcomings. This fiber optic temperature measurement system is ideal for monitoring the temperature profile in tube reactors, along the length of furnace tubes, or in any application that requires a robust, high-resolution measurement with a very small cross-section.

Fiber optic temperature sensing probes can range in length from several inches to more than fifty (50) feet and can be packaged in sheaths as smaller than 1/8" in diameter. The individual temperature sensors can be spaced as close as one inch apart. Laboratory experiments have shown that unsheathed fiber optic sensors respond to temperature changes in excess of 400°F in less than one second.

It is now possible, with fiber optic sensing systems, to make thirty-two (32) or more temperature measurements along the length of a catalyst tube with a system that is rugged enough to survive the high velocity gas flow in the dome of a reactor. Because of the small cross-section and flexibility of optical fiber and because of the innovative packaging of the sensors, installation time of the sensor probe is minimal. It is even possible to install/replace a sensor probe while the reactor is in operation and to remove a sensor probe at the end of a run for use in the next turnaround cycle.

Rugged multipoint connectors provide a quick and reliable connection of the sensors to the signal conditioner. The signal conditioner provides a seamless interface with existing control systems including 4-20mA, 0-5 volt, RS-485, Modbus, and Fieldbus and can be located safely hundreds of feet away from the hazardous process. High-resolution signal conditioners can be multiplexed with thirty-two or more sensors providing a cost-effective solution for multipoint temperature measurements in hazardous environments.

SYSTEM DESCRIPTION

The temperature measurement system consisted of a 46-foot long probe, a 100-foot long cable, and a thirty-two-channel signal conditioner. The probe was made of ¼' diameter 316 stainless steel. The probe actually contained thirty-seven (37) fiber optic temperature sensors spaced twelve inches apart beginning three feet from the end. The thirty-seven optical fibers exited the ¼' tube and were terminated in a multipoint fiber optic

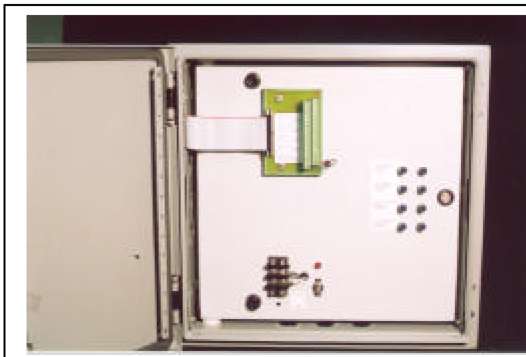

Figure 1 – Signal Conditioner

connector.

This multipoint connector enabled the probe to be connected and disconnected easily and assured the integrity of the system configuration. The connector mated with a 100-foot armor sheathed cable and linked the thirty-seven (37) temperature sensors to the signal conditioner. The signal conditioner converted the optical signals to temperature readings and transmitted these readings to the process control computer via standard 4-20mA current loops. The system specifications are defined in Table 1 below.

System	Operating Range:	-100 to 550°F
	Operating Pressure:	300psi
	Accuracy:	± 3°F
	Upscale burnout:	Fail to maximum reading (20mA)
Probe	Sheath Material:	316 SS ¼' OD with 0.049 wall
	Sensors:	37 in one-foot increments beginning 3 feet from the end
	Cabling/Connectors:	100 feet of armored cable with a single 37-pin connector
Signal Conditioner	Channels:	Thirty-two (32) multiplexed channels
	Update Rate:	10 seconds
	4-20mA Scaling:	0 to 1000°F or 0 to 600°C
	Power Input:	24VDC; 1 Amp
	Enclosure:	NEMA 4

Table 1 – System Specifications

TEST SETUP

The fiber optic sensor probe centered in a catalyst tube that was centered inside a 6" diameter reactor. The 2" annular space between the internal tube and reactor wall contained kerosene. At ambient temperatures, the kerosene level was 29 feet from the top of the reactor.

The catalyst tube was filled with inert material and not actual catalyst. During the test, nitrogen gas flowed through the inert catalyst and served as a heat transfer medium.

Only sixteen (16) 4-20mA lines were run from the control room to the signal conditioner and so only sixteen of the thirty-seven sensors in the probe were monitored. Five (5) reference thermocouples located in the annular space between the jacket and the catalyst tube were also monitored and used for

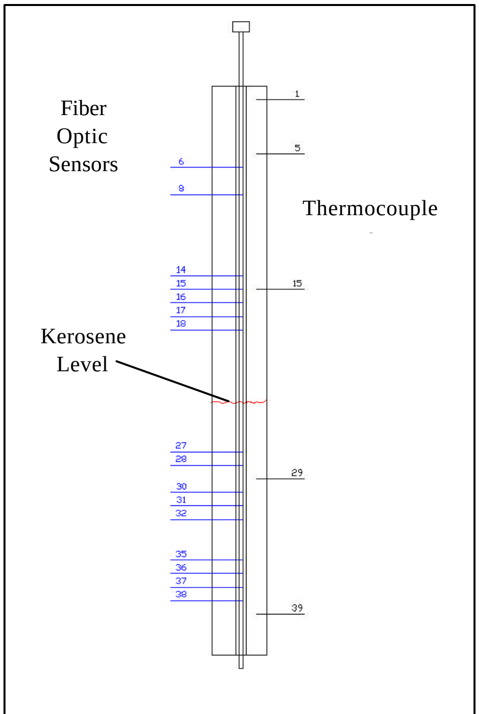

Figure 2 – Sensor Location

comparison purposes. These thermocouples were located at elevations (measured from the top of the reactor) of 1, 5, 15, 29 and 39 feet. The sixteen active sensors were selected from locations near the reference sensors to provide a distribution of temperature measurements along the length of the reactor near the reference thermocouples. The location of the fiber optic sensors and the reference thermocouples are illustrated in Figure 2. Note that two of the reference thermocouples, i.e. the thermocouples located at 29 feet and at 39 feet, were in the kerosene liquid and the others were in the kerosene vapor phase.

The reactor was cycled through the following schedule:

- Ramp the temperature to 500F and maintain the reactor at 500°F through the first day
- Shutdown the reactor at the end of the first day, allow it to cool passively overnight
- Ramp the temperature to 500F and maintain the reactor at 500°F through the second day
- Shutdown the reactor at the end of the second day, allow it to cool passively overnight
- Open the reactor and remove the probe on the third day.

The slow rate of passive cooling during the night provided a great amount of information and provided an excellent basis for evaluating the performance of the fiber optic sensing system.

TEST RESULTS

The test demonstrated the signal conditioner survived shipping, handling, and installation. This test showed the seamless linkage between the fiber optic signal conditioner and the existing control system via the conventional 4-20mA-communication protocol. It also demonstrated the simultaneous communication to other computers via RS-232 serial digital protocol. A separate system monitor and calibrated sensor standards were used to provide a stable and immediate comparison between the readings displayed at the control system and the signal being sent from signal conditioner.

The test demonstrated the ease of installing and connecting the sensor probe to the reactor and to the signal conditioner. This involved positioning the forty-six (46) foot long temperature sensing probe into the reactor and completing the connection via the multipoint fiber optic connector. Once the system was installed and operational the functionality test began.

Figure 3 shows the temperature versus time for the fiber optic sensors at their respective elevations in the reactor along with the five thermocouple signals. In Figure 3, the temperature axis for each sensor is offset in relation to its position within the reactor. Several observations from Figure 3 are worth noting:

- The performance of the fiber optic sensors over the test period was very good and is especially apparent during the slow cool-down time periods.
- The temperature profile over time shows the delay in heating of the top of the reactor relative to the bottom.

- During the second heat-up cycle, it is obvious that an abrupt drop in temperature occurred near the top of the reactor.
- Near the end of the test, it is clear when the reactor was opened – the sensors near the bottom of the reactor show a step change to lower temperature and the sensors at the top of the reactor show a step change to higher temperature (chimney effect).
- Although all sixteen channels were operational and displayed on both the system monitor and the control system, due to a setup error, two of the sixteen channels were not stored in memory and thus are not displayed on the graph in Figure 3.

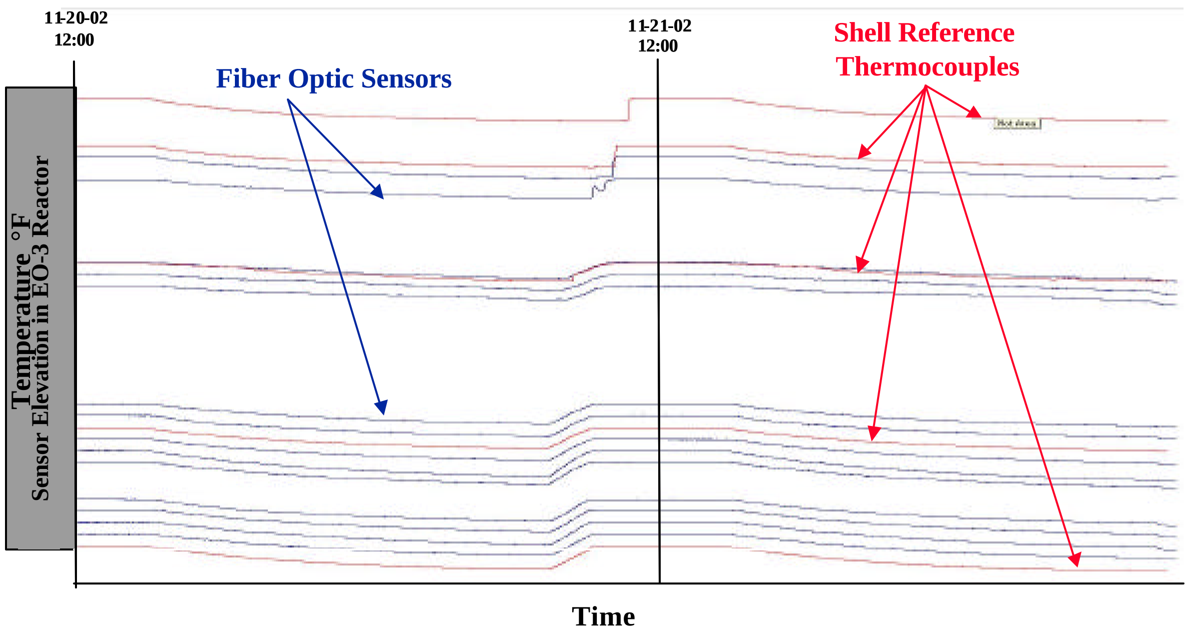

Figure 3 – Summary Temperature Profile

CONCLUSION

This test of the fiber optic temperature measurement system has shown great potential for overcoming the shortcomings of conventional thermocouples for applications where high resolution, multipoint measurements are required. The small cross-section of the fiber optic probe provided reliable temperature profile measurements with minimal effect on the process which should lead to safer and more efficient reactor operations. The fiber optic instrumentation can be used for:

- Detection of hot spots that could compromise the integrity of the reactor
- Prediction of the end of life for the catalyst

This beta test demonstrated the following:

- The capability of packaging thirty-seven (37) fiber optic temperature sensors in a probe with a ¼" OD.
- The durability of the cabling, probe, and instrumentation to survive shipping and handling during installation.
- A convenient connector/cable design that provided quick and reliable installation and configuration of the sensors relative to the signal conditioner.
- A thirty-two channel, time-based multiplexing capability with an update rate of ten seconds for each channel.
- A seamless and direct interface between the signal conditioner and the existing control system via standard 4-20mA loop outputs.
- The capability to provide the required scaling, engineering units, and upscale burnout readings.
- The capability to communicate the measurement results to a remote host computer via standard serial communication channel (RS232, RS422, RS485).