

A Development of On-Line Temperature Measurement Instrumentation for Gasification
Process Control

Semi-Annual Technical Report

For the period ending 9/30/02

Author: Bruce W. Noel

Issued November 15, 2002

DOE Award Number DE-PS26-99FT40686

Submitted by
FluoreScience, Inc.
1010 Commerce Park Drive, Suite B
Oak Ridge, TN 37830

Participating Organization:

Tennessee Technological University
Center for Electric Power
Box 5032
Cookeville, TN 38505

Disclaimer

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, process, or service by trade name trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Abstract

This progress report covers continuing work to develop a temperature probe for a coal gasifier. A workable probe design requires finding answers to crucial questions involving the probe materials. We report on attempts to answer those questions.

We designed, assembled, and tested a portable test fixture that can give relative quantitative data on the condition of phosphors. It needs a more-sensitive detector for optimum performance. We ordered an appropriate detector.

An experimental test of the survivability of thermographic phosphor in an ambient environment similar to that in a slagging gasifier showed no substantial deterioration of the phosphor. We consider this result so important that we delayed the date of publication of this report by one month to accommodate it.

We assembled the first version of a prototype probe and were preparing to test it at the time of this report.

Table of Contents

Disclaimer	2
Abstract	3
Introduction	5
Experimental	5
Results and Discussion	6
Conclusions	7
References	8

Introduction

FluoreScience, Inc. (FSI) is developing a probe to measure temperature in developmental slagging coal gasifiers. FSI is collaborating with faculty and graduate students from Tennessee Technological University (TTU) in this work. The temperature-measurement method uses thermographic phosphors (TPs) as the temperature sensors. The basis of the method and many of its applications are amply covered in the literature.¹ Reference 1 is a review article that includes references to other work.

The idea behind TP temperature measurements is conceptually straightforward. In practice, the method is complex. TPs are ceramics and similar materials that exhibit repeatable characteristics that are functions of temperature. One generates these characteristics by depositing the TPs on the surface whose temperature is to be measured, then subjecting the TPs to ultraviolet (UV) light. The resulting fluorescence, which exhibits the temperature-sensitive characteristics, is converted to an electrical signal by an appropriate photoelectronic detector. The electrical signal is directly related to the temperature. It is thus possible to build an instrument that measures temperature by using TPs as sensors.

For use in coal gasifiers, we have proposed using a probe with TP deposited on the inside of the tip. The probe would, like existing thermocouple probes, be inserted so that the probe tip projects into the interior of the gasifier. The biggest advantages of the TP probe would lie in the expected durability and low cost.

This progress report covers further work intended to answer several crucial problems regarding the probe design and construction. One way to phrase these questions is as follows.

1. What numbers and/or conditions can we assign to the environmental parameters? The parameters include number and location of probes; type of materials used to construct the gasifier walls and their thermal characteristics; thickness of the walls; composition of the gases; and pressures, temperatures, etc.
2. Is there a suitable optimum ceramic material for the probe body? The ceramic will handle the stresses caused by temperature. It will be durable in the high-temperature-gas environment. It will sufficiently resist diffusion of high-pressure, hot gas such that a simple purge-gas technique can remove reactive gas from the interior.
3. Is there a satisfactory inexpensive method for coating TP durably onto the inside of the tip?
4. At the beginning of the project, we did not suspect – because we had insufficient information about the products of combustion in a gasifier – that there might be a materials issue with our phosphors. Now we know that this is a possibility. The question then is, can any of the products of combustion have a chemical effect on the normally inert phosphors such that it would render them nonoperative in the combustor environment?

Any of these questions could be of the “go/no-go” variety.

Experimental

Work scheduled to resume in May was postponed once again because our pending experiment to test phosphor survivability was rescheduled again, this time to be resumed in late September. We considered the outcome from that experiment to be so important that a strongly negative result might cause the project to terminate. Therefore, there was no point in doing any further work on the probe until we got that result.

We completed the assembly of our portable phosphor tester and evaluated its performance. The unit is small enough to fit in a travel case, so can be transported to any site (such as a coal gasifier) where it is needed.

Because the portable tester was not yet usable for measuring the TP under test, we used our laboratory simulator to measure the baseline luminescence from YAG:Dy in the two cubic chambers that we had fabricated in preparation for the upcoming field test. One of the two boxes was scheduled for insertion into the test facility, while the other was kept as a reference.

Our contact at the test facility notified us that the proposed May test had been rescheduled for September. We sent one of the two test boxes to the test facility, located at the DOE-funded Power Systems Development Facility (PSDF) operated by the Southern Company. With the cooperation of PSDF personnel, and in collaboration with Tennessee Tech, we ran the first in a planned short series of tests to determine what – if any – negative effects occur on thermographic phosphor (TP) when it is subjected to a coal-gasifier ambient environment.

PSDF personnel inserted the test box into the PSDF and ran it at temperatures between 1740 and 1550°F and nominal pressure of 200 psi for 308 h, then retrieved the box. They returned the box to our lab, where we determined and evaluated the results.

Results and Discussion

We found that the detector in our portable phosphor tester is not sensitive enough to cover all the situations where the tester might be used (including the rescheduled survivability test in the coal gasifier). We ordered a more-sensitive detector and plan to install it during the next reporting period.

Using our laboratory simulator, we verified that the outputs from the two cubic boxes were the same within expected experimental error.

After the test at the PSDF, with the sample box back in our laboratory, we first examined the TP visually by removing the box lid. There was a small amount of grayish material on the surface. Lacking a means of chemical analysis, we could not tell if this was "junk" that had gotten under the lid or if it was reduced former YAG. We measured the luminescence with our simulator and found that it had decreased only about 20% relative to the reference. This was a very exciting positive result. We then removed the TP, stirred

it, repacked the box, and measured it again. We got a luminescence decrease of about 10% relative to the reference.

Conclusions

Chemical theory predicts that metallic oxides will reduce to the elemental metal(s) in sufficiently reducing environments. Our TPs are all metallic oxides. The TP we plan to use for our probe, YAG:Dy [currently proprietary information], is yttrium aluminum garnet, an oxide activated with dysprosium. In our proposed probe design, the TP is inside the probe tip, which shields it somewhat from the gasifier ambient. But it is shielded only partially because the gasifier products can diffuse through the ceramic tip. The diffusion is greatly accelerated at high temperature (going as $e^{-D/kT}$, for example, with temperature). No data are currently available in the literature for either the diffusion constant or the reduction rate of oxides due to hydrogen sulfide and hydrogen at high temperature and pressure. The PSDF can be thought of as a test bed to obtain such data.

By comparing the results before and after stirring the TP in the test box, we can infer that the grayish material we observed was, in fact, junk deposited by the test vehicle. The results are consistent within the expected experimental error for such a crude initial experiment. The important outcome here is that the TP showed only a slight luminescence decrease, and some of this could have been due to the junk.

The experiment results suggest that the TP inside a ceramic probe might last a long time because the probe interior is shielded from the gasifier ambient and, besides, it is nitrogen-purged.

Our phosphor-survivability experiment, although simple, provided the first-known experimental results in this area of TP research. (We plan to publish a research note on it). The results are, at this point, only semiquantitative, and intentionally so. We were trying to estimate the effect of the gasifier ambient on the TP. If its optical properties vanish in this experiment, and visual inspection shows that the TP is radically changed (to, say, its elemental form), then it is quite likely that the TP probe is a no-go, because the TP would not last long enough for good service. Further, it would be unreliable as a process feedback-control sensor. Our result suggests the opposite, that the probe will survive long-term and it will make a reliable sensor for process control. However, the result must be interpreted with some caution. Useful as it is, the PSDF operates at much lower temperature and pressure than the slagging gasifier. Given the strong functional dependence of the diffusion and the reduction rate on the temperature and pressure, it is still possible that the TP might not survive long in the slagging gasifier environment. If we had good fundamental data (of the kind that could be obtained with painstaking experimentation in the PSDF), then we might predict that immediately.

We now finally have some initial information relative to Question 4 of the Introduction, based on the results from the reducing-gas-environment test, both if and how long the phosphors will survive such an environment. We can assert with some confidence that the

TP-based probe will be durable with a purge gas, such as the Delta probe incorporates. This is an important determinant in our probe's potential commercial success.

Reference

¹ B. W. Noel, W. D. Turley, and S. W. Allison, "Thermographic-Phosphor Temperature Measurements: Commercial and Defense-Related Applications," Proc. 40th International Instrumentation Symposium (Instrument Society of America, 1994), pp. 271-288.