Gasification Facilities for Testing Tunable Diode Lasers at High Pressure Conditions

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ABSTRACT

A new sensor concept is needed to provide measurement of temperature and chemical composition inside a gasification flowpath. This sensor concept could greatly improve the control and efficiency of gasifiers used in the electrical power generation. The tunable diode lasers in development at Stanford University are one promising approach that needs further high pressure and high temperature testing in a gasification environment.

In this report, the capabilities of five research facilities are documented to determine which will provide the most correct gasification environment for testing the laser probe. The instrumentation and control approach of four commercial facilities are also documented in order to understand the needs and gain the insights of the gasification industry.

It is the recommendation of this study to use the facility at the University of Utah to test the Stanford laser probe in manner that will advance the development of the technology towards a field demonstration at a commercial gasification facility in the near future.

BACKGROUND AND THEORY

Coal gasification has potential to balance the use of coal, the nation's most abundant fossil fuel, with the emission standards need to reduce the release of greenhouse gasses into the atmosphere. Using gasification for electrical production is a fairly new concept and there are many practical challenges that need to be solved before gasification can be truly economically viable with the current fossil fuel methods of producing power. One of the biggest challenges facing gasifiers is the difficulty in acquiring any kind of temperature or flow constituent data from inside the gasifier. Typical operation occurs above 1800° F and pressures of 150-750 psi.

This is above the fusion point of the ash by product from the coal causing it to melt into a corrosive slag and flow down the sidewalls of the reactor. All these factors combine to produce an extremely harsh environment. A rugged, reliable diagnostic system would allow for gasifiers to be dynamically controlled that would lead to better fuel economy as well as an improvement life and reliability. A diagnostic system would also provide valuable information for other systems downstream particularly heat values for the combustion turbines that can improve their efficiency and thus maximizes gasification's great potential.

Tunable diode laser technology has the potential to be used in these harsh environments. It is non-invasive and only the laser light will interact with the destructive environment, thus the instrumentation equipment will no be damaged. There is, however, one major challenge that this type of laser diagnostic encounters with gasification measurement. The pressures at which the gasifier will operate broaden the absorption spectra of the constituents making it difficult to achieve a clear wavelength at which absorption takes place detailed in figure 1.

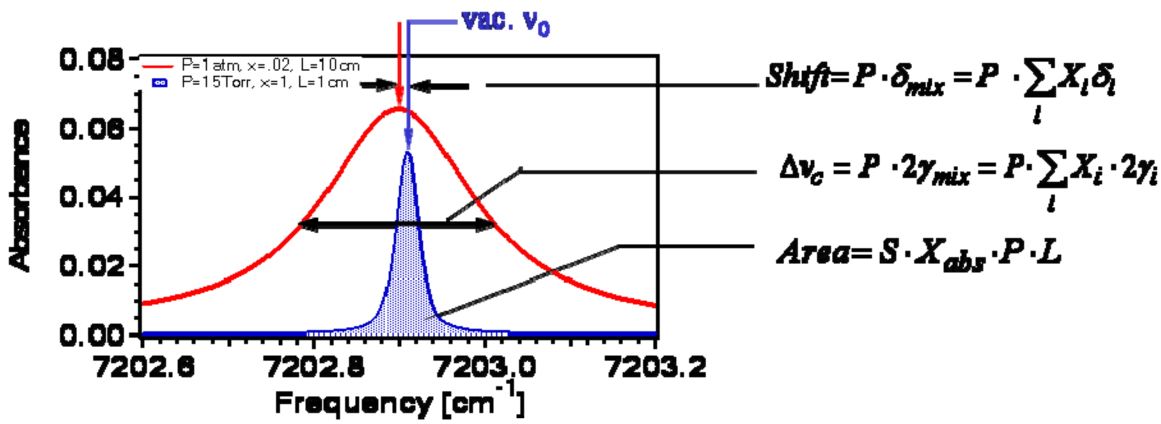

Figure 1

Stanford's High Temperature Gas Dynamics Laboratory has addressed this issue and has produced a probe that can accurately measure temperature and flow constituents at 147 psi at 80° F to match the density of 734 psi at 2240° F. The Stanford probe makes use of a wavelength-multiplexed approach that will produce light at different wavelengths. The precise temperature can then be calculated by measuring the ratios of absorption from the different wavelengths provided by the laser. This process is shown in figure 2.

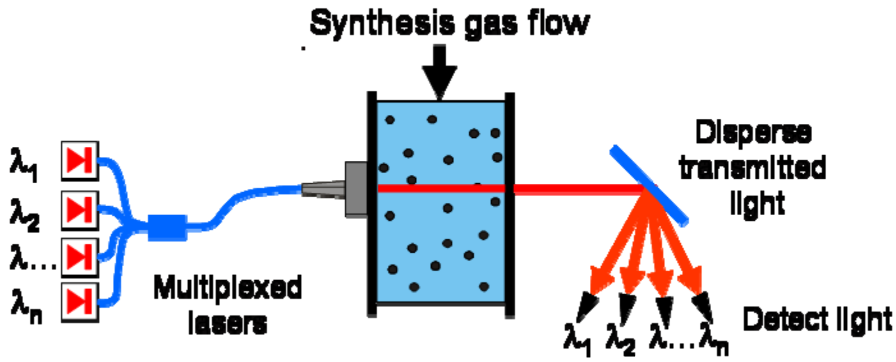

Figure 2

The research group at Stanford University has made tremendous progress in the development of the probe for high pressure and high temperature applications. The next step towards implementation in a commercial grade gasification plant is to apply the probe to a pilot scale research facility to investigate any practical application challenges and prove the probes functionality. The purpose of this report is to document the research facilities available, as well as the specific needs of a commercial plant, and to make a recommendation for future testing of the probe.

RESEARCH FACILITIES

In order to test the probe in the most thorough manner possible it is necessary to document as many gasification research facilities. In order to do this a letter was sent to all known research and pilot-scale facilities asking them to answer the following questions:

- Please identify the type of gasifier (i.e. fluidized bed, entrained flow, etc.) or high temp/pressure combustion rig.
- What are the feedstocks used in the system?
- What are the operating parameters of the gasifier? Specifically:
  - Running temperature and pressure
  - Flow rates of fuels, oxidizers, water, and process products
  - Physical dimensions of gasifier

- Please describe the composition of the flow of the system, particularly the particulate matter as it matter inhibit optical measurement

- What are any challenges that may present themselves in modifying the system to implement the Stanford laser diagnostic system?

- What is the cost and availability for future testing?

Answers to these questions were used to conduct an accurate analysis of the facilities. The facility best suited for testing the Stanford probe was be chosen. Six of the original thirteen facilities were considered to potential test sites based on the information provided. The following seven facilities did not respond or were immediately eliminated based on their lack of gasification capabilities:

- Air Force Research Laboratory
  - Contact, Dr. Joe Zelina
  - Phone, (937)355-7487
  - email; joseph.zelina@wpaft.af.mil
- Brigham Young University
  - Contact, Dr. Dale Tree
  - Phone; (801)422-8306
  - Email; treed@byu.edu
- Combustion Science and Engineering
  - Contact; Dr. Mike Klassen
  - Phone; (410)884-3266
  - Email; mklassen@csefire.com
- Georgia Institute of Technology
  - Contact; Dr. Tim Lieuwen
  - Phone; (404)894-3041
  - Email; tim.lieuwen@ae.gatech.edu
- Idaho National Laboratory
  - Contact; Richard Boardman

- Phone; (208)526-3083
    - Email; Richard.Boardman@inl.gov
- Pennsylvania State University
    - Contact; Dr. Dom Santavicca
    - Phone; (814)863-1863
    - Email; das8@psu.edu
- University of California-Irvine
    - Contact; Dr. Vince McDonnell
    - Phone; (949)824-5950, X121
    - Email; mcfonnell@apep.uci.edu

The six research facilities investigated for possible testing are: CANMET Energy Technology Centre-Ottawa, General Electric Global Energy Research Facility, Gas Technology Institute's Flex-Flex Test Facility, Southern Company's Power Systems Development Facility, the University of North Dakota Energy and Environmental Research Center, and the University of Utah's Gasification Research Facility. The information obtained from these facilities is detailed below. The most desirable qualities from a facility is the ease with which the probe can be implemented and the ability to test in as commercially realistic conditions as possible.

CANMET Facility

The CANMET facility has an oxygen-blown entrained flow gasifier as a well as well three fluidized bed reactor to be run on oxygen, air, and steam. The entrained flow reactor has a 10 in inner diameter and is about 7 feet in length, it is a slagging gasifier that is suitable for coals, petroleum coke, liquids from C4 to asphaltenes, gases and biomass. The gasifier can be blown with any nitrogen/oxygen mixture desired. Existing feed systems include liquids (slurry or pure liquid) with pumps for 0-65 lb/hr, 0-0.5 USGPM, and 0-1 USGPM, and dry fuel (entrained) up to 45 lb/hr (130+ lb/hr currently in design). Maximum operating refractory wall temperature is 3300° F with maximum operating pressure of 220 psi (minor upgrades will allow 290 psi).

CANMET is currently looking into laser diagnostic systems of its own, so the implementation of the Stanford probe should not be a problem. The cost to test at CANMET is around $25,000 a week and it may be possible to piggyback our testing onto another project at the facility to reduce cost. The first availability of the facility is fall 2008. I have also inquired as to the details of the fluidized bed facilities and am still waiting on that report. CANMET is an attractive option depending on how easily the laser can employed with the reactors current configuration. My contact at CANMET is Robin Hughes, phone, (613)996-0066, email, RHughes@NRCan.gc.ca.

GE Global Energy Facility

GE's Global Energy Research facility has a bench scale fluidized bed gasifier that can accommodate a full range of temperatures and pressures. The facility has done a great of modeling the kinetics inside a gasifier and the bulk of the information received from them has been focused on their modeling work. Rob Steele and Jay Jefferies visited this facility on August 14, 2008 and those details will be included in a future report. The contact with GE has been Vladimir Zamansky, phone, (949)330-8989, email, zamansky@research.ge.com.

GTI Facility

GTI's Flex Fuel Test Facility is a fluidized bed gasifier 11 in. in diameter. The gasifier is capable of handling 833 lb/hr of any rank coal when oxygen blown, 1666 lb/hr air blown. It can also process biomass at a rate of 1666 bl/hr while oxygen blown and 3333 lb/hr air blown. It is capable of operating at pressures up to 420 psig. GTI was not able to quote a price for testing without more specific details, but suggested it may again be possible to piggyback testing of the Stanford probe with other testing in order to reduce cost. The facility with be conducting fluidized bed testing for the next 9 months with entrained bed testing for the 12-15 months after that.

The EPRI inquiries into the ability to test laser diagnostics have not yet been answered. This facility may prove to be prohibitively expensive since the dedicated testing was approximately $1MM a week. This cost combined with not knowing the ability with which laser system can be implemented limits the desirability of this facility. My contact at GTI has been Bruce Bryan, phone: (847)768-0591, email: Bruce.Bryan@GASTECHNOLOGY.org.

Power Systems Development Facility

The Power Systems Development Facility in Alabama houses a KBR transport gasifier. This is a circulating fluidized bed gasifier nominally one foot in diameter. The feedstock used is primarily power river basin coal, but also uses lignite and bituminous at a rate of 4000 lb/hr with oxygen 12,000 lb/hr blown with air. The gasifier has an operating temperature of 1800° F and an operating pressure of 200 psig. Installing the probe should not be a problem since the gasifier has opposing viewports that can provide a line of sight for the laser. There is no cost for vendor testing as long is the test is DOE approved and passes a safety review. This a good pilot scale facility, however, the KBR transport reactor design is not seen in any US power generating facilities and thus may not be the best facility to test the Stanford probe. My contact at Southern Company has been Frank Morton, phone, (205)670-5874, email, FCMORTON@southernco.com.

University of North Dakota Facility

The Environment and Energy Research Center at the University of North Dakota has five gasification systems that are either currently operational or will be expected to come online in the next six months. All five gasifiers have warm gas clean up capabilities from a portable bench scale clean up train. The primary feedstocks for these systems are coal and biomass. The cost estimations are based on running the system twenty four hours a day for five days which is defined as a week of operation.

System 1

The first system is the Continuous Fluid-Bed Reactor is a bench scale fluidized bed gasifier. The gasifier has a feed rate of 4 lb/hr and has a syngas production of 8 scfm on air or 2 scfm on oxygen. The metal reactor can withstand temperatures of 1525° F and pressures of up to 150 psi. The system is currently operational and has an estimated cost of $85,000 a week.

System 2

Next is the Transport Reactor Development Unit. This is a pilot scale transport reactor. The system is capable of processing 200-500 lb/hr with a syngas output of 400 scfm on air and 250 scfm on oxygen. This is a refractory lined vessel that is operated at a nominal temperature of 2000° F and a system pressure of 120 psi. This system is also currently available and has an estimated cost of $225,000 a week.

System 3

The Entrained-Flow Gasifier is a bench scale unit with a feed rate of 8-10 lb/hr outputting 16-20 scfm of syngas. The reactor is refractory-ceramic lined and has a nominal operating temperature of 2730° F and a system pressure of 300 psi. The system is currently under construction and should be ready to begin testing in late summer 2008. The estimated cost of operation is $110,000 a week.

System 4

The Fluid-Bed Gasifier is a bench scale fluidized bed system. It has a feed rate of 15-20 lb/hr producing 30-40 scfm of syngas. The nominal system temperature is between 1600 and 1800° F depending on the system pressure which ranges from 30-40 psi. This system is also currently under construction and is expected to begin operation sometime in the fall of 2008. The estimated cost to run is $110,000 a week.

System 5

The final gasification system at UND EERC is the Carbonizer. This is a pilot scale fluidized bed reactor. The reactor will process 100-150 lb/hr of feed and will produce 150 scfm syngas on air. It is a refractory lined vessel that will has a nominal operating temperature between 1200-1800° F at a system pressure of 150 psi. The system is currently operational and has an estimated operating cost of $150,000 a week.

While UND has a very diverse facility, unfortunately none of the systems are equipped with opposing viewports so they would have to be modified in order to achieve a line of sight for the probe. This could prove to be costly and is a major downfall of the EERC facility. My contact at EERC has been Mike Jones, phone, (701)777-5152 email, mjones@undeerc.org.

University of Utah Facility

The Gasification Research Facility at the University of Utah has two gasification systems. Both are pilot scale and will be operational in by the end of the year.

System 1

The first system is a pressurized entrained flow slagging gasifier. The physical dimensions of the unit are 60 inches in length with an inner diameter of 8 inches and an outer diameter of 30 in. This uses liquid feedstock primarily coal slurry and black liquor. The gasifier is designed to operate at a temperature of 2500° F and 300 psi pressure with its maximum temperature at 2730° F and a max pressure of 450 psi. The feed rate for the gasifier is variable, but is typically run at 70 lb/hr fuel and 70 lb/hr oxygen producing 2200 scfh dry syngas. The entrained flow system does not have opposing viewports for a laser system and thus the system would have to be modified which may prove to be difficult. The cost for dedicated testing is $35,000 a week, but piggybacking on another test is possible to reduce cost. This unit is still under construction and is expected to be available in late 2008.

System 2

The second system is a steam blown bubbling fluidized bed gasifier which can also be able to run on air or oxygen enriched steam. The feedstock used is primarily solid biomass and black liquor. The designed operating temperature for this unit is 1470° F with a max temperature of 1515° F. The designed operating pressure is 100 psi with a max 300 psi vessel rating, however, only 150 psi steam is available. The bed is the reacting zone of the fluidized bed is nominally 10 inches diameter by 60 inches length. The freeboard is directly above the bed to return non-reacted solids back to the bed and is about 10 feet and expands from 10 to 14 inches diameter. The outer diameter of shell is 30 inches. The feed rate for the gasifier is variable, but is typically run at 30-70 lb/hr fuel and 50-200 lb/hr steam producing 2100 scfh dry syngas. There are opposing viewports at six levels in the freeboard. This will make implementing the probe fairly simple. The cost of dedicated testing is $30,000 to $35,000 a week and the option of piggybacking testing is available to reduce cost. The gasifier has run over 1000 hours on black liquor and is expected to a lot of biomass testing over the next few years.

The University of Utah facility is promising as the fluidized bed system already has line of sight viewports ready to implement the probe. The entrained flow system is also available to test the system with a harsher environment which would mirror more closely current industry practices. My contact at Utah has been Kevin Whitty, phone, (801)585-9388, email, kevin.whitty@utah.edu.

COMMERICAL FACILITIES

In order to effectively test the Stanford probe, it is important to investigate current commercial plants. This is done to see the current methods of temperature and flow composition measurements as well as to discuss the industries difficulties in measurement systems and what their most pressing needs for a diagnostic system. For this investigation three facilities were looked into: Siemens Gasification Research Facility in Freiburg, Germany, Tampa Electric Company's Polk Power Station in Tampa, Florida, and the Wabash River Coal Gasification Repowering Project in Terre Haute, Indiana.

The TVA Gallatin power station was also evaluated and a site visit was made by the author. It is a standard pulverized coal boiler, but it employs a laser diagnostic system that can be compared to the probe considered for gasification.

Siemens Gasification Research Facility

The facility in Freiberg is claimed by Siemens to be one of the most comprehensive gasification research facilities in the world. The centerpiece of the facility is a five MWth entrained flow reactor with an operating pressure of 377 psi. Currently, the temperature is measured with an open loop system that monitors the cooling water temperature into and out of the cooling screen. Flow composition is found from gas analyzers downstream of the particle collectors. The residence time in the reactor zone and quench is four seconds each. Because of this short residence time, having measuring equipment downstream of the reactor is too late to effectively control the gasifier.

Dr. Schmid believes it would be too problematic to achieve a line of sight through the gasifier and measuring the temperature of the reactor will be very difficult or impossible. Therefore, Siemens has no interest in the Stanford probe or any other laser-based system. Dr. Schmid works in business development with Siemens and can be reached at: phone; +49 (3731)785-310, email; christiane.schmid@siemens.com

TECO Facility

The Polk Power station is an Integrated Gasification Combined Cycle plant nominally producing 250 MW of electricity. The plant employs a Texaco style entrained flow slagging gasifier. The gasifer is refractory lined and nominally operates between 2400 to 2700° F consuming approximately 2500 tpd coal and other solid fuels. The TECO general manager of the plant has expressed a need for a more rugged temperature measurement system. Currently, temperature is measured by a ruby-ceramic matrix thermocouple. Because of the extremely hot and corrosive environment inside the gasifier the expensive thermocouples are prone to failure every three months. Down stream of the reactor the flow composition is taken with gas spectroscopy and gas chromatograph giving a coal/oxygen ratio. This ratio coupled with the temperature from the thermocouple is the primary method for controlling the gasifier.

Another problem for the temperature measuring is when the gasifier is started up, there is an aggressive light off which can cause the three layers of refractory brick to shift around and shear off the thermocouples.

The Polk Plant has experimented with two types of optical pyrometer but with little success.

The first is a two color optical pyrometer from GE. The main downfall of this diagnostic system is that it requires purged windows which lowers the wall temperature of the gasifier and in turn, causes the slag to harden over the window and potentially occlude the sight path.

The other pyrometer is a single crystal sapphire fiber that is very resilient to the harsh environment of the gasifier. The flaw in this system is that it requires the light source to be aimed at a sapphire disk and the violent shifting of the refractory during start up can misalign the light source or even damage the probe itself.

Because of these two unsuccessful attempts to implement an optical pyrometer TECO is extremely wary of a laser-based system. The TECO staff have expressed that their most important instrumentation need is a temperature measuring device that is extremely rugged and dependable to complement the gas analysis already in place in order to effectively control the gasifer. The point of contact, Mark Hornich, can be reached by phone at (863)428-5988 or by email at mjhornick@tecoenergy.com.

Wabash Facility

The Wabash River Coal Gasification Repowering Project is a 262 MWe IGCC plant in Terre Haute, IN. The project employs a Conoco-Phillips E-gas gasifier. This gasifier is a two stage, oxygen-blown, entrained flow, continuous slagging system. The system operates at a nominal temperature of 2600° F and pressure of 400 psia.

Multiple unsuccessful attempts were made to make contact with the site staff at Wabash to comment on their current measurement practices or needs for temperature control. A report filed for the DOE in 2000 documents Wabash's frustration with their indirect temperature measurement techniques and their need to find a rugged, reliable, direct temperature measurement system which would most likely interest them in the

Stanford probe. It is likely, though, that their continuous slagging, refractory-lined reactor would present challenges to implementation that TECO has faced with its optical measurement endeavors.

The contact at the Wabash facility was Keith Thompson phone; (317)-481-2482, email; Keitht@wvpa.com. Keith pointed me to Mike Hickey at SG Solutions phone: (812)535-6000 for more specific information and he has yet gotten back to me.

TVA Gallatin Faciilty

The TVA power station in Gallatin, TN is a pulverized coal fired boiler that has net power generating capacity of 988 MWe. The power station has implemented the ZoloBoss tunable diode laser spectroscopy system that that is similar to the Stanford probe at ambient pressure. The system employed at Gallatin makes use of 15 lasers running at different elevations in the superheat and the reheat areas of the furnace. Each laser measures the temperature and the percent composition of oxygen, water, carbon monoxide, and carbon dioxide. The laser system was easily mounted to preexisting furnace inspection ports and have no impact on the structural integrity of the furnace.

The nominal operating temperature of the furnace is 2400° F. An air purge system is implemented to keep the system cool and help clean the view ports. The lasers and sensitive electronic components are kept with other control systems in a cooled room away from the furnace. As a result, there is very little wear on system components and minimal equipment replacement costs. The laser signal is then transported up to a distribution box close to the furnace by optical fiber. The laser signal is split by the distribution box and sent to each viewport. The largest interference of sight path is the collection of ash in the viewport. The system does use the purge air to remedy this, however ash can still build up behind the lip of the viewport and cause an outage. This interference, however, is minimal and is easily solved with monthly or bi-monthly maintenance. The system is self aligning and takes only fifteen seconds to take a measurement when aligned. The system is very rugged and reliable.

Bob Burbage, the project manager of power supply technologies for TVA, expressed confidence in the accuracy of the readings as well as the reliability of the overall system. The system is not currently being used for dynamic control of the furnace, but rather for direct observation of the furnace temperature and composition for demonstrative purposes. Mr. Burbage can be reached at: phone; (423)751-7044, email rwburbage@tva.gov. Rick Himes at EPRI was also contacted for background information since he was instrumental in the initial testing of laser use at Gallatin. His contact information is: phone; (949)766-8470, email; rhimes@epri.com.

CONCLUSION

In order for coal gasification to become an alternative to pulverized coal-fired boilers as an economically viable method of producing electricity, there are many practical challenges that must be overcome. One of the most pressing of these challenges is the need for direct temperature measurement inside the extreme environment of the gasifier. Laser technology holds promise to solve this problem. Stanford has solved the technical challenges to adapt lasers to the high pressure environment of the gasifier. However, there is still work to be done to overcome the practical challenges that have been seen and documented in commercial gasification plants.

From these commercial facilities several observations can be made. First from Gallatin it is seen that the laser system there works well for the measurement of temperature and flow composition. Next all three gasification facilities have expressed a strong need for direct measurement of gasifier temperature that is rugged and reliable. Finally both TECO and Siemens have expressed skepticism that despite the Stanford probe is technically feasible, it will no be able to overcome the practical challenges presented by the harsh gasification environment. Because of this skepticism the probe needs to be tested in such a way as to show that the probe is rugged enough to be reliable in the challenging environments to be had in commercial gasification.

Although the CANMET facility is an attractive option, the University of Utah facility is the better choice with the given information. They both have entrained flow reactors that may need to be modified, but Utah also has a fluidized bed system with known line of sight viewports, making it the more diverse option.

RECOMMENDATION

The recommendation of this study is to move forward with testing at the University of Utah since they have the most diverse system that can be most easily adapted to suit the needs of the Stanford probe. It is essential to keep in mind the challenges that have already been encountered by TECO and the other commercial plants, so that a measurement system can be presented that is capable of meeting the industry's needs.