FUEL EVALUATION FOR THE U-GAS® FLUIDIZED-BED
GASIFICATION PROCESS

A. Rehmat and A. Goyal
Institute of Gas Technology
Chicago, Illinois 60616

Keywords: Gasification; U-GAS Process; Fuel Evaluation

ABSTRACT

The gasification characteristics of a solid carbonaceous fuel in the U-GAS fluidized-bed gasification process can be predicted by laboratory examination of the fuel, which includes chemical and physical characterization, and thermobalance and agglomeration bench-scale tests. Additional design information can be obtained by testing the feedstock in the U-GAS process development unit or the pilot plant.

INTRODUCTION

The Institute of Gas Technology (IGT) has developed an advanced, single-stage, fluidized-bed gasification process, the U-GAS process, to produce a low- to medium-Btu gas from a variety of solid carbonaceous feedstocks, such as coal, peat, wood/biomass, sludge, etc. The development of the process is based on extensive laboratory testing of these feedstocks as well as large-scale tests in a low-pressure (50 psig) pilot plant and a high-pressure (450 psig) process development unit conducted over a period of several years. Up to 98% feedstock utilization with long-term steady-state operation has been achieved. The testing has provided information related to the effect of various gasification parameters, such as pressure, temperature, and steam-to-carbon feed ratio, on gasification characteristics of the feedstocks. The concept of *in-situ* desulfurization by simultaneous feeding of dolomite/limestone has also been established. Reliable techniques have been developed for start-up, shutdown, turndown, and process control. The process represents the fruition of research and development in progress at IGT since 1974. The product gas from the process will be a low-Btu gas that is usable as a fuel when operating with air, and a medium-Btu or synthesis gas when operating with oxygen. The medium-Btu or synthesis gas can be used directly as a fuel, can be converted to substitute natural gas, or can be used for the production of chemical products such as ammonia, methanol, hydrogen, and oxo-chemicals. The low- and medium-Btu gas can also be used to produce electricity generated by a combined cycle or by fuel cells.

On the basis of the operational results with numerous feedstocks, IGT has developed an experimental program for the evaluation of a solid carbonaceous fuel for use in its fluidized-bed gasification technology.

U-GAS PROCESS

The U-GAS process employs an advanced single-stage fluidized-bed gasifier (Figure 1). The feedstock, which is dried only to the extent required for handling purposes, is pneumatically injected into the gasifier through a lockhopper system. Within the fluidized bed, the feedstock reacts with steam and air or oxygen at a temperature dictated by the feedstock characteristics; the temperature is controlled to maintain nonslagging conditions of ash. The gases are introduced into the gasifier at different compositions at different points at the bottom of the gasifier. The operating pressure of the process depends on the ultimate use of the product gas and may vary between 50 and 450 psi. Upon introduction, the feedstock is gasified rapidly and produces a gas mixture of hydrogen, carbon monoxide, carbon dioxide, water, and methane, in addition to hydrogen sulfide and other trace impurities. Because reducing conditions are maintained in the bed, nearly all of the sulfur present in the feedstock is converted to hydrogen sulfide.

The fines elutriated from the fluidized bed are separated from the product gas in two stages of external cyclones and are returned to the bed where they are gasified to extinction. The product gas is virtually free of tars and oils due to the relatively high temperature of the fluidized-bed operation, which simplifies the ensuing heat recovery and gas cleanup steps. The process yields a high conversion, especially because of its ability to produce ash agglomerates from some of the feedstocks and selective discharge of these agglomerates from the fluidized bed of char.

FUEL EVALUATION

Three steps are required to evaluate the suitability of a potential feedstock for the process:

1. Laboratory analyses

2. Bench-scale tests

3. Process development unit (PDU) or pilot plant gasification test.

Laboratory Analyses

Table 1 lists those fuel properties that are normally determined for assessing a solid fuel for use in the process. Additional analyses are performed as required with unusual feedstocks. For example, run-of-mine coals with a high mineral content may require mineral identification and evaluation of the effect of high mineral content on ash fusion properties.

The bulk density, heating value, ash content, and elemental composition of the organic portion of the feedstock usually have no direct effect on the behavior of the feedstock in fluidized-bed gasification. However, they do influence the oxygen requirement, the gas yield, and the gas composition. The higher heating value (HHV) is a measure of the energy content of the feedstock. It relates, with other factors, to the amount of oxygen needed to provide the desired gasification temperature levels. If a feedstock has a low HHV, more oxygen is needed to maintain the gasifier temperature at an acceptable operating level. If the HHV is higher, less oxygen will be required to maintain the desired temperature levels.

The ash fusion temperature reflects the ease of agglomeration of the ash in the gasifier. The free swelling index (FSI) indicates the caking tendency of the feedstock; for highly caking feedstocks, a proper distribution of the feed material, as it enters the gasifier, is critical. In the U-GAS process, the Pittsburgh No. 8 bituminous coal with an FSI of 8 has been successfully gasified and agglomerated with overall coal utilization of 96%. The feedstock is generally sized to 1/4-inch x 0 before it is fed to the gasifier. If a finer size is available, the fluidization velocity is reduced accordingly.

To utilize a feedstock today, one needs to know a great deal about it prior to purchase. It is essential to know the sulfur content to comply with airborne emissions standards and the ash content and its constituents to ensure compliance with solid waste regulations. Other standards are still evolving as new environmental and energy legislation is enacted.

The range of various properties of the feedstocks that have been tested in the U-GAS process development unit or pilot plant is given in Table 2.

Bench-Scale Tests

Three types of bench-scale tests are conducted to evaluate the fuel. These bench-scale tests establish a range of operating conditions that can be used to plan tests in the process development unit or the pilot plant facility, and to perform material and energy balances for the gasifier and estimate its throughput. These tests are described below.

Thermobalance Tests

The gasification of a solid carbonaceous fuel consists of two major steps: 1) initial rapid pyrolysis of the feedstock to produce char, gases, and tar and 2) the subsequent gasification of the char produced. (In addition, some combustion reactions take place if gaseous oxygen is present; these reactions are very rapid.) Because the rate of the second step is much slower than that of the first step, the volume of a gasifier (or the carbon conversion in the gasifier) is primarily dependent on the gasification rate of the char. Due to the relatively well-mixed nature of a fluidized-bed gasifier, the char particles undergoing gasification are exposed to gases consisting primarily of CO, CO_2, H_2, H_2O, and N_2.

The thermobalance testing is performed to determine a relative reactivity constant for the feedstock for comparison with the reference coal, Western Kentucky No. 9 bituminous coal, which has been extensively tested in the thermobalance (Goyal *et al.*, 1989) as well as in the U-GAS process. In the thermobalance, a small quantity of the feedstock is continuously weighed while being gasified at a specific temperature, pressure, and gas composition. This measured weight loss data versus time and the thermobalance operating conditions and analyses of feed and residue are used to calculate the specific relative reactivity constant for the feedstock. The kinetic data, in conjunction with the reference coal information, are used to plan tests in the PDU or pilot plant. As an example, Figure 2 shows the gasification rate for maple hardwood char, peat char, and bituminous coal char, as determined by the thermobalance.

Ash-Agglomeration Tests

Prior to the large-scale testing, the ash-agglomeration tests are conducted in the laboratory to determine the possibility of agglomerating the feedstock ash in the gasifier. These tests are performed in a 2-inch fluidized-bed reactor capable of operating at temperatures up to 2200°F. Several tests have successfully demonstrated that ash agglomerates can be produced in this bench-scale unit at conditions that can be related to the pilot plant operating conditions. The 2-inch reactor has a unique grid design that allows close simulation of the pilot plant fluidized-bed dynamics and mixing characteristics, which are essential for proper ash agglomerate formation, growth, and discharge. The tests are generally conducted at different temperatures, superficial velocities, gas compositions, and operating times to evaluate conditions favoring ash agglomerate formation and growth. The results are quantified using size distribution curves of feed, residue, and fines to show size growth of particles. Visual evaluation of the agglomerates includes separation of the +8 mesh fraction (normally 100% agglomerates) in the residue and, if required, separation of agglomerates by float-sink techniques for each size fraction. The agglomerates thus separated can be easily photographed or examined petrographically. An example of the test results with different coal samples is given in Table 3.

Fluidization Test

A fluidization test in a glass column at ambient conditions may also be conducted to determine the minimum and complete fluidization velocities of the material. This information is then translated into the necessary operating velocity in the PDU or pilot plant test. The fluidization test is conducted only if the feedstock is unusual or if the feedstock size is different than that typically used (1/4 in. x 0) in the process. This test is conducted with the char produced from the feedstock.

Process Development Unit (PDU) or Pilot Plant Test

IGT has two continuous U-GAS gasification units: 1) The 8-inch/12-inch dual-diameter high-pressure process development unit, which can be operated at up to 450 psig and has a nominal capacity of 10 tons per day (at 450 psig operation), and 2) The 3-foot-diameter low-pressure pilot plant, which can be operated at up to 50 psig and has a nominal capacity of 30 tons per day. In addition, a 2-foot/3-foot dual-diameter high-pressure pilot plant has recently been constructed at Tampere, Finland, and its shakedown has begun. Plans are under way to further test various coals, peat, wood and bark waste, and pulp mill sludge in this unit.

A test in the PDU or pilot plant provides the following information:

- It confirms the suitability of the candidate feedstock for the U-GAS process.
- It establishes the base design operating conditions as well as an operating window for the gasifier.
- Design data for fines characteristics, ash agglomeration characteristics, and gas characteristics are obtained.
- Estimates for gas quality, gas yields, and process efficiency are established.

- Necessary environmental data to define the environmental impact are taken.

- Various samples, such as bed material samples, ash discharge samples, fines samples, and wastewater samples, are collected and saved and provided as needed for use during detailed engineering.

The PDU testing is recommended where high-pressure gasifier operation would be required. Each test in the PDU usually consists of 2 days of operation, whereas one 5-day-duration test is usually conducted in the pilot plant with the candidate feedstock. During the test, the gasifier is operated in ash-balanced, steady-state conditions, during which most of the design data are procured. A detailed test plan is generally prepared based on a comparison of the feedstock with a similar feedstock or from information obtained from bench-scale testing. Depending on the feedstock characteristics, the gasifier is operated at a temperature of up to 2000°F and a superficial velocity of up to 5 ft/s.

Numerous solids samples are collected regularly during the test run so that accurate material balances can be prepared. Process sample points include the coal feed, fluidized bed, ash discharge, and cyclone diplegs (for the pilot plant). Samples from the fluidized bed are also collected and analyzed hourly during the test to help the operators determine and maintain steady-state operation.

All process solids and gas flow streams are measured and recorded. Temperatures are recorded for all process streams and at several locations within the reactor. Redundancy is provided for the reactor pressure taps used for bed density and height.

A product gas sample stream is drawn continuously from the gasifier freeboard for chromatograph analysis. The chromatograph system provides accurate on-line analysis for CO, CO_2, CH_4, H_2, N_2, H_2O and H_2S. The chromatograph sequencing is microprocessor-controlled for flexibility in the scope and frequency of the analysis. The product gas samples are also collected in gas bombs for later laboratory analyses.

Special sampling and instrumentation are available for complete chemical characterization (organic compounds as well as trace elements) of the product gas and wastewater streams. Test results of this nature are necessary to satisfy environmental permitting requirements and for proper design of downstream processing equipment. Equipment is also available for determination of product gas dust loading after one, two, or three stages of cyclone separation.

These units use a microprocessor-based data acquisition system to ensure accurate, timely, and reliable collection of all process data of interest. About 85 process data points (temperature, pressure, flow, etc.) for the pilot plant and about 40 data points for the PDU are scanned repeatedly throughout the test. A full scan is completed in approximately 10 seconds and is repeated at 3-minute intervals. The reactor operating status, including various flows, pressures, temperatures, and velocities (grid, venturi, bed, freeboard, cyclone), bed density, bed height, etc., is calculated and displayed on the computer CRT screen. The data are stored on magnetic tape in both raw signal and converted form. The converted data are averaged hourly, and an hourly average report of all data points and the operating status is automatically printed in the control room; in addition, a shift report is printed every 8 hours to allow a shift engineer to review the operation of a previous shift. Particular emphasis is placed on the use of the data acquisition system as an operating tool. Specialized programs have been developed to aid the operators in the approach to and confirmation of steady-state operation. This results in more steady-state operating time, and therefore more useful design data, per test run.

The details of the PDU system and some test results are given by Goyal *et al.*, (1989, 1991). The details of the pilot plant system and some test results are given by Goyal and Rehmat (1984, 1985).

In September 1989, IGT entered into a licensing agreement with the Power Industry Division of Tampella, Ltd., Tampere, Finland, which will result in the commercial application of the process. Tampella selected the pressurized fluidized-bed technology because of its versatility and applicability to a wide variety of feedstocks, including coal, peat, forestry waste, etc. As a first step toward commercialization, a 10-MW pressurized (450-psi) pilot plant has been designed and constructed at Tampella's R&D Center in Tampere, Finland. Various coals, peat, wood and bark waste, and pulpmill sludge will be tested in this unit. To demonstrate the application of the technology to the Integrated Gasification Combined Cycle (IGCC), a detailed engineering of a 650-ton/day plant will begin in 1991 and will be commissioned in 1993-1994. Tampella also plans to demonstrate its IGCC process in other parts of the world, including the United States.

REFERENCES

Goyal, A., B. Bryan and A. Rehmat, "Gasification of a Low-Rank Coal," in *Proceedings of the Fifteenth Biennial Low-Rank Fuels Symposium*, p. 447-464, DOE/METC-90/6109, CONF-890573, May 1989.

Goyal, A., B. Bryan and A. Rehmat, "High-Pressure Gasification of Montana Subbituminous Coal," in *Proceedings of the Sixteenth Biennial Low-Rank Fuels Symposium*, May 1991.

Goyal, A. and A. Rehmat, "The U-GAS Process -- From Research to Commercialization," Paper presented at the AIChE Annual Meeting, San Francisco, California, November 25-30, 1984.

Goyal, A. and A. Rehmat, "Recent Advances in the U-GAS Process," Paper presented at the 1985 Summer National AIChE Meeting, Seattle, Washington, August 25-28, 1985.

Goyal, A., R. F. Zabransky and A. Rehmat, "Gasification Kinetics of Western Kentucky Bituminous Coal Char," *Ind. Eng. Chem. Res.*, *28*, No. 12, 1767-1778, (1989) December.

Table 1. LABORATORY ANALYSES OF THE FUEL

- Proximate Analysis
- Ultimate Analysis
- Higher/Lower Heating Value
- Bulk Density
- Particle-Size Distribution
- Grindability
- Equilibrium Moisture
- Free Swelling Index
- Ash Fusion Temperatures (Reducing Atmosphere)
- Ash Mineral Analysis

Table 2. RANGE OF FEEDSTOCK PROPERTIES TESTED IN THE U-GAS PROCESS

Moisture,* %	0.2 to 41
Volatile Matter,** %	3 to 69
Ash,** %	6 to 78
Sulfur,** %	0.2 to 4.6
Free Swelling Index	0 to 8
Ash Softening Temperature, °F	1980 to 2490
Higher Heating Value,** Btu/lb	2,330 to 13,630

* As received
** Dry basis

Table 3. 2-INCH ASH-AGGLOMERATION TESTS WITH VARIOUS FEEDSTOCKS

Coal Sample	Run Temp., °F	Char Initial Ash, %	Run Time, h	Fluidizing Velocity, ft/s	Comments
FC-1	1985	31.5	2.0	1.0	Sinter particles plus some agglomerates
FC-1	2100	31.5	1.5	1.5	Agglomerates formed, little or no sinter
FC-2	1990	45.5	1.0	1.5	Small agglomerates present
FC-2	1988	45.5	1.3	1.5	Larger agglomerates found
FC-3	2080	45.4	2.5	1.5	Agglomerates formed
FC-4	1960	15.5	1.0	2.1	No agglomerates found
FC-4	1920	20.9	3.0	1.5	Small agglomerates found
FC-4	2000	15.5	2.5	1.6	Greater number of large agglomerates
KY #9	2000	51.0	1.3	1.5	Many agglomerates produced

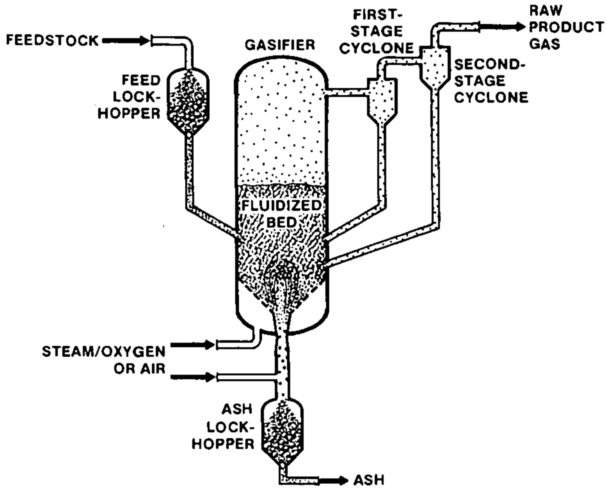

Figure 1. SCHEMATIC DIAGRAM OF THE U-GAS GASIFIER

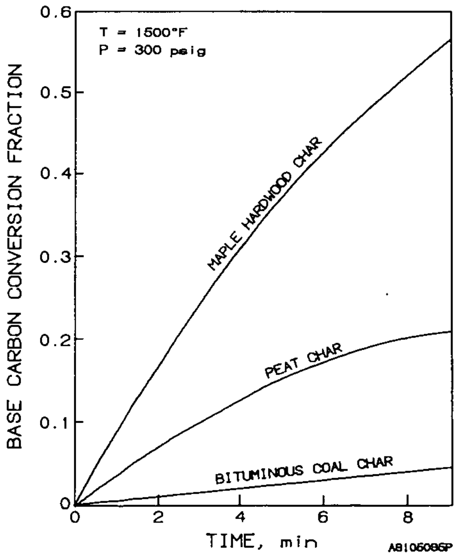

Figure 2. GASIFICATION RATES FOR MAPLE HARDWOOD CHAR, PEAT CHAR, AND BITUMINOUS COAL CHAR