Industrial scale gasification of T-grade coal via fixed bed technology

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Abstract. The gasification of solid fuel is known technology suitable for many purposes which has found quite limited applications worldwide. The one of the major reasons is deficiency of practical operation experience of industrial scale units. The paper reports the data on T-grade coal gasification by air via 4 ton per hour pilot scale VTI gasifier situated in Tomsk polytechnic university (Tomsk, Russia). The tests were carried out for bituminous coal of Kuznetsk basin. The results presented were obtained in nonstationary regime for single 4 t load of fuel. The characteristics temperatures into gasifier as well as generator gas composition were determined. Obtained results allowed to conclude that T-grade coal is suitable fuel for VTI gasification technology.

1. Introduction
Fixed bed gasification systems has several important advantages compared to other gasification technologies [1] like low oxygen consumption, high cold gas efficiency and no requirements for raw fuel grinding. All this features made it possible to create the effective technology for air-blown fixed bed gasification of coal significantly reducing capital costs and increasing reliability of system in general due to absence of air separation unit [1]. In Russia such technology was created by All-Russia Thermal Engineering institute and was named VTI [2]. The core VTI gasification technology is air-blown fixed bed gasifier with liquid slag removal and counter-current movement of fuel and blast [3]. The raw lump coal was used as fuel.

The one of the main drawbacks of current gasification technology is lack of practical experience in start-up commissioning and continuous operation of such systems. For example, ZeroGen project [4] in Australia was cancelled due to incorrectly evaluated costs of project realization while Kemper project [5-8] was put into operation with significant delay and price increasing. That’s why pilot-scale demonstration projects are so important for successful introduction of gasification technology into practice. However, high price of such setups made them relatively rare. There are several such pilot-scale projects for entrained flow gasification technologies [9–14] because of their wide application for chemical industry. To the best of authors knowledge, the Sotacarbo plant [15] is the only operational setup based on fixed bed approach. The VTI technology is unsuitable to be studied via this setup due to significant differences in construction, majorly, in construction of slag removal system, and significantly different operating conditions (lower pressure and ash removal temperature).

Current article is reporting experimental data on practical experience of industrial-scale pilot gasification plant operated using T-grade coal of Kuzbass basin. The experimental setup is situated on in Tomsk polytechnic university (Tomsk, Russia).

2. Materials and methods
2.1. Fuel characterization

The raw T-grade bituminous coal of Alardinskaya mine (Kemerovskaya region, Russia) was used for current study. Proximate analysis of fuel (calorific value, moisture, ash and volatile matter content) was performed according to standard ISO methods: ISO 589:2008 "Hard coal - Determination of total moisture", ISO 1171:2010 "Solid mineral fuels — Determination of ash" and ISO 562:2010 "Hard coal and coke - Determination of volatile matter", ISO 1928:2009 "Solid mineral fuel. Determination of gross calorific value and calculation of net calorific value". Fixed carbon content was determined as a difference between 100 % and sum of mentioned parameters. The results are presented in Table 1.

| Data of technical analysis, wt. % | Calorific value, kJ/kg |
|----------------------------------|------------------------|
| A – ash content. | M – moisture content. | VM – volatile matter content. | FC – fixed carbon content. |
| 18.37 | 10.52 | 24.93 | 25.35 | 18.37 |

2.2. Description of experimental setup

The pilot-scale gasification setup is situated on the territory of Tomsk power plant TEC-3 in the complex gasification technology testing center (Figure 1), which is part of research center “Ecoenergy 4.0” of Tomsk polytechnic university. The resources for experiments (electrical power, technical and boiler water) were provided by power plant through connection with its infrastructure. The simplified scheme of fixed bed gasification unit in presented in Fig. 2.

![Image of complex gasification technology testing site.](image)

Figure 1. Image of complex gasification technology testing site.

The gas generator is a cylindrical vessel (Figure 2(a)), insulated with heat-resistant lining bricks from the inside (Figure 2(b)). There is no lining in the lower part of the gasifier because there is a slag bath...
filled with water, into which slag from the gasifier is removed. Before launch of gasifier, the lining of the gas generator was heated to a 800 °C using a special burner operating on liquid fuel. Coal with a 5-50 mm particle size after the fuel preparation system was fed to the upper fuel bunker using a steeply inclined transporter and then through the sluice system to the gas generator. When loading coal into the gasifier, nitrogen was used as a sluice agent, supplied to the sluice fuel bunker from a nitrogen generator.

![Diagram](image)

Figure 2. Principal scheme of fixed-bed gasification unit: 1 – raw fuel receiving bunker; 2 – vibrating screen; 3 – sorted fuel receiving bunker; 4 – sluice fuel bunker; 5 – fixed bed gasifier; 6 – sluice slag bunker; 7 – gas cooler; 8 – cyclone; 9 – cyclone dust lock; 10 – reducing device; 11 – recuperative air heater; 12 – battery-type cyclone; 13 – flare unit.

The gasifier was supplied with compressed air from the compressor heated to 300 °C by the heat of the exhaust gases, as well as superheated steam from the steam generator and superheater with 200-300 °C temperature. The nominal pressure in the gas generator was 0.6 MPa. Inside the gasifier the solid fuel was converted into a combustible gas, while the molten slag was removed into a slag bath. After the bath the slag was removed from there through the lock bunker into a dump. The resulting generator gas with 800-1100 °C temperature entered the gas cooler, where it was cooled to 500-600 °C by water injection. A cyclone (the first stage of ash collection – Figure 4), a reduction device (in which the pressure is reduced to near-atmospheric values), a heat exchanger (in which the gas gives off part of the heat to the air), a battery cyclone (the second stage of ash collection – figure 4) compose the synthesis gas line. Then the generated gas was fed to the flare unit for combustion.

The gas generator and gas cooler have cooling jackets, through which cooling technical water was continuously circulated during unit heating and operation. Thus, the risk of damage to the most stressed (in terms of temperature) parts and equipment was prevented. The cooling water circulated through the following separate circuits: gas generator casing, gas generator cup, the gas generator bottom, steam nozzles jacket, air nozzles jacket, gates of slag pool, gas cooler casing. The water for cooling was provided by the power plant, the regulation of the water flow rate through the individual circuits was carried out manually using hand valves. After passing through the appropriate cooling circuit, water flowed through the drain pipes to the water collection tank situated on the roof. The water from the tank was used to feed the cooling system pump, which fed it to the injection of the gas cooler and slag bath.
Figure 3. Image of gasifier: (a) outside view, (b) inside view.

Figure 4. Image of syngas line equipment.

2.3. Experimental procedure
The experimental study was performed according to following procedure. Before fuel loading the gasifier internal lining was slowly heated to ensure absence of large temperature gradients during actual operation. The heating was performed using diesel-fired burner for 24 hours in advance before actual experiments. After heating of lining the air and steam supply to the gasifier core was stopped and high pressure air was supplied into vessel to increase temperature to 0.5 MPa (due to limitations of the compressor the actual pressure was chosen to be 0.5 MPa for the testing). The 4 ton of fuel was supplied to the upper sluice fuel bunker, then the pressure into bunker was increased to 0.5 MPa using nitrogen. The bunker valves were open to supply fuel into gasifier. Then the gasifier was supplied with the air at the low flow rate. The gas composition and flow rate was controlled as well as pressure and temperature in the main points of experimental setup via the specialized software. Interface of this software is presented in Figure 5. After reaching the designed temperature in point 23 the flow rate of air was reduced to nominal value to ensure effective gasification of fuel. In current study the steam was not supplied into the gasifier due to problems with steam generator.

![Figure 5. Software interface screenshot (into stand-by mode).](image)

3. Results and discussion
The experimentally obtained dependences of the carbon monoxide, carbon dioxide, hydrogen and methane concentrations on time of experiment are presented in Figure 6. Small local peaks is connected to periodical maintenance of the gas analyzer. The steam concentration is not presented due to the limitation of the gas analyzer used. The nitrogen concentration after 5th minute of the experiment was nearly constant and equal to the ~50 vol. %. The oxygen concentration was close to 0 vol. % for all experiment meaning complete oxygen consumption and effectiveness of organized gasification process. The temperature of the gas was varied in range 800-1000 °C and tend to increase with the experiment duration. The initial peak into methane and hydrogen concentrations is likely connected to the volatiles release during heating of raw fuel while later (from minute to the end of experiment) the char gasification stage took place. Later concentration of methane and hydrogen were stabilized and tend to decrease due to absence of steam. In steam medium the hydrogen concentration was expected to increase. The carbon monoxide concentration tend to increase while carbon dioxode concentrations decrease meaning that complete combustion of carbon was substituted by its incomplete oxidation with formation of carbon monoxide. The stable combustion of produced gas on the flare was being observed during experiment
Figure 7. Composition of obtained gas made it acceptable for application in energy and chemical industries.

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Figure 6. Dependence of the syngas composition on time during experiment.

Figure 7. Combustion of produced syngas on the flare of setup.
4. Conclusion
The suitability of VTI fixed bed air blown gasification technology for using T-grade bituminous coal was proved into conditions of semi-industrial pilot-scale experimental setup with 4ton per hour fuel consumption. The stable flow of the syngas was observed during experiment as well as its stable combustion on the flare. The composition of syngas allowed its industrial application for purposes of energy production and for some chemical processes. The next step of technology testing is expected to be devoted to continuous operation of the unit for the several days in order to study the transient regimes and stability of gasifier operation.

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