



Fate of inorganic matter in entrained-flow slagging gasifiers: Pilot plant testing

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ABSTRACT

The focus of this paper is on the behavior of inorganic fuel components since the end goal is to develop a CFD model which includes inorganic matter transformations. Using CanmetENERGY's 1 MW_{th} gasifier, five gasification tests have been completed with three different coal fuels and a limestone as fluxant. The refractory liner from the upper section of the gasifier was removed for analysis after each test. The liners were made of sintered alumina or castable alumina–chromia refractory. Carbon conversions and cold gas efficiencies for the gasification tests ranged within 97.0–99.6% and 33.7–61.9%, respectively. Solid samples from the refractory liners, in-situ gas sampling probe sheaths and impingers, the slag tap, the slag pot, quench discharge water and scrubber water were collected and characterized. Char and fly ash samples indicate that most of the inorganic matter melted and formed spheres. Devolatilization and interaction with the gasifier refractory affected the composition of slag collected from the gasifier. Signs of refractory spalling/erosion were detected. The slag layers formed on the alumina liners are smooth with some rivulets and spotting. The slag layers formed on the alumina–chromia liners are rough and bubbly. Slag penetration fractions were determined for all liners.

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1. Introduction

Gasification is a flexible industrial technology which is used for electricity generation, hydrogen production, steam raising and liquid fuel production [1]. Furthermore, it can utilize one or more feedstocks such as coal, biomass, municipal waste and petroleum coke. This versatility, in addition to being adaptable to various emissions control technologies, including carbon capture, renders it an attractive option for the foreseeable future [2]. Most of the successful high throughput coal gasifiers developed in the past 60 years are of the entrained-flow slagging type [1]. This study is the second part of a three-part research program which involves fuel characterization, testing in a 1 MW_{th} gasifier, and computational fluid dynamics (CFD) modeling for entrained-flow slagging gasification. The focus of this program is on the behavior of inorganic fuel components in the gasifier as this is still poorly understood even though it can be the determining factor in designing and operating entrained-flow gasifiers [3].

The motivation for pilot-scale testing is to provide data for a comprehensive CFD model which includes ash particle formation, gas–particle transport, particle sticking, slag flow and slag–refractory interaction.

Multiple studies have been conducted with pilot scale or larger gasifiers [3–7]. Emphasis is often on the syngas composition and fuel conversion. Limited experimental data is provided on the ash and slag produced. The current study investigated inorganic matter phenomena throughout the gasification process by systematically collecting samples which represent each step of ash and slag transformations. These samples were characterized by various techniques to obtain data for CFD model validation. The pilot testing program was based on results from fuel and limestone characterization which included screening of potential fuels, gasifier operation, gasifier design and CFD modeling inputs [8]. Of the four coals that were characterized, one was eliminated at the screening step due to its high ash content combined with its requirement of a fluxing agent. The three fuels remaining were coded F1, F3 and F4. Their proximate analyses, ultimate analyses and gross calorific values are presented in Table 1. F1 fuel is a lignite coal from Saskatchewan, Canada. F3 fuel is a beneficiated sub-bituminous coal from Alberta, Canada. F4 fuel is another sub-bituminous coal from Alberta, Canada. Within the fuel characterization study, it was determined that F1 does not require fluxing for proper gasifier operation, while optimal fluxing ratios with L1, a limestone from a Canadian power company, were determined for F3 and F4. These optimal blends for F3 and F4 fuels were dubbed F3L1 and F4L1, respectively. The intention was to use F1, F3L1 and F4L1 for the pilot plant tests. However, the available quantity of L1 was insufficient. L2, a limestone from Nova Scotia, Canada, was used instead of L1. Due to their similar

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Table 1
Proximate analysis, ultimate analysis and gross calorific value.

	F1	F3	F4
Proximate analysis			
Moisture (wt.%)	6.43	3.32	6.08
Ash (wt.%)	13.87	10.52	24.72
Volatile (wt.%)	36.27	34.76	26.87
Fixed carbon (wt.%)	43.43	51.4	42.33
Ultimate analysis			
Carbon (wt.%)	57.7	67.8	52.2
Hydrogen (wt.%)	3.64	4.22	3.05
Nitrogen (wt.%)	1.02	0.86	0.79
Sulfur (wt.%)	0.93	0.27	0.3
Oxygen (wt.%)	16.41	13.01	12.85
Gross calorific value (MJ/kg)	22.15	26.67	19.98

compositions, the same fuel-to-limestone mass ratios were used for F3L2 and F4L2 as for F3L1 and F4L1, respectively. Inorganic matter composition, particle size distribution, X-ray diffraction analysis and computer-controlled scanning electron microscopy analysis for L2 limestone are available in Supplementary data Tables S1–S4, respectively. Experimental methods for these results are as described by Duchesne et al. [8].

In total, five pilot-scale gasifier tests were performed: tests T1–T3 were with F1 fuel, test T4 was with F3L2 fuel and test T5 was with F4L2 fuel. The operating conditions and gasifier design used are described and justified based on fuel characterization and operational experience. Mass balances on ash and carbon were performed, and subsequently carbon conversion and cold gas efficiency were determined for each test. Solid samples were collected from the refractory liner, the gas probe sheath and impingers, the slag tap, the slag pot, quench discharge water and scrubber water. In addition to validation data for CFD models, characterization of these samples provides insight on often overlooked features of inorganic matter transformations in entrained-flow gasifiers.

2. Experimental

2.1. Gasifier system

The CanmetENERGY pressurized entrained-flow slagging gasifier was configured for single-stage slurry-fed gasification as shown in Fig. 1. Water, coal and limestone (when required) were combined in the slurry tank in sufficient quantity to complete each gasification test. The slurry components were vigorously mixed using both a helical mixer that sweeps the full volume of the tank and a slurry circulation pump with its suction at the bottom dish of the tank with a flow rate sufficient to provide a minimum of eight tank changeovers per hour. Slurry samples were taken before and after each test to ensure that the moisture content and slurry viscosity remained constant throughout the test. During gasification tests, the slurry was pressurized and metered into the gasifier using a progressing cavity pump. The slurry flow rate was determined by loss-in-weight from the slurry tank based on the feedback from load cells with a resolution of ± 0.5 kg. Oxygen was supplied from a cryogenic oxygen tank equipped with a vapourizer. The oxygen flow rate was measured using thermal mass flow meters and controlled by plug valves. Automation and data collection for the pilot gasifier facility are accomplished using an ABB Freelance 2000 distributed control system. No steam or other moderators were injected during the gasification tests.

Slurry and oxygen were premixed within the down-fired gasifier burner in a Delavan Air Swirl nozzle providing a finely atomized hollow cone spray and subsequent flame in the gasifier reactor which was operated at 1.5 MPa (gauge). Details of the slurry spray characteristics under these conditions including spray angle, droplet size distribution, and axial mass flux at various elevations and radial positions are provided by Daviault et al. [9].

The insulation and refractory system from the gasifier shell to the gasifier hot face are made up of the following layers: alumina paper insulation, alumina board insulation, alumina bubble castable refractory and finally the hot face. The hot face is comprised of three sections. The upper section shown in blue (upper refractory liner) in Fig. 1 is removed

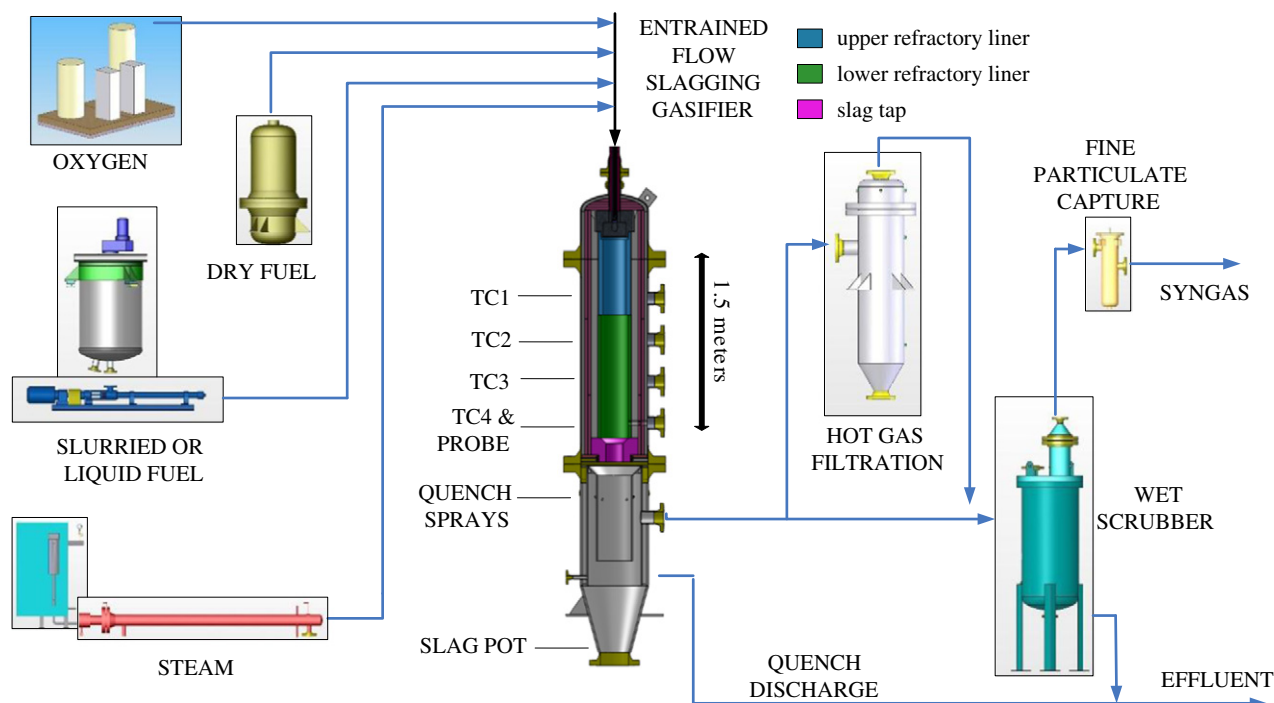


Fig. 1. Schematic diagram of CanmetENERGY's pressurized entrained-flow gasification system.

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