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Numerical modeling of a downdraft plasma gasification reactor

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ABSTRACT

Gasification, a method of producing hydrogen, is an alternative way to obtain clean, sustainable, and domestic energy using coal and biomass resources. Gasification can be achieved with several methods or using various reactor designs, and plasma gasification is one of these methods. Plasma gasification has advantages compared to conventional gasification systems regarding syngas cleaning and gasification rates. Tar production, the greatest problem in fixed bed gasifiers, can be reduced and higher carbon conversion rates can be achieved with plasma gasification systems.

In this study, a 10 kW microwave plasma-integrated down-draft coal gasifier was modeled with ANSYS FLUENT. A novel design is simulated in order to obtain the swirl effect and observe the increase in the residence time for coal particles inside the reactor. Plasma ionization is ignored due to the overlapping of the MHD (MagnetoHydroDynamics) module and combustion models. Therefore, plasma inlet conditions are determined via experimental studies instead of activating the MHD module in Fluent. SIMPLE algorithm is selected for pressure–velocity coupling. Turbulence variables are calculated with the k-ε turbulence model. The interaction between gas phase and discrete phase is followed by Eularian-Lagrangian approach and 10 injection time steps are chosen for the continuity of the reactions. The Finite Rate Chemistry/Eddy Dissipation model is selected for both combustion and gasification models. DO radiation model is used for radiation modeling. Temperature, species (CO, H_2, CO_2, H_2O), and velocity results on different planes are obtained. According to the results, approximately 1350 K average temperature is obtained inside the reactor. Grid independency study is also performed. The results show that it is possible to obtain a syngas with 18.4% H_2 and 37.2% CO mole fractions, respectively. The cold gas efficiency of the gasifier is found to be 55.3%.

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Introduction

Coal is the main energy source for many countries for centuries. Although the interest for alternative energy sources has increased with developing technologies; however, it has never lost its value and importance worldwide due to its availability and price. Efficient utilization of the coal in combustion and gasification systems has been investigated. Gasification can be defined as producing H_2 and CO in a lean oxygen medium. Plasma gasification is a relatively new technology compared to the conventional gasification methods. Atom, radical, and ion mediums, as a result of the plasma formation at high temperature and velocity, have a positive effect on the gasification process, which uses air and water vapor plasma and increases the gasification efficiency [1,2]. Plasma gasification technology decreases the harmful emissions such as NO_x, dioxins, and furans. In addition, it provides fuel flexibility for the designer and operator. The ash is inert, non-hazardous glassy slag that can be used as a by-product of construction aggregate. It is shown that radicals, charged electrons, and ions have positive effects on the gasification of different types of fuels. Because of its high temperature, the time required for the reactions is decreased. Kalinci et al. [3] performed an exergoeconomic research for hydrogen production from sewage waste with plasma gasification. Three different methods were used in the analysis. Chemical composition of the waste was investigated and, from chemical decomposition to devolatilization, all of the processes and the production mechanism of each species were discussed. According to their results, it was concluded that the sewage waste can be treated as a biomass source. Also, it was indicated that the plasma gasification systems are convenient for the capability of producing high purity hydrogen. Byun et al. [4] investigated solid waste gasification and production of 99% purity hydrogen. The produced syngas was considered to be used in PEM (Proton Exchange Membrane) fuel cells due to its high H_2 content. High temperature plasma was used for the gasification and three reasons were considered in the selection of plasma gasification systems, namely, higher reactor temperatures, fuel flexibility, and stable operation due to higher reaction rates. Yoon et al. [5] investigated the gasification of glycerol with a microwave plasma. Nitrogen was selected as the plasma medium in the study and it was found

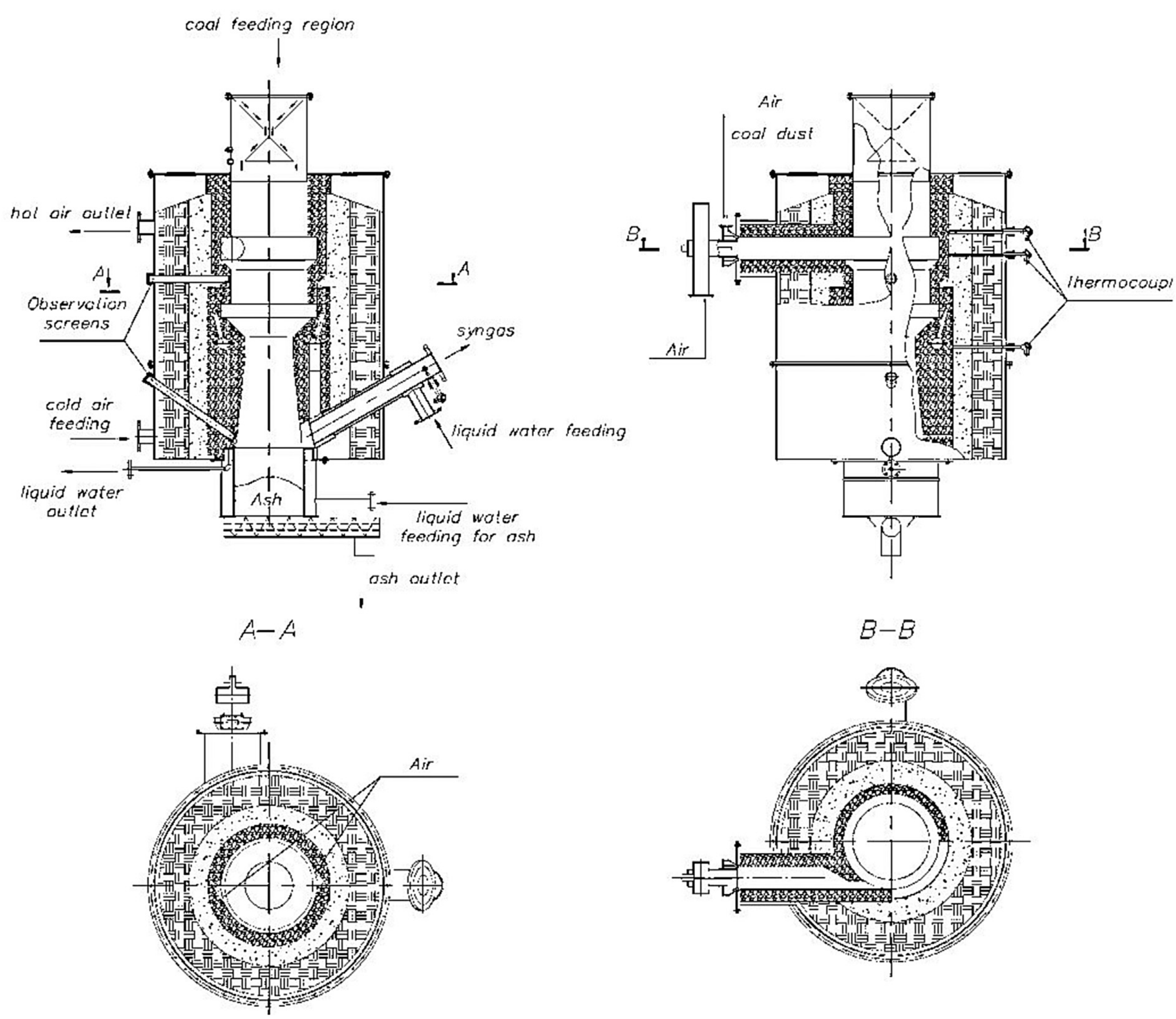

Fig. 1 – Technical drawing of the down-draft gasifier.