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Development of a novel reformer for tar-free syngas production

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Abstract

A novel reformer using highly efficient heat regeneration for tar-free syngas production is developed and its performance demonstrated in a pilot-scale plant using steam gasification. Basic design parameters of the regenerative tar reformer, namely residence time and amount of oxidant are determined based on numerical results. It has been predicted that good performance could be achieved at an operation temperature about 1573 K, the residence time exceeding 4 sec and an oxidant addition of 12% of the syngas flow rate. The regenerative tar reformer so designed shows stable operation. Over 99% of light and heavy tars are reformed to gas in the case of 11.3% oxygen addition to syngas. Further it is seen that a reduction of oxygen consumption more than 30% compared to a conventional oxidation reformer can be achieved. The formation of a high temperature zone has a strong influence on the tar reforming efficiency.

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Keywords: Tar reformer; regeneration; steam gasification

1 Introduction

Gasification of solid feedstock for syngas production or heat and power generation increasingly attracts interest all over the world [1, 2]. Steam gasification in a fluidized bed gasifier generally yields a higher cold gas efficiency compared to gasifiers working under high temperature and pressure. Twin IHI gasifier called TIGAR has been developed by the authors [3] over the years. TIGAR can produce syngas of high calorific value using steam gasification in the circulating fluidized bed. However, the presence of tar from the process of low temperature gasification can cause pipe blockage and also reduces the overall cold gas efficiency of the process. It is, therefore, necessary to realize a high conversion of the tar to gases. One of the basic methods for tar conversion is partial oxidation reforming with high temperature combustion. On the other hand, there is the problem of reducing the total cold gas efficiency due to consumption of syngas, when large amounts of oxidant are used [4]. Thus, a novel tar reformer using the technology of highly efficient heat regeneration is developed in this study.

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The combination of regenerative burners [5] forms a heating system which allows self-heat recovery of exhaust gas in the combustion process. Cyclic regenerative combustion operates on the principle of short-term heat storage using ceramic heat exchangers. The flow direction is periodically changed by switching valves. Owing to reduction of fuel consumption and NO_x emission, this system has been specifically adopted and popularized in high temperature furnaces. However, to the authors' knowledge, the regenerative technique has not been applied to tar reforming yet. The main objective of this study is to design and show the performance of a regenerative tar reformer, which allows a decrease of oxygen supply and thereby an increase in cold gas efficiency.

2 Numerical methods and results

Before starting with the detailed engineering, basic design parameters of the regenerative tar reformer have been determined based on numerical results. For this purpose two commercial software packages, CHEMKIN-Pro and FLUENT 15.0, have been used (conditions of simulation model are shown in Table 1). In a first step, the relationship between residence time and reactor temperature is investigated by perfectly stirred reactor (PSR) calculations using detailed chemistry including tar [6]. The results reveal the necessary temperature which has to be provided for effective tar reforming. Then, the amount of oxygen to achieve this temperature is estimated from 3D-calculations with simplified gas combustion chemistry [7]. All hydrocarbons with aromatic rings are regarded as tar components. In the 3D-calculations, radiation is modeled by the Discrete Ordinate method; heat loss to the boundaries is evaluated by solving 1D-heat conduction through the walls. Syngas is supplied with the preheating temperature of 1170 K; composition and amount of tar are set with reference to experiments performed in the TIGAR pilot gasification facility using woody biomass. The amount of oxygen addition is expressed by the volumetric ratio R_{O2} of oxygen to syngas (Equation 1). Figure 1 shows the relation between residence time in the reactor and tar reforming efficiency (Equation 2) with reactor temperature as parameter. It is seen that the residence time necessary to accomplish almost complete tar reforming becomes shorter, when the reactor temperature is increased. Thus, a smaller reactor can be realized with higher reactor temperature. However, a high temperature must be obtained by oxidizing syngas, which diminishes the energy efficiency of the gasification process.

$$R_{O2} = \text{volume of oxygen / volume of syngas (wet)} *100\% \quad (1)$$

$$\eta_{tar} = (1 - \text{total mass of tar at outlet / total mass of tar at inlet}) *100\% \quad (2)$$

Table 1. Conditions of simulation model

Reaction condition		Software	CHEMKIN-Pro	FLUENT 15.0
		Flow field	Unsteady	Steady state
Inlet gas condition	Gas composition, wt%	H_2	1.78	
		H_2O	32.59	
		CO	29.63	
		CO_2	18.00	
		C_mH_n	9.58	
		N_2	6.34	
		Tar	2.08	
	Temperature, ℃		1170	
Temperature condition			Constant	1D heat conduction
Reaction model			Detailed chemistry [6]	Reduced chemistry [7]
Radiation model			-	Discrete Ordinate
Emissivity			-	0.5
Thermal conductivity, W/mK			-	2.18

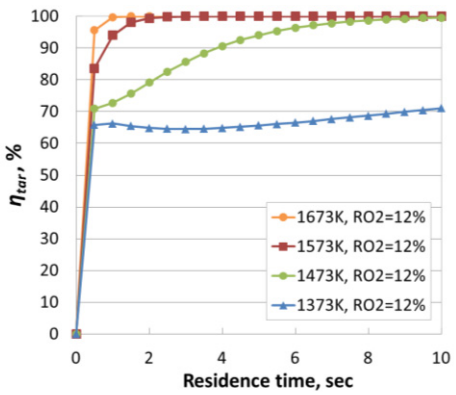

Fig. 1. Tar reforming efficiency vs. residence time.