New reactor concept for sorption-enhanced Fischer-Tropsch synthesis

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Abstract

The Fischer-Tropsch (FT) synthesis is from particular interest nowadays, as means of producing liquid hydrocarbons from various non-fossil feedstocks. Special attention is given to sorption-enhanced (SE) reaction processes due to negative effects of water on conversion and catalyst reported in literature. Therefore, a new reactor concept of two connected slurry bubble columns (SBC) for FT reaction with in-situ water removal and sorbent regeneration was designed and a cold flow model of the reactor was built up. The liquid circulation rate and thus the residence times in the columns as one of the most important designing parameters were studied with respect to the superficial gas velocity in a water-air experiment.

1. Introduction

The Fischer-Tropsch synthesis has gained lots of interest in the past few years due to the possibility of producing carbon neutral energy carriers from various feedstocks, such as biomass or plastic waste.
Besides long-chain hydrocarbons, water is the main by-product and has different effects on the reaction. Bartholomew et al. [1] reported a critical value for faster catalyst deactivation at water partial pressures p_{H2O} > 6 bar considering Cobalt-based catalysts. Furthermore, large amounts of water (25 %) can lead to severe irreversible catalyst deactivation [2]. Additionally, it is reported that water acts as kinetic inhibitor due to adsorption on the active sites of the catalyst [3]. Using water-gas-shift (WGS) active Iron-based catalysts, a removal of water leads to an equilibrium shift in favour of the production of carbon monoxide which can be converted to long-chain hydrocarbons in the following FT-reaction [4]. Consequently, a SE FT synthesis can have several advantages, such as conversion enhancement and extended catalyst life-time. Zeolites (water sorbents) were already successfully used in other SE reactions, such as WGS or methane synthesis [5, 6].

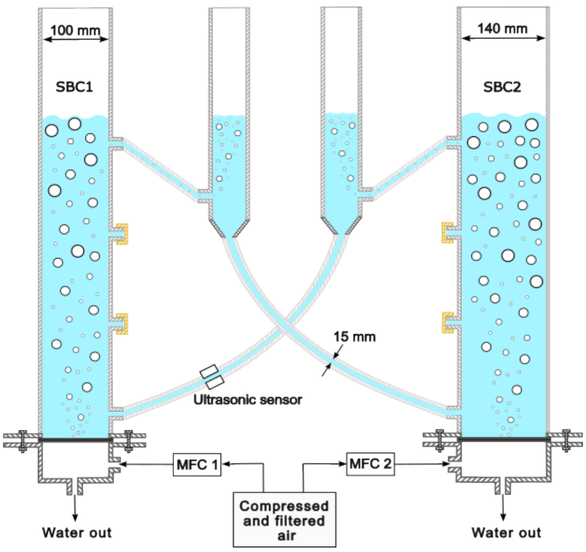

Fig. 1: Cold flow model of connected SBC as new reactor concept for the SE FT synthesis.

SBC are commercially used three-phase reactors in the FT synthesis. For a continuous operation of FT reaction with in-situ water removal in one SBC and sorbent regeneration in the other SBC, a new reactor concept of two connected SBC was designed (Fig.1). The principle of particle circulation between the columns is based on density differences of the slurry and is commonly used in airlift reactors [7]. Jafarian et al. [8] already introduced a cold model of two connected bubble columns with the same diameter (85 mm) and proved the concept successfully. However, in three-phase systems particles need to have different residence times in the columns (e.g., desorption takes longer than adsorption), which can be achieved with different column diameters. Thus, in a first step the dependency of the circulation rate and residence time on the gas flow will be examined for a cold model with two different column diameters.

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2. Material and methods

The reactor consists of two cylindrical columns with diameters of 100 and 140 mm (Fig.1). The columns are connected via two tubes (diameter = 15 mm). Water flows in the tubes from one column to another passing a funnel where entrained gas is separated, producing the necessary density differences for the circulation. Compressed air is sparged in two sinter metal plates at the bottom of the columns. The liquid circulation rate between the columns is measured with an ultrasonic flow sensor (SONOFLOW CO.55/160 V2.0) from Sonotec under ambient pressure and temperature.

3. Results and discussion

Fig. 2 shows the impact of the superficial gas velocity on the liquid circulation rate. First, the liquid circulation rate increases with increasing superficial gas velocity until a maximum is reached at u_s = 3 cm/s. Subsequently, the liquid circulation rate decreases until it starts to increase again with rising standard deviation. One reason for this behaviour may be the transition between homogenous and heterogenous bubble regime. Both, in bubble and slurry bubble columns, the regime depends on the superficial gas velocity [9]. In the heterogenous regime large bubbles arise and the water amount entering the tubes is neither sufficient nor constant, resulting in a decreasing liquid circulation rate and increasing standard deviation. At one point (7 cm/s) the effect of density differences which is the driving force of the circulation takes into account and the circulation rate increases to almost the same level as before (~ 7 l/min). Jafarian et al. [8] observed a similar behaviour in the heterogenous regime. The residence time shows the inverted manner. The residence time of both columns differ by a factor of 1,96 depending on the column diameters.

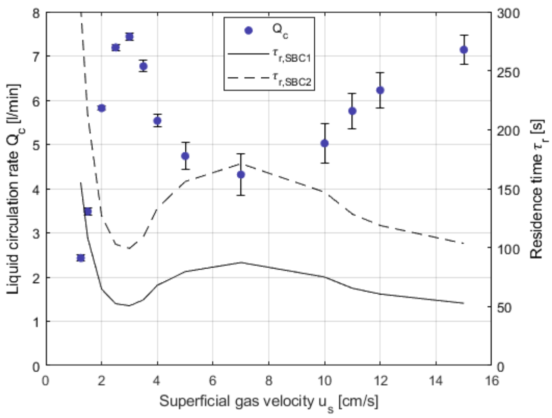

Fig. 2: Impact of superficial gas velocity u_s on liquid circulation rate Q_c with standard deviation and residence time τ_r in SBC 1 and 2.

4. Conclusions

A new reactor concept for the SE FT synthesis was introduced and a cold model was set up. The variation of the superficial gas velocity shows an impact on the liquid circulation rate. After the transition between homogenous and heterogenous regime the liquid circulation rate increases with higher gas velocities. It was shown that depending on the column diameters, different residence times can be achieved which is sufficient for SE reaction processes, such as FT synthesis when desorption takes longer than adsorption. In a next step, the influence of other design parameters on the circulation rate should be studied in a three-phase system as well as the particle behaviour.

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