R1.4 Gas-Phase Industrial Reactor/Process

Synthesis gas contains a mixture of carbon monoxide and hydrogen and can be obtained from the combustion of coal or natural gas. This gas can be used to produce synthetic crude by the Fischer–Tropsch reaction. Describe two industrial reactors used to convert synthesis gas to a mixture of hydrocarbons by the Fischer–Tropsch process.

Solution

Reactions. The Fischer–Tropsch reaction converts synthesis gas into a mixture of alkanes and alkenes over a solid catalyst usually containing iron. The basic reaction for paraffin formation is as follows

$$nCO + (2n+1)H_2 \longrightarrow C_nH_{2n+2} + nH_2O \qquad \text{(RE1-4.1)}$$

Making Gasoline

For example, when octane, a component of gasoline, is formed, Equation (RE1-4.1) becomes

$$8CO + 17H_2 \longrightarrow C_8H_{18} + 8H_2O \qquad \text{(RE1-4.2)}$$

Similarly, for the formation of olefins,

$$nCO + 2nH_2 \longrightarrow C_nH_{2n} + nH_2O \qquad \text{(RE1-4.3)}$$

For ethylene formation, Equation (RE1-4.3) becomes

$$2CO + 4H_2 \longrightarrow C_2H_4 + 2H_2O \qquad \text{(RE1-4.4)}$$

The other type of main reaction that occurs in this process is the water-gas-shift reaction

$$H_2O + CO \rightleftarrows CO_2 + H_2 \qquad \text{(RE1-4.5)}$$

In addition to the simultaneous formation of paraffins and olefins, side reactions also take place to produce small quantities of acids and nonacids (e.g., ethanol).

Reactors. Two types of reactors will be discussed, a *straight-through transport reactor*, which is also referred to as a *riser* or *circulating fluidized bed*, and a *packed-bed reactor* (PBR), which is also referred to as a *fixed-bed reactor.*

Riser. Because the catalyst used in the process decays rapidly at high temperatures (e.g., 350°C), a *straight-through transport reactor* (STTR) (Chapter 10) is used. This type of reactor is also called a *riser* and/or a circulating bed. A schematic diagram is shown in Figure RE1-4.1. Here the catalyst particles are fed to the bottom of the reactor and are shot up through the reactor together with the entering reactant gas mixture and then separated from the gas in a settling hopper. The volumetric gas feed rate of 3×10^5 m^3/h is roughly equivalent to feeding the volume of gas contained in the University of Michigan football stadium to the reactor each hour.

A schematic and photo of an industrial *straight-through transport reactor* used at Sasol are shown in Figure RE1-4.2 together with the composition of the feed and product streams. The products that are condensed out of the product stream before the stream is recycled include Synoil (a synthetic crude), water, methyl ethyl

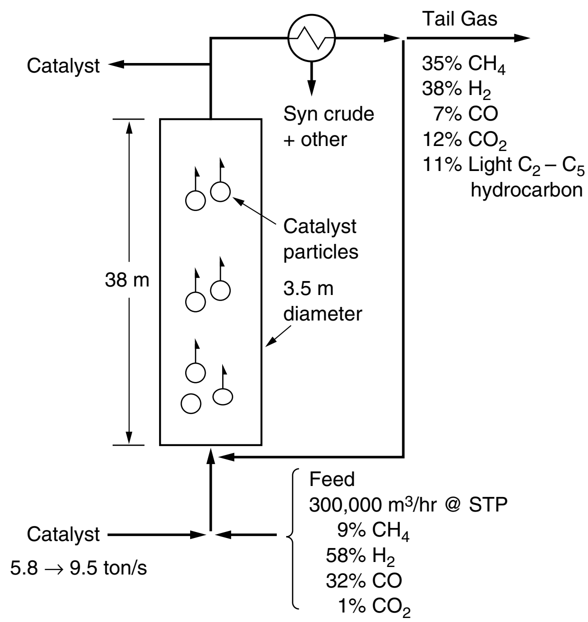
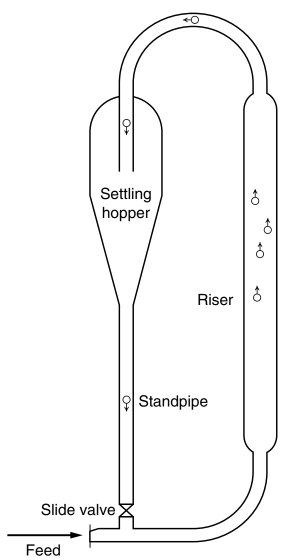


Figure RE1-4.1 Schematic of Sasol Fischer–Tropsch process.



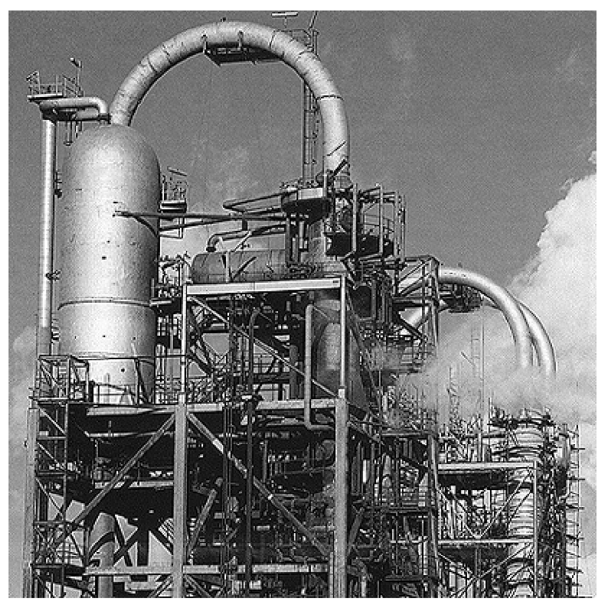
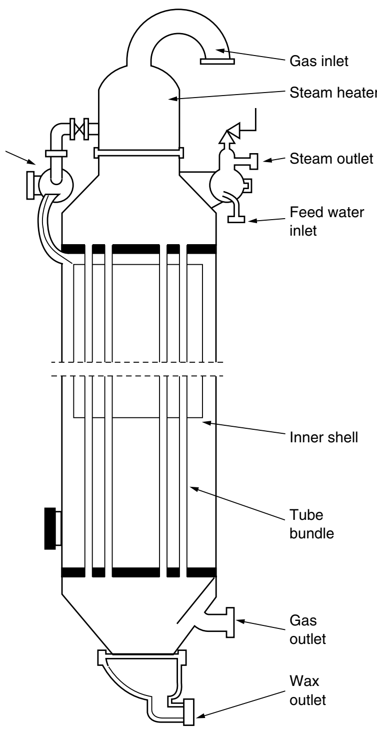


Figure RE1-4.2 The reactor is 3.5 m in diameter and 38 m tall. (Schematic and photo courtesy of Sasol/Sastech PT Limited.)

ketone (MEK), alcohols, acids, and aldehydes. The reactor is operated at 25 atm and 350°C and at any one time contains 150 tons of catalyst. The catalyst feed rate is 6 to 9.5 tons/s, and the gas recycle ratio is 2:1.

Use to produce wax for candles and printing inks.

Packed Bed. The packed-bed reactor used at the Sasol plant to carry out Fischer–Tropsch synthesis reaction is shown in Figure RE1-4.3. Synthesis gas is fed at a rate of 30,000 m^3/h (STP) at 240°C and 27 atm to the packed-bed reactor. The reactor contains 2050 tubes, each of which is 5.0 cm in diameter and 12 m in length. The iron-based catalyst that fills these tubes usually contains K_2O and SiO_2 and has a specific area on the order of 200 m^2/g. The reaction products are light hydrocarbons along with a wax that is used in candles and printing inks. Approximately 50% conversion of the reactant is achieved in the reactor.



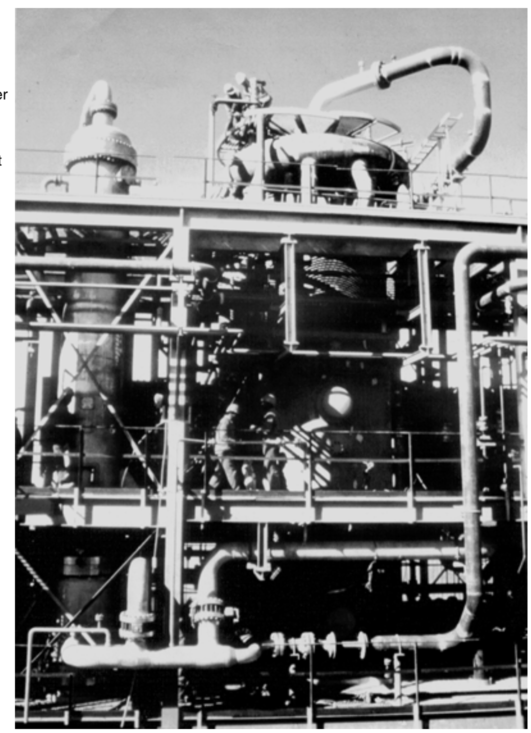


Figure RE1-4.3 Packed-bed reactor. (Schematic and photograph courtesy of Sasol/Sastech PT Limited.)

The aim of the preceding discussion on commercial reactors is to give a more detailed picture of each of the major types of industrial reactors: batch, semibatch, CSTR, tubular, fixed-bed (packed-bed), and fluidized-bed. Many variations and modifications of these commercial reactors are in current use; for further elaboration, refer to the detailed discussion of industrial reactors given by Walas.*

* S. M. Walas, *Reaction Kinetics for Chemical Engineers* (New York: McGraw-Hill, 1959), Chap. 11.