Pulsed compression: advanced technology for synthesis gas production

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Introduction

Production of synthesis gas by steam reforming or by partial oxidation involves rather high temperatures of 800 – 1400 ^oC. The required heating of the feed and recovering of thermal energy of the product entail high capital and operating costs. As a result the available synthesis gas based processes for the production of synthetic fuels are currently not economically attractive (Lange and Tijm, 1996).

A fundamentally new chemical reactor concept, namely the free piston pulsed compression reactor (Glouchenkov 1997, 1999), permits a breakthrough in synthesis gas production in terms of energy efficiency, capital costs, and portability. The novel reactor technology is totally opposite to the current trends. Instead of developing better catalysts and decreasing the process temperature no catalysts is used and the reactions occur at very high temperatures of 1500 – 3000 ^oC. Success of the novel reactor concept is achieved via cycling operation and integration of all process steps in a single unit.

Reactor concept

The basic idea of the reactor is schematically shown in Figure 1. The reactor consists of a double-ended cylinder and a free piston, which divides the cylinder into two compression-reaction chambers. The cylinder has inlet and outlet ports in its wall for feeding the reactants and exhaust of the reaction products. The piston reciprocates compressing in turn the feed gas, until it reacts, in the lower and upper chamber. The reciprocation is maintained by the released reaction energy. An essential feature of the reactor is that the piston-cylinder assembly has no sealing rings. Gas leakage through the annular piston-cylinder gap is prevented by using contactless labyrinth seals. Small gas leakage is even desired to prevent any contact of the piston with the cylinder wall by means of self-centering and self- alignment of the piston in the cylinder (gas lubrication or gas bearings).

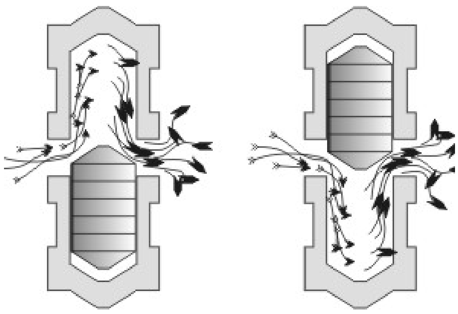

Figure 1. Operating principle of the pulsed compression reactor.

The reactor design permits achieving very high compression ratios (ratios of the initial and final volumes) and frequencies of the piston oscillation (up to 400 Hz). The very short duration of the extreme conditions prevents significant heat exchange between the hot, compressed gas and the reactor walls. Thus, unique combinations of pressures and temperatures from several hundreds to several thousands of bars and up to several thousands of K can be obtained. These conditions are ideal for almost instantaneous completion of many industrial chemical reactions. The high frequency of the piston oscillation results in very high space velocities (GHSV ~ 10^6). Huge rates of temperature and pressure change (up to 10^7 K/s, 10^7 bar/s) afford an excellent way of “freezing” the high temperature products and producing a better yield.

Cooling of the reactor is unnecessary because no piston rings and lubricating oil are used. The energy losses due to friction and gas leakage are much smaller than the losses in the conventional processes. The reactor comprises the entire processing train: gas compression, heating of the reactants, reaction itself, cooling of products and utilization of the released reaction energy. It is ideally suited for synthesis gas production by partial oxidation of various hydrocarbon feedstocks.

Experiments and results

Firstly, the basic performance of several reactors was studied doing experiments with compressed air. The reactors demonstrated unique performance in terms of the achieved combinations of compression, frequency, temperature and pressure which cannot be achieved in other known piston-compression machines (Glouchenkov et al., 2002).

The feasibility of the novel reactor concept was demonstrated using two reactors– one with a single working chamber and a second with two working chambers as shown in Fig. 1. The inner diameter of the both reactors was 60 mm. The experiments were conducted mainly with propane/air mixtures. Concentration of propane in the feed gas varied from 0.8 to 20 vol % (fuel/air equivalence ratio, ϕ = 0.2 – 6.0). Also methane/air mixtures were studied.

At first, the conditions required for the reactions were studied in experiments without gas flow through the reactors. The occurrence of the reactions manifested through a significant increase of the maximum pressures (20 – 200 bar) compared to that at similar conditions but only with air. Figure 2 shows the influence of propane on the pressure change. Extremely short reaction times (~ 10 μs) and huge rates of pressure change can be seen. Figure 3 shows an examples of the pressure change during continuous operation of the reactor. The analysis of the product composition revealed significant yield of synthesis gas.

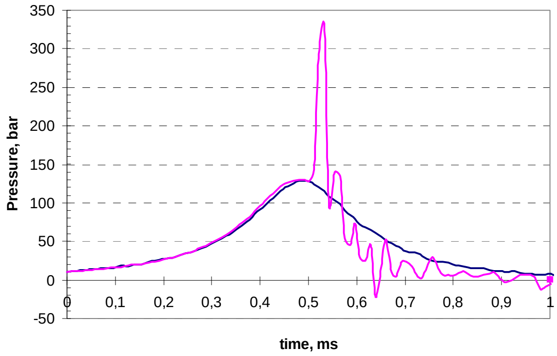

Figure 2. Influence of propane on the pressure change in the single-chamber reactor; dark blue line – without propane, purple line – with propane (ϕ = 0.63).

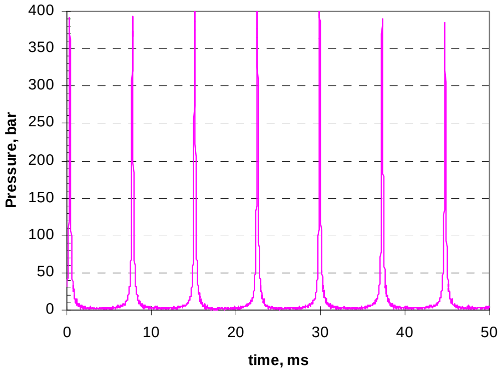

Figure 3. Pressure change in the single-chamber reactor during continuous syngas production: ϕ =3.6.

Conclusions

Experiments have shown that the free piston pulsed compression reactor is feasible for economic synthesis gas production. No other reactors integrate so many functions and allow so high pressures and temperatures, so high quenching rates and so high space velocities. The new technology is anticipated to be superuior for conducting many other industrially important reactions, e.g. manufacturing acethylene, ethylene and propylene by pyrolysis of methane and othere hydrocarbons.

References

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