FLUIDIZED BED REACTORS

The principle of fluidization is the foundation of the fluidized bed reactor. In such a reactor the fuel together with inert bed material behaves like a fluid. This behavior is obtained by forcing a gas (fluidization medium) through the solid inventory of the reactor. Air, steam, steam/O_2 mixtures are examples of commonly used fluidization media. Silica sand is the most commonly used bed material, but using other bulk solids, especially those that exhibit catalytic action in the process can be beneficial.

Depending on the velocity of the fluidization medium in the reactor, the fluidized bed reactors are divided in bubbling fluidized beds (BFB) and circulating fluidized beds (CFB). Bubbling beds operate at relatively low gas velocities (typically below 1 m s^{-1}), while the circulating fluidized beds operate at higher gas velocities (typically 3–10 m s^{-1}), dragging the solid particles upwards with the gas flow. These particles are separated from the gas in the cyclone and recycled to the bottom of the fluidized bed. In both cases most of the reactions during the conversion of a fuel into a product gas take place within the dense bed region (bubbling bed); to a lesser extent they continue in the freeboard (tar conversion).

The inert bed enhances the heat exchange between the fuel particles, and therefore a fluidized bed can operate under nearly isothermal conditions. The maximum operating temperature is limited by the melting point of the bed material and will typically lie between 800 and 900 ◦C. At these relatively low operating temperatures and also relatively short gas residence times the (slow) gasification reactions do not reach their chemical equilibrium if no catalyst is applied. This is the reason for the presence of the hydrocarbons (tar, methane) in the product gas; the tar production falls between that of an updraft and downdraft fixed bed gasifier.

The conversion rate of the feedstock is typically high. Due to their geometry and excellent mixing properties, fluidized beds are very suitable for scaling up. The energy throughput per unit of reactor cross-sectional area is higher for a CFB than for a BFB. Both configurations can be operated under pressurized conditions, which will further increase the throughput, and will also be beneficial when the downstream process requires a pressurized input stream, as for instance in the case of Fischer-Tropsch synthesis.

Intense mixing also allows the reactor to accept a wider particle size distribution of the fuel feed, starting already from relatively fine particles. Furthermore, in contrast to other reactor systems presented here, the fluidized bed gives the possibility for the use of additives, e.g., for the in-situ removal of pollutants (like sulphur) or the primary measures to increase tar conversion. The weakest point of the fluidized bed technology emerges when fuels with high content of ash, and alkali metals in particular, are applied.

When the fraction of alkali metals in the fuel is high, those compounds can form eutectics with silica present either in the bed material, or in the fuel ash itself. The presence of chlorine amplifies this effect. Those eutectics have melting points that are considerably lower than that of pure silica. Therefore they will start to melt at process temperature, likely causing stickiness of the particles, eventually leading to the formation of bigger lumps ("agglomerates"). Their presence will dramatically change the hydrodynamics of the reactor, ultimately leading to "defluidization" and necessary shut-down of the reactor.

Those phenomena are discussed further sections. Nonetheless, by applying proper countermeasures, the fluidized bed will still be able to accept fuels with an ash content higher than those allowable for a fixed bed reactor. Van der Drift et al. tested ten residual biomass fuels (from demolition wood to sewage sludge and verge grass) in an air-blown CFB gasifier and concluded that this technology seems to be very suitable for the gasification of all types of different biomass materials.

Depending on the way that heat is supplied for the gasification reactions, the (circulating) fluidized beds can be divided into the directly heated and indirectly heated units. In the directly heated concept, a part of the product of the gasification process is burned directly in the gasification reactor. Obviously the designs should be optimized for the maximal interaction of the entering oxygen with the recirculated char.

However, due to the intense mixing it is nearly inevitable to avoid the combustion of some fraction of the product gas as well. To overcome this, and to avoid the dilution of the product gas by nitrogen but without the use of pure oxygen instead of air, the indirectly heated gasifier concept has been developed. The principle of operation is based on two interconnected reactors: usually a steam-blown gasification reactor and an air-blown combustion reactor. The bed material and the char are transported from the gasification reactor to the combustion reactor where char is oxidized with air, generating the necessary heat for the gasification part. The heated bed material is recirculated back to the gasification reactor to complete the cycle. Several implementations of that concept exist.

The most well-known are the Battelle’s Silvagas R process, the Fast Internally Circulating Fluidized Bed (FICFB) developed by TU Vienna, and the Milena gasifier developed by ECN. The schematics of the classical directly heated CFB as well as of the three indirectly heated gasifier concepts are presented in Figure. At present it is difficult to state which process is better. Certainly, there is more practical experience with the classical CFB concept, and also with its operation under pressurized conditions.

The gas produced using the indirectly heated CFB is richer in hydrogen and there is less CO2 present, but the content of methane is also higher. Together with the relatively low product gas temperature (circa 650 ◦C compared to 850 ◦C in a directly heated gasifier) this process seems to be more suitable for tar removal by scrubbing and subsequently the production of substitute natural gas (SNG), while the directly heated concept is likely to be followed by methane and tar reforming and the production of secondary liquid energy carriers. Both reactor concepts and various combinations of downstream processes are now subject to intense investigations.

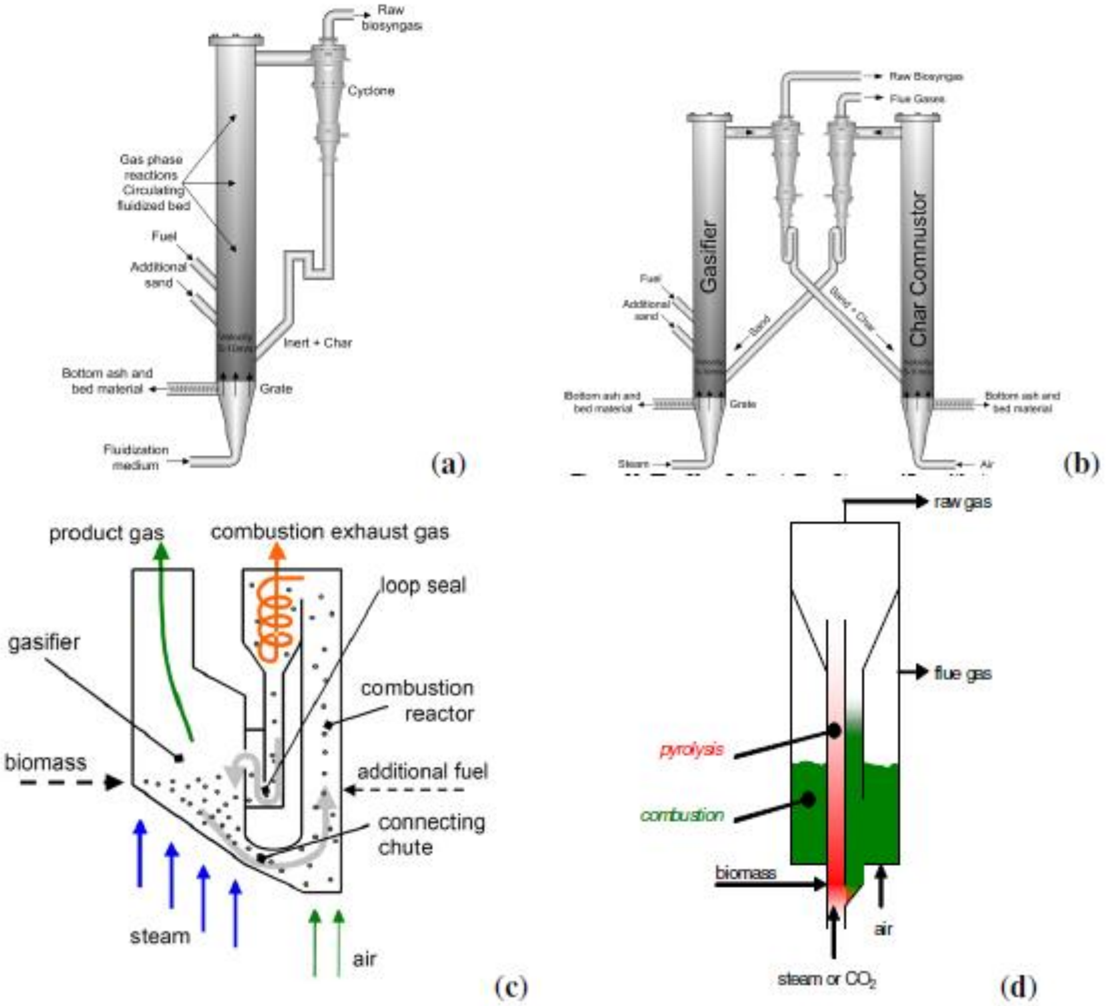
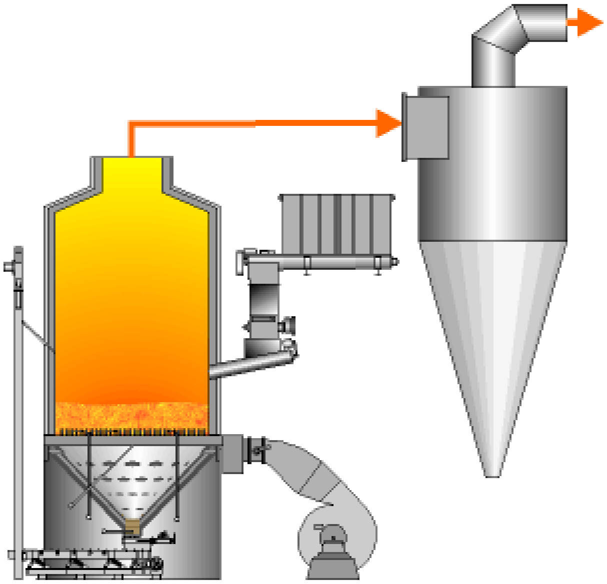


Fig. Different CFB gasification concepts: (a) classical, directly heated [49]; (b) indirectly heated dual CFB, Battelle [49]; (c) indirectly heated FICFB, TU Vienna [50]; (d) indirectly heated Milena, ECN [51]

FLUIDIZED BED GASIFIERS

In fluidized bed gasifiers, the biomass is brought into an inert bed of fluidized material (e.g. sand, char, etc.). Such systems are less sensitive to fuel variations but produce larger amounts of tar and dust. They are more compact but also more complex, and usually used at larger scales. Fluidized bed gasifiers are operated with significantly higher gas flow velocities than fixed bed gasifiers. The fuel bed and a carrier material (e.g. sand) are fluidized by the gas flow (fumigator and recirculated product gas). Thus, the gasification reaction takes place in a fluidized bed but only 5-10% wt of the bed is fuel.



Fluidized bed Gasifier

The fuel is fed into the system either above-bed or directly into the bed, depending upon the size and density of the fuel and how it is affected by the bed velocities. During normal operation, the bed media is maintained at a temperature between 1000EF and 1800EF. When a fuel particle is introduced into this environment, its drying and pyrolyzing reactions proceed rapidly, driving off all gaseous portions of the fuel at relatively low temperatures. The remaining char is oxidized within the bed to provide the heat source for the drying and de-volatilizing reactions to continue. In those systems using inert bed material, the wood particles are subjected to an intense abrasion action from fluidized sand. This etching action tends to remove any surface deposits (ash, char, etc.) from the particle and expose a clean reaction surface to the surrounding gases. As a result, the residence time of a particle in this system is on the order of only a few minutes, as opposed to hours in other types of gasifiers. Thus, higher fuel throughput rates are achievable.

Since the fluidized bed allows an intensive mixing and a good heat transfer, there are no distinguished reaction zones. Hence, drying, pyrolysis, oxidation and reduction reactions take place simultaneously. The temperature distribution in the fluidized bed is relatively constant and typically ranges between 700°C and 900°C. The large thermal capacity of inert bed material plus the intense mixing associated with the fluid bed enable this system to handle a much greater quantity and, normally, a much lower quality of fuel.