Fixed Bed Catalyst Reactors – Design Aspects

Temperature and residence time are the key factors which determine catalyst performance in fixed bed platinum group metal (pgm) catalysed gas phase reactions. Practical economic considerations dictate individual pellet shape and catalyst bed configuration.

One of the commonest applications of fixed bed pgm catalysts in the non-petrochemical industries is to produce high purity gases. This uses pelleted catalysts generally comprising $\leq$ 0.5% by weight of pgm, supported on either ceramic extrudates, compressed tablets or spheres. With such a catalyst, traces of oxygen (O_2) can be removed from hydrogen (H_2) and *vice versa*. O_2 or H_2 can also be removed from inert gases, such as nitrogen or argon, by adding slightly superstoichiometric amounts of H_2 or O_2, respectively, according to the Equation:

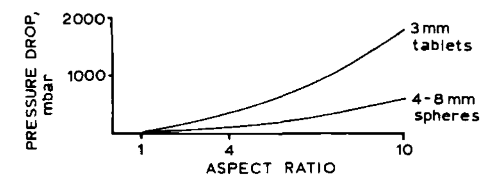
$$2H_2 + O_2 \rightarrow 2H_2O \qquad \Delta H = -241.8 \text{ kJ mol}^{-1}$$

The catalyst bed temperature should be at least 10°C above the dew point (to avoid masking the active pgm sites with liquid water) but always be below the recommended maximum of ~ 600°C. Overheating causes irreversible pgm crystallite agglomeration with consequential loss of catalytic activity. A temperature increase of 164°C is experienced by the reaction of 1 vol.% O_2 in H_2, so the capacity of a single reactor is limited. However, higher contaminant levels can be removed using multiple catalyst beds fitted with inter-bed gas cooling.

The amount of catalyst needed for a given application depends on the gas hourly space velocity (GHSV) – total hourly normalised volumetric gas flow rate ($Nm^3\, h^{-1}$) / catalyst bed volume – which in turn depends on the amount of contaminant in the inlet gas and the maximum allowed level of contaminant in the exit gas. In these water/steam forming reactions, a typical operating GHSV is 10,000 h^{-1} (residence time 0.36 s). Usually the catalyst pellets are housed in a cylindrical reactor. For a given volume of catalyst, many combinations of bed diameter and bed length are possible. The ratio of catalyst bed length:diameter is called the 'aspect ratio'. A high aspect ratio produces high linear gas velocity, high tortuosity (contact with many active pgm catalyst sites) and high pressure drop across the catalyst bed.

In practice a compromise is made between the benefit of high tortuosity and possible detrimental effects of high pressure drop and high linear gas flow through the bed. The catalyst bed diameter must always be at least 10× the individual pellet size to ensure that 'channelling' at the reactor wall has no disproportionate effect on the reaction efficiency.

For a given GHSV, catalyst volume and aspect ratio, the pressure drop will depend on pellet size, shape and packing density (the greater the voidage, the smaller the pressure drop). Using the operational data below, pressure drops can be calculated for different pellet geometries and aspect ratios.



Pellets must be physically strong and resistant to attrition losses (dusting). An increasing pressure drop indicates pellet disintegration and can result in a deteriorating catalyst performance.

Consider the removal of 0.1 vol.% O_2 from H_2 with a total volumetric gas flow of 13,000 $Nm^3\, h^{-1}$, GHSV of 10,000 h^{-1}, and an inlet gas temperature of 50°C and pressure of 5 barg. A conversion efficiency of > 99% (exit O_2 concentration < 10 ppmv) can be expected with standard 0.5% pgm on alumina pellets. For higher conversions, either a higher inlet gas pressure or a lower GHSV (adding more catalyst) should be considered.

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