Vacuum Pressure Swing Adsorption

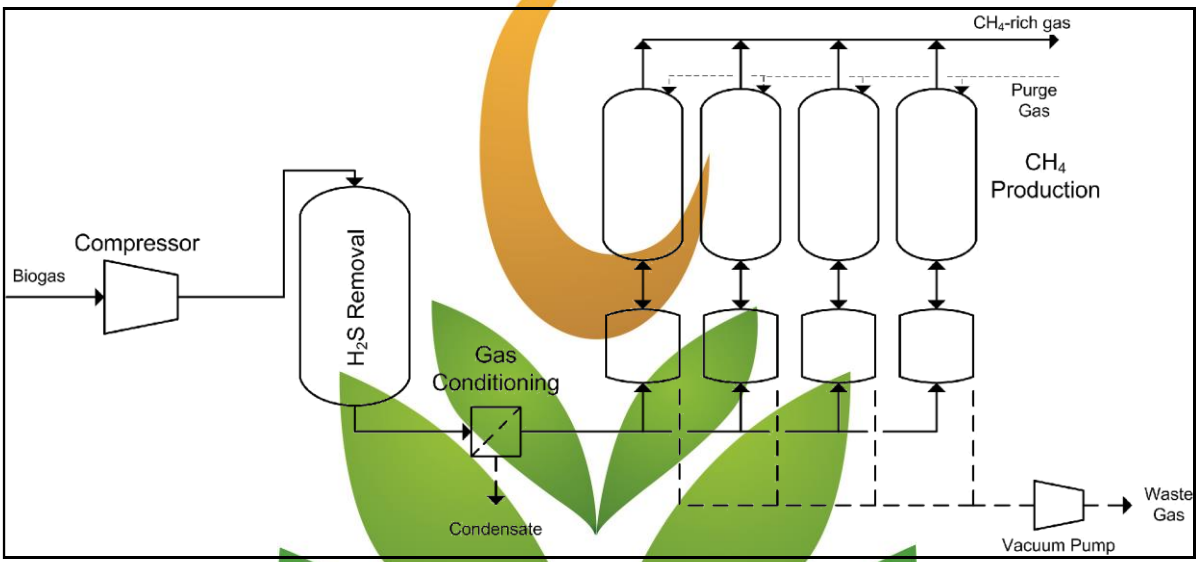
Introduction:-

In VPSA process, biogas is compressed at a pressure between 1-12 bar and is fed in to a column where it is kept in contact with adsorbent which selectively retains CO_2. The adsorbent is a porous solid, normally with high surface area. Some of the adsorbents employed in the commercial processes are carbon molecular sieves (CMS), activated carbons, Zeolite molecular sieves and other materials (Titanosilicates). The purified CH_4 is recovered at the top of the column with a very small pressure drop. After several times of usage, the adsorbent is saturated with CO_2, and the column needs to be regenerated by reducing the pressure (normally to vacuum for biogas upgrading). The adsorption of H_2S is normally irreversible in the adsorbents and thus a process to eliminate this gas should be placed before the VPSA. Alternatively, depending on the choice of the adsorbent, the humidity contained in the biogas stream can be removed together with CO_2 in the same unit. Multi-column arrays are employed to emulate a continuous process. For small applications subjected to discontinuities, a single column with storage tanks may be used. One of the most important properties of the VPSA process is that it can be adapted to biogas upgrading in any part of the world since it does not depend on the availability of cold or hot sources.

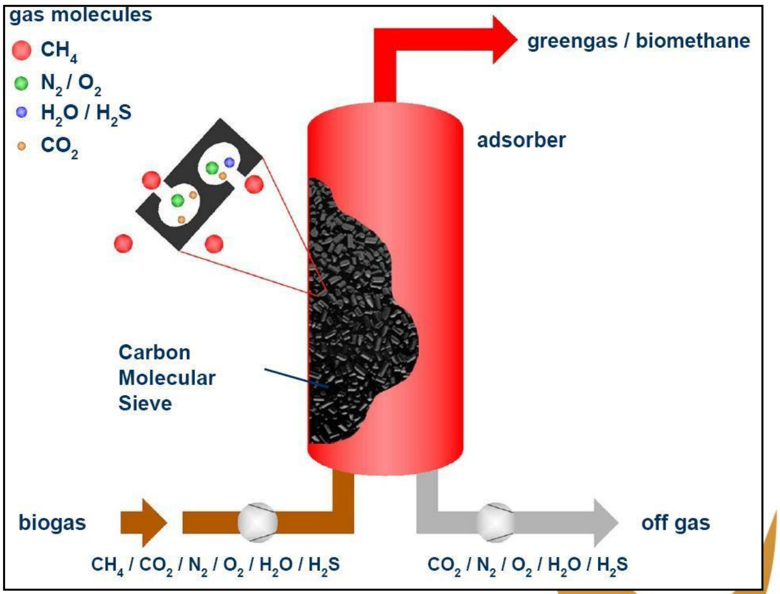
Principle:-

In a VPSA unit for biogas upgrading, an adsorbent material is subjected to pressure changes to selectively adsorb and desorb CO_2. Adsorption is an exothermic spontaneous process and the loading of CO_2 in the adsorbent depends specifically on the properties of the material employed (surface area, composition, pore size, etc). Once the material is specified, then its regeneration should be realized. Note that since the material is continuously used and regenerated, there comes a point where the process achieves a “cyclic steady state” (CSS). The largest part of engineering a VPSA process rely in designing a regeneration protocol for the adsorbent able to spent small amount of energy (reduce energetic penalty) and do it in the fastest way possible (increase productivity).

During normal operation, each adsorber operates in an alternating cycle of adsorption, regeneration and pressure build-up. During the adsorption phase, biogas enters from the bottom into one of the adsorbers. When passing the adsorber vessel, CO2, O2 and N2 are adsorbed on the adsorption material surface. The gas leaving the top of the adsorber vessel contains more than 97% CH4. This methane-rich stream is substantially free from siloxanes components, VOC's, water and has a reduced level of CO2.



Before the adsorption material is completely saturated with the adsorbed feed gas components, the adsorption phase is stopped and another adsorber vessel that has been regenerated is switched into adsorption mode to achieve continuous operation. Regeneration of the saturated adsorption material is performed by a stepwise depressurization of the adsorber vessel to atmospheric pressure and finally to near vacuum conditions. Initially, the pressure is reduced by a pressure balance in an already regenerated adsorber vessel. This is followed by a second depressurization step to almost atmospheric pressure. The gas leaving the vessel during this step contains significant amounts of CH_4 and is recycled to the gas inlet. These significant amounts of CH_4 were trapped within the voids of the adsorbent particles. Before the adsorption phase starts again, the adsorber vessel is re-pressurized stepwise to the final adsorption pressure. After a pressure balance with an adsorber that has been in adsorption mode before, the final pressure build-up is achieved with feed gas.



Pictorial representation of principle of Vacuum Pressure Swing

Selection of Adsorbents for VPSA:-

It can be said that the adsorbent material is the "heart" of the VPSA unit. All the properties of the cycle (operating conditions and operating mode) depend on the initial choice of the adsorbent. As mentioned before, several materials can be employed in VPSA technology.

A good adsorbent is a solid that have good adsorptive capacity and good adsorption kinetics so that the solid must have a higher surface area or a micropore volume and must have a large pore network, that is, a high porosity. In this case, physical characterization is mainly more important than chemical characterization.

Alumina, silica gel, activated carbon and zeolite are the most common adsorbents; They are used in diverse processes. The most important characteristic of an adsorbent is its high porosity. The range of pore size according to the classification recommended by IUPAC is: micropores ($d < 2$ nm), mesopores ($2 < d < 50$ nm) and macropores ($d > 50$ nm).

The parameters need to consider for the selection of Adsorbent for the VPSA are:-

A. Isotherm Data

1. Uptake / Release measurements
2. Pre-treatment conditions
3. Aging upon multiple cycles
4. Multicomponent effects

B. Mass Transfer Behaviour

1. Interface character
2. Intra particle diffusion
3. Film diffusion
4. Dispersion

C. Particle Characteristics

1. Porosity
2. Pore size distribution
3. Specific surface area
4. Density
5. Particle size distribution
6. Particle shape
7. Abrasion resistance
8. Crush strength
9. Composition / stability
10. Hydrophobicity

The adsorbents should have a higher selectivity to CO_2. This gas should be more "attached" to the surface of the material than CH_4; in most solids CO_2 can create stronger bonds with surface groups than CH_4. This kind of materials will be termed as equilibrium-based adsorbents since its main selectivity is due to differences of interaction forces between CO_2 and CH_4 on the surface.

The pores of the adsorbent can be adjusted in such a way that CO_2 (kinetic diameter of 3.4 Ǻ) can easily penetrate into their structure while larger CH_4 molecules (kinetic diameter of 3.8 Ǻ) have size limitations to diffuse through them. These materials will be termed as kinetic adsorbents since its main selectivity is due to diffusion constraints.

Advantages of VPSA:-

- Economy in production with comparatively high purity.
- Capital cost is moderate.
- Relatively quick installation and start up
- More than 98% CH_4 enrichment
- Lower power demand
- Adsorption of N_2 and O_2 to the maximum level
- Low maintenance
- Dry process
- No use of chemicals
- No process water demand
- No waste water
- Durable & Flexible
- No bacterial contamination of off gas