Prepurification of Air using an Advanced Thermal-Pressure Swing Adsorption (TPSA) Cycle

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Introduction

In the cryogenic distillation of air, it is essential that trace components such as carbon dioxide, water and hydrocarbons (e.g. acetylene) are removed beforehand as they can potentially freeze out in the column. The industrial technique of choice for removing such impurities from air is adsorption. Two types of adsorption cycle are commonly used and these are known as TSA or temperature swing adsorption (1) and PSA or pressure swing adsorption (2).

In both these methods, impurities are removed from the air stream by adsorbing them onto the surface of a packed bed. The concentration of each component removed will be highest at the upstream end of the bed and tail off over a mass transfer zone. If the process is conducted indefinitely, then the mass transfer zone moves progressively downstream until it breaks through at the outlet of the bed. This would result in impurities entering the distillation process and it is therefore necessary to regenerate the adsorbent before this occurs.

In the PSA system, regeneration is achieved by first stopping the air flow, depressurizing the adsorbent and passing regeneration gas through the bed counter-current to the feed direction. The pressure of the regenerating gas is generally at a lower pressure than that of the air and free of impurities.

During the feed step, the adsorption process generates heat which causes a thermal pulse to progress downstream through the bed. During the regeneration process, this same amount of heat must be supplied to desorb the impurities which have been adsorbed. In PSA, the aim is to commence regeneration before the heat pulse mentioned above has reached the downstream end of the bed. The direction of the heat pulse is reversed by the regeneration process and the heat which derived from the adsorption stage is then used for desorbing the impurities during regeneration. This avoids having to add heat during the regeneration step.

In the alternative procedure of TSA, the cycle time is extended and the heat pulse mentioned above is allowed to exit the adsorbent bed during the feed period. To achieve regeneration it is therefore necessary to supply heat to desorb the impurities. To this end the regenerating gas is heated for a period to produce a heat pulse which moves through the bed counter-current to the feed direction. This flow of heated regenerating gas is usually followed by a flow of cool regenerating gas which continues the displacement of the heat pulse through the bed toward the upstream end.

Each procedure has its own characteristic advantages and disadvantages. TSA is energy intensive because of the need to supply heat to the regenerating gas. Typically, there will be more than one unwanted gas component which is removed in the process and generally one or more of these components will adsorb strongly and others much more weakly. The temperature used for regenerating in TSA needs to be sufficient for desorption of the more strongly adsorbed component. The temperatures required for the regenerating gas are typically sufficiently high, e.g. 150°C to 200°C, as to place demands on the system engineering costs.

Whilst the PSA system avoids many of these disadvantages by avoiding the need for coping with high temperatures, the short cycle time which characterizes PSA brings its own consequences. In each cycle of operation the adsorbent is subjected to a feed period during which adsorption takes place followed by depressurization, regeneration and repressurization. During depressurization, the feed gas in the bed is vented off and lost and this known as the "switch loss". The short cycle time in the PSA system gives rise to high switch losses. Also, because the cycle is short it is necessary that the repressurization be conducted quickly. This rapid repressurization causes transient variations in the feed and product flows which can adversely affect the plant operation, particularly the operation of processes downstream from the adsorption system.

In order to address some of the problems related with TSA and PSA, two new technologies have been developed for air prepurification known as TPSA or temperature-pressure swing adsorption (3) and TEPSA or thermally enhanced pressure swing adsorption (4). These are both hybrid regeneration cycles, which combine many of the benefits of PSA and TSA whilst minimizing the associated costs.

TEPSA (Thermally Enhanced Pressure Swing Adsorption)

The TEPSA process has been described previously (5) and is basically an improvement upon the PSA cycle through supplying a low temperature regeneration heat pulse (40°C – 100°C). This increases the removal of CO_2 from the bed and allows the cycle time to be extended. The benefit of doing this versus a conventional PSA system is that the resulting switch losses are lower which increases the cost effectiveness of the cycle.

TPSA (Temperature Pressure Swing Adsorption)

Whilst TEPSA is essentially a PSA process that is enhanced by the addition of heat, TPSA is a TSA cycle in which some of the adsorbate is removed by unheated regeneration gas (i.e. by PSA style regeneration).

With TSA, a heat pulse is supplied that must be capable of fully removing all the adsorbates from the bed each cycle. A significant amount of heat energy is therefore required for the process to work and it must also be at a relatively high temperature (>150°C). TPSA works in a similar manner to TSA, except that less heat energy is used and the maximum temperature of the heat pulse can be lower (>100°C). The result of supplying a smaller amount of energy is that the heat pulse becomes extinguished within the bed and part of the adsorbent remains unregenerated. However, by continuing to supply unheated regeneration gas, some of the remaining adsorbate can be removed (i.e. regeneration in a PSA style). Within a few cycles, a steady state is reached in which the amount of material added during the feed step is equal to that removed during the regeneration step. However, the benefit of the TPSA cycle is that this can be achieved at a fraction of the heater energy required for operation with a full TSA cycle.

To further demonstrate the difference between TSA and TPSA, Figure 1 shows an example of a TSA bed that is initially fully saturated with adsorbate. The regeneration step begins by introducing heated gas at the top of the bed which causes a heat pulse to form. This heat pulse is then pushed through the bed by supplying additional unheated regeneration gas. In order to maintain a high enough temperature throughout the bed, some of the heat pulse energy is lost as it exits out of the bottom. However, at the end of the regeneration step, all the adsorbate has been removed from the bed.

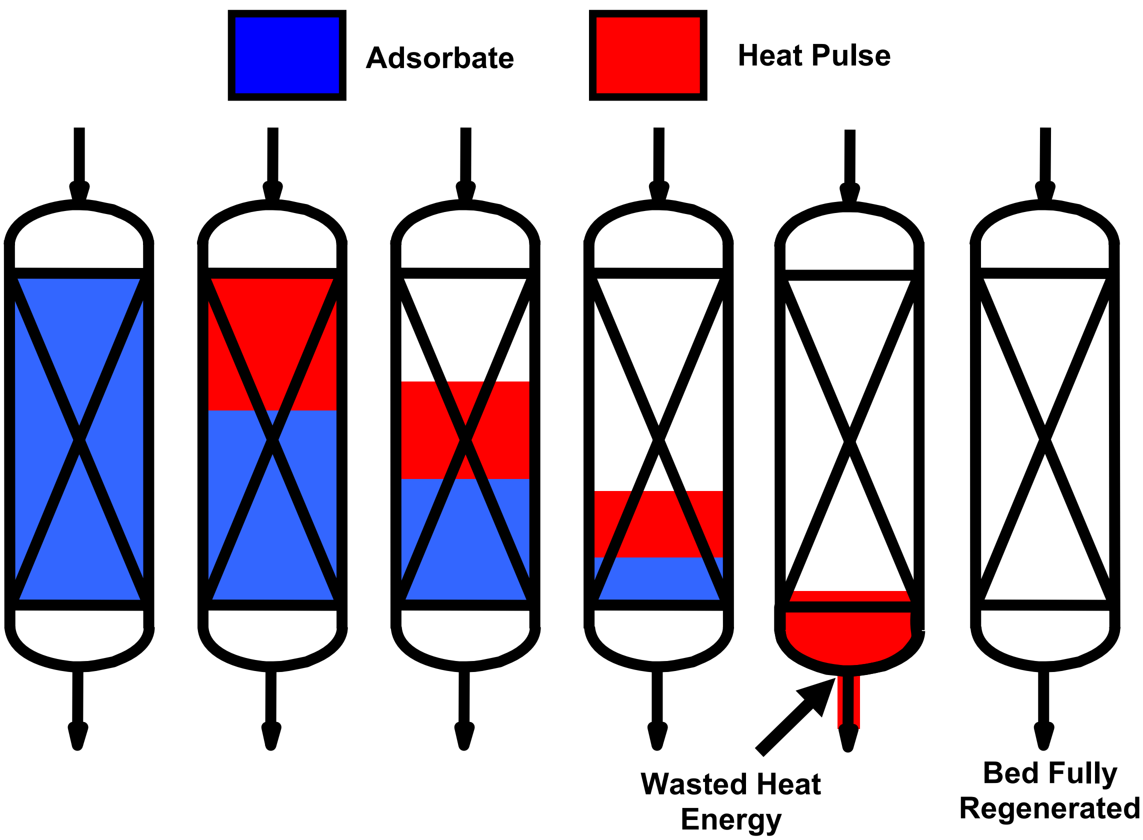

Figure 1. TSA Style Regeneration

The impact of choosing the alternative approach of TPSA is shown in Figure 2. Here the heat pulse used is smaller and it eventually becomes extinguished inside the bed. However, this means that all the heater supplied energy has been used for desorption and no heat is lost from the bottom of the bed. As the heat pulse did not pass the full distance, then the bottom part of the bed remains unregenerated. By supplying additional unheated regeneration gas, some of the remaining adsorbate can be removed in a similar manner to PSA. With TPSA, the bottom part of the bed may still have adsorbate loaded on it at the start of the feed step (in a similar manner to PSA). This reduces the available feed time compared with TSA before the bed becomes saturated. However, because the TPSA heating and cooling steps are also shorter than with TSA, the cycle time balance can be met without requiring additional adsorbate or regeneration gas.

The use of a high CO_2 capacity alumina can also produce significant benefits when combined with a TPSA system (6).

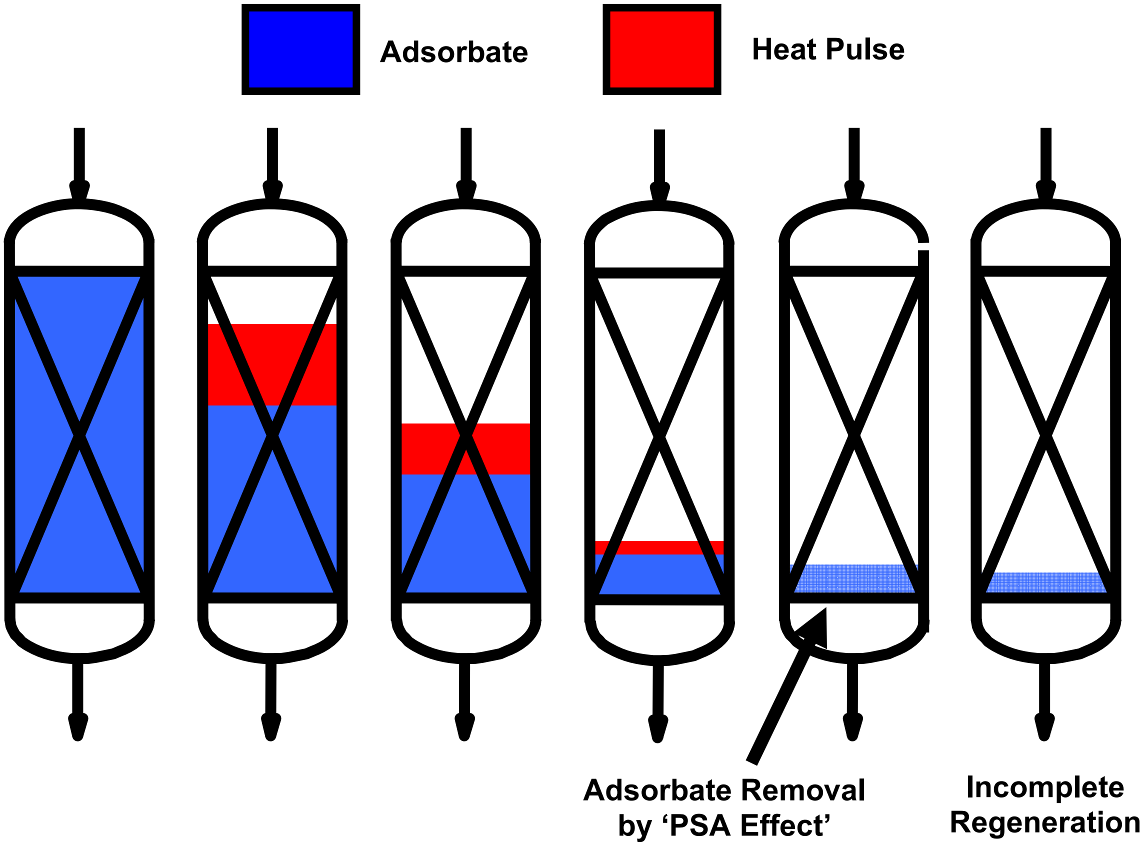

Figure 2. TPSA Style Regeneration

Results

The TPSA cycle has been intensively investigated through both experimental and theoretical approaches. An adsorption model has been developed of the TPSA process to calculate the required regeneration conditions needed for a cyclic steady state to be achieved. This has been tested against a wealth of pilot plant data and shown to accurately predict the performance of these systems. Experimental data was obtained from a two column unit with vessels 203.5 mm in diameter and 2700 mm in length.

The model has also been used to develop designs for use in the field and has proven successful when scaled-up to both large and small plants.

The costs savings for using a TPSA over a TSA can be measured in terms of the time averaged heater power used. As an example, for a medium sized plant the following power savings can be obtained.

Table 1. Example of the difference in power requirements between TSA and TPSA

	TSA	TPSA	Reason for better TPSA performance than TSA
Heat power used to desorb adsorbate (kW)	247	233	Some adsorbate is removed by PSA type regeneration
Heat power lost in heat pulse exiting bottom of the bed (kW)	66	0	Heat pulse is extinguished inside the bed
Heat leak from vessel (kW)	17	12	Smaller heat pulse means less heat leak from vessel walls
Total heater power required (kW)	330	245	

The actual power savings for TPSA versus TSA is known to be a complex function of the adsorbate(s) used, feed conditions (temperature, pressure, etc.) and obtainable regeneration gas (flow rate, temperature, etc.). The availability of a simple model that can simulate TPSA systems is therefore extremely valuable in the design of these cycles.

Conclusions

An APCI patented process termed TPSA, that combines aspects of TSA and PSA, offers an excellent alternative to traditional air pre-purification cycles. Compared with a TSA system, it has been possible to make heater power savings in the order of 20% - 60% by moving to a TPSA cycle. It is also possible with TPSA to supply the reduced heat pulse energy by using a lower regeneration temperature (<150°C) than would traditionally be used with TSA. This can reduce the cost of the vessel and accompanying pipe-work.

The major advantage of TPSA over PSA, is that this thermal energy saving can be realized without requiring a significant decrease in cycle time. Therefore, considerable power reductions can be achieved without having to pay the cost of increased switch losses and dealing with operating problems due to rapid pressure transients.

References

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