Course: Adsorption Science and Technology: Fundamentals and Applications

Instructor: Prof Sourav Mondal

Department: Chemical Engineering

Institute: Indian Institute of Technology Kharagpur

Week 06

Lecture 28 | Introduction to Pressure Swing Adsorption (PSA)

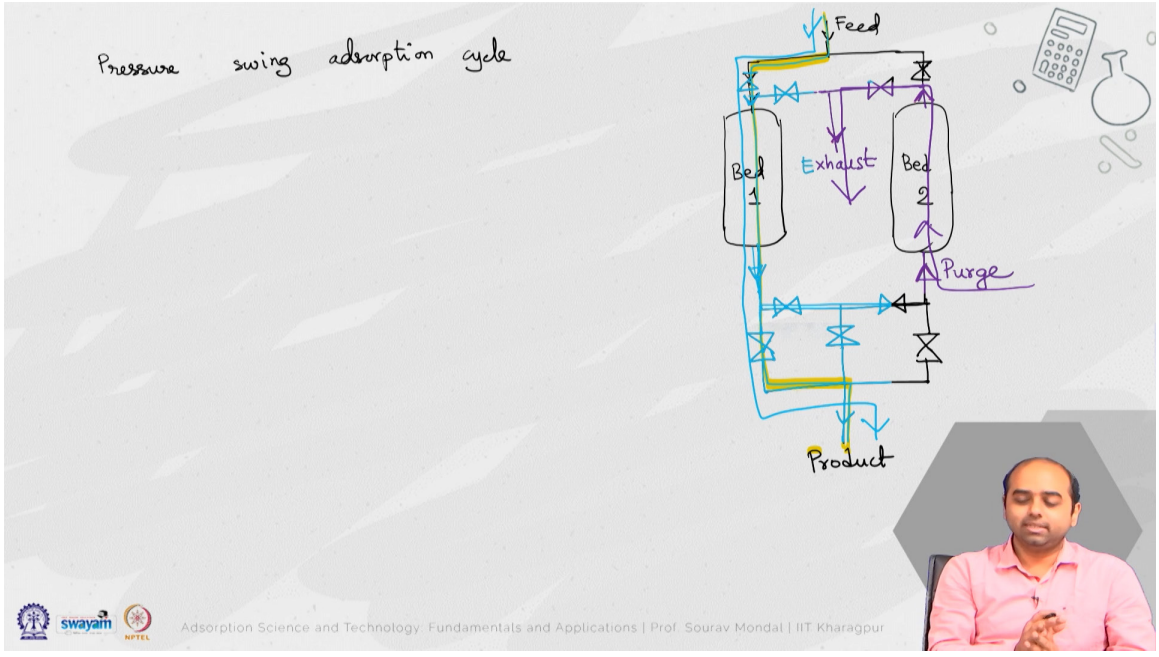
Hello everyone, in this lecture I am going to talk about the pressure swing adsorption. So, pressure swing adsorption as you know is a very important you know technology that exploits the fundamentals or this idea of adsorption to produce a continuous you know stream of outlet in actual scenarios or particularly using you know gas based systems. So, in this pressure swing adsorption the idea is to regenerate the bed simultaneously you know in a cyclic way along with adsorption. So, pressure swing adsorption is one of the most I would say the biggest you know market of adsorption technology. And this is widely used in many process industries for gas purification, for you know carbon capture, for hydrocarbon separations, methane gas separation or capture. Nitrogen generators oxygen concentrators that we have seen in the during this COVID pandemic on the need of producing high purity medical grade oxygen is actually you know provided through these help of oxygen concentrators which are nothing but basically this PSA based or pressure swing adsorption based systems.

So, we will talk about the design and the details of this pressure swing of this oxygen concentrator towards the end of this week. But in this class today I am going to introduce what essentially this pressure swing adsorption means what do you mean by cyclic operation adsorption desorption regeneration you know. We will talk about this Skarstrom cycles in this lecture today itself. Now basically pressure swing adsorption is actually based on the fact, it is a very simple operation based on the fact that now, with the increase in pressure or with the increase in the chemical potential of the target gas or the adsorbate molecules it undergoes preferential adsorption in the adsorbent and then when the adsorbent bed is saturated.

So, typically this pressure swing columns or pressure swing adsorption based columns

the adsorbent does have very low capacity in general and moreover the adsorbate species has extremely high concentration. For example to produce you know for let us say for a nitrogen generation system using this pressure swing adsorption one has to remove the other gases besides nitrogen and in that case the nitrogen would be purified. So it is almost like the other gases which is present in the system which is mostly oxygen and carbon dioxide constitutes almost 21% by volume. So adsorption of 21% of concentration by volume is a significant amount and typically that is why this beds quickly attain saturation or they can no longer be useful or the capacity would be finished and in that case you need to regenerate this bed. So, this regeneration is actually through a desorption cycle where you reduce the applied pressure and now the adsorbed molecules will actually get desorbed.

And essentially the adsorbent or the solid phase would be regenerated so that it will be again ready for another cycle of adsorption. So, this is how the cyclic process is done and that is why the name swing comes in the picture that it is a you know pressure swing system where you increase the pressure and then at others some other time or later time after or in the next cycle or in the half of the half period of the same cycle you reduce the pressure. So, there is a swing in the pressure which facilitates this adsorption and regeneration. The same idea is also exploited in thermal swing systems. Of course, we will not talk about the thermal swing where with the help of you know temperature you can either reduce or increase this adsorption capacity and in the process you will be regenerating your adsorbent.



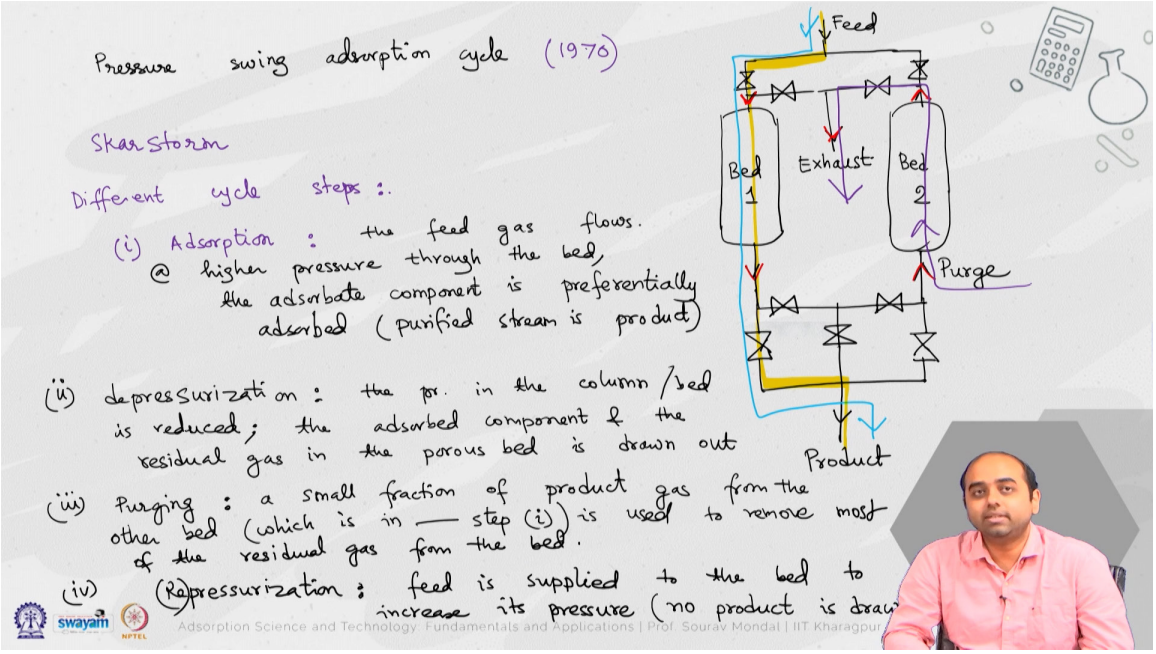
So, this this the some of the major advantage of this pressure swing adsorption over this thermal swing is that in thermal swing you need a lot of energy. And this does not the work well for dilute stream whereas, these are generally the you know the major you know plus points of the evolution or the development of this pressure swing technology over thermal swing methods. Now, essentially this is originally the pressure swing method was originally developed for the purification of gases to remove for example, moistures and some other trace gases or contaminant gases from the stream. But this is found that this idea can be actually expanded or translated for you know even not only for purifying gaseous streams or to remove trace components. It can also be used to produce certain enriched stream of gases within the say system or from atmosphere.

You know you can also produce nitrogen or oxygen from this system. So, typically in this pressure swing cycle or this pressure swing adsorption. So, typically in this pressure swing adsorption cycle you must have at least a minimum of 2 beds that is in continuous operation. So, let us say this is bed 1, and you have another bed that is bed 2. So when you have when one of the bed is undergoing adsorption or essentially when you do this adsorption you are essentially separating the you know the desired molecule from the stream and in the way this can also be sometimes referred to as the production cycle.

So, this bed 1 and bed 2 operates in synchronization. So, when there is adsorption in bed 1 there will be desorption in bed 2. And now when the role is reversed when adsorbed bed 1 is exhausted it will lead to it will put that in adsorption mode sorry desorption mode for regeneration and bed 2 will now become adsorption in in the adsorption you know setting or mode and that will be producing. So, at any point of time one of the beds will be producing and one of the beds would be getting regenerated. So, there is continuous supply of the output desired gas from either of these two beds.

So, in this fixed whatever this you know you have this feed line that is controlled smartly by you know this 5 by 2 valves or some kind of this non return valves and actually any at any one point of time one of these valves is in operation and there is also a stream between these two which is connected by the non return valves to take care of the exhaust. And now these are the product lines. So, the TP this is a typical you know this direction or whatever I call this arrangement of the flow direction of this bed 1 and bed 2. So, here essentially you can see that one of these beds i mean the valve position is placed in such a way so that always when one of the bed is actually in desorption or is not producing and it is going to this exhaust so this is the purge line So the purge line is used

to regenerate this bed or to go to this exhaust. The other bed will be producing the product.



So that is the reason why this valve arrangement is so crucial so that to ensure that you know you have you can segregate these two lines of where one of this you know through one of these lines you have the purge and through one of these lines you have the feed and the product. So when bed one is producing you are essentially having the line from the feed side, it goes through this path. so what i try to somehow this eraser is creating a problem so what i try to mention here is this when we are having the feed operation the or the you know this product production so this is the path of the this is the path of this um you know the flow direction when you are having the purge line or this regeneration it is actually through this point coming from here. So, this is the part of the purge. Similarly, the roll can be reversed and the purge can also go into from the to the bed side and accordingly it can be you know released from the exhaust.

So, typically this cycle of you know adsorption and desorption happening simultaneously or synchronizing in synchronization was actually or you know invented by this person Scar Storm. Back in 1960s and by 1970s this PSA method was actually more or less developed and even though this is like half a century old method still it is very useful and there has been continuous innovations on how to improve this operation particularly on the cycle time. Different cycle steps in this process. So, the first step is adsorption. So, in this case the feed gas flows at high pressure, higher pressure through

the bed and hence the species or whatever this adsorbate adsorbate component is preferentially adsorbed.

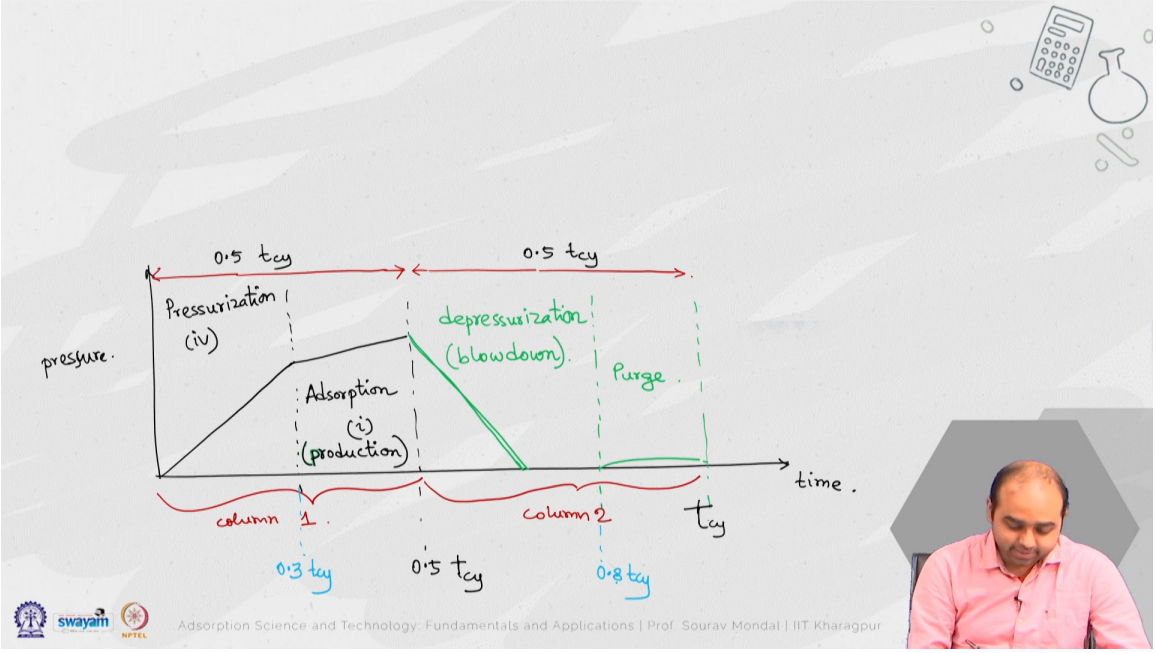
And in this case the purified gas or whatever the separated stream is the product. So, after you see that no longer the separation is happening or you realize that the output product is no longer you know you know different than the inlet you realize that the bed is saturated. Similar to this is nothing, but a fixed bed. So, there will be a time at which the saturate the capacity is saturated and it will lead to no longer you know any adsorption. So, in that case you have to start.

The second step which is depressurization. So, during this steps of depressurization the pressure in the column or the bed is reduced Also what happens here the adsorbed component and whatever the residual gas that is present in the porous bed is drawn out. Now next is so it means that during the depressurization as pressure is reduced whatever the you know this amount that is dissolved from the adsorbent is actually you know removed with the help of this you know actually removed at pressure is reduced and it is actually drawn out. So, typically the adsorption happens at a pressure higher than the atmospheric pressure. So, if you bring it to the atmospheric pressure or if you further give some vacuum normally whatever is absorbed will actually come out because of desorption during the depressurization cycle.

Next is purging. In this case of purging a small fraction of product gas, from the other bed which is actually producing which is in step one is actually used here to remove most of the residual gas from the bed. So essentially what is done is that in this purging a part of the fraction or a part of the product gas which is produced let us say by the other bed which is in step 1 is actually used to purge out or to flush out any of these residual gas. It may be noted that the product gas is the least favourable you know adsorbed component by this bed. So, the tendency or the affinity of the bed or the adsorbent towards that product gas will be much smaller compared to the adsorbed you know or the you know the more favourable or the preferentially adsorbed component which we are trying to remove. So, the product gas does not come you know have that component which will be preferentially adsorbed.

So, giving or to purging or flushing out this system with a low or the least favourable

compound will actually help out to remove most of the residual gas that is adsorbed and whatever the adsorption sites which is captured, or it is still under you know under this adsorption mode or still bound to this adsorbs adsorbent phase or the solid phase can essentially be removed by this method of this purging. So, essentially with this purging you are creating a you know situation so as to you know almost regenerate the bed to its original capacity. And, the final step once this purging is done is repressurization. So, repressurization in this case the feed is supplied to the bed to increase or to raise So, prior to adsorption the pressure inside the bed or inside the column has to be increased and in this case you actually supply the feed into your bed so that the relative pressure inside the bed is increased for favourable adsorption to happen. So, this is the step of the repressurization or the pressurization in fact and it may be noted that during this part no product is withdrawn.



No product is actually drawn in this state so during this pressurization the outlet is absolutely closed and you do not allow any product to be produced any product to be drawn in this scenario and this is an important step here because if you start you know getting the product start from the from the pressurization step itself you do not provide sufficient time for the adsorption to happen or the pressure to actually reach the desired level for adsorption to happen. So, these are the four different you know steps in this case let us try to see pictorially or graphically the concentrations at this different steps. So, during the pressurization or this depressurization let us see how the pressure profile looks like. So, this is like time. So during the pressurization the pressure would rise so let us call this as the time for the pressurization.

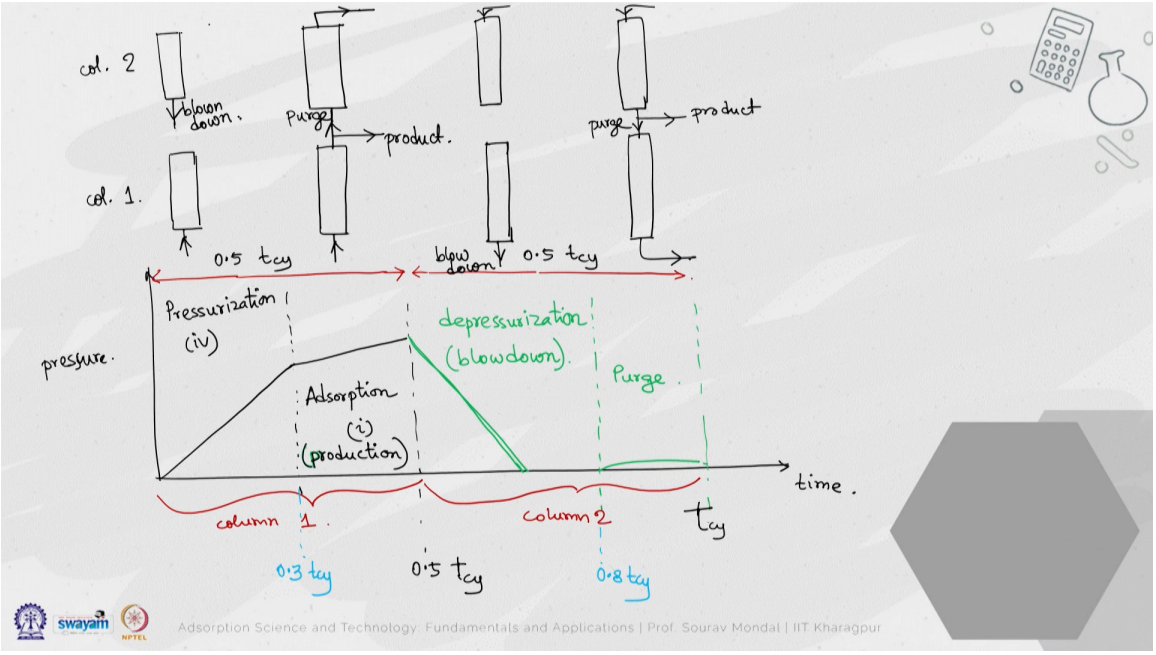
After that you have this adsorption happening. So, in this case pressure remains more or less steady, but since you are trying to draw the product during this pressurization there can be some you know you know changes in the pressure. So, to compensate for the product drawn generally you apply some more feed. So, the pressure in this case slightly increases during the adsorption. So, let us call this as till this part at the adsorption step.

So, compared to the I mean comparing to the previous notation this is like step 4 this is like step 1. So, after this part we have the you know this part of depressurization where you reduce the pressure to 0 or to a very low value and during. So, let us call this step up to this much and you hold that at zero pressure why I will tell you and during purging also the pressure is very low. So, this is like the depressurization in process technology it can also be referred to something like blow down. Adsorption can also be referred to as production sorry we should use the other colour as production cycle and finally this is the purge stream.

So, here if you note carefully this is the part where let us say column 1 is operating in that case the other column will be under this kind of operation. So, this is like column 2, in operation. So, when column 1 is undergoing pressurization and adsorption column 2 will be actually in the regeneration mode or in the depressurization and the purge cycle mode. Now for continuous operation for continuous operation it is very important to realize that the time of this I mean the time of operation of this column 1 and of this column 2 has to be same. So, these two time has to be same otherwise both these columns cannot be interchanged.

So, it is like if the column if the if the time is not same there will be a point when the when the other column is ready, but this column is still under a different setting of either pressurization or adsorption and essentially will not be having a proper regeneration or in other words if the regeneration time is much larger. Then, in that case the other you know this column which is in pressurization and adsorption setting has will have to wait for the depressurization of the other one to be over so that it can switch to the other mode. So, both of these two columns cannot be in pressurization and depressurization mode at the same time and that is practically impossible. So, this is why these two columns actually work in you know tandem or in sync. So, this time let us call this total time to be like cycle time if I call this as like cycle time or t c y then this point would be like 0.5 t c y or

a total cycle time in this case. So, this part this zone is like 0.5 times of cycle time or half cycle time and this is the case of the cycle time. So, now typically this portion of the bed or the pressurization is actually up to 30 percent of the cycle time. Adsorption time is typically you know 20 percent.



Depressurization even though that is even even depressurization is very quick, but still to maintain that depressurization plus purging has to be almost like 50 percent of the cycle time. This depressurization is typically around 30 percent of the cycle. Cycle time and 20 percent is the purge time. But all of these times are generally flexible and mostly the depressurization and the purge time requirements is generally much lower, but in order to have sufficient adsorption and you know production as well as pressurization that time is generally more. But since the you have to you necessarily need to have like 50 percent of the cycle time for depressurization.

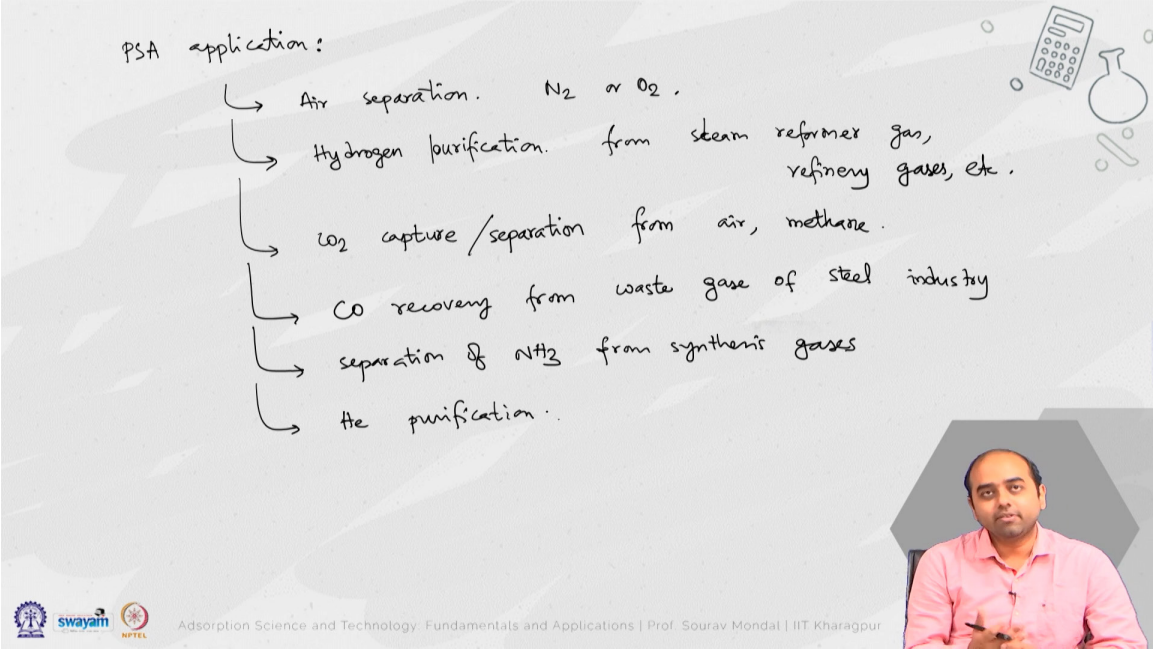
So, that is how the depressurization even though what it is not required that much time it is typically extended. So, this optimization of the cycle time is very very important and it depends on several factors the product purity that you want on the you know this flow rate the size of the bed that is how there is a wide range of products this this pressure swing adsorption cycle time and still there is an ongoing R and D for different you know systems with scaling up does the cycle time can be different or made different what should be the level of the depressurization ratio with respect to the adsorption pressure all of these plays a very important role in this context. Now I will just quickly before we finish today's class I will just show that just to make things absolutely clear what happens

during this pressurization during this adsorption let us say if you have two columns. So let us say I have two columns I refer this as column 2 and I refer to another one as column 1. So, during the pressurization column 2 will actually be sorry column 1 will actually be you know getting pressurized.

So, there is no outlet and on the other hand side column 2 will be actually in this depressurization mode. So, this will be actually giving out some gas at low pressure. During the feed of course column 1 would be producing and column 2 would be actually purging and that is the reason why I am saying that part of the product here is actually purge. So, this is the purge line and this is the production line.

This is the purge gas release. In the case of depressurization, so when column 1 is in depressurization mode. So, this will be like sorry depressurization of column 2 when column 1 is in adsorption. Now, when column 1 is in depressurization, column 2 will be actually getting pressurized. And finally, during the purge phase of column 1, column 2 would be in production mode. So, this is product, this is purge, this would be the exit.

So, better to draw this also properly, this is pressurization. So, we can understand. So, this is like blow down of column 1, this is blow down of column 2. So, you can understand how these two different you know columns work in tandem or work in you know synchronization or reciprocating this alternate cycles of adsorption and desorption as well as this desorption this depressurization and the purging. So, this is how this you know this pressure swing adsorption actually happens.



So, there are various types like vacuum swing adsorption where you actually reduce the pressure during the depressurization cycle to vacuum levels. So, that this pressurization and this ratio of pressurization to depressurization can be increased and further desorption or regeneration is very useful. So, I hope I could give you a fair understanding of the process of adsorption and desorption and these has various applications. So, pressure swing PSA applications is mostly in air separation and to produce nitrogen or oxygen. It is also used for hydrogen purification from steam reformer gas or other refinery gas.

Also CO2 capture or separation from air, methane. Then you have CO recovery from waste or flue gases of steel industry. Then separation of ammonia from synthesis gas. Helium purification. So, the major advantage that you can realize of this PSA unit is the flexibility in the scale of production and it has a high turn down ratio.

So, even the unit may even run at 10 percent of its rated capacity and it is still convenient as well as cost effective to run that unit on that site. So this scalability of the operation, this easy for continuous generation of separation systems and high turn down ratio is actually some of the major advantages of this PSA based system. So, I hope all of you you know found this introductory lecture on pressure swing adsorption to be useful. In the next class we will try to see what is the you know this mathematical description of

these different processes and this unit as a overall. Thank you and see you everyone in the next class.