Course: Adsorption Science and Technology: Fundamentals and Applications

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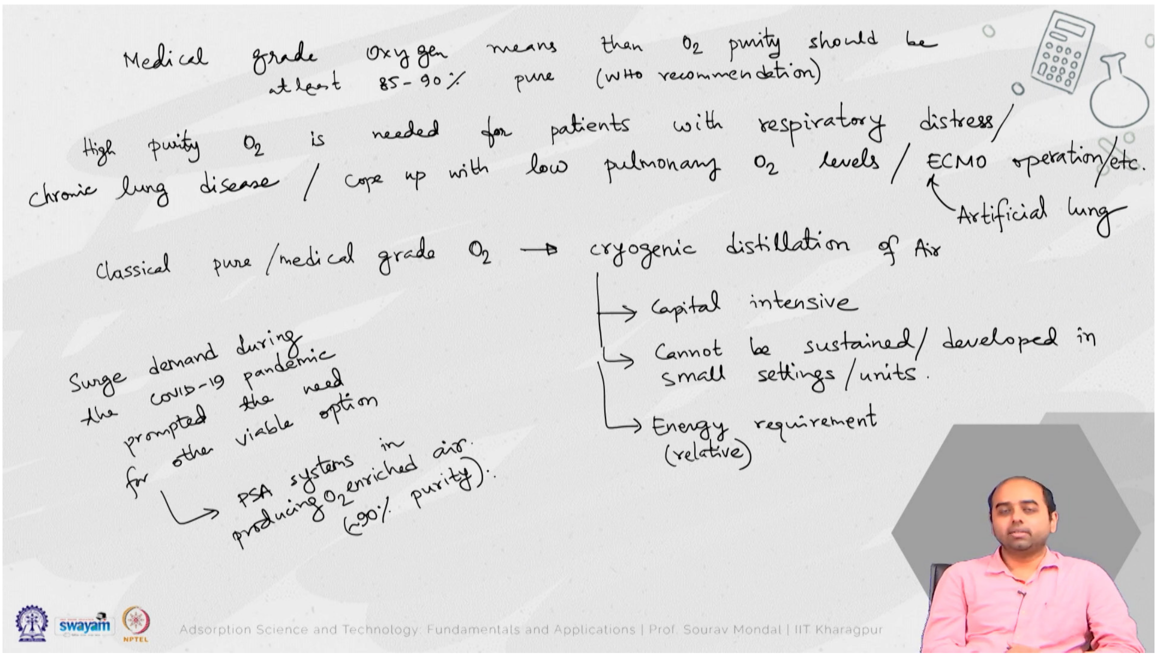
Week 06

Lecture 30 | Design of Medical Grade Oxygen Concentrator

Hello everyone, welcome to this last lecture of this week. Today we are going to talk about you know the basics and some design aspects of a medical grade oxygenator or oxygen concentrator. Now, many of you have already heard about it during the this COVID pandemic when there was a huge you know shortage and particularly demand of medical grade oxygen oxygen to treat the chronic patients from you know this lung disease and respiratory distress. Now oxygen is actually you know produced from cryogenic distillation typically that is how standard of the standardized process that exist in the currently in the market that you try to do a cryogenic distillation of air and in that you try to liquefy the air at very low temperature then you try to do a fractionation of that very similar to the principles of distillation so that you can get you know pure oxygen in the process. Now some of the disadvantage of this technology is actually that it is very capital intensive, it requires huge amounts of energy and it cannot be produced in a small scale environment or particularly in a household setting or something like that. And, since the demand was very high during the pandemic, there was a look out or need for developing some alternate ways on how this you know medical grade oxygen can be produced in house or in situ in perhaps in you know this hospital settings or in you know small healthcare units and that prompted the design of this you know systems where you use the technology of adsorption to selectively separate nitrogen from air or adsorbed nitrogen from air and in the process you will be getting an enriched you know this O2 enriched stream.

Now the term medical grade oxygen actually means that the oxygen purity, so the medical grade oxygen actually refers to the fact that one needs oxygen purity means that O2 purity should be at least 85 to 90 percent pure as per WHO recommendations. And this high purity O2 is needed for patients with respiratory distress, chronic lung disease, in simply to cope up with very low pulmonary oxygen levels then for ECMO operation ECMO stands for extra corporeal membrane oxygenator where you actually provide you know pure oxygen to directly oxygenate your blood without. So, it is like an artificial lung. So, ECMO process is very similar to an artificial lung where if the lung capacity has if it is significantly reduced or if it is poor then in that case you try to oxygenate your blood stream externally with the help of this device and in that the high purity oxygen levels are needed.

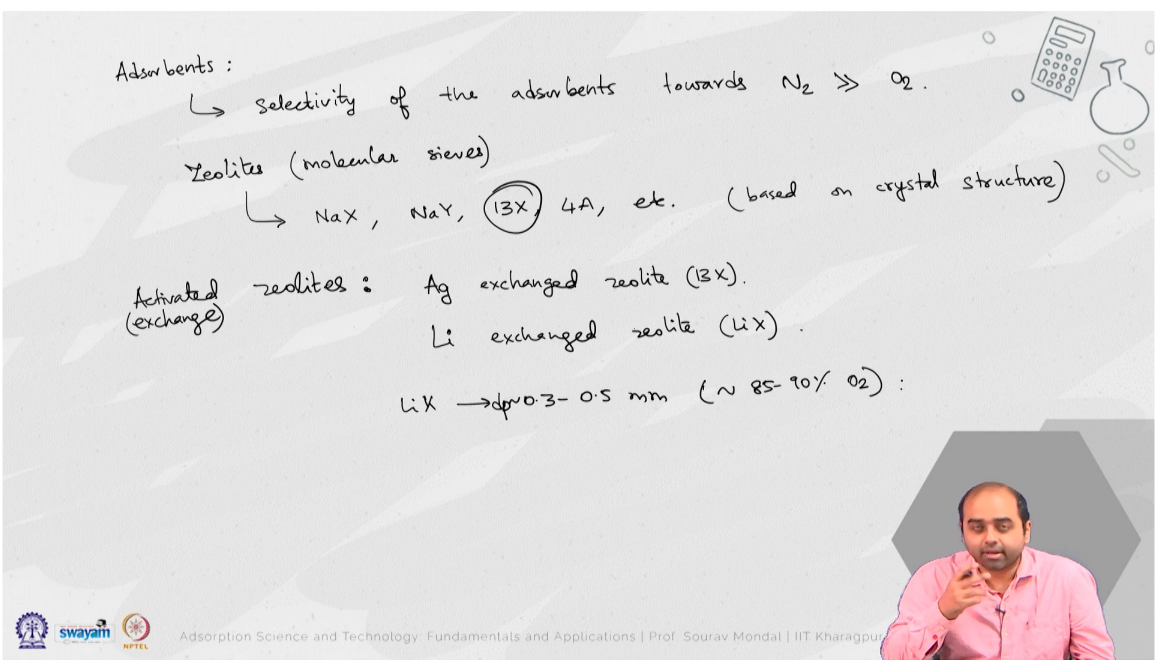


Now, classically oxygen classically pure or medical grade. O2 is produced from this cryogenic distillation of air. And then you have Linde engineering, air liquidate these are like the you know market leaders in this direction and we produce you know ultra pure grade of more than 99 percent pure O2 stream. But then as I said this cryogenic distillation is capital intensive. So, it requires huge investments in terms of infrastructure.

It cannot be sustained or developed in small settings or units absolutely not portable and it requires a lot of energy. So, of course, energy requirement is relative because given that if you are producing a large amount of O2 then the cost of the energy can be offset like the energy per unit kg of the O2 that is produced in a very large scale plant can be reduced. So, the energy requirement is again relative in nature. Nevertheless, setting up you know such cryogenic distillation units overnight is almost impossible and since the surge in the demand during the pandemic made people to look for other alternate options during the COVID-19 pandemic. prompted the need for other viable option.

And that is how the rise of this pressures swing adsorption based systems in producing this you know enriched O2 enriched air capable of almost 90 percent purity. Now one of the important things is the choice of the adsorbent. Now typically this adsorbent which is used for this you know PSA based systems could be you know they are generally you know this zeolite type. So let me just quickly talk about the different kinds of adsorbent that is used then I will go into the system design and the mode of operation of this unit. So typically the adsorbents which are used here should selectively adsorb more nitrogen compared to oxygen.

So, the selectivity selectivity of the adsorbent towards N2 should be more than O2 that is the general requirement and typically you have you know zeolites molecular sieves of various types which some extent shows this enhanced selectivity toward nitrogen. So, particularly talking about the different types of zeolites we have you know this Na x then 13X, 4A these are various types of you know zeolites that are available in the market and they does show a certain degree of selectivity towards nitrogen over oxygen. But then these zeolites all have the different properties based on their you know their crystal structure. So this Na x, Na y, 13X all these differentiation or distinction that we mentioned is based on their crystal structure, based on crystal structure and generally So, the using these or any of these particularly 13X is the most popular adsorbent among all of these. So, this 13X was used and it was found that the purity is around you know 40 to 50 percent of O2 or the selectivity is around 3 or so.



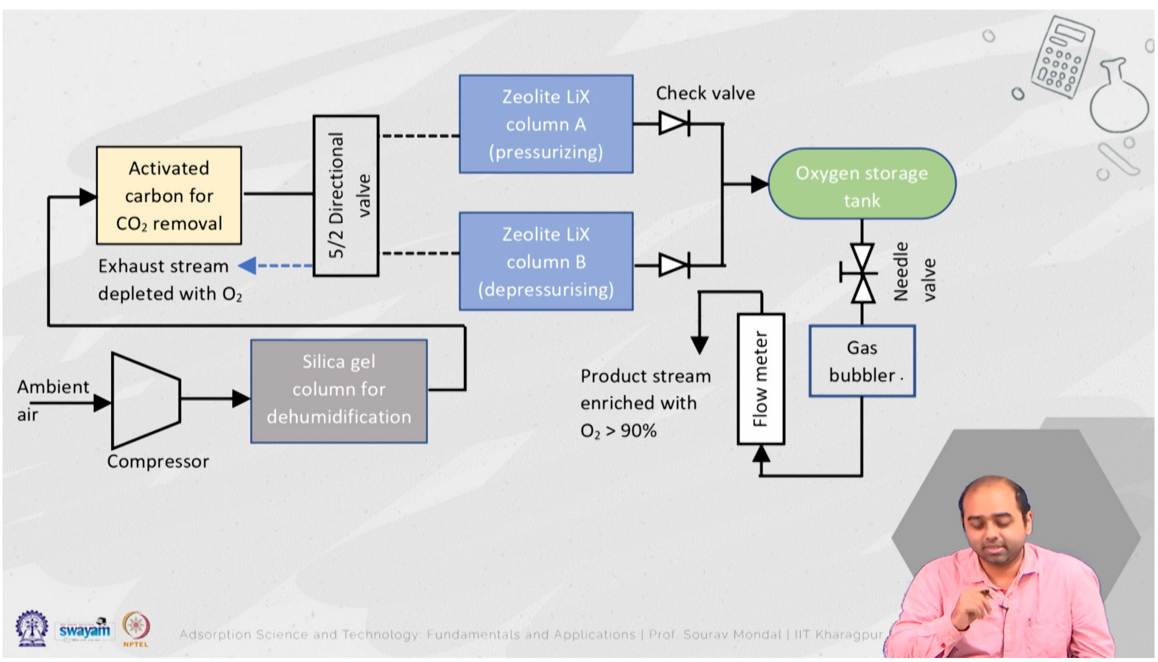
In fact around 2 to 2.5. So, the selectivity of this nitrogen over oxygen is around 2 to 3 or 2 to 2.5. By selectivity I mean the you know if you recall the like new isotherm the coefficient at the denominator with the you know concentration or the partial pressure the ratio of that coefficient over the other coefficient can define to some extent the selectivity and 13X generally shows among all of this slightly more selectivity towards nitrogen, but that is not sufficient for the production of you know enriched O2 stream.

So, other zeolites or activated zeolites what we call activated or exchanged zeolites are you know looked upon and particularly you know silver exchanged zeolite all 13x was used to you know replace the sodium ion in that cage structure or the molecular structure of this 13x zeolite with you know this silver lithium exchange zeolite known as lithium LiX. There are other transition metals which are also tried for this activation or enhanced selectivity and it was found because of the you know high charge density of lithium compared to the other you know metallic or the transition metal ions. This lithium LiX zeolite is particularly very selective and useful for enhancing the selectivity of nitrogen towards over oxygen and the selectivity is around 7 to 8 times and this is found suitable for the production of nitrogen, almost 90 percent, 85 to 90 percent pure oxygen stream. Of course, this performance depends a lot on the size of the particle. So, typically lithium, this LiX zeolite of size around 0.

3 to 0.5 millimeter particle size is found to be the optimum and to have the least mass transfer resistance, intraparticle mass transfer resistance and this can produce almost 85 to 90 percent pure O2 stream. Now of course, the amount of the you know this lithium zeolite or the bed size factor and that how much of the mass of the adsorbent that you need to produce per kg of pure oxygen is a big question and that depends on the flow rate of the stream as well as the temperature etcetera also. Now, coming to the design of these O2 concentrators let us look into this it is a dual column you know this oxygen PSA based system where one of these columns act you know in both of these act in synchronization and when one of them produce other is in regeneration phase. In the depressurization mode that is something that all of you are aware of from the previous classes that we talked in detail regarding pressurization and depressurization. Now coming to the entire setup so this is like the entire you know this schematic or the layout this is the entire process scheme or this layout.

So, first as the ambient air is introduced with the help of a compressor or compressed gas, first this should be dehumidified because the zeolite that is used or the adsorbent that is used for absorbing nitrogen over oxygen also absorb this moisture in the air competitively and naturally if the moisture gets attached nitrogen is not removed and in the process the O2 purity drops. So, there is a column or there is a unit for you know this continuous dehumidification of this air and here again this is done with the help of adsorption using silica gel. Once silica gel is introduced next is the optional step that if you wish to you know remove CO 2 from the air stream, but normally CO 2 is not something which is adsorbed strongly by the lithium zeolites, but then you do not want to dilute your you know O 2 purity with the presence of carbon dioxide. So, in the case of carbon dioxide presence in significant amount this could be an optional you know item to have this activated carbon for CO2 removal even in trace amounts. Next is the important stuff where you where we actually have this 5 by 2 directional or programmable valve.

So, this valve actually helps in directing the flow towards this column appropriately while other column is in depressurization mode. So, what happens is this 5 by 2 valve has 5 ports, and where the connections can be interchanged with the help of a solenoid actuator. So now this is then inlet stream and we have two connections to each of these columns A and column B. So, during column A when it is pressurizing, there is a connection between this and this valve. So, this connection is actuated with the help of this solenoid actuator and since when the column A is in pressurizing condition, column B is in depressurizing condition.



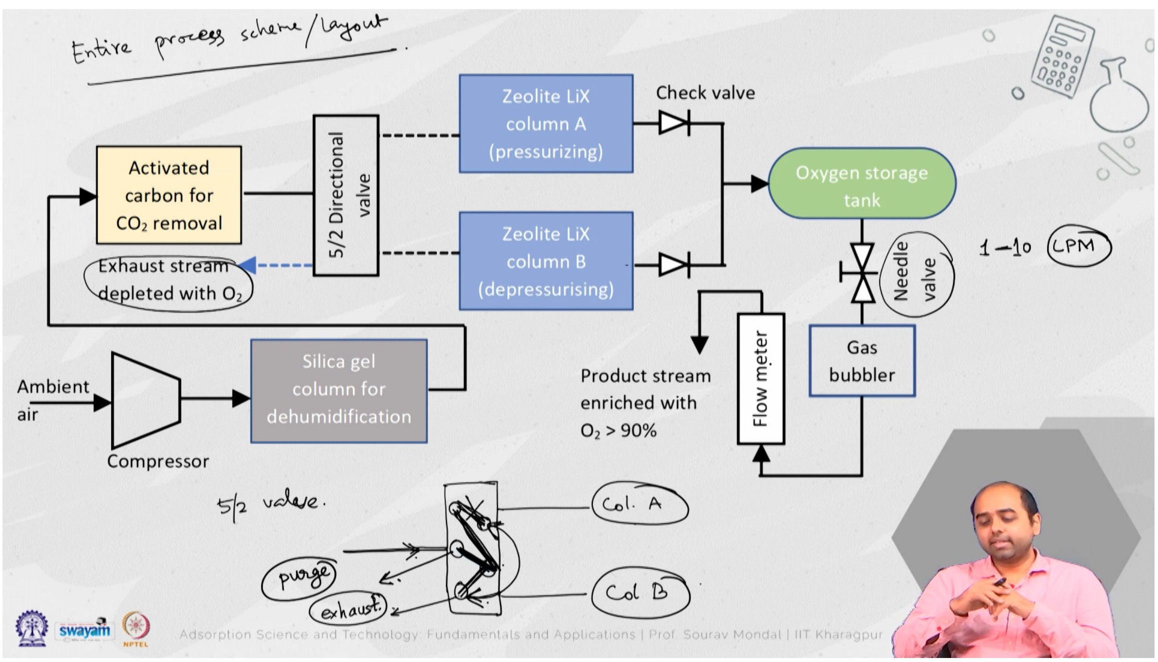
So, in that case column B is actuated through this line where this is I mean this is like the exhaust connection right. Now when column B and this is the exhaust connection and this third output at the centre is like the is like the purge connection. So, this is the purge connection. So now when this you know this mode of exhaustion is over then column B is switched from this connection to the other connection in this way where it can be purged or flushed with you know some O2 that is produced by column A part of it can be used to flush out column B which is called as the purging step. Now when the role is reversed when column A goes to depressurization mode and column B goes to pressurization mode then the solenoid actuator makes this primary connection of the feed line inlet from here to this side instead of this connection right and alternatively or you know simultaneously the connection for column A is made from this side to this side.

This connection is enabled so that column A can go to depressurization or desorption mode. So, this interchanging of the connection is done by only a single you know solenoid actuator which is operated by the electromagnet. So, this is the primary role of this 5 by 2 directional valve so that the connections can be alternatively interchanged between pressurization and depressurization as it is programmed for doing. On the exit of the two columns you have this two check valves. So, there is no back flow of oxygen during the depressurization mode.

So, for example, in this case column B is in depressurizing mode we do not want the part of this you know O 2 that is produced or stored in the oxygen tank makes back flow into column B even back flow in both column A or column B in any stage is prevented. There is one additional connection for the you know during the purging that is not shown here. So, during the purging this oxygen tank is connected to this directional valve and the purge happens in co-current way along with the this during as co-current to pressurization mode or co-current to adsorption mode. So, during depressurization again this valve check valve takes care that there is no oxygen back flow and whatever is adsorbed etcetera is desorbed and that is how the exhaust stream is shown here. Of course, the purge line is not shown here.

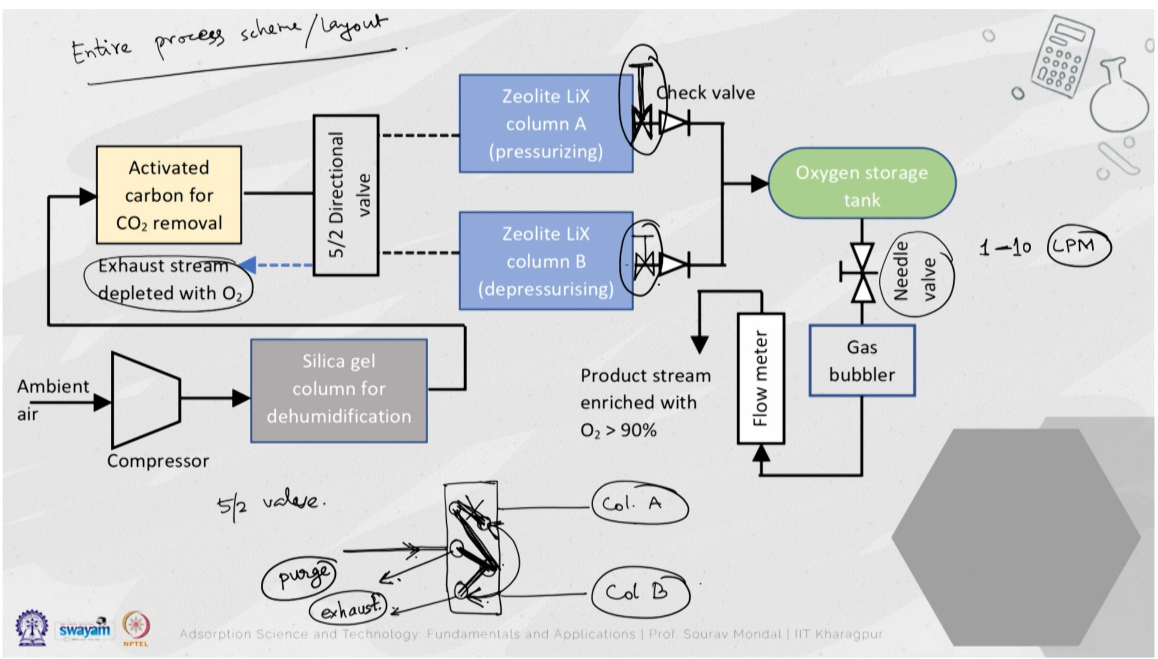
So, part of this oxygen that is produced by column A, is actually back flowed into column B or to column A depending on which mode is I mean which of these column is in depressurizing state and then it is connected to the purge valve or the purge opening in the directional 5 by 2 directional valve. After the storage tank this there is a control valve to make sure that one get the desired flow rate for the patient. So, generally the this outlet from these column A or column B is much more than the outlet value from this desired setting. So, this control valve at from the exit of this storage helps to control the desired flow. So, typically for personalized you know this O2 oxygen concentrator that is present in households and for individual use the typically the need unless you are in your chronic state or you need hospitalization the typical need is around 1 to 10 LPM, liters per minute of oxygen.

So, that is made that is ensured through the you know operation of this needle valve or this control valve here. Since the air is already dried by you know silica gel in the beginning and also whatever trace amounts of moisture are present will be you know also absorbed by the zeolite beds. So, the air the humidity of this air after I mean through after this storage tank is extremely dry I mean humidity falls below 2 percent in fact and that is detrimental for the patient as it will you know affect the you know lung tissues at well as well as this you know air flow pipes and you know this nasal route and everything. So, what is done is to humidify this air further this is bubbled through a liquid and then it passes through a flow meter or this rotameter to check the flow rate and to ensure that whatever you are operating and you are setting is actually depending on the need of the patient is actually achieved by checking through this flow meter. Typically in hospital units the system is slightly larger and you know during the depressurization vacuum is also used to assist the level of depressurization or to increase this pressure ratio of pressurization to depressurization.



So that you know this the requirement of pressurization or the requirement of high pressure step during adsorption is reduced. So, normally the operating pressure for this you know system is around 2 bar gauge pressure. So, if you apply vacuum even you can operate it at 1.5 bar also of course, in gauge pressures I am talking about 2 to 2.5 is typically the operating pressure and it shows very high selectivity I mean the selectivity does not increase beyond 2.5 bar. So, there is no point in operating it higher. And this oxygen storage tank is also pressurized up to 2 bar and that is how this operation works with the help of the storage tank. The storage tank also ensures that during a particular operation or during one cycle of this operation where one column is producing pure oxygen or how to enrich stream the oxygen profile is generally you know not steady or not constant it actually goes up during the high pressure and then quickly falls down. So, since this is stored in the oxygen tank it is also ensured that the patient receives almost an averaged steady averaged value of the O2 level rather than this cyclic surges of the concentration profile from this adsorption step. Since at any point of time one of this unit is in operation there is a continuous flow of the outlet.

And the oxygen storage tank helps to normalize the O2 concentration produced in a particular cycle where there is a significant difference between the you know peak and the you know final value depending on the cycle time. Now basically the cycle time is very important. Each manufacturer or any designer will optimize the cycle time based on the quality of the adsorbent as well as the flow rate. And accordingly the programmable valve will be set I mean will be programmed based on that cycle time so that this alternate cycles of pressurization or depressurization is achieved. One more important thing that must be understood here is that there is a, also one control valve here at this stage which is programmed to operate that during the pressurization or during this pressurization mode it is closed and once the pressurization so this is like a kind of a you know pressure release valve.



So, unless the pressure reaches the set value this valve. So, even though I call it as a this control valve. So, this is like a pressure release valve which suggests that unless the pressure reaches that particular value or it goes beyond the particular value that valve will not be closed or will not be opened in that state. So, this particular valve which is present in both this column A as well as in column B, is a kind of a pressure release valve that is actuated by the you know this pressure or pneumatically by the pressure from this column. So, which ensures that during pressurization there is no output and when the pressure you know reaches the desired level this output is open.

So, this is one is a you know brief overview of the operation of this you know say this oxygen concentrator. There are many DIY videos that is present online and I suggest all of you to look into it to understand the operation in a better way how this columns are you know designed what is the shape how the adsorbent is actually packed inside how the this 5 by 2 valve is programmed with respect to the cycle time, and you will get a fair idea about this process. So, I hope all of you have found this lecture to be useful in regarding the design of this O2 concentrator and how it actually works in reality. Thank you. See you everyone in next week.