Hydrogen Energy: Production, Storage, Transportation and Safety
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Lecture - 37
Linear and Liquid Hydrogen Compressors

In the previous class we have seen two different types of mechanical compressors, the reciprocating type and the diaphragm type of compressor. In this class we will see few more types of mechanical compressors. So, starting with the linear compressor, these linear compressors are basically used for cryogenic applications and these are driven by Stirling cycle coolers they use hydrogen or helium and they are also used for domestic refrigeration.

They have very less number of moving parts as against the previously studied compressors, in them the crank shaft, the connecting rod these components are absent.

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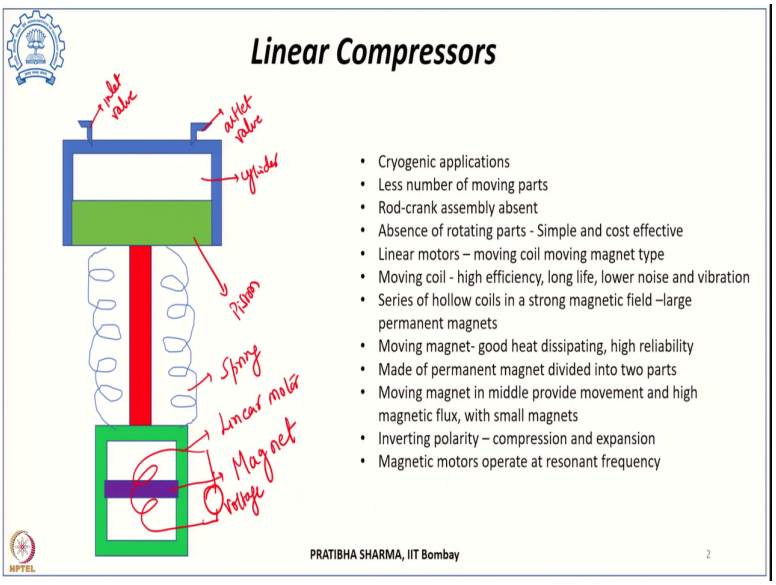

Now, because of the absence of the rotating components the design of these linear compressors this is relatively simpler and we can have cost saving also as against the other reciprocating type of compressors. Now, if we look at these compressors, then we have an inlet wall, we have an outlet wall or the discharge wall, then we have cylinder we have a piston, a spring, there is a linear motor with a magnet and then there is a helical coil which is in fact connected to a DC voltage. A voltage is provided to the coil.

So, in fact, in these type of linear compressors, there is a linear motor and that is responsible for providing movement to the piston and this is connected to the piston by means of a resonating spring system. So, the piston movement is provided by this linear motor through a resonating spring system.

Now, these linear motors, these are of magnetic type and these can be like moving coil and moving magnet type. Now, if we look at the moving coil type of these linear motors then these have very high efficiency, they have long life, they have lower noise and vibrations. And in them then there are series of hollow coils and those hollow coils they are in a strong permanent magnetic field which is provided by a permanent magnet.

But with in the case of moving coil type of linear motors, the requirement is of a large permanent magnet and that becomes the major disadvantage of these moving coil type of the linear motors which are actually used for various aerospace applications. Now in order to address that we can also have other linear motors which are based on the moving magnetic type, these moving magnetic type of motors they provide very good heat dissipation.

So, they have a low out gassing capacity, at the same time they are highly reliable and they are made up of permanent magnet and that is divided into two parts. So, there is a sort of moving magnet in the middle and that moving magnet provides this motion to the movement to the piston and in these moving magnet type of linear motors, with the use of small magnet a high magnetic flux could be created.

So, as there is a polarity change we can achieve even the compression or expansion, with the change in the polarity in this linear motor, in the voltage which is supplied to the these coils. So, the compression and suction stroke is provided by means of this coupling through the spring and with inverting that polarity which is provided we can have the compression and expansion of the gas which is there in the compression chamber.

And the magnetic motors which are used they usually operate at their resonant frequency so that the losses could be less, so that the ohmic losses are less and there then there is a direct coupling of these motors with the piston.

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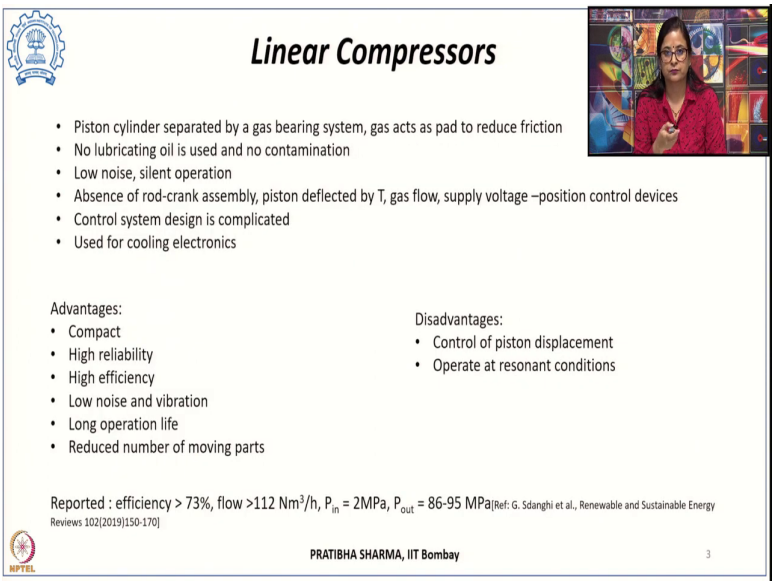

Now, in these type of compressors, the biggest advantage is that they have a sort of gas bearing system which separates the piston cylinder and this gas bearing system it also acts as a sort of that reduces the friction and losses. So, without even the using of the lubricating oil, we can reduce with the use of this gas bearing system which can act as a pad to reduce the friction.

And even we are not using any lubricating fluid oil, but still we are able to reduce the losses and we can even achieve a reduced contamination. So, no contamination we can get, pure hydrogen at the same time the operation of these compressor is noise free. So, it is a silent operation with low noise, there is an absence of crank and rod assembly. So, the piston here is deflected by means of the linear motor.

So, since there is this absence of crank rod assembly, this has a certain challenge also. That in that case the piston could even get deflected by the gas properties, like if there is a change in temperature or the gas flow or the supply voltage there will be a deflection associated in the piston. And as such to control that piston movement, we can have position control devices.

But the use of these position control devices it adds up to the complexity of the system. So, there needs to be a control system design that has to be incorporated and that will further increase the complexity. These type of compressors are used for basically cooling the various electronic circuitry. So, these compressors linear compressors have advantages, they are quite

compact, they are reliable they have high efficiency, they produce low noise and low vibrations.

At the same time they have a long operation life, they have reduced number of moving parts, but at the same time there are disadvantages also that, you have to control the piston displacement because that could be governed by various other parameters like the temperature gas flow and supply voltage. So, the controlling devices needs to be integrated and that increase on to the complexity.

At the same time it has to operate under the resonant condition. So, that synchronization is essential. The reported efficiencies have been with these linear compressors, higher than 73 percent with a flow rate of higher than 112 normal meter cube per hour, for an inlet pressure of 2 MPa and an outlet pressure in the range of 86 to 95 MPa.

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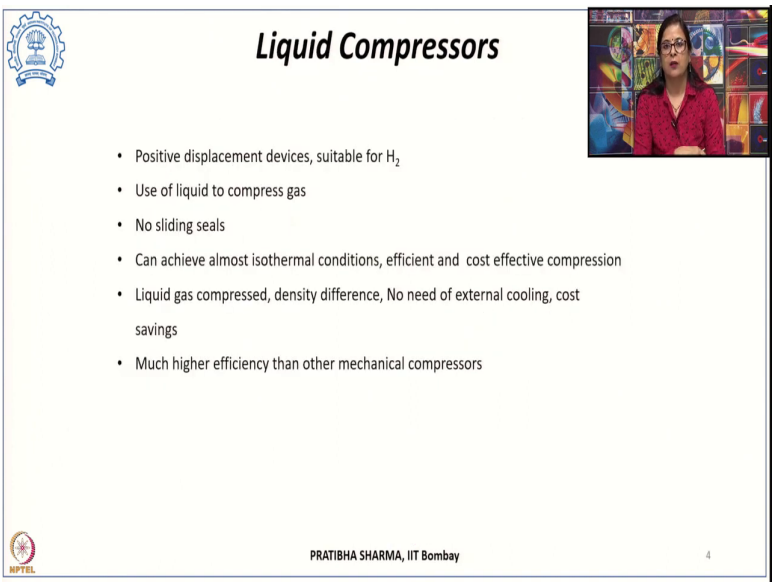

Now, the another class of compressors which can be used for hydrogen and they are very much suitable for hydrogen compressor are the liquid compressors. Again, they are the positive displacement type of devices and they compress hydrogen with the use of a piston, but that piston is now a liquid. So, the movement or the compression of the gas is provided by means of a liquid as such these are known as liquid compressors.

There is no sliding seal because there are no as such moving components involved in the compressor chamber and since we are using liquid and gas for compressor, since the liquid

which will be used that is having a very good specific heat, a heat capacity as such these type of compressor they operate under almost isothermal condition.

Since, they operate under near isothermal conditions the required work of compressor is lower, they have a better efficiency and the process is more cost effective than the other reciprocating type of compressors we have learnt so far. Now, in this type of compressors, both the liquid and gas they are compressed together and these liquid and gas they are compressed in a chamber.

And since the density of these liquid and gas it is different, at the same time the heat capacities of these are different. During the compression whatever heat is being produced that heat is absorbed by the liquid and as such there is no requirement of any external heat exchanger or any external cooling with these type of compressors. So, we can have a cost saving when we are using these type of compressors. They are much more efficient compared to the other mechanical compressors.

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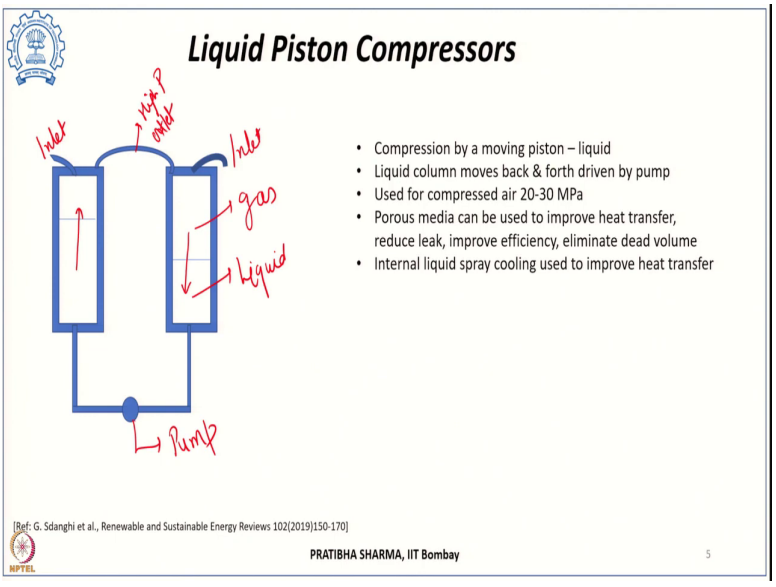

Now, if we look at these type of compressors, then we have two chambers which are connected by means of a pump which controls the flow, we have liquid and gas in these compression chambers which are connected by means of pump. And then we can have compression and expansion in these two chambers and there are inlet walls and then you can get a high pressure hydrogen at outlet.

So, in these type of liquid piston type of compressor, the compression is achieved by moving piston and this piston is not a physical piston, this is the interface between the gas and the liquid. So, the liquid column that acts as a piston and that moves back and forth so as to achieve compression and expansion in the whole process. Now, this movement of liquid inside these liquid piston compressors this is achieved by means of a pump, a fluid pump.

Now, as during the one of the stroke, when the gas is taken low pressure gas is taken in the pump drives that fluid to the other chamber so that there is a gas which is taken in the suction stroke, while the reverse happens in the compression stroke. So, during the compression the liquid level rises. So, the volume available volume reduces and as such compression is achieved and the high pressure gas could be collected.

So, there is a series of compression and expansion that will occur and that is driven by the liquid column and that liquid column movement is by means of a pump. Usually these type of compressors are used for compressed air storage and they can provide compressed air energy storage at pressures of say 20 to 30 MPa and these are integrated with renewable power plants.

Now, we can achieve although there is a very good heat transfer involved, because whatever is the heat of compression which is being produced this is absorbed by this liquid and this can be cooled down. So, this operates under isothermal condition, but we can further improve the heat transfer characteristics by including a porous media. Now, this porous media that will have several pores, there will be several interconnected pores in which the liquid can flow and that can provide high surface area and that will result into a better heat transfer.

At the same time the presence of that porous media can further reduce the chances of leakage, can improve efficiency, can achieve better heat transfer and that will also eliminate the dead volume, which is there. At the same time this heat transfer can further be improved by having an internal liquid spray cooling. Now, in this not only provide these droplets will not only provide high surface area for a better heat transfer, but at the same time for the liquid compressors this these will finally, condense back and come into the liquid.

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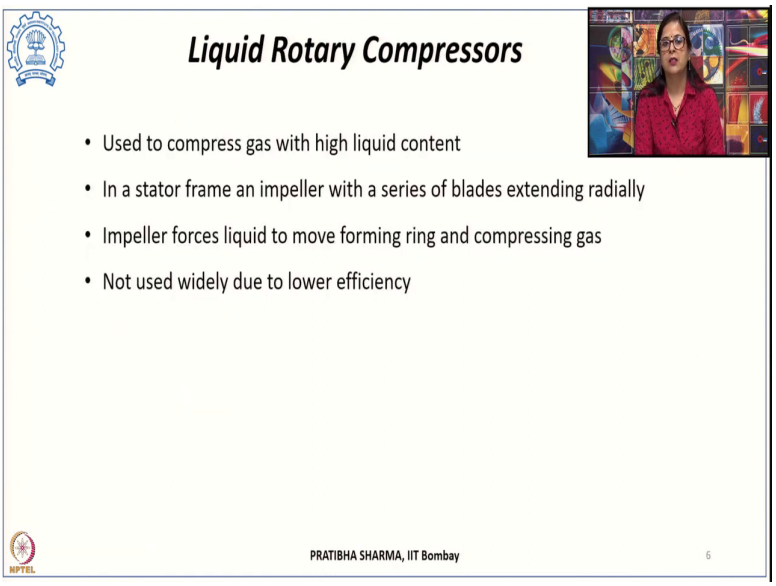

So, these type of compressors can; that was a liquid piston type of compressor, we can also have a liquid rotary type of compressor and these rotary type of compressors these are specifically used to compress gas which has a high liquid content. So, that is a saturated gas, which has a very high liquid content can be compressed using these liquid rotary type of compressors.

Now, in them there is a stator frame inside that it is an impeller which has series of blades and the kinetic energy is used to compress the gas and these blades these extend radially. Now, the problem with these rotary type of compressors or like in the case of centrifugal compressors also that lies is the low density of hydrogen is the major challenge and we get a very lower efficiency with these rotary type of compressors.

So, the impeller which is present in the stator that forces the liquid to move and that forms the ring and in that way that compresses the gas. But these type of compressors these are not widely used, because the efficiency associated with these type of compressors is very less. So, it is less than 50 percent efficiency that we can achieve.

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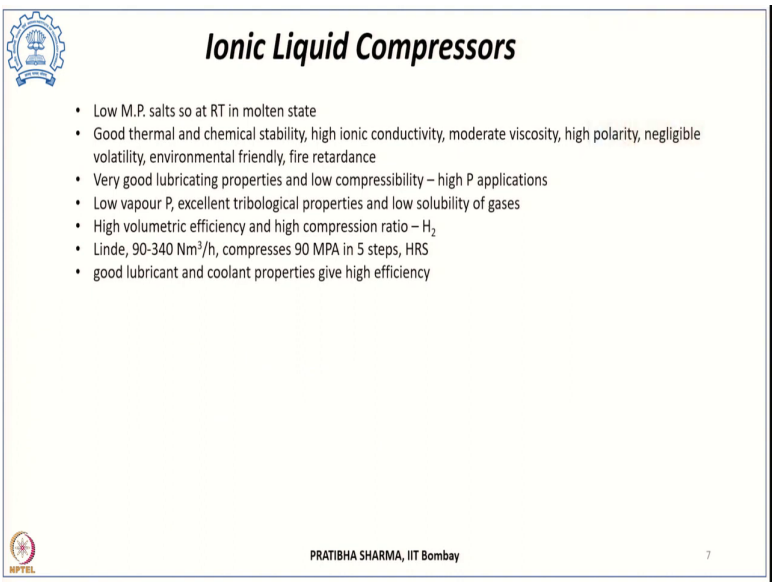

Now, another type of compressor could be ionic liquid type of compressor. So, again these are liquid compressors, but the liquid which is used is an ionic liquid, these ionic liquid are low melting point salts. So, under the room temperature conditions these are present in their molten state. But they have several advantages that they have very good thermal and chemical stability, they have got very high ionic conductivity, they have moderate viscosity, they have high polarity, they are they have a negligible volatility and that is very important.

So, as such the loss of that liquid should be lower, they are very environmental friendly, they are fire retardant and they have a very good characteristic which is a good lubricating properties and that could reduce the associated losses, friction wear and the leakages as well. So, they have very good lubricating properties and they have got a very low compressibility, as such they are very ideal towards hydrogen compression and using these liquid ionic compressors we can achieve high pressures.

So, these are again liquid compressors the principle of working is same as we have learnt, the only difference is the liquid which is used is an ionic liquid. And this ionic liquid this has a low vapor pressure and very good tribological properties. This is essential so that the loss of the liquid should be lower and it has also at the same time low solubility of gases and it is very low for hydrogen. So, as such the loss of hydrogen will be very less when ionic liquids are used.

So, these compressors are highly volumetric efficient, they can provide high compression ratios when it is considered for hydrogen compressor the company which produces ionic liquid compressor is the well known Linde company. And they have supplied compressors which could compress hydrogen in 5 steps, less number of steps with less number of moving components which could supply hydrogen at a pressure of 90 MPa at a flow rate of 90 to 340 normal meter cube per hour.

And these compressors have been supplied for various hydrogen refueling stations, where these are used for compressing hydrogen to the required pressure for FCEVs for filling in the vehicle tanks and for various other storage vessels. So, these compressors since with the use of ionic liquid they have a good lubricating properties, that is and they have also very good coolant properties. So, the problem of thermal management is not there and that leads to a very high efficiency.

So, the typical efficiencies of these ionic liquid compressors is even higher than 83 percent and that is the biggest advantage. So, ideally these are very advantageous towards hydrogen compression.

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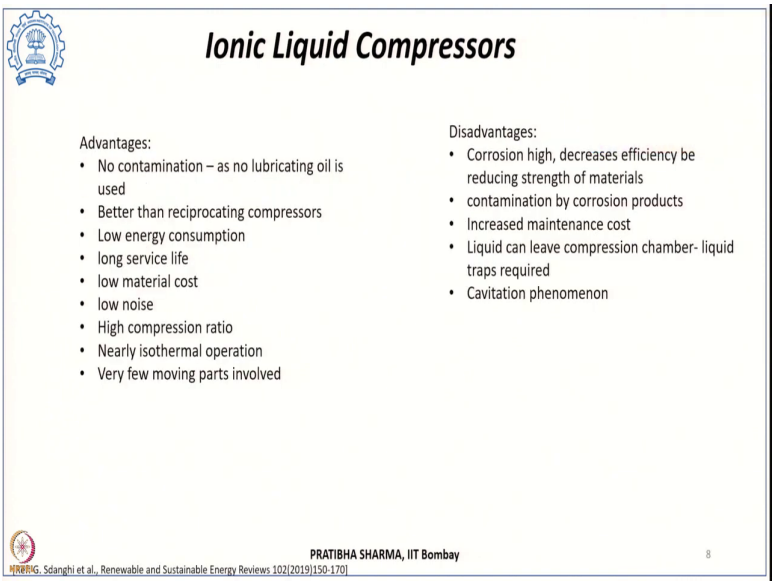

So, the major advantages associated with the liquid ionic compressors is that the gas which is compressed does not have any contamination, because we are not using any lubricating oil. They are comparatively better than the reciprocating type of compressors. The requirement of

energy is much lower they work almost under isothermal conditions, the work of compression required is lower, they have a higher efficiency, they have a long service life.

The cost of the materials which we are using is lower at the same time there are less of moving parts, less of vibration less of noise and we can achieve very high compression ratios with these type of compressors. They operate under isothermal conditions, they have very low very less number of moving parts, but the disadvantages associated with the ionic liquid compressors is the ionic liquids can cause corrosion and then there are high risks of corrosion.

Because of these corrosion challenges the strength of material could reduce over a period of time and that can decrease the efficiency of these compressors. At the same time because of the corrosion, there could be different corrosion products that will be formed and that can lead to contamination. So, the contamination could be driven by the corrosion products and because of the corrosion there will be an associated cost which will be of maintenance. So, an increased maintenance cost can result.

At the same time since the liquid and gas they are present in the compression chamber at times this liquid can also come along at the time of discharge. So, this liquid can also leave the compression chamber and as such to remove the liquid which comes along with the gas, we need to have liquid traps to separate from the gas. At the same time if there is a low pressure created, then that gas can also get trapped into the liquid.

So, not only liquid can come along with gas, but gas can also get into the liquid and that is what is known as the cavitation. So, cavitation phenomena can also lead to loss of the gas in these compressors.

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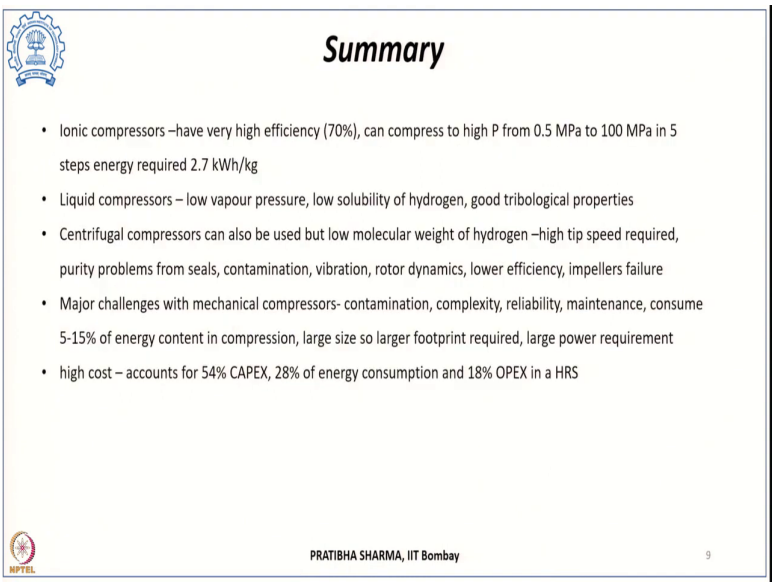

To summarize this part the ionic compressors that we have seen they have very high efficiency, even higher than 70 percent. They can compress gas to high pressures, we can achieve hydrogen pressures if the suction pressure is say 0.5 MPa, we can still get a pressure of 100 MPa at the delivery. And the number of steps which are involved in these type of compressors is very less, even in 5 steps we can get such high pressures at the same time they are very energy efficient, the energy required for compression is 2.7 kilowatt hour per kg.

As against 4 or 5 kilowatt hour per kg for many of the reciprocating compressors. If we talk about the liquid compressors then they have a low vapor pressure of the liquids, they have low solubility of hydrogen, they have good tribological properties. So, these are the characteristic of the ionic liquid and that make them very favorable for hydrogen compressor.

Now, the another choice could be a centrifugal compressor, but the major problem in using centrifugal compressor is; since the molecular weight of hydrogen is very low so, as such if we want to compress hydrogen to an appreciable pressure a high tip speed will be required.

And then there will be again problems which will be associated with the contamination, because that will contamination will come from seals, there will be vibrations associated because of the high tip speed, there will be problems associated with the rotor dynamics, the efficiency with these type of systems is also very poor and then there could be impeller failures.

So, the volumetric type of compressors are preferred compared to the centrifugal type of compressors for hydrogen compression among the mechanical type of compressors. So, we have seen that the major challenges that lies with the mechanical compressor is, there could be contamination of the gas because of the moving parts because of the lubricating oil use, because of the seal materials which is used in the seals, the design of these compressors is complex, there are challenges associated with the reliability of these compressors.

Then since they have moving parts as such there is a cost associated with maintenance and a regular maintenance is required a monitoring of these devices for failure is required. At the same time, they consume a lot of energy in compression. So, typically 5 to 15 percent of the content of hydrogen which is being compressed it goes in the compression. So, this is that of the lower heating value which may be required for compression, depending upon which particular technology we are using.

At the same time these mechanical compressors they are larger in size. So, the size requirement is big as such the required footprint area is also large and they require a lot of power for driving the compression process. So, a large power requirement associated with the mechanical compressors and they have a higher cost.

And these cost if we take a typical example of a compressor at a hydrogen refueling station, this may account for 54 percent of the capital expenditure in a hydrogen refueling station, 28 percent of the required energy consumption and 18 percent of the operating and maintenance cost could come from these compressors, mechanical compressors in a hydrogen refueling station.

So, what could be the alternate? The alternate to the mechanical compressor could be non mechanical compressors and that non mechanical compressors we will see in the next class.

Thank you.