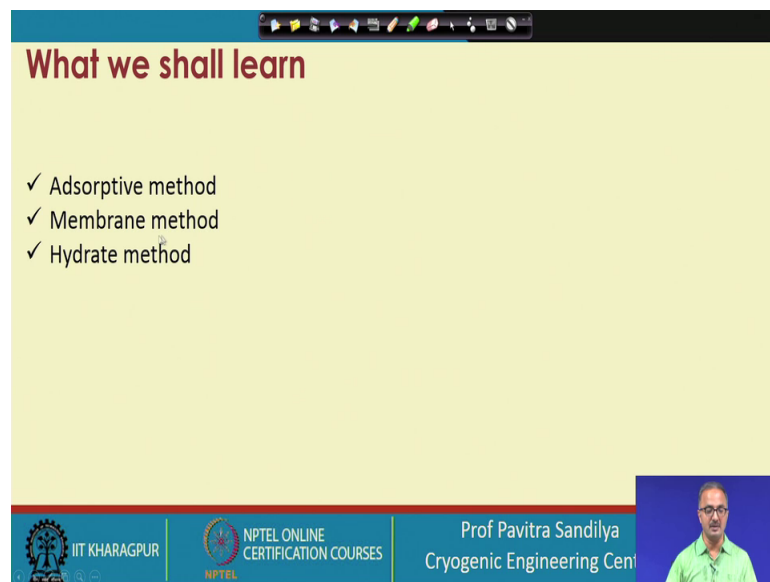


**Upstream LNG Technology**  
**Prof. Pavitra Sandilya**  
**Department of Cryogenic Engineering Centre**  
**Indian Institute of Technology, Kharagpur**

**Lecture – 46**  
**Nitrogen removal in natural gas system- II**

Welcome, today we shall be looking into some of the more techniques we about removal of the nitrogen from the natural gas. In this particular lecture, we shall be looking into adsorption, membrane and gas hydrate modes of separating the nitrogen from the natural gas systems.

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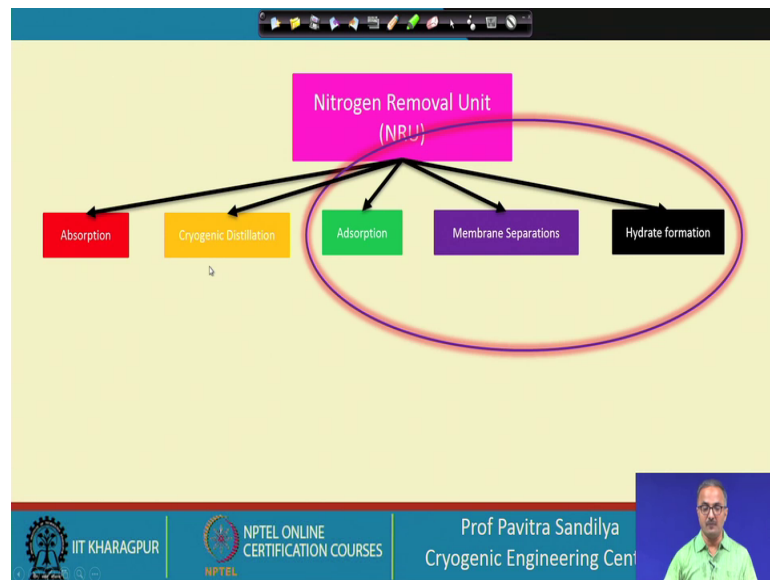
**What we shall learn**

- ✓ Adsorptive method
- ✓ Membrane method
- ✓ Hydrate method

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So, we shall be learning about these 3 methods adsorptive separation, membrane separation and hydrate separation.

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So, what we have learnt earlier there are 5 methods; these 2 absorptions cryogenic distillation we covered earlier and in this lecture we shall be covering the, these 3 types of natural removal methods.

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### Adsorptive Nitrogen removal

- Adsorption is the choice after cryogenic distillation.
- Pressure swing adsorption is used because of high amount  $N_2$  (adsorbate) and low heat of adsorption.
- Adsorption pressure: 10 – 100 kPa, and adsorption temperature: 273 – 323 K.
- Heat of adsorption: 15 – 22 kJ/mol.

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Now, coming to adsorptive nitrogen removal; so, first we see that the adsorption is the choice after cryogenic distillation. And in this case we use generally pressures in adsorption or what we call PSA to remove high amount of nitrogen, which is the

adsorbate at a low heat of adsorption. And the adsorption pressure is about 10 to 100 kilo Pascal and the adsorption temperature varies between 273 to 323 Kelvin.

The heat of adsorption is between 15 to 22 kilo Joule per mole. So, these are some typical figures for carrying out adsorption and the heat of adsorption is significant because this decides that how much energy we would need for the regeneration of the spent adsorbents.

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### Principle of commercial adsorption separation

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### Principle of commercial adsorption separation

The diagram illustrates a two-bed adsorption system. Feed enters from the top and is distributed to Bed 1 and Bed 2. Bed 1 produces Product, while Bed 2 produces Exhaust. A Purge stream is also shown. The graph plots Adsorption capacity (mmol g<sup>-1</sup>) against Pressure (kPa). It shows two curves: a red curve for TSA (Temperature Swing Adsorption) and a black curve for PSA (Pressure Swing Adsorption). The TSA curve is higher, indicating greater capacity at higher pressures. Key points on the graph include  $Q_{des-PSA}$ ,  $Q_{des-TSA}$ ,  $Q_{ads}$ , and  $T_{ads}$ . The PSA process is shown to occur at  $T_{des} > T_{ads}$ , while the TSA process occurs at  $T_{des} = T_{ads}$ .

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So, the principle of these adsorption separation is that this is the figure we can see here that we need at least 2 beds for carrying out PSA depending on the time of adsorption and the for the bed to get saturated and the time of regeneration. So, here we saying the figure we have 2 beds here and all this valves have been given different symbols like this Sind valves are showing that there is the flow going on and these empty things are showing that these are closed.

So, in this case we understand that when one bed is undergoing adsorption, the other bed has been taken for regeneration. Now if we trace this particular feed we find that the feed is coming suppose it is coming and suppose in this case it will be coming to this unfiled or these blank valves. So, it will be coming through this while this particular thing is kept closed. So, it will go through this and then it gets adsorbed over here and then it comes through this particular valve and goes out the product.

Now, suppose this particular bed get exhausted then what we have to do? We shall be switching of this. So, we shall be closing this valve and we shall be opening this one now the same process we go to the feed will now come here and it will go through pass through this bed and it will go for the production.

Now, valve in case of regeneration what is happening that this particular bed is undergoing regeneration. So, what is happening that we are putting some kind of a may be hot stream through this bed and this bed from this adsorbents the adsorbs solutes. For example, in this case if we are adsorbed nitrogen the nitrogen will be carried over from this particular adsorbing bed and this will be taken out and then this bed will be ready for the adsorption.

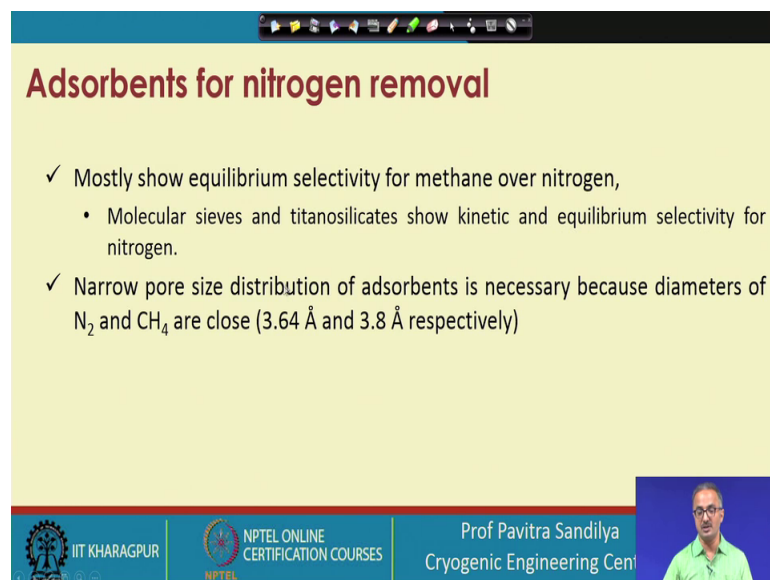
And in this particular figure what we see is that how the loading capacity or the adsorption capacity varies with pressure. And here we see that we are comparing this PSA and TSA; now suppose we have this particular red line in which we are showing that how this then this taking place at one temperature and this is taking place at another temperature. Obviously, since adsorption is favored at lower temperature so this t adsorption must be lower than the t desorption.

So, suppose we start initially from this particular point; that means, at this particular pressure, at this particular temperature now if we are carrying out PSA; that means, we are reducing the pressure what we have to do for remember that we go to like this. So,

that we are going to an at the same received then isothermally. So, the; we are going on a same isotherm, but we are just reducing the pressure. So that we can find that the loading of the bed decreases; so, that is how we are able to regenerate the bed.

On the other hand, if we want to use TSA then what we need to consider is this at the same pressure for we move with move down the heat of the bed. And then we go to another isotherm and that is at we find that this  $t$  desorption is more than  $T$  adsorption. So; that means, this particular vertical line show the TSA; that means, the Thermal Swing Adsorption way of regenerating the catalyst adsorbent. And this shows this PSA that is the pressure variation how will we regenerate the adsorbent by varying the pressure. So, these 2 things can be carried out in this pair of beds.

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**Adsorbents for nitrogen removal**

- ✓ Mostly show equilibrium selectivity for methane over nitrogen,
  - Molecular sieves and titanosilicates show kinetic and equilibrium selectivity for nitrogen.
- ✓ Narrow pore size distribution of adsorbents is necessary because diameters of  $N_2$  and  $CH_4$  are close (3.64 Å and 3.8 Å respectively)

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Now, in case of nitrogen removal what we found find that the mostly the absorbance show equilibrium selectivity for methane over nitrogen. That means, methane is select selectively taken up by the adsorbents of course, it dependence on the type of adsorbent, but the most of the adsorbent show that more selectivity towards methane; that is nitrogen is purged out while methane is retained.

And molecular sieves and titanosilicates show kinetic and equilibrium selectivity for nitrogen; we shall learn in a while what is kinetic and what is equilibrium selectivity. Now, narrow pore size distribution of adsorbents as we learnt earlier that pore size

distribution is very important that decides that how selectively we can adsorb the various solutes.

So, in this case we find that the this the diameters of the nitrogen and this methane molecules are very close about 3.64 Angstrom and 3.8 Angstrom that is by we find that the pore size is of the adsorbent have to be very very carefully made so, that we can differentiate between these 2 types if molecules which are very close diameters. So, that is where we find that in this case kinetic and equilibrium selectivity is preferred rather than steric selectivity.

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**Mechanisms of adsorptive separation**

- ✓ Thermodynamic equilibrium mechanism
  - Differences in the adsorbate–surface interactions and/or adsorbate-packing interactions, when the system reaches equilibrium.
- ✓ Steric mechanism
  - Differences in the size and/or shape of gas molecules: Molecules larger than the adsorbent pores are excluded.
- ✓ Kinetic mechanism
  - Differences in the diffusion rates of molecules through the adsorbent pores.

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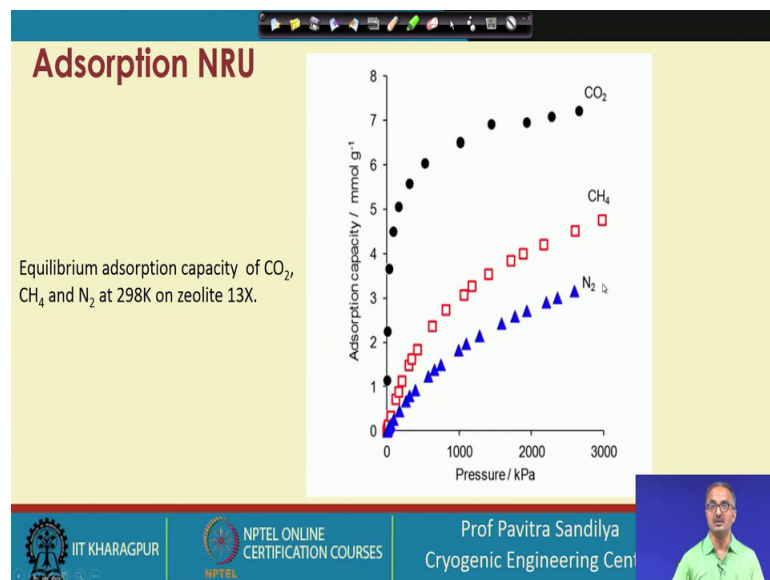
So, this is what that is a now we see that the mechanism for the adsorptive separation. So, first we have the thermodynamic equilibrium mechanism; what it means is this that it shows the differences in the adsorbate and the surface interactions and or adsorbate and packing interactions when the system reaches equilibrium. That means, we allow all the solutes to reach equilibrium and then measure the respective concentrations on the adsorbate.

So, depending on the adsorbate adsorbent interaction; various solutes will be adsorb to depend extents at equilibrium. And this extent the difference in the extents will determine the separation and the selectivity of the various solutes by the particular adsorbent at equilibrium. Then we have another mechanism that is the Steric mechanism; in this what we do that differences in the size and or shape of gas molecules dictate.

That means, the molecules which are larger than the pore size will not be allowed to the adsorbent. Whereas, those molecules which are smaller than the pore size will be allow to enter the adsorbent particles and then get adsorbed; so this is called the Steric mechanism. And lastly we have the kinetic mechanism in which the difference in the rates of diffusion of the various solutes through the adsorbent particle determinants their separation.

That means, in this kinetic separation all or some of the solutes are allowed to pass through the pores of the adsorbent. But depending on the rate at which their travel inside the pores will determine their respective adsorption capacities.

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Now, next we have this adsorption NRU that is the Natural Removal Unit; in this case we find that this is the kind of characteristic which are you found that this curve shows the equilibrium cap adsorption capacity of carbon dioxide, methane and nitrogen at 298 Kelvin on zeolite 13 X.

This zeolite 13 X is one of the absorbance on this particular adsorbent at this particular temperature; this is a typical curve, which have been shown for the 3 components. And what we find that the zeolite 13 X adsorbent adsorbs carbon dioxide preferentially in comparison to methane and nitrogen. That means, from this we conclude that carbon dioxide if we want to remove carbon dioxide from natural gas; then we should go for this zeolite 13 X.

And once carbon dioxide is removed then we can see that next is the methane; that means, this 13 X; zeolite 13 X adsorbs methane more than nitrogen. So, then what we find that this particular after removal of carbon dioxide, this particular adsorbent may be used to remove the methane from the nitrogen.

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### Common adsorbents used in nitrogen removal

Survey of pressure-swing adsorption processes for CO<sub>2</sub> and N<sub>2</sub> separations from CH<sub>4</sub> in operation or in patent claims.

Vendor/licensor	Adsorbent	More adsorbed component	Less adsorbed component	Flow rate (MMscfd)	Refs.	
M3100 Xebec Rotary-valve	Xebec	Metal-based	CO <sub>2</sub>	CH <sub>4</sub>	<2.5	Toreja et al. (2011)
CO <sub>2</sub> Sponge	IACX Energy	Activated carbon	CO <sub>2</sub>	CH <sub>4</sub>	0.2-5	CO <sub>2</sub> Sponge (2011)
Molecular Gate	Guild Associates	Titanosilicates	CO <sub>2</sub>	CH <sub>4</sub>	0.5-50	Guild Associates (2007)
UOP MOLSIV	UOP	Zeolite	CO <sub>2</sub>	CH <sub>4</sub>	UOP (2010)	UOP (2010)
Polybed PSA/Nitrex	UOP	Zeolite	CH <sub>4</sub>	N <sub>2</sub>	2.3	UOP (2010)
Micro-scale N <sub>2</sub> rejection unit	American Energies Corporation	Activated carbon	CH <sub>4</sub>	N <sub>2</sub>	0.075-0.5	(American Energies Pipeline, 2009; Nhattacharya et al. (2009)
Nitrogen rejection unit	TGPE	Activated carbon	CH <sub>4</sub>	N <sub>2</sub>	0.0003-15	TGPE (2009)
Nitrogen Sponge	IACX Energy	Activated carbon	CH <sub>4</sub>	N <sub>2</sub>	0.3-5	Reinhold (2010)
Nitrotec	CMS Energy	Activated carbon	CH <sub>4</sub>	N <sub>2</sub>	15	Richter et al. (1985) and Tagliabue et al. (2009)
Molecular Gate	Guild Associates/BASF	Titanosilicates	N <sub>2</sub>	CH <sub>4</sub>	0.5-10	Guild Associates (2007), Mitariten (2009)

Ref: Rufford T E, Smart S, Watson G C Y, Graham B F, Boxall J, Diniz da Costa J C, May E F. The removal of CO<sub>2</sub> and N<sub>2</sub> from natural gas: A review of conventional emerging process technologies, J Petroleum Science and Engineering, vol 94-95, p 123, 2012.

Here in this particular table we have listed some of the commonly used adsorbents for the nitrogen removal. And here we find the different reference have been given here and we find that various this from which are the vendors; who can supply these particular kinds of this adsorbent. And we find that some metal based, some is activated carbon then titanosilicate, then zeolite and all these things and we are finding that which of the components is selectively adsorbed on this particular adsorbents.

Like for example, in its metal based adsorbent, carbon dioxide is the more adsorbed than methane. Then activated carbon also carbon dioxide is preferentially adsorbed to methane; then in this way we find at this particular zeolite this is this niterx polybed nitrex, this particular thing we find that in this case methane we selected selectively adsorbed 2 nitrogens.

So, this way by looking at these particular figures we can find out that which adsorbent you choose from. And here in this particular column we are shown the kind of the capacities of this various kinds of adsorbent beds.



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Capacities and selectivities of adsorbents for CH<sub>4</sub> and N<sub>2</sub> at 100 kPa and 1000 kPa.

Adsorbent name	Type	CH <sub>4</sub> capacity (mol kg <sup>-1</sup> )	N <sub>2</sub> capacity (mol kg <sup>-1</sup> )	CH <sub>4</sub> /N <sub>2</sub> equilibrium selectivity	CH <sub>4</sub> /N <sub>2</sub> kinetic selectivity	T (K)	P (kPa)	Ref.
Si-ETS-4, activated 543 K	Titanosilicate	1.30	2.00	0.65	0.17	273	100	Marathe et al. (2004b)
GZC112 (Talsoda)	AC	1.18	0.38	3.11		298	100	Oganesy et al. (2003)
Norit RB1 extra	AC	1.10	0.39	2.77		298	100	Dresbach et al. (1999)
AC31 (MMSI)	AC	1.09	0.31	3.52		293	100	Scallé et al. (2000)
PET-EX-9-CVD	AC/CMS	1.06	0.25	4.24	4.63	298	100	Cançado et al. (2010)
WSG2 (Chermission)	AC	1.02	0.39	2.62		303	100	Belmabhouf et al. (2004)
MSC-3K-161	CMS	1.01	0.36	4.25	0.17	298	100	Wagner et al. (2009), Cavatini et al. (2005)
BPL (Calgon)	AC	1.01	0.34	2.97		298	100	Belmabhouf et al. (2004)
Columbia Grade L	AC	0.94	0.34	2.81		303	100	Valenzuela and Myers (1989)
Natural chabazite	Zeolite	0.89	0.45	1.96	1.86	303	100	Jensen et al. (2011)
Masuzob	AC	0.88	0.32	2.76		300	100	Sheikh et al. (1996)
SA (Sinopac)	Zeolite	0.84	0.56	1.50		298	100	Saba et al. (2010)
Mg-clinoptilolite	Zeolite	0.80	0.45	1.78	0.10	295	100	Jayaraman et al. (2004)
Na-Mordenite	Zeolite	0.75	0.44	1.70		303	100	Delgado et al. (2006)
Sunifite-Specialman Carbon	AC	0.71	0.27	3.41		298	100	Estevés et al. (2008)
MOF-177	MOF	0.67	0.17	3.94		298	100	Saba et al. (2010)
NAX (Linde)	Zeolite	0.65	0.41	1.59		305	100	Dunne et al. (1996)
Na-Beta	Zeolite	0.63	0.41	1.54		303	100	Xu et al. (2008)
13X (CECA)	Zeolite	0.59	0.28	2.11		298	100	Cavatini et al. (2004)
SA (WR Grace & Davison)	Zeolite	0.58	0.20	2.90		303	100	Nam et al. (2005)
Si-ETS-4, activated 543 K	Titanosilicate	0.22	0.20	1.09		323	100	Cavatini et al. (2009)
Ca-ETS-4, activated 543 K	Titanosilicate	0.20	0.22	0.93	0.14	323	100	Cavatini et al. (2009)
MOF-5	MOF	0.13	0.11	1.18		298	100	Saba et al. (2010)
Si-ETS-4, activated 543 K	Titanosilicate	0.10	1.46	0.07		298	100	Kuznicki et al. (2001)
Si-ETS-4, activated 588 K	Titanosilicate	0.02	0.24	0.08	0.05	295	100	Jayaraman et al. (2004)
PET-EX-0	AC/CMS	0.02	0.08	0.26	0.02	298	100	Cançado et al. (2010)
Norit RB1 extra	AC	4.00	2.02	1.98		298	1000	Dresbach et al. (1999)
Sunifite-Specialman Carbon	AC	3.69	1.82	2.03		298	1000	Estevés et al. (2008)
Columbia Grade L	AC	3.47	1.78	1.95		303	1000	Valenzuela and Myers (1989)
13X (CECA)	Zeolite	3.06	1.83	1.67		298	1000	Cavatini et al. (2004)
MSC-3K-161	CMS	2.73	1.33	2.05	0.18	298	1000	Wagner et al. (2009), Cavatini et al. (2005)
MSC-3K-162	CMS	2.10	1.40	1.50	0.17	303	1000	Bae and Lee (2005)
Na-Mordenite	Zeolite	1.70	1.50	1.13		303	1000	Delgado et al. (2006)
Natural chabazite	Zeolite	1.69	1.46	1.16		303	1000	Wagner et al. (2011)
Si-ETS-4, activated 543 K	Titanosilicate	0.90	3.80	0.24		298	1000	Kuznicki et al. (2001)

And here are some more of these adsorbents to these adsorbent these things are very exhaustive; exhaustive list of the various adsorbents that may be considered for the removal of the various types of impurities from natural gas like carbon dioxide, nitrogen etcetera. These come handy whenever we are supposed to design and adsorption column, for the removal of these particular impurities from natural gas.

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## Membrane NRU

- ✓ Limited to pre-treatment and compression of feed stream to produce the desired driving force.
- ✓ Natural gas is generally at sufficient pressure, still compression may be required for membrane separation.
- ✓ Membrane performance is characterized by:
  - Permeability
  - Selectivity
- ✓ Not commonly used due to low selectivity of similar sized nitrogen and methane.
  - Selectivity: < 3 for glassy polymers, and < 5 for rubbery polymers.
  - Addition of inorganic fillers increases selectivity by making mixed matrix membrane.

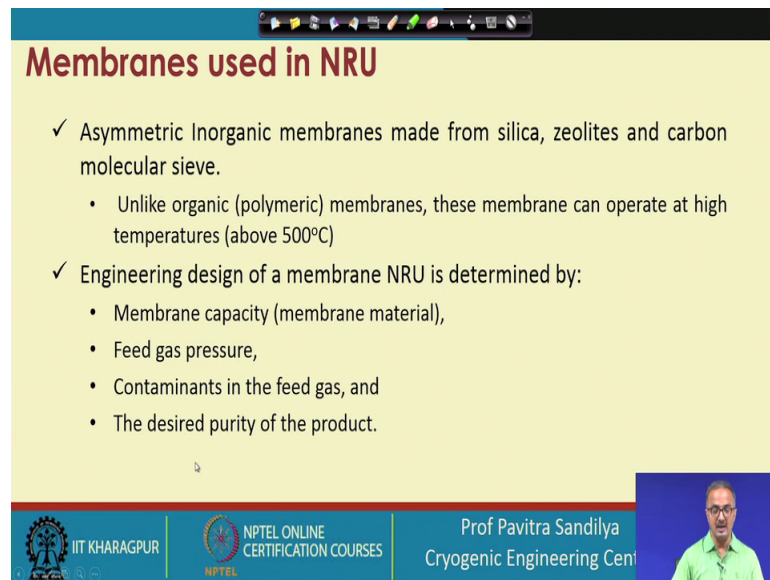
Now, next we come to the membrane; nitrogen removal units. Now these membrane units are limited to pretreatment and compression of feed stream to produce the desired driving force.

And natural gas is generally at sufficient pressure, but still we mean where we need compression for membrane separation. As we learnt earlier that the separation through membrane depends on the difference in the partial pressures of the particular solute across the membrane on the; that means, the permit side and the glitented side and we know that if we increase the pressure at a given mole fraction; the partial pressure of the particular solute will increase.

So, we need to pressurize the gas to be separated at very high pressure. And in case of natural gas even your natural gas come sought from the earth at sufficiently high pressure; still more pressure pressurization may be needed if we take it for membrane separation. And the membrane performance is characterized by the permeability and the selectivity of the main. The permeability we refers to that how much the membrane will the allow some particular solute will pass through. And selectivity means that preferential which of the solutes will be allowed to pass through the membrane.

And these membranes are not commonly used due to low selectivity of similar sized nitrogen and methane; that means, if we want to separate nitrogen and methane then generally this is not (Refer Time: 13:46) much and the selectivity we find that is less than 3 for glassy polymer membrane and less than 5 for rubbery polymer membranes. And addition of some inorganic fillers is done to increase the selectivity by making the mixed matrix membrane. So, we use some figures so that we can overcome this kind of small selectivity of the membranes.

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**Membranes used in NRU**

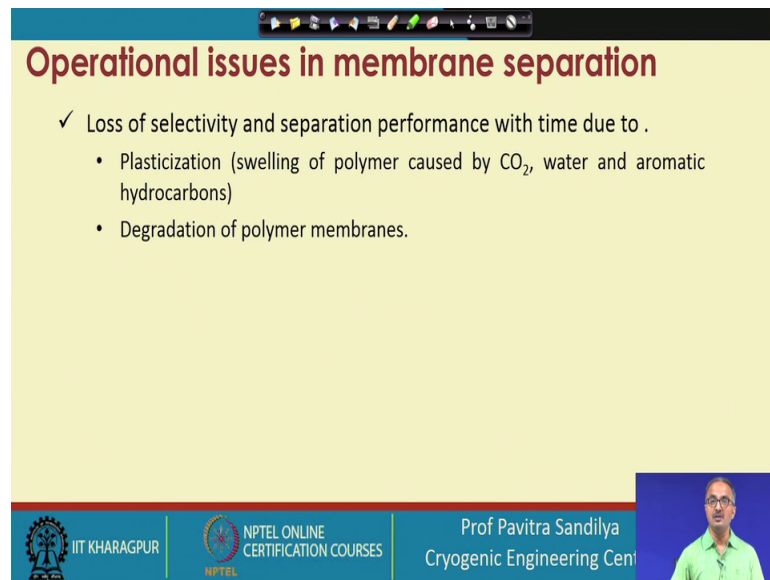
- ✓ Asymmetric Inorganic membranes made from silica, zeolites and carbon molecular sieve.
  - Unlike organic (polymeric) membranes, these membrane can operate at high temperatures (above 500°C)
- ✓ Engineering design of a membrane NRU is determined by:
  - Membrane capacity (membrane material),
  - Feed gas pressure,
  - Contaminants in the feed gas, and
  - The desired purity of the product.

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Now, we use asymmetric inorganic membranes made from silica, zeolites and carbon molecular sieve and unlike this organic membranes these membrane can operate at high temperatures. So, we find that organic membranes may get destroyed at high temperature. So, the inorganic membranes are used and asymmetric as we learnt earlier that asymmetric means we have a very thin skin of the membrane which is supported by a quite porous and thin support that is asymmetric membrane. So, these kind of asymmetric membranes are used for the separation of the this impurities.

And the design of this membrane NRU is determined by the membrane capacity that is the dictated by the membrane material. Then the feed gas pressure the kind of contaminants we have in the feed gas and the desired level of purity of the product .

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**Operational issues in membrane separation**


- ✓ Loss of selectivity and separation performance with time due to .
  - Plasticization (swelling of polymer caused by CO<sub>2</sub>, water and aromatic hydrocarbons)
  - Degradation of polymer membranes.

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There are 2 operational issues in the membrane with sometimes restrict the use of the membrane of the impurities separation. In this case, we find loss of selectivity and separation performance may occur for a long period of time; why? Because of basically 2 reasons one is plasticization; that means, the membrane polymer swells.

And this swelling of the membrane is caused by the carbon dioxide water and other aromatic hydro carbons which are present in the natural gas or the degradation of the polymer membranes. So, this needs to the loss of the selectivity and the performance of the membrane and to prevent the plasticization what is done? Some cross linking of the polymer networks and use of some figures. So, these are something which are taken we are not going to detail of this things. So, we chemically treat this membranes so that we can prevent the plasticization of the membrane.

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**Operational issues in membrane separation**

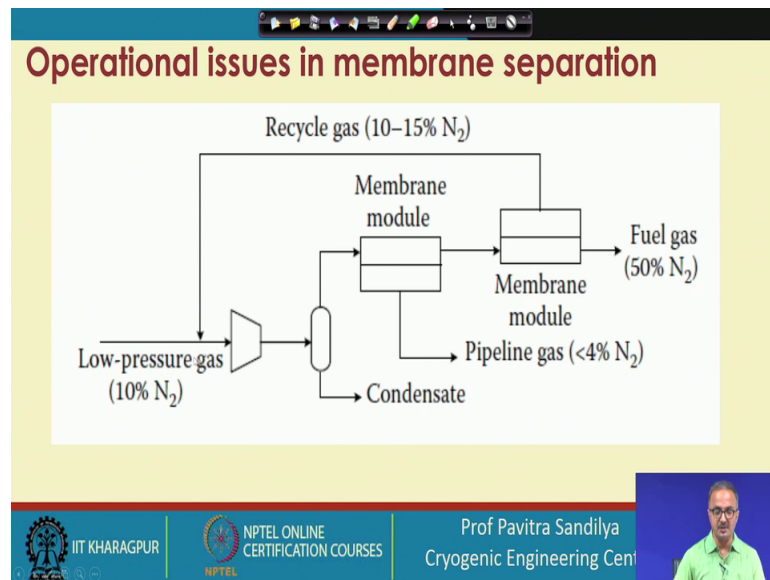
- ✓ Pretreatment of feed gas is required to
  - Remove the plasticizer-contaminants,
  - Alleviate fouling by removing oil mists and particulates,
  - Prevent condensation of the heavier hydrocarbons and water on membrane surface.

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And also we need for we need to go for pretreatment of the feed gas so that we can remove any kind of contaminants which encored which can enhance the plasticization. So, like for for example, we can use the carbon dioxide or water and then alleviate fouling by removing the oil mists and the particulates.

As we learnt earlier fouling means the deposition of undesirable components on the membrane surface which prevent the diffusion of the solutes to the membrane. So, we need to prevent the fouling and then prevent the condensation of the heavier hydrocarbons and water on the membrane surface.

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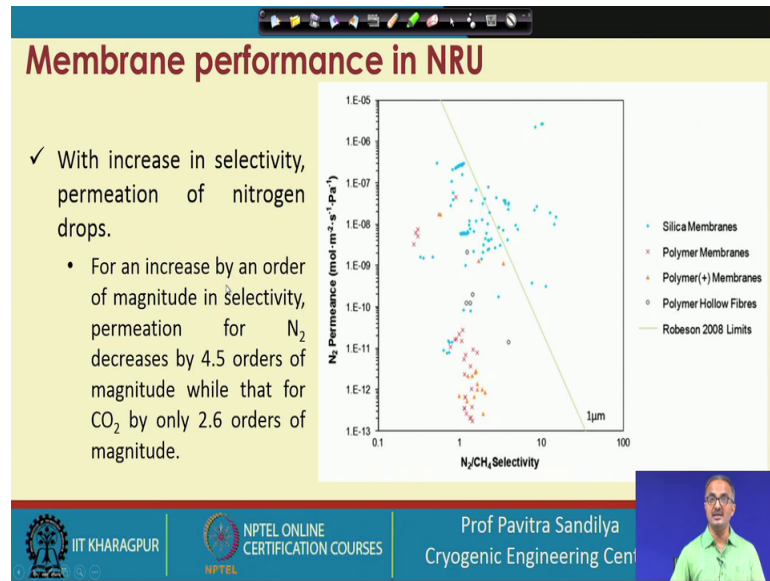


So, here we find the typical membrane module that some lower pressure gas say about 10 percent nitrogen; this coming through this. And we find that it is first going through the typically its first going through one membrane module.

And in this case the permeate is taken out at the pipeline gas which has less than 4 percent nitrogen. And the returned it is again taken to next membrane module and here we find that we can get the fuel gas. And the permeate from here this is about 10 to 15 percent nitrogen is send back to the with stream and again after this compression and after this filtering again we said it back to the membrane modules.

So, this is a typical membrane separation unit for this nitrogen removal.

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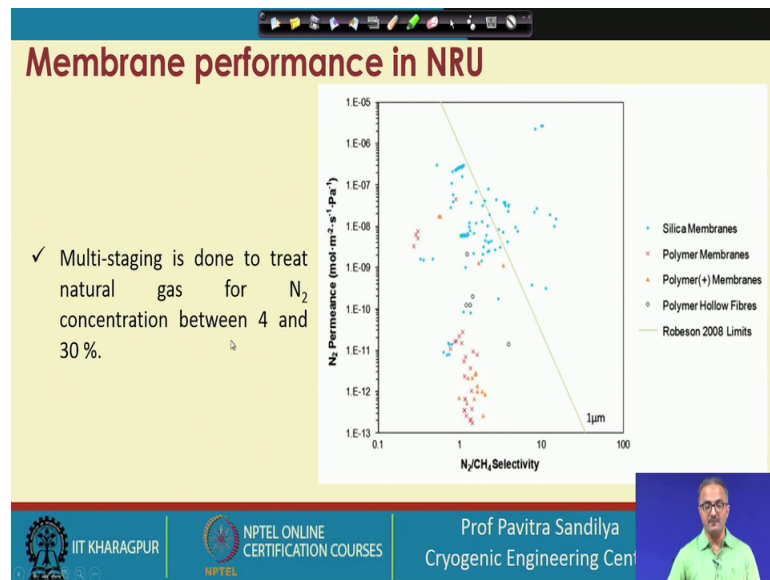


And here we find that the membrane performance which has been plotted with the nitrogen permeance against the nitrogen to methane selectivity. And what we find here is this that as the selectivity increases; the permeation decreases; that means, for an increased by an order of magnitude in selectivity permeation for nitrogen decreases by 4.5 orders of magnitude; while for carbon dioxide decreased by 2.6 orders.

That means, order of magnitude means suppose we go for 10 times increase a in in the in the selectivity; then what we find? Then the permission decreases more rapidly than the selectivity for for the carbon dioxide for the nitrogen; then for carbon dioxide.

And here we find what are the various kinds of membranes have which have been put silica membranes, polymer membranes then some hollow fiber to be find for different types of membranes; we find different types of this relationship between the selectivity and the permeance. But the overall trend is that the selectivity decreases with and increase in the permeance.

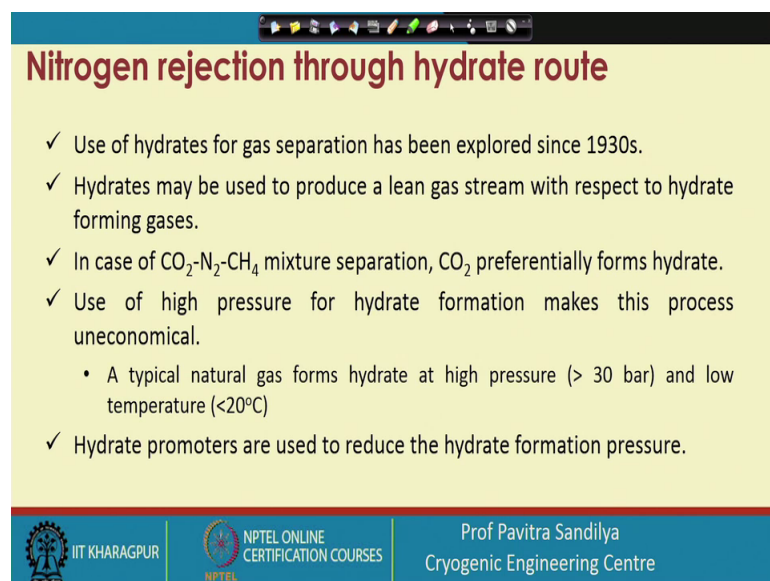
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And that is why what we do we need to do multi staging to treat the natural gas for nitrogen concentration between 3 and 30 percent; So, when we have sorry 4 and 30 percent; when we have this kind of amount of that we will go for multi staging; that means, we use number a number of membrane modules .

Lastly we come to the another thing which is the nitrogen rejection by hydrate route.

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And use of hydrate has been done for separation since 1930s that is it is not a very new process. And hydrates may be used to produce a lean gas stream with respect to hydro

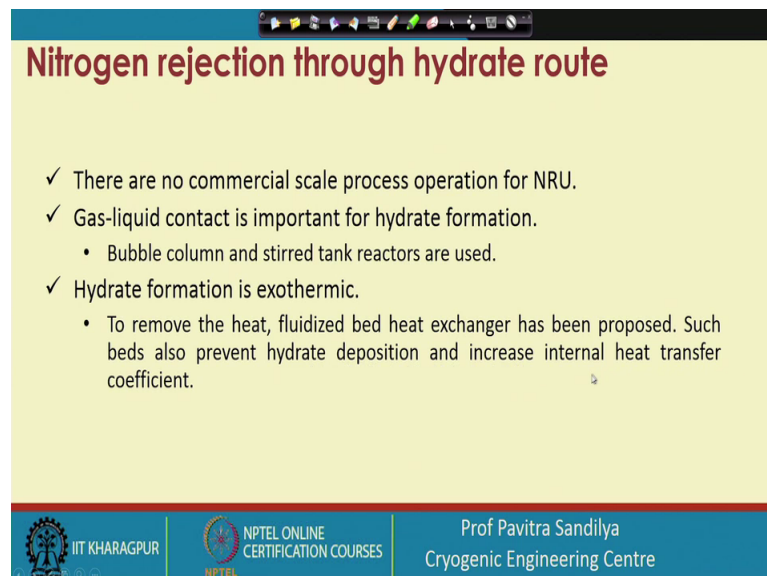


forming gases; that means, hydrate forming gases are mainly we learned the carbon dioxide,  $H_2S$ ; then the water water if the react with this when we get hydrates. So, with respect to this hydrate forming gases are carbon dioxide, nitrogen,  $H_2S$ ; etcetera we this hydrate route may be used to get a leaner gas; leaner gas means which will be having less amount of this particular impurities

So, in case of carbon dioxide, nitrogen and methane mixture carbon dioxide is preferentially forms the hydrate. And use of high pressure for hydrate formation makes this process uneconomical because we know that hydrate is formed at high pressure and low temperature. To to make this particular process possible with separate carbon dioxide or nitrogen; we need high pressure and this high pressure and its own challenges.

So, that is why it makes the process uneconomical and a typical natural gas forms hydrate at pressure more than 30 bar and at a temperature less than 20 degree centigrade. And to make the high the out of facilitate the hydrate formation some kind of hydrate promoters sometimes used to reduce this formation pressure, but we have to understand that whenever we are using some promoter; we are; that means, we are also adding some kind of impurity to the system.

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**Nitrogen rejection through hydrate route**

- ✓ There are no commercial scale process operation for NRU.
- ✓ Gas-liquid contact is important for hydrate formation.
  - Bubble column and stirred tank reactors are used.
- ✓ Hydrate formation is exothermic.
  - To remove the heat, fluidized bed heat exchanger has been proposed. Such beds also prevent hydrate deposition and increase internal heat transfer coefficient.

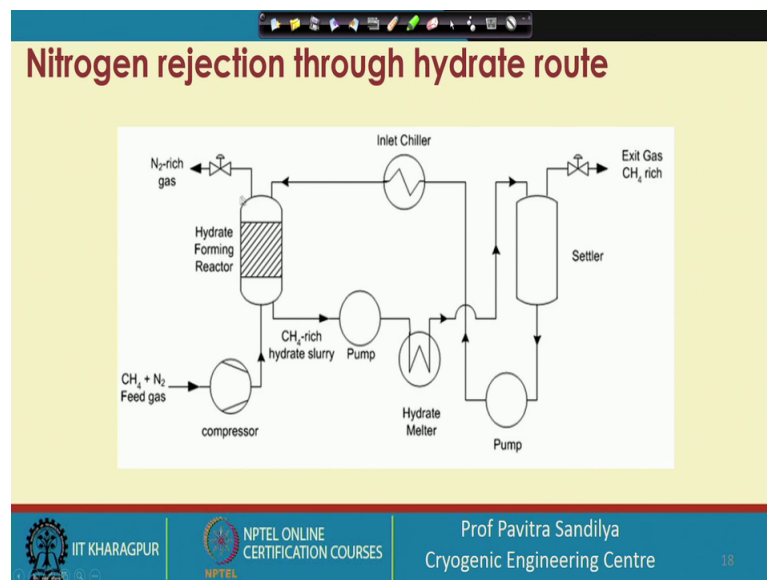
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So, ; so, then there are no commercial scale process operation for NRU and gas liquid contact is very important for hydrate formation because unless the gas comes in contact

with water we cannot form the hydrate. So, it is very important you have to assure that these 2 phases get properly mixed in a particular system.

So, in this case bubble columns and stirred tank reactors are used; hydrate formation is exothermic; that means, it is accompanied by release of energy. So, to remove the heat of hydrate formation what we need? We need to quickly take out the heat. So, and for that various devices may be used one of them may be a fluidized bed heat exchanger. And this kind of heat exchangers prevent the hydrate deposition and increase the internal heat transfer coefficient. So, fluidized bed do not allow the hydrate solid hydrate to remain inside the particular chamber.

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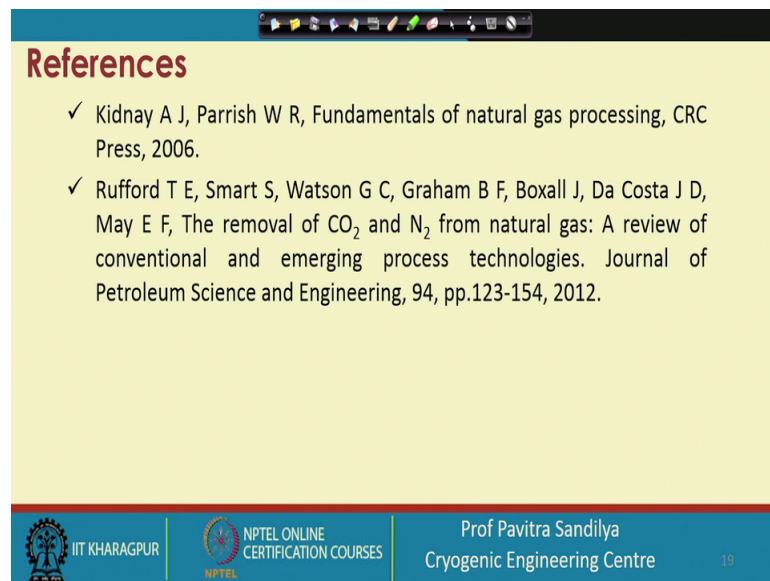


And here is a typical flow diagram for this hydrate formation that here we find we have the feed gas. And in this particular chamber we are having the hydrate formation and we find that if carbon dioxide some hydrates than the, but this outgoing gas will be richer in nitrogen.

And then the this particular thing will be richer in methane and this will be going to a some pump and it will go through this hydrate melter. And it will be taken to to this particular chamber where we shall be separating of the water and the water gets; that means, we are basically heating up this melting means we are heating up the hydrates.

And to separate out the water from the methane and in this exit gas; we are having the the methane rich exit gas. Whereas, the water comes down and is recycled to this particular hydrate forming chamber; that means, in this particular system; we are first forming the hydrate and then next time what we are doing? We are recovering the water and sending it back to the hydrate column and this recycling is enabling us to reduce the use of the fresh water; we are able to recycle these things and here are some of the references which we have refer to to get more information on this particular topic

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**References**

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Thank you.