

Technologies for Clean and Renewable Energy Production
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Lecture - 23
Syngas to Liquid Fuel Production

Hi friends, now we will discuss on the topic syngas to liquid fuel production. So in the previous class, we have discussed how the syngas can be produced from the natural gas and now we are going to discuss how this syngas will be converted to liquid fuels.

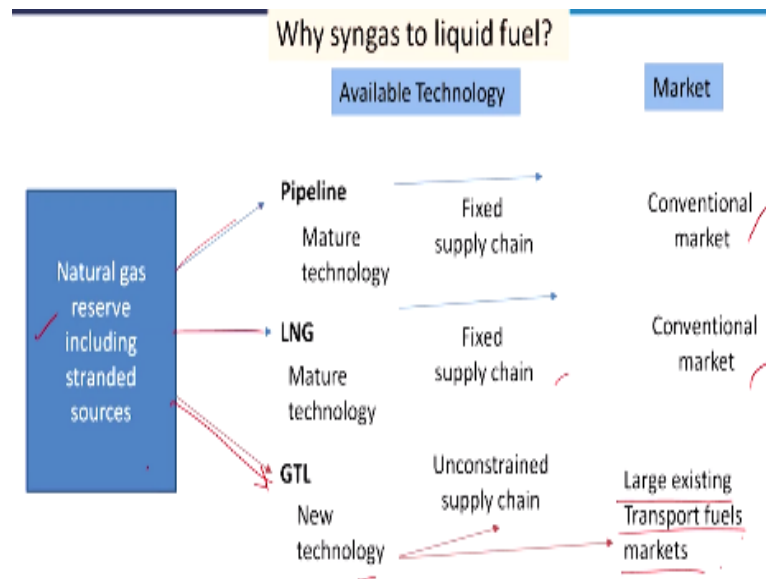
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Contents

- Why syngas to liquid fuel?
- Some important routes for liquid fuel production from syngas
 - F.T synthesis
 - Methanol synthesis
 - DME synthesis

So the contents of this class is why syngas to liquid fuel and then some important routes for liquid fuel production from syngas. So, why syngas to liquid fuel? Already we have discussed that if we convert syngas to liquid fuel, then we will be getting more market, we will be getting the value-added products, different types of chemicals or some liquid fuels. So that is the major features of this liquid fuel conversion.

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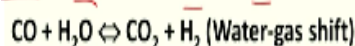
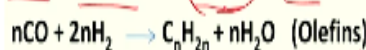
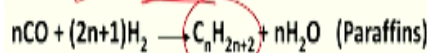
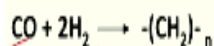
Now we see natural gas which is available in nature, so from this reserve, it can go through the pipeline and then it can be used in different application, particularly for heat application, say it go to conventional market or it can be liquefied. So liquefied natural gas, then also we have some supply chain arrangement already existing and then it will go into conventional market. So these are the 2 conventional routes, but if you go through this third one route that is the GTL route, then this is a new technology.

Here we get some large existing transport fuels, market, we have good market and can get chemicals also. So that is the advantage and that is why people are trying to convert it into liquid fuels. Another is natural gas has low energy density, but if it is converted to liquid fuels, energy density will be increased, so application of these in transport fuel will be easier than the natural gas.

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Reactions

The syngas is converted to wax, naphtha and diesel, which are followed by upgradation. The wax is hydrocracked to diesel and other products. Main reactions are:



Overall reaction is strongly exothermic

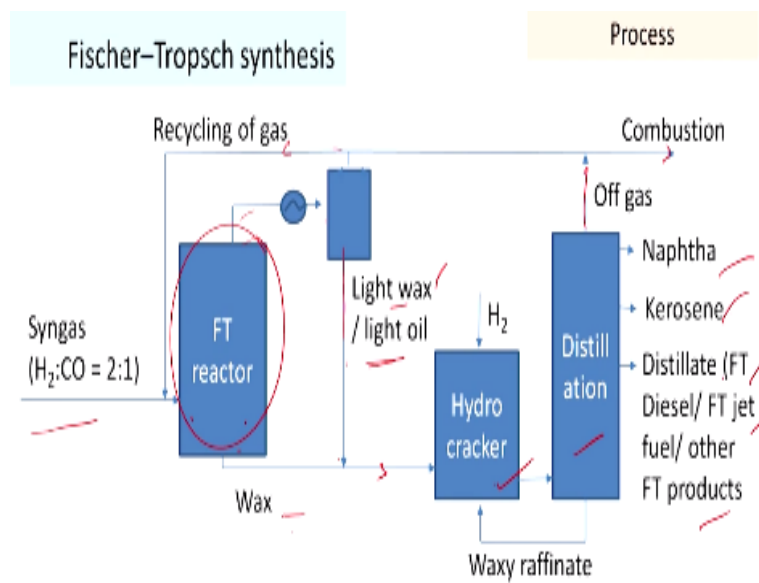
$$(\Delta H = -180 \text{ kJ/mol})$$

Now we will see different methods which are used for this syngas to liquid fuel conversion. So, one is Fischer-Tropsch synthesis. So in Fischer-Tropsch synthesis, syngas is converted to liquid fuels that is called say diesel, petrol, kerosene, etc. So what happens in this case? At first, we get wax, then wax is hydrocracked to get different products of it after fractionation. So the basic reaction so you can see here $\text{CO} + \text{H}_2$ we have in the syngas so that will produce the hydrocarbon chain as mentioned here CH_{2n} .

So this hydrocarbon chain we can get or $n\text{CO} + (2n+1)\text{H}_2$, this reaction can take place $\text{C}_n\text{H}_{2n+2} + n\text{H}_2\text{O}$. So we are getting paraffin type of compounds. Again same other reaction can take place $n\text{CO} + 2n\text{H}_2$, so $\text{C}_n\text{H}_{2n} + n\text{H}_2\text{O}$, olefin type of compounds you may get. Again $\text{CO} + \text{H}_2\text{O} \rightarrow \text{CO}_2 + \text{H}_2$, water-gas shift reaction can also take place. So overall reaction is strongly exothermic, -180 kilojoule/mol in these reactions. So we are getting basically hydrocarbons or paraffin and olefins basically.

So once the paraffins are produced and carbon number is, if this n number, higher, then we will be getting wax. So that wax is the major product by this fast type of this FT synthesis, then that will be converted to different liquid.

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So if you see the flow sheet, then we are having the syngas, so 2:1 hydrogen is to CO ratio, then it is coming to FT reactor, then FT reactor will basically give us olefins and paraffin type of compounds, so higher carbon paraffins means wax. So we will be having wax here or we may get some oil, light oil, and light wax will also get. So it will be gas phase, it is coming here, so it is going out as a vapor, and then it is coming as gas and vapor.

So gas is recycled and the condensed part is coming out that is we are talking about light oil and light wax and this is wax from the bottom of the reactor we are getting. So this light wax and heavy wax, these 2 wax will be hydrocracked here. So after hydrocracking, there will be the conversions of the high molecular weight paraffins to low molecular weight paraffins and then we will get the distillation and we will get different fractions.

So, we will get off gas that can be combustion as shown and then naphtha, we can get kerosene, we can get distillate, diesel FT fuel, other FT products. So that way, we can get the liquid fuels from the natural gas. Now these reactions at what part we are taking the reactions and what type of catalyst we can use that will influence the distributions of these different products and that part will go to discuss now.

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Fischer-Tropsch synthesis		Process conditions and catalysts
Operating conditions	Values	
H ₂ /CO ratio	2-2.2	
Pressure	15-30 bar	
Temperature	High temperature 325-370 °C Low temperature 220-270 °C	
GHSV	700 h ⁻¹	
Catalysts	<ul style="list-style-type: none"> Fe based (fuel flexible) Co based (suitable for high H₂/CO ratio; preferable for natural gas based syngas) ZSM-5 supported bimetallic FT catalysts for gasoline synthesis 	

So here we see the process conditions and catalyst. So H₂/CO ratio is 2-2.2 and then pressure is 15-30 bar and temperature as we mentioned there are 2 temperature range has been reported, that is 325-370 degrees centigrade high temperature and low temperature 220-270 degree centigrade. Obviously, we will see the variations in the product quality by the application of different temperature range and GHSV, gas hourly space velocity, is 700 per hour.

The catalyst basically has been used is iron based, cobalt based, and ZSM-5 supported bimetallic FT catalyst for gasoline synthesis. So this Fe based, iron based, catalyst are fuel flexible, but Co based catalyst suitable for high hydrogen/CO ratio and preferable for natural gas based syngas. So we are talking about natural gas, so CO will be preferred for this case.

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Fischer-Tropsch synthesis		Performance
Industrial F-T plant performance data: Fischer-Tropsch synthesis plant may be operated in both high-temperature regime (300-350°C) and low-temperature regime (220-270°C) and with Fe or Co based catalysts.		
Typical product distribution for High Temperature F-T Synthesis	Typical product distribution for low Temperature F-T Synthesis	
C ₅ +: 50-80 wt%	C ₅ +: 20-30 wt%	
Low wax: 4.0 wt%	wax: 50 wt%	
Gasoline/diesel ratio: 2:1	Gasoline/diesel ratio: 1:2	
Cetane number: 50-60	Cetane number : 80	

As we mentioned, we have 2 temperature range, one is 300-350 and another is 220-270 degrees centigrade and under these 2 different operations, we will see the distributions of the product. So here high temperature range is 300-350 degrees centigrade, we are getting C_5^+ is equal to 50-80% and here we are getting C_5^+ 20-30%. So low wax we are getting, high temperature, lower percentage of low wax, and here we are getting 50% of wax. So wax we are getting higher when the temperature is less.

Gasoline to diesel ratio at high temperature we are getting more gasoline, at low temperature we are getting more diesel. At high temperature, we are getting cetane number 50-60, low temperature we are getting cetane number 80. So at low temperature, we are getting more diesel with more cetane number. So depending upon the need in the market, we can choose what type of FT synthesis reaction we will prefer, at low temperature or high temperature.

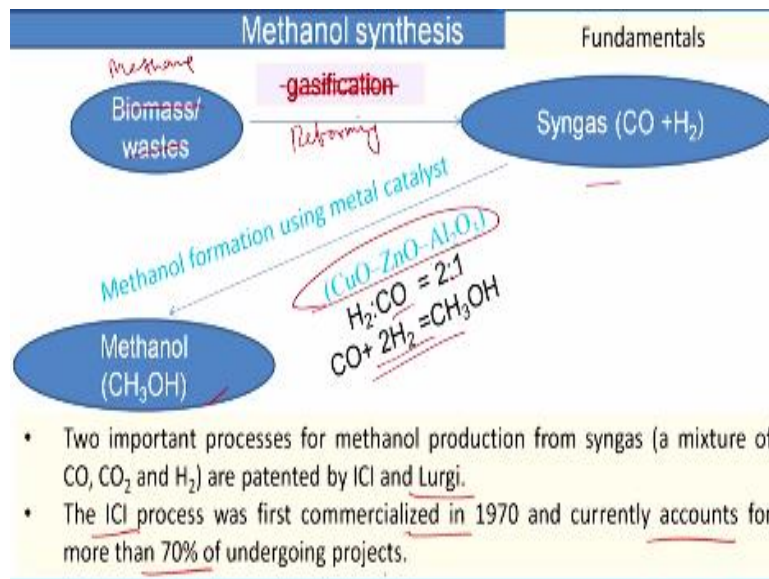
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Fischer-Tropsch synthesis				Commercial GTL Plants	
Plant	Feed for syngas	Capacity	Catalyst	Technology	Year
GTL Plant at N.W. Australia	-	10000 bpd lube oils and chemical	-	-	-
Pearl GTL Project, Qatar	Natural gas	140000 bbl/d	-	Shell	2006, Project
Sannizaro Refinery, Italy	Natural gas	20 bpd paraffin, upgraded to diesel	Proprietary catalyst	Axens with Eni & ISP, Gasel™ Technology	2001-2006
Sasol Plants (I, II & III), S. Africa	Natural gas	-	-	-	1990
Mossas Plant, South Africa	-	-	Iron	-	1992
Bintulu Plant, Malaysia	-	12000 bbl/d of kerosene & gasoline	Proprietary catalyst	Shell	1993

Now we will show some commercial plant available in the world for this liquid fuel production from the natural gas. So one is Australia here, then Qatar, Italy, South Africa and then Malaysia. So here some plants are already available on the basis of natural gas and these are the capacity. So we see here these are very big capacity also and with it, they have used proprietary catalyst and some iron based and proprietary catalyst not shown here.

The technology licensors are Shell and Axens with Eni and ISP and Gasel™ technology is also used some cases. So these are the technology licensors and we also see that the plants are not very old, it is started in 90s and 2006 one like this

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Now we are coming to methanol synthesis. So methanol can be produced from syngas. So how we will do it, so this is our biomass waste to syngas, but in our case, this is methane, reforming, then it will give us syngas. So then that syngas which we are getting that will be converted to methanol. So what is the condition, we need one catalyst, that is copper based catalyst has been used widely and copper zinc oxide alumina and then H₂:CO ratio 2:1 and this is the reactions. So that way, we can produce methanol.

Overall reactions very simple we have mentioned here, but this is not very simple because it is gas phase, gas and solid phase reaction. So I will discuss more. Then for this conversion, 2 technology licensors are capturing the market basically. So one is ICI technology and other is Lurgi technology. So this ICI process was first commercialized in 1970 and currently accounts for more than 70% of undergoing projects. So, this ICI process is having more application.

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Methanol synthesis
Conventional Methanol Technology

- Methanol synthesis from carbon oxides and hydrogen is usually achieved over copper and zinc oxides catalysts ($\text{CuO-ZnO-Al}_2\text{O}_3$) according to the following main reactions:

$\text{CO} + 2\text{H}_2 \leftrightarrow \text{CH}_3\text{OH}$
 $\text{CO}_2 + \text{H}_2 \leftrightarrow \text{CO} + \text{H}_2\text{O}$
 $\text{CO}_2 + 3\text{H}_2 \leftrightarrow \text{CH}_3\text{OH} + \text{H}_2\text{O}$

$\Delta H_{R, 298\text{ K}}^\circ = -90,550 \frac{\text{J}}{\text{mol}}$
 $\Delta H_{R, 298\text{ K}}^\circ = +41,120 \frac{\text{J}}{\text{mol}}$
 $\Delta H_{R, 298\text{ K}}^\circ = -49,430 \frac{\text{J}}{\text{mol}}$

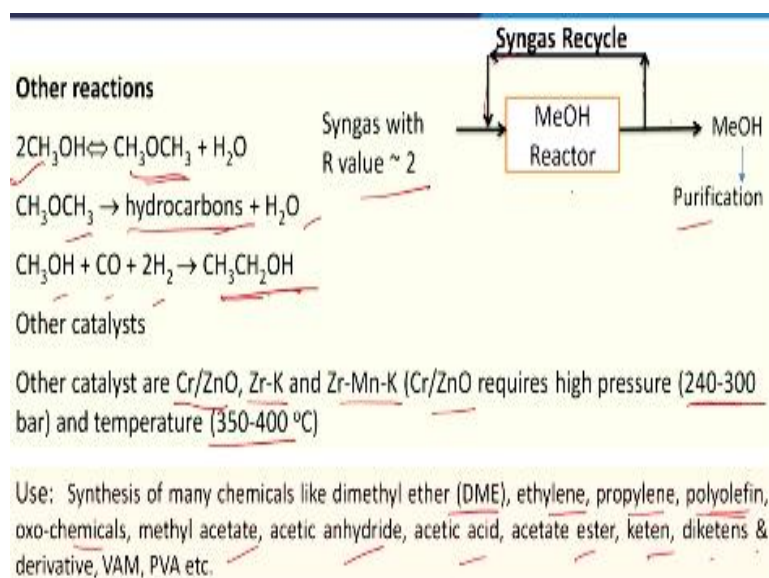
$\text{H}_2:\text{CO} = 2$
 $\text{R} = \frac{\text{H}_2 - \text{CO}}{\text{CO} + \text{CO}_2}$
- Methanol synthesis is exothermic reaction and favoured at high pressure and low temperature. Syngas feed is characterized by R-value $[(\text{H}_2 - \text{CO}_2)/(\text{CO} + \text{CO}_2)]$, the desirable R-value is around 2. Due to equilibrium constraint, per pass CO conversion is limited to around 25 percent.
- The process operates at 220 to 250 °C and 5 to 8 MPa pressure and uses a series of catalytic adiabatic reactor beds

Now we will see what are the reactions which take place during this methanol synthesis? So actually we have seen that CO and H₂ we have, so it is giving CH₃OH and we need some carbon dioxide for the initiation of the methanol reactions and so that CO₂+H₂ ->CO+H₂O and it is believed that CO is first converted to CO₂ and then CO₂ reacts with CO and H₂ and then it gives methanol. So the CO₂+ this H₂, this is the major reactions for methanol synthesis.

So from these different reactions, we have different ΔH value as mentioned here, somewhere we are getting exothermic, somewhere we are getting endothermic. So the one important condition or pre-requirement to get required conversion syngas to methanol, the R-value that is described as H₂:CO ratio that is around equal to 2, it is used for this application, but here later another factor has been developed because of this complex reaction scenario, that is what is R is equal to it is given here, H₂-CO₂/CO+CO₂.

So this what is the concentration of these 3 gases that will give the R-value as per this expression. So R-value is basically around 2, when we maintain it at around 2, we get suitable conversions of the syngas to methanol. As it is a solid-gas phase reaction in the conventional reactors, so one pass conversions of CO is around 25%, so that is why we need a very big reactor for the conversion of syngas to methanol. The process operates at 220-250 degrees centigrade and 5 to 8 megapascal pressure and uses a series of catalytic adiabatic reactor beds.

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So this is the important features of the methanol synthesis reactions. So apart from those major reactions, there are some other reactions that take place. As you see here, methanol is converted to CH_3OCH_3 , dimethyl ether, and then dimethyl ether to hydrocarbons and $+\text{H}_2\text{O}$ and you methanol $+\text{CO}+2\text{H}_2\text{O}$ that can also give us $\text{CH}_3\text{CH}_2\text{OH}$. So what we are getting, some side reactions are going on in this reactor that produces hydrocarbons, higher alcohols, even some amount of ether.

So these are the other reactions which can take place. So we can get syngas R-value around 2, so methanol reactors, we can get the unconverted syngas recycling and then methanol purifications. So this is the concept of methanol production and the catalyst basically copper and zinc oxide based catalyst and other catalysts have been used of chromium zinc oxide, zirconium potassium, zirconium manganese potassium, and zirconium zinc oxide on high pressure 240-300 bar, so this is not that efficient one because high pressure and high temperature is required.

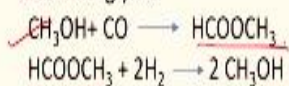
So once we get the methanol, so that can be used as a building block for different types of chemicals. Some of the chemicals which you can get as mentioned here we can get dimethyl ether, we can get ethylene, we can get propylene, we can get polyolefin, we can get oxo-chemicals, methyl acetate, acetic anhydride, acetic acid, acetate ester, keten, diketens, etc. and many more.

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Low temperature low pressure MeOH synthesis (Homogeneous phase reaction)

Two processes have been proposed for this method:

- Brookhaven National Laboratory (BNL) method
 - It employs a homogeneous Ni catalyst and alkoxide in an organic solvent (triethylene glycol dimethyl ether, i.e., triglyme)
- Methyl formate (MF) formation method
 - Employs a mixture of copper-based oxide and alkoxide as a catalyst in organic solvent triglyme



Both processes are operated at around 100 °C, where high equilibrium conversion of carbon monoxide to methanol is expected. Pressure is around 20-25 bar.

So conventionally, methanol is produced in a gas-solid phase reactor and heterogeneous catalysts are used and we have already seen that 25% conversion is possible and the catalyst requires high purity of the syngas. If small amount of sulphur is present, then the catalyst life reduces and it harms the whole process. So to eliminate those limitations, the low temperature low pressure methanol synthesis methods are being developed and in this case, we use some homogeneous phase reactions and homogeneous catalysts are used.

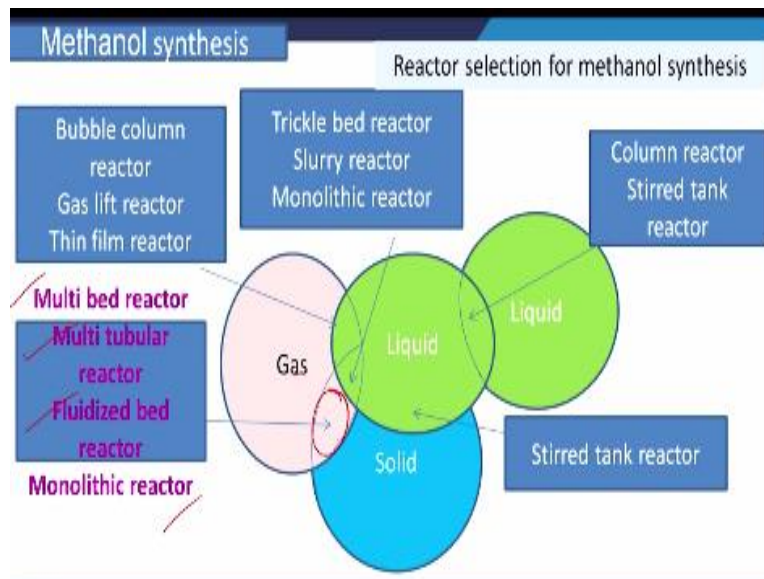
Some examples are Brookhaven National Laboratory, BNL, method. So they have a homogeneous nickel catalyst and alkoxide in an organic solvent that is triethylene glycol dimethyl ether, triglyme, so this organic solvent is used where nickel catalyst and alkoxides are mixed. Then in this liquid phase, syngas is passed through it and reaction takes place. Another is methyl formate formation method. So this employs a mixture of copper-based oxide and alkoxide as a catalyst.

So one is nickel-based catalyst, another is copper-based catalyst, and then alkoxide and this triglyme media solvent that people have used and studied the conversion of syngas to methanol. Basic reaction has been reported as $\text{CH}_3\text{OH} + \text{CO}$, HCOOCH_3 particularly for methyl formate process, so we are getting methyl formate, and then methyl formate is further converted to methanol okay.

So both these processes we see here, this requires around 100 degrees centigrade and it requires 20-25 bar, unlike say 60-80 or 90 bar or somewhere 200 bar, we are getting here with 20-25 bar and temperature is also less 100 degree centigrade. So, now it has been

reported that if we can use some nano-material based catalyst, then this performance will can be further increased, but this is under development stage and not in commercial scale.

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Now we will see how we will select the reactor type, what will be the type of reactor for the methanol synthesis? So this is the thumb rule we can say that the reactor selection for methanol synthesis we have given here say we have liquid-liquid reactions may take place, liquid-solid reaction may take place, liquid gas solid reaction may take place, gas liquid solid reaction can take place.

So different types of phases may be available during the reactor and depending upon that, we can select a particular type of reactor for that too far from that specific reaction. In our case, we have syngas that is $\text{CO} + \text{H}_2$ in gas phase and then solid catalyst. So we need gas and solid, so this is our domain, we have to choose, so for this application you get multi bed reactor, multi tubular reactor, fluidized bed reactor, and monolithic reactor.

So these reactors are more suitable for the conversions of syngas to methanol. What we have discussed, there is a multi tubular reactor that is used commercially in most of the technology available in market.

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Methanol synthesis

Conventional Methanol Technology

- Generally, a multi-tubular packed bed reactor with recycle stream is employed in methanol synthesis.
- In the typical plant operation, the catalyst lifetime is about 2 years. However, the catalyst is highly sensitive to sulphur poisoning. Therefore, sulphur level in feed gas needs to be reduced to less than 0.5 ppm.
- Catalyst deactivation also occurs due to thermal sintering of catalyst. Above 300 °C, CuO starts to crystallize which reduces the activity of catalyst.
- Plant economy is the function of operating temperature, pressure and recycle ratio.
- CO₂ is considered as carbon source for methanol rather than CO. CO is interconverted to CO₂ through water gas shift reaction. Also, 5-8% of CO₂ in syngas feed is required to initiate the methanol synthesis reaction.
- Temperature of reactor is controlled by controlling steam pressure through shell side.

We see the typical plant operation, the catalyst lifetime is about 2 years, but if sulphur is present, then it reduces. So sulphur condition, sulphur in the syngas should be less than 0.5 ppm. Catalyst deactivation also occurs due to thermal sintering of catalyst. Above 300 degree centigrade, copper oxide starts to crystallize which reduces the activity of catalyst. Then plant economy is the function of operating temperature, pressure, and recycle ratio.

As we have discussed, the carbon dioxide is required for the reactions and 5-8% of carbon dioxide in syngas feed is required to initiate the methanol synthesis reactions. The temperature of the reactor is controlled by controlling steam pressure through shell side.

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Methanol synthesis

Reaction Mechanism

- Froment proposed a redox type mechanism along with water shift reaction. Both reactions proceed on the copper phase of the catalyst. The role of ZnO is limited to structural promotion, at least under the typical industrial conditions.

$$\text{CO} + \text{H}_2\text{O} \leftrightarrow \text{CO}_2 + \text{H}_2 \leftrightarrow \text{CH}_3\text{OH} + \text{H}_2\text{O}$$

Reaction scheme for the synthesis of methanol and the water gas shift reaction

We see the reaction mechanism. So overall the reactions although we have CO+H₂O, it is giving up CO₂+H₂ and then CH₃OH. So carbon monoxide is converted to CO₂ and then it is

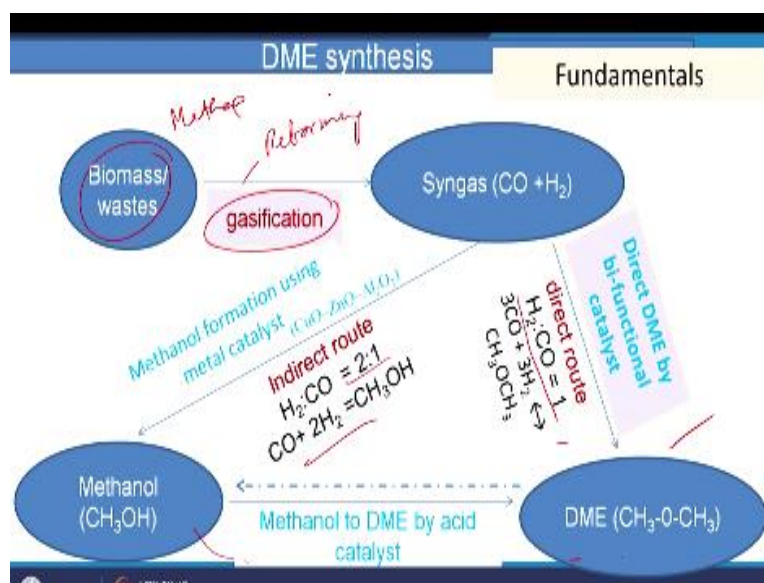
giving us methanol, this is the overall reaction, but how it happens, this is not very so simple. Then Froment proposed a redox type of mechanism. So here carbon dioxide, so what happens in this case?

So you are using your syngas and it is going through the catalyst bed, so diffusion of the gas molecules to the pores is the first step, then the active sites are there in the catalyst, so reactions of the active site takes place. So when carbon dioxide it is coming with this reactor site say solid s so that is it is giving us $O_2 + Os$ solid and then CO or it can also give this Os , one Os and another s , carbon dioxide can also mix with these and gives us $CO_3 2s$, two sides commonly it gives $CO_3.2s$.

Then $CO_3.2s$ some ages may combine and give this one, further this can combine with another s and then it can give this one. So that way, different types of products, intermediate products are formed. Here also, we can get Os which we are getting that can react with Hs another site containing hydrogen so that can give us this one, similarly this, this one, so this ultimately we are getting H_2O , we are ultimately getting CH_3OH and here hydrogen is added, CO_2 and hydrogen that we are talking about CO_2 and hydrogen.

So this hydrogen is converted to $2Hs$, so this is the source for Hs and this is the source of Hs . So this is the scheme through which the methanol and water is formed. This is proposed by Froment and they have modeled the reaction.

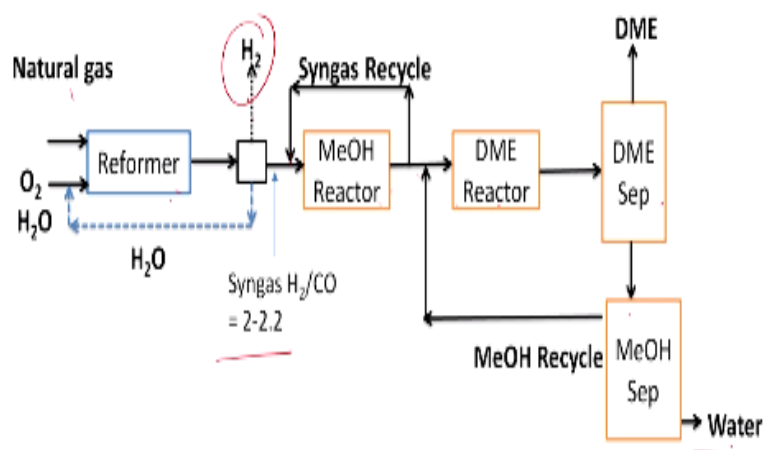
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Now coming to DME synthesis. So DME synthesis, we can get here as we have seen that methanol to DME, just dehydration reaction is required, so we can get the methanol first from the syngas, then dehydration, will be using some special catalyst, and after dehydration, we will get the DME or direct from syngas to DME is also possible using another type of catalyst, bi-functional catalyst we can do it, but here basics will be we are having a biomass waste at this zone, but we can use methane also.

Then gasification will be replaced by reforming and then we will get syngas and this will be the reactions, already we have discussed this one and this is methanol, this is dehydration and DME or this is direct route also, but here we see H_2/CO requirement is 1:1, but here we need 2:1 for methanol, then further dehydration. So, this is the difference between the H_2/CO requirements for these two routes.

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This is your flow sheet say natural gas, it will go to reformer, so if it is steam use of reforming, then we can get more hydrogen, hydrogen can be separated and 1:1 H_2/CO requirement for direct method and 2:1 for methanol synthesis route, so that is 2 to 2.5 is maintained here, rest hydrogen is recovered, then it is going to methanol, then methanol unconverted syngas, then it is dehydrated.

For dehydration, it is going to DME reactor and after dehydration, we will get DME, DME will be separated, and again if unconverted methanol that will be recycled back here for the further DME conversion and here we will be getting the water. So this is the flow sheet through which the DME can be produced from the natural gas.

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DME synthesis

Reactions and catalysts

using dehydration catalyst like alumina along with the Cu/Zn /Al based catalysts

Properties

DME has low auto-ignition temperature, very high cetane number, high oxygen content, very low particulate emissions.

Use

DME is suitable as source of hydrogen for Fuel Cells. It can also be used as additive to bio-fuels (methanol) to improve their ignition characteristics. LPG substitute, diesel engine.

Technology licensors

Chevron, Haldor Topsoe, TOTAL, NKK, Itochu, Mitsubishi and others are offering their technology for new DME plants

So DME synthesis, we see reactions and catalyst. So using dehydration catalyst like alumina along with copper, zinc, and aluminum based catalyst we can get DME from the methanol. If we get DME, then it has low ignition temperature, very high cetane number, high oxygen content, very low particulate emissions, that is the advantage of DME. It is suitable as source of hydrogen for fuel cells.

It can also be used as additive to bio fuels to improve their ignition characteristics, LPG substitutes, and diesel engine, it has versatile application. Then these are the technology licensors for DME that is Chevron, Haldor Topsoe, TOTAL, NKK, Itochu, Mitsubishi etc.

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DME synthesis

Commercial plants

- China's current annual output of DME is 120,000 tons.
- It plans to produce 20 million tonnes of DME based on coal feedstock by 2020. Already on the roll is a 200,000 tonnes coal to DME plant at Shanghai being developed by XinAo group.
- Other countries which are taking strides in setting up DME plants are Japan, Iran, Russia and Qatar.

Now we will see some example of DME plants. So China is the leader of the DME synthesis and China's current annual output of DME is 120,000 tons. It plans to produce 20 million tons of DME based on coal feedstock by 2020 and already on the roll is 200,000 tons coal to DME plant at Shanghai, so coal to syngas and like this, so natural gas can also be processed like this to syngas, natural gas to syngas and then syngas to DME. Other countries which are taking strides in setting up DME plants are Japan, Iran, Russia, and Qatar.

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Issues with syngas utilization from stranded natural gas
<ul style="list-style-type: none">▪ Competitiveness in fuel market.▪ FT fuels/ Methanol/ DME can be competitive either by increasing the plant capacity or reducing heat loss by heat integration in the process.▪ Conventional GTL technology utilized by Shell and Sasol is only economic for plants producing <u>30,000 barrels per day</u> or more.
<ul style="list-style-type: none">▪ Stranded natural gas is available in remote places in lesser amount. Hence for its application through this route , compact reactors with heat integration are necessary.▪ Development of micro reactors and other compact reactor with heat integrations increases the possibility of this fuel production routes from stranded resources.

Note there are some issues with syngas utilization from stranded natural gas. So natural gas may be available in some remote area in less amount, in that case the technology should be different. So small scale reactors are basically needed for that application and it has been reported that the gas to liquid conversion processes can be economically feasible when the plant capacity is very high, that is 30,000 barrels per day or more, but these stranded natural gases will be having less reserve and it is in remote area, so we need to convert it at lesser amount, so that is why it requires some development in the reactor side.

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Small scale plants for fuel production from syngas	FT fuels
<ul style="list-style-type: none"> Recently, smaller scale GTL plants are designed to be economic at <u>1,500 b/d</u> to <u>15,000 b/d</u> by <u>Velocys</u>. Reactor is microchannel reactor Velocys' first commercial plant is now under construction in <u>Oklahoma City, OK</u>. The plant is a joint venture between Velocys, <u>Waste Management Inc</u>, <u>NRG Energy</u>, and <u>Ventech Engineers</u> Another plant in the planning stages is in <u>Ashtabula, Ohio</u> near <u>Lake Erie</u> using natural gas from the <u>Marcellus Shale</u>. Initial production will be <u>2,800 b/d</u> with expansion potential up to <u>10,000 b/d</u> as well as high-value solvents, <u>lubricants</u> and <u>waxes</u>. 	

<http://breakingenergy.com/2014/11/03/small-scale-gtl-could-be-the-next-big-thing/>

So small scale plants for fuel production from syngas is required and recently smaller scale GTL plants are designed to be economic at 1500 barrels per day to 15,000 barrels per day. So initially, it was reported 30,000 barrels per day will be economic, but due to the development in the reactor side, now it is possible to 1500 barrels per day to 15,000 barrels per day. The Velocys have reported it.

Then the Velocys' first commercial plant is now under constructions and the plant is jointly ventured between Velocys, Waste Management. Another plant in planning stage is Ashtabula, Ohio near Lake Erie using natural gas from the Marcellus Shale. So, initial productions will be 2,800 barrels per day.

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Small scale plants for fuel production from syngas	MeOH and DME
<ul style="list-style-type: none"> <u>Oberon fuel</u> has developed small scale MeOH plant, which can utilize syngas produced from natural gas as well as bio gas containing upto <u>50 % of CO₂</u>. Typical capacity of the plant using syngas derived from NG as well as biogas is <u>10000 gallons/day DME</u> Or <u>11,300 gallons/day methanol</u> Foot print of the plant is <u>40000 square feet</u>. Feedstock requirement is <u>12,40,000 standard cubic feet NG /day</u> Or <u>15,40,000 standard cubic feet biogas (72% CH₄ / 28% CO₂) per day</u> 	
<p>http://www.oberonfuels.com/products/production-units/</p>	

Then Oberon fuel has developed small scale methanol plant which can utilize syngas from natural gas as well as biogas containing 50% of carbon dioxide. Typical capacity of the plant using syngas derived from natural gas as well as biogas is 10,000 gallons for day DME or 11,300 gallons per day methanol. Footprint of the plant is 40,000 square feet. Feedstock required is 12,40,000 standard cubic feet natural gas per day, 15,40,000 standard cubic feet biogas per day.

So we have discussed on the processes how to convert liquid fuel from the syngas which can be derived from the natural gas, so up to this in this class. Thank you very much for your patience.