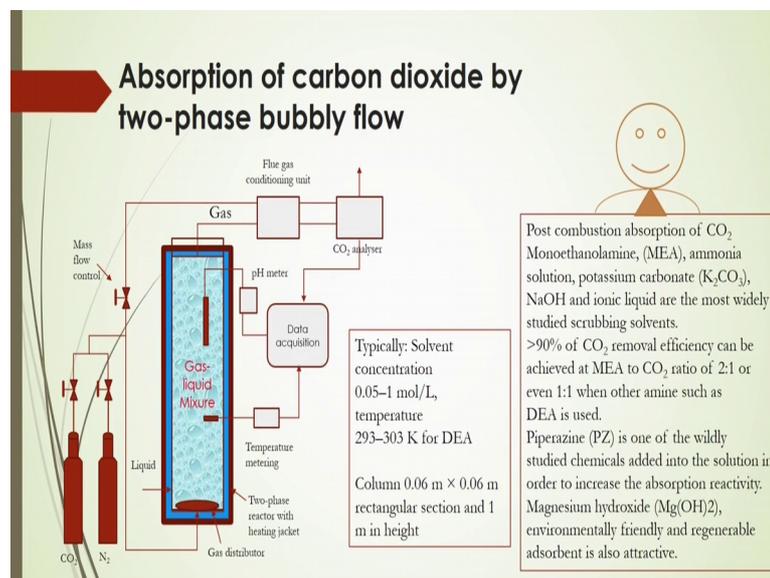


**Fluid Flow Operations**  
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**Module – 12**  
**Multiphase flow phenomena and its application-Part 4**  
**Lecture - 33**  
**Applications of multiphase flow**

Hello welcome to a massive open learning course on Fluid Flow Operations. So, this is the lecture number 33 as module 12. In this lecture, you will discuss more about that multiphase flow phenomena and its application and finally, we are having here the applications of multiphase flow phenomena. So, in this lecture, we will include the different applications of like gas liquid flow, gas solid flow and gas liquid solid flow, what are those applications that are being actually processed in industry for different yield.

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Now, let us consider the application for gas liquid flow. So, you know that there are several pattern of the multiphase flow. For the gas liquid flow, we got like bubbly flow slug flow, plug flow even stratified flow, wavy stratified flow, missed flow. So, one of the important flow pattern out of those flow patterns is called bubbly flow. Now what are the applications of that bubbly flow? Now if we consider the absorption of carbon

dioxide or any suppose pollutant gas in a atmosphere. So, how to actually reduce those gases by these two phase bubbly flow system?

Now, in this case let us consider that carbon dioxide which is most important aspects of environmental concerns that carbon dioxide to be removed anyway. So, based on that there are several actually process are being developed even going research on that particular field how to absorb that carbon dioxide or remove that carbon dioxide from the atmosphere. So, as a two phase bubbly flow systems how actually the process is being developed for the absorption of carbon dioxide in a liquid medium. So, in this case if we see here in the slides that that one actually process unit, it is called gas liquid unit and it is specially named as bubble column.

So, in this case how this bubble column bubbly flow systems are being used for absorption of carbon dioxide. Before going to talk about that, let us consider that carbon dioxide gas where actually can be absorbed. Of course, there will be some solubility of this carbon dioxide, optimal solubility of that carbon dioxide in a certain solution or solvent. So, this carbon dioxide gas as per solubility, you cannot absorb in simple water.

So, in this case, you can apply you can use different types of solvents to absorb this carbon dioxide. One of the important solvent, it is called monoethanolamine and some other solutions like ammonia solution, potassium carbonate, sodium hydroxide even nowadays ionic liquids also are the mostly widely studied scrubbing solvents for this carbon dioxide absorption.

Now, in that case you will see with those these solvents more than 90 percent of the carbon dioxide can be removed from the atmosphere. And, in a updated scale it is achieved at methyl ethyl amine and 2 carbon dioxide ratio up to 2 is to 1 or even 1 is to 1 when other amine such as diethylamine is used. And for that you know, some chemicals sometimes being added to increase the efficiency of the absorption. In that case piperazine denoted by PZ is one of the widely studied chemicals that is added into the solution in order to increase the absorption reactivity. Even nowadays magnesium hydroxide environmentally friendly and regenerable absorbent is also attractive to use for the absorption of carbon dioxide.

Now, how then the process is actually carried out for this carbon dioxide gas absorption into two phase bubbly flow system? So, let us consider here that column here and in this

column at the bottom side, you see one distributor gas distributor. It is sometimes called spurger and which is made of a plate of n number of holes which is specially arranged whether this triangular arranged or square arranged or sometimes some distributor will be used as a nozzle systems through which gas will be coming into the column and the gas will be dispersed as a dispersed phase of bubbles in the column.

So, in this case if we consider that from the cylinder of carbon dioxide and along with nitrogen ah; if it is coming into the what is that column through the spurger as a disperse phase of bubbles in a solvent. Now solvent may be that either of the solvent methyl ethyl acetone or ammonia solution or potassium carbonate. Here it is given in the list. So, either solution you can use. So, in the solution then carbon dioxide gas that is taken from the atmosphere by blower or by suppose carbon dioxide from the cylinder if you pass it what will happen through, the distributor it will be dispersed in the solvent as a disperse phase of bubbles.

Now, whenever the bubbles will be forming what you will observe ? You will see that there will be a formation of interface between this bubble and the liquid. So, through the interface, there will be a transfer of the carbon dioxide molecules to the liquid. So, here there is a mass transfer is called mass transfer whenever carbon dioxide gas molecules is transferring from the carbon dioxide gas bubbles to the liquid solvent. So, it is called mass transfer and there will be a interface and through which this some molecules will be cross and there will be a resistance of this interface. And upon considering all those resistances so, there will be a some coefficient or factor for which there will be a transfer of these molecules.

Now, what is that factors and this is called concentration gradient? You will see there will be a carbon dioxide gas molecules that will be in the surface the molecules surface of the bubbles or interfaces then what is the concentration there at the entire phase and what is the concentration of carbon dioxide molecules or gas in the bulk liquid or in the solvent initially. So, if there is a concentration gradient, you will see there will be a driving force of transferring of molecules from the carbon dioxide gas bubbles to the liquid.

And this concentration differences will give you the efficiency of that mass transfer a happen. Now in this case this transfer molecule number of molecules or you can say the flux of the molecules that is flux means per unit that is mole of that is gas or carbon

dioxide transfer to the liquid per unit time per unit cross sectional area; per unit area unit surface area. So, it will be called as a flux. So, that flux will be actually proportional to that driving force of concentration differences. So, and that proportionality constant; it is called overall mass transfer coefficient.

Now, this overall mass transfer coefficient actually based on the concentration in the bulk of the carbon dioxide bubble and the concentration at the, what is that bulk of the solvents. So, there will be a concentration differences at bulk of the carbon dioxide gas and to the bulk of the liquid. So, that is a overall mass transfer coefficient.

If suppose there is a concentration difference; if you are considering that from the interface to its equilibrium concentration of that carbon dioxide molecule, then you will get that individual mass transfer coefficient. Therefore, the gas and also for the liquid also there will be a increase of concentration of carbon dioxide from its beginning to the what is that final equilibrium stage. So, there will be a concentration gradient.

So, if you are considering that concentration differences in the gas as well as liquid individually, then you can obtain based on that theory of that is diffusion or mass transfer; then you will be having that what is that individual mass transfer coefficient. If you are considering that the bulk consideration of the carbon dioxide and bulk concentration in the liquid and the differences as if driving, then it will be called the overall mass transfer coefficient.

Now this overall mass transfer coefficient actually depends on the interfacial area. So, that is why carbon dioxide gas is being supplied through the liquid as a dispersed phase of bubbles where you can get more interfacial area. So, in this interfacial through this interfacial, there will be a mass transfer area.

So, this is the process by which you can absorb this carbon dioxide gas from the gas to the liquid gas mixes to the liquid. So, this is the mechanism here how this absorption of this carbon dioxide being happened. And if you are considering this is only physical absorption, then there will be no reaction, then in that case only simple carbon dioxide molecules will be the liquid or absorption.

Now, if there is a reaction that parallely the carbon dioxide with some other I mean solutions, there is reaction then what will be that may be sodium hydroxide sodium

carbonate will be formed or other carbonate form will form in the organic medium. Then you can say that that will be reactive mass transfer there. So, in that case also this interfacial area is very important. So, if you get these interfacial area, you are making the carbon dioxide gas bubbles to get more mass transfer there.

Now, question is that why then why should make this bubble without just you can supply the carbon dioxide gas in a column in the core region in the central region from the bottom. And if you supply the liquid from the top of the column that is called weighted column. You can get also surface area, but the surface area will not be enough to get the more mass transfer compared to this bubbling system. So, that is why the two phase bubbling system as here as an example of carbon dioxide gas absorption that is one important process.

Even some other several processes in bubbling systems also happen not only carbon dioxide gas absorption, you can apply it for other gas nox gas; also you can apply a based on this principle. So, this is one example that is for multiphase distillation. So, here generally in this system typically you can say that solvent concentration generally 0.0521 mole per liter is being considered and temperature is 293 to 303 K for DEA that is diethyl amine.

And column diameter typically you can also scale up this column diameter that it typical one that column diameter is 0.06 into 0.6 meter rectangular column. You can make or even cylindrical column also you can use. So, there are several studies there are several research components also here to increase that mass transfer efficiencies. Sometimes if you produce more finer bubbles of carbon dioxides, then you can get more surface area, then you can have more mass transfer efficiency there.

So, more carbon dioxide gas within a less time. So, what you have to do that you have to then analyze that how much carbon dioxide is being absorbed that is being done by that carbon dioxide gas analyzer by mass balance. And also if you analyze that liquid sample, how much carbon dioxide gas is dissolved in liquid that you can measure. And also some other parameters, what should be the flow rate of that carbon dioxide gas and if you change the gas flow rate, you will see your hold up of this gas will be more.

And then hold up of the gas will give you more surface area, because we have already studied in our previous lecture that interfacial areas specific interfacial area is depending

on the gas hold up and that is actually estimated by that  $6$  into  $\epsilon_g$  by diameter of the bubble there.

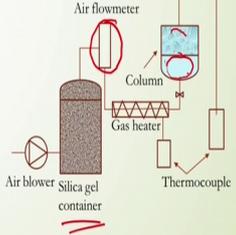
So, based on which we can say that if we produce more finer bubbles more interfacial area will be produced and in that case more mass transfer can be observed. So, one of the important variables here is gas flow rate. If you increase the gas flow rate, you can get more hold up even another important physical properties of this liquid like this. If you are using different type of solvent based on their physical properties, accordingly the gas hold up and mass transfer efficiency will come. Sometimes you know that if you change the pH of this solution may have sometimes effect on the absorption capacity.

So, this is one important. So, from the bottom you are supplying carbon dioxide and from the top carbon dioxide gas will be coming out and then it will be analyzed and carbon dioxide gas remaining carbon dioxide gas will be coming again to the atmosphere. Even do again gas of this carbon dioxide, then you can think reduce more carbon dioxide there. So, this is one process of application of these two phase bubbly process system.

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### Sterilization process by bubbling two-phase flow

- The process is based on a bubble column using the bubble coalescence inhibition phenomenon to produce high bubble densities.
- The column contained hot bubbles ranging in sizes from 1–3 mm which rapidly transfer heat to sterilize water contaminated with biological species at temperature, upto 250 °C.



Shahid (2015) Journal of Water Process Engineering, 8(2015) e1-e6.

Let consider another application of bubbling two phase flow. One of the important process like I have called sterilization process. So, in this case the process is generally based on a bubble column using the bubble coalescence inhibition phenomena to produce high bubble densities there. So, here you see that in this case, there will be a

high bubbled densities are produced and in this case the column will contain hot bubbles that will be ranging in sizes from 1 to 3 millimeter which rapidly transfer the heat at to sterilize water contaminated with biological species at temperature up to 250 degree centigrade.

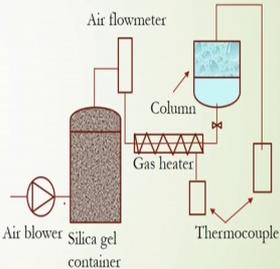
So, in this case what you are going to do that you are blowing air and that before going to that column formation of bubble what you have to do? You have to clean that air bubble is there any moisture content or not and to remove that moisture content, you are actually applying that silica gel. And after that through a rotameter that is air flow meter, it is called through a rotameter.

You have to pass that gas and then you are allowing that gas through a gas heater to heat up that gas at a certain temperature and that temperature it will be passed through the what is that column. And column and that is filled with what is that biological species reached water which will be removed by this sterilization process. Now, if you bubbling this hot air there, you will see there through the interface, there will be heat transfer and that heat transfer. Of course, will be useful or mainly actually governs this process of this sterilization. So, this is another one important process for this two phase bubbly flow system.

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### Desalination of sea water

- Desalination of sea water using the creation by evaporation mechanism.
- Evaporator (BCE) process with a high temperature gas (air) flowinlet dried air temperatures at more than 150 °C.
- A high surface area air/water interface is continuously produced by pumping air through a distributor into an open top glass column filled with solution to allow complete and efficient removal of water vapor.



The diagram illustrates the experimental setup for desalination. It starts with an air blower that pumps air into a silica gel container for drying. The dried air then flows through an air flowmeter to measure its rate. Next, the air passes through a gas heater to reach a high temperature. Finally, the hot air is bubbled through a column containing a solution. A thermocouple is used to monitor the temperature of the air as it exits the column.

Another important application of these two phase bubbly system is desalination of sea water. You see how to desaline this sea water, you have to remove the salt from this sea

water. So, what you have to do? You have to evaporate that water by bubbling systems. So, in this case, evaporator bubbling evaporation process with a high temperature gas air that is flow inlet dried at temperature at more than 150 degree centigrade that will be supplied through the liquid mediums.

So, that the liquid will be evaporated in a column and that evaporated vapor will be collected and condensed and it will be collected as a what is that liquid gas. So, in that case, you will see that sodium chloride solution or other salt; if it is there it will be actually thickened at the bottom of that column. Whereas, this moisture or water will be evaporated as this as a moisture and after then it will be condensed and it will be stored as a liquid there.

So, for this the bubbling process is efficient because in that case the more mass transfer will happen through the surface of this bubble just by what is that there will be inert mixing of the gas and liquid; there by this bubbling process and through the interface of this hot air bubbles, there will a efficient heat transfer there. So, based on these, they are desalination of the sea water being processed in industry.

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### Ammonia removal from wastewater by ozonation

- Ammonia is decomposed to  $N_2$  by ozonation in the presence of  $Br^-$ .
- The mechanism of break-point reaction of ammonia by hypobromite. The hypobromite can be continuously produced by ozonation of  $Br^-$  and  $Br^-$  can be utilized repeatedly.
- A pilot-scale bubble column can be constructed and used for continuous ammonia removal by ozonation in the presence of  $Br^-$ .

The diagram illustrates a pilot-scale bubble column system for ammonia removal. It consists of an ozone generator, a bubble column, a pH sensor, an  $NH_4^+-N$  monitor, an ozone destructor, and an ozone controller. Waste water enters the bubble column from the top, and NaOH is added. The column contains a pH sensor and an  $NH_4^+-N$  monitor. Exhaust gas from the top of the column goes to an ozone destructor, which is also connected to an ozone controller.

Now, ammonia removal from waste water by ozonation process, there are several applications of the waste water treatment by this two phase system by bubbling systems there. One of the important applications like here we can say that ammonia removal or what is that; arsenic removal or you can say dye removal by this ozonation process. Now

what is that? Whenever you are going to oxidized by the ozonation process of this ammonia contents inverter, what you have to do? You have to make ozone bubbles there and so that you can get more inter special area.

And then there will be a what is that reaction between these ammonia contents or oxidation of this ammonia contents. And it will be converted to the ozone derivative products or what is that other derivatives by this ozonation process. And in the case of ammonia removal; ammonia is decomposed to nitrogen by ozonation process in the presence of bromide.

Now, the mechanism of the break point reaction of this ammonia by hypo bromide actually is there and the hypo bromide can be continuously produced by ozonation of bromide. And bromide can then be actually utilized repeatedly for further ammonia decomposition. Now in this case, here see one pilot scale bubble column can be constructed and it can be used for continuous ammonia removal by ozonation in the presence of bromide.

So, here from the bottom here, ozonated you know ozone; ozone bubbles will be supplied and in the column there will be a ozone bubbles and that ozone bubbles by bubbling systems that there will be a reaction. And then you will get the derivative as well nitrogen here ammonia what is that to be decomposed into nitrogen and then it will be passing out and then unreacted ozone will be coming out from the reactor. It will be what is that destructed by ozone destructor and it will happen at a certain pH value and that you have to actually allow the sodium hydroxide there to control the pH there.

So, at a certain pH you can get the optimized value of this decomposition of the ammonia and generally the ammonias smell will be in the liquid. So, to remove that ammonia remove smell generally, this ozone gas is supplied there to get the advanced oxidation of this ozone to decompose this ammonia. Another example like suppose arsenic removal, what you have to do? You will see that in ground water, there are several regions in India even in other neighbor countries; the arsenic reach the ground water there.

Now, how to remove that arsenic by this two phase bubbly flow systems? In this case, generally ground water; the arsenic is stated as a arsenic three compounds. So, in that case you have to convert this arsenic 3 to arsenic 5 because the arsenic three cannot be

removed by any absorption process whereas, arsenic 5 is easier to absorb in certain absorbent. So, generally this arsenic 3 is initially converted to arsenic 5 by this ozonation process.

Now in that case, you have to supply the ozone bubbles to convert this arsenic 3 to arsenic 5 and whenever this arsenic 5 is being converted and it will be then absorbed into a absorption suitable absorbent. Then in this way you can remove the arsenic from the ground waters. So, this is also one example of these bubbling flow systems.

So, here the ozone gas to be supplied not only here simple gas cannot be possible to supply. So, you have to supply as a bubbling system. So, that is why bubbling bed or you can say that is two face bubbling or bubbly flow system that is applied for these particular processes there.

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### Decolorization of dye in textile wastewater

- Decolorization of wastewater containing direct dye (Sirius Blue SBRR) by ozonisation
- The decolorization process of the direct dye can be carried out by bubbling ozone at the bottom of a column reactor containing the dye solution at a suitable basic condition (e.g., pH 12).
- The dye concentration time data during decolorization can be analyzed spectrophotometrically.
- The dye named commercially Sirius Blue SBRR (Direct Blue 71)  $(C_{40}H_{23}N_7Na_4O_{13}S_4)$  are generally present in textile wastewater.
- The reduction of the absorbance of the direct dyestuff wastewater can be achieved 97.4% after 26 min of the reaction.

The diagram illustrates a vertical column reactor used for the decolorization of textile wastewater. At the top, 'Waste water' and 'NaOH' are introduced into the column. At the bottom, an 'Ozone generator' provides 'Ozone gas' which bubbles up through the liquid. A 'pH sensor' is positioned at the base of the column. 'Exhaust gas' exits from the top of the column, passing through an 'Ozone destructor'. A 'Hydrostatic pressure Sample for analysis' is drawn from the side of the column. Additionally, 'Ozone analysis by 2-5% KI solution' is shown as a separate analytical step.

Now, another example decolorization of the dye in textile waste eater, you will see decolorization of the waste water, that contains direct dye stuffs and you can remove that color that is sometimes it is called what is that Sirius Blue SBRR or other several dyes also there at different colors.

So, to remove that, you have to do this decolorization by ozonation process. Now in this case, if you colored dye is being processed by this ozone bubbles may be micro bubble systems even sometimes conventional bubbling systems. You will see after a certain time

whatever dye compound are there, it will be actually degraded and it will be converted to colorless.

And then you can say that the advanced oxidation of ozone by this bubbling system will be effective for this particular process. And it will happen for a particular pH value whether it will be acid or basic medium that is important to know generally decolorization of this dye process is being happened.

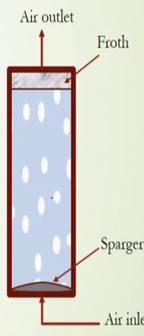
And, it optimize at basic medium around pH will be equals to 12. And the dye concentration time data during decolorization can be analyzed that is by spectrophotometrically and the dye named that is commercially Sirius Blue SBRR. That is direct blue 71. It is called and the chemical formula is given here in this slides generally present in textile waste water to. Now reduction of the absorbance of this direct dye stuff, waste water can be achieved around 97.4 percent after 26 minutes of the reaction with ozone.

So, that is one important application of this ozonation process that is called two phase system; two phase application. And another process it is called deinking process by two phase mixing. Sometimes you know that paper industry, they are removing that what is that ink from that waste paper. And then they are reprocessing it to make further paper there. So, in that case, recovered paper is generally disintegrated in water based solution and the principle chemicals here is generally being used in the pulp as a sodium hydroxide and hydrogen peroxide. There it will be gradient to actually advanced oxidation process.

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### De-inking process by two-phase mixing

- Recovered paper is disintegrated in water-based solution
- The principal chemicals generally used in the pulper are sodium hydroxide and hydrogen peroxide
- The pH adjustment to about 9–10 with NaOH to make pulp at a temperature 40–45 deg C
- Air is sparged into the reactors
- Liquid mixing time ( $t_m$ ) is an important qualitative index used frequently to represent overall mixing property in the reactors
- After specific times of flotation (10, 20, 30 min), the deinked pulp obtained from flotation step is carefully washed by tap water. The deinked pulp is then set to dry overnight after screening and pressing the final pulp by hand.
- An increase in brightness up to 5% and a decrease in number of ink spot up to 16% could be obtained by changing from high to low dilution ratio.



The diagram illustrates a vertical cylindrical reactor used for de-inking. At the bottom, there is an 'Air inlet' leading to a 'Sparger' which disperses air into the liquid pulp. The air bubbles rise through the liquid, creating 'Froth' at the top. An 'Air outlet' is located at the very top of the reactor, above the froth layer.

In this case, the pH adjustment to about nine to ten with sodium hydroxide to make pulp at a temperature of a 40 to 45 degree centigrade and this happen for this mixing process just by bubbling system and by air bubbling by air. So, air is dispersed into the reactors and in that case, liquid mixing time is one important factor to actually make it efficient process. And in that case how to actually calculate that mixing time that is generally by residence time distribution technique by which you can get how long actually the liquid will be reside inside the column that is important there. So, that will be denoted by the mixing time.

So, in that case one important that is qualitative index that is called mixing time frequently used to represent overall mixing property in the reactors. And after specific times of this what is that rotation of the paper in a column to remove that ink generally up to 30 minutes that the ink pulp obtained from floatation step is carefully washed by tap water there and the deinked pulp is then set to dry overnight after screening and processing the final pulp by hand.

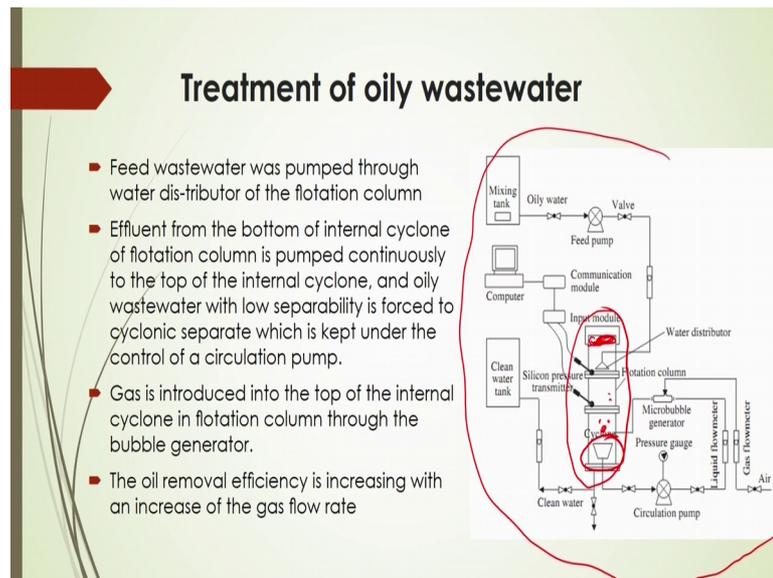
So, in that case you will see, after processing by this floatation techniques of this paper with a certain minute at a certain minute of that is 10, 20 or 30 minutes and then what is that you will see those pulp, the color of that pulp will be removing at a certain percentage. Now more efficient process of course, it will enhance that removal of color.

Now, an increase in brightness so, that is removal of colorness to 5 percent decrease in number of ink spot to up to 68 percent can be obtained by changing from a high to low dilution ratio. So, it is very important that how must dilution of this pulp, you are being used for this process because in the column; if you are using densed pulp.

So, in that case it is very difficult to actually float that pulp in the columns. So, it is generally being used as a diluted pulp. So, that that aeration process from the bottom that air will be supplied and in that case aeration process, will give you the better mixing and it may yield more than 60 percent or even better actually removal of ink or what is that getting more brightness of the paper it can happen.

So, this is one of the simplest way to actually process the what is that paper wasted paper to remove its color and getting its more brightness of this color there.

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And also another important application of these two phase fluid is called treatment of oily wastewater. Here you will see very interesting that sometimes wastewater contains, some oils that is used for certain operations like suppose grease or what is that for what is lubrication purposes some oils are being used in motor. Or even in industry there has huge amount of oil is waste is through a, what is that in a particular processes and it will be left in wastewater.

Now, how to recover all those oil? Now in that case waste water of that oily content was actually is pumped through water distributor in a floatation column. Here in this example and in that case this affluent with the oil wastewater is actually supplied from the top of the column and from the bottom.

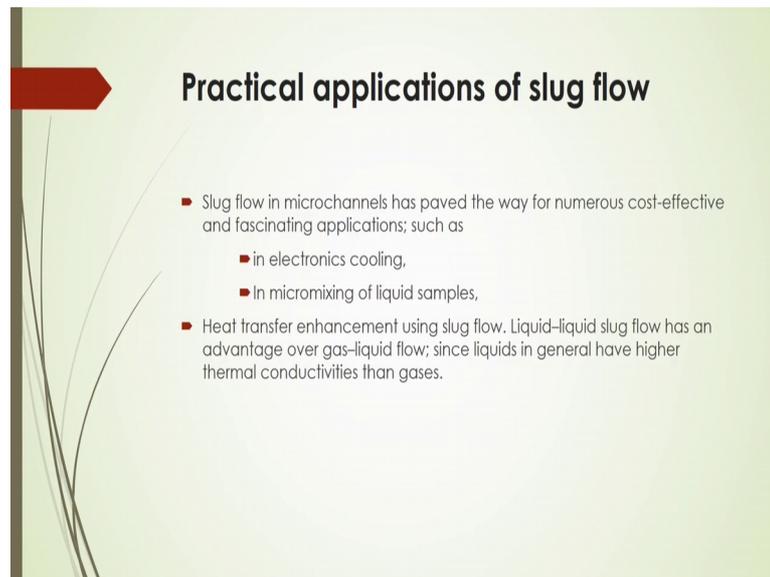
Through a cyclone systems gas is supplied and disperse phase of bubbles and whenever this oily wastewater is coming in contact with the gas, then you will see that at the surface of the bubbles this oil contents will be attaching. And it will be going up as a floating agents and then at the top, it will be dissolved and then the oil will be actually making a separate layer at surface top surface. And in this case, you have to use some frother also to get more oil recovery to gets its more efficient efficient process.

So, in that case, you have to select some frother and you can produce the bubbles in different way also not a cyclone systems, but other way also you can produce the bubble. Through a spurger also you can use some, but you have to use distributor in such a way that oil should not be clogged in the pores of the spurger.

So, anyway if you are making efficient spurger and it will be attached in the bottom part of the column and through the spurger if you are distributing gas from the bottom part, then as a disperse phase of bubbles will be coming up and from the top waste wastewater that is greased with oil and it will be coming downward and at the counter current operation during that the bubble surface will attach to that oil content and it will be separated at the top. And then finally, you can get how much soil is recovered, you can calculate based on the calculation of initial contents of the oil and final content whatever that is the solution.

So, based on which you will be able to calculate and this is the process is given in this diagram. And in this diagram you can actually study how actually the oil content can be removed efficiently by this spurging process of the bubble.

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**Practical applications of slug flow**

- Slug flow in microchannels has paved the way for numerous cost-effective and fascinating applications; such as
  - in electronics cooling,
  - in micromixing of liquid samples,
- Heat transfer enhancement using slug flow. Liquid-liquid slug flow has an advantage over gas-liquid flow; since liquids in general have higher thermal conductivities than gases.

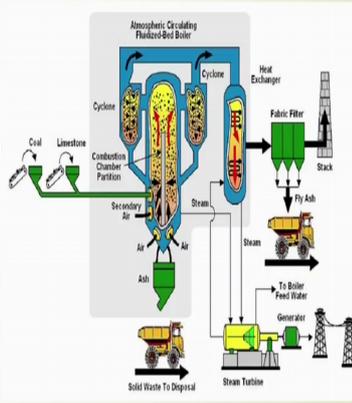
Now, practical applications of other slug flow like other flow pattern like slug flow if you are considering that nowadays slug flow in microchannels has paved the way for numerous cost effective. And fascinating applications such as in electronics cooling and micromixing of fluid samples even micro reactor sometimes this slug flows are being used there to actually have more efficient reaction and also yield of the reactions there.

And heat transfer enhancement also can be done by this slug flow system liquid slug flow has an advantage over gas liquid flow since liquids in general have higher thermal conductivities than gases. And also you will see for microchannel based heat transfer equipment are being developed nowadays based on the application of the slug flow or advantages of the slug flow in the microchannel system.

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### Application of Gas-solid flow

- Coal combustion for power generation
- The pulverized coal is generally blown through the burners into the combustion chamber where it is fired in suspension.
- Heat in the flue gas exiting the hot cyclone is recovered in a series of heat recovery sections of the boiler to produce steam.
- The superheated steam leaving the boiler then enters the steam turbine, which powers a generator to produce electricity



Another applications this gas solid flow system this is the heart of this chemical engineering process you can say there are several applications of the gas solid flow there. If we consider that there is a solid is just floating in a gaseous medium or flowing in a gaseous medium how then the solid particles will take part or gas solid flow will be actually used for a particular process to get certain a yield.

Nowadays whatever power we are actually having here as a what is that electric power that is actually how it is being processed and how it is actually produced and that depends on this you know that certain applications certain wok process and that process is generally gas solid flow.

Now, let us consider that it is called coal combustion actually power is produced by what is that combustion of coal. In that case, coal is binding in a system in a reactor in a or column just by fluidizing coal particles there and in that case whenever coal is burning, you will see several gases will be producing. And, also there will be a what is that heat generation or heat distribution will be there.

And upon that burning processes or producing gas flow and this will convert that several different other gaseous components which are being used. Nowadays you know that propylene propane even other products also can be obtained by this coal combustion and also this coal combustion is being done to produce the steam and by that steam, there

will be a what is that useful of this steam to steam turbine for generating this electric power.

Now, in this case generally pulverized coals is being used and it is being blown through the burners into a combustion chamber; here it is shown the picture. And where it is fired in suspension? This suspension means coal particles will be suspended in the hot or what is that yeah burnt gas there or you can say that hot air high that high temperature and then the heat in the flue gas that is exiting the hot cyclone is recovered in series of heat recoveries sections of the boiler to produce a steam.

So, in this case, you can say whenever you are burning the coal, there are several components of the flue gas that is coming together and that flue gas are. So, heated that if you supply through a what is that boiler sections, you will see that steam will be boiled and it will be generating that steam and that steam. It will be utilized to rotate that turbine to produce that electricity. So, that is why this is the main process here.

Now this coal combustion chamber, it is called fluidized based coal combustion bed. So, in this bed you will see whenever coal is burning, there are very several coal particles will be along with coming out with the flue gas. Now you have to separate that coal particles small coal particles and it can be separated by a cyclone separator. In the cyclone separator due to the centrifugal action that solid particles will be separated and it will be coming downward and may be used again in the combustion chamber. And after separating by this cyclone separator whenever gas is coming out from the top and it will be actually utilized in a boiler where the water or liquid will be boiled and steam will be generated and that steam will be used in a what is this steam turbine to generate this power.

Now, not only by producing this power is generated sometimes direct flue gas is being used to actually rotate that turbine to produce this power. And also another way that fluidizing or burning or combustion of this coal, you will see several different type of gaseous components will be coming out in the flue gas. Now, that will be separated and you can get different products of the gases and that gas to be actually upgraded into several commercial products. In that case, you may expect that you may get that what is that we are getting whatever we are getting propane propylene ethylene, ethyl chloride

even some other organic gases you can have from this coal combustions, then it will be actually upgraded by different other process there.

So, this is the one way of that producing the power as well as other valuable products of gases from this coal combustion. And this is basically a gas solid flow operation. Another important application of gas solid flow system, it is called vinyl chloride production. You know that maximum product for daily things that pipe even plastics goods.

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### Vinyl chloride production (Gas-solid operation)

- Direct or oxy chlorination of hydrocarbons is basically done for vinyl chloride monomer production. Almost 70% VCM production is done via direct chlorination of ethylene at low temperature in presence of iron chloride

$$C_2H_4 + Cl_2 \xrightarrow{FeCl_3} CH_2ClCH_2Cl$$

All are actually produced by this vinyl chloride polyethylene or other several monomers also. Now in this case direct or oxy chlorination of hydrocarbons is basically done for this production of vinyl chloride monomer and from this vinyl chloride monomer, you can get the polyethylene different types of products.

And then to produce this vinyl chloride monomer from the hydrocarbons may be liquid petroleum or may be from the coal also. You can get these hydrocarbons and from this hydrocarbons, you can produce this. What is the vinyl chloride monomer and how to do that? You have to do the oxidation process; now by chlorination. So, it is called oxy chlorination of hydrocarbon and it is generally done for vinyl chloride monomer production.

Now, in this case almost 70 percent of vinyl chloride monomer production can be done by a direct chlorination of ethylene at low temperature in presence of iron chloride. So, this is one important process of gas solid operations.

So, iron chloride is one catalyst particles. So, in this case ethylene gas and chlorine gas to be supplied at a bottom of the column in presence of what is that iron chloride and at a certain temperature and pressure. Then you can get what is that after oxy chlorination in the column in presence of gas solid, that is mixing at a certain temperature and pressure and then, you can get that vinyl chloride monomer. After that it will be separated or purified by different processes. So, this is one process of producing vinyl chloride production by gas solid operation.

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**Polymerization of Olefins**

Ethylene + Butene  
→ Polyethylene

75-100°C, 20 atm.

$H/L = 2.6 - 4.7$

Union Carbide Company

Process: Unipol

Chromium  
Titanium  
(Halo-oxides)  
Compounds  
on silica  
carrier

Ethylene  
&  
Co monomer (butene and higher)

6 times of  
minimum fluidized  
velocity of polyethylene  
particles.

granular  
polyethylene

Separator

Reactor

Compressor

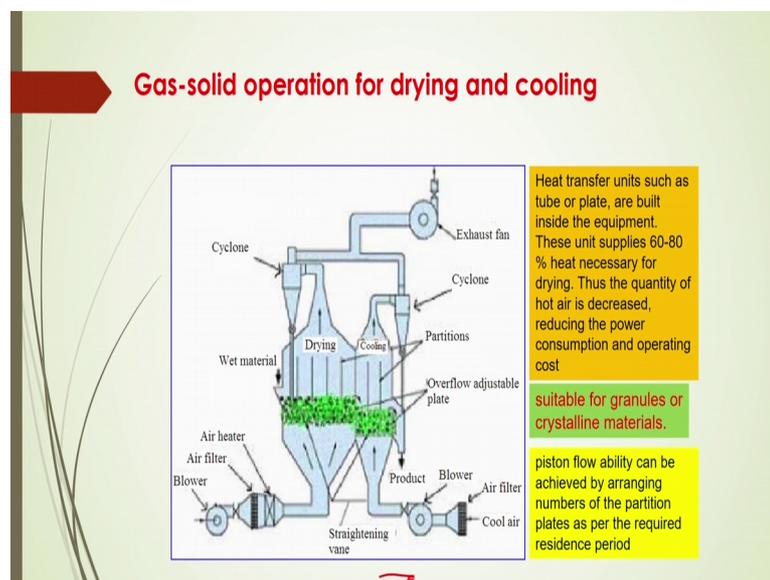
Cooler

Another important application polymerization of olefins also is important ah; in this case, polyethylene to be produced from the ethylene and butane gas. So, in this case, ethylene and butane both will be what is that supplied from the bottom of the bed that is fluidized bed at 70 to 100 degree centigrade. And at around 20 atmospheric pressure and with a certain presence of certain what is that catalyst particles like, you can use that chromium or titanium particles are there. In that case, in presence of this particles this mixture of ethylene and butane it will be fluidized. And in the fluidized column, then after processing you can get this what is that polyethylene and after that it will be separated

and granulated to a polyethylene. And then allowed or passes through further operations there.

So, in this case application is simply that gas and solid application generally in union carbide company. They are producing polyethylene based on this concept, this ethylene and butane is fluidized at this 75 to 100 degree centigrade 20 atmospheric pressure. And the column is designed at high to length ratio is 2.6 to 4.7. So, based on these principles of gas and solid operation, you can produce polyethylene.

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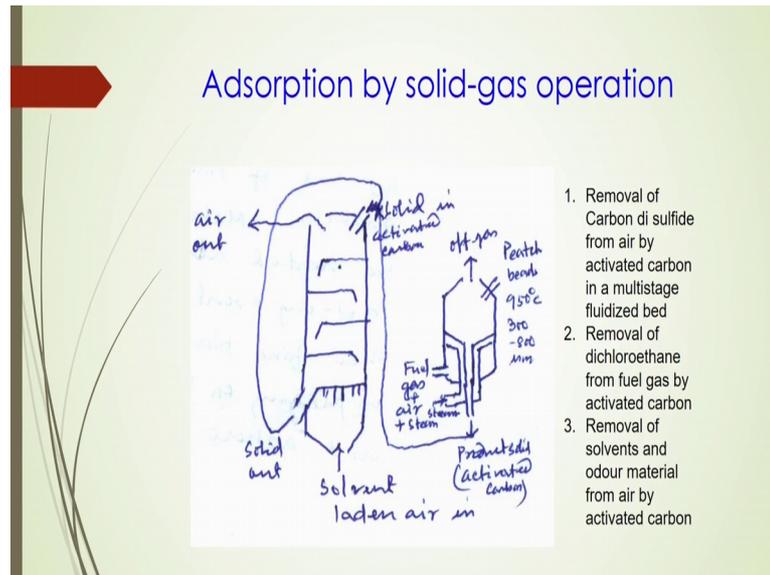


Now, another application, that is physical operation of gas solid system. Generally it is being used for drying and cooling. What is that for drying operation? What you have to do which solids to be actually placed in a what is that column and after allowing that how air from a blow air, it will be fluidized that bed and after certain times of at a particular temperature. You will see this wet solids or wet material will be dried at a certain time. So, just by evaporating that, what is that moisture from the wet material.

So, this is basically a physical process of gas solid operation and it would be fluidized in a column. And to unwanted solid particles which is coming out through the vapor, it will be separated by a cyclone separator and then solid particles will be used or recycled for further drying processes. So, this is another important process here. So, in this case heat transfer is basically main operation to get the efficient this (Refer Time: 45:46).

So, you have to study the heat transfer what are the heat transfer coefficient how the heat is being transferred, what would be the heat duty that everything should be known for you. Generally that further actually course for heat transfer operations. This is the example just example what are the different processes of different multiphase flow systems.

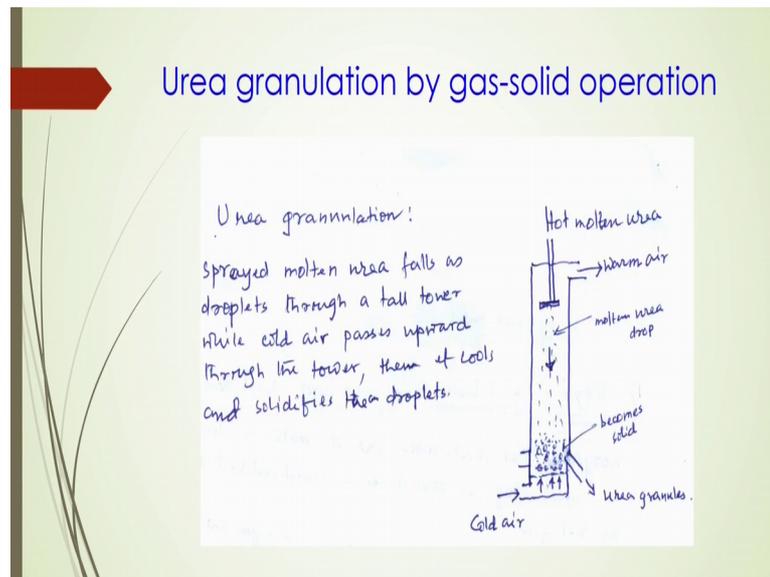
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Now, another important adsorption by solid gas operation here; if you want to remove carbon di sulfide from air by activated carbon in a multi stage fluidized bed, what to do? That you have to supply this carbon di sulfide and air mixture in a bed of solid particles of activated carbon and then, at a certain flow rate and at a certain temperature, you can remove that carbon di sulfide. Even removal of di chloro ethane from the fuel gas, you can also do it in presence of activated carbon in the fluidized bed operation system of gas solid operation.

Even removal of solvents and odor for materials from air by activated carbon can also be done just by fluidizing the activated carbon particles by air. So, these are the physical application of this gas solid operation.

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Even you know that urea granulation by gas solid operation. How this urea that is particulate urea? You are obtaining generally whenever urea is being produced it is coming as a molten urea that is slug as a slug it is coming.

Now, you have to make that is granular in size what to do? You have to supply the cold air that is very a near about 2-3 degree centigrade that a cold air to be supplied from the bottom of the column. And from the top that hot molten urea to be supplied or sprayed from the top and whenever this droplet of this molten urea is falling downward through this cold air, you will see that hot molten urea, it will be you know that converting to a hard; you know that granular urea there.

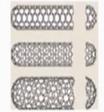
So, this is one application for this gas solid operation just by fluidizing this urea there what molten urea to become to make it urea granules.

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**Other gas-solid flow applications**

**Advanced materials**

- Silicon production for semiconductor and solar industry
- Coated nanoparticles
- Nano carbon tubes



**Chemical and Petrochemical**

- Cracking of hydrocarbons
- Gas phase polymeric reactions

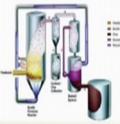


**Physical operations**

- Coating of metal and glass objects
- Drying of solids
- Roasting of food
- Classify particles

**Combustion/pyrolysis**

- Combustion/gasification of coal
- Pyrolysis of wood waste
- Chemical looping combustion



**Pharmaceutical**

- Coating of pills
- Granulation
- Production of plant and animal cells

<http://www.chemsoc.org/timeline/pages/1961.html>  
<http://physicsweb.org/article/world/11/1/9>  
[www.unb.ca/che/che5134/fluidization.html](http://www.unb.ca/che/che5134/fluidization.html)  
<http://www.niroinc.com/html/drying/fluidtype.html>  
<http://www.dynamotive.com/biooil/technology.html>

Other several applications like advanced materials silicon production for semiconductor and solar industry even coated nanoparticles nano carbon tubes. Even sometimes cracking of hydrocarbons like gas phase polymeric reactions here and also combustion or pyrolysis combustion or gasification of coal, pyrolysis of wood waste, chemical looping, combustion coating of metal glass objects, drying of solids, roasting of food, classifying particles.

Even in pharmaceutical industries, you will see coating of pills like tablets even also granulation process they are production of plants and animal cells all are actually this fluidization operation based on this gas solid. Even gas liquid solid also there some operations there come to that point.

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### Application of liquid-liquid operation

- Fractionation of citrus essential oil by liquid-liquid extraction using a perforated rotating disc contactor
- Liquid-liquid extraction process using a PRDC and hydroalcoholic solvents.
- Citrus essential oils are important raw materials used in the formulation of many products, including soft and alcoholic drinks, flavoring agents, cosmetics, perfumes and toiletries.
- Main objective is to separate terpenic hydrocarbons and oxygenated compounds

(1) extraction region; (2) top separation region; (3) bottom separation region; (4) perforated disc; (5) solvent input; (6) disc axis; (7) feed input; (8) extract and raffinate streams interface height; (9) raffinate stream output; (10) extract stream output; (11) jacket; (12) water (at  $T = 293.15\text{ K}$ ) input and output; (13) screw to union the equipment parts; (14) feed stream distributor.

Now if you consider the liquid liquid operation that is also one type of multiphase flow operation. Now if you want to extract some unwanted components from a liquid by another liquid that will be your liquid liquid operation like, one example that citrus essential oil that is being fractionated or the components of unwanted components from this essential oil that can be actually done by liquid liquid extraction. Now using a perforated rotating disc contactor, it can be performed. Now, liquid liquid extraction process using this rotating disc and hydrochloric solvents can be easily done efficiently.

Now, citrus essential oils are important raw material used generally formulation of many products that will includes soft and alcoholic drinks. Even you know that favoring agents cosmetics perfumes and toiletries. So, all those actually applications are there for these citrus essential oils. So, in this case, there contains you know sometimes terpenic and hydrocarbons and also oxygenated compounds are there. So, you have to remove all those components from these essential oils.

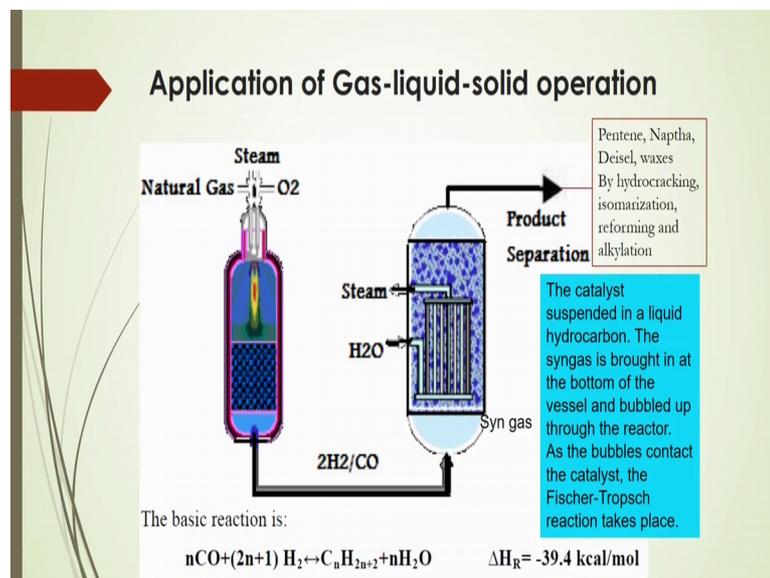
So, because it will be harmful if you direct use this raw oils, there in you are may be skin in some other you know that drinks in that case if you use this oil directly that will be your health problem or hazardous for you. So, in this case, you have to remove those terpenic hydrocarbons when oxygenated compounds there by liquid liquid extraction.

So, you have to use some solvent like generally hydro chloric, hydro chloric acids generally being used to extract those unwanted compounds there. And this is being done

in what is that rotating disc contactor generally the contactor here. In this case, you will see some disc will be actually baffled in a axial location here; in this column as shown here.

So, whenever it will be rotating you will see that liquid and liquid solvents and what is that oils will be mixed to each other and making a droplet there. And through the droplet, you will see there will be a transfer of what is that unwanted compounds or components from one phase to the another phase one liquid to the another liquid. So, this is called extraction. So, based on this process this separation is being done in liquid liquid operation.

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Another application, it is called gas liquid solid operation. You see whatever you will see we are producing some producer gas even natural from the natural gas, how to produce that producer gas is there form that producer gas. We are having different synthesis gases in our daily life. In that case from the natural gas or steam or some oxidation process, you can convert this natural gas like ammonia or some other things. Then you can directly convert this natural gas to that what is that producer gas that is mixture of hydrogen and carbon monoxide.

And then this hydrogen and carbon monoxide mixture to be actually supplied through a three phase system it is called gas liquid solid system that is gas is here mixture of hydrogen carbon monoxide and it will be supplied through a liquid medium and that

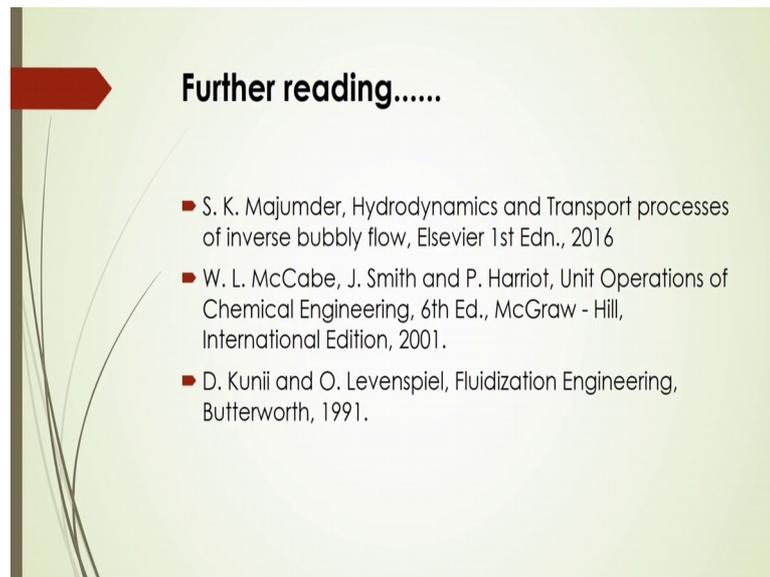
liquid medium will be heated up to a certain temperature by a steam. And then it will be converted after that this hydro producer gas should be converted at a certain temperature and pressure in presence of some catalyst which will be suspended in a liquid hydrocarbon there.

So, the steam gas is brought in at what is that at the bottom of the vessel and bubbled up through the reactor and as the bubbles contact the catalyst the Fischer Tropsch reaction will be taking place. So, basically this synthesis gas of hydrogen or carbon monoxide mixture or producer gas. It will be converted to a several products of that is hydro carbons like pentene, naphtha, diesel waxes and it will be produced just by Fischer Tropsch synthesis in presence of catalyst.

So, this catalyst and this hydrogen and carbon monoxide gas mixture and plus this liquid that is hydro carbon that is the three phase mixture will be here in the columns. So, that is why gas liquid solid operation gas is here mixture of hydrogen carbon monoxide liquid is hydro carbon and solid is catalyst particles.

So, three phase will be there and after mixing at a certain temperature and pressure and you see there will be a conversion of this synthesis gas to different products like pentene, naphtha, diesel, wax. And then after up gradation of this mixture of this product, you can get several different like separate of this pentene, naphtha, diesel, waxes by hydro cracking isomerization reforming and alkylation process there. So, this is one important process of this gas liquid solid operation. This is called slurry bubble column reactor in which this operation is being done. It is called slurry bubble column reactor. So, in this case you are getting then three phase system.

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So, I want to stop here that since we are getting several operations you can get more than whatever I have shown here. You can get more I think chemical engineering even bio chemical engineering processes based on these multiphase flow systems. And I would suggest you to flow this books specially here in third one D Kunii and Levenspiel, Fluidization Engineering and this books will be giving you a huge information regarding this gas solid operation and ok.

So, thank you for your attention and I would now actually end of this lecture series here for this particular course like fluid flow operations. So, in this course we have learnt the basic understanding of the single phase flow, then multiphase flow system and its applications. So, I think you will enjoy this course I would like to wish you a for learning this course and enjoying this course.

Thank you.