Indian Institute of Technology Madras

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Chemical Engineering Thermodynamics

by

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Lecture 32

Absorption refrigeration

I thought I will discuss the option refrigeration I have got some numbers these numbers are from I forget which book I took it from but these are numbers from.

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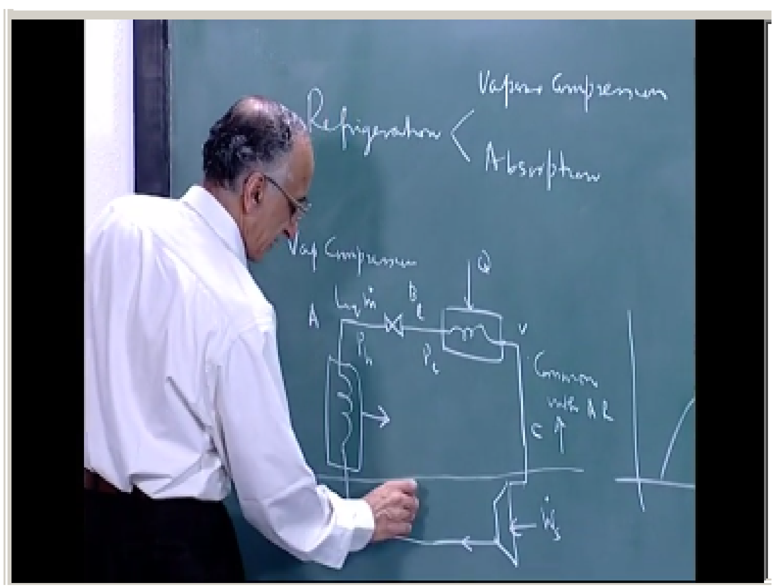

Basically I will put the picture down when put the numbers in now we have I am going to discuss this was omitted earlier when I discuss refrigeration we discussed vapor compression we name discuss absorption refrigeration I postponed this because we needed to discuss solutions in enthalpy concentration variations I mean vapor compression you have a throttle wall in which the liquid refrigerant is throttled and comes out at very low temperature you have liquid here comes out at a lower pressure this is p high and this is P low this passes through a heat exchanger which absorbs heat from the surroundings thereby cooling it and this, this is vapor here this is still liquid.

And this is vapor this vapor is then compressed I think you just you do some work on it WS dot we have some liquid at some I am dot some flow rate this compressed liquid is then cooled in a heat exchanger where heat is removed and this is your vapor compression refrigeration in absorption refrigeration this part of the cycle remains the same this part with absorption refrigeration exactly like in a vapor compression refrigeration you have a pure liquid that comes in here at this stage.

This is compressed this is still vapor this vapor is cooled and condensed in this liquid at some rate MDOT is throttled to a lower pressure so this pressure is P high it works between two pressures soon the thermodynamic diagram pure flow diagram the process looks like this if you want to label these points a before throttling B C and D so a before throttling B C and D in absorption refrigeration what you do is turn the same thing around.

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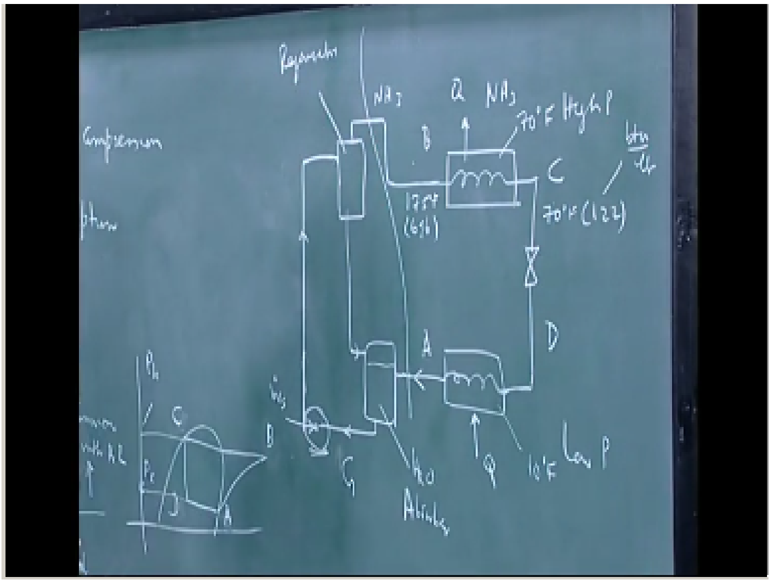

It is in this part is the same I still have the throttling but I have another heat exchanger this part is common then this in this case usually the refrigerant is fluoro hydrocarbon or a variation it is a projection of our 103a and so on some refrigerant I have what you do is take this case it is usually ammonia and putdown some numbers I have got the numbers from the ammonia diagram I have put the numbers here for example typically this point is what have I called it here I think I will real able these things be is here throttle a heat exchanger know what these numbers are just before this is I have called the see if you do not mind.

Let us change some of these labels alone because for refuge the absorption refrigeration I have got this notation this is see after these after throttling it is d and before the throttling at C it is B wait a minute a HC and then before this, this is B and this is okay that means the corresponding points here before C and B this is C D then throttling then heat exchanger D this is evaporation T 2a and a2b B C D as is common to the absorption refrigeration so I label these points this is B this is C then I have B after this, this is a here I have an absorber this is usually ammonia comes out of the it is after throttling this is the place where the heat is picked up this is cooling this is high pressure, this is low pressure.

So these two pressures this pressure and this pressure are determined this is P hit his is P low these are determined by the thermodynamic properties of ammonia and the temperatures you want for example in absorption refrigeration typically it is large industrial applications you try to keep this at 10^0C at 10^0 F and the other one will be room temperature 80^0 roughly so the corresponding saturation pressures are the saturation pressures of ammonia corresponding to those temperatures so those two are fixed.

So this part is still the same a b c d a is the same instead of using a compressor you do its lightly differently compressing a gas requires much more energy than pumping a liquid and also you take advantage of enthalpy changes during absorption what I have here is a leak is water and this ammonia comes in it is absorbed here so a concentrated solution of ammonia will be taken out here this is what all numbers so I want to keep the labels the same this is G and this is typically this is a centrifugal pump so shown inflow sheets this is pumped up to what is called a regenerator from the regenerator it comes down here okay.

And put down some concentrations and we will describe the whole process because I have some work here and describe the whole process again this is absorber this is regenerator what comes out here is ammonia negligible amount of water so this part of the cycle the right-hand side is the same as the upper part of this cycle except instead of the refrigerant I have ammonia instead of our one zero three one zero four etcetera I use ammonia as the refrigerant this part I will put down some numbers to give you a feel this is works between ten and seventy degrees F.

So this is at ten degrees F this is at 70^0 F the corresponding high pressure will be saturation pressure of ammonia at 70^0 F this is the saturation pressure of ammonia at 10^0 F and I will put some numbers down directly and this the regenerator this, this thing is at 175^0 F and within parenthesis I will put down enthalpy values and tell you where I got them from one chart is coming to your now this part is pure ammonia so you just have to take the pH chart and read the enthalpies on it just these numbers I have read I have just put it down here.

And this one is 70^0 70 is at the outlet then this is122 is the enthalpy all the enthalpies are in BTU per pound refrigeration industry still works primarily in British units then I have throttling the temperature here is 10^0F and the enthalpy is122 choice enthalpy this here after the heat has been absorbed it is this is just evaporation so it is still at 10^0 F but the enthalpy is 6 1-3 that represents the latent heat of evaporation of ammonia only a good 3 X then after absorption what you get is a saturation this temperature is 70^0 F it is heated essentially in the absorber the temperature goes up to70^0 F with an enthalpy of -25 in the same in the concentration is 46.5% ammonium this is by weight of ammonia.

This is pumped in the condition here the enthalpy here is minus twenty four point seven from minus 25 to minus twenty four point seven it is all it takes to pump liquid in the regenerator outlet this is this is 175^0 F and 35 points even percent by weight of ammonia that is all we need so this is 10 this is 175 this is the liquid coming back this is water with 3735.7% this absorbs more ammonia and the concentration of ammonia increases to forty six point five percent these temperatures this 10^0 in 175depending on the amount of each substance you go to get a final temperature about 70^0 F.

This is pumped here in the ammonia that comes out here at 175^0 finally comes to this for 70^0 is what I should put on when I say high pressure it is at 70corresponding to the temperature is 70only here at the outlet similarly it is not 10 in the heat exchange is low pressure is at 10 degrees which is all I need then I have some numbers here okay for the absorption part I have given you a chart there as chart this from I think it is Dow Bert's thermodynamics book but it is also available in theory more comprehensive chart is available in chemical engineers handbook should realize when you look at enthalpy this is absorption.

And essentially by heating it you are reducing the solubility so you are removing the ammonia from there the big difference between that and this, this looks much more complicated but you have to have a compression huge compressor for gases here for the vapor phase here you have only a pump which is much more rugged and the work for pumping a liquid is much less than the work required for compressing a gas from hereto here so you are hopefully you have less leasing and because the pump maintenance is trivial this part of it these are only stationary devices this part of it is maintained easily for large scale refrigeration even now this is what is used now let me do the calculation so this part I have got a table of numbers.
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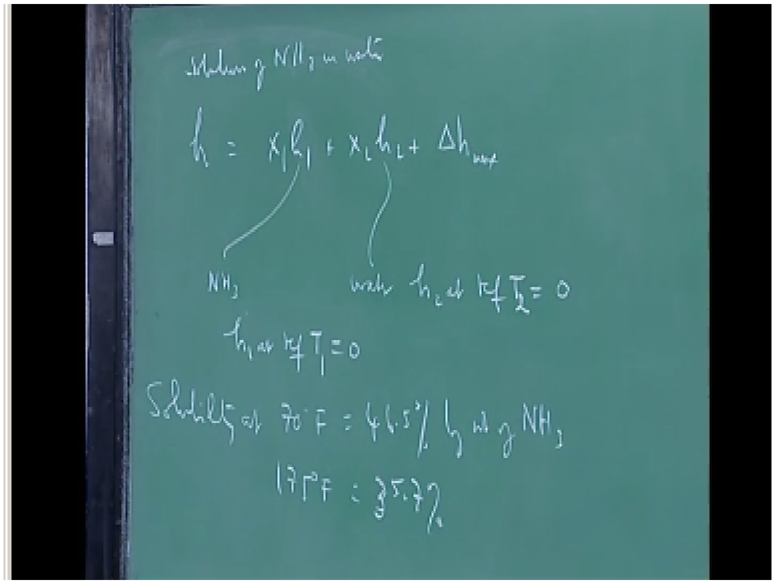

But let me explain if you have a concentration a solution enthalpy of a solution of ammonia and water typically would be simply I use X1 H 1 or I should use small H 1+X 2H 2 + Δ H of mixing this is measured in a typical chart like this we will assume H 1 equal to this is pure say this is ammonia let us say this is water 2 is water these charts are prepared so when you mix charge you have to be careful H 1 at some reference temperature equal to 0 similarly H 2 it could be a completely different reference temperature equal to 0 I will Call this reference T 1 reference T 2 but if you take differences between two points in the chart your enthalpy differences are what you will use.

But when you use it in conjunction with a pure ammonia chart you have to make sure that in the ammonia chart also the enthalpy has the same reference value so this part of the data you will get from a pure ammonia chart this part of the data this side left side you get from enthalpy concentration diagram if you the part of the diagram that you will use here is very small part of this whole diagram Avenue you first of all you use only the saturated liquid part of it is a function of temperature it should actually strictly be a function of pressure as well but the properties of the condensed phase are negligibly dependent on pressure so really pressure would not come into this thing.

So you will find there is a saturated liquid curve you take sixty degrees for example curve the sixty goes out take one hundred for example at one hundred degrees F this saturated liquid has a concentration of 0.78 point seven in this case this is mass fraction so at seventy percent by weight of ammonia for ammonia water system these two are approximately the same because the molecular weights are17 and 18 so mole fraction and mass fraction would not be very different but anyway about 70% is the saturated solution represents a saturated solution of ammonia and water by weight.

So in his case you have in the absorber when the ammonia comes out here this is in the in the case of this thing what you do is simply your this is your refrigerator in the refrigerator there is a coil to which the heat is absorbed from the outside so the temperature outside is maintained at 10 degrees actually in practice if this is 10 this temperature outside will be about 12 or13^0 you will have some differential actually 5^0F typically so 15^0 will be the refrigeration temperature.

So this will pick up the heat and this is essentially isobaric it is just at one pressure it is evaporation so this is pure vapor ammonia which is bubbled through water this absorb or design is important they will have various devices for making sure that the ammonia is mixed well with the liquid so what you get out of it is a saturated solution of ammonia at the temperature that you have that comes out of this balance at 70^0 you can read the saturation temperature here you know gas solubility will decrease as the temperature goes up so here let us assume that read this as the saturation concentration I will double check on that but the thing the nature of the graph is correct there will be lines representing the saturated liquid.

And you should be able to read the saturation temperature from that inter solubility point you think there is a shift in numbers there but you will find differences will probably be the same and come back to it so at 70^0 46 point five is the concentration of ammonia and you pump this up here essentially you have to provide heating this there will be a heater here where you supply heat this thing will be heated to 175^0 as I shown 175^0 this is the solubility I will put down these numbers this is solubility at 175 at 70^0F is 46.5% by weight of ammonia and at 175 ^{0}F this is 35. 7.

So I have some numbers should be calculated this quantity the quantity that is flowing here is X I have to get my notation right whether I just put down numbers here then yeah this circulation rate is MDOT everywhere here it is MDOT this is X and this is y that is the question is what are x and y given this these are the conditions that are given the user specifies 10^0 here and 70^0 here. Because this is when you lose heat to the air to the atmosphere, so if this is if the outside temperature is 80˚F and you will get about 70 here and similarly if you keep this at 10 you probably get even 20 15 or 20 ˚ inside the refrigerator. So these are user specifications this determines the pressure automatically this temperature determines the pressure this temperature determines the low pressure.

In this case the pressures are also given this pressure at 70 it is 128 and 38, this is 128 pounds per square inch absolute and low pressure is 38 pounds per square inch absolute, these are this whole thing is from the ammonia chart. So working between two pressures 38 psa and 128 psa, now this part is what you have to design you have an absorber and a regenerator and what you are asked is what are x and y and of course the total $\dot{m}$ this enthalpy that you pickup from the refrigerator is fixed per unit mass of ammonia.

Because it comes from this chart here this is the amount that you pick up you are looking at after throttling you are looking at this part right, hA-hD is the enthalpy per pound that is picked up so your total refrigeration demand divided by this will give you a $\dot{m}$, so this $\dot{m}$ is fixed again in the design of the refrigeration unit. So let me put down this chart you can verify this my suggestion is I am sorry that this chart turned out to be the wrong one please look at Perry handbook of come.

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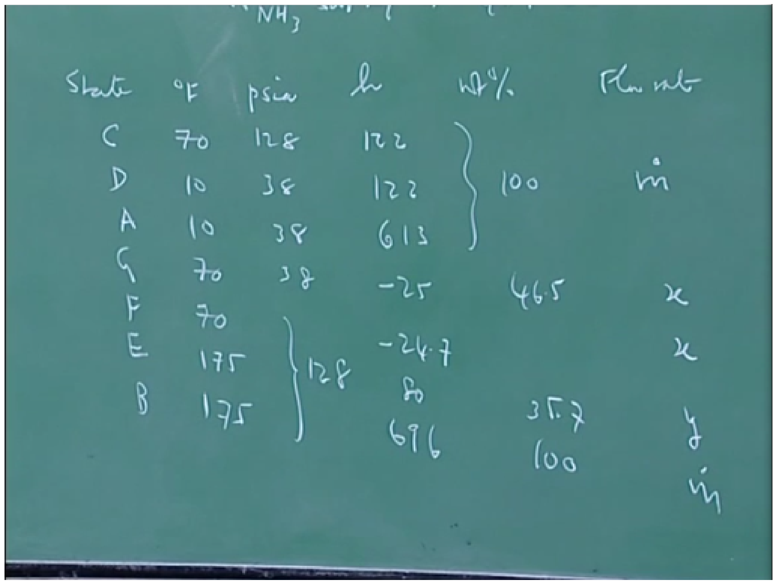

Have you ever looked at this book you can graduate without looking at the book is it is called handbook of chemical engineers and it is still finally the book you refer to and you actually go to industry and do any design the thing is it is fairly boring but if your life depended on it becomes terribly interesting, because if your boss says design this and if you do not design it in one week you lose your job that one week you will read very like nobody business and you will have great value for it how wonderful in this book is what information you see.

Actually every one of us gets used to one edition I have got used to the fourth edition but a lot of the data is the same in subsequent editions also a lot of it is thermo chemical data. I do not know if this is available actually I am so dated in terms of ICT that I do not know how this is available online I have to double check I have not it is available online should be by logically, so you can look it up in your only thing then the chart will appear and I have got this I took it from the fourth edition and I do not know why anybody would want to steal a fourth edition from me.

But let me I will check who has it this is the basis here is enthalpy h of ammonia you know I told you about the reference, the basis in the h ammonia enthalpy of pure ammonia saturated liquid at -40˚F=0 we can check that here. If you look at this is mass fraction of ammonia, if you look at mass action equal to 1 you get the enthalpies at saturated liquid at minus 40˚ this is given you saturated actually you cannot see it in this 160 goes in steps of 40 so can sort of extrapolate I still cannot it seems in this case the enthalpy comes to below 0 right, on the chart on the xy axis 0 is actually does not correspond to saturated liquid remaining temperature but it corresponds to something like just below the saturated liquid at 100˚ something.

But 140˚ so there is a translation of numbers here so this chart does not give you these numbers but let me put down P, and put down a chart table here I am going to say state this is C D A G F I should have made a, I can make a Xerox copy of this or I will print it out for you because I have scribbled all over it this is 70˚F 10 and 10 then 70 again and 175, 70 twice 175, 175 I will double check this, the pressure here is 128, 38, 38 this is psia then 128, 38 3 times the rest is 128.

Then the enthalpy here this is 122, 122 then 613, -25, - 24.7 we have two more 80 and 696 then weight percent is 3 or 100% this is pure ammonia when you begin the solutions G is 46.5 and then the last two are this is where is B, B is 100% again in the before B this is 35.7 okay, and then the flow rate for these three it is $\dot{m}$ and then for g this is x as I have marked there then it is x again f is also x then this is y and again $\dot{m}$.

Do all the calculations per ton of refrigeration this you starting here at C this is $\dot{m}$ at 70˚F at 128 psia and enthalpy of 122 the enthalpy remains the same across the throttling process so you still have 122 but the temperature is 10˚ right. In the pressure here is 38 psia then passes through the refrigeration refrigerator where it picks up the heat and the enthalpy at A is 613.

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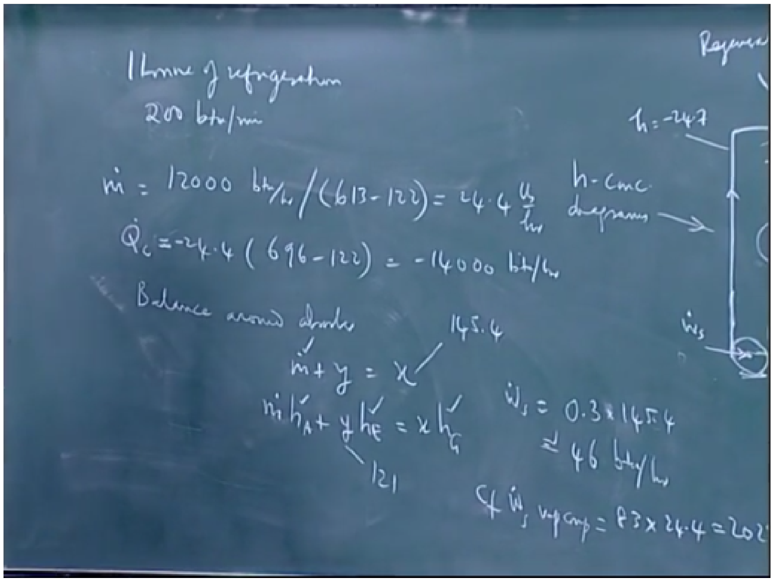

So if you want the $\dot{m}$ let us say one tonne of refrigeration you know this is 200 btu/minute or 12,000 btu/ hour divided by your enthalpy at A-enthalpy at D, so 613 - 120 okay, this is your $\dot{m}$ got this so you know what the value is what I have done this it says hC-hB I made a mistake here, circulation rate is determined here and tell me this value you have to work this number out if you made some mistake. No, no, this is all right this comes to 24.4 pounds per hour correct this is okay hA-hB.

But 524 is alright 24.4 okay, this is your evaporator and this is your condenser, so you can calculate your condenser heat load $\dot{Q}c$ is simply this 24.4 into the difference in enthalpy between C and B that is 696 and 122 this will be as far as system is concerned there it is losing heat there will be a minus sign, this comes to 14-14,000 btu/hour then if you do a balance around the absorber this is the calculation that you do to calculate these quantities you need to know how much of water has to be used in circulation.

You will get m=x+y or $\dot{m}$=x+y but not $\dot{m}$+y=x, y is coming in $\dot{m}$ is coming in $\dot{m}$+y =x then $\dot{m}$ into hA enthalpy at a +y into enthalpy at E is the energy balance =X into enthalpy at g. Now $\dot{m}$ is known and all these enthalpy are known. You can play around with these temperatures if you like but these are just happened this 70 is prescribed you can play around with 175 you can go up or down 10˚ 15˚ and so on the point is to get a significant difference in the solubility 46.5 is that difference is what will give you the difference in the enthalpy of absorption you get essentially these are heat effects in absorption in B absorption if you like.

I have solved this you can double check these numbers you get 145.4 for x this comes to145.4 and your y is 121, your pump work $\dot{W}s$ is between see this is adiabatic pumping $\dot{W}s$ a simply Δh, $-\Delta h$ so enthalpy 24.7-25 so you get 0.3 in this is your enthalpy per pound into 24.4 which is $\dot{m}$ it comes to 72 something the material is 24.43 is the enthalpy difference that is correct. Pardon that should be multiplied by x that is the mistake you are right, X is 144.7 you are right. Now that comes to 46 you can with numbers are approximate this is your btu/hour.

Whereas your vapor compression if you have done vapor compression you would have to take it from this enthalpy of 613 to 696 directly and 613 to 696 is what, so compare CF, $\dot{W}s$ for vapor compression, 696-613 which is 83 but into $\dot{m}$ only in this case $\dot{m}$ is 24.4 it comes to 2029 btu is the difference. Usually used in large installations basically ammonia is toxic for use in homes so it is only industrial this thing where safety can be guaranteed that they use this absorption refrigeration, we like the basis but you can see the big difference in the work required. Any questions basically I just go through this, this part of it is identical so there is nothing to discuss here it is identical with your vapor compression refrigeration it is fairly trivial.

This is the only part that you replace you go through a absorption process and at the end of the absorption you look at the enthalpies here, enthalpies you go from 613 now I am looking at A to G gone to an enthalpy of -25 here and then I go through a regeneration, regeneration goes from effectively G, I do not have a label for this is, this is F we have called it F I have an F there yeah, that is F, G to F is a negligible thermodynamic change.

But F splits into two streams at 175 there so from F you are going to E, F to E enthalpy changes from -24.7 to 80. There is heat addition here I do not have to put a coil that is heat addition here and heat removal Q regenerator this is heat removal here Q absorber that those numbers also have calculated, the absorber comes to right here Q absorber is 28297 and Q regenerator is 3279 these are big numbers.

Remember this is what you have fixed Q evaporator is fix this is one term this is 12,000 btu/hour you are comparing vapor compression with absorption refrigeration for the same refrigeration load. So you have to buy two more heat exchange essentially what people do in practice is these two streams are heat exchanged this is what in chemical industry that is what makes it so confusing this is the process but in practice you have this going up you are going to add heat here you are going this is coming out at 70˚, this is coming down at 175˚ and you want to cool it so what you will do is heat exchange these two streams will have one stream we will be the in the shell side one stream will be in the tube side of a heat exchanger.

And so instead of 175 you will come down here at 160 or 150 and there will be a corresponding rise in temperature here, so this load will go down this heat removed will be less this kind of optimization is done all the time and chemical industry right. So when you go to an actual chemical industry you think it is it looks like a large number of pipes connected to a few equipment it does not look like equipment with pipes attached to it. The number of pipes are so large in refinery is alone you will have about thousand kilometers of piping typically you can stop there.

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