

Principles and Practices of Process Equipment and Plant Design
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Module - 03
Lecture - 46
Design of Shell and Tube Heat Exchangers - a general overview (Contd.)

Hello welcome to the course again. What we do is we continue with what we have been talking about - the design of Shell and Tube Heat Exchangers and we are having a general overview on the topic.

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Design Steps

1. Evaluate heat load Q ✓
2. Finalise temperatures (in/out) ✓
3. Estimate U after preliminary selection of HE type
4. Estimate Required A
5. Design for providing A and verify validity of any assumption in the steps

Q. What is a heat release curve? What is its use?

The slide features a background diagram of a shell and tube heat exchanger with handwritten annotations. The equation $Q = U A \Delta T_m$ is written in red. A graph shows temperature T versus heat load Q with a curve labeled 'Constant'. A schematic of a heat exchanger shows inlet temperature T_1 , outlet temperature T_2 , and flow rates V_1 and V_2 . The heat load Q is also labeled as kJ/kg . The NPTEL logo and 'NPTEL Online Certification Courses IIT Kharagpur' are visible at the bottom.

We start with same step or the same point which what we discussed earlier, like the basic design steps while you design any shell and tube heat exchanger the first step is evaluation of the heat load Q . When you evaluate a heat load Q you normally you will be knowing at least the either the heat load or at least 2 of the temperatures and the flow rate and actually the physical properties of the 2 fluids.

That means, by the end of this you will have your four temperatures known to you; that means, both the in and outlet temperatures are known. The next step is a preliminary selection of the heat exchanger type whether it is double pipe or it is a shell and tube or if it is a shell and tube what type of it is we make educated guess mostly based on our past

experience with similar systems. We have a rough estimate of the overall heat transfer coefficient U after that and then what we do is we go for evaluating it in more details.

Once we have estimated U quite naturally the basic equation of heat balance Q is equal to $U A \Delta T$ effective, since we know all the temperatures and the exchanger configuration we know this we know U we know Q , so we have an estimate of A . So, once we have estimated A we have to realize it and that is the design part of your double pipe or shell and tube exchanger. You design for providing this A in reality and then verify validity of all the assumptions you have made so far in arriving at it.

Now, one thing I did not speak in the last class that is very often in the classical design step, there is a term which is called heat release curve which we will be learning in more details later on when you talk about heat exchanger network analysis. But you often see this curve in the calculations provided by Vander's.

You have if you have a fluid which is getting cooled from a temperature T_1 to a final temperature T_2 it is cooling, then what you do is you start with the temperature T_1 here and if you reduce the temperature by a particular amount what happens is you get some heat released from that particular stream.

So, naturally this Q will be kilo joule per kg of the fluid, if it is a super heated vapor say if it is a super-heated vapor you will be initially losing the super heat that is definitely the sensible heat of the vapor. Then what you have is you keep on losing at the constant temperature the latent heat and once everything has become liquid if you cool it further by removal of heat it will be the sensible heat of the liquid.

So, from here to here the change is due to the presence of vapor plus liquid here it is liquid and in this zone it is vapor. Suppose this gives us I mean a very big advantage if I am going to design a de superheater condenser; that means, what enters at a temperature T_1 we know from this curve that how much will be the quantity of heat removed in desuperheating how much will be the heat removed during condensation and if you have a sub cooling what will be the quantity of heat removed during the sub cooling of the liquid.

That means you will have three components Q_1 Q_2 and Q_3 and your total load will be the sum total of this per kg of your fluid, this clearly tells you about something it makes

your calculations much easier for designing as you consider in such heat exchangers 3 different zones of heat transfer and then you go for your design. This I had I have just told you because you may love to have this in hand before you start your design work particularly if you are going to have phase changes.

I have one question for you what I have drawn here is basically for a pure component and how do you know it I a pure component? It is pure component, because the λ or the heat of the latent heat is removed at a constant temperature of condensation and it is obvious this is drawn at a constant P. If it is a mixture of components you will have a shape something like this, it will be T here the vapor above the vapor above the vapor above the bubble point you have a stream like this the line will be something like this then you have a bend and then you have.

That means, the removal of the vapor and the liquid is not over a constant temperature where you have more than one component in your mixture and this basically is the point of condensation which is a bubble point which is the dew point and this temperature is the bubble point of your component at constant pressure. This is very common with hydrocarbon systems and it is there in case of many other systems and this helps you in designing exchanger's mode with phase change.

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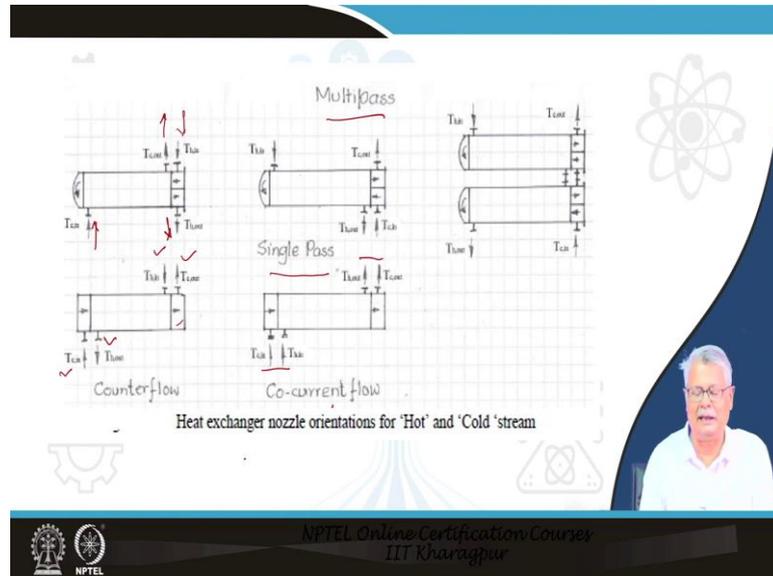
The slide is titled "Shell and Tube Heat Exchangers". It lists the following components:

- Tube bundle assembly
- Shell, nozzles, support
- Heads/End cover

The slide contains two diagrams of a shell and tube heat exchanger. The top diagram is a schematic cross-section showing the internal tube bundle and shell. The bottom diagram is a 3D perspective view of the exchanger with colored arrows indicating flow paths. A handwritten red "2-4" is visible near the bottom diagram. The slide also features a small inset photo of a man in the bottom right corner and the NPTEL logo in the bottom left corner.

We come back to the old design. So, what we do is we know the components now. What we have here is a 1-1 shell and tube exchanger and what we have here is a 2-4 shell and tube exchanger.

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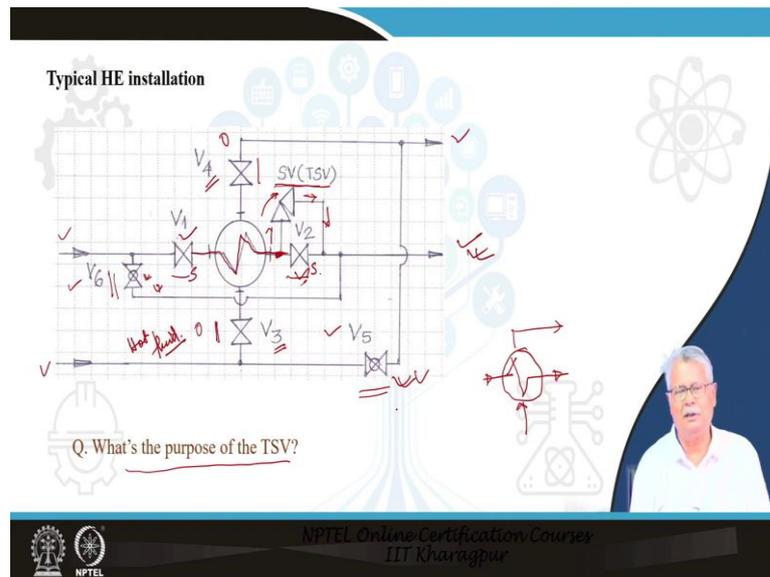


And we also know that such services could be definitely with different multi pass configurations and quite naturally one fluid will be hotter than the one fluid will be getting heated the other fluid will be getting cold. The hot and the cold streams and in case of multi pass and in case of single pass there are typical standard configurations which allow the entry and exit to be there.

Here you will see that in case of a counter flow and a co current flow the matter is simple usually you will have the cold fluid inlet here in the tubes typically coming out through this it is it enters here and it exits here the shell fluid will enter from the top and it will come here from the bottom. In case of co current both will enter from here at the bottom and exit from the top.

In case of this what you have is a 1-2 exchanger and what you have here is basically the tube side the hot fluid entry is from here it goes like this comes out through this and your cold side entry is through the shell bottom ah nozzle and it comes out through this. We will not go into the details because these are basically configurations and you can refer to this particular diagram whenever you are going to design your heat exchanger.

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Now, if you look at a typical exchanger installation well the exchanger is not just the piece of equipment that you are going to design, you are going to design a heat exchange system; that means, you have to design things around the exchanger also. The exchanger is as shown here is only this naturally the tube side fluid comes here from the left, it leaves from the right and you have a shell side fluid which is coming from this end and it is leaving here.

So, this is basically the tube side fluid which comes in it goes out the shell side fluid comes in here and it goes out. You will notice one thing that it is not just that there is only one entry and one exit, there are other piping involved also let us look and try to justify why these pipings are provided. You will notice that you have valves the valves are used for either on off condition or shut open condition or therefore regulations.

The regulatory valves are the globe valves with the symbols, the valves which are used for full open and full closed conditions are the gate valves and these are the gate valves. That means, here you have 4 numbers of gate valves and 2 numbers of regulatory valves which are the globe valves as shown here V 6 and V 5.

Now, what happens is if you would like to have a bypass of your tube side stream what you will be doing is you have to open this; that means, these are for regulating the bypass across the exchanger. When will when this may be required? When I would like to have continuation of this tube side fluid flow when, but my exchanger is decommissioned it is

not in use in that case I will shut this, I will shut this, I will shut this, I will shut this open this bypass it and continue my flow here.

The same thing is true in case of the shell side fluid also, for bypassing the shell side fluid you have the globe valve set in here and when you bypass naturally you have to shut V 3 and V 4. Now, there is one thing which is new to you which we have not talked about, I have mentioned here SV which stands for a Safety Valve and within bracket I have put here TSV which stands for Thermal Safety Valve these things we will detail later on, but we will see why this is required.

A safety valve is basically to release over pressure, you will notice when it releases the releases through this particular path. That means, if I have over pressure at this particular point some amount of liquid will be flowing through the safety valve depending on its setting and it will come here and in the process it will get depressurized or rather the pressure will get released.

Now, let us see when this may happen this happens and this facility is provided when there is chance of over pressure, it is not just the common overpressure because what happens what can happen is if you have this valve shut if you have this valve shut. And if you have this valve open and if you have this valve open and if this is a hot fluid possibly hot liquid the liquid which is cooped up between these 2 valves will get heated and it will expand.

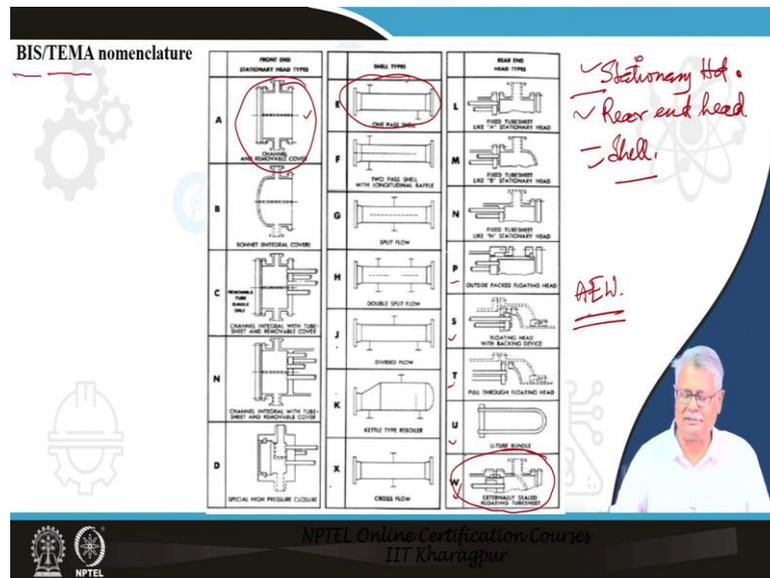
The expansion of liquid is always much larger compared to the metals. So, you will have an over pressure here or the pressure inside will keep on increasing. So, in order to release this pressure so that it does not damage your equipment mechanically, this safety valve allows a passage of the over pressure liquid and reduces the pressure.

So, I believe you now get that why such safety valves are called thermal safety valves also. Remember that thermal safety valves do not have any relationship with thermal actuation of the safety valve no it does not it is not like a pressure cooker safety valve, it is just the common safety valve which is used for releasing the overpressure due to thermal changes

So, we know now what exactly is the purpose of a thermal safety valve and why it is provided in typical heat exchanger installations. In the last slide what we have seen we

have seen various multi pass and single pass installations and each of these installations will have these details of valves and possibly as required you may have the thermal safety valve arrangement as well.

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Now, we come to a very important part of this topic we are aware that bureau of Indian standard IS 4503 is a standard for shell and tube exchangers in India and almost a world over the tubular exchanger manufacturers association which is the TEMA they have the standards for their exchangers.

Now, we already know that any exchanger will have a stationary head, a stationary head will definitely be the stationary head connected to the shell it will have the rear end and it will have the shell. But depending on the type of these 3 both BIS and TEMA they have classified the exchangers and here is the classification diagram. You can see here the front end of the stationary head could be this type- A type, B type, C type, N type or D type, let us look at, similarly, you can have E F G H J K and X type for the shell.

The rear end could be similarly L M N P S T U and W. So, what you do is whenever you see a specification being stated as AEW immediately you will be referring to this and say that this is a type of stationary head I have, this is the type of the shell I have and here I have an externally sealed floating tube sheet. That means, it is for a high pressure and high thermal stress surface.

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BIS/TEMA
Nomenclature: Front end

FRONT END
STATIONARY HEAD TYPES

A
CHANNEL
AND REMOVABLE COVER

B
BONNET INTEGRAL COVER

C
REMOVABLE
TUBE
SHEET ONLY
CHANNEL INTEGRAL WITH TUBE-
SHEET AND REMOVABLE COVER

Q. What's the difference between C and N?

N
CHANNEL INTEGRAL WITH TUBE-
SHEET AND REMOVABLE COVER

D
SPECIAL HIGH PRESSURE CLOSURE

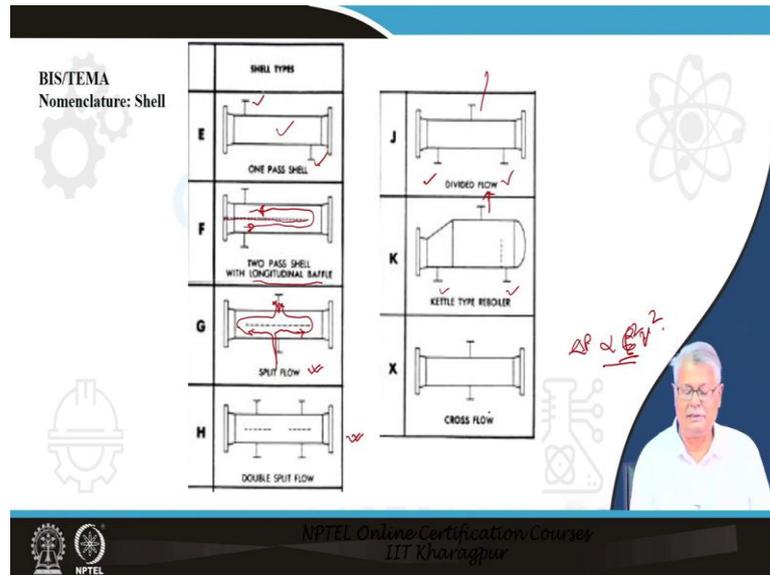
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We just have a look at these classifications once more. The front end here you have a channel and a removable cover the removable cover is this one it is bolted and you have a split a channel splitter here the same thing is true. But, here in this case you have the integral bonnet you will notice here that you do not have a removable cover, it is an integral bonnet. So, if I have to remove I have to remove the entire channel itself.

The bonnet is integral with the cover in this case what we have the channel is integral with the tube sheet you will notice something, this is your tube sheet to which in which the tubes come and end. So, you have this channel integral, so this and this they are built together and you have an external removable cover.

In case of n what you do you have a channel integral with a tube sheet and removable cover. So, basically what you have is this which is slightly different from C and N. So, I would like to know from you to go through these two and compare and find out what are the exact differences and where do they differ next what I have is a special high pressure closure. So, this is definitely for a high pressure system.

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Now, we look at the shells this one pass shell is the simplest; that means, you have the 2 shell nozzles one here and the second one here, the F type is a 2 pass shell. So, you have a pass partition in the shell itself the fluid flow will be this way, either from the left to right here and here or it could be the other way also depending on the design that you have, but you have a longitudinal baffle.

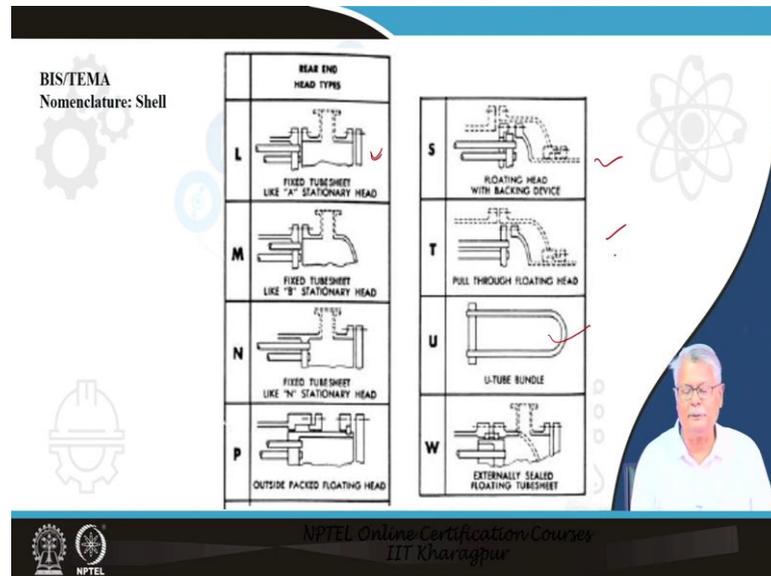
So, whenever you have F in the middle you know that it is a 2 pass shell with a longitudinal baffle. If you ever find that your shell side fluid require I mean pressure drop is large possibly what you would like to do is you would like to split the flow. So, the fluid in the shell will come here get split here come here and go out and this will reduce your pressure drop, why will it reduce your pressure drop.

If you look at the pressure drop equation ΔP is proportional to the flow rate square the flow rate square or rather the velocity square. If you have the velocity the pressure drop is supposed to be 1 by 4th. So, if you make these additions and approximately you will see your split flow will lead to a lower pressure drop.

You can have a single split flow or a double split flow you can have a divided flow as well divided flow is very often used when you have a liquid coming in here a liquid coming in here and a vapor leaving for the top. The same thing you can see in this kettle type of reboiler as well the vapor leaves from the top the there are two liquid connections

here. Now, you can have a cross flow shell as well, but cross flow shells are rather less popular.

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Because your thermal efficiency in such case will be pretty low. Now, we look at the rear end covers the simplest is a U tube bundle or you can have a fixed tube sheet here with a rear end fitted onto it with a removable cover, it is very similar to a type stationary head. You can have other types also, but most of these like pull through floating head or a floating head with a backing device and these are usually for slightly high pressure systems.

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Input process data for Shell/Tube side fluid

	SI ✓	Metric ✓	Requirement	Notes
Fluid Name	-	-	YES	
Flow Rate	kg/s or kg/hr	kg/hr	YES	
Operating Pressure	kPa(g) or MPa(g)	kg/cm ² (g)	YES	
Operating Temperature	°C	°C	YES	
Vapour Fraction ✓	w/w	w/w	(YES)	For 2-phase ✓
Heat Duty	kW or MW	MM kcal/hr	YES	
Fouling Factor	m ² /W	m ² ·hr·°C/kcal	YES	
Vapour	Thermal Conductivity ✓	W/(m ² ·K)	kcal/(m·hr·°C)	YES
	Viscosity ✓	mPa.s	cP	YES
	Enthalpy ✓	kJ/kg	kcal/kg	YES
	Specific Heat ✓	kJ/(kg·K)	kcal/(kg·°C)	YES
	Density ✓	kg/m ³	kg/m ³	YES
Liquid	Thermal Conductivity ✓	W/(m ² ·K)	kcal/(m·hr·°C)	YES
	Viscosity ✓	mPa.s	cP	YES
	Enthalpy ✓	kJ/kg	kcal/kg	YES
	Specific Heat ✓	kJ/(kg·K)	kcal/(kg·°C)	YES
	Density ✓	kg/m ³	kg/m ³	YES
Boiling	Critical Pressure	kPa(abs.)	kg/cm ² (abs.)	(YES) For boiling
	Range (Dew-Bubble)	°C	°C	(YES) For boiling

Now, once you have decided the type of exchanger that you need according to TEMA or BIS code IS4503 you go for the input process data for the shell and the tube side fluid. In fact, this is supposed to be the data sheet with which you will start working, you require for the vapor and the liquid all the data what all data you require you require the thermal conductivity viscosity enthalpy specific heat and density.

That means, if you have to calculate you need to know how to evaluate this it will be either in SI unit or in metric unit the requirements whether you require or not. They are given here the question of vapor fraction comes only for 2 phase flow and naturally the range of dew point at a bubble point that has said will come in case of boiling or in case of condensation.

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Data sheet for shell and tube exchanger (TEMA)

1	Company: XYZ Co.					
2	Location: Kharagpur, India					
3	Service of unit: Vapour condenser ✓			Our Ref.: J122E01		
4	Item no.: 10E01			Your Ref.: 10E01		
5	Date: Jan 09, 2020	Rev. No.: 0	Job No.: J1222			
6	Size (mm): 4150	Type: BEM	Connected in: 1 parallel, 1 series			
7	Surface/unit (effective) (m ²): 269	Shell/unit: 1;	Surface/shell effective) (m ²): 269			
8	PERFORMANCE OF ONE UNIT					
9	Fluid allocation ✓		Shell side		Tube side	
10	Fluid name		Inlet vapour		Cold water	
11	Fluid quantity, Total	kg/s	12.5		105	
12	Vapour (In/Out) ✓	kg/s	12.5	0	0	0
13	Liquid ✓	kg/s	0	12.5	105	105
14	Non-condensable ✓	kg/s	0	0	0	0
15						
16	Temperature (In/Out) ✓	°C	46	44	20	30
17	Dew/Bubble point ✓	°C	46	44		
18	Density Vapour/Liquid ✓	kg/m ³	10.8/	/564	.999	.997
19	Viscosity ✓	mPa.s	0.0085/	/0.122	/1.016	/0.804
20	Mol. wt. Vapour		58.6			
21	Mol. wt. non-condensable					
22	Specific heat	kJ/(kg.K)	1.76/	/2.47	/4.19	/4.19
23	Thermal conductivity	W/(m.K)	0.0174/	/0.102	/0.5937	/0.6067
24	Latent heat	kJ/kg	337.4	338.4		

I think with this you will start your actual design work which will be covered in from the next class onwards. But let us also have a look what should be the deliverables from that particular design step. Here what we have is a filled up data sheet for a hypothetical company at Kharagpur. So, it is a vapor condenser normally all such details are to be provided because every designer will have a particular reference and that reference will be there depending on the order that comes.

So, these are the data pertaining to that information, you have a gross surface area of the exchanger you have the surface of the shell which is also the same basically it could be slightly different it could be slightly different because you may have some special type of units. Now, whenever you are definitely have to find or you have to know from your design the fluid allocation, the fluid name obviously the details of the vapor and the liquid in and out a presence of non condensable.

The temperatures have to be there if it is a mixture of fluids you have to specify the dew and the bubble point, the density of the vapor and the liquid has to be there the viscosity data. So, basically what we have in this particular thing which is the initial part of your total design output specification table and the rest of the table is there in the next slide.

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PERFORMANCE OF ONE UNIT						
			Shell side	Tube side		
25	Pressure (abs.)	bar	4.9	4.8	5	4.9
26	Velocity	m/s	9.9		0.87	
27	Press. drop. allow. (calc.)	bar	0.3	0.08	0.07	0.08
28	Fouling Resist. (min)	MFK/W	0.00009		0.00018; 0.0002 A, based	
29	Heat exchanger	4300 kW;	MTD corrected		19.9 °C	
30	Transfer rate service	W/(m ² ·K)	Disty: 850.7		Class: 1274	
CONSTRUCTION OF ONE SHELL						
31			Shell side	Tube side		
32	Design/vac/hst pressure	g	6$...$	6$...$		
33	Design temperature	°C	85	85		
34	No. passes per shell		1	2		
35	Corrosion allowance	mm	3	3		
36	Connections	in	438	305		
37	ID	mm	134	255		
38	ID	mm	134	255		
39	Tube nos.	1166; OD 19 mm; Tks-Avg: 1.2 mm; Length: 4120 mm; Pitch: 33.8 mm				
40	Tube type		Material: CS plain tubes	Tube pattern: 60		
41	Shell	mm	ID 930	OD 974		Shell cover: -
42	Channel or basket	- CS		Channel cover		-
43	Tube sheet - stationary	- CS		Tube sheet flaring		-
44	Floating head cover			Impingement protection		None
45	Ball	- CS	Type: Segmental	Con%: 40	Spacing: 385 (C-C)	mm
46	Ball	- CS	Type: Segmental	Con%: 40	Spacing: 385 (C-C)	mm
47	Ball	- CS	Type: Segmental	Con%: 40	Spacing: 385 (C-C)	mm
48	Support-tube	U-bend	Type			Inlet: 570 mm
49	Support-tube	U-bend	Type			
50	Support-tube	U-bend	Type			
51	Support-tube	U-bend	Type			
52	Support-tube	U-bend	Type			
53	Support-tube	U-bend	Type			
54	Code requirement	ASME Sec. VIII Div 1		FDMA class R - refinery service		
55	Weight-Shell	3500	Filled with water	8720	Bundle	3045 kg
56	Remarks					
57						
58						

Let us have a look here again we have the shell side and the tube side data the pressure, velocity, pressure drop, fouling resistance, heat exchanger thing and the construction of the shell is also given here. One thing we will note and here that is we have the nozzles the sizing of the nozzle normally is based on the factor rho into V square. Depending on what the velocity is and what the velocity of the what the density of the fluid is we have a rho V square value which from based on which we decide the nozzle size this we will come and we do later on.

So, with this I think you have been given an idea that what exactly is a shell and tube exchanger, what is general procedure for design and finally, what I have tried to give you is an idea that what should be your final deliverables of your design step which you are going to learn next. There is only one thing beyond this that is a fabrication drawing details which we have not included here right now. I think I will stop here today.

Thank you.