Designing of HEAT EXCHANGER using Fusion - 360 & Simulation with **ANSYS**

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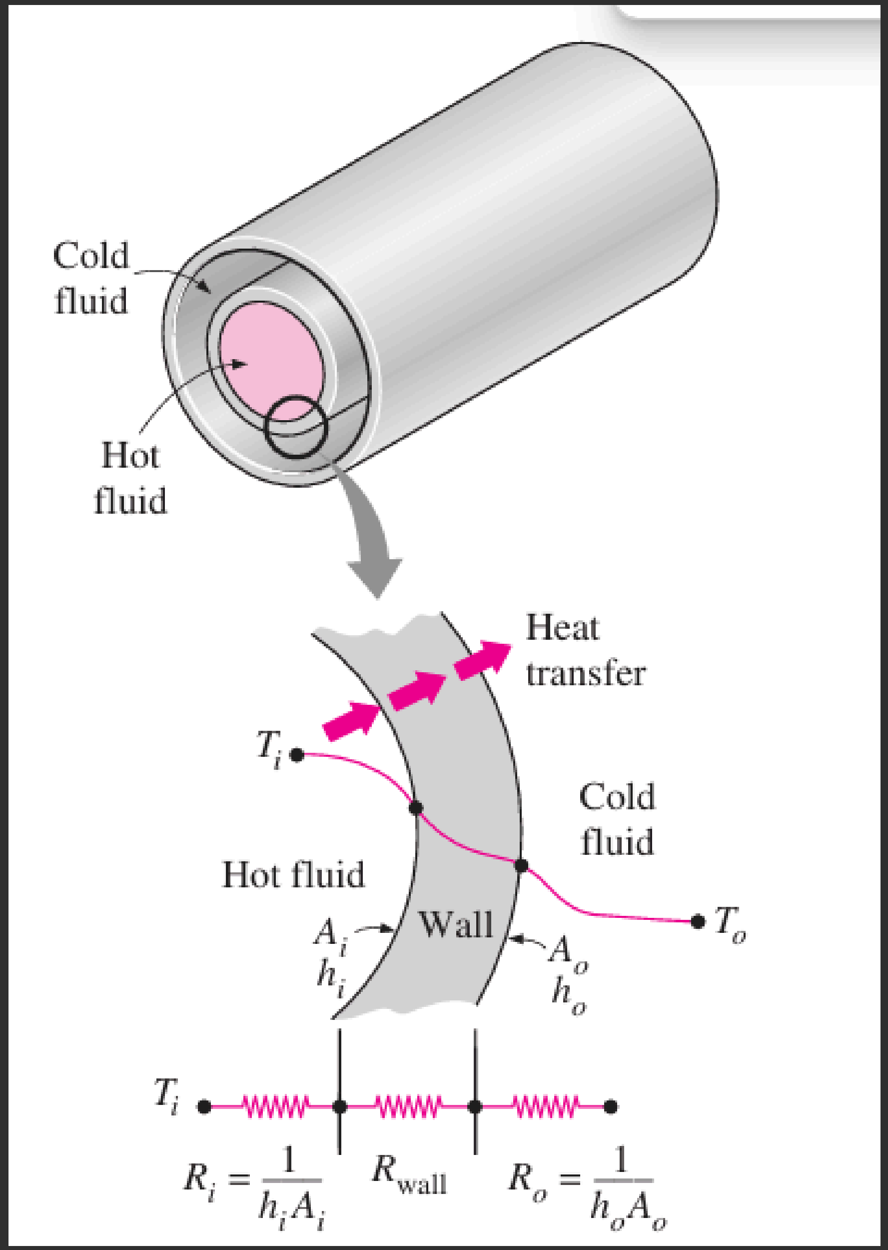
BASIC THEORY

Heat exchangers are devices that facilitate the exchange of heat between two fluids that are at different temperatures while keeping them from mixing with each other.

Heat transfer in a heat exchanger usually involves convection in each fluid and conduction through the wall separating the two fluids.



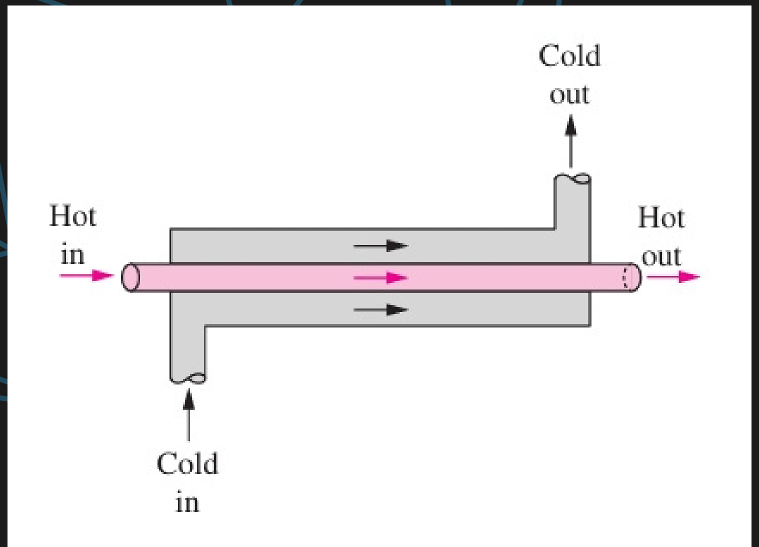
Applications:

Households: Heating and air-conditioning systems.

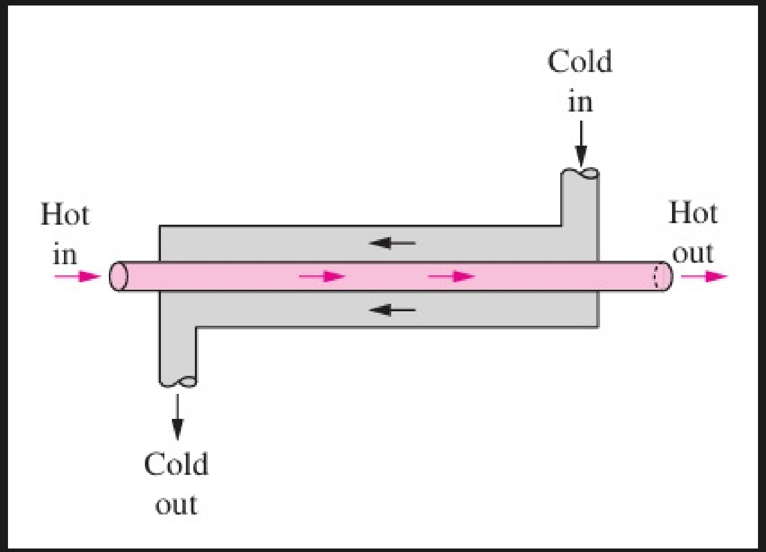
Industry: Chemical processing, power plants.

Transportation: Car radiators, engine cooling

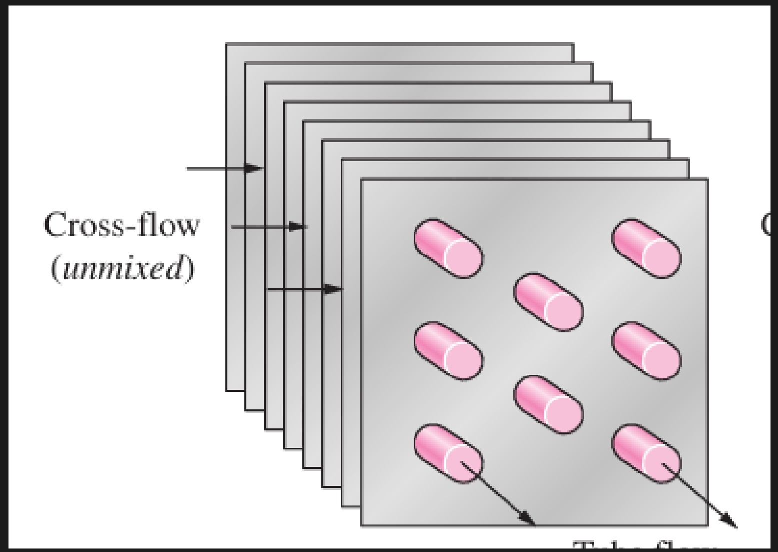
TYPES OF HEAT EXCHANGER



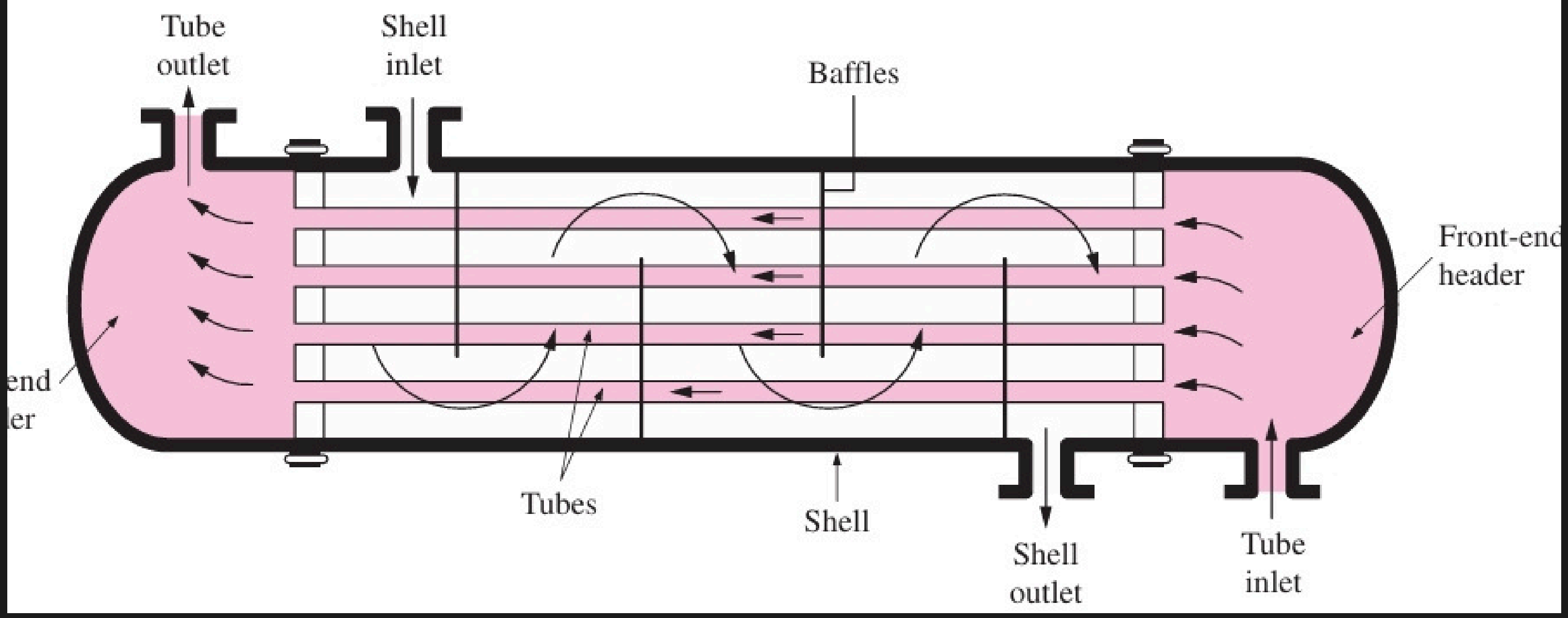
PARALLEL FLOW



COUNTER-FLOW



CROSS FLOW



SHELL AND TUBE
HEAT EXCHANGER

& many
more........

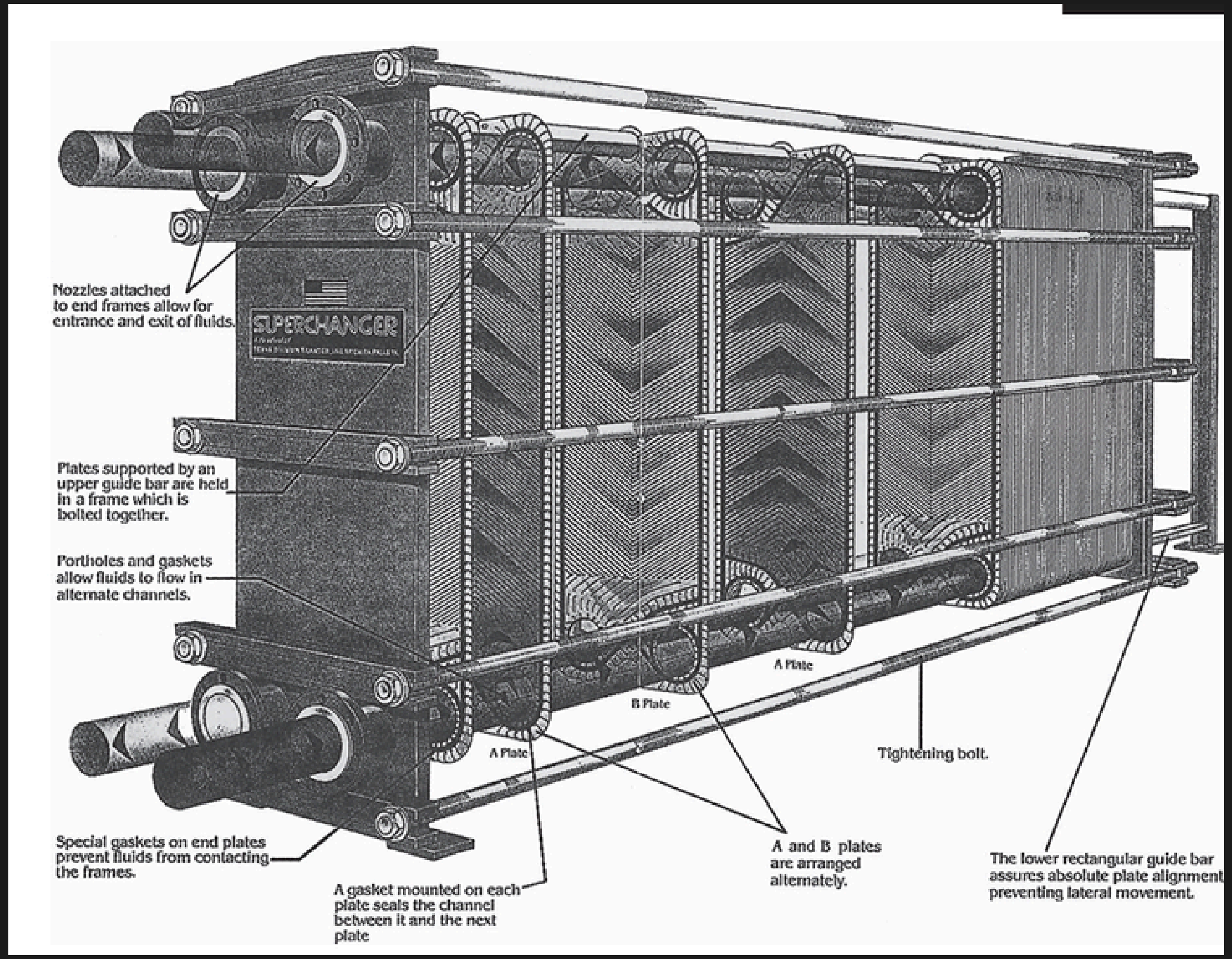
FACTS

In plate and frame heat exchanger , there are series of plates for the cold and hot fluid to pass in alternative passages. Also each cold stream is surrounded by the 2 hot fluid streams

Baffles are generally fitted to maintain the distance between the tubes and also enhances the heat transfer between the fluids

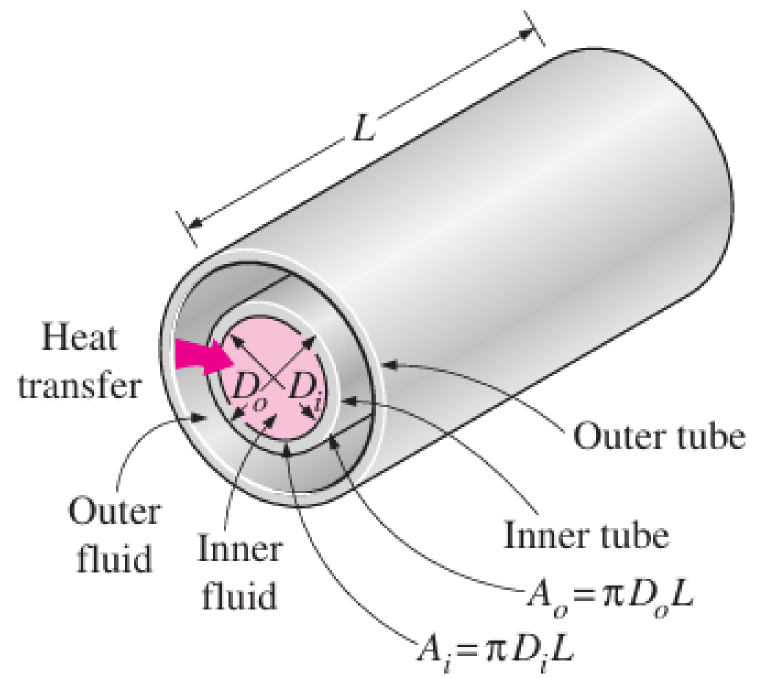
Condensers and boilers are also type of heat exchangers

PLATE AND FRAME HEAT EXCHANGER



THE OVERALL HEAT TRANSFER COEFFICIENT

$$\frac{1}{UA_s} = \frac{1}{U_iA_i} = \frac{1}{U_oA_o} = R = \frac{1}{h_iA_i} + R_{\text{wall}} + \frac{1}{h_oA_o}$$



When one fluid flows inside a circular tube and the other outside of it, we have Ai= pi*Di*L and Ao= pi*Do*L

$$\dot{Q} = \frac{\Delta T}{R} = UA\,\Delta T = U_iA_i\,\Delta T = U_oA_o\,\Delta T$$

$$R_{\text{wall}} = \frac{\ln(D_o/D_i)}{2\pi kL}$$

where U is the overall heat transfercoefficient, whose unit is W/m2 · °C, which is identical to the unit of the ordinary convection coefficient h.

Note that UiAi =UoAo, but Ui is not Uo unless Ai =Ao

FOULING FACTOR (Rf)

The layer of deposits represents additional resistance to heat transfer and causes the rate of heat transfer in a heat exchanger to decrease. The net effect of these accumulations on heat transfer is represented by a **fouling factor Rf**, which is a measure of the **thermal resistance** introduced by fouling.

$$\frac{1}{UA_s} = \frac{1}{U_i A_i} = \frac{1}{U_o A_o} = R = \frac{1}{h_i A_i} + \frac{R_{f,i}}{A_i} + \frac{\ln(D_o/D_i)}{2\pi k L} + \frac{R_{f,o}}{A_o} + \frac{1}{h_o A_o}$$

The fouling factor is **obviously zero** for a new heat exchanger and increases with time as the solid deposits build up on the heat exchanger surface. The fouling factor depends on the operating temperature and the velocity of the fluids, as well as the length of service. Fouling **increases** with increasing temperature and decreasing velocity.

SOME thermo..

First law of thermodynamics requires that the rate of heat transfer from the hot fluid should be equal to the rate of heat transfer to the cold one.

$$\dot{Q} = \dot{m}_c C_{pc}(T_{c,\text{ out}} - T_{c,\text{ in}})$$

$$\dot{Q} = \dot{m}_h C_{ph}(T_{h,\text{ in}} - T_{h,\text{ out}})$$

$\dot{m}_c, \dot{m}_h$ = mass flow rates
C_{pc}, C_{ph} = specific heats
$T_{c,\text{ out}}, T_{h,\text{ out}}$ = outlet temperatures
$T_{c,\text{ in}}, T_{h,\text{ in}}$ = inlet temperatures

In heat exchanger analysis, it is often convenient to combine the product of the *mass flow rate* and the *specific heat* of a fluid into a single quantity. This quantity is called the *heat capacity rate* and is defined for the hot and cold fluid streams as

$$C_h = \dot{m}_h C_{ph} \quad \text{and} \quad C_c = \dot{m}_c C_{pc}$$

$$\dot{Q} = C_c(T_{c,\text{ out}} - T_{c,\text{ in}})$$

$$\dot{Q} = C_h(T_{h,\text{ in}} - T_{h,\text{ out}})$$

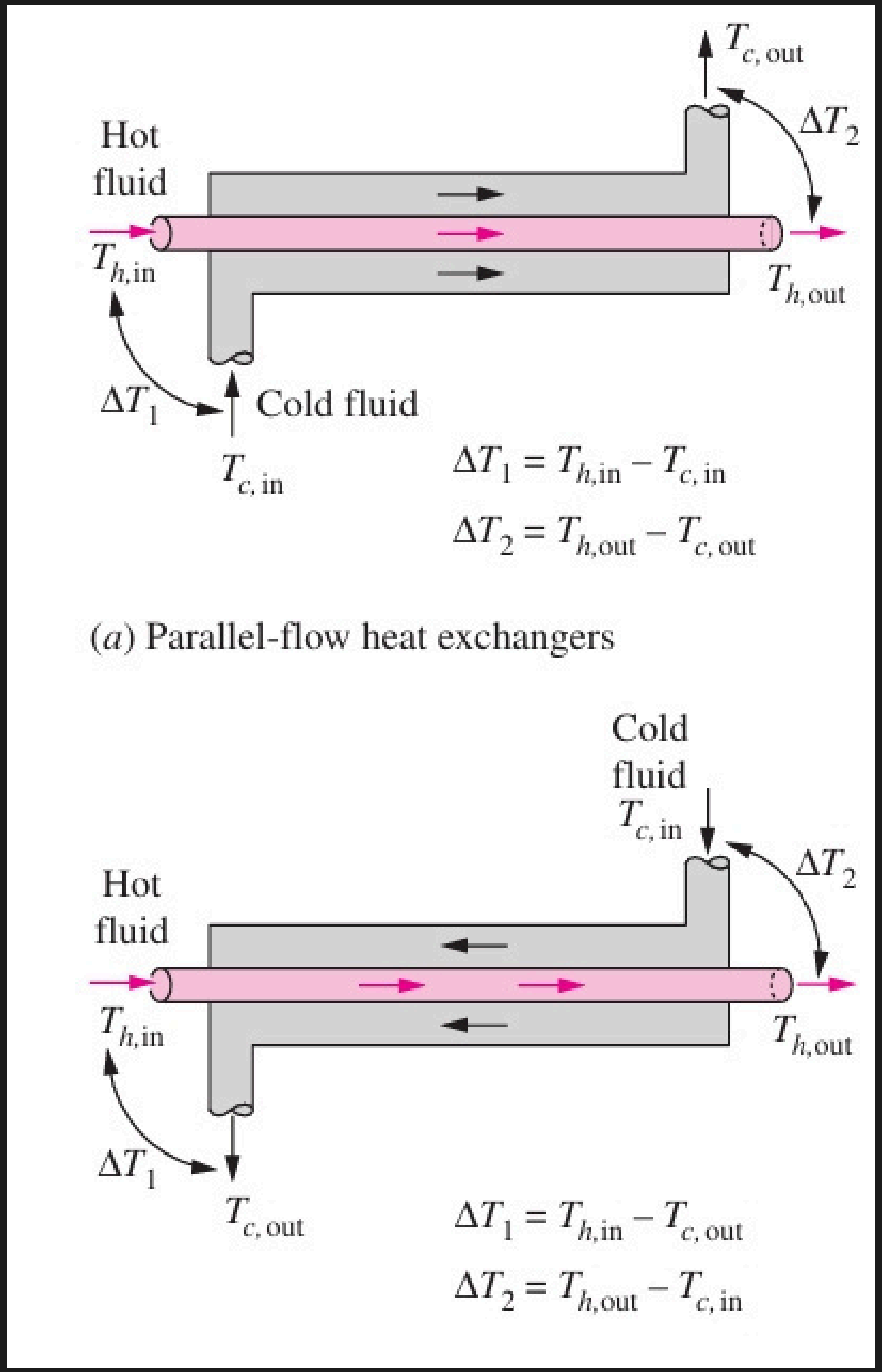
ANALYSIS OF HEAT EXCHANGERS

LMTD METHOD

With the LMTD method, the task is to select a heat exchanger that will meet the prescribed heat transfer requirements. The procedure to be followed by the selection process is:

1. Select the type of heat exchanger suitable for the application.
2. Determine any *unknown inlet or outlet temperature* and the heat transfer rate using an energy balance.
3. Calculate the *log mean temperature difference Tlm* and the *correction factor F*, if necessary.
4. Obtain (select or calculate) the value of the overall *heat transfer co efficient U*.
5. Calculate the heat transfer *surface area* As.

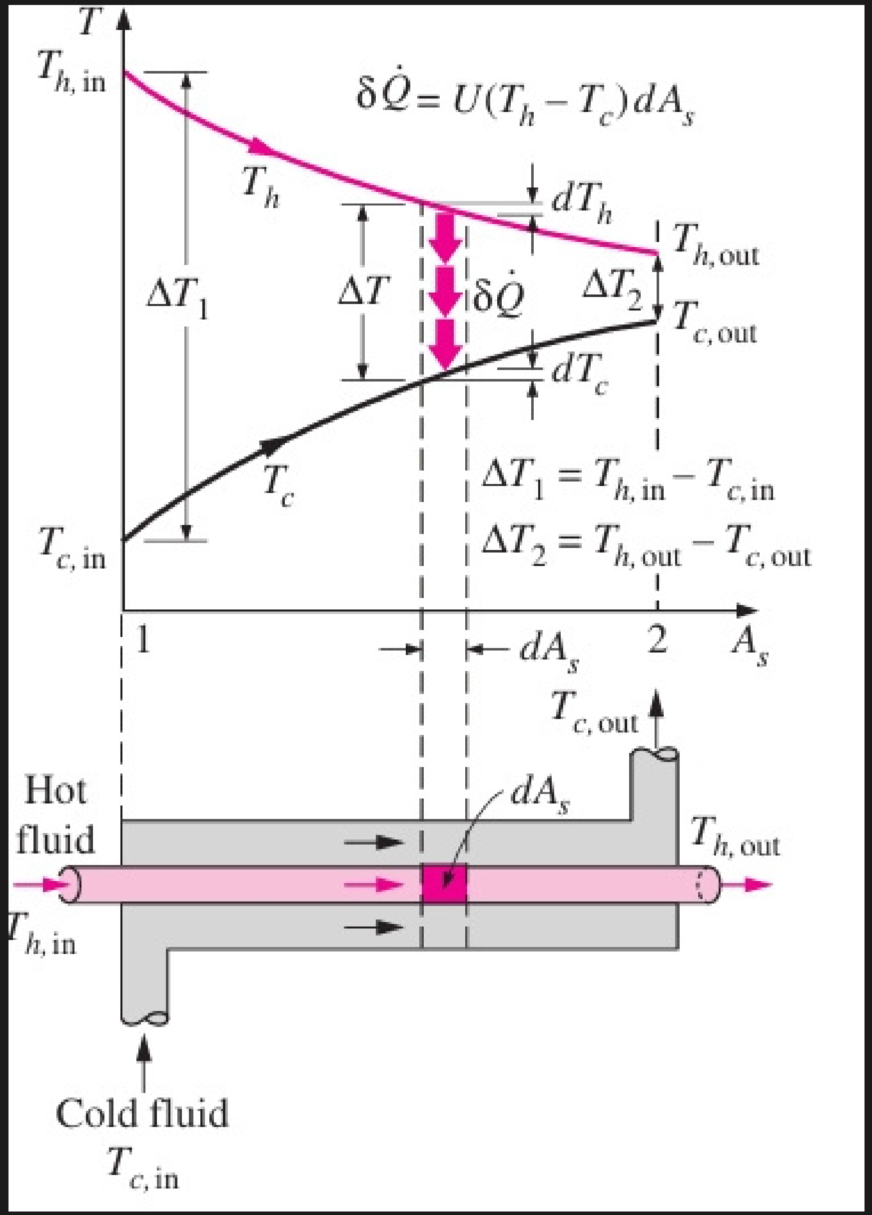
LMTD CONTINUES



(*a*) Parallel-flow heat exchangers

- Note that del.Tlm is always less than del.Tam. Therefore, using del.Tam in calculations instead of del.Tlm will overestimate the rate of heat transfer in a heat exchanger between the two fluids.

- The error increases to undesirable levels when del.T1 differs from del.T2 by greater amounts.



$$\dot{Q} = UA_s\,\Delta T_{\mathrm{lm}}$$

$$\Delta T_{\mathrm{lm}} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1/\Delta T_2)}$$

Therefore, we should always use the logarithmic mean temperature difference when determining the rate of heat transfer in a heat exchanger

Multipass and Cross-Flow Heat Exchangers: Use of Correction Factor

$$\Delta T_{\text{lm}} = F\,\Delta T_{\text{lm},\,CF}$$

The correction factor F for a heat exchanger is a measure of deviation of the del.Tlm from the corresponding values for the counter-flow case.

$$R = \frac{T_1 - T_2}{t_2 - t_1} = \frac{(\dot{m}C_p)_{\text{tube side}}}{(\dot{m}C_p)_{\text{shell side}}}$$

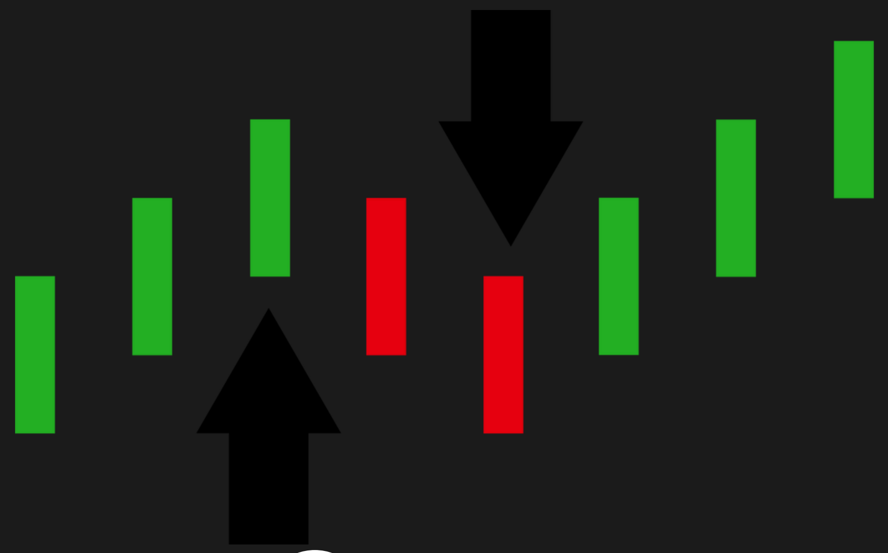
Value of R ranges from 0 to infinity , if R =0 there is phase change in shell side and if infinity there is phase change along tubeside

$$P = \frac{t_2 - t_1}{T_1 - t_1}$$

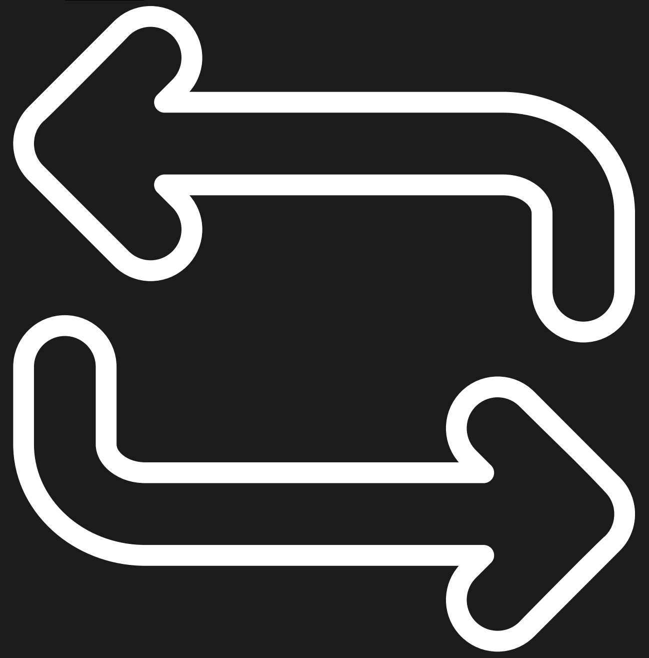
Values of P ranges from 0 to 1, and for the condensers and boilers ,the value of correction factor will be 1 of course

EFFECTIVENESS NTU METHOD

A second kind of problem encountered in heat exchanger analysis is the determination of the **heat transfer rate** and the **outlet temperatures** of the hot and cold fluids for prescribed fluid mass flow rates and **inlet temperatures** when the **type and size** of the heat exchanger are specified.



- **Effectiveness (ϵ)**: A dimensionless parameter which measures the efficiency of a heat exchanger.
- **Number of Transfer Units (NTU)**: Indicates heat transfer performance



the value of NTU is a measure of the **heat transfer surface area As.** Thus, the larger the **NTU**, the larger the heat exchanger.

IMPORTANT RELATIONS

$$\text{NTU} = \frac{UA_s}{C_{\min}} = \frac{UA_s}{(\dot{m}C_p)_{\min}}$$

number of transfer units NTU

$$\dot{Q}_{\max} = C_{\min}(T_{h,\,\text{in}} - T_{c,\,\text{in}})$$

maximum heat transfer rate

$$c = \frac{C_{\min}}{C_{\max}}$$

Heat capacity Ratio

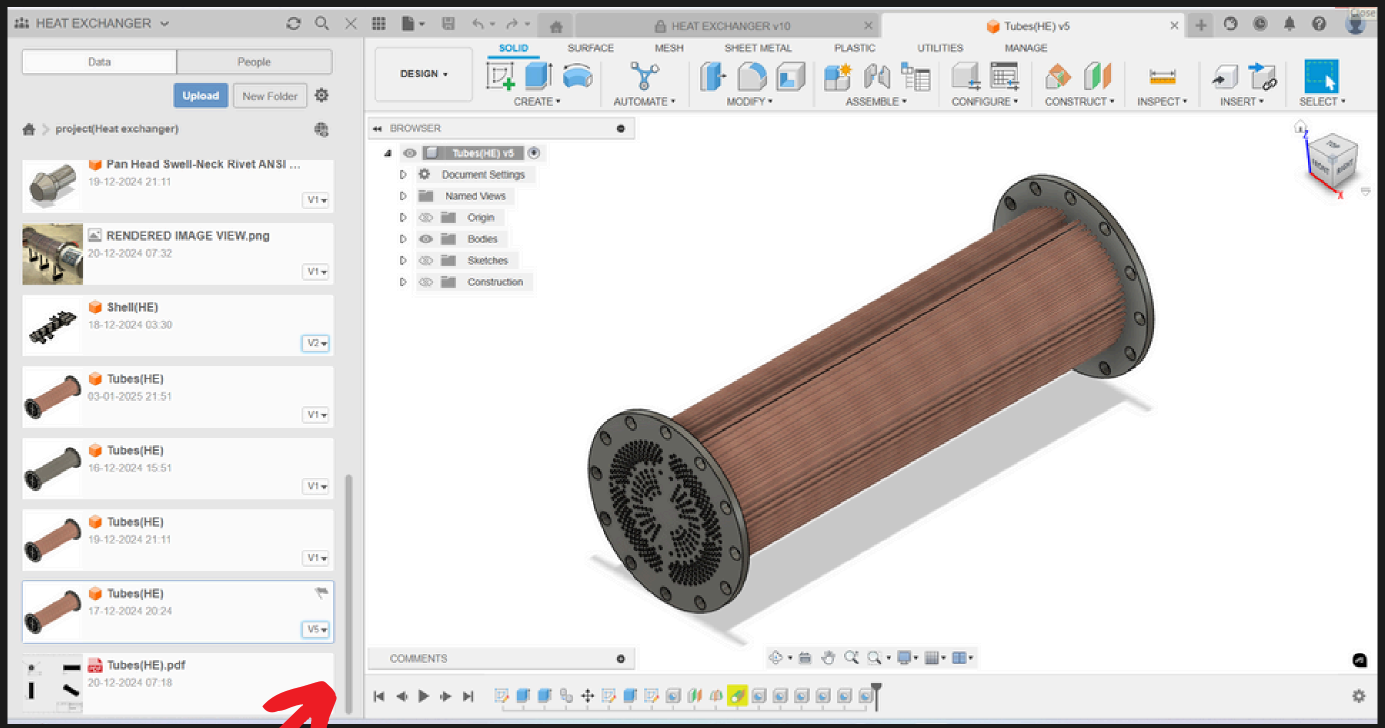
$$\Delta T_{\max} = T_{h,\,\text{in}} - T_{c,\,\text{in}}$$

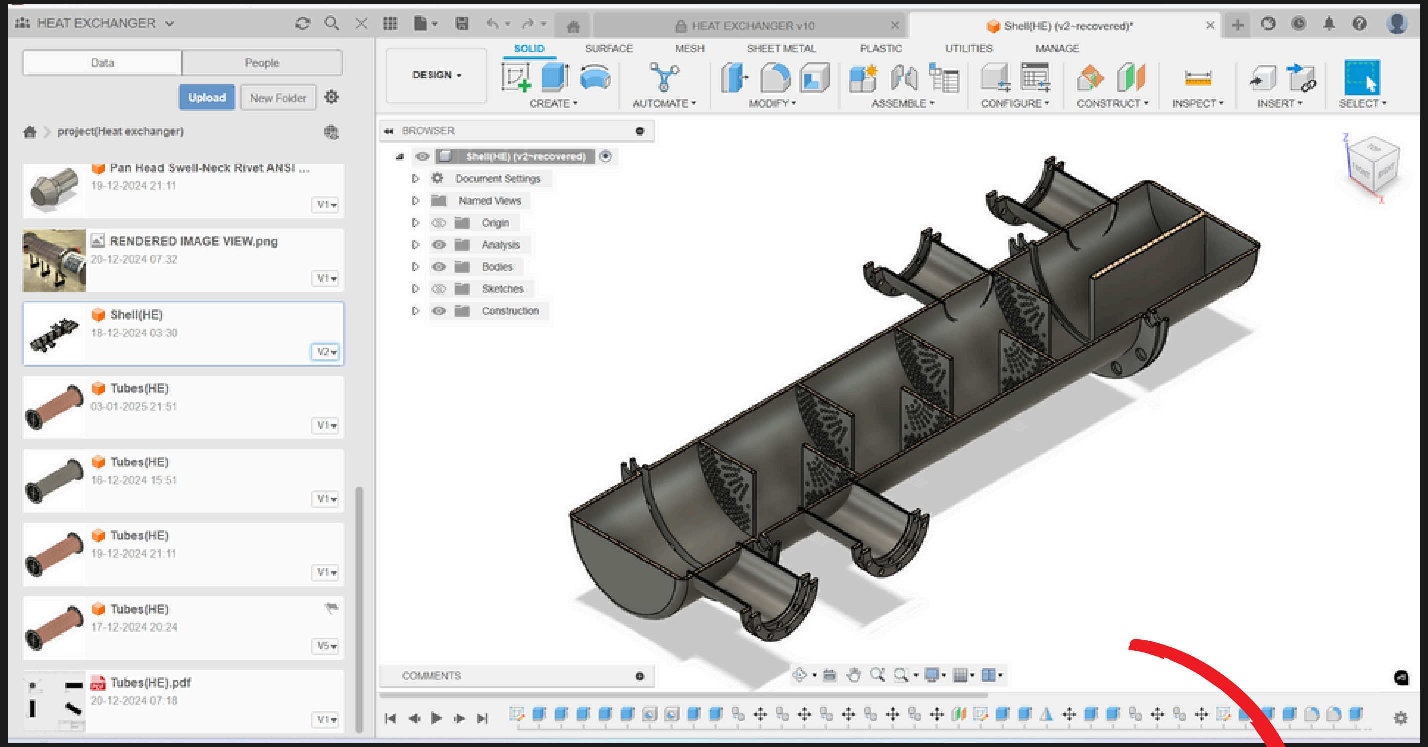
maximum temperature difference

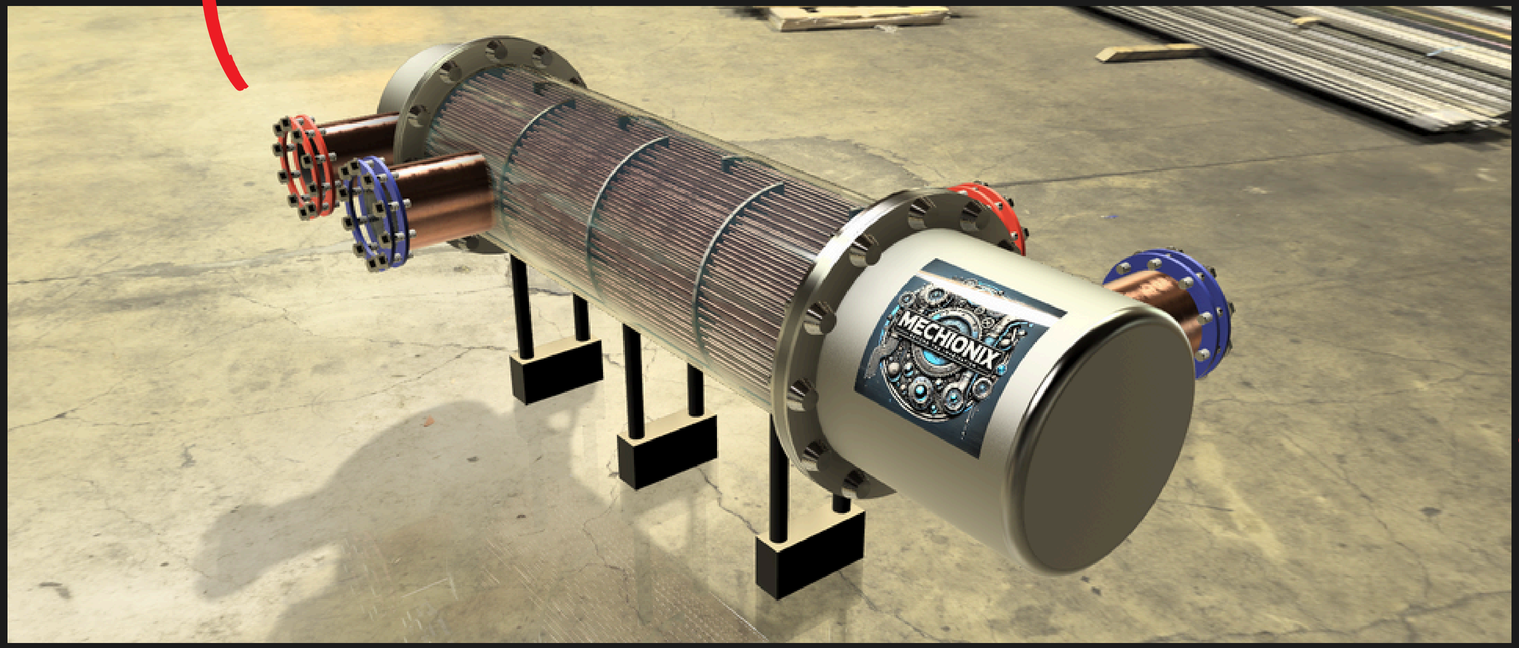
$$\varepsilon = \frac{\dot{Q}}{\dot{Q}_{\max}} = \frac{\text{Actual heat transfer rate}}{\text{Maximum possible heat transfer rate}}$$

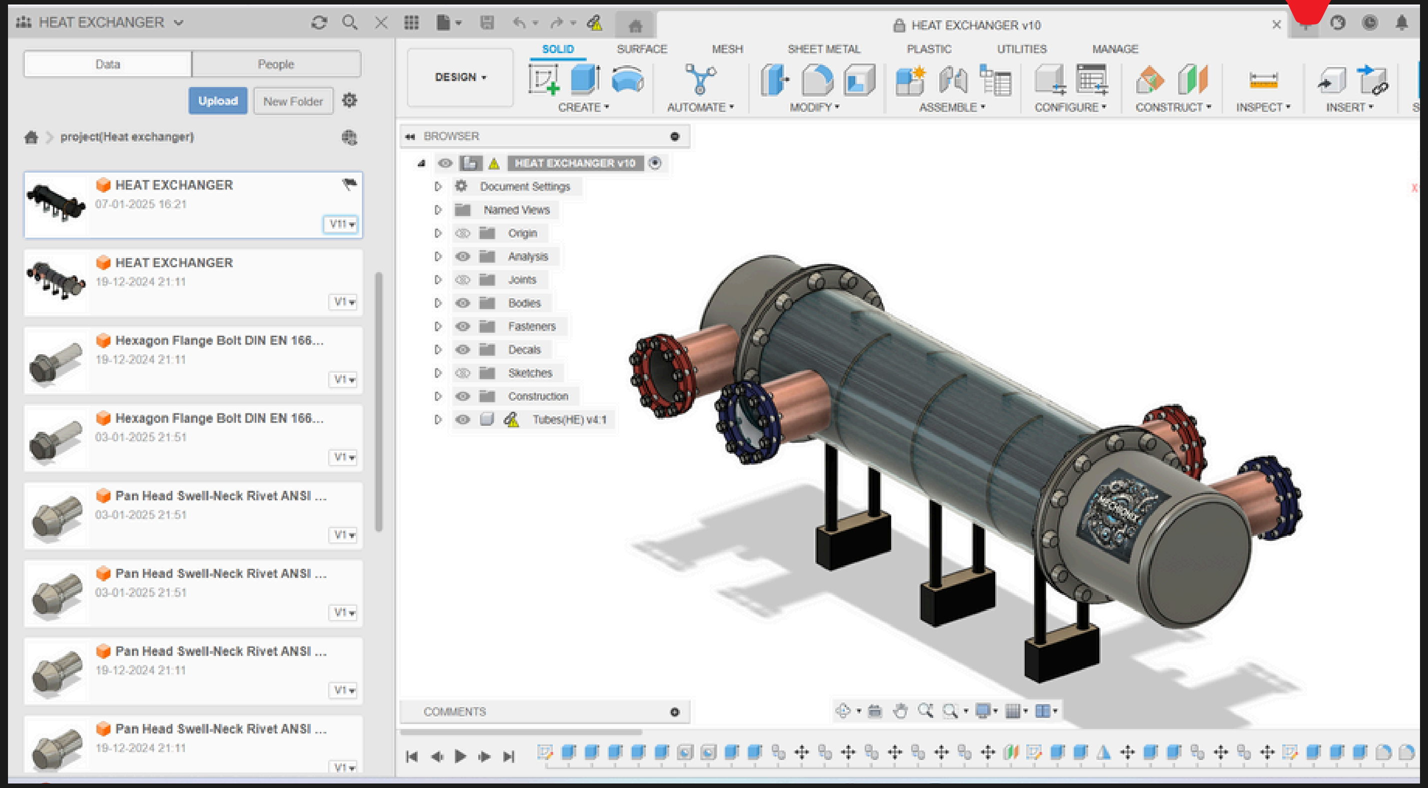
Effectiveness

FUSION - 360 (journey begins)



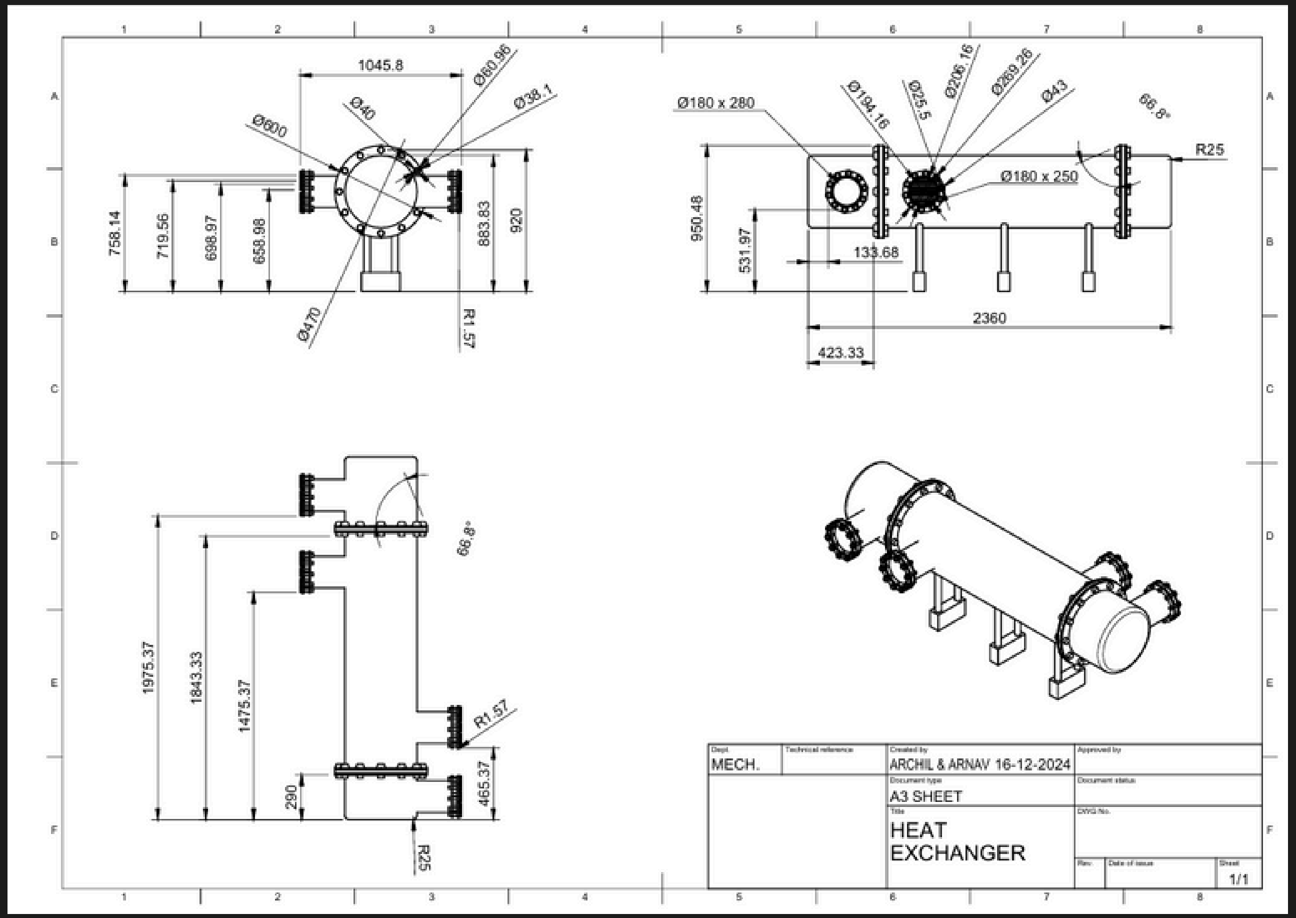


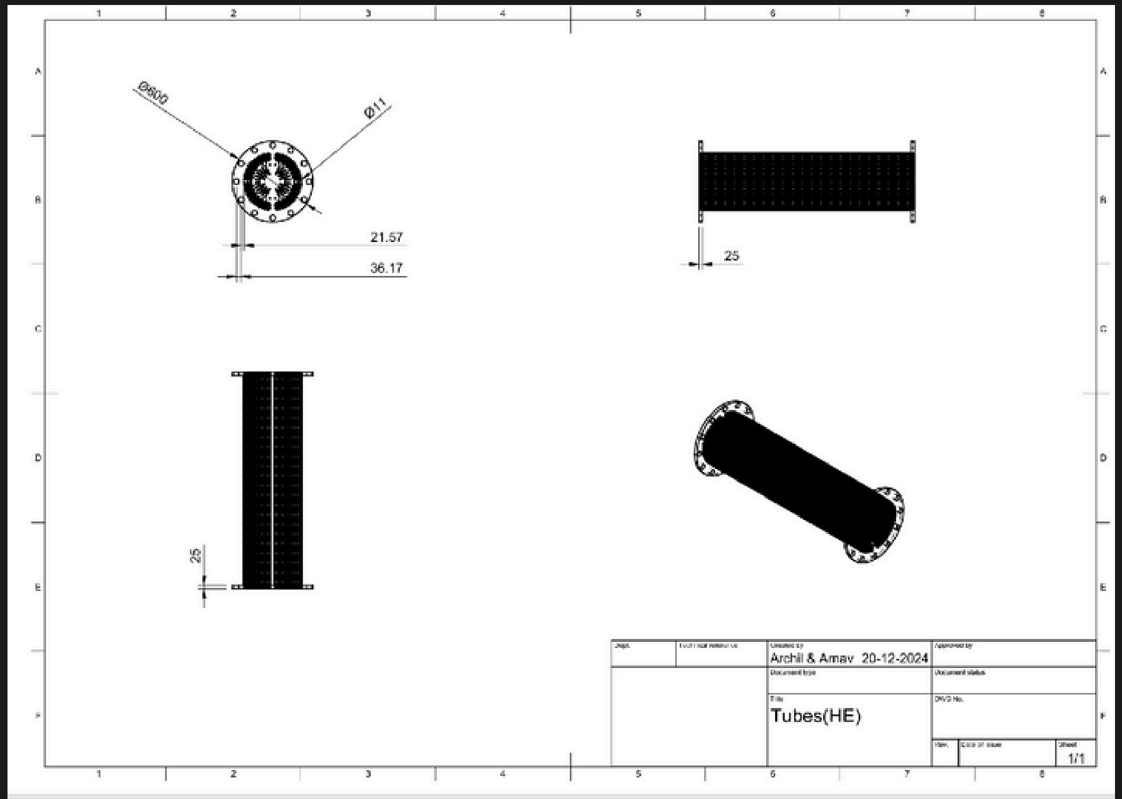




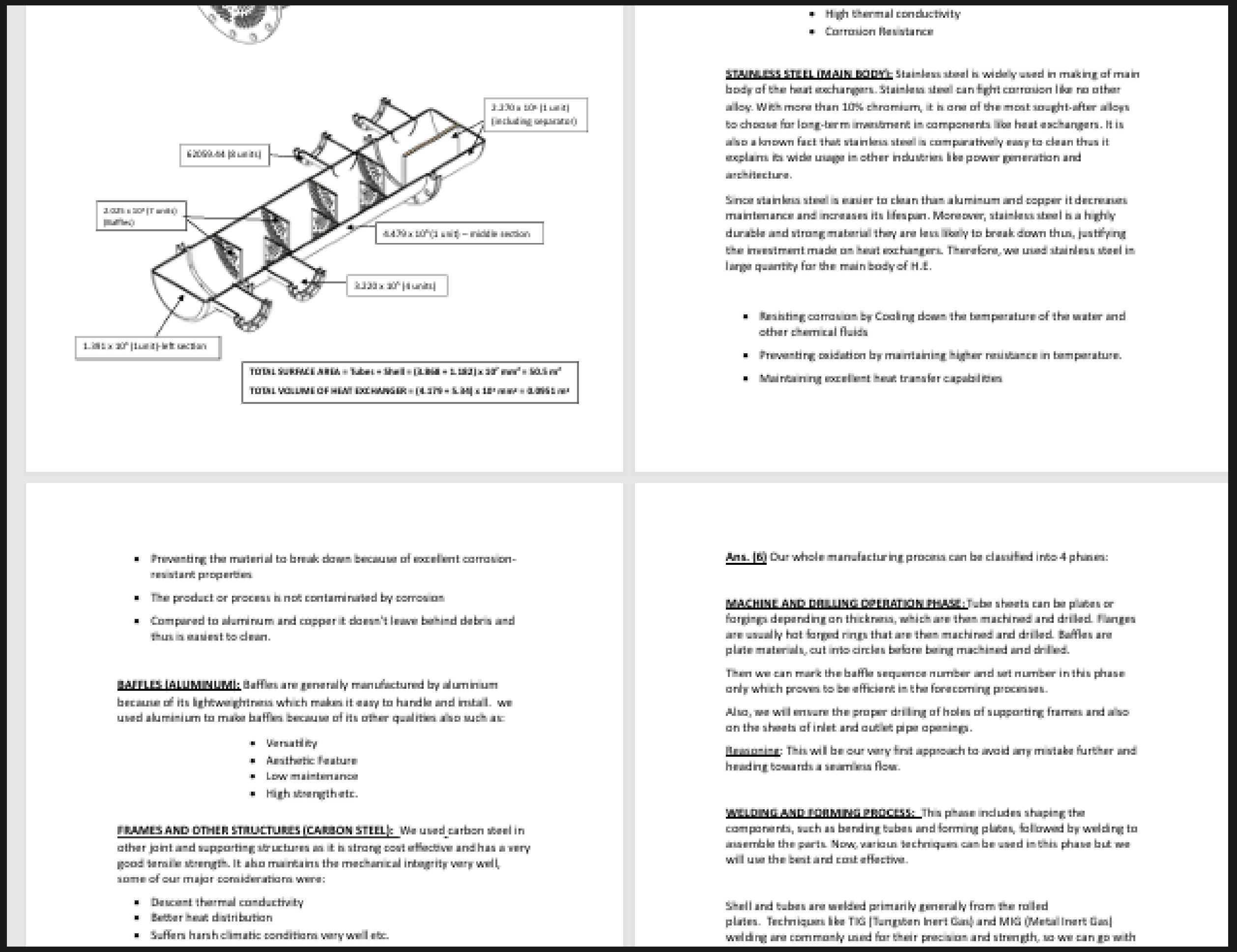
mid term eval

- CAD model with detailed rendering
- Drawing of our heat exchanger with detailed views
- Applications of our heat exchanger
- Material selection Justification
- Manufacturing Techniques
- Overall cost estimation
- Surface area and volume calculation





Mid-term eval
report



TOTAL SURFACE AREA = Tubes + Shell = (3.868 + 1.182) x 10⁷ mm² = 50.5 m²

TOTAL VOLUME OF HEAT EXCHANGER = (4.179 + 5.34) x 10⁸ mm³ = 0.0951 m³

- High thermal conductivity
- Corrosion Resistance

STAINLESS STEEL (MAIN BODY): Stainless steel is widely used in making of main body of the heat exchangers. Stainless steel can fight corrosion like no other alloy. With more than 10% chromium, it is one of the most sought-after alloys to choose for long-term investment in components like heat exchangers. It is also a known fact that stainless steel is comparatively easy to clean thus it explains its wide usage in other industries like power generation and architecture.

Since stainless steel is easier to clean than aluminum and copper it decreases maintenance and increases its lifespan. Moreover, stainless steel is a highly durable and strong material they are less likely to break down thus, justifying the investment made on heat exchangers. Therefore, we used stainless steel in large quantity for the main body of H.E.

- Resisting corrosion by Cooling down the temperature of the water and other chemical fluids
- Preventing oxidation by maintaining higher resistance in temperature.
- Maintaining excellent heat transfer capabilities

- Preventing the material to break down because of excellent corrosion-resistant properties
- The product or process is not contaminated by corrosion
- Compared to aluminum and copper it doesn't leave behind debris and thus is easiest to clean.

BAFFLES (ALUMINUM): Baffles are generally manufactured by aluminium because of its lightweightness which makes it easy to handle and install. we used aluminium to make baffles because of its other qualities also such as:

- Versatility
- Aesthetic Feature
- Low maintenance
- High strength etc.

FRAMES AND OTHER STRUCTURES (CARBON STEEL): We used carbon steel in other joint and supporting structures as it is strong cost effective and has a very good tensile strength. It also maintains the mechanical integrity very well, some of our major considerations were:

- Descent thermal conductivity
- Better heat distribution
- Suffers harsh climatic conditions very well etc.

Ans. (6) Our whole manufacturing process can be classified into 4 phases:

MACHINE AND DRILLING OPERATION PHASE: Tube sheets can be plates or forgings depending on thickness, which are then machined and drilled. Flanges are usually hot forged rings that are then machined and drilled. Baffles are plate materials, cut into circles before being machined and drilled.

Then we can mark the baffle sequence number and set number in this phase only which proves to be efficient in the forecoming processes.

Also, we will ensure the proper drilling of holes of supporting frames and also on the sheets of inlet and outlet pipe openings.

Reasoning: This will be our very first approach to avoid any mistake further and heading towards a seamless flow.

WELDING AND FORMING PROCESS: This phase includes shaping the components, such as bending tubes and forming plates, followed by welding to assemble the parts. Now, various techniques can be used in this phase but we will use the best and cost effective.

Shell and tubes are welded primarily generally from the rolled plates. Techniques like TIG (Tungsten Inert Gas) and MIG (Metal Inert Gas) welding are commonly used for their precision and strength, so we can go with

CFD for Simulation

CFD enables the study of **fluid behaviour** across various conditions without expensive prototype

Navier-stokes Theorem play a very important role as the governing equations for the fluid flow in CFD

CFD Analysis is **cost efficient**, provide detailed insights of the fluid flow , saves time and is versatile

We knew about **Laminar flow** , transition and turbulent flow along with significance of **reynold's number**

- **Boundary COND.**
- Neumann (gradient)
- dirichlet (direct)
- mixed

- **Initial COND.**
- Crucial (uniquqe & reliable solution
- Inorrect I.C. leads to convergence issues.

FINITE VOLUME METHOD

Step 1: Domain Division

The computational domain is divided into finite volumes to facilitate analysis.

Step 2: Governing Equations

Governing equations are integrated over each finite volume for precise calculations.

Step 3: Boundary Fluxes

Fluxes are applied at the boundaries of each volume to maintain flow continuity.

Mass Conservation

Ensures conservation of mass, crucial for accurate simulations in fluid dynamics.

Momentum Conservation

Maintains momentum conservation, essential for realistic fluid behavior.

Energy Conservation

Supports energy conservation, vital for thermal analysis in fluid flows.

CONVECTION

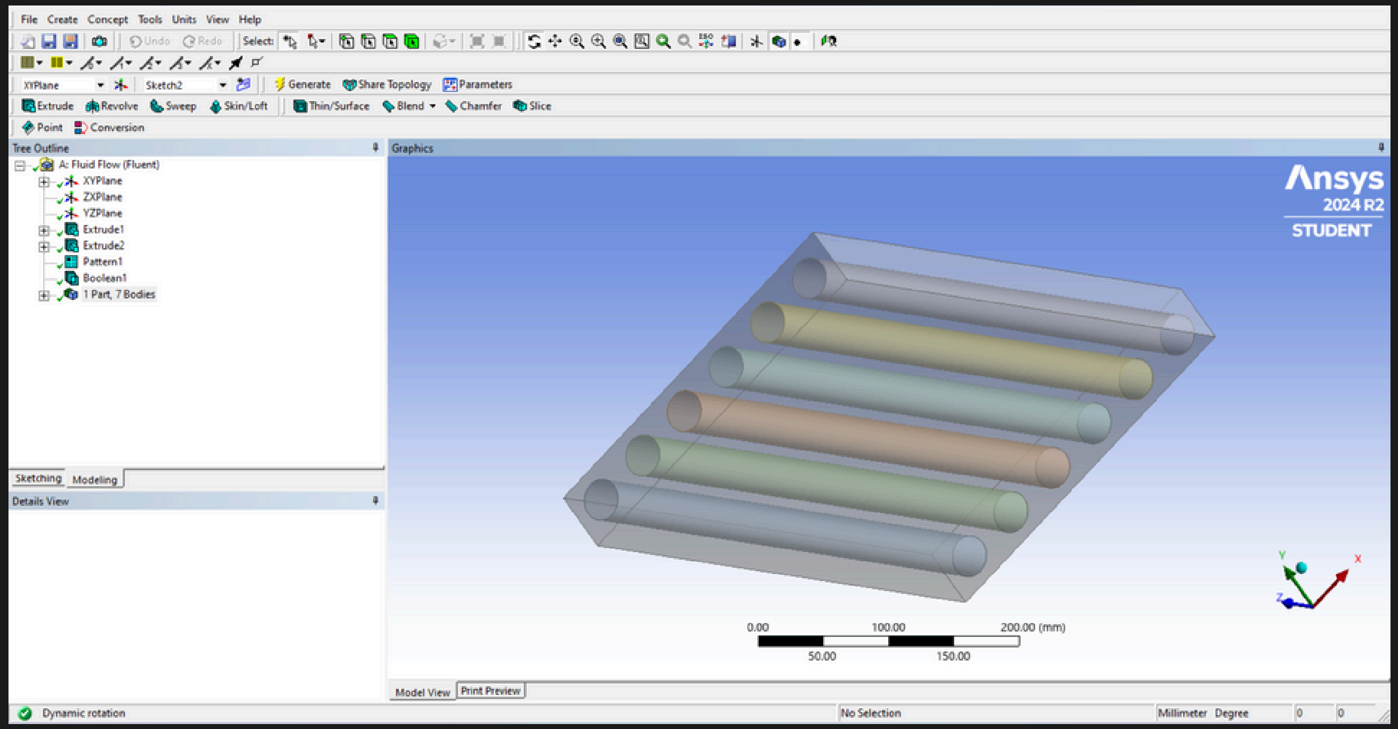
Process of heat transfer in the movement of fluids

NATURAL CONVEC. : When fluid motion is caused by density differences due to temperature variations

Forced convec. : Induced by external forces like fans and pumps ,enhace the heat transfer efficiency

ANSYS

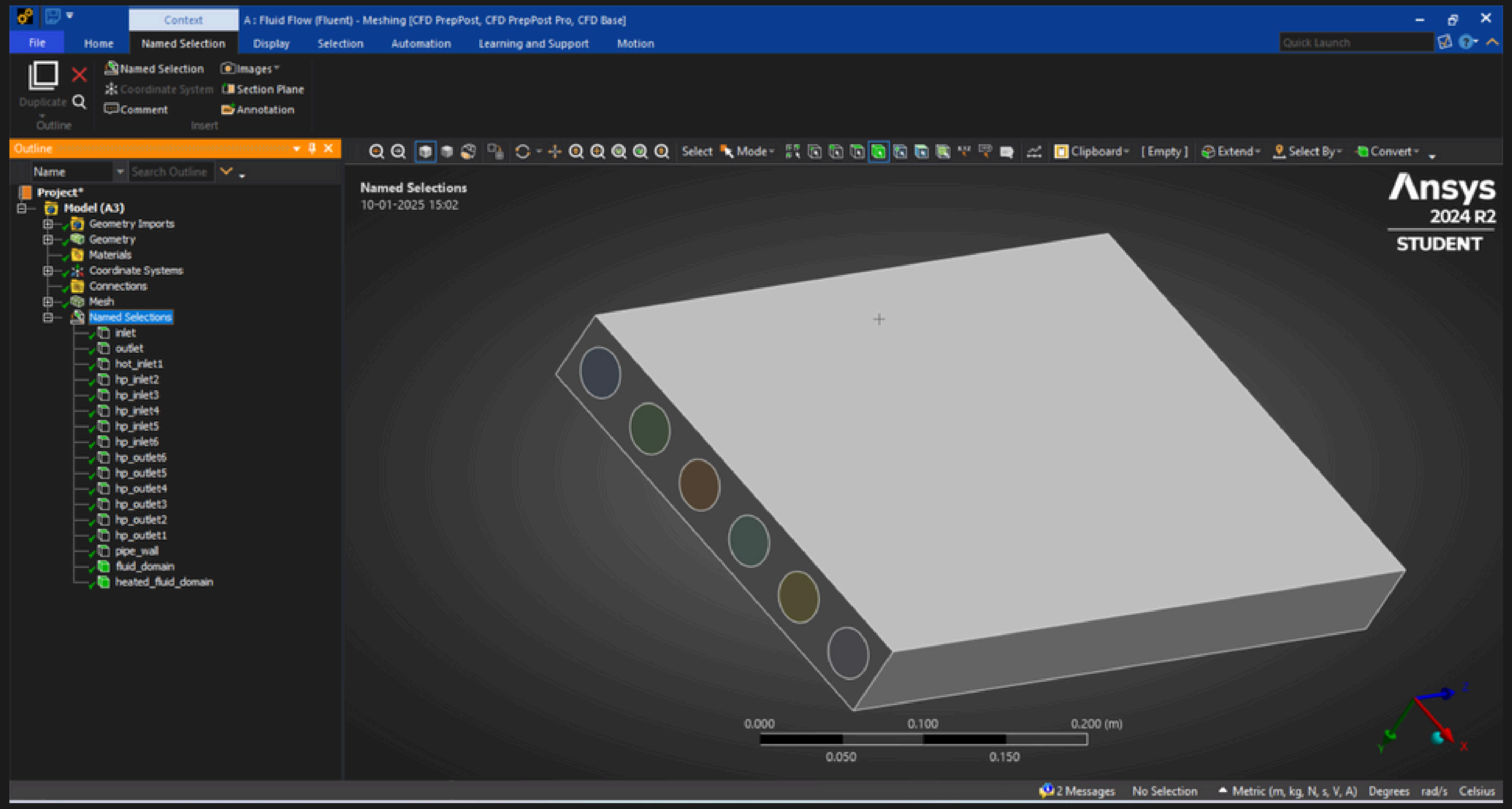
Simulation of cross-flow heat exchanger

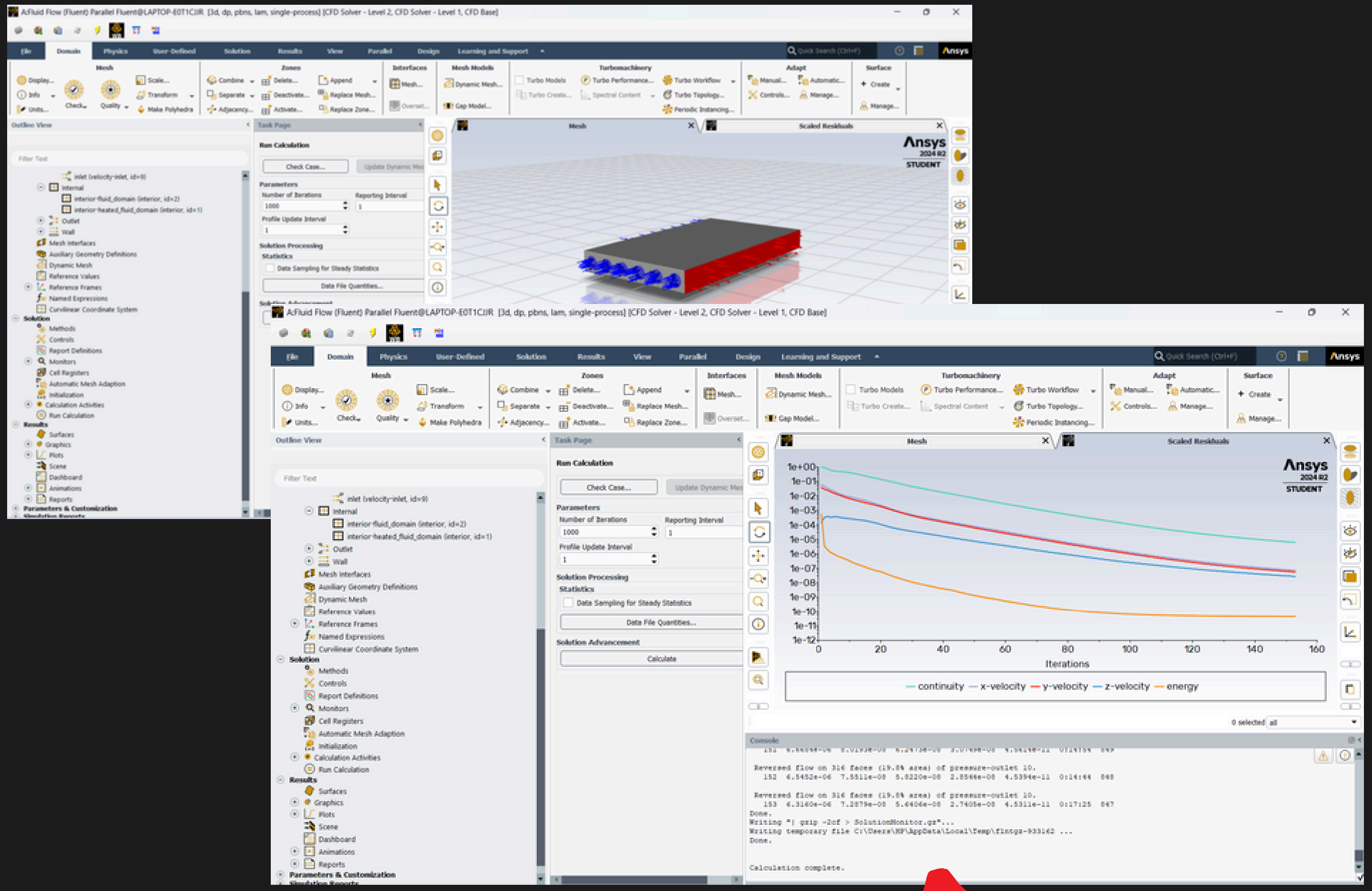


Creating Geometry in in DESIGN MODELLER

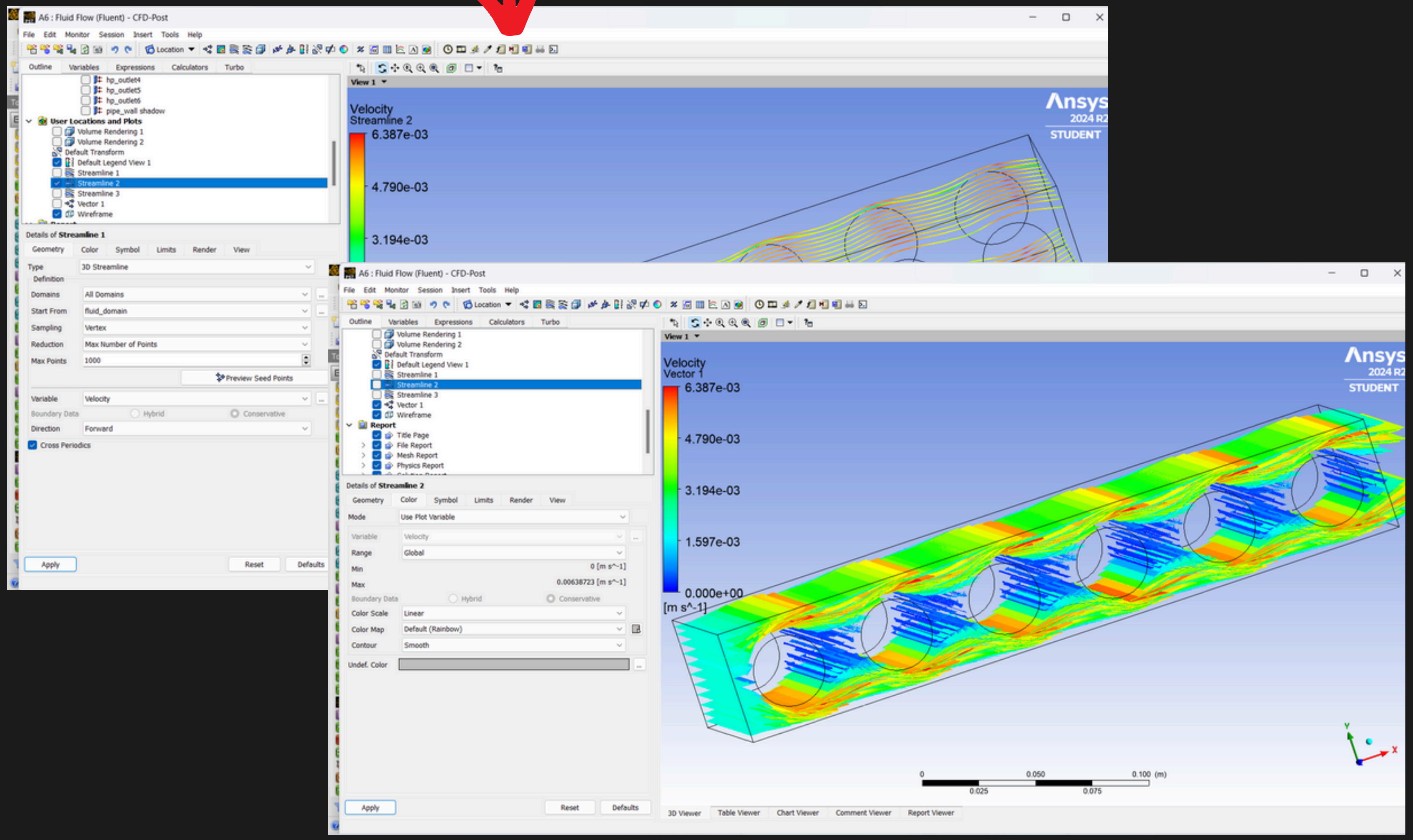
[CROSS flow heat exchanger with 6 tubes for heated fluid and outer shell for cold fluid]

Meshing in Ansys mechanical , dividing the geometry into finite meshes for proper iterative solution





Solution setup in FLUENT SOFTWARE , including initial and boundary conditions , method selection , residuals , error analysis , etc.



Final Simulation in CFD post analysis , in which we can simulate different profiles including temperature , velocity for all the selected domains

THANK YOU