Department of Mechanical Engineering
Bangladesh University of Engineering and Technology

ME 310
Thermo-Fluid System Design

1.5 Credit Hours

INTRODUCTORY CLASS

COURSE OBJECTIVES

- The design, operation and performance of mechanical equipment commonly used in thermo-fluid systems will be reviewed.
- Methods in system simulation and optimization will be introduced.
- Prior courses in **Thermodynamics, Fluid Mechanics and Heat Transfer** will be integrated.
- Based on the knowledge gained in the relevant courses, the students will need to make a **group effort for a thermo-fluid system design.**

COURSE OUTCOME

- This design course will give the students a **meaningful design experience** making the use of the knowledge gained in previous lectures/courses on *Heat transfer, Fluid mechanics, Thermodynamics, and Economics.*
- The students will learn to use **different software** (AutoCAD/SOLIDWORKS, 3E Plus®, HTRI and more) for the design and analysis **in addition to technical calculations on paper**.
- **The students will learn to present their design**
- The students will learn how to **write a technical report detailing both technical and non-technical aspects.**

ENGINEERING DESIGN—DEFINITION

Process **of devising a system, subsystem, component, or process** to meet **desired needs**

A decision making process (often iterative) in which basic science, mathematics and engineering sciences are applied to convert resources optimally to meet a stated objective

TYPES OF DESIGN IN THERMO-FLUID SCIENCE

Process Design: The manipulation of physical and/or chemical processes to meet desired needs.

Example: (a) Introduce boiling or condensation to increase heat transfer rates.

System Design: The process of defining the components and their assembly to function to meet a specified requirement.

Examples: (a) Steam turbine power plant system consisting of turbines, pumps, pipes, and heat exchangers. (b) Hot water heating system, complete with boilers.

Subsystem Design: The process of defining and assembling a small group of components to do a specified function.

Example: Pump/piping system of a large power plant. The pump/piping system is a subsystem of the larger power plant system used to transport water to and from the boiler or steam generator.

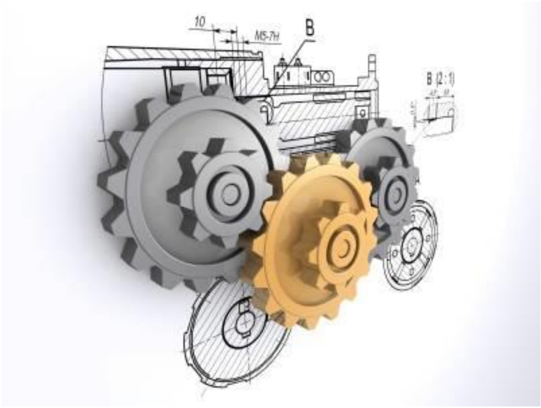
Component Design: Development of a piece of equipment or device.

DIFFERENCE BETWEEN DESIGN AND ANALYSIS

Analysis: **Application of fundamental principles to a well-defined problem.** All supporting information is normally provided, and one **closed-ended solution is possible.**

Design: Application of fundamental principles to an undefined, open problem. All supporting information may not be available and assumptions may need to be made. Several alternatives may be possible. **No single correct answer exists.**

SELECTION VERSUS DESIGN

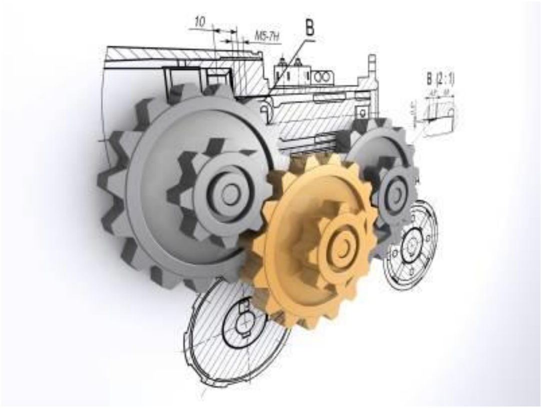


Selection: Largely involves determining the specifications of the item from the requirement for the given task. Based on the specifications, **a choice is made from the various types of items available** with different ratings or features.

Design: Application of fundamental principles to an undefined, open problem. All supporting information may not be available and assumptions may need to be made. Several alternatives may be possible. No single correct answer exists.

Selection and design is frequently employed together in the development of a system

CLASSIFICATION OF THE DESIGN



- Modification of an existing device for

  (a) cost reduction

  (b) improved performance and/or efficiency

  (c) satisfy government codes and standards

  (d) satisfy customer/client preferences

- Selection of existing components for the design of a subsystem or a complete system.

- Creation of a new device or system.

DESIGN PARAMETERS:

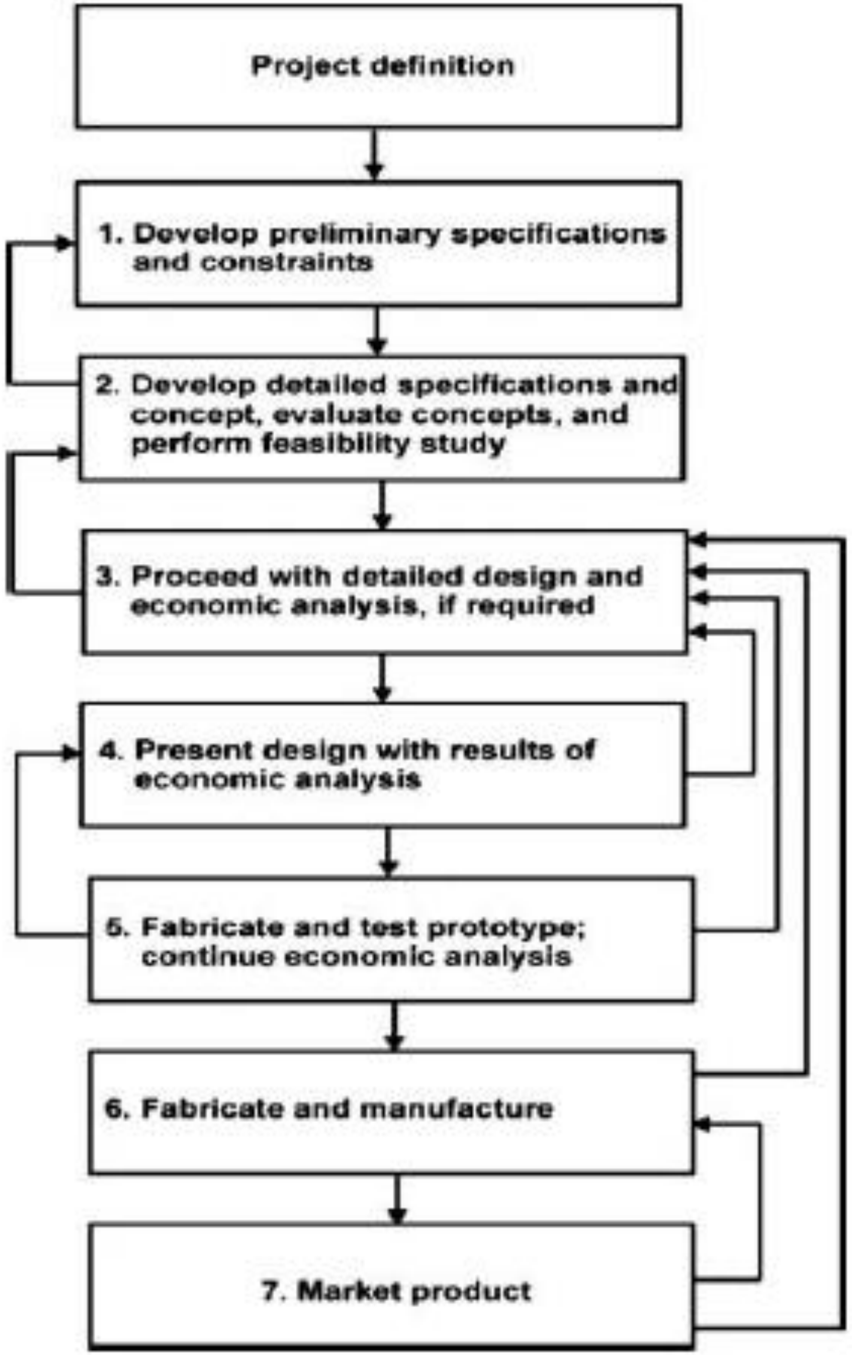
- Materials, cost and economics
- Safety and reliability
- Choice and availability
- Optimization
- Cyclic service
- Codes and Regulations

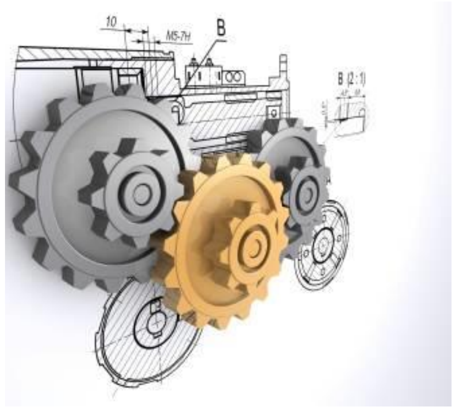
CODES AND STANDARD

A standard is **a set of technical definitions and guidelines** that function as instructions for designers, manufacturers, operators, or users of equipment. **Standards do not have the force of law**, and are voluntary guidelines. **A standard becomes a code when it has been adopted by one or more government agencies and is enforced by law**, or when it has been incorporated into a business contract.

- **International Organization for Standardization (ISO)**
- **American Petroleum Institute (API)**
- **American Society for Testing and Materials (ASTM)**
- **Bangladesh National Building Code (BNBC)**
- **Uniform Mechanical Code (by IAPMO)**
- **Uniform Plumbing Code (by IAPMO)**

GENERAL STEPS IN DESIGN





OPTIMIZATION

It is not enough to obtain a workable system that performs the desired tasks and meet the given constraints.

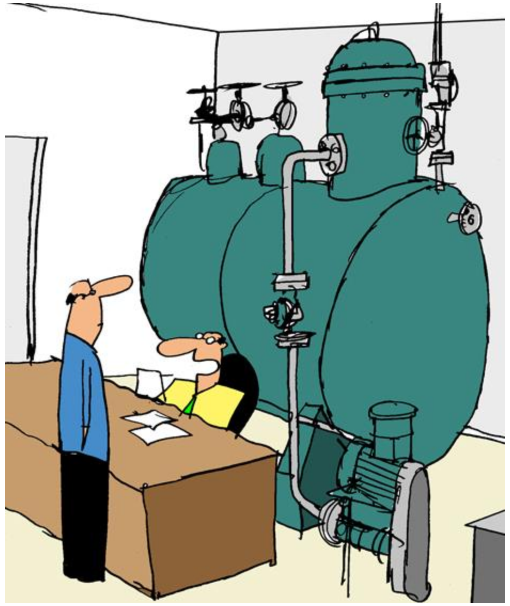
The design that serves the purpose may not be the best. **The definition of best is based on cost, performance, efficiency and some other measures.**

WHAT IS THERMAL/FLUID DESIGN

- Implies calculations and activities based on principles of thermodynamics, heat transfer and fluid mechanics.
- Components - fans, pumps, compressors, engines, heat and mass exchangers, etc.
- Thermal systems generally use a large number of components.
- Processes usually involve fluid motion.

TYPICAL THERMO-FLUID SYSTEMS

- Heat exchangers
- Two phase heat transfer equipment:
  - Boiler
  - Evaporator
  - Condenser
  - Cooling tower
- Thermal systems with internal heat source



TOPICAL COVERAGE

- **Engineering Design:** defining a need, specifying success criteria, identifying alternatives, analysis and optimization, design of experiments, the design report, team work.
- **Thermal Science Review:** thermodynamic fundamentals, fluid properties and basic equations, heat transfer fundamentals.
- **Piping Systems:** Piping and tubing standards, friction factors, pipe roughness, minor losses, major losses, valves, system behavior, measurement of flow rate and pressure drop.

TOPICAL COVERAGE

- **Heat Exchangers:** method of analysis, LMTD, heat transfer in a tube, double piped heat exchangers, shell and tube, cross flow, heat recovery, system design.
- **Economic analysis:** time value of money, comparing alternatives, depreciation and taxes.
- **Optimization:** Introduction and survey of mathematical methods of design optimization.
- **Team Skills:** Effective leadership methods, Efficient meeting skills, Conflict resolution, decision making methods, aspects of organizational behavior.

HOW ARE WE GOING TO DO ALL THAT?

- You will have to do **a design project (group wise)**

- *Your final grade will be a combination of group and individual grades of this* ***project, class performance, assignment, final quiz, presentation etc.***

OVERVIEW OF THE DESIGN PROCESS

- Concept
- Design
- Calculation
- Component selection
- Specification preparation
- Design Report & Presentation

DESIGN PROCESS

Design Problem:

- Design a shell and tube heat exchanger for this service.

Given data:

Hot fluid inlet temperature (T_1)= 160°F

Hot fluid outlet temperature (T_2) = 120°F

Cold fluid inlet temperature (t_1) = 75°F

Cold fluid outlet temperature (t_2) = 120°F

Fouling factor of hot fluid (R_{dg}) = 0.0005 (for gasoline)

Fouling factor of cold fluid (R_{dk}) = 0.001 (for kerosene)

P_{inlet} (for hot fluid) = 50 psia

P_{inlet} (for cold fluid) = 50 psia

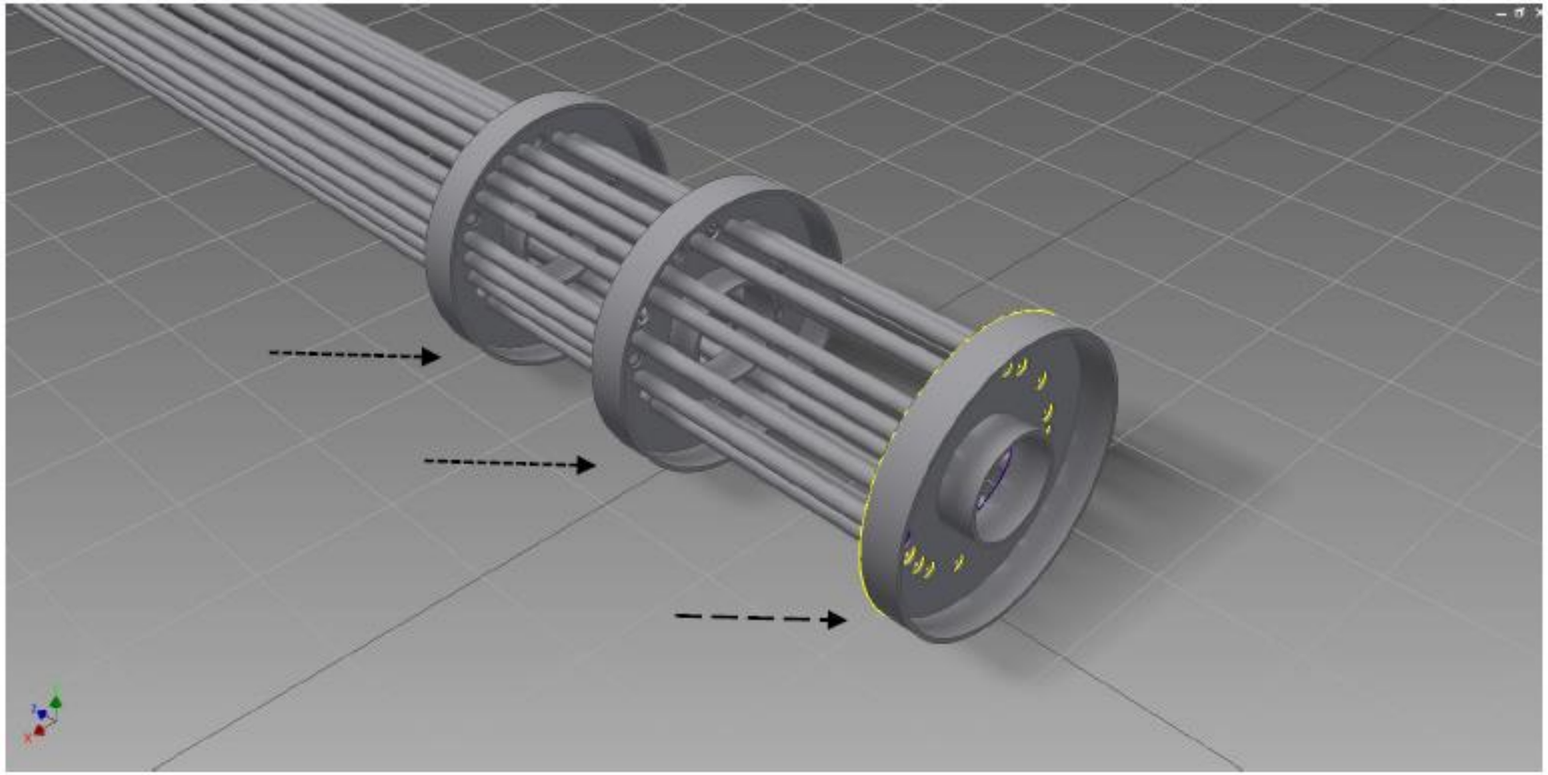
Δp_{max} (for hot fluid) = 7 psi

Δp_{max} (for cold fluid) = 10 psia

Mass flow rate of cold fluid ($\dot{m}_k$) = 150000 $lb.h^{-1}$

DESIGN PROCESS

Design/Drawing of the component/system:



DESIGN PROCESS

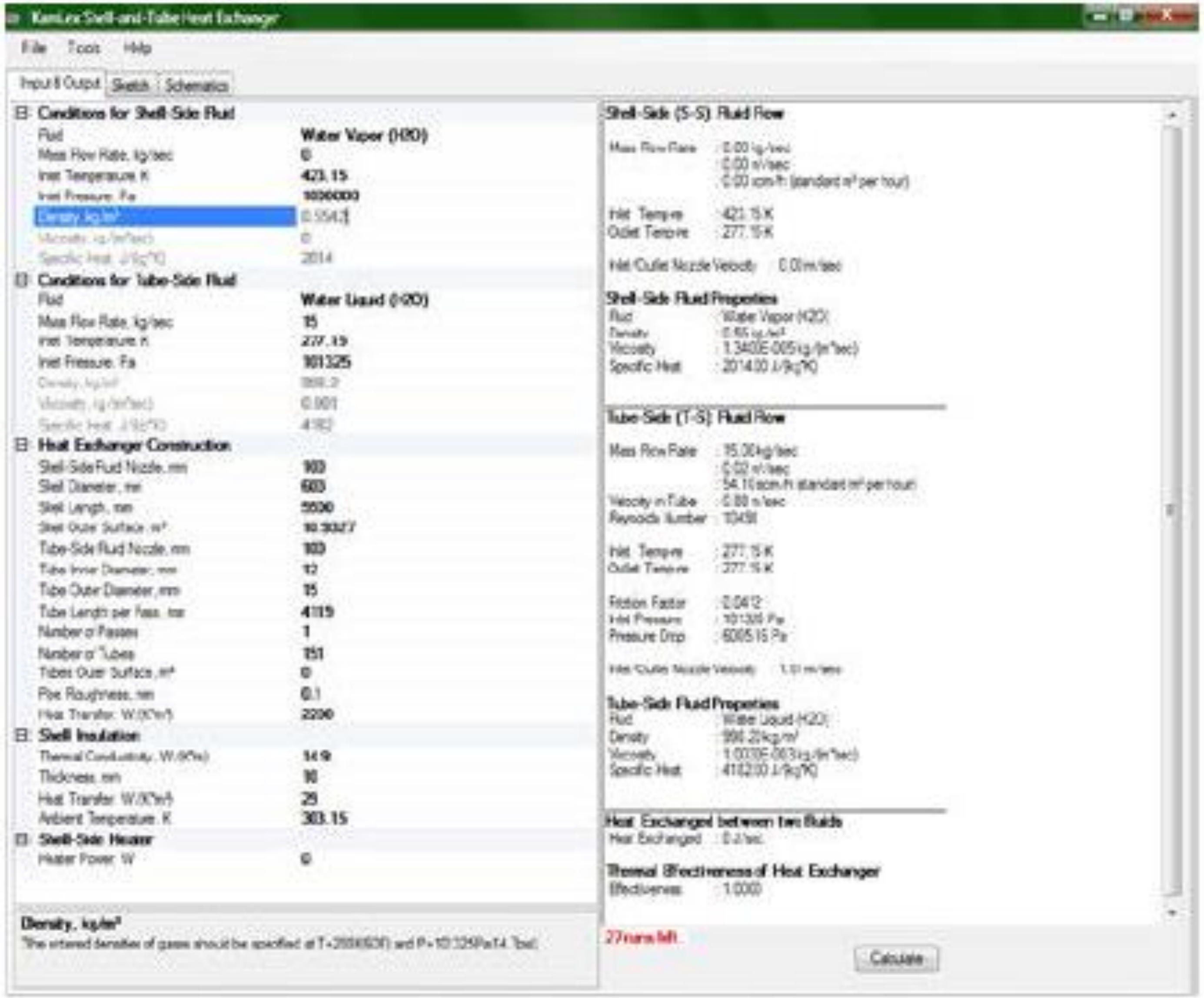
Table: Material Selection Decision Matrix

	Heat Resistance	Inexpensive	Workability	Corrosion Resistance	Availability	Total (High Temp)	Total (Low Temp)
Category Weight	x5	x3	x2	x1 for low temp, x2 for high temp	x2		
Aluminum	1	5	1	4	5	40	31
Carbon Steel	2	5	4	1	5	45	34
Stainless Steel 304	4	3	3	4	3	49	25
Stainless Steel 316	4	2	3	4	2	44	20
Titanium	5	1	2	5	1	44	14

DESIGN PROCESS

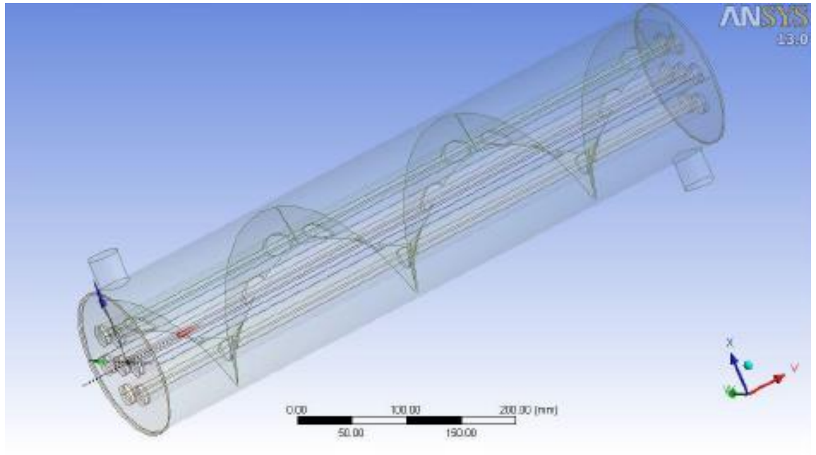
Calculation:

Natural Convection Calculations		
	Initial	Final
gβρ^2/μ^2	1.75E+07	5.70E+07
N.Gr	6.06E+10	8.46E+10
N.Pr	0.708	0.708
Gr*Pr	4.29E+10	6.00E+10
Vertical Cylinders		
h (W/m^2*K)	6.936	5.229
q (W)	393	127
Horizontal Cylinders		
h (W/m^2*K)	6.936	5.229
q (W)	393	127

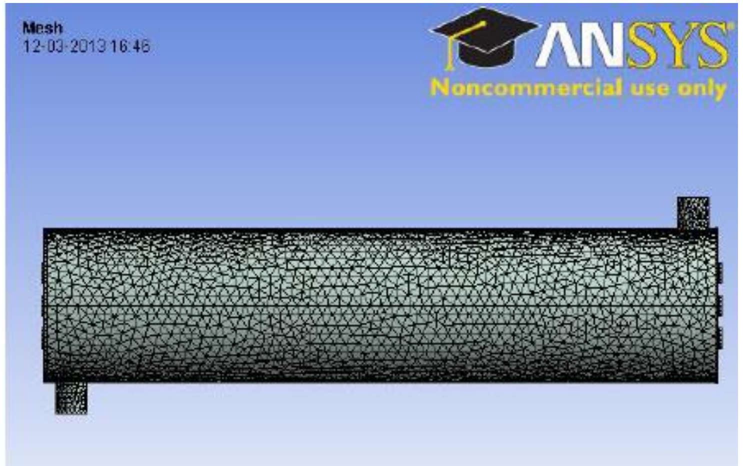


DESIGN PROCESS

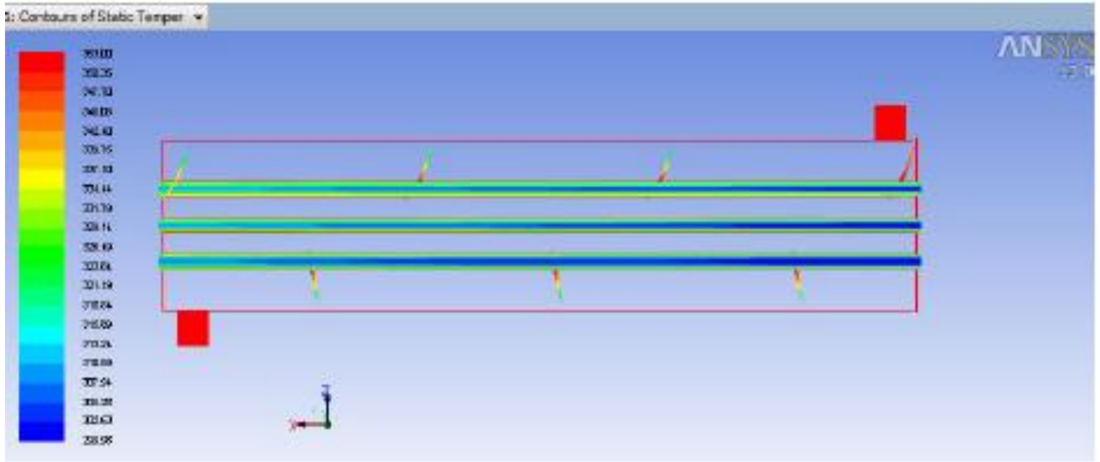
Analysis:



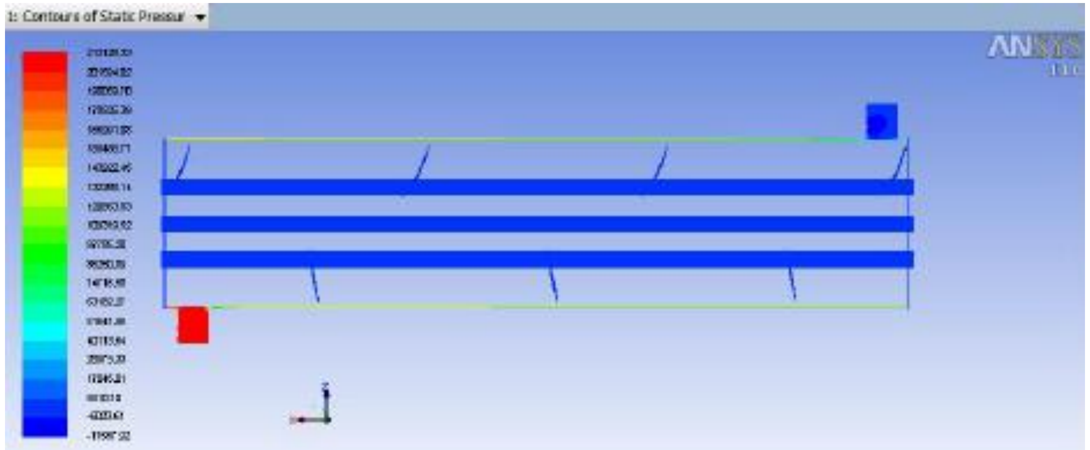
Heat Exchanger configuration



Meshing



Temperature distribution along the shell and tubes



Velocity distribution along the shell and tubes

DESIGN PROCESS

Heat Exchanger Specification Sheet

HTRI

HEAT EXCHANGER SPECIFICATION SHEET

Page 1

SI Units

		Job No.			
Customer		Reference No.			
Address		Proposal No.			
Plant Location		Date	11/10/2015	Rev	
Service of Unit		Item No.			
Size	154.050 x 1037.97 mm	Type BEU	Horz.	Connected In	1 Parallel 1 Series
Surf/Unit (Gross/Eff)	0.70 / 0.68 m2	Shell/Unit	1	Surf/Shell (Gross/Eff)	0.70 / 0.68 m2

PERFORMANCE OF ONE UNIT

Fluid Allocation		Shell Side		Tube Side	
Fluid Name		hot water		cold water	
Fluid Quantity, Total	kg/hr	1080.01		2711.89	
Vapor (In/Out)					
Liquid		1080.01	1080.01	2711.89	2711.89
Steam					
Water		1080.01	1080.01	2711.89	2711.89
Noncondensables					
Temperature (In/Out)	C	90.00	70.84	30.00	37.66
Specific Gravity		0.9722	0.9722	0.9844	0.9844
Viscosity	mN-s/m2	0.3540	0.3540	0.7250	0.7250
Molecular Weight, Vapor					
Molecular Weight, Noncondensables					
Specific Heat	kJ/kg-C	4.1964	4.1964	4.1781	4.1781
Thermal Conductivity	W/m-C	0.6702	0.6702	0.6232	0.6232
Latent Heat	kJ/kg				
Inlet Pressure	kPa	100.001		100.001	
Velocity	m/s	9.572e-2		0.60	
Pressure Drop, Allow/Calc	kPa	100.002	0.563	100.002	3.021
Fouling Resistance (min)	m2-K/W	0.000200		0.000200	

Heat Exchanged W	24116.9	MTD (Corrected)	45.0 C		
Transfer Rate, Service	781.91 W/m2-K	Clean	1199.87 W/m2-K	Actual	787.39 W/m2-K

LET'S GO THROUGH

AN EXAMPLE!

Designing a Heat Exchanger

Design a shell and tube heat exchanger that will remove 44.6 kilowatts from the process steam.

- **Cooling water**
  - Inlet temperature 30 °C
  - Exit temperature
- **Process steam**
  - Inlet temperature of steam 130 deg-C
  - Inlet pressure 3.5 bar

DESIGN REQUIREMENTS

Meet 44.6 kilowatts of heat transfer

Minimize tube and shell side pressure drops

Minimize cost

- Heat exchanger weight
- Selected material

Minimize the heat exchanger volume

CALCULATION

Case	Over Design	Duty (MegaWatts)	Shell DP (kPa)	Tube DP (kPa)	Shell ID (mm)	Baffle Spacing (mm)	Tube Length (m)	Tube Dia. (mm)	Tube Pitch Ratio	Cross Passes
1	463	0.0446	0.044	10.086	152.400	150.000	0.762	12.700	1.5	3
2	467	0.0446	0.043	10.068	152.400	225.000	0.762	12.700	1.5	3
3	244	0.0446	0.040	5.798	152.400	150.000	0.762	16.850	1.5	3
4	246	0.0446	0.040	5.791	152.400	225.000	0.762	16.850	1.5	3
5	98	0.0446	0.038	6.637	152.400	150.000	0.762	21.000	1.5	3
6	100	0.0446	0.038	6.631	152.400	225.000	0.762	21.000	1.5	3

CALCULATION

DOE #1
- Shell flow rate
- Shell ID
- Tube OD
- Tube Length
- Type of Flow
- Fluid Allocation

DOE #2
- Baffle
- Square Tube Layout
- Tube thickness
- Number of Tube Passes
- Baffle Space
- Baffle Cut

DOE #3
- Tube Material
- Shell Material
- Triangular Tube Layout

15 Engineering Variables

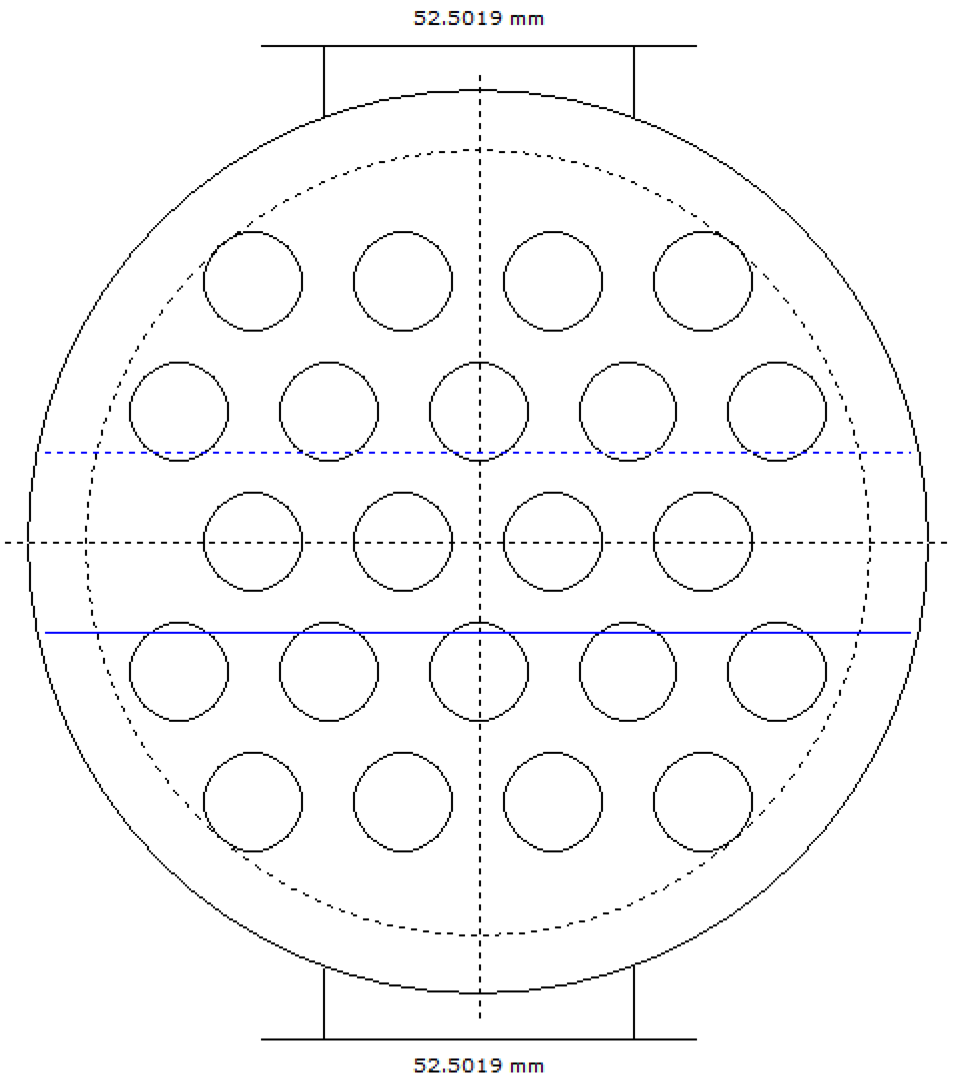
- Tube OD
- Shell ID
- Tube Length
- Shell flow rate

4 Final Variables

Optimization

CONCLUSIONS

Using the MATLAB and other tools provided, the original design was optimized in order to satisfy the design requirements.



TEMA type	AEL
Shell diameter	152.400 mm
Outer tube limit	132.675 mm
Height under inlet nozzle	23.997 mm
Height under outlet nozzle	23.997 mm
Tube type	Plain
Tube diameter	16.850 mm
Tube pitch	25.275 mm
Tube layout angle	30
Number of tubes (specified)	18
Number of tubes (calculated)	18
Number of tie rods	4
Number of seal strip pairs	1
Number of passes	1
Baffle cut % diameter	40

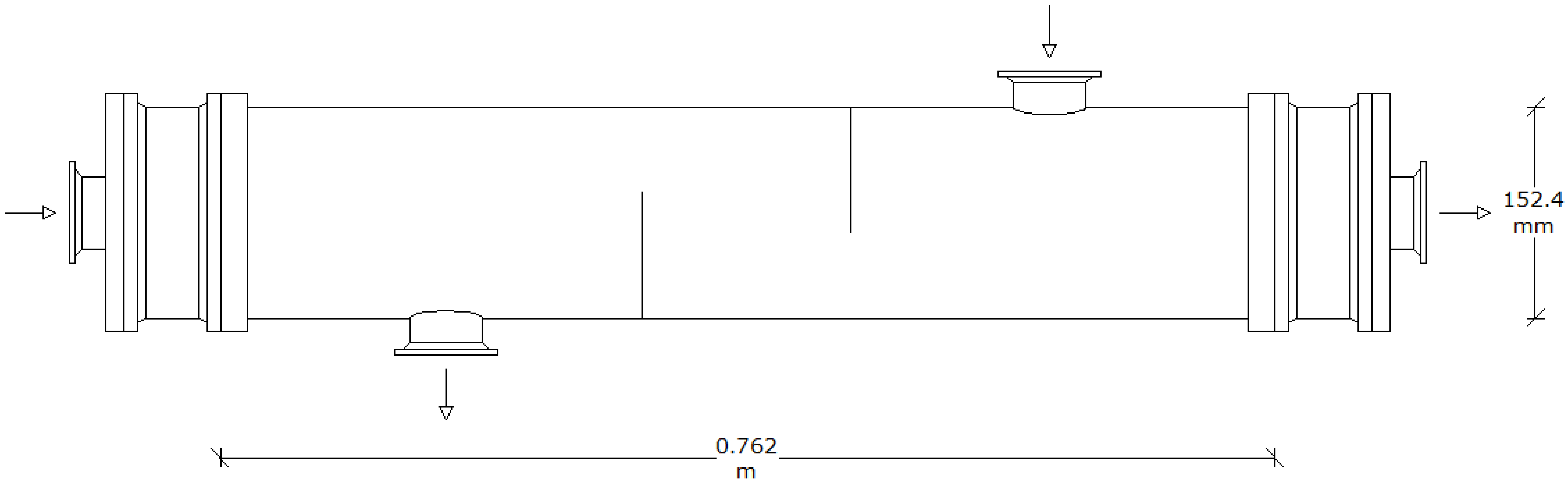
TUBEPASS DETAILS

Pass	Rows	Tubes	Plugged
1	5	22	0

SYMBOL LEGEND

- Tube
- Plugged tube
- Tie rod
- Impingement rod
- Dummy tube
- Seal rod
- Seal strip/Skid bar

TEMA type	AEL
Shell diameter	152.4 mm
Tube length	0.762 m
Dry weight	170 kg/shell
Wet weight	192 kg/shell
Bundle weight	18 kg/shell



ASSIGNMENT

Make a 3D model of the heat exchanger in solid works

Thank You!