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Software Development for Thermal Design of Shell and Tube Heat Exchanger

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Abstract— thermal design of shell and tube heat exchanger for different size and requirement become very time consuming and complicated. Despite of such a long time consuming designing procedure the final design obtain is not optimum, heat exchanger rate is less comparatively and moreover the space required is also felt more. In this paper an attempt is made to develop software for thermal design of shell and tube heat exchanger so that thermal design become very fast accurate, and more optimum in terms of number of tubes, baffle spacing and allowable pressure drop to achieve maximum heat transfer coefficient and minimum heat transfer area, which is not possible In case of manual calculation.

Keywords— shell and tube heat exchanger; software architecture; flow diagram; thermal design; optimum design

I. INTRODUCTION

A heat exchanger is a device, which transfer internal thermal energy between two or more fluids at different temperature. Without this essential piece of equipment most industrial process would be impossible. There are various types of heat exchangers, each of which is designed to accommodate the requirements of the specific needs at hand. Shell and tube heat exchanger are by far the most common because of their relative simplicity and ability to handle the largest variety of fluids. They are also used in conventional energy production as condenser, feed water heaters, and steam generators for pressurized water reactor plants. They are proposed for many alternative energy applications including ocean thermal and geothermal. And they are used in some refrigeration and air conditioning services.

The design of shell and tube heat exchanger based on thermal and mechanical aspects. The both - thermal and mechanical design of shell and tube heat exchanger for different size and requirement become very time consuming and complicated. Despite of such a long time consuming designing procedure the final design obtain is not optimum, heat exchanger rate is less comparatively and moreover the space required is also felt more. Hence the main requirements for the given problem are as under. (1) Increase heat transfer rate. (2) Reduce the space required. (3) Reduce the cost of the unit. (4)Reduce the time required for the thermal and mechanical design of shell and tube heat exchanger. In this paper an attempt is made to develop software for thermal design of shell and tube heat exchanger so that thermal design become very fast accurate, and more optimum because of the numbers of iterations are done to get optimum number of tubes and baffle spacing in term of allowable pressure drop to achieve maximum heat transfer coefficient and minimum heat transfer area, which is not possible In case of manual calculation.

II. BASIC ASPECT OF HEAT EXCHANGER DESIGN [1,3]

For the efficient design of shell and tube heat exchanger following basic aspect should be consider.

2.1. Size restrictions

It is often important to limit the length, height, width, volume, or weight of a heat exchanger because of requirements peculiar to a particular application. These limitations may apply not only to the heat exchanger itself but also to provisions for maintenance. For example, it may be essential that the heat exchanger casing be installed in such a way that individual tubes or the entire tube bundle be removable simply by opening a flange at one end of the exchanger. The space available is often such that the length of the tube bundle that can be handled is limited. The fluids inventory is likely to be an important consideration for expensive, toxic or combustible fluids. It may also be necessary to impose special requirements for drainage vertical removal of the tubes or the tube bundle, or the like.

2.2. Stress considerations

Stress considerations are usually relatively unimportant in the design of heat exchangers unless system pressures above 1.38 N/mm2 (200 psi) or metal temperatures above 93°C are employed. For pressure over 6.89 N/mm2 (1000 psi) or temperatures above 538°C, stress considerations probably will be dominant. In these regions the tube headers are particularly likely to be the controlling factor in the selection of the heat exchanger geometry, and stress considerations are a major factor in determining the choice of the material to be employed.

Differential thermal expansion is likely to pose important limitations on the design of the heat exchanger if temperature differences of 37.8°C or more are to be expected between the tubes and the shell; hence it is important to note this item in outlining the requirements to be met.

2.3. Safety and environmental requirements

The growing body of government regulations and legal liabilities cases has introduced an exceptionally difficult set of demands on equipment designers. The health and safety of employees in the manufacturer's plant and in plants in which the product may be installed as well as the general public have become dominant considerations. In effect, companies are now supposed to foresee any possible adverse condition that might arise not only from a design fault, but also from any conceivable mistake or mishandling by a system operator or someone engages in maintenance. In fact in some cases the manufacturer may be held liable even in the case of deliberate sabotage. A review of litigation stemming from product failures shows that accidents are caused less often by the designer's failure to consider how the equipment might be used. The environment effects of leakage to the atmosphere or hydrosphere of process fluids, blow-down, and wastes from cleaning introduce complex problems.
Governmental regulations generally impose limits that are as tight as it is technically possible to achieve, and juries are inclined to impose heavy penalties even if there are substantial uncertainties in the causes or magnitudes of adverse effects. Thus the designer must try to envision every unpleasant contingency, an exercise that requires much effort and a fertile imagination simulated by a review of product liability cases and OSHA regulations in the area involved. From the environmental standpoint, the items that must be given particular attention include the handling and disposal of wastes from blow-down, sludge, and cleaning fluids.

2.4. Cost factors

Cost factors are often dominant in the choice of a heat exchanger. These include not only the initial capital cost of the heat exchanger but also the costs of plant operations and maintenance. These effects may be complex as, for example, in a chemical processing plant where the value of one or more product may be affected. The situation in a steam power plant is somewhat simpler, because the capital cost of the equipment can be related directly to the efficiency of the power plant and hence to the costs of producing electrical power.

To achieve minimum overall costs it is necessary to balance operating costs against capital charges. The problem can be illustrated by considering a particular case. Once a basic transfer matrix geometry is selected on the basis of fabrication, performance, and maintenance considerations, the amount of heat that will be transferred from one fluid to the other for a given set of fluid temperatures in a given size of heat exchanger will depend largely on the flow rates of the two fluid streams. If the flow rates are doubled, the capital charges will be cut almost in half, but the pumping power requirement will be increased by approximately a factor of eight.

2.5. Maintenance

Maintenance is very important aspect of design. This will help the designer to minimize their occurrence, provide good access for cleaning and inspection, and make the design such that repairs can be carried out as readily as possible. Probably the most important point to remember in design work is that, if something might go wrong, it probably will Valuable insights into problems in the field and corrective measures can be obtained by participating in user's groups that meet periodically to pool their experience.

2.6. Tube bundle vibration

Shell side flow may produce excitation forces, which result in destructive tube vibrations. Existing predictive correlations are inadequate to insure that any given design will be free of such damage. The vulnerability of an exchanger to flow induced vibration depends on the flow rate, tube and baffle materials, unsupported tube spans. Tube field layout, shell diameter, and inlet/outlet configuration. The 'Recommended Good Practice' section of these Standards contains information, which is intended to alert the designer to potential vibration problems. Because of the uncertainties involved, the manufacturer will not necessarily attempt to analyze for vibration in any unit unless specifically requested to do so by the customer, and then only if sufficient information is supplied.

III. SOFTWARE ARCHITECTURE AND FLOW CHART

The software for thermal design of shell and tube heat exchanger is developed to save time as well as cost of design. It is design to gives optimum results in terms of maximum shell and tube side heat transfer coefficient within permissible pressure drop for different geometrical conditions. For the thermal design of shell and tube heat exchanger, method given by Kern [7] is followed and it is limited to liquid to liquid type of heat exchanger. Figure 1. Show the detail architecture and Figure 2. Show the detail flow chart of software. Detail design and different input and output value required for program is described in flow chart. Following databases are used in the program.

- *Following* physical properties of both stram like
  - Thermal conductivity W/m°C
  - Specific heat, kJ/kg°C
  - Density, kg/m3
  - Viscosity, Ns/m2
- fouling factor
- *di*, do Tube inside & outside diameter
- *Thermal* conductivity of tube wall kw
- Constant K1, N1
- *Shell* and tube side heat transfer factor
- Shell and tube side friction factor

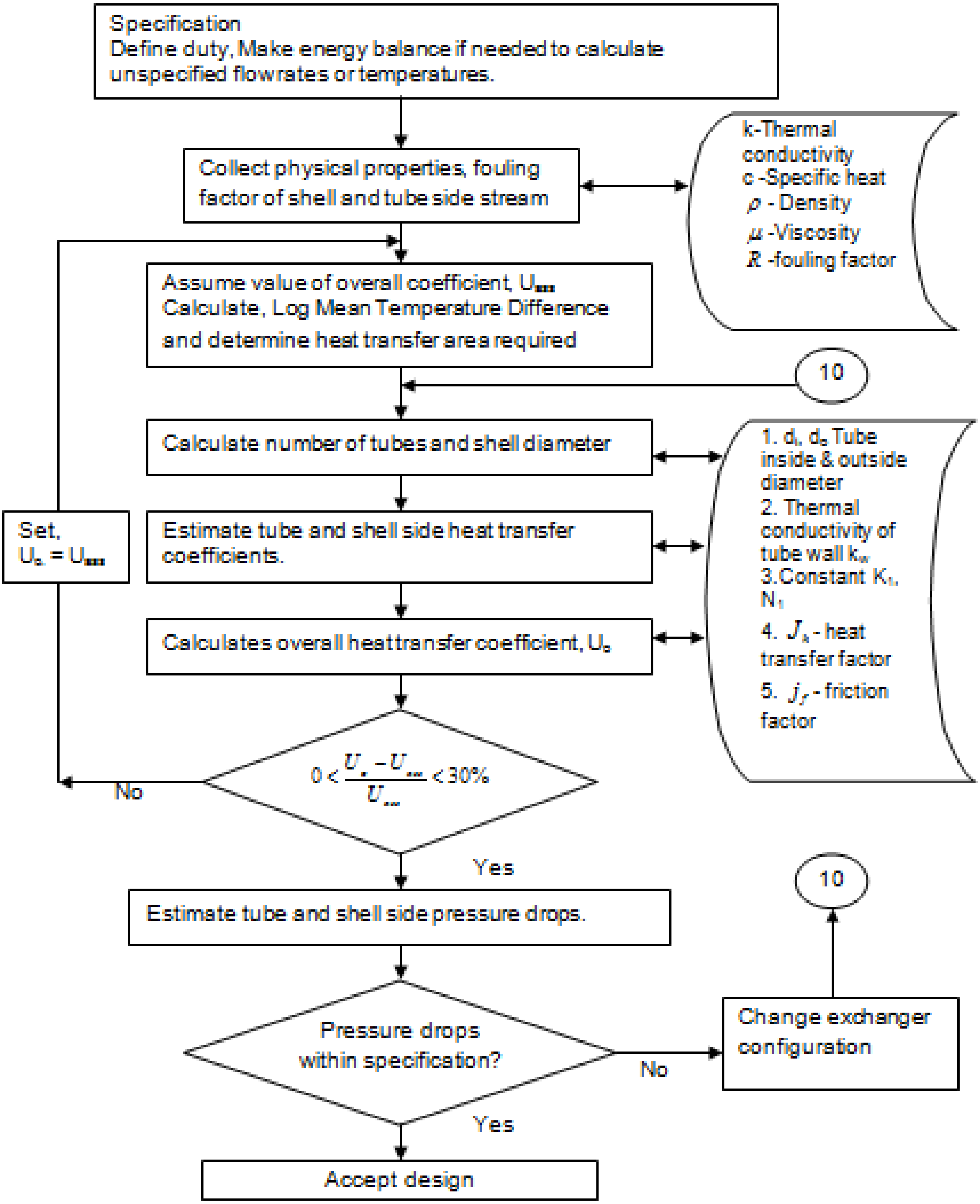
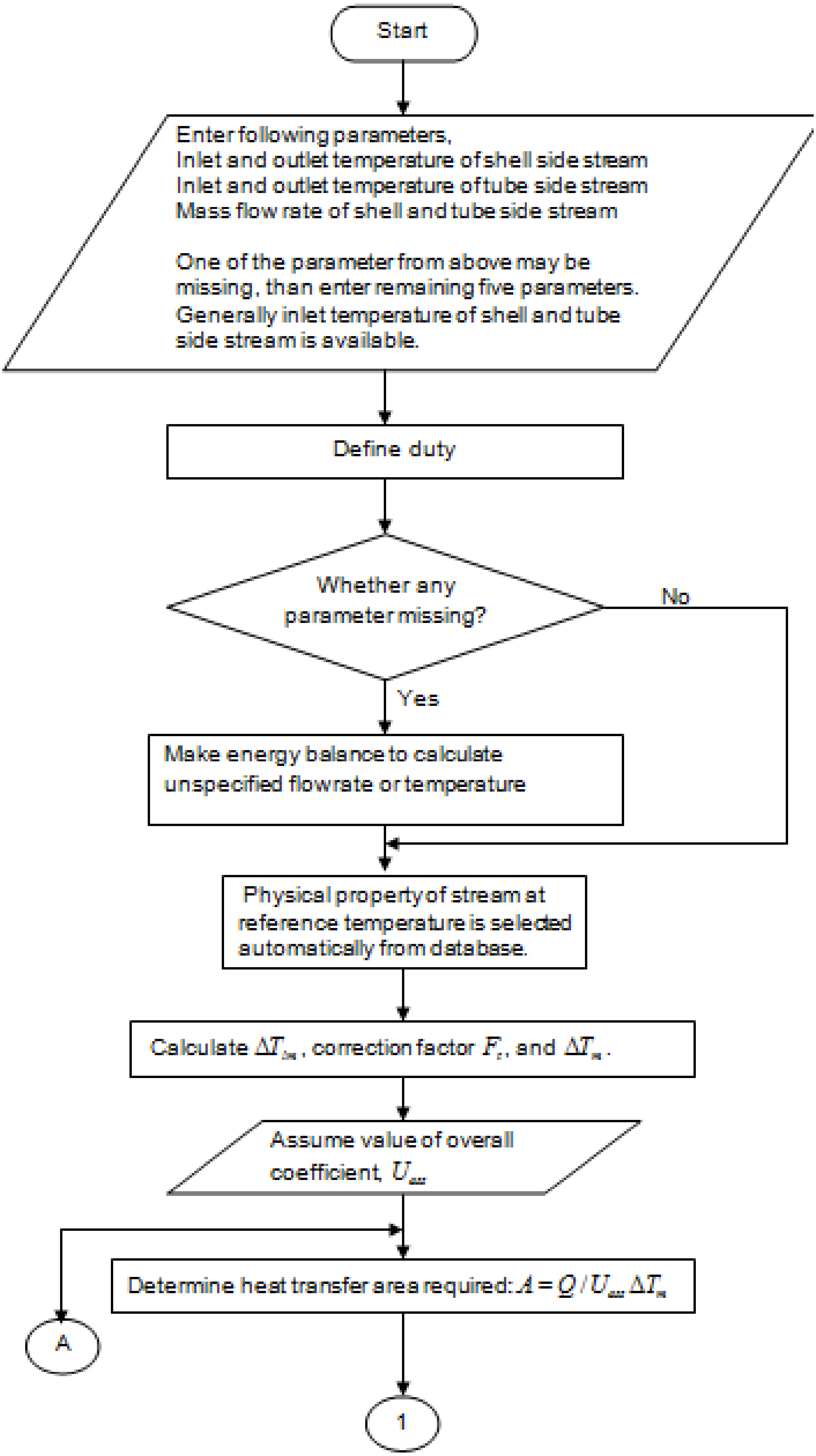
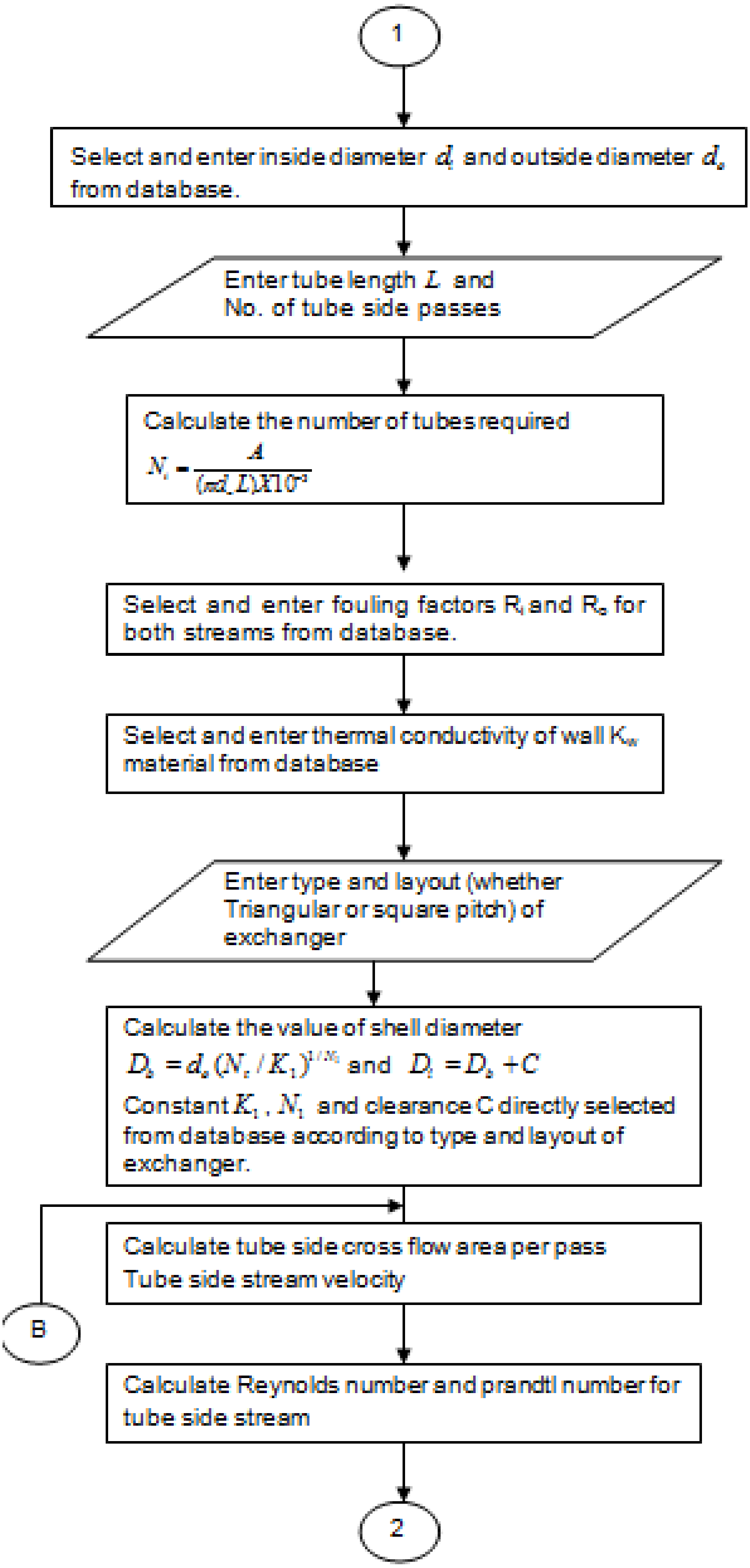


Figure 1. Software architecture for shell and tube heat exchanger Thermal Design.


Start
Enter following parameters,
Inlet and outlet temperature of shell side stream
Inlet and outlet temperature of tube side stream
Mass flow rate of shell and tube side stream
One of the parameter from above may be missing, than enter remaining five parameters.
Generally inlet temperature of shell and tube side stream is available.
Define duty
Whether any parameter missing?
No
Yes
Make energy balance to calculate unspecified flowrate or temperature
Physical property of stream at reference temperature is selected automatically from database.
Calculate ΔT_{lm}, correction factor F_t, and ΔT_m.
Assume value of overall coefficient, U_{ass}
Determine heat transfer area required: $A = Q / U_{ass} \Delta T_m$
A
1


1
Select and enter inside diameter d_i and outside diameter d_o from database.
Enter tube length L and No. of tube side passes
Calculate the number of tubes required
$N_t = \frac{A}{(\pi d_o L)X10^{-3}}$
Select and enter fouling factors R_i and R_o for both streams from database.
Select and enter thermal conductivity of wall K_w material from database
Enter type and layout (whether Triangular or square pitch) of exchanger
Calculate the value of shell diameter
$D_b = d_o (N_t / K_1)^{1/N_1}$ and $D_s = D_b + C$
Constant K_1, N_1 and clearance C directly selected from database according to type and layout of exchanger.
Calculate tube side cross flow area per pass
Tube side stream velocity
B
Calculate Reynolds number and prandtl number for tube side stream
2

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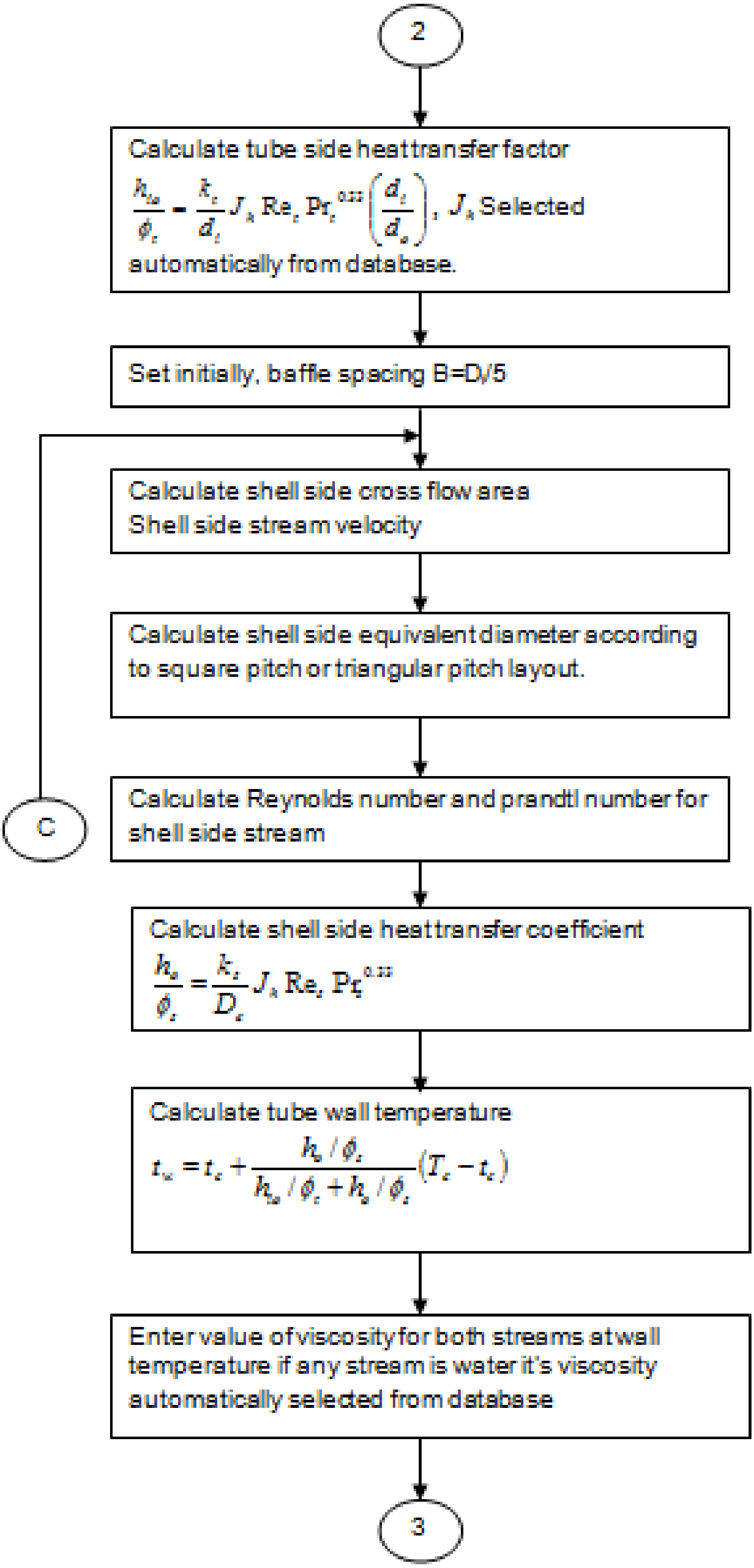

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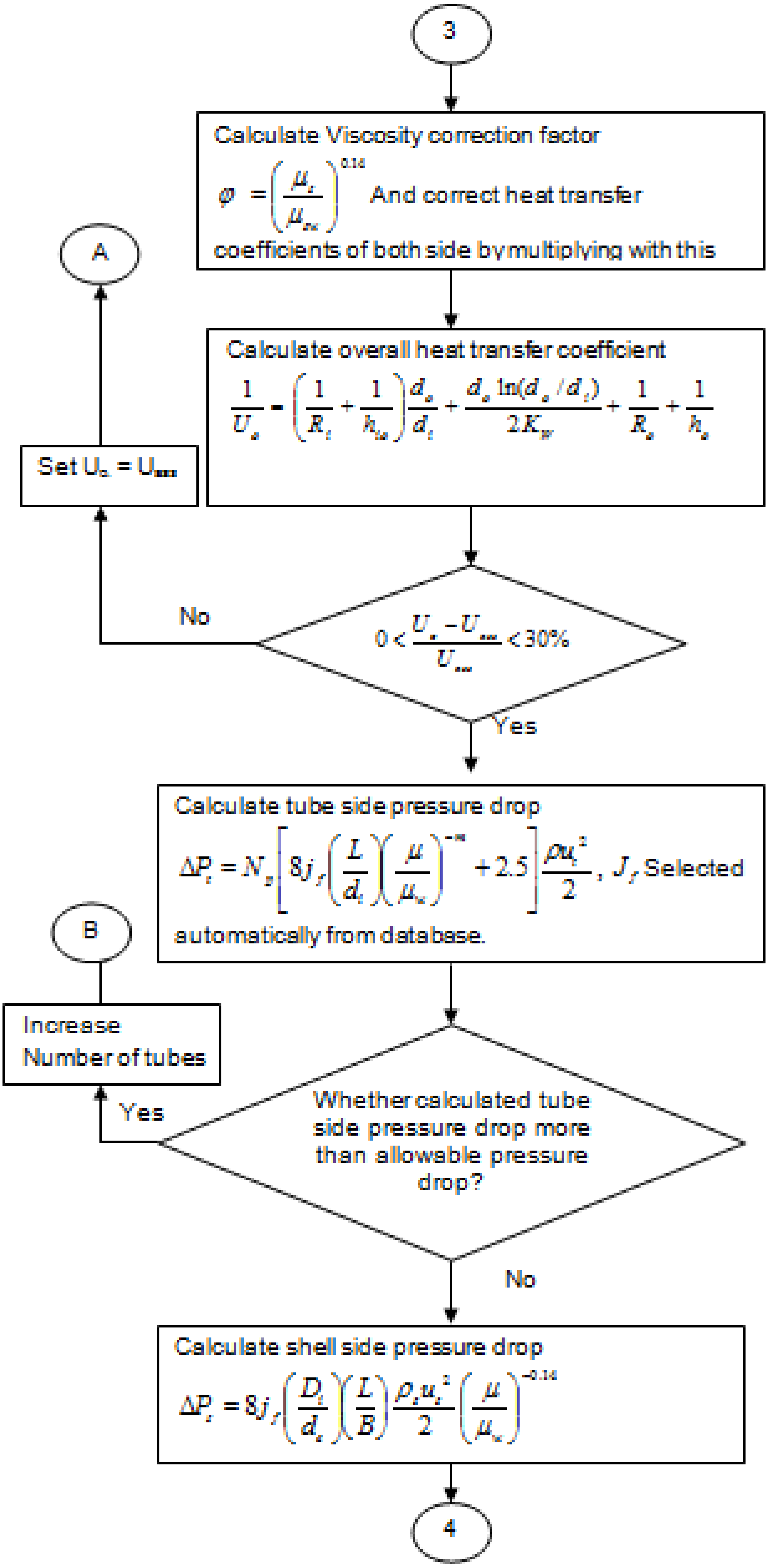

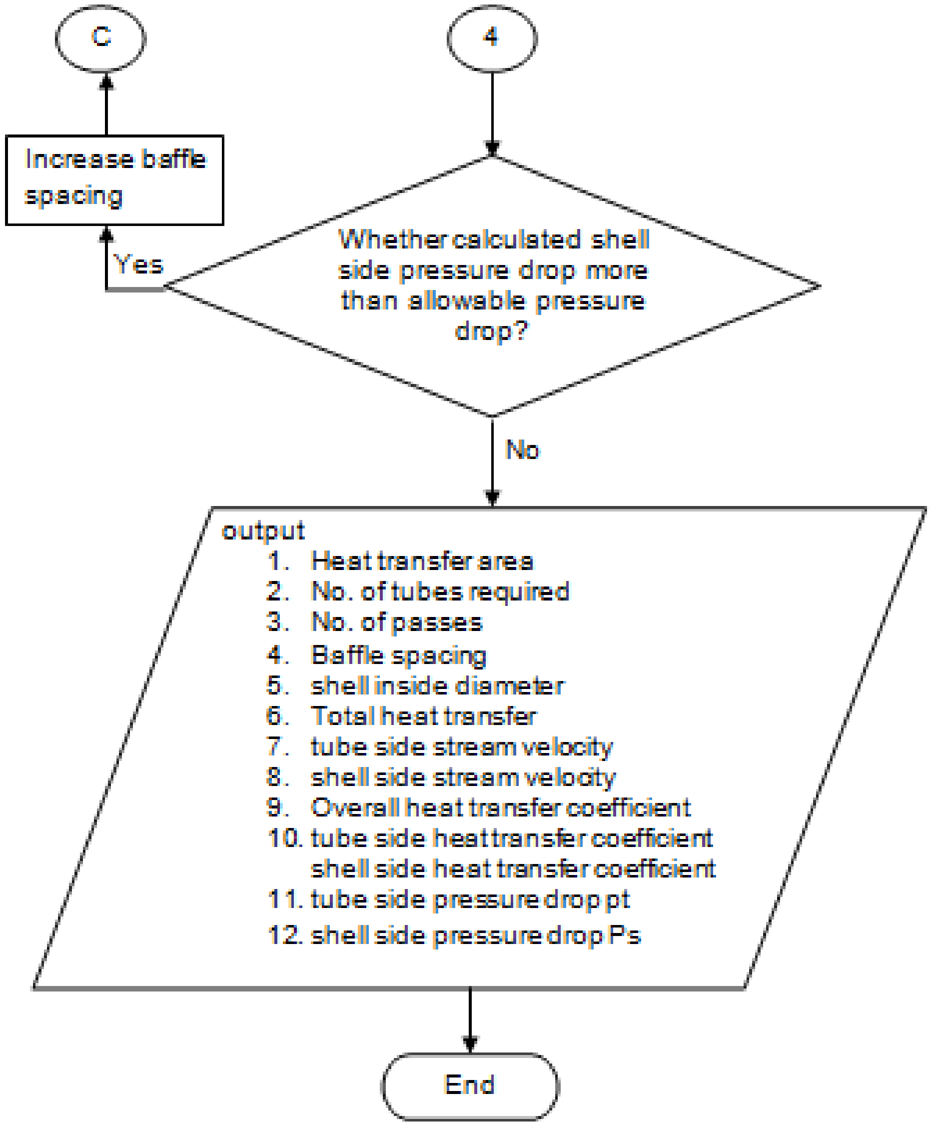

Figure 2. Flow chart for thermal design of shell and tube type heat exchanger

IV. CASE STUDY DETAILS

Water cooler is taken as a case study used in Indian oil corporation ltd. Detail design data is given below.

- Inlet temperature of shell side water = 5°C
- Inlet temperature of tube side water = 36°C
- Outlet temperature of shell side water = 10°C
- Outlet temperature of tube side water = 30°C
- Mass flow rate of tube side water = 3500 Kg/hour
- Tube length = 1 meter
- Design gauge pressure on shell side = 6.5 Kg/cm2 (0.637 N /mm2)
- Design gauge pressure on tube side = 7 Kg/cm2 (0.686 N /mm2)
- Shell side allowable pressure drop = 0.03 bar (3 x 10-3 N /mm2)
- Tube side allowable pressure drop = 0.02 bar (2 x 10-3 N /mm2)
- Corrosion allowance on shell and tube side = 1.5 mm
- Joint efficiency on shell and tube side = 0.9
- Fouling factor for shell side stream = 3500 W/m2°C
- Fouling factor for tube side stream = 3000 W/m2°C

V. THERMAL DESIGN OUTPUT AND SELECTION OF OPTIMUM SOLUTION

Design of water cooler of case study is done based on different geometry conditions to find out number of optimum solutions and select best one. There are number of parameter which can vary, here the tube diameter and number of passes is change to find out number of different optimum solutions.

Here, two types of commonly use tubes, one with outer diameter of 19.05 mm and inner diameter of 15.75 mm and other with 12.7 mm outer diameter and 10.21 inner diameter tubes are used and find out optimum solutions with one and two passes. With the help of software we can find out different solutions as given in table 1.

Form results shown in table 1, it become clear that in case of 1 tube passes 12.7mm tube become more economical because cost of 19.05 mm diameter tube is around 1.5 times more than 12.7 mm diameter, whereas requirement of 19.05 mm diameter tubes is 40 and requirement of 12.7mm diameter tubes is 41 so, it is almost equal. Another disadvantage of 19.05 diameter tubes is that outer diameter of shell require is 228 mm which is more than the inside diameter equipment of 158 mm with the use of 12.7 mm diameter tubes.

In case of 2 tube passes the number of tubes require for 19.05 mm diameter is 27 is very low compare to 46 tubes require of 12.7 mm diameter tubes. Hove ever cost point of view there are not big difference between the cost of 19.05 diameter 27 tubes and cost of 12.7 mm diameter 47 tubes. But, in case of 19.05 diameter tubes inside shell diameter require is around 203 mm which is more than inside shell diameter of require for 12.7 mm tubes which is around 178 mm. So, in case of overall consideration 12.7 mm diameter tubes is more suitable for 2 tube pass because it reduce the shell inside diameter which reduce total cost, area and weight of heat exchanger.

If compare of all four results than, it is very easy to say that with one pass and use of 12.7 mm diameter tubes is most optimum solution because in this case number of tubes require is 41 which is less than two tube passes and shell inside diameter require is 158 mm, which is also less compare to other configurations.

No.	Thermal design parameter	Tube pass= 1		Tube pass =2	
		19.05 mm diameter tubes	12.7 mm diameter tubes	19.05 mm diameter tubes	12.7 mm diameter tubes
1	Heat transfer area required, m^2	2.36	1.60	1.57	1.87
2	No. of tubes required	40	41	27	47
3	Baffle spacing, mm	99.15	124.32	98.33	115.39
4	Shell inside diameter, mm	228	158	203	178
5	Total heat transfer, Kw	24.33	24.33	24.33	24.33
6	Tube side stream velocity, m/s	0.13	0.29	0.37	0.51
7	Shell side stream velocity, m/s	0.27	0.30	0.31	0.31
8	Overall heat transfer coefficient, W/ m^2 °C	368.08	546.50	564.21	646.99
9	Tube side heat transfer coefficient, W/ m^2 °C	924.43	1977.66	2204.21	3086.92
10	Shell side heat transfer coefficient, W/ m^2 °C	2229.28	2868.74	2392.61	2903.93
11	Tube side pressure drop, bar	0.0006	0.0036	0.0080	0.0196
12	Shell side pressure drop, bar	0.0226	0.0244	0.0256	0.0293

Table 1 optimum solutions for different geometrical conditions

VI. CONCLUSION

Thermal design software gives optimum results in terms of maximum shell and tube side heat transfer coefficient within permissible pressure drop for different geometrical conditions. Optimization in case study is carried out for 12.7 mm and 19.05 mm outer diameter tubes and for 1 and 2 tube passes. From the results obtained from thermal design software based on these parameters, it become clear that in case of 1 tube passes and 12.7mm outer diameter tubes more optimum solution obtain in term of space requirement and cost, because in this case lowest shell diameter (158 mm) required compare to other solutions. However, in this case 41 tubes required which is higher than 19.05 mm outer diameter tubes with one and two passes, but the approximate cost of 12.7 mm diameter is 1.5 times less than 19.05 mm diameter, so the overall all cost for tubes will also less with this configuration.
The limitation of this software is, it is limited to liquid to liquid type of heat exchanger, the thermal design software for different type of heat exchanger like gas to gas, gas to liquid, and different phase change conditions like steam generator, condenser etc., can be developed.

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