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On the Optimal Design of Shell and Tube Heat Exchanger for Nuclear Applications

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The actual design of heat exchanger not only relies on thermohydraulic considerations but also on economical aspects and radiological safety considerations. For optimal design of heat exchanger for a specific application a compromise should be made for determining the important factors affecting the design.

In this paper, an optimization model is presented for shell and tube heat exchanger, which could be considered as a tool for computer aided design. A case study is presented to explore the present adopted model.

ON THE OPTIMAL DESIGN OF SHELL- AND -TUBE HEAT EXCHANGER FOR NUCLEAR APPLICATIONS

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ABSTRACT

In the nuclear industry, heat exchanger plays an important role in the transfer of heat from reactor core, where heat is generated, to the Ultimate Heat Sink (UHS), and then is dissipated.

The actual design of heat exchanger for nuclear applications not only relied on thermohydraulic considerations but also on economical aspects and radiological safety considerations. For optimal design of heat exchanger for specific application a compromise should be specified for determining the important factors affecting the design.

In this paper, an optimization model is presented for shell and tube heat exchanger, which could be considered as a tool for computer aided design, A case study is presented to explore the present adopted model.

KEY WORDS

Heat Exchanger, Shell-and-Tube, Optimization, Design, Nuclear Safety.

NOMENCLATURE

A	=	area of heat transfer, m^2,.
B_i	=	correction factor to account for friction due to sudden contraction, sudden expansion, and reversal of flow direction, dimensionless.
B_o	=	correction factor to account for friction due to reversal of flow direction, recrossing of tubes, and variation in cross section, dimensionless.
C_p	=	heat capacity, Kj./ kg °k prime refers to process fluid.
CA_o	=	installed cost of heat exchanger per unit of outside-tube heat-transfer area, L. E/m^2.
C_i	=	cost for supplying. N.m. to pump the fluid through the inside of the tubes, L. E/m^2.
C_o	=	cost for supplying 1m. N.m.. to pump the fluid through the shell side of the exchanger, L. E/N.m.
C_T	=	total annual variable cost for heat exchanger and its operation, L. E. / year.
C_u	=	cost of utility fluid, L.E. /kg.
D	=	diameter or distance, m.
D_c	=	clearance between tubes to give smallest free area across shell axis, m.
E	=	power loss per unit of outside-tube heat-transfer area, N.m. / h.m^2.
F_i	=	Fanning friction factor for isothermal flow, dimensionless.
F'	=	special friction factor for shell-side flow, dimensionless.
F_c	=	friction due to sudden contraction, N.m./ kg.
F_e	=	friction due to sudden enlargement, N.m./ kg.
F_T	=	correction factor on logarithmic-mean Δt for counterflow to give mean Δt, dimensionless.
G	=	mass velocity inside tubes, kg/m^2.
G_s	=	shell-side mass velocity across tubes based on the minimum free area between baffles across the shell axis, kg/h. m^2.
h	=	film coefficient of heat transfer, w/m^2.k.
H_y	=	hours of operation per year, h/year.
K	=	thermal conductivity, w/m.k.
K_F	=	annual fixed charges including maintenance, expressed as a fraction of the initial cost for the completely installed unit, dimensionless.
L	=	heated length of straight tube or length of heat-transfer surface, m.
n_d	=	number of baffle spaces = number of baffles plus one, dimensionless.
n_p	=	number of tube passes, dimensionless.
N_c	=	number of clearances between tubes for flow of shell-side fluid across shell axis, dimensionless.

N_r	=	number of rows of tubes across which shell fluid flows, dimensionless.
N_T	=	total number of tubes in exchanger = number of tubes per pass. n_p. dimensionless.
N_V	=	number of rows of tubes in a vertical tier, dimensionless.
q	=	rate of heat transfer, (w).
R	=	temperature ratio for evaluating F_Y. dimensionless.
R_{dw}	=	combined resistance of tube wall and scaling or dirt factors, [w/m^2.k].
S	=	temperature ratio for evaluation F_T. dimensionless;.
S_i	=	cross-sectional flow area inside tubes per pass, m^2.
S_o	=	shell-side free-flow area across the shell axis, m^2.
t	=	temperature, ^{o}c, subscript 1 refers to the entering temperature, and subscript 2 refers to the leaving temperature.
t'	=	temperature of second fluid in a heat exchanger, ^{o}c.
T	=	absolute temperature ^{o}K
U	=	overall coefficient of heat transfer, w/m^2.k.
V	=	velocity, m/h.
V'	=	velocity, m/s.
W	=	mass flowrate, kg/h.
W'	=	total mass flowrate of process fluid, kg/h.
X	=	length of conduction path, m.
X_L	=	ratio of pitch parallel to flow to tube diameter.
X_T	=	ratio of pitch transverse to flow to tube diameter.

Greek Symbols :

Δ	=	Δt designates temperature-difference driving force, ^{o}c; $\Delta t_1 = t'_2 - t_1$; $\Delta t_2 = t'_1 - t_2$; ΔP and Δp designate pressure drop; $\Delta p = -\Delta P$.
λ	=	Lagrangian multiplier, dimensionless.
μ	=	absolute viscosity, Kg/(h) (m).
ρ	=	density, kg/m^3.
φ	=	correction factor for nonisothermal flow, diminsionless.
Ψ_i, Ψ_o	=	dimensional factors for evaluation of E_i and E_o.

Subscripts

b	=	bulk
c	=	convection
c_o	=	conduction
d	=	dirt or fouling
f	=	across film or at average film temperature.
i	=	inside pipe or tube, based on average bulk temperature.
L	=	liquid at average liquid temperature.
m	=	mean.
n_o	=	per tube
o	=	outside pipe or tube, based on average bulk temperature.
o_r	=	original
oa	=	overall.
W	=	tube or pipe wall, based on temperature at wall surface.
u	=	utility
1	=	inlet
2	=	exit

INTRODUCTION

In nuclear reactors, the amount of reactor power generation is limited by thermal rather than by nuclear considerations. The reactor core must be operated at such a power level, that with the best available heat- removal system, the temperature of the fuel and cladding any where in the core must not exceed safe limits. Otherwise, accidents leading to fuel element meltdown could happen causing radiological releases. Thus., the optimum design of reactor cooling system would result on extracting heat from the reactor core without exceeding the design SAFE LIMITS [1]. Heat generated in reactor core is transferred to the Ultimate Heat Sink (UHS) through Reactor Cooling System (RCS). Figure. (1) present (RCS) for Egypt first Research Reactor and Figure (2) presents as Schematic Idealization of a PWR Power Generating System.

The coolant in the RCS of most nonpower reactors serves more functions than just efficient removal of heat [2]. The coolant can act as a radiation shield for the reactor, In many designs the reactor coolant also act as a core moderator and reflector. The reactor coolant system design is based on selecting among inter dependent parameters, including thermal power level, research capability, available fuel type, reactor core physics requirements and radiation shielding, [2],[3] and [4]. The Design Bases of the features of RCS is to respond to potential accidents or to mitigate the consequences of potential accidents.

Nuclear Regulatory Body has a stringent requirements for Construction materials and Fabrication specification of safety related components and coolant quality requirements operation and shutdown conditions including PH and conductivity as a minimum for giving construction permit and operation permit for nuclear installations.

The essential components in RCS are:- heat source (reactor core), heat sink (heat exchanger), pumps, piping, valves, control and safety instrumentation interlocks and other related subsystems. Thus, heat exchanger represents one of the essential components in RCS, and the optimal design for nuclear application is an optimization between functional requirements of heat exchanger, nuclear safety requirements in the design and total cost of production per unit of production or per unit time.

Heat Exchangers are in so many sizes, types, configurations and flow arrangements according to its application. However, it could be classified according to either transfer process, number of fluids, surface compactness heat transfer mechanisms, constructions and flow arrangements [5] and [6]. The shell and tube heat exchange is the most common of the various type of heat transfer equipment use in industry. It is desirable for high pressure operations. For an optimum, safe and economic, design most favorable conditions should be chosen. The optimum economic design occurs at the conditions where the total annual costs of Heat exchanger is a minimum [7] and [8].

The reactor coolant flow and temperatures is specified a prior from reactor core thermohydraulics. Thus, the flow of secondary coolant and temperatures are depending on the design of heat exchanger. In general, increased flow velocity results in large coefficient of heat transfer and consequently less heat transfer area and whence lower heat exchanger costs for a given rate of heat transfer. On the other hand, the increased fluid velocity causes an increased in pressure drop and greater pumping costs.

The optimum economic design occurs at the conditions where the total cost is a minimum. Therefore, the basic problem is to minimize the sum of the variables for annual costs for the heat exchanger and its operation and maintenance [9],[10]. Thus, the main objective of this study is to devise a procedure for an economical and safe design for heat exchanger suitable foe nuclear installations.

RADIATION EFFECTS

In principle, the overall safety objective for nuclear reactor is to protect individual, society and the environment by establishing and maintaining an effective defense against radiological hazards.

The more detailed radiation protection objective in design is to ensure that the operation and utilization of nuclear reactor and its associated systems are justified (justification principle) to ensure that during operational states of the reactor the radiation exposure of site personnel and the public remains below limits prescribed by national authorities and is kept as low as reasonably achievable (ALARA) (optimization principle). Also to ensure mitigation of radiation exposure in case of accidents (Intervention principle,) [2] and[12].

So, the optimum design of heat exchanger equipment for nuclear reactor utilization should ensure radiation optimization principle (ALARA) Optimization Principle and Intervention Principle. Heat Exchanger in reactor cooling system is one of the equipment important to safety (safety related) for which dynamic qualification should be performed. This qualification is performed considering general design criteria for nuclear installation bases, combining effects of normal and accident conditions with the effects of natural phenomena such as earthquake.

SHELL AND TUBE HEAT EXCHANGER

The shell and tube heat exchanger is the most common of the various types of heat transfer equipment used in industry. Although it is not especially compact, however it is robust and its shape makes it well suited to pressure operation, it is also versatile and it can be designed to suit almost any application. Figure (3) presents a schematic diagram for Shell and Tube heat exchanger.

OPTIMUM DESIGN OF HEAT EXCHANGERS

The optimum economic design of heat exchanger occurs at the condition where the sum of the total annual costs for the exchanger and its operation is a minimum.

The variable annual costs of importance are the fixed charges on the equipment, the cost for the utility fluid, and the power cost for pumping the fluids through the exchanger. The total annual cost for optimization, Therefore, Can be represented by the following equation:

$$C_t = A_0 K_f C_{A_0} + w_u H_y C_u + A_0 E_i H_y C_i + A_0 E_0 H_y C_0 \tag{1}$$

The heat transfer area A_0 could be related to the flow rates and the temperature changes by an overall heat balance, and the rate equation. Therefore A_0 could be represented as a function of h_i, h_o, and, Δt_2 as shown by the following equation:

$$\frac{\Delta t_m}{q} = \frac{1}{U_O A_O} = \frac{1}{A_O}\left(\frac{D_o}{D_i h_i} + \frac{1}{h_o} + R_{dw}\right) \tag{2}$$

$$\frac{F_T(\Delta t_2 - \Delta t_1)}{q \ \ln(\Delta t_2 / \Delta t_1)} = \frac{1}{U_o A_o} = \frac{1}{A_o}\left(\frac{D_o}{D_i h_i} + \frac{1}{h_o} + R_{dw}\right) \tag{3}$$

Power loss inside and outside tubes for conditions of turbulent flow and shell, side fluid flowing in a direction normal to the flow are developed as follows [7]

Power loss inside tubes

$$-\Delta P_i = \frac{B_i^2 f_i G^2 L_{np}}{g_c \rho_i D_i \Phi_i} = \frac{2 f_i G_i^2 L_{np}}{g_c \rho_i D_i \Phi_i t} + (F_e + F_c + F_r) n_p \rho_i \tag{4}$$

where $\Phi_i = 1.02\left(\frac{\mu_i}{\mu_{wi}}\right)^{0.14}$

$A_o = N_t \pi D_o L$

$f_i = \frac{0.046}{(N_{Re})^{0.2}} = \frac{0.046}{(D_i G / \mu_i)^{0.2}}$ (For turbulent flow in tubes.).

S_i = cross-sectional flow area inside tubes per pass $\left(S_i = \frac{\pi D_i^2 N_t}{4n_p}\right)$

Power loss inside tubes :

$$E_i = \frac{-\Delta p_i w_i}{\rho_i A_o} = \frac{-\Delta p_i G S_i}{\rho_i A_o} = \frac{-\Delta p_i G D_i^2}{4\rho_i D_o L n_p} = \frac{0.023 B_i \mu_i^{0.2} D_i^{0.8} G^{2.8}}{g_c D_o \rho_i^2 \Phi_i} \tag{5}$$

Combining Eqs. (A), (B), and (C),

The mass rate inside tubes in given by:

$$\frac{h_i D_i}{k_i} = 0.023\left(\frac{D_i G}{\mu_i}\right)^{0.8}\left(\frac{c_{pi}\mu_i}{k_i}\right)^{1/3}\left(\frac{\mu_i}{\mu_{wi}}\right)^{0.14}$$

$$G = \left[\frac{h_i D_i^{0.2} \mu_i^{0.8}}{0.023 k_i}\left(\frac{k_i}{c_{pi}\mu_i}\right)^{1/3}\left(\frac{\mu_{wi\,1.14}}{\mu_i}\right)\right]^{1.25} \tag{6}$$

Substitute the value of Φ_i in Eq. (5), then

$$E_i = h_i^{3.5} B_i \frac{D_i^{1.5} \mu_i^{1.83} (\mu_{wi}/\mu_i)^{0.63}}{(1.02)(0.023)^{2.5} g_c D_o \rho_i^2 k_i^{2.33} c_{pi}^{1.17}} \tag{7}$$

Power Loss outside Tubes

$$-\Delta p_o = \frac{B_o 2 f' N_r G_s^2}{g_c \rho_o} \tag{8}$$

The power loss outside tubes can be calculated from the following equation.

$$E_o = \frac{-\Delta p_o w_o}{\rho_o A_o} = \frac{-\Delta p_o G_s S_o}{\rho_o A_o} = \frac{-\Delta p_o G_s S_o}{\rho_o N_t \pi D_o L} \tag{9}$$

where:

$$S_o = \frac{N_c D_c L}{n_b}$$

$f' = b_o \left(\frac{D_o G_s}{\mu_{fo}}\right)^{0.15}$ (For turbulent flow across tubes,)

Combining Eqs. (8)and (9), Then:

$$E_o = \frac{2 B_o b_o \mu_{fo}^{0.15} D_c G_s^{2.85} N_r N_c}{\pi g_c D_o^{1.15} \rho_o^2 n_b N_t} \tag{10}$$

$$\frac{h_o D_o}{k_{fo}} = \frac{a_o}{F_s}\left(\frac{D_o G_s}{\mu_{fo}}\right)^{0.6}\left(\frac{c_{po}\mu_o}{k_o}\right)^{1/3},$$

The shell-side mass velocity across tubes is give by.

$$G_s = \left[\frac{h_o D_o^{0.4} \mu_{fo}^{0.6} F_s}{k f_o a_o}\left(\frac{k_o}{c_{po}\mu_o}\right)^{1/3},\right]^{1.67} \tag{11}$$

Combining Eqs. (10) and (11), Then :

$$E_o = h_o^{4.75} \frac{B_o N_r N_c 2 b_o D_c D_o^{0.75} F_s^{4.75} \mu_{fo}^{1.42}}{n_b N_t \pi a_o^{4.75} g_c \rho_o^2 k_{fo}^{3.17} c_{pfo}^{1.58}} \tag{12}$$

For staggered tubes:

$a_o = 0.33$ $\quad b = 0.23 + \frac{0.11}{(x_T - 1)^{1.08}}$

For tubes in line:

$a_o = 0.26$ $\qquad b = \dfrac{0.08\,x_L}{(x_T - 1)^{0.43 + 1.13/x_L}}$

All the terms in the brackets are set by the design conditions or can be approximated with good accuracy on the first trial. The value of B_i and B_o/n_b are not completely independent of the film coefficients, but they do not vary enough to be critical. As s first approximation, B_i is usually close to 1, and B_o is often taken to be equal to or slightly greater than the number of baffle passes n_b. The value of the safety factor F_s depends on the amount of bypassing and is often taken as 1.6 for design estimates.

The ratio $N_r N_c/N_t$ depends on the tubes layout and baffle, arrangement. For rectangular tubes bundles and no baffles, this ratio is equal to 1.0. For other tubes layouts and segmental baffles, the ratio is usually in the range of 0.6 to 1.2.

The power loss inside and outside tubes are then represented as:

$$E_i = \Psi_i\, h_i^{3.5} \qquad (13)$$

$$E_o = \Psi_o\, h_o^{4.75} \qquad (14)$$

where:

$$\psi_i = B_i \left[\frac{12{,}200\, D_i^{1.5}\, \mu_i^{1.83} (\mu_{wt}/\mu_i)^{0.63}}{g_c D_o \rho_i^2 k_i^{2.33} c_{pi}^{1.17}}\right] \text{ and,}$$

$$\psi_o = \frac{B_o}{n_b}\frac{N_r N_c}{N_t}\left(\frac{2b_o D_c D_o^{0.75} F_s^{4.75} \mu_{fo}^{1.42}}{\pi a_o^{0.75} g_c \rho_o^2 k_{fo}^{3.17} c_{pfo}^{1.58}}\right)$$

Equation (1) can be expressed in terms of the variables Δt_2, h_i and A_o as :

$$C_T = A_o k_f C_{Ao} + \frac{q H_y C_u}{C_P(\Delta t_1 - \Delta t_2 + t_1' - t_2')} + A_o \Psi_i h_i^{3\text{-}5} H_y C_i + A_o \Psi_i h_o^{4\text{-}75} H_y C_o$$

by using lagrange multiplier method [8 and 9] then,

$$C_T = A_o K_F C_{Ao} + \frac{q H_y C_u}{C_P(\Delta t_1 - \Delta t_2 + t_1' - t_2')} + A_o \Psi_i h_i^{3.5} H_y C_i + A_o \Psi_o h_o^{4.75} H_y C_o + \lambda\left[\frac{F_T(\Delta t_2 - \Delta t_1)}{q \ln(\Delta t_2/\Delta t_1)} - \frac{1}{A_o}\left(\frac{D_o}{D_i h_i} + \frac{1}{h_o} + \right) + R_{dw}\right] \qquad (15)$$

optimum value of h_o.

The following relationship between the optimum values of h_i is obtained by taking the partial derivative of E_q. (15) with respect to h_i and then with respect to h_o, setting the results equal to zero, and eliminating A_o and λ:

$$\frac{\partial c_T}{\partial h_i} = 3.5 A_{o,opt} \psi_i h_{i,opt}^{2.5} H_y C_i + \frac{\lambda D_o}{A_{o,opt} D_i h_{i,opt}^2} = 0$$

$$\frac{\partial c_t}{\partial h_o} = 4.75 A_{o,opt} \psi o h_{o,opt}^{3.75} H_y C_o + \frac{\lambda}{A_{o,opt} h_{o,opt}^2} = 0$$

$$h_{o,opt} = \left(\frac{0.74 \psi_i C_i D_i}{\psi_o C_o D_o}\right)^{0.17} h_{i,opt}^{0.78} \qquad (16)$$

optimum value of h_i.

The optimum value of h_i can be determined by setting the partial derivatives of Eq. (15) with respect to A_o and with respect to h_i, setting the results equal to zero and eliminating A_o and λ. This gives a result with $h_{i,opt}$ and $h_{o\cdot opt}$ as the only unknowns, and simultaneous solution with Eq. (16) yields Eq.(17), where $h_{i,opt}$ is the only unknown.

$$\frac{\partial C_T}{\partial A_o} = K_F.C_{Ao} + \psi_i h_{i,opt}^{3.5} H_y C_i + \psi_o h_{o,opt}^{4.75} H_y C_o + \frac{\lambda}{A_{o,opt}^2}\left(\frac{D_o}{D_i h_{i,opt}} + \frac{1}{h_{o,opt}} + R_{dw}\right) = 0$$

$$h_{i,opt}^{3.5}\left[2.5\psi_i H_y C_i + \frac{3.5\psi_i H_y C_i D_i R_{dw} h_{i,opt}}{D_o} + 2.9\left(\frac{\psi_i C_i D_i}{D_o}\right)^{0.83}(\psi_o C_o)^{0.17} H_y h_{i,opt}^{0.22}\right] = K_F C_{Ao} \tag{17}$$

optimum value of U_o:

A trial-and error can be used to obtain $h_{i.opt}$ from Eq (17). Then, by Eqs. (2) and (16), the value of $U_{o.opt}$ can be determined as:

$$U_{o.opt} = \left(\frac{D_o}{D_i h_{i,opt}} + \frac{1}{h_{o,opt}} + R_{dw}\right)^{-1} \tag{18}$$

optimum value of Δt_2:

$\Delta t_{2,opt}$ can be determined by setting the partial derivatives of Eq.(15) with respect to Δt_2 and with respect to A_o equal to zero and eliminating λ. The result can be combined with Eqs. (3), (13) and (14) to give.

$$\frac{F_i U_{o,opt} H_y C_u}{C_{pu}\left(K_F C_{Ao} + E_{i,opt} H_y C_i + E_{o,opt} H_y C_o\right)} = \left(1 + \frac{t'_1 - t'_2}{\Delta t_1 - \Delta t_{2,opt}}\right)^2 \left(ln\frac{\Delta t_{2,opt}}{\Delta t_1} - 1 + \frac{\Delta t_1}{\Delta t_{2,opt}}\right) \tag{19}$$

Optimum value of A_o:

Since $\Delta t_{2,opt}$ and, therefore, $\Delta t_{m,opt}$ are now known, $A_{o.opt}$ can be determined from Eq. (3)

Optimum value of G and G_s:

Equations (6) and (11) give G_{opt} and $G_{s,opt}$, respectively, in terms of $h_{i,opt}$ and $h_{o,opt}$.

Optimum value of w_u:

The flow rate of the utility fluid (w_u) is set by the value of Δt_2. Therefore, when $\Delta t_{2,opt}$ is known, $w_{u,opt}$ can be calculated from the Eq. [7]:

$$w_{u,opt} = \frac{q}{Cp_u\left(\Delta t_1 - \Delta t_{2,opt} + t'_1 - t'_2\right)} \tag{20}$$

Optimum values of S_i **and** N_t. The optimum flow area inside the tubes per pass can be calculated from the following equation:

$$S_{i,opt} = \frac{w_i}{G_{opt}} \tag{21}$$

The optimum total number of tubes in the exchanger is

$$N_{t,opt} = \frac{4n_p S_{i,opt}}{\pi D_i^2} \tag{22}$$

Optimum value of L:

The optimum length per tube is set by the optimum heat-transfer area and the total number or tubes. Thus, for a given tube diameter

$$L_{opt} = \frac{A_{o,opt}}{\pi D_o N_{t,opt}} \quad (23)$$

Optimum values of S_o, N_o and n_b:

The following equation gives the optimum shell-side free-flow area across the shell axis:-

$$S_{o,opt} = \frac{w_o}{G_{s,opt}} \quad (24)$$

The number of clearances N_c for flow between tubes across the shell axis is determined by the number of tubes in the shell, the pitch of the tubes, and the arrangement of the tubes. For the common case of a cylindrical shell and trans-verse clearances giving the minimum free area, the following equations can be used to obtain an approximation of $N_{c,opt}$

With square pitch and N_t greater than 25

$$N_{c,opt} = 1.37 (N_{t,opt})^{0.475} \quad (25)$$

With equilateral triangular pitch and N_t greater than 20

$$N_{c,opt} = 0.94 + \left(\frac{N_{t,opt} - 3.7}{0.907} \right)^{1/2} \quad (26)$$

The optimum number of baffle spaces can be estimated from the Eq. [7]:

$$n_{b,opt} = \frac{N_{c,opt} D_c L_{opt}}{S_{s,opt}} \quad (27)$$

Using the above methods a computer program for optimum design of heat exchanger is developed (flow chart schematic 1).

CASE STUDY

The optimal design case study is given below for a heat exchange cooling gas by water:

1- Heat Exchanger specifications

- cross flow steel shell- and tube with one pass.
- waters as cooling agent passes on shell side.
- Tubes outside diameter = 25 mm
- Tubes inside diameter = 20 mm
- Triangular pitch of Staggered tube = 24 mm
- Installation cost = 0.15 total cost
- Annual fixed charge = 0.2 total cost
- Cooling water cost (including pumping cost) ≅ 0.50 L.E. / M^3
- Energy cost = 25 P.T / KWH.
- Annual working hour = 7000 hr.

II: INPUT DATA :

Gas is to be cooled with water.

- Exit cooling water temperature = 43 °C.
- Average Δt over cooling-water film = 0.1 total Δt
- Average Δt over air film = 0.8 total Δt
- Inlet air temperature = 66 °C.
- Exit air temperature = 38 °C.
- Gas mass flow = 2.5 kg / sec.

- Tube side fluid

- Density = $10.88\ kg/m^3$.
- Specific heat = $1.04\ kj/kg\ ^{o}k$.

- shell side fluid

- Density = $1000\ kg/m^3$.
- Specific heat = $4.18\ kj/kg\ ^{o}k$.

- General

- Correction factor to account for friction, sudden contraction = 1.2
- Nº of clearance between tubes X nº of rows / total no of tubes = 1
- Clearance between tubes = 0.61 E-2

III: Output Results :

- Number of Tubes = 45 tube.
- Tube length = 3.26 m
- Installed cost = 18.000 L. E.
- hi, opt. = $483\ w/m^2.K$
- Uo, opt. = $312\ w/m^2.K$
- Δt_2, opt. = $6\ ^{o}C$
- A_o, opt. = $1.2\ m^2$.

SUMMARY AND CONCLUSIONS

1- An optimal design of heat Exchanger for nuclear installation based upon thermohydraulic considerations, economical aspects and radiological safety considerations is presented.

2- The presented design of shell and tube heat exchanger is optimized analytically.

3- A computer program: based upon the presented analytical optimization analysis is developed for computer as a computer aided design package.

4- A case study for optimal design of shell and tubes heat exchanger based upon the devised computer program is presented.

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[HEAT EXCHAGER]

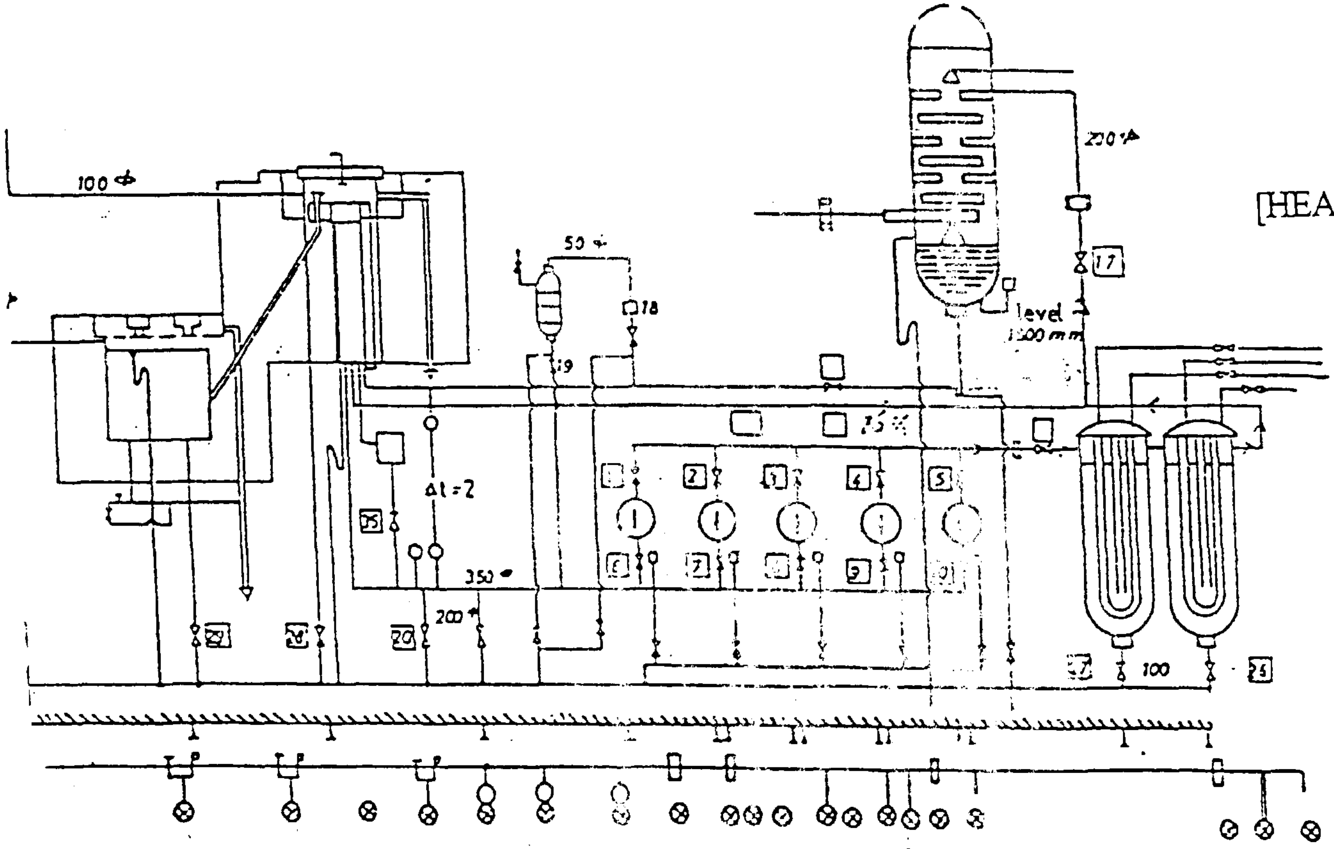
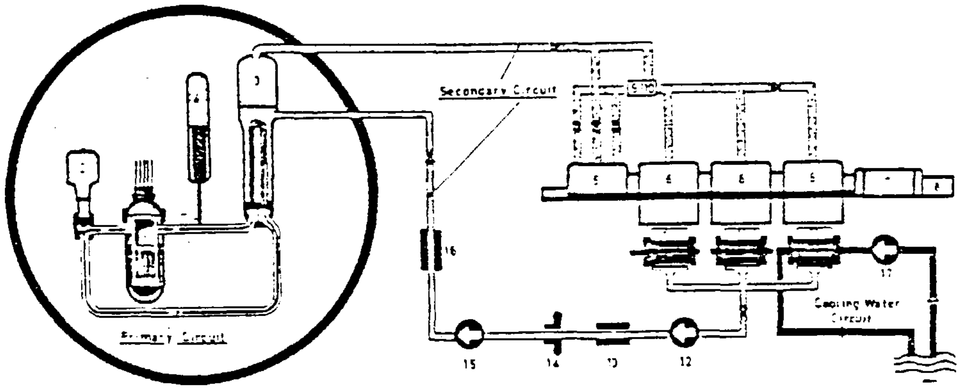


Fig. 1 : Reactor Coolant System of ETRR1

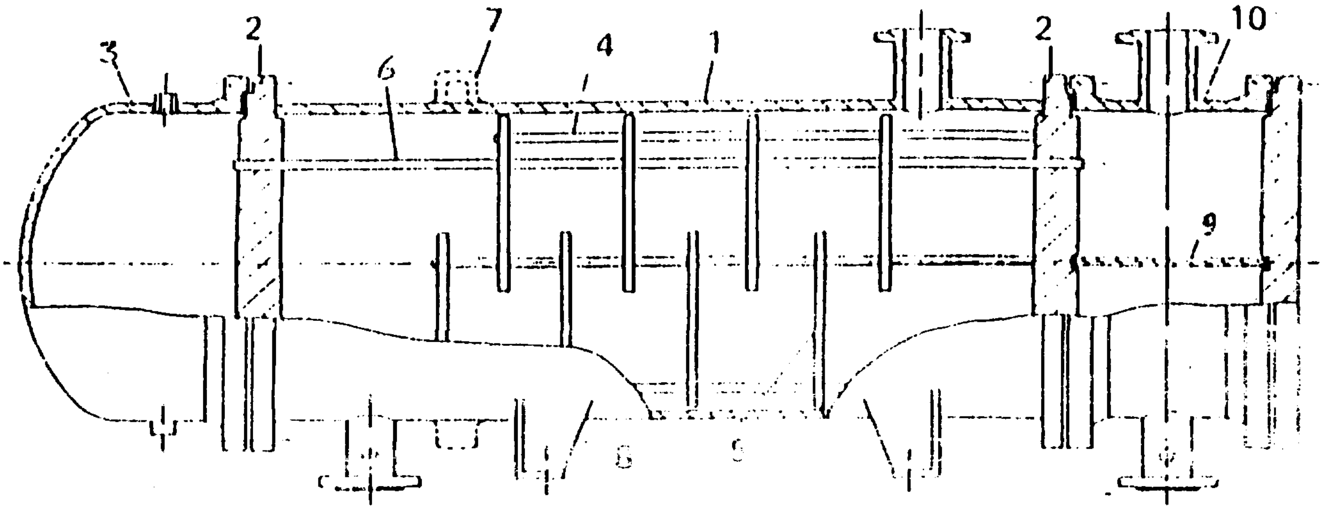


Primary Cooling Circuit
1 Reactor Pressure Vessel
2 Coolant Circulation Pump
3 Steam Generator
4 Pressurizer

Secondary Cooling Circuit
5 Turbine, high-pressure part
6 Turbine, low-pressure part
7 Generator
8 Exciter Unit
9 Water Separator
10 Superheater
11 Condensers
12 Main Condensate Pump
13 Low-Pressure Preheater
14 Feedwater Storage Tank
15 Main Feedwater Pump
16 High-Pressure Preheater

Cooling Water Circuit
17 Main Cooling Water Pump

Fig. 2: Schematic Idealization of a PWR Power Generating System



1- Shell

2 - Stationary tubesheet .

3 - Stationary (or rear) head-bonnet .

4 - Tie rods and spacer .

5 - Baffles .

6 - Tubes .

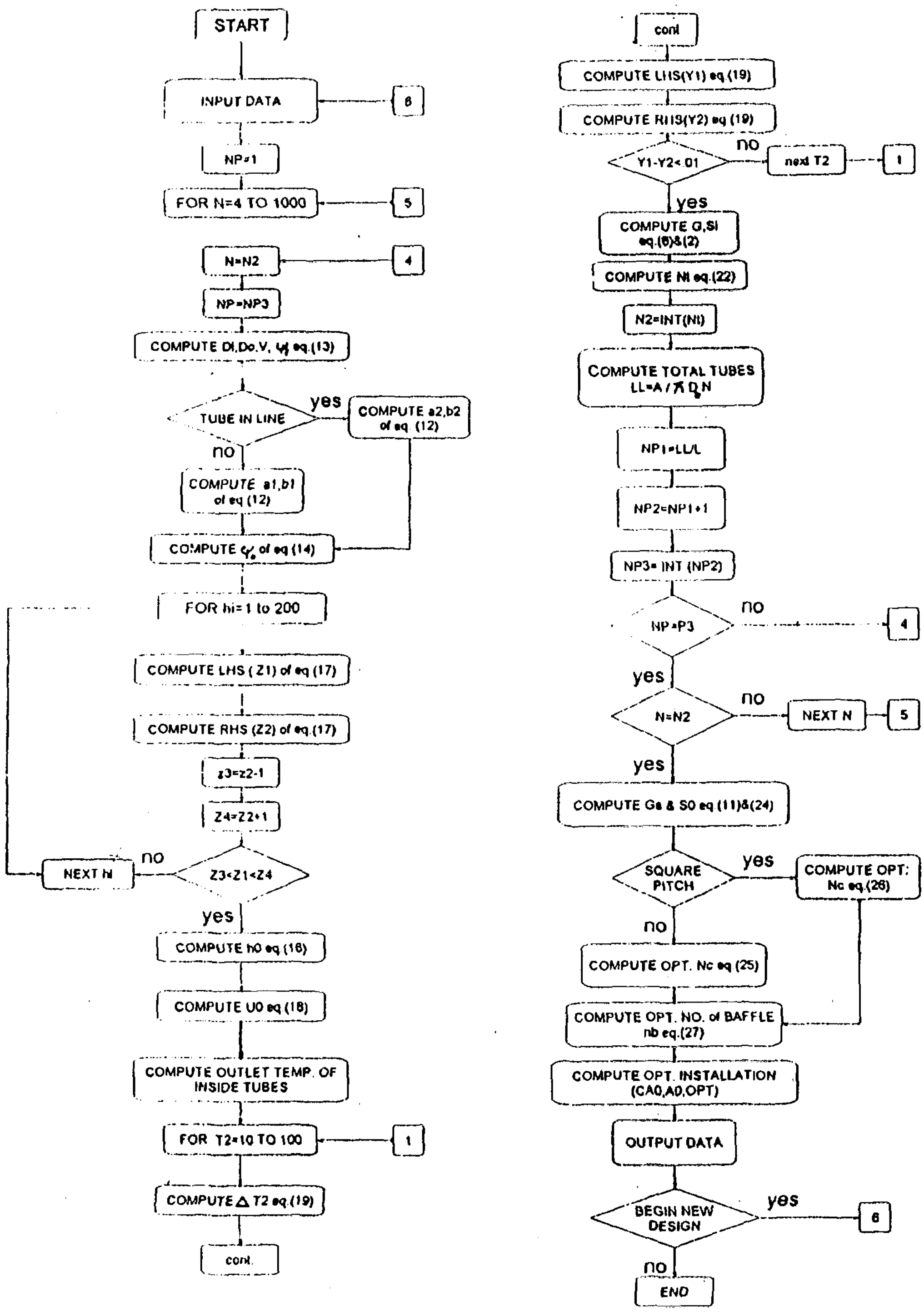
7 - Expansion joint .

8 - Saddle .

9 - pass partation .

10 - Stationary (or rear) head- channel .

Fig. 3: Shell and tube heat exchanger (fixed tubesheet exchanger (AEM) refer to TEMA table) .



Schemat (1) : computer program flowchart

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