DESIGN AND FABRICATION OF A CONCENTRIC TUBE (DOUBLE PIPE) HEAT EXCHANGER.

BY

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2003/14942EH

DEPARTMENT OF CHEMICAL ENGINEERING

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NIGERIA.

NOVEMBER, 2008.

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A PROJECT SUBMITTED TO THE DEPARTMENT OF CHEMICAL ENGINEERING FEDERAL UNIVERSITY OF TECNOLOGY MINNA IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF BACHELOR OF ENGINEERING (B.ENG) DEGREE IN CHEMICAL ENGINEERING.

NOVEMBER, 2008.

DECLARATION

I **Akhanemeh Asegiemeh Martin** with registration number **2003/14942EH** declare that this project report is my original work and has not been represented else where to the best of my knowledge.

....17-11-2008......

Akhanemeh A. Martin **Date**

CERTIFICATION

This research project by Akhanemeh M.A. has been examined and certified under the supervision of Engr. Mrs. M.D. Yahaya to be adequate in scope and quality for partial fulfillment of the requirement for the award of Bachelor of Engr. (B.Engr.) in chemical engineering.

.... 11-11-2008

Engr. Mrs M.D. Yahaya **Date**

Supervisor

....

Dr. M O.Edoga **Date**

Head of department

....

External Examiner **Date**

DEDICATION

This project is dedicated to the Almighty God whose grace and mercies has sustained me.

I also want to dedicate this project to my parents Mr. and Mrs. J A. Itsibor (KSM).

ACKNOWLEDGEMENT

My profound gratitude goes to the almighty God for His grace and mercies in my life. My special regards goes to my able supervisor Engr. Mrs. M.D. Yahaya for her tremendous support during the cause of my project work. It gives me great pleasure and a heart full of profound gratitude to acknowledge the support of my parents, Mr. and Mrs. J A. Itsibor (KSM); and my siblings; Audrey, Joseph, Jude, Emmanuel and Maria for their support, love, care and encouragement throughout the course of my study in this University. Also my gratitude goes to the following people; Emmanuel Theophilus who is my partner in this project, Mathias, Timothy, Demola and all my friends to numerous to be mention.

ABSTRACT

The detailed design and fabrication of a concentric tube heat exchanger has been carried out. The major work done include a complete material and energy balances across the heat exchanger, a detailed design of the heat exchanger with all auxiliary equipment specified. From the design calculation the overall heat transfer coefficient was gotten to be $721.4 w/m^{20}C$ with a heat transfer area of $0.1197 m^2$. Also fabrication and test running of the heat exchanger were carried out and the heat exchanger effectiveness from calculation was 0.87.

TABLE OF CONTENT

CHAPTER ONE

CHAPTER TWO

CHAPTER THREE

CHAPTER FOUR

CHAPTER FIVE

CHAPTER ONE

1.0 INTRODUCTION

Heat transfer from a warmer fluid to a cooler fluid, usually through a solid wall separating the two fluids is common in chemical engineering practice. The heat transferred may be latent heat accompanying a phase change such as condensation or vaporization, or it may be sensible heat from the rise or fall in the temperature of a fluid without any phase change as in the case of heat exchangers. (McCabe et al, 2001).

In an industry, it is generally desired to "extract" heat from one fluid stream and add to another. Devices used for this purpose have passages for each of the two streams separated by a heat exchange surface in the form of plates or tubes and are known as heat exchangers. Heat exchangers are equipment for the transfer of heat between two fluids through a separating wall. They are equipment primarily for transferring heat between hot and cold streams. They have separate passage for the two streams and operate continuously. (Walas, 1990).

Being the most widely used kind of process equipment is a claim that is made easily for heat exchangers. A classified directory of manufacturers of heat exchanger by walker has several hundreds items, including about 200 manufacturer of shell and tube equipment. (Walas, 1990).

Heat exchangers have wide applications, for instance the automobile radiator, the hot water heater, the steam boiler, the condenser and evaporator on either the house hold refrigerator or air conditioner, and even the ordinary cooking utensil in every day use are all heat exchangers. (Coulson and Richardson,1999).

Heat exchangers are of different types, the various types of heat exchangers available are; concentric tube (double pipe), shell-and-tube, plate, finned tube unit, spiral, compact and scraped surface heat exchangers. (Coulson and Richardson, 1999).

In power plants, oil refineries and chemical plants, two commonly used heat exchangers are the shell-and-tube and the double pipe (concentric tube) heat exchangers. The first consist of a bundle of tubes inside a cylindrical shell. One fluid flow inside the tubes and the other between the tubes and shell. The double pipe type consist of one fluid inside the inner tube and the other flowing in the annular space between the tubes. In both cases, the tube walls serve as the heat exchange surface. (Perry, 1984).

1.1 AIMS AND OBJECTIVES

i. To design and fabricate a concentric tube (double pipe) heat exchanger with high efficiency.

ii. To study the effectiveness of the concentric tube heat exchanger under counter current flow.

1.2 PROBLEM STATEMENT

In this design, it is required to design and fabricate a concentric tube (double pipe) heat exchanger that would make use of water as its fluid to determine the rate of heat exchange between hot and cold fluid separated by surface.

1.3 SCOPE OF WORK

The scope of these of work covers the following;

i. Design of a concentric tube heat exchanger.
ii. Fabrication of a concentric tube exchanger.
iii. Determination of the efficiency of the fabricated concentric tube exchanger.

1.4 JUSTIFICATION AND RELEVANCE OF THE PROJECT

This project constituting both the design and fabrication of a concentric tube heat exchanger will provide interesting and instructive experimental work for all students studying heat transfer and would be of particular interest to lecturers and those studying thermodynamics, chemical engineering, mechanical engineering, marine engineering, plant and process engineering, refrigeration, food processing technology, air conditioning, etc. This project would also serve as a reference for student doing research or design work on related topic in the future.

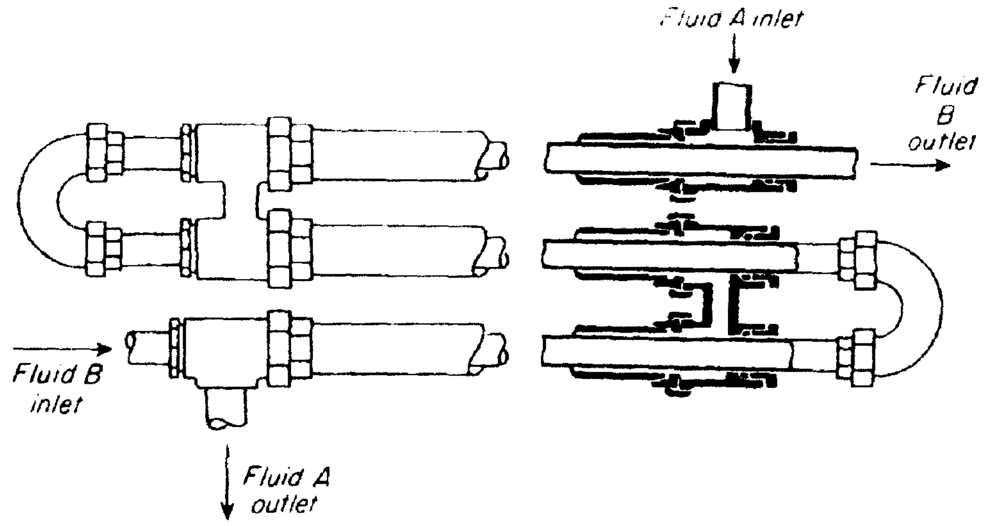
CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 CONCENTRIC TUBE HEAT EXCHANGER

The double pipe (concentric tube) heat exchangers have been used for many years primarily for low rates and high temperature ranges. These double pipe sections are well adapted to high temperature, high pressure applications because of their relatively small diameters, which allow the use of small flanges and thin wall sections as compared with conventional shell-and-tube equipment. (Richardson and Coulson, 1994).

The double pipe exchanger is assembled of standard metal pipe and standard return bends and return heads, the latter equipped with stuffing boxes. One fluid flow through the inside pipe, and the second fluid flows through the annular space between the outside and inside pipe FIGURE 2.0 Double-pipe heat exchanger (McCabe et al, 2001)



The function of a heat exchanger is to increase the temperature of a cooler fluid and decrease that of a hotter fluid. In a typical exchanger the inner pipe diameter may be $1^1/4$in., and outer pipe $2^1/2$in., both IPS (Iron Pipe Size). Such an exchanger may consist of several passes arrange in vertical stack. Double pipe exchangers are useful when not more than 100 to 150ft^2 of surface is required. For larger capacity, more elaborate shell-and-tube exchangers containing up to thousand of square feet of area are used. (McCabe et al, 2001)

Double-pipe sections permit true counter current flow, which is of particular advantage when very close temperature approaches are required. The number of sections and series parallel arrangement can be varied to meet conditions. Double-pipe extended surface sections are particularly useful when one fluid has a relatively low heat transfer coefficient and can be placed on the outside of the tins. (Bennett, 1992).

Multi-tube double-pipe sections are available with 8 and 16 inch pipe sections. Tubing may be either bare or with longitudinal fins. Design pressures of 600lb per square inch on the tube side have been used. The tubes are rolled into a tube sheet at one end and have individual u-bend connectors at the other. General appearance is much like that of the conventional double-pipe section. (Perry, 1984).

2.2 OTHER TYPES OF HEAT EXCHANGERS

Apart from the double pipe heat exchangers which have been discussed extensively, other types of heat exchangers include; the shell-and-tube and the plate type which is available in several distinctively different forms, spiral, plate (and frame), brazed plate-fin and plate fin. (Perry 1984).

The shell-and-tube heat exchanger is the most common of the various type of heat transfer equipment used in industries. Although it not compact, it is robust and it shape make it suitable for pressure applications. Specific-forms differ according to the number of shells and tube passes and the simplest form which involves single tube and shell pass. Baffles are usually installed to increase the convective coefficient of the shell side fluid inducing turbulence. The plate type heat exchanger consists of standard plates, which serve as heat transfer surfaces and a frame to support them. The design principle is much like that of the plate and frame filter press. Pressure drop is low and inter leakage of fluid is impossible. (Perry, 1984).

The brazed-plate fin heat exchanger which was first manufacture for air craft application during the second world war are used today in aluminum-plate-fin exchangers for the process industries, particularly for services below 50 degree Fahrenheit, and in gas separation processes operating between 400 and 450 degree Fahrenheit. The plate-fin heat transfer surface is made up of a stack of layers, with each layer consisting of a corrugated fin between flat metal sheets sealed off on two sides by channels or bars to form one passage for the flow of fluid. (Bennett, 1992).

Air-cooled heat exchangers in which ambient air is forced or induced by a fan to flow across a bank of externally finned tubes. A typical air cooler has a horizontal section containing finned tubes, a steel supporting structure with plenum chambers and fan ring, axial flow fan, drive assembly and miscellaneous accessories such as lowers, fan guards, fencing and ham screens. (Bennett, 1992).

With this flow pattern, it is not possible to cool the hot fluid to the input temperature of the cold fluid. Alternatively, the two streams are made to flow in opposite directions this is described as counter current flow. Now, if the exchanger is efficient enough the hot stream can be cooled almost to the temperature of the incoming cold stream. This is the most popular flow pattern in heat exchangers and generally most efficient. Finally, it may be that the flows of the fluids inside and outside the tubes are at right angles to one another. This is described as cross current flow. (Perry, 1984).

2.3 FLOW PATTERNS IN HEAT EXCHANGERS

The majority of industrial heat exchangers use fluid (either gas or liquid) as a medium to transfer heat energy. In order to improve the efficiency of such devices the fluid are normally in motion through the exchanger either under natural convention or by pumping. The nature of the flow pattern will have a substantial effect on the efficiency and operating characteristics of the exchanger and needs to be considered. This can be done under two headings. (Perry, 1984).

2.3.1 FLOW PATTERN WITHIN A SINGLE STREAM

The flow of a single stream can first of all be described in terms of the Reynolds number and descriptively as laminar or turbulent. The mixing implicit in turbulent flow improves the heat transfer, but at the cost of the extra work, which must be between heat transfer and fluid velocity. (Perry, 1984)

2.3.2 COMPARATIVE FLOW BETWEEN DIFFERENT STREAMS

The flow of a single stream can first of all be described in terms of Reynolds and descriptively as laminar or turbulent. The mixing implicit in turbulent flow improves the heat transfer, but at a cost of the extra work which must be done to obtain the high fluid velocity. The correlation between heat transfer and fluid flow has been discussed. Where heat transfer is to be between two fluid streams, three flow patterns must be considered: co-current, counter current and cross current flow. If one fluid is contain within a pipe or tube and flowing parallel to the tube, the other can be flowing outside the tube but in the same direction or sense as the flow inside. This is referred to as co-current. In this case, the two liquid will tend to read the same temperature at the exit. This temperature will be mid way between the two input temperatures, though the exact value will depend on the relative flow rates and specific heat. (Coulson and Richardson, 1999).

2.4 HEAT TRANSFER

Heat can be transferred from a source to a receiver by conduction, convection or radiation provided that a temperature difference exit between two parts of a system, heat transfer could take in any one or more of 3-different ways. In many cases, the exchange occurs by a combination two or three of these mechanisms. When the rate of heat transfer remains constant and unaffected by time, the flow of heat is designated as being in a steady state. An unsteady state exit when the rate of heat transfer at any point varies with time. Most industrial operations in which heat transfer is involved are carried out under steady state condition. However, unsteady state condition are encountered in batch processes, cooling and heating of material such as metals or glass and certain types of regeneration. (Coulson and Richardson,1984).

2.4.1 CONDUCTION

In a solid, the flow of heat by conduction is the result of the transfer of vibrational energy from one molecule to another, and in fluid it occurs in addition as a result of the transfer of kinetic energy. Heat transfer by conduction may also arise from the movement of free electrons. This process is particularly important with metals and account for their high thermal conductivity. (Coulson and Richardson, 1984).

2.4.2 CONVECTION

Heat transfer by convection arises from the mixing of element of fluid. If this occurs as a result of density differences as for example when a pool of liquid is heated from below, the process is known as natural convections. If the mixing resulted from eddy movement in the fluid, for example when a fluid flow through a pipe heated from the outside it is called forced convection. It is important to note that convection requires mixing of fluid element and it not govern by temperature difference as in the case of conduction and radiation. (Coulson and Richardson, 1984).

2.4.3 RADIATION

Radiation is a term given to the transfer of energy through empty space by electromagnetic waves. If radiation is passing through empty space, it is not transform to heat or any form of energy, nor is it diverted from its path. If how ever, matter appears in its path, the radiation will be transmitted, reflected or absorbed. It is only the absorbed energy that appears as heat, and this transformation is quantitative. For example, fused quartz transmits practically all radiation that strike it, a polished opaque surface or mirror will reflect most of the radiation impinging on it. A black or matte surface will absorb most of the radiation receive by it and will transform such energy quantitatively to heat.

2.5 BASIC EQUATION FOR THERMAL DESIGN

2.5.1 OVERALL COEFFICIENT OF HEAT TRANSFER

The simplest of equation which represent heat transfer operation may be written as;

$$Q = UA\Delta T$$

Where

Q = heat transfer per unit time

A = area available for transfer of heat

ΔT = is the difference between the source and the receiver

U = the overall heat transfer coefficient.

In a solid heat is normally transferred by conduction, some materials such as metal have a high thermal conductivity while others such as ceramics have a low conductivity. Transparent solid like glass transmit radiant energy particularly in the physical part of a spectrum. Liquids also transmit heat readily by conduction, though circulating current are frequently set up and the resulting convective transfer may be considerably greater than the transfer by conduction. Many liquid also transmit radiant energy. (Coulson and Richardson, 1984).

For a liquid heated or cooled the duty required to be performed by the exchanger is known as the outset.

$$Q = mCp(T-t)$$

Cp = specific heat of fluid at average temperature

T = higher temperature

t = lower temperature

m = flow rate of stream

Q = rate of heat transfer into streams

2.5.2 LOGARITHMIC MEAN TEMPERATURE DIFFERENCE (LMTD)

For two fluids to be in counter current flow, the effective temperature differential is the logarithmic mean temperature. For a counter current flow, the two fluids enter at different ends of the exchanger, shown in figure 2.0 and pass in opposite directions through the unit. The temperature profile is shown below.

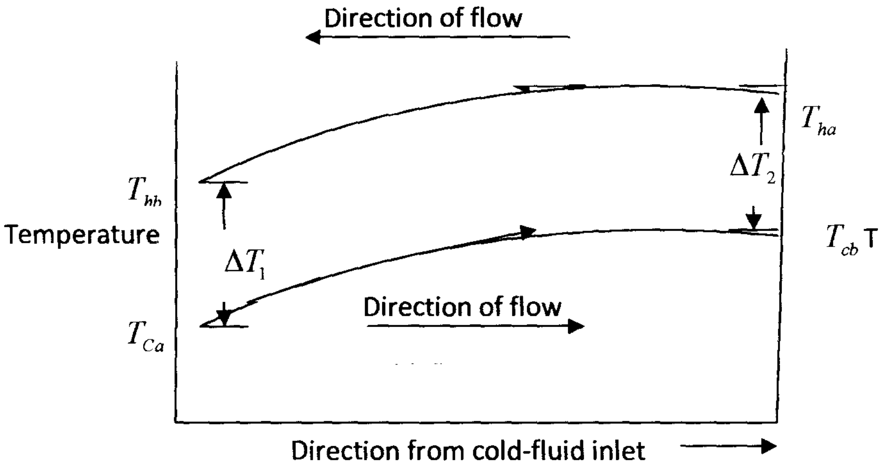


Fig.2.1. Counter – current flow direction

Temperature of entering hot fluid T_{ha}

Temperature of leaving hot fluid T_{hb}

Temperature of entering cold fluid T_{ca}

Temperature of leaving cold fluid T_{cb}

The temperature approaches are

$T_{ha} - T_{cb} = \Delta T_2$ and $T_{hb} - T_{ca} = \Delta T_1$

Therefore the logarithmic mean temperature difference (LMTD) is written as;

$\Delta T_L = (\Delta T_2 . \Delta T_1) / \ln(\Delta T_2 . \Delta T_1)$

Where, ΔT_L = Logarithmic mean temperature difference.

2.5.3 HEAT EXCHANGER PERFOMANCE

One of the useful methods of evaluating the performance of an exiting heat exchanger or to asses a proposed design is to determine its effectiveness Ω, which is defined as the ratio of the actual rate of heat transfer Q to the maximum rate Q_{max} that is thermodynamically possible. (Coulson and Richardson, 1984).

$$\Omega = Q / Q_{max}$$

2.6 DESCRIPTION OF EXCHANGER TO BE FABRICATED

This is a classic concentric tube type with hot water flowing through the central tube while cooling water flows through the annular space. The heat exchanger has been divided into three equal sections in order to allow examination of the intermediate stream temperature conditions and temperature distribution through the exchanger. Thermometers sense the hot and cold stream temperature at the four stations of entry and exit.

2.6.1 HOT WATER CIRCUIT

Hot water provided by an electrical heater which is fed by a 0.5 horse power pump into the upper end of the central tube of the heat exchanger. The water cools as it flows through the heat exchanger.

2.6.2 COLD WATER CIRCUIT

The cold water is fed with a 0.5 horse power pump from a cold water tank. The cold water passes through a valve mounted on the pipe.

2.6.3 INSTRUMENTATION AND CONTROL

Valves are provided to control the flow rate of the hot and cold streams of water. Thermometers with $0.1^{0}C$ resolution are provided to sense the temperature of the hot and cold streams respectively. Water heater is provided to heat the hot fluid to the required temperature. Two 0.5 horse power pumps were provided for the pumping of the water streams.

CHAPTER THREE

3.0 METHODOLOGY

Methodology is a systematic study of the principle guiding scientific philosophical investigation. Every research must have a scientific method to employ in the research work, which depends on the nature of the investigation. For investigation, the performance of a concentric tube heat exchanger in order to determine the proposed design effectiveness which would be accessed from the procedures below.

3.1 APPROACH TO HEAT EXCHANGER DESIGN.

The prime objective of this design (concentric tube heat exchanger) is to determine the surface area required for the specified duty (rate of heat transfer), using the temperature differences available. The overall coefficient is the reciprocal of the overall resistance to heat transfer, which is the sum of several individual resistances.

3.2 DESIGN PROCEDURES

The strategies employed in designing heat exchanger are in the following steps.

a. Process specification

b. Preliminary problem analysis

c. Detailed thermo- dynamic design

d. Mechanical and metallurgical design

e. Architectural design aspect

f. Operation, control and maintenance considerations.

A. Process Specification

1. Specification of heat exchanger type – Horizontal

2. Specification of temperature, pressure and flow rate of fluid streams and the composition of the materials and other physical properties are as follows, 65^0c, 1 atm.

3. Specification of permissible pressure drop

4. Specification of the fouling resistance of both fluids and area over design factor.

5. Specification of tube size (e.g. number, diameter, length etc.)

6. Calculation of effectiveness.

B. Preliminary problem Analysis.

1. Approximation of size estimates

  - Calculation of heat transfer coefficient
  - Calculation of the mean temperature
  - Determination of size (Area required) from $Q = UA\Delta T$

2. The distribution of the thermal resistance under clean and fouled condition would be determined

3. Identification of the resistive considerations e.g.

- Thermal profile i.e. if counter current is necessary due to closeness of the streams.

- Fouling; if fouling resistance is apparent, then the defensive measures could be or could not be placed e.g. flow velocity, material types etc.

- Other factors e.g corrosively, high pressure etc, such materials, is to be placed in tube side because of material cost.

- Alternative design suggestions

- Safety considerations to be provided

C. Detailed thermo- hydraulic Design.

Possible thermodynamic properties that would effectively interact with other disciplines or mechanical and metallurgical design. Type consideration e.g. double pipe tube based on cost, construction materials, fouling minimization and ease of clearing. Arrangement e.g. straight counter flow thermal profile analysis e.g. exchanger duty conductivity e.tc.

D. Mechanical and Metallurgical Design Aspect.

  - Selection of proper materials
  - complying of paths
  - General mechanical design integrity e.g. joints, welds

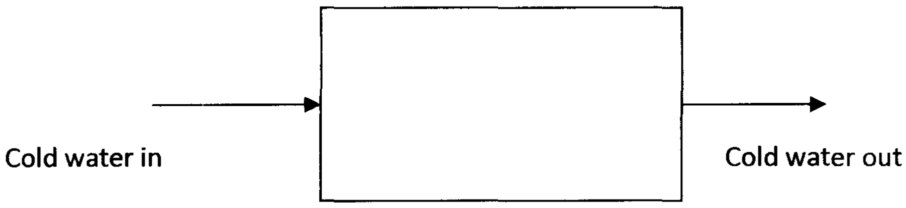
E. Architectural Design Aspect

  - Integration within the piping network
  - Support types required
  - Ease and access for cleaning

F. Control, Operation and Maintenance Consideration

- Routing activities during operations
- Commissioning and monitoring activities
- start up and shut down.
- Maintenance consideration.

3.3 MATERIAL BALANCE ON FLUID



Material balance across heat exchanger for cold water since;

Input = Output

Taking into consideration, the equipment runs at estimated flow rate of about 864L/hr; experimentally i.e. continuous flow of cold water was taken as 864L/hr

Converting 864L/hr to m3/s

864L	1 m3	1hr
hr	1000L	(60x 60)s

$$= 2.4 \times 10^{-4} \text{ m}^3/\text{s}$$

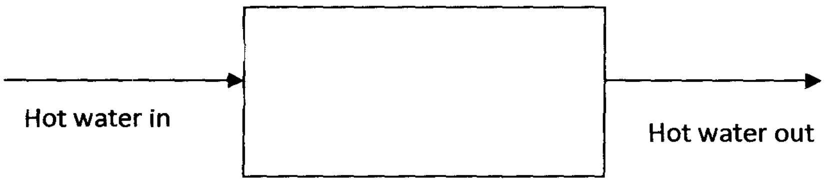
To convert volumetric flow rate to mass flow rate, we have;

Mass flow rate = volumetric flow rate x density

Density of water = 1000kg/m^3

Mass flow rate = 2.4×10^{-4}m3/s x 1000kg/m^3

Mass flow rate of cold water = 0.24 kg/s



Material balance across the heat exchanger for hot water.

Since; input = output

Also taking into consideration, expected experimental value for hot water flow.

Continuous flow rate of hot water is taken to be 250L/hr

Converting 250L/hr to m^3/s.

250L	1m3	1hr	
hr	1000L	(60 * 60)s	= 6.94×10^{-5} m3/s

To convert volumetric flow rate to mass flow rate, we have

Mass flow rate = volumetric flow rate x density

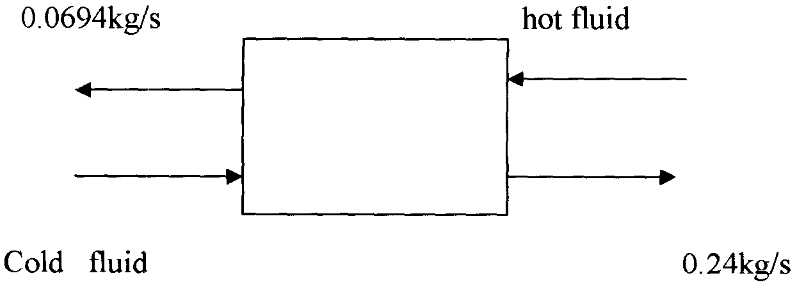
Density of water = $1000 kg/m^3$

Mass flow rate = 6.94×10^{-5} m3/s x 1000 kg/m^3

Mass flow rate of hot water = 0. 0694 kg/s

3.4 ENERGY BALANCE

Energy balance across the heat exchanger



From the related formulae

$M_hC_Ph(T_{ha} - T_{hb}) = MC_{PC}(T_{cb} - T_{ca})$ (McCabe et al, 2001).

Where;

C_Ph = specific heat capacity of hot water

C_pc = specific heat capacity of cold water

M_h = mass flow rate of hot water

M_c = mass flow rate of cold water

T_{ha} = temperature of inlet hot water

T_{hb} = temperature of outlet hot water

T_{Ca} = temperature of inlet cold water

T_{Cb} = temperature of outlet cold water

By substituting values we have

M_h = 0.069kg/s

C_ph = 4.18kj/kgk

T_{ha} = 650c = 273+65 = 338^0k

T_{hb} = 55^0c = 273 + 55 = 328^0k

M_c = 0.24kg/s

T_{ca} = 25^0c = 273 + 25 = 298^0K

T_{cb} =?

From $qh = M_hC_ph\Delta T$

= 0.069 x 4.18 x (338 – 328)

= 2.8842 KW or 2884.2W

$qc = M_cC_{pC}\Delta T$

$= \quad 0.24 \times 4.2 \times (T_{cb} - 298)$

But $qh = -qc = q$

Therefore

$$0.24 \times 4.2\ (T_{cb} - 298) = 2.8842$$

$$T_{cb} = (2.8842/\ 1.008) + 298$$

$$T_{cb} = 2.86 + 298 = 300.86 = 301^0\text{k}$$

$$T_{cb} = 301^0\text{k or } 28^0\text{c.}$$

3.5 LOGARITHMIC MEAN TEMPERATURE DIFFERENCE ($LMTD$)

Assumption.

i) The overall coefficient u is constant

ii) The specific heat capacity of hot and cold fluids are constants.

iii) Heat exchange with the ambient air is negligible

iv) The heat flow is steady. (Mc Cabe etal, 2001).

Once these assumptions are made, we can therefore say,

$$LMTD, \Delta T_L = \frac{\Delta T_2 - \Delta T_1}{\ln(\Delta T_2 / \Delta T_1)}$$

Where ΔT_L = logarithmic mean temperature difference ($LMTD$)

For counter- current flow such as fig 2.1, we have

$$\Delta T_1 = 328 - 298 = 30^o\text{k}$$

$$\Delta T_2 = 338 - 301 = 37^o\text{k}$$

$$;.\quad \Delta T_L = \frac{37 - 30}{\ln 37/30}$$

$$= 33.4\,^o\text{k}$$

3.6 CALCULATION OF HEAT TRANSFER AREA

Diameter of tube = 1in = 0.0254m

Length of shell = length of tube = 1.5m

;. Area available for heat transfer = πDL

$$= \pi \text{ x } 0.0254\text{m}$$

$$= 0.1197\text{m}^2 \ .$$

3.7 CALCULATION OF OVERALL HEAT TRANSFER COEFFICIENT

$$q = UA\Delta T_L$$

$$U = \frac{q}{A\Delta T_L} = \frac{2884.2}{0.1197x33.4}$$

$$U = 721.4W / m^2k = 721.4W / m^2o_c$$

Specifications:

Diameter of inner pipe = 1in = 0.0254m

Length of shell = length of tube = 1.5m.

3.8 EFFECTIVENESS FROM DESIGN DATA.

The concept of a transfer unit is useful in the design of heat exchangers and in assessing their performance, since its magnitude is less dependent on the flow rates of the fluids than the transfer coefficient (Coulson and Richardson, 1999).

$$N = \frac{UA}{C_{\min}} \text{ -- } 3.1$$

Where $C_{\min}$ is the lower capacity rate of the two fluids, N is the ratio of the heat transferred for a unit temperature during force to the heat absorbed by the fluid stream when its temperature is changed by 1k. (Coulson and Richardson, 1993). Thus, the number of transfer unit gives a measure of the amount of heat, which the heat exchanger can transfer. The relation for the effectiveness of the heat exchanger in terms of the heat capacities of the streams is now given for a number of flow conditions.

Considering co- current flow for an elementary area dA of a heat exchanger, the rate of transfer of heat dQ is given by;

$dQ = UdA(T_1 - T_2) = UdA\theta$ ------------------------------------3.2

Where T1 & T2 are the temperatures of the two steams and 0 is the point value of the temperature difference between the streams,

The effectiveness (E) is given by the definition,

$E = 1 - \frac{\exp(-N(1+C))}{1+C}$ --3.3

C is the capacity ration $= \frac{C_{\min}}{C_{\max}}$

For the particular case where $C_{\min} = C_{\max,}$

$E = 0.5(1 - \exp(-2N))$ --3.4

For a very large exchanger $(N - \alpha)$ $E \longrightarrow 0.5$.

Considering a counter- current flow, a similar procedure may be followed, although it should be noted that in this case, $\theta = T_1 - T_2$

The corresponding equation for the effectiveness factor,

E is then,

$E = \frac{1 - \exp(-N(1-C))}{1 - \exp(-N(1-C))}$ --3.5

For the case where $C_{\min} = C_{\max,}$, it is necessary to expand the exponential term to give

$E = \frac{N}{1+N}$ --3.6

In this case, for a very large exchanger, $N \longleftarrow \alpha, n \longrightarrow 1$, if one component is richly undergoing a phase change at constant temperature, Cmin is effectively zero and both equation 3.3 and 3.5 reduce to

$$E = 1 - \exp(-N)$$

But, number of transfer unit

$$N = \frac{UA}{C_{\min}}$$

Where $C_{\min} = (GC_P)\min$

$(GC_P)\min$ = 0.069 x 4.18 = 0.2884KN/k

U = coefficient of heat transfer = 721. 4 W/ m2k

A = Available area for heat transfer = 0.1197m2

$$;.\ N = \frac{721.4x0.1197}{0.288x10^3}$$

$$N = 0.3$$

Effectiveness from design data using equation 3.3

$$E = \frac{1 - \exp(-N(1 + C))}{1 + C}$$

Where $C = C_P h / C_P c = \frac{4.18}{4.2} = 0.996$

$$E = 1 - \exp\frac{(-0.3(1 + 0.996))}{1 + C}$$

$$E = 1 - \exp\frac{(-0.3(1 + 0.996))}{1 + 0.996}$$

$$E = 1 - \frac{0.251884}{1 + 0.996}$$

$$E = 0.874$$

%Effectiveness E = 0.874 x100 = 87.4 %

3.9 HEAT EXCHANGER PERFORMANCE.

One of the most useful methods of evaluating the performance of an existing heat exchanger to access a proposed design is to determine its effectiveness ŋ, which is defined as the ratio of the actual rate of heat transfer Q to the maximum rate Qmax that is thermodynamically possible or

$$ŋ = \frac{Q}{Q_{\max}}$$

$Q_{\max}$ is the heat transfer rate which would be achieved if it were possible to bring the outlet temperature of the stream with the lower heat capacity to the inlet temperature of the other stream. Using the nomenclatures below and taking stream 1 (hot stream) as having the lower value of GCp, then;

$$Q_{\max} = G_1 C_{p1}(T_{11} - T_{21})$$

An overall heat balance gives

$$Q = G_1 C_{P1}(T_{11} - T_{21}) = G_2 C_{P1}(T_{22} - T_{21})$$

Thus, based on stream 1;

$$\eta = \frac{G_1 C_{P1}(T_{11} - T_{12})}{G_1 C_{P1}(T_{11} - T_{21})}$$

And based on stream 2;

$$\eta = \frac{G_2 C_{P2}(T_{22} - T_{21})}{G_1 C_{P1}(T_{11} - T_{21})}$$

Where G = mass flow rate of liquid.

Flow of hot water

$$(GC_P)hot = (0.069x4.18) = (GC_P)\min = (G_1 C_{P1})$$

$$(GC_P)hot = 0.288kW / k$$

Flow of cold water

$$(GC_P)cold = (0.24x4.2) = G_2 C_{P2}$$

$$(GC_P)cold = 1.008kW / k$$

Effectiveness, $\eta = \dfrac{1.008(338-328)}{0.288(338-298)}$

$\eta = 0.875$

Percentage effectiveness = η x100

= 0.875 x100

= 87.5 %.

CHAPTER FOUR

4.0 DETAILED DESIGN OF CONCENTRIC TUBE HEAT EXCHANGER.

Detailed design of the concentric tube heat exchanger is analyzed as follows;

Tube side coefficient;

Using a standard 25.4mm (outer diameter) and 20.0mm (internal diameter) tube;

Mean hot water temperature $= \frac{65 + 55}{2} = 60^{o}c$

Tube cross-sectional area $= \frac{\pi}{4} x 20^2$

$= 314.16mm^2$

$= 3.1416x\ 10^{-4}m.$

Hot water mass velocity $= \frac{flowrate}{area}$

$= \frac{0.069}{3.1416x10^{-4}}$

Density of hot water = $995kg/m^3$

Water linear velocity $= \frac{219.6}{995} = 0.22m/s$

$$hi = \frac{4200(1.35 + 0.02t)U_t^{0.8}}{di^{0.2}}$$

Where hi = inside coefficient, for water, $W/m^{2o}c$

T = water temperature, ^0c

U_t = water velocity, m/s

di = tube inside diameter, mm (sinnott, 1999)

$$hi = \frac{4200(1.35 + (0.02x60)x0.22^{0.8})}{20^{0.2}}$$

$hi = 1,751.95W/m^2$

Shell- side coefficient

Using a plastic shell of 76.2mm (outer diameter) and 72.2mm (inside diameter)

Cross – flow area of shell = $\frac{\pi}{4} x 72.2^2 mm$

= 4,094.15mm

= 4.094 x 10^{-3}m

= 58.62kg/sm^2

Equivalent diameter, *de* = outer diameter of shell- inner diameter of tube

= 76.2 -20.0 = 56.2mm

Mean shell temperature = $\frac{28+25}{2} = 26.5^{\circ} c$

Cold water density = 1000kg/m^3

Viscosity = 0.862 C_P $\left(0.86 x 10^{-3} Ns/m^2\right)$

Heat capacity = 4.2 kj/kg^0 c

Thermal conductivity of water at 26.5^0 c = 0.609W/m ^{0} c

Reynold's number, Re = $\frac{Gsde}{\mu}$

$= \frac{58.62 x 56.2 x 10^{-3}}{0.86 x 10^{-3}}$

Re = 3,830.75

Prandt number, Pr = $\frac{C_P \mu}{K_f}$

$= \frac{4.2 x 10^3 x 0.86 x 10^{-3}}{0.609}$

= 5.93

$$ho = \frac{K_f j_h \operatorname{Re} \operatorname{Pr}^{1/3}}{de}$$

Where ho = shell side coefficient or outside fluid film coefficient of tube.

J_h = shell- side heat transfer factor

From chart, $J_h = 4.8 \times 10^{-2}$

$$ho = \frac{0.609x4.8x10^{-2}x3,830.75x5.93^{0.33}}{56.2x10^{-3}}$$

$$ho = 3600W/m^{0}c$$

Calculation of overall coefficient from individual coefficient

$$\frac{1}{Uo} = \frac{1}{ho} + \frac{1}{hod} + \frac{dolin\left(\frac{do}{di}\right)}{2kw} + \left(\frac{do}{di}x\frac{1}{hid}\right) + \left(\frac{do}{di}x\frac{1}{hi}\right)$$

Where Uo = the overall coefficient based on the outside area of tube, $W/m^{o}c$

ho = outside fluid film coefficient $W/m^{o}c$

hi = inside fluid film coefficient $W/m^{o}c$

hod = outside dirt coefficient, (fouling factor), $W/m^{o}c$

hid = inside dirt coefficient, $W/m^{o}c$

kw = thermal conductivity of the tube wall material, $W/m^{o}c$

di = tube inside diameter

do = tube outside diameter.

Taking the fouling coefficient from table 12.2 (sinnott, 1999). Of water water to be 5000 $W/m^{o}c$

Thermal conductivity of iron (galvanize) = 60 W/m ^{0}c

$$\frac{1}{Uo} = \frac{1}{1,751.95} + \frac{1}{5000} + \frac{25.4x10^{-3}lin\left(\frac{25.4}{20}\right)}{2x60} + \left(\frac{25.4}{20} + \frac{1}{5000}\right) + \left(\frac{25.4}{20}x\frac{1}{3600}\right)$$

$$\frac{1}{Uo} = 5.71x10^{-4} + 2.0x10^{-4} + 5.06x10^{-5} + 2.54x10^{-4} + 3.53x10^{-4}$$

$$\frac{1}{Uo} = 1.4286x10^{-3}$$

$$Uo = 700W/m^{o}c$$

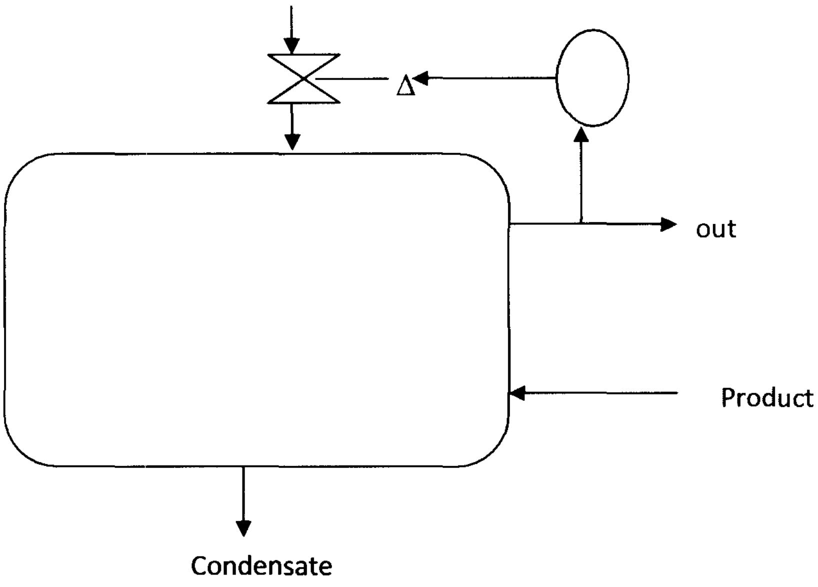
It could be clearly seen that the value of the overall coefficient gotten from the design equation in chapter3 using $Q = UA\Delta T_L$ is very close to that gotten when calculating using the individual coefficient,

Using design equation $\mu = 721.4W/m^{o}c$

Using individual coefficient $700W/m^{o}c$

4.1 CONTROL OF THE HEAT EXCHANGER

In any equipment where interfaces exist between two phases, e.g. between liquid-liquid, and liquid-vapor, some means of maintaining the interface at the required level must be provided. This may be incorporated in the design of the equipment, as usually done for decanters or by automatic control of the flow from the equipment.



Fig; 4.1 control of heat exchanger

The actual area of the heat exchanger can now be calculated.

$$A = \frac{Q}{U\Delta T_m}$$

$$A = \frac{2884.2}{700 \times 33.4} = 0.1234\text{m}^2$$

4.2 EQUIPMENT SPECIFICATION

1) Tube

Type; Galvanized Iron.

Quantity; 1

Tube Characteristics

Length	*m*	1.5
Diameter	*mm*	25.4 *o.d* 20.0*i.d*
Thickness	*mm*	2.5
Curved – surface – Area	m^2	0.1197

2) Shell

Type; plastic

Quantity; 1

Shell Characteristics

Length	*m*	1.5
Diameter	*mm*	76.4*o.d*, 72.0*i.d*
Thickness	*mm*	2
Curved – surface – Area	m^2	0.359

3) Pump

Manufacturer; INTERDAB

Type; Electro pomp

Quantity; 2

Pump Characteristics

Max.pumping heigth	m	35
Max.flowrate	$l/\min$	35
Voltage	v	220-240
Power	h_p	0.5

4) Thermometer

DIAL Size (phase diameter) = 4inch

Quantity; 2

Thermometer Characteristics

Dial Size	*inch*	4
Range	^0c	0-120
Stem Length	*mm*	150

5) Thermometer

Type; glass thermometer

Quantity; 2

Thermometer Characteristics

Dial Size	*inch*	10
Range	^0c	$0-100^0c$
Stem Length	*mm*	140

6) Water tank

Type; plastic

Quantity; 2

Tank Characteristics

Heigth	*cm*	42
Diameter	*cm*	30
Volume	*l*	30

7) Heater

Type; Electric

8) Valves

Type; Metals

4.3 MATERIAL SELECTION, FOR CONSTRUCTION AND FABRICATION.

Selection of materials of construction for process equipment, is a major factor to be considered when selecting engineering materials, in recommending materials that will be suitable for the process condition, our task is to analyze and give variable function of equipments necessary for fabrication. The major materials necessary for concentric tube heat exchanger fabrication are;

i) Galvanized iron pipe

ii) Plastic pipe (shield)

iii) Electric pomp

iv) Thermometer

v) Tank

vi) Electric heater.

vii) Valves

a) Galvanized iron pipe.

Galvanized iron pipe is an elastic strong iron gauge material; iron pipe covered with a protective coating of zinc that greatly reduces its tendency to corrode and extends its life expectancy. It may be used in residential water supply lines, but not for hot gas line, because natural gas causes the zinc to flake off and clog the system. In fabrication the galvanized pipe is laid horizontally with it's curve bends to rechannel flow direction. Galvanic corrosion of iron is a major factor that affects the better performance of the iron pipe for heat transfer, i.e. when identified with corrosion effect, heat transfer would be defective, due to either cracked zone parts or leakage ion pipe lining but galvanized iron pipe is preferred for this construction because of effective heat transfer compared to other metallic material

b) Plastic pipe (shield)

. Plastics are soft ductile material, used in the form of sheets or (as linings) or pipe as cover for an inner pipe, which are good corrosion-resistant materials for chemical plant construction although there are different types of plastics depending on temperature setting and cross-linked structure. But our concern here is to design a plastic material suitable as shell tube for an inner galvanized iron pipe. The mechanical strength and operating temperature of plastics are low compound with that of metals. This plastic pipes detect the interface of heat transfer between the two fluid streams, plastic pipes are of different sizes but for our desired design we make use of 3" diameter pipe.

c) Electric pump.

Pump is an equipment that transfers liquid fluid or material from one point to another, i.e. from one vessel to another; the pump is made up of different component parts like the rotor, blade (fan), propeller, there are also different types of pump, examples are the centrifugal pump, turbine pump, rotary pump, gear pump, reciprocating pump, screw pump, diaphragm pump etc. The standard pump rating to be used for this project work is 0.5hp, (370w) 50HZ pump, with maximum flow rate and max height as 35L/m and 35m respectively, also with 1.mot/v220 and 2850min^{-1} time factor, this pump should be able to pass current at 2.5Amp, with a continuous duty thermal protector of 550w.max, 10μf capacitance and 40v, Vl. The operating condition for this pump as designed to pump neutral clean liquid in which no abrasive solids are suspended at temperature of not more than 80^{0}c (60^{0}c for electric pumps with plastic impellers or diffusers). The major task on this, is the process of start-up and shut down and maintenance of the pump, two pumps would be provided for the cold and hot fluids.

To start up a pump

i) To confirm that the electric motor/drive is energized

ii) To confirm cooling water circulation is o.k. by checking the sight glass balls on the return line.

iii) To confirm that the drain valve is closed

iv) Confirm that pump is crack opened on vent to release displaced gas to the atmosphere.

iv) Develop format to register any problem, when pump is running.

To shut-down a pump

i) Press the stop button and observe the deceleration of the pump shaft.

ii) Close the discharge valve to reserve the material away from pump.

d) Thermometer.

Thermometer is an instrument that measures the temperature of either a fluid or material. Thermometers, w3ould be provided for the fabrication of concentric tube heat exchanger, which forms parts of the auxiliary equipment. 0.1^{0}c resolution is used to detect the inflow and outflow of fluid from the heat exchanger, which are expected to meet the desired specification of 60^{0}c. Two concentric standards gauge thermometer was used to mount on each end of the tube.

e) Water Tank

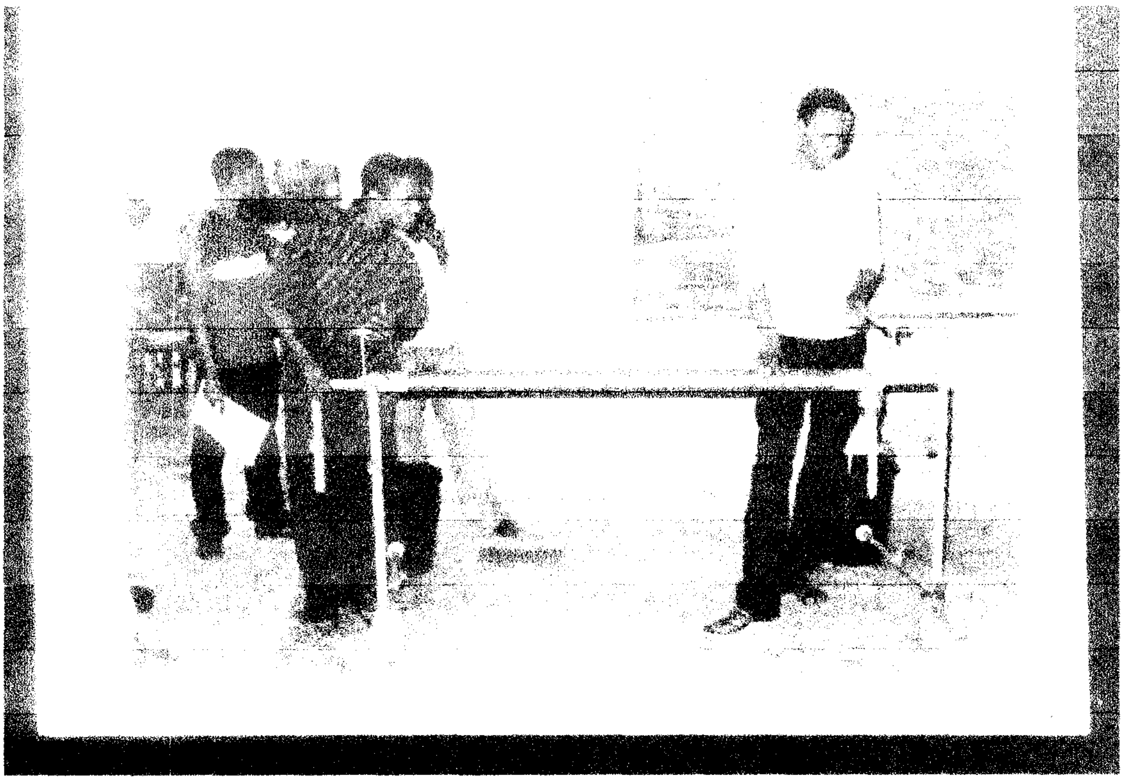
The water tank could be either plastic or metal depending on the choice or taste for design, water tank contains the required volume of water or fluid required for discharge. In this design and fabrication two tanks are required, i.e the cold and hot water tank, the hot water tank has an electric heater inbuilt inside the tank, to heat water to a required temperature, where as the cold water tank is mounted and fixed, the tank could come in different sizes, depending on required volume of fluid for flow.

f) Electric heater

Electric heater is a material made with iron steel pipe and plastic or rubber material. With wires connected to it. It is used to heat fluid example is water, the electric heater has control switch to control the heating process for a required temperature regulation.

g) Valves

The valves are metallic materials used for the control of flow rate or pressure of fluid from discharge. This apparatus has a great important in the design and fabrication of the concentric tube heat exchanger because it regulates the inflow of fluid to the required discharge point.



4.4 PREDICTING DYNAMICS OF CONCENTRIC PIPE HEAT EXCHANGER.

For several decades automatic control has been used in chemical plants to reduce operating costs, to increase product yield and quality, and to maintain a high level of safety. Traditionally, the process equipment for these plants has been designed or a steady – state basis, without much consideration of the dynamic behavior which is so vitally important in determining performance under automatic control. The process design was then handed to instrument personnel who proceed to specify the instrument "hardware" required. It was hopefully assured that the built-in flexibility of the instruments, together with a high degree of self-regulation designed into the process equipment would permit" adjustments," after the plant was constructed, to achieve stable and satisfactory control performance.

However, even recent trends in process equipment design toward high throughput rates and low holdup of material in process have reduced the self-regulation usually inherent in most chemical process equipment. In addition, the permissible ranges of variation of process operating conditions have been markedly reduced in recent years in order to achieve uniform production of high quality products. These trends have resulted in the evolution of many chemical process requiring very precise and fast-acting instrumentation systems, which in many cases cannot be built up from off-the-shelf components. Moreover, the economic stakes are getting too large gamble on being able to correct the instrument and process design after the plant construction is completed. In the face of these developments, plant equipment designers as well as instrument personnel, must be supplied with efficient and quantitative methods for ensuring proper control performance in the design stages. This requires that methods for quantitatively predicting the dynamic behavior of chemical process equipment be made available in a form useful for design of automatic control systems. This report presents two methods of dynamic prediction as applied to a specific example from the heat transfer field-a concentric double-pipe heat exchanger. These methods are based on simple mathematical model and passive electrical network analogs. These results predicted by both schemes for a particular heat exchanger was confirmed by experimental dynamics measurement.

4.5 SAFETY CONSIDERATION

The preparation and undertaking of safety measures is part and parcel of any chemical Engineering design, in the design and fabrication of concentric tube heat exchanger various factor would be considered.

i) Safety against Fire Outbreak

Fire is as a result of chemical combustion of products, very hazardous and could cause injury to operator or individual operating should ensure that all functional parts of the exchanger such as the electric pump, valves, heaters are in good working conditions.

ii) Safety against Corrosion.

Corrosion could result as a process of rust of inner pipes due to absorption of fluids for a very long period of time or suspended layer particles deposition within the pipe.

Effects of Corrosion

1. stress-corrosion

2. Erosion-corrosion

A) Stress-Corrosion

Corrosion rate and the form of attack can be changed if the material is under stress generally, the rate of attack will not change significantly within normal design stress values, however, for some combinations of metal corrosive media and temperature, the phenomenon called stress-cracking can occur. This is the general name given to a form of attack in which cracks are produced that grow rapidly, and can cause premature, brittle failure, of the metal.

The conditions necessary for stress corrosion cracking to occur are;

a. Simultaneous stress and corrosion

b. A specified corrosive substance; in a particular solution due to the presence

$$cl,^{-}\ OH,^{-}\ NO_3^{-} or, NH_4^{-} ions.$$

B) Erosion- Corrosion

The term erosion corrosion is used to describe the increased rate of attack caused by a combination of erosion and corrosion. If a fluid stream contains suspended particles or where there is high velocity or turbulence erosion will tend to remove the products of corrosion and any protective films, and the rate of attack will be markedly increased. More resistance materials must be specified, for example, plastics inserts are used to prevent erosion-corrosion it is inserted into the heat exchanger tubes.

4.6 COSTING AND PROJECT EVALUATION.

Cost estimation is a specialized subject and a profession in its own right. We the designer's engineer, however needs to be able to make quick, rough ,cost estimates to decide between alternative designs and for project evaluation. Chemical plants are built to make a profit and an estimate of the investment required and the cost of production are needed before the profitability of a project can be assessed.

The accuracy of an estimate depends on the amount of design detail available; the accuracy of cost data available and the time spent on preparing the estimate. Capital cost estimate for chemical process plants are often based on an estimate of the purchase cost of the major equipment items required for the process, the other costs being estimated as factors of the equipment cost.

Table 4.1 Cost of various equipments and estimates

Description	quantity	size	Rate ₦	Total Amount, ₦
Galvanized iron pipe	1	6m	2800	2800
Plastic pipe (shield)	1	6ft	450	450
Plastic bends	2	-	60	120
Electro pomp	2	0.5hp	4000	8000
Dial size phase Thermometer	2	0-120°c	5000	10,000
Glass thermometer	3	0-110°c	300	600
Water tank	2	30litres	350	700
G^{-1} elbow	4	1 inch	60	240
Break nut	2	-	300	600
Control Valves	6	1inch	400	2400
PVC bend	2	4inch	100	200

Socket	2	1inch	100	200
Electric heater	1	-	250	250
Electric wire	1	6Yards	300	300
Plug head	2	13Amp	50	100
				= ₦ 26,960.

Capital Expenditure

Labor	₦ 4000
Transportation	₦ 2000
Miscellaneous	₦ 2000
	₦ 8000

Total Cost of estimate = total cost of equipments + Capital Expenditure

= ₦ 26,960 + ₦ 8000 = ₦ 34,960.00

4.7 DISCUSSION

For a complete design process, the main objective of the system is to be able to generate possible information that could be used to formulate the estimation, cost of equipment, working facilities, and fabrication materials and make various economic analyses that could help to obtain the final operation in essence.

In experimenting hot and cold fluid for heat exchange the conductivity of the fluid is very essential because it entails the proper estimate of temperature of fluid either high or low depending on the direction of flow. Using a 1 inch diameter galvanized iron pipe and 3inch plastic pipe as shell or shield to the former as analyzed for this design, gives an in depth of approximate estimation of effectiveness. A material balance of $2.4x10^{-4}m^3/s$ for the cold fluid and $6.94x10^{-5}m^3/s$ for the hot fluid was obtained, of which mass flow rate of cold fluid was 0.24kg/s and that of the hot fluid was 0.0694kg/s respectively. Possible value of heat flow by calculation from the Energy balance across the heat exchanger was obtained as hot fluid = cold fluid = $q_h = -q_c = q$ = 288420W or 2.8842KW.

Temperature of cold fluid was obtained as 28^0C, practically for the size of this equipment in control, the expected analysis could now be generalized, when test runned the temperature of the hot fluid dropped from $65^0C$to 57^0C as compared to expected value of 55^0C, while the cold fluid temperature rose from 25^0C to 28^0C as seen in the designed work and the heat transfer was gotten as $0.1197m^2$.

CHAPTER FIVE

5.0 CONCLUSION

The design of heat exchanger (concentric tube), which yields an efficiency of 87.4% effectiveness to an overall performance in operation, could be analyzed promptly, for research purposes. The heat exchanger is expected to work effectively for about 12hours daily, and proper maintenance should be ensured on each parts of the equipment. Detailed design of the heat exchanger was carried out. The heat exchanger is used to exchange heat between hot and cold fluid in a directional channel. The overall area of the heat exchanger design from the given calculation was $0.1197m^2$ and the overall heat transfer coefficient from the design equation is $721.4W/m^{20}C$ respectively. The cost of the heat exchanger as designed was also estimated as ₦ 34,960.00.

5.2 RECOMMENDATION

For the complete design and fabrication of a heat exchanger it is recommended that the preliminary problem analyses, detailed thermo-dynamic design and mechanical design are considered. Also the design of the equipment should be done considering its operation, control and maintenance procedures because it helps in the following ways.

i. Giving quality, quantity, capacity and standard in the equipment design.
ii. Prescription of uniform maintenance procedure and practices.
iii. Increase advantages both economically and technically.

APPENDIX

MATERIAL BALANCE.

For Cold fluid, flow rate = $2.4 \times 10^{-4} m^3/s$

For Hot fluid, flow rate = $6.94 \times 10^{-5} m^3/s$

Density of fluid = $1000 kg/m^3$

ENERGY BALANCE

Heat balance $q_h = q_c = q$ = 2884.2W or 2.8842KW.

For $qh = M_h C_p h \Delta T$

For $qc = M_c C_{pC} \Delta T$

LOGARITHMIC MEAN TEMPERATURE DIFFERENCE (LMTD)

$$LMTD, \Delta T_L = \frac{\Delta T_2 - \Delta T_1}{\ln(\Delta T_2 / \Delta T_1)}$$

Area available for heat transfer = πDL

Overall heat transfer coefficient;

$$U = \frac{q}{A \Delta T_L}$$

Effectiveness, $E = \frac{N}{1+N}$ or

$$E = \frac{1 - \exp(-N(1+C))}{1+C}$$

No of transfer unit, $N = \frac{UA}{C_{\min}}$ and Ŋ $= \frac{Q}{Q_{\max}}$

TUBE AND SHELL SIDE OVERALL HEAT TRANSFER COEFFICIENT

$$hi = \frac{4200(1.35 + 0.02t)U_t^{0.8}}{di^{0.2}}$$

$$ho = \frac{K_f j_h}{de} \mathrm{Re}\,\mathrm{Pr}^{1/3}$$

Reynold's no, $\mathrm{Re} = \frac{Gsde}{\mu}$

Prandtl no, $\mathrm{Pr} = \frac{C_P \mu}{K_f}$

Overall coefficient from individual coefficient

$$\frac{1}{Uo} = \frac{1}{ho} + \frac{1}{hod} + \frac{dolin\left(\frac{do}{di}\right)}{2kw} + \left(\frac{do}{di} x \frac{1}{hid}\right) + \left(\frac{do}{di} x \frac{1}{hi}\right).$$

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