OPTIMISATION OF A COMPUTER AIDED-DESIGN (CAD) MODULE OF A VAPORISER

BY

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CERTIFICATION

This thesis titled "Optimisation of a computer aided – design (CAD) module of a vaporiser" by Zakariah Adu Adejoh, meets the regulations governing the award of master of Engineering (M . ENG) of Federal University of Technology, Minna and is approved for its contributions to scientific knowledge and literary presentation.

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DEDICATION

This project is dedicated to God Almighty in heaven my creator.

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NUMENCLATURE

a	-	Interfacial area	m^2
A	-	Heat transfer area	m^2
Ao	-	Outside area required for heat transfer	m^2
CAD	-	Computer Aided-Design	
C_{AO}	-	Installed cost of heat exchanger unit of outside hat transfer area	$\$/m^2$
C_i	-	Cost of pumping fluid flowing through inside of tubes	$/Nm
Co	-	Cost of pumping fluid flowing outside of tubes	$/Nm
Cp	-	Specific heat capacity	KJ/Kg ^oC
CP_L	-	Specific heat capacity of liquid	KJ/Kg ^oC
C_{Pu}	-	Specific heat capacity of utility fluid	KJ/Kg ^oC
C_T	-	Total annual variable cost for heat exchanger and its operation	$/year
C_u	-	Cost of utility fluid	$/kg
D_i	-	Inside tube diameter	m
Do	-	Outside the diameter	m
Dt/dx	-	Temperature gradient in the direction of the heat flow	Kw/M^2

E_i	-	Power loss inside tube per unit of outside tube area	Kw/M^2
E_o	-	Power loss outside tube per unit of outside tube area.	Kw/M^2
F_T	-	Correction factor on logarithmic – mean Δt for counter flow to give Δt .	
g	-	Gravitational acceleration	M/S^2
h	-	Heat transfer coefficient	$W/M^2\,{}^{O}C$
h_i	-	Inside film coefficient of heat transfer	$W/M^2\,{}^{O}C$
h_{ub}	-	Nucleate, pool boiling coefficient	$W/M^2\,{}^{O}C$
h_o	-	Outside film coefficient of heat	$W/M^2\,{}^{O}C$
H_y	-	Hours of operation per year	hr/year
K	-	Thermal conductivity	$W/M^2\,{}^{O}C$
K_f	-	Annual fixed charges including maintenance expressed as a fraction of initial cost for completely installed vaporiser.	
K_l	-	Liquid thermal conductivity	$W/M^2\,{}^{O}C$
L_{hv}	-	Latent heat of vaporization	KJ/Kg
MF	-	Mass flow rate	KJ/Kg
P	-	Operating pressure	Bar
Pc	-	Critical pressure	Bar

P_s	-	Saturation pressure corresponding	
		to the boiling liquid	Bar
P_w	-	Saturation pressure corresponding	
		to the wall temperature	Bar
q	-	Heat flex	Kw/m^2
q_c	-	maximum critical heat flux	Kw/m^2
q^l	-	Duty or heat transfer rate	Kw
R_{dw}	-	Combined resistance of the tube wall	
		and scaling factor or dirt factor	$W/m^2\ ^oC$
T	-	Absolute temperature	^oC
T_1	-	Minimum temperature	^oC
T_2	-	Boiling point temperature of feed	^oC
T_s	-	Saturation temperature of steam at a	
		Given steam pressure	^oC
T_w	-	Wall, surface temperature	^oC
ΔT_m	-	Mean temperature difference	^oC
T_1	-	Initial temperature of process fluid	^oC
t'_2	-	Final temperature of process fluid	^oC
Δt_1	-	Initial difference in temperature	^oC
Δt_2	-	Final difference in temperature between the	
		Utility and process fluid	^oC
U	-	Overall heat transfer coefficient	$W/m^2\ ^OC$

W_u	-	Flow rate of Utility Fluid	Kg/hr
б	-	Surface Tension	N/m^2
Є	-	Emmisivity	
ρ_L	-	Liquid density	Kg/m^3
ρ_V	-	Vapour density	Kg/m^3
λ	-	Latent heat	KJ/Kg
μ_L	-	Liquid viscosity	NS/M^2
λ	-	Lagrangian multiplier	-
Ųi, Ų0	-	Dimensional factor for evaluation of E_i and E_o	-

ABSTRACT.

A Computer Aided – Design module was developed for the optimisation of the computer Aided-Design of a vaporiser involving twenty vaporising substances and their collected physical properties. Only thermal design of a vaporiser was considered.

On running the program, the design parameters were calculated and their values agreed with those of manual calculations according to the problem statement. The time taken to achieve a desirable output was less than manual. The variations in some of the design variables used for these vaporising substances give rise to an increase or decrease in the values of the parameters considered for the design.

Optimisation was achieved as the annual variable cost of thermal design of the vaporiser and its operation were observed to have a remarkable change in value on any change effected on the parameters used for design purpose.

CHAPTER ONE

INTRODUCTION

1.1 General Introduction and Background of Study

In design, construction and maintenance of many industrial systems, engineers and other personnel have to take many decisions aimed at either minimising the effort required or maximising the desired benefits (Ayoade, 1994). In real life situations, such desired benefits or required effort can be expressed as a function of several decision variables. Optimisation can therefore, be defined as the procedure for obtaining the best solutions to certain mathematically defined problems, which are often models of physical reality. It involves the study of optimality criteria for problems, the determination of algorithmic methods of solution, the study of the structure of such methods both under trial conditions and on real life problems. Much of the selection and choice in the design process will depend on the intuitive judgment of the designer who must decide when mere formal optimisation technique can be used to advantage. The task of formally optimising the design of a complex processing plant involving several hundred variables, with complex iterations, is formidable, if not impossible (Richardson and Coulson, 1991). The task can be reduced by dividing the process into more manageable units, identifying the key variables and concentrating work where the effort involved will give the greatest benefits.

In general, when setting out to optimise any system, the first step is clearly to identify the objective and the criterion to be used to judge the system performance. In engineering design, the objective will invariably be an economic one. For a chemical process, the overall objective for the operating company will be to maximise profits. This will give rise to sub-objectives which the designer will work to achieve. The main sub-objective will usually be to minimise operating costs. Other sub-objectives may be to reduce investments, maximise yield, reduce labour requirements, reduce maintenance, and operate safely.

When choosing his objectives, the designer must keep in mind the overall objective. Minimising cost per unit of production will not necessarily maximise profits per unit time, market factors, such as quality and delivery, may determine the best overall strategy.

The second step is to determine the objective function, the system of equations and other relationship, which relate the objective with the variables to be manipulated to optimise the function. If the objective is economic, it will be necessary to express the objective function in economic terms (cost).

The third step is to find the value of the variable that give the optimum value of the objective function. The best techniques to be used for this step will depend on the complexity of the system and on the particular mathematical model used to represent the system.

A vaporiser is a heat exchanger specifically designed to supply latent heat of vaporisation to a fluid (Ulrich, 1998). If the vapour formed is steam, the heat exchanger is commonly called an evaporator. If it is used to supply the heat requirements at the bottom of a distillation tower, it is called a reboiler. Vaporisers are employed to transform a pure liquid or a mixture of volatile liquid into a vapour without causing separation. They are employed where it is necessary to convert a liquid feed to a vapour for subsequent transport or processing. Vaporisation of LNG for introduction into the pipeline is an example, (Ulrich, 1998).

Sarma et al. (1973) discuss the development of a computer program for vertical thermosyphon reboiler design, and give algorithms and design equations.

Pricket (1973) programmed rigorous design method for computer solution and used it, together with operating data on commercial exchangers, to derive a general correlation of heat transfer rate with reduced temperature for vertical thermosyphon reboilers (Richardson and Coulson, 1991).

Adebola (1998) developed a computer software for the computer aided – design module of a vaporiser.

This research work will go a long way in developing a computer software that will be used in the optimisation of a computer aided – design module of a vaporiser.

1.2 Aim and Objectives

The aim of this research work is to develop a computer software that can be used in the optimisation of a Computer Aided-Design module of vaporiser in terms of the overall cost of operation.

The objectives of this work are:-

1. Choose a design problem for vaporisers and work out the calculations manually.
2. Develop a Computer Aided-Design (CAD) module for the solution of the design problem chosen in (1) and compare the results of the manual calculations and CAD module.
3. Use the CAD module to optimise the design problem.

CHAPTER TWO

LITERATURE REVIEW

2.1 Heat Transfer

In the majority of chemical processes heat is either given out or absorbed and fluids must often be either heated or cooled in a wide range of plant, such as furnaces, evaporators, distillation units, dryers and reaction vessels where one of the major problem is that of transferring heat at the desired rate. The control of the flow of heat at the desired rate forms one of the most important areas of chemical engineering, provided that a temperature difference exists between two parts of the system (Richardson and Coulson , 1997).

Heat transfer is therefore that science which seeks to predict the energy transfer which may take place between material bodies as a result of a temperature difference. Thermodynamics teaches that this energy transfer is defined as heat. The science of heat transfer seeks not merely to explain how heat energy may be transferred but also to predict the rate at which the exchange will take place under certain specified conditions. The fact that a heat transfer rate is desired objective of an analysis points out the difference between heat transfer and thermodynamics. Thermodynamics deals with systems in equilibrium, it may be used to predict the amount of energy required to change a system from one equilibrium state to another, it may not be used to predict how fast a change will take place since the system is not in equilibrium during the process. Heat transfer supplements the first and second principle of thermodynamics by providing additional experimental rules which may be used to establish energy transfer rates as in the science of thermodynamics, the experimental rules used as a basis of the subject of heat transfer are rather simple and easily expanded to encompass a variety of practical situation.

2.1.1 **Mechanism of Heat Transfer.**

There are three ways in which heat may be passed from a source to receiver, although most engineering applications are combination of two or three. These are conduction, convection and radiation (Kern, 1950).

Conduction: - Conduction is the transfer of heat through a fixed material such as a stationary wall. The direction of heat flow will be at a right angle to the wall if the wall surface is isothermal and the body is homogenous and isotopic.

When a temperature gradient exists in a body, experience has shown that there is an energy transfer from high temperature region to a low temperature region. We say that the energy is transferred by conduction and that the heat transfer rate per unit area is proportional to the normal temperature gradient.

$$\frac{q'}{A} \alpha \frac{dT}{dx} \quad \ldots\ldots 2.1$$

When the proportionality constant is inserted

$$q' = -Ka \frac{dT}{dx} \quad \ldots\ldots 2.2$$

where q' is the heat transfer rate and dT/dx is the temperature gradient in the direction of the heat flows. The positive constant k is called the thermal conductivity of the material, and the minus sign is inserted so that the second principle of thermodynamics will be satisfied.

Convention: Convention is the transfer of heat between relatively hot and cold portions of a fluid by mixing. Suppose a can of liquid was placed over a hot flame. The liquid at the bottom of the can becomes heated and becomes less dense than before owing to its thermal expansion. The liquid adjacent to the bottom is also less dense than the cold upper portion and rises through it transferring it heat by mixing as it rises. The transfer of the remainder is natural or free convention. If any other agitation occurs such as produced by a stirrer, it is forced convection. This type of heat transfer may be described in an equation which creates the form of conduction equation and is given by;

$\partial q' = ha\partial T$ 2.3

The proportionality constant h, called the heat transfer coefficient is a term which is influenced by the nature of the fluid. When Equation 2.3 is written in integral form,

$q' = h\,A\Delta T$ 2.4

It is called Newton's law of cooling.

RADIATION: Radiation involves the transfer of radiation energy from a source to a receiver. Part of the energy is absorbed by the receiver and part reflected by it. Based on the second law of thermodynamics, Boltzmann establish that the rate at which a source gives of heat is

$\partial q' = \sigma \epsilon A dT^4$ 2.5

This is known as the fourth - power law in which T is the absolute temperature, σ is known as Stefan-Boltzmann constant, and ϵ is a factor peculiar to radiation and is called emissivity.

2.1.2 **Process Heat Transfer**

Heat transfer has been described as the study of the rates at which heat is exchanged between heat sources and receivers. Process heat transfer deals with the rates of heat exchanges as they occur in the heat transfer equipment of the engineering and chemical processes. This approach brings to a better focus the importance of the temperature difference between the source and receiver, which is after all the driving force whereby the transfer of heat is accompanied. A typical problem of process heat is concerned with the quantities of heat to be transferred, the rates at which they may be transferred because of the natures of the bodies, the driving potential, the extent and arrangement of the surface separating the source and the receiver, and the amount of mechanical energy which may be expended to facilitate the transfer. Since heat transfer involves an exchange in a system, the loss of heat by the whole body will equal the heat absorbed by another within the confines of the same system (Kern, 1950).

2.1.2.1 **Boiling Heat Transfer Fundamentals**

The mechanism of heat transfer from a submerged surface to a pool of liquid depends on the temperature differences between the heated surface and the liquid. At low temperature differences, when the liquid is below its boiling point, heat is transferred by natural convection. As the surface temperature is raised, incipient boiling occurs, vapour bubbles forming and breaking loose from the surface. The agitation caused by the vapour bubbles, and other effect caused bubbles generation at the surface, result in a large increase in the rate of heat transfer. This phenomenon is known as nucleate boiling. As the temperature is raised further, the rate of heat transfer increases until the heat flux reaches a critical value. At this point, the rate of vapour generation is such that dry patches occur simultaneously over the surface, and the rate of heat transfer falls rapidly. At higher temperature differences, the vapour rate is such that the whole surface is blanketed with vapour, and mechanism of heat transfer is by conduction through the vapour film. The maximum heat flux achievable with nucleate boiling is known as the critical heat flux. In a system where the surface temperature is not self-limiting such as a nuclear reactor fuel element, operation above the critical flux will result in a rapid increase in the surface temperature and in the extreme situation the surface will melt. This phenomenon is known as "burn-out". The heating media used for process plant are normally self-limiting. For example, with steam the surface temperature can never exceed the saturation temperature. Care must be taken in the design of electrically heated vaporisers to ensure that the critical heat flux can never be exceeded.

The critical flux is reached at surprisingly low temperature differences, around 20 to 30 ^{O}C for water and 20 to 50 ^{O}C for light organics (Richardson and Coulson, 1991).

2.1.2.2 **POOL BOILING:**

Pool Boiling is the name given to nucleate boiling in a pool of liquid. In the nucleate boiling region the heat transfer coefficient is dependent on the nature and condition of the heat transfer surface, and it is not possible to present a universal correlation that will give accurate prediction for all systems. Palen and Taberek (1962) have reviewed the published correlation and compared their suitability for use in vaporiser design. The correlation given by Forster and Zuber (1955) can be used to estimate pool boiling coefficient, in the absence of experimental data. Their equation can be written in the form:-

$$hnb=\left[0.00122\right]\left[\frac{K_L^{0.79}\, C_{PL}^{0.49}\, \rho_L^{0.49}}{\sigma^{0.5}\, \mu_L^{0.29}\, \lambda^{0.24}\, \rho v^{0.24}}\right](Tw - Ts)^{0.24}\,(Pw - Ps)^{0.75} \quad \ldots\ldots 2.6$$

Where hnb = nucleate, pool, boiling coefficient, w/m^2 ^{o}C

K_L	=	Liquid thermal conductivity W/M^2 ^{o}C
C_{pl}	=	Heat capacity, KJ/Kg^o C
ρ_l	=	Liquid density, Kgm^{-3}
μ_l	=	Liquid viscosity, Ns/m^2

λ = Latent heat, KJ/Kg

ρ_v = Vapour density, kgm^{-3}

T_w = Wall, surface temperature, ^oC

Ts = Saturation temperature of boiling liquid, ^oC

Pw = Saturation pressure corresponding to the wall temperature, Tw. N/m^2

Ps = Saturation pressure corresponding to Ts, N/m^2

б = Surface tension, N/m.

The reduced pressure correlation given by Mostinski (1963) is simple to use and gives values that are reliable as those given by more complex equations.

$$hnb = 0.104\,(Pc)^{0.69}(q)^{0.7}\left[1.8\,(P/Pc)^{0.17} + 4\,(P/Pc)^{1.2} + 10(P/Pc)^{10}\right] \qquad \text{.......2.7}$$

Where P = operating pressure bar

Pc = Liquid critical pressure bar

q = heat flux, W/m^2

2.1.2.3 Critical Heat Flux

Heat flux can be estimated based on the heat transfer area, given by

$$q = \frac{q'}{A} \qquad \text{...2.8}$$

Where q'= maximum heat load (duty), Kw

q = Heat flux, Kw/m^2

A = outside area for heat transfer, m^2

It is important to check that the design and operating heat flux is well below the critical flux. Several correlations are available for predicting the critical flux. The one given by Zuber (1964) has been found to give satisfactory predictions for use in vaporiser design. The Zuber equation can be written as:

$$q_c = 0.131\,\lambda \left[6g\,(\rho_L - \rho_V)\,\rho_V^{2} \right]^{1/4} \quad \ldots\ldots\ldots\ldots 2.9$$

Where qc = maximum critical heat flux, w/m^2

g = gravitational acceleration, 9.81 m/s^2

Mostinski (1963) also gives a reduced pressure equation for predicting the maximum critical heat flux.

$$q_c = 3.67 \times 10^4\, Pc(P/Pc)^{0.35} \left[1 - (P/Pc) \right]^{0.9} \quad \ldots\ldots\ldots\ldots 2.10$$

2.1.2.4 **Mean Temperature Difference**

When the fluid being vaporised is a single component and the heating medium is steam (or other condensing vapour), both shell and tubes side pressure will be isothermal and the mean temperature difference will supply the difference between the saturation temperatures (Richardson and Coulson, 1991).

2.1.2.5 **Overall Heat Transfer Coefficient**

Typical values of the overall heat transfer coefficient for vaporisers are given below.

Heater Fluid	Heat Transfer coefficient ($w/m^{2\,O}C$)		
Steam aqueous solution	1000	-	1500
Steam light organics	900	-	1200
Steam Heavy organics	600	-	900

2.1.2.6 **Fouling Factors (Dirt Factors)**

Most process and service fluids will foul the heat transfer surfaces in an exchanger to a greater or lesser extent. The deposited material will normally have a relatively low thermal conductivity and will reduce the overall coefficient. It is therefore necessary to oversize an exchanger to allow for the reduction in performance during operation. Fouling factors are usually quoted as heat transfer resistances, rather than coefficients (Richards and Coulson ,1991).

Typical values for the fouling coefficients of some process fluids are given below:-

Fluid	Fouling factors (w/m^2 ^{o}C)		
River water	3000	-	12000
Sea water	1000	-	3000
Cooling water	3000	-	6000
Town's water (soft)	3000	-	5000
Town's water (hard)	1000	-	2000
Steam condensate	1500	-	5000
Industrial gases	5000	-	10,000
Organic vapour	5000		
Organic liquids	5000		
Light hydrocarbons	5000		
Heavy hydrocarbons	2000		
Boiling Organics	2500		
Condensing organics	5000		
Heat transfer fluids	5000		
Aqueous solutions	3000	-	5000

2.2 **Vaporising Process**

Vaporisers are often called upon to fill the multitude of latent heat services which are not part of evaporative or distillation process. The heat requirements are usually very simple to compute. If steam is the heating medium, the corrosive action of the air in the hot condensate usually makes it advantageous to carry out the vaporisation in the shell (Kern, 1950).

Operation in a vaporiser is often at high pressure and it is usually too expensive to provide disengagement space in the shell, since the inclusion of disengagement space at high pressure correspondly increases the shell thickness. For this reasons vaporisers are usually designed for internal disengagements. Instead, some external means such as an inexpensive welded drum is connected to the vaporiser wherein the entrained liquid is separated from the vapour.

When the vapour evaporates from the surface of a pool, it is possible to vaporize 100 percent of the liquid fed to it without reducing the level of the pool provided the vaporiser was originally filled to operating level with the liquid.

The reason less than 100 percent of the feed is normally vaporised is because residue accumulates and it is necessary to provide a blow down connection for its removal. If the feed were completely vaporised in the vaporiser, it would emerge as a vapour and any dirt which was originally present would be left behind on the tube surface over which total vaporisation occurred, fouling it rapidly.

If less than 100 percent of the feed is vaporised in an exchanger, the residual liquid can be counted on to prevent the accumulation of dirt directly on the heating element. A maximum of about 80 percent vaporisation appears to provide favorable operation, although higher percentage may be obtained in vessels having internal disengagement space.

2.2.1 Vaporisers:

Vaporisers satisfy the latent heat requirements to a boiling fluid and the heat duty for this type of exchanger is easily computed. Many different design arrangements are available depending upon the service.

Heat transfer coefficients for vaporisers are a complex function of such items as flow rates, fraction of liquid vaporised, heat transfer area, physical design etc. Physical design heat fluxes are of the order of magnitude of 20,000 Btu/hr.f^2.

2.2.2 Forced and Natural Circulation Vaporisers.

When liquid is fed to a vaporiser by means of a pump or gravity flow from storage the vaporiser is fed by forced circulation (Kern, 1950). A typical example is shown in Figure 2.1.

The circuit consists of a 1-2 exchanger serving as the vaporiser and a disengagement drum from which the unvaporised liquid is withdrawn and recombined with the fresh fed. The generated vapour is removed from the top of the drum.

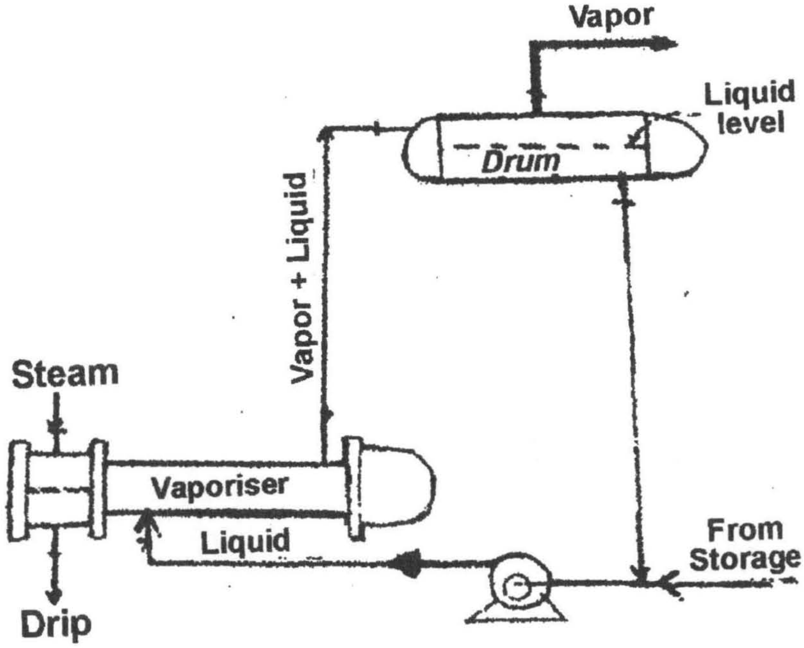


Fig. 2.1: Vaporising Process with Forced Circulation

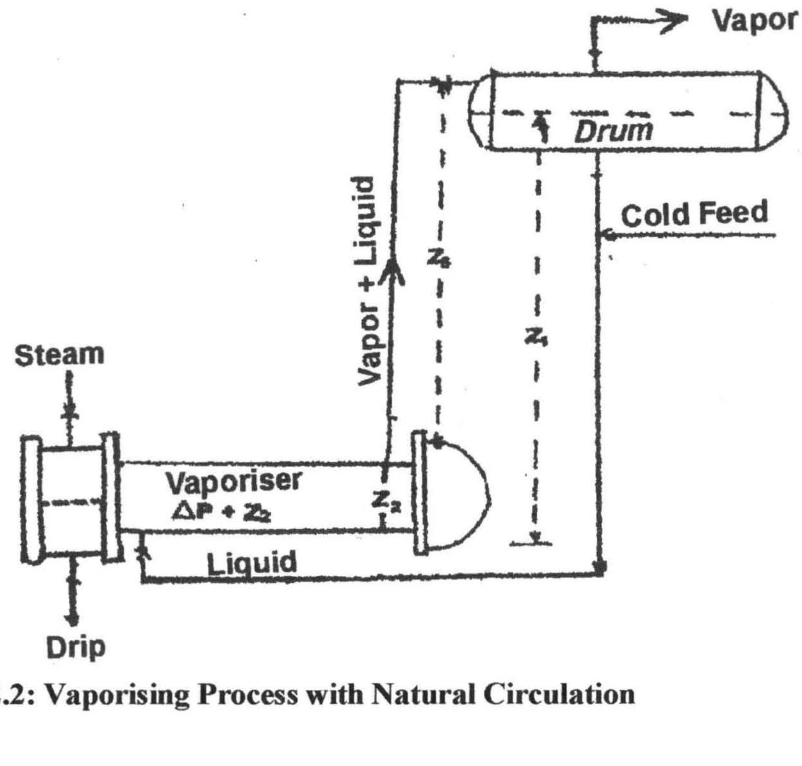


Fig. 2.2: Vaporising Process with Natural Circulation

The vaporiser may also be connected with a disengagement drum without the use of a recirculation pump. This scheme is a natural circulation and is shown in Figure 2.2.

It requires that the disengaging drum be elevated above the vaporiser. Recirculation is effected by the hydrostatic head difference between the column of height, z_l , and the column of mixed vapour of liquid of height, z_3. The head loss in the vaporiser itself due to frictional pressure drop corresponds to z_2. The hydrostatic head difference between z_3 and z_l is available to cause liquid to circulate at such a velocity that it produces a pressure drop z_2 in the vaporiser equal to the hydrostatic difference between z_2 and z_l.

The advantages of forced circulation or natural circulation are in part economic and part dictated by space. The forced circulation arrangement required the use of a pump with its continuous operating cost and fixed charges. If a natural circulation arrangement is used, pump and its operational problems are eliminated but considerably more headroom must be provided and circulation cannot be controlled so readily.

2.3 Basic Design Theory of a Vaporiser

Like any other heat exchanging equipment, the equation for heat transfer across a surface of a vaporiser is given by;

$$q' = UA\Delta T_m \qquad \text{.......... 2.11}$$

Where q' = heat transfer per unit time, (kw)

U = the overall heat transfer coefficient, ($w/m^2 \, {}^0C$)

A = Heat transfer area, (m^2)

ΔT_m = the mean temperature difference, (${}^0C$)

In the design of a vaporiser, the duty is calculated as sum of the sensible heat and the amount of heat required for vaporisation of the liquid (Richardson and Coulson, 1991).

2.3.1 General Design Information and Data

Information on manufacturing processes, equipment parameters, cost and physical properties of process material are needed at all stages of design (Richardson and Coulson, 1991). The information on manufacturing processes available in the general literature can be used at the initial stages of process design, for screening potential process, it is usually mainly descriptive, and too superficial to be of much use for detailed design and evaluation.

Chemical process industries are competitive and the information that is published on commercial processes is restricted. The article on particular processes published in technical literatures and in textbooks invariably gives only superficial account of the chemistry and unit operation used. They lacked the detailed information needed on reaction kinetics, process conditions, equipment parameters, and physical properties needed for the process design. The most comprehensive collection of information on manufacturing processes is probably the Encyclopedia of Chemical Technology edited by Kirk Orthman (1978, 1991), which covers the whole range of chemical and associated products. Another encyclopedia covering manufacturing processes is that edited by Ketta (1977), several books have also been published which gives brief summaries of the production processes used for the commercial chemicals and chemical products. The most well known of these is probably Shreve's book on the Chemical Process Industries, now updated by Austin (1984). Others worth consulting are those by Faith et al. (1965), Groggins (1958), Stephenson (1966) and Weissermal and Arpe (1978).

Books quickly become outdated and many of the processes described are obsolete, or at best obsolesced. More up to date descriptions of the processes in current use can be found in the technical journal such as Hydrocarbon Processing. Hydrocarbon Processing (Richardson and Coulson, 1991) published an annual review of petrochemical processes, which was entitled Petrochemical Development and is now called Petrochemical Notebook. This publication gives flow-diagrams and brief process descriptions of new process developments. Patents are useful source of information but it should be remembered that the patentee will try to write the patent in a way that protects his invention, by disclosing the least amount of useful information because of the competitors.

2.3.2 **Source of Physical Properties**

International Critical Tables (1933) is still probably the most comprehensive compilation of physical properties, and is available in most reference libraries (Richardson and Coulson, 1991). Though it was first published in 1933, physical properties do not change except in as much as experimental techniques improve, and ICT is still a source of engineering data.

Tables and graphs of physical properties are given in many handbooks and textbooks on chemical engineering and related subjects. Many of the data given are duplicated from book to book, but the various handbooks provide quick, easy access to data on the more commonly used substances.

An extensive compilation of thermo physical data has been published by Plenum Press, Touloukian (1970-77). This multiple volume work covers conductivity, specific heat, thermal expansion, viscosity and radiation properties (emittance, reflectance, absorptance and transmittance). Elsevier publishing company have published a series of volumes on physical properties and thermodynamic data.

The Engineering Science Data Unit (ESDU) was set up to provide authenticated data for engineering design. Its publications include some physical property data and other design data and method of interest to chemical engineering designers. They also cover data and methods used in the mechanical design of the equipment, caution should be exercised when taking data from the literature, as topographical errors often occur. If a value looks doubtful it should be cross-checked in an independent reference, or by estimation.

The results of research work on physical properties are reported in the general engineering and scientific literature. The Journal of Chemical Engineering Data specialized in publishing physical property data for use in chemical engineering design. A quick search of the literature for data can be made by using the abstracting journals, such as Chemical Abstracts (America Chemical Society) and engineering index (Engineering Index Incorporated New York).

Computerized physical property data banks have been set up by some organizations (Richard and Coulson, 1991) to provide a service to the design engineer. They can be incorporated into computer aided design programs and are increasingly being used to provide reliable, authenticated, design data.

2.3.3 **Prediction of Physical Properties**

Whenever possible, experimentally determined values of physical properties should be used. If reliable values cannot be found in the literature and if time or facilities are not available for their determination, then in order to proceed with the design, the designer must resort to estimation. Techniques are available for the prediction of most physical properties with sufficient accuracy for use in process and equipment design (Richardson and Coulson, 1991).

Group contribution techniques, which are based on the concept that a particular physical property of a compound can be considered to be made up of contributions from the constituent atoms, groups and bonds, the contribution being determined from experimental data, provide the designer with simple, convenient methods for physical property estimation, requiring only a knowledge of the structural formula of the compound.

Also useful and convenient to use, are prediction methods based on the use of reduced properties (corresponding states); provided that values for critical properties are available or can be estimated with sufficient accuracy.

The property program developed by the Design Institute for Physical Properties of the American Institute of Chemical Engineers known as DIPPR is widely known and used (Peters and Timmerhaus 1991). The personal computer (PC) version of DIPPR contained twenty six (26) constant and thirteen temperature dependent, pure component properties for seven hundred and sixty six common industrial chemicals. There are at least twenty physical property databases commercially available as online data services Richardson and Coulson, 1991).

2.4 **Computer Aided-Design (CAD)**

Computing hardware and software are tools - of - the trade of engineers (Peters and Timmerhaus, 1991). The capabilities provided by computers for fast calculation, large storage and logical decisions plus the available technical mathematical software permit engineers to solve larger problems and to do it much more rapidly than ever before possible. The engineer's emphasis can therefore shift from problem solving to planning, conceiving, interpreting and implementing with the information made available. Design is one of the engineering functions that have been enhanced by computer. Chemical engineering stresses the processes for manufacturing chemicals and chemical based products. In this effort, the emphasis of the chemical engineer tends to be on the process rather than on the product. The computer aids most useful to chemical engineers in design are process rather than product - oriented. The more widely known CAD/CAM (Computer-Aided Design/ Computer-Aided Manufacturing) software is usually concerned with product – as – object and is highly graphical and spatial. Chemical process computer-aided design, on the other hand is much less graphical. It is more concerned with the performance of process units (such as the classical unit operations of chemical engineering) and the integration of these units into complete, consistent, efficient processes to produce chemical products.

An engineer may write a programming language code to solve a particular design problem. Before the explosive growth of software, this commonly was done. There is still a place for it when appropriate software is not available or as learning and debugging is usually quite time consuming. It is recommended that available software be used and that a specific design program be written only after determining that appropriate software is not available.

Hundreds, even thousands, of programs have been written to solve problems commonly encountered by chemical engineers. Many of these have become available for purchase. In turn, many of these programs are for the design of individual units of chemical process equipment.

2.4.1 **Introduction to Computer Programming**

A computer program is a series of instructions that is given to the computer to obey. It is usually written in a particular programming language, and named according to the language used in writing it.

A computer language (programming language) is composed of a set of characters, words and rules that can be used to write a computer program. Such programming language can be classified according to their levels as machine language (level 1), symbolic language (level 2), and higher level language (level 3).

Machine language is low level language that is native or natural to the hardware of the computer. It consists of O'S and 1's. Every computer model has its own machine language which is defined by its hardware structure. Thus, this language depends on the particular computer model, for this it is said to be machine dependent. The early days of computer programming was almost exclusively machine language programming. It was very difficult and tasking in programming computers using machine language. Because of this, advances in programming techniques led to the development of symbolic languages.

Symbolic languages are mnemonic codes to represent machine instructions. The computer does not understands these codes, because of this, they have to be translated to machines language using appropriate translator. To translate an assembly language program into machine language an assembler is needed.

An assembler is a machine language instruction or program that translates symbolic language (such as Assembly language instruction) into machine language instructions.

Higher level languages are intermediate codes developed to enable the programmer code computer instructions in a way that resemble his thinking process using English like expressions. The language is procedure oriented rather than machine oriented. They focus on the data processing procedure to be accomplished and not on the coding requirements of a particular computer machine. Thus, it is machine independent and very easy to use. This means that programs written in higher level language are not restricted to be used with particular computer models. These higher level programming languages are Beginners All-purpose symbolic instruction code (BASIC), Common Business Oriented Language (COBOL), A UNIX based system programming language ©, PASCAL – named after the French mathematician, Blaise PASCAL, Formula Translation (FORTRAN), etc.

Programs written in higher level languages must be translated into the machine understandable form using appropriate translators.

A translator is a machine language program that translates source codes written in either symbolic or higher level language to machine language program as the object language.

If the source program (source code) is a higher level language program such as FORTRAN, PASCAL, COBOL, C, the translator that produces the object code in machine understandable form is called compiler. A compiler is a machine language program that translates or compiles the source code to machine language equivalence called the object code.

The compiler reads the source code and generates the machine code (object code), and saves it onto disk file. When the program is to be executed, the computer simply loads the object code into memory and executes it. At the point of execution, the program asks for inputs data or read input data from appropriate file to generate required output.

There is another kind of translator called interpreter. If the source code is a higher level language program such as BASIC, an interpreter is required to translate the source program to machine understandable form. An interpreter is a translator which reads the source program directly, line by line, starting from the beginning of the source program each time it is to be executed and generates machine codes necessary to carry out the instructions as they proceed through the program, without saving it on disk.

Another kind of translator is the assembler. If the source program is a low level language, the translator that produces the object code in machine understandable form is the assembler (Okike, 1998).

2.5 Optimisation Techniques

A well-known approach to principle of optimisation was first scribble centuries ago on the walls of an ancient Roman bathhouse in connection with a choice between two aspirants for emperor of Rome. It read - "De doubus malis, minus est semper aligendum" of two evils, always choose the lesser (Edgar and Himmeblau, 1989).

The existence of optimisation methods can be traced to the days of Newton, Lagrange and Cauchy (Ayoade, 1994). However, very little progress was made until the advent of computers in 1945. It came of age as a subject in the 1950's when the well-established methods of differential calculus were combined with the highly successful new techniques of mathematical programming which were being developed at that time. The term programming by the way is synonymous with optimisation and was originally used to mean optimisation in the sense of optimal planning.

The 1940's and 1950's saw the development of an important branch of the subject known as linear programming. The work of Kuhn and Tucker in 1951 on the necessary and sufficient conditions for the optimal solution of programming problems laid the foundation for a great deal of later research in non linear programming. Also, in the post war period, the "hill-climbing" methods were developed, these methods were at first very crude, insufficient and did not rely on any special structure in the problem. Since that time, the development of the subject has grown at a fast rate and has included methods for a variety of problems.

Classical optimisation techniques are analytical in nature (Ayoade, 1994). They are applicable to subjective functions which are continuous and easily differentiable. Practical usage of this technique is, however, limited in scope since a sizable number of objective functions of practical importance are either not easily differentiable or leads to more complex algebraic equations on differentiation. Nonetheless, it is necessary to understand the principles of this technique since it forms the basis for developing most of the numerical optimisation techniques.

Analytical methods for optimising a function of several variables include those functions with equality or inequality constraints. In general terms the classical optimisation techniques for solving problems in which the objective function and constraints are fairly simple interms of the decision variables.

However, many engineering design problems have objective functions and/or constraints which cannot be written explicitly interms of the decision variables. In such a case, one has to resort to the numerical methods of optimisation. Such methods for optimising the function under the assumption that no constraints are imposed on the decision variables could be achieved under one-dimensional unconstrained optimisation techniques. Broadly, these methods could be classified into two groups:-direct and gradient search methods. The direct search method involves evaluating a function at a sequence of point 1,2, etc., and comparing the values in order to reach the optimum value. These methods are based on rough and ready ideas without much theoretical background. They are in general less efficient than the gradient methods. The gradient methods, however, require in addition to function evaluation, the evaluation of the first and sometimes higher order derivatives of the objective function.

In practical terms, one dimensional search techniques are used for line searches within a multi-variable optimisation method. The available methods could be classified into two groups – bracketing and interpolation methods. Bracketing methods include Fibonacci search, golden section search, binary search and the recently developed one-dimensional simplex search. Interpolation techniques include quadratic interpolation and cubic interpolation. It should be noted that all the methods assume that the function is unimodal, that is, it contains one minimum point in the domain of interest. In addition, univariate search techniques can in general, be used for multivariant optimisation through successive perturbation of each decision variable. This approach only works if there is no strong interaction between the decision variables.

CHAPTER THREE

METHODOLOGY

3.1 Design Problem Statement

Design a vaporiser to vaporise 5000 kg/hr n-butane at 5.84 bar. The minimum temperature of the feed (winter conditions) will be $0^{o}C$,steam is available at 1.7 bar. Optimise the design by building cost into it.

3.2 Design Procedure of a Vaporiser

The design procedure followed in this work is tailored toward the thermal design of a vaporiser in the sense that most of the parameters used and the calculated values are temperature and heat related.

The following procedure was used in the design calculations of a vaporiser.

1. The specifications from the problem statement were first outlined.

2. The necessary physical properties were collected, these includes boiling point, specific heat, latent heat of vaporisation and critical pressure.

3. The duty of the vaporiser was calculated. This involved calculating the sensible heat required by the vaporising substance from the initial temperature to get to the boiling point in addition to the heat required to vaporise the substance. The equations for calculating the duty are as follows;

Heat loads:-

Sensible heat (maximum) (SHM) = $C_P\Delta T = C_P (T_2 - T_1)$.................................. 3.1

where, C_P = Specific heat capacity, kJ/kg ^OC.

T_2 = boiling point temperature of the feed, ^OC

T_1 = minimum temperature of the feed, ^OC

Total heat load (THL) = (SHM + L_{HV}) MF.. 3.2

Substituting Equation 3.1 into Equation 3.2

THL = ($CP\Delta T$ + LH_V) MF 3.3

Add 5 percent due to heat losses; (Design standard)

Maximum heat load (q') = 1.05 (THL + L_{HV}) MF 3.4

Where, MF = mass flow rate, Kg/hr.

L_{HV} = Latent heat of vaporisation, kJ/kg.

Equation 3.4 gives the duty of the vaporiser.

4. An overall heat transfer coefficient was assumed from standard textbook (Richard and Coulson,1991).

5. The mean temperature difference was calculated from the saturation temperature of steam.

6. The outside heat transfer area required was calculated from the assumed value of the overall heat transfer coefficient, (U) and the mean temperature difference. The equation for this relation is as follows;

$$\Delta T_M = T_S - T_2 \quad \text{……………… 3.5}$$

Where, ΔT_M = mean temperature difference, ^oC

T_S = saturation temperature of steam at a given steam pressure, ^oC.

The basic design equation of a vaporiser is given by:

$$q' = UAo\Delta T_M \quad \text{……………… 3.6}$$

$$\text{Therefore, } Ao = \frac{q'}{U\Delta T_M} \quad \text{……………… 3.7}$$

7. The value of the estimated area was used to calculate the heat flux as follows:

$$q = \frac{q'}{Ao} \quad \text{……………… 3.8}$$

Where q = heat flux (Kw/m^2).

8. The boiling coefficient (hnb) was calculated to be used in getting the actual value of the overall heat transfer coefficient (U). Using Mostinski's equation by already knowing the heat flux (q) based on area Ao, we obtain

$$hnb = 0.104\,(Pc)^{0.69}(q)^{0.7}\left[1.8(P/Pc)^{.17} + 4(P/Pc)^{1.2} + 10(P/Pc)^{10}\right] \quad \text{……………… 3.9}$$

Where, Pc = Critical pressure, bar.

P = Operating pressure, bar.

3.3 **Development of Optimisation Equation of a Vaporiser.**

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 annual cost for optimisation therefore, can be represented by the following equations.

C_T = Ao K_F C_{AO} + WuH_Y Cu+ Ao Ei H_Y Ci + Ao Eo H_Y Co 3.10

where, C_T = Total annual variable cost for heat exchanger and its operation, \$/year.

C_{AO} = installed cost of heat exchanger per unit of outside – tube heat transfer area, \$/m^2

C_U = Cost of utility fluid, \$/ kg.

Ci = Cost for supplying 1 NM to pump fluid flowing through inside of tubes, \$/Nm.

C_O = Cost for supplying 1 NM to pump fluid flowing through outside of tubes, \$/Nm.

A_O = area of heat transfer, m^2

K_F = annual fixed charges including maintenance, expressed as a fraction of initial cost for completely installed unit, dimensionless,

Wu = Flow rate of utility fluid, Kg/hr.

H_Y = Hours of operation per year, hr/year.

Ei = power loss inside tubes per unit of outside tube area, kw/m^2.

E_O = power loss outside tubes per unit of outside tube area, kw/m^2.

The heat transfer area A_o can be related to the flow rates and the temperature changes by an overall heat balance and the rate equation. If heat losses are assumed as negligible and q' is designated as the rate of heat transfer to the utility fluid,

$$q' = W_u C_{pu}(t_2 - t_1) = W'C'_p(t'_1 - t'_2) = U_o A_o \Delta T_m \qquad 3.11$$

Where the primes refer to the process fluid. subscript 1 refers to the entering temperature, and subscript 2 refers to the leaving temperature.

From equation 3.11,

$$W_U = \frac{q'}{C_{PU}(\Delta t_1 - \Delta t_2 + t'_1 - t'_2)} \qquad 3.12$$

Where,

$$\Delta t_1 = t'_2 - t_1 \qquad 3.13$$

And

$$\Delta t_2 = t'_1 - t_2 \qquad 3.14$$

Since q', C_{pu}, Δt_1, t'_1 and t'_2 are constant. W_u is a function of independent variable Δt_2 (Peters and Timmerhaus, 1989).

For general heat exchanger.

Substitute Equation 3.12 into Equation 3.10 to obtain

$$C_T = A_O K_F C_{AO} + \frac{q'}{C_{PU}(\Delta t_1 - \Delta t_2 + t'_1 - t'_2)} H_Y C_U + A_O E_i H_Y C_i + A_O E_O H_Y C_O \qquad 3.15$$

The following relationships for power loss inside tubes and power loss outside tubes are developed for conditions of turbulent flow and shell-side fluid flowing in a direction normal to the tubes which are similar to analysis presented by Cichelli and Brinn (1956).

Power loss inside tubes per unit of inside tube area is given by:

$$Ei = Ų_i h_i^{3.75} \qquad 3.16$$

and

power loss outside tubes per unit of outside tube area is given by:

$$E_O = \text{Ų}_O\, h_O^{4.75} \qquad \text{......3.17}$$

where;

$$\text{Ų}_i = B_i \left[\frac{12{,}200 D_i^{1.5}\, \mu_i^{1.83}\, (\mu_{wi}/\mu_i)^{0.63}}{g_c D_o \rho_i^2 k_i^{3.33}\, C_{pi}^{1.17}} \right] \qquad \text{......3.18}$$

And

$$\text{Ų}_o = \frac{B_o\, N_r N_c}{n_b\ N_t} \left[\frac{2boDcDo^{0.75}\, Fs^{4.75} \mu_{fo}^{1.42}}{\pi a_o^{4.75}\, g_c \rho_o^2 k_{fo}^{3.17} C_{pfo}^{1.58}} \right] \qquad \text{......3.19}$$

All the terms in the brackets are set by the design conditions or can be approximated with good accuracy (Peters and Timmerhaus, 1989). The values 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 a 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 tube layout and baffle arrangement. For rectangular tube bundles and no baffles, this ratio is equal to 1.0. For other tube layouts and segmental baffles, the ratio is usually in the range of 0.6 to 1.2 (Peters and Timmerhaus, 1989).

Using Equations 3.16 and 3.17 in Equation 3.15

$$C_T = A_O K_F A_O + \frac{q'\, H_Y C_U}{C_{PU}(\Delta t_1 + \Delta t_2 + t'_1 - t'_2)} + A_O \text{Ų}_i h_i^{3.5} H_Y\, C_i + A_O \text{Ų}_O h_O^{4.75} H_Y C_O \qquad \text{......3.20}$$

Using Lagrange multiplier λ to accomplish the optimisation of general case of heat exchanger:

$$\lambda \left[\frac{F_T \Delta T_M}{q'} + \frac{1}{A_O} \left(\frac{D_O}{D_i h_i} + \frac{I}{h_O} + R_{dw} \right) \right] = 0 \qquad \text{......3.21}$$

By adding Equation 3.21 and 3.20 we have:

$$C_T = A_O K_F C_{AO} + \frac{q' H_Y C_U}{C_{PU}(\Delta t_1 - \Delta t_2 + t'_1 - t'_2)} + A_O \text{Ų}ih_i^{\ 3.5} H_Y C_i + A_O \text{Ų}oHo^{\ 4.75} H_Y Co$$

$$+ \lambda \left[\frac{F_T \Delta T_M}{q'} + \frac{1}{A_O}\left(\frac{D_O}{D_i h_i} + \frac{I}{h_o} + R_{dw}\right)\right] = 0 \text{ ....3.22}$$

Where, λ = Lagrangian multiplier, dimensionless.

F_T = Correction factor on logarithmic – mean Δt for counter flow to give Δt, dimensionless.

Ųi, Ų_0 = dimensional factors for evaluation of Ei and Eo.

Di = Inside tube diameter, m.

Do = Outside shell diameter, m

hi = inside film coefficient of heat transfer, $w/m^{2\ O}C$

ho = Outside film coefficient of heat transfer, $W/m^{2\ O}C$

R_{dw} = combined resistance of tube wall and scaling factor or dirt factors, $W/M^{2\ O}C$.

Equation 3.22 is considered for the general case of steady-state heat transfer in shell and tube exchanger with no change in fluid phase, with a specified tube diameter, wall thickness, number of passes and arrangement of baffles and tubes are assumed. These are the assumptions considered in this work.

a) For vaporiser, the power cost is immaterial as the steam and vaporising fluid entered under pressure no pumping cost is necessary, therefore, Ci and Co in Equation 3.22 becomes zero.

b) The operating pressure do not exceed the critical pressure, therefore, no fouling is expected.

c) The steam pressure must not be too high to generate high temperature difference. It must equally be chosen in such a way that the surface temperature must be below the saturation temperature.

d) No pass was assumed and no counter flow was considered. In this case, Rdw and F_T in Equation 3.21 are equal to zero.

e) hi and ho were not considered as only the critical pressure and Mostinski's (1963) equation was used for the design in which a case of pool boiling coefficient, h_{nb}, is desirable.

From the above assumptions or analysis, the third, fourth and fifth terms of Equation 3.22 become zero, and the optimisation equation for vaporiser becomes.

$$CT = A_O K_F C_{AO} + \frac{q H_Y C_U}{C_{PU} \Delta T_M} \qquad \text{.........................3.23}$$

Where, $\Delta T_M = \Delta t_1 - \Delta t_2 + t'_1 - t'_2$ 3.24

For a vaporiser as Δt_2 is constant.

To get the unit of C_T in \$/year, the hours of operation per year is converted to seconds per year and the final equation becomes:

$$C_T = A_O K_F C_{AO} + 3600 \frac{q' H_Y C_U}{C_{PU} \Delta T_M} \qquad 3.25$$

The values of the parameters such as the heat transfer area (A_O), duty of the vaporiser (q'), and mean temperature difference (ΔT_M) were already present in the design calculation. These were linked with Equation 3.19 which in addition has the annual fixed charges (K_F), hours of operation per year (H_Y), cost of steam per kilogram (C_U), provide by the designer; and heat capacity of steam (C_{PU}) to give the total annual variable cost for vaporiser and its operation in \$/year. The variables like flow rate, overall heat transfer coefficient, steam pressure were varied to optimise the design. This was tested for all the vaporising substances.

3.4 **Equipment and Utility Fluid Cost**

Equipment cost may be gotten by consulting cost texts, journals and extrapolated data using cost indices or by assumptions. Consideration was given to the cost of vaporiser per unit heat transfer area required ($\$/m^2$).

The cost of steam or utility fluid depends very much on the steam pressure. The steam pressure ranges from exhaust (low pressure steam) to medium pressure steam or pressure between 100 and 500 psig; and finally to high pressure steam or pressure from 500 psig and above. These range in steam pressure give corresponding price range in dollars per 1000 lb of steam (\$/1000 lb). The table given in 1986 (Edgar and Himmelblau, 1989), for the cost of industrial utilities was used. This table was converted to S.I. unit for the calculation of the cost of steam or utility fluid (C_U) in \$/Kg.

Table 3.1: **Cost of Steam for a given steam pressure**

Steam Pressure	**Cost $ (1986)**
500 Psig (HPS)	(4.00 – 5.00)/1000 lb (4.00-5.00/454 Kg)
100 Psig (MPS)	(3.00 – 4.00)/1000 lb (3.00-4.00/454 Kg)
Exhaust (LPS)	(2.00– 3.00)/1000 lb (2.00-3.00/454 Kg)

The values were converted into bar, and cost of steam was estimated per kilogram to get CU as shown below.

Table 3.2 **Converted cost of steam per kilogram for a given steam pressure**

Steam pressure (bar)	**Cu $ (1986)**
34.48	0.0088 – 0.11/kg
6.90	0.0066 – 0.0088/kg
Exhaust	0.0044 – 0.0066/kg

The calculation for the conversion is shown in Appendix D. Any value in the above ranges can be chosen as the value of cost of steam per kilogram (Cu) depending on the steam pressure.

3.5 Computer Aided – Design Module for a Vaporiser

The computer program was written in FORTRAN77. The program is made up of twenty one subroutines consisting of twenty subroutines for the vaporising substances and one for steam. The necessary design steps and optimisation procedure are shown in the program flowchart – Figures 3.1-3.3 – and the listing of the source code is shown in Appendix B. The program was coded in FORTRAN and run on FORTRAN 77. Some of the output from the runned program with the headings "PHYSICAL PROPERTIES OF" followed by the name of the substance to be vaporised is shown in Appendix C.

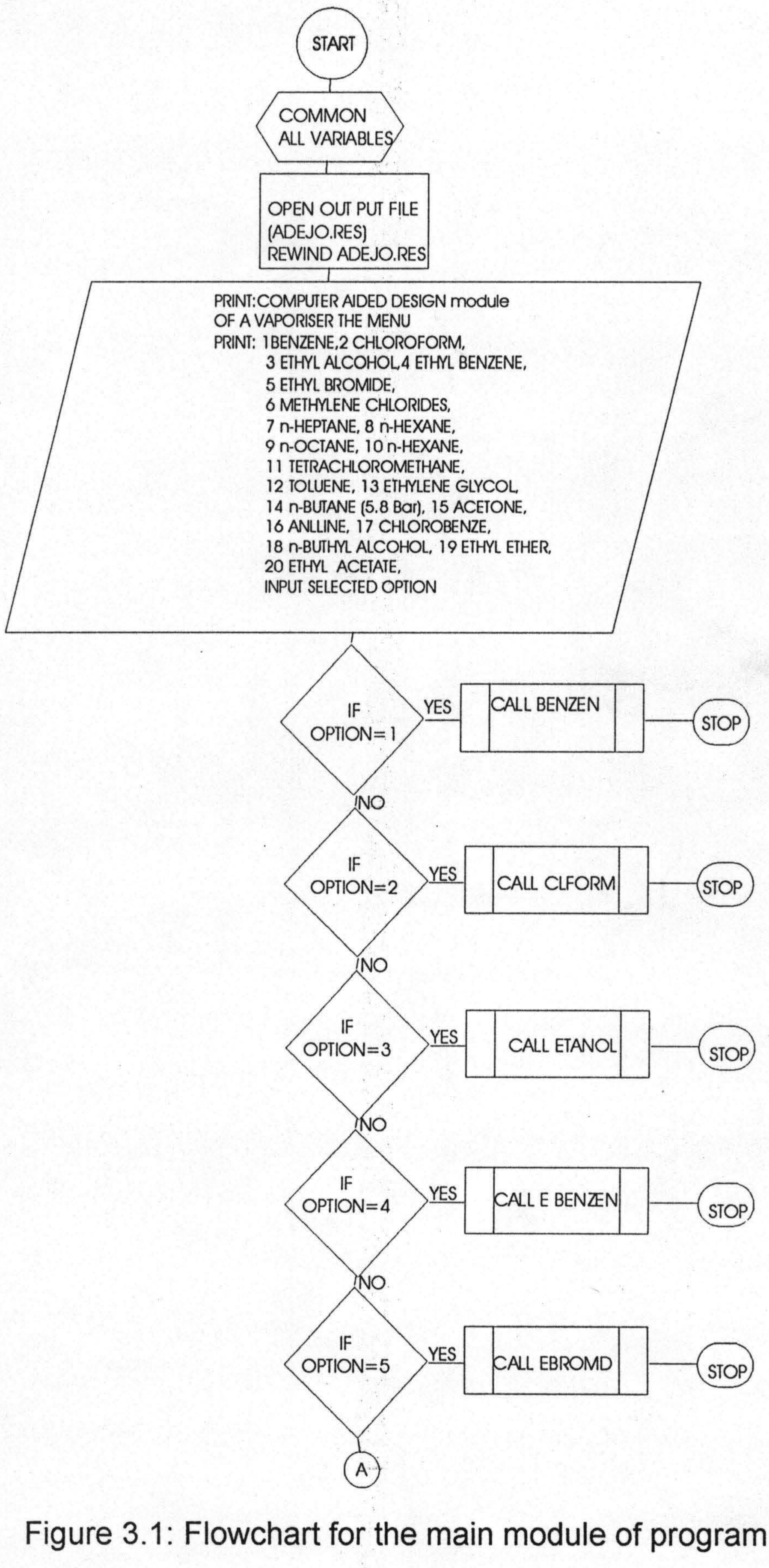


Figure 3.1: Flowchart for the main module of program CADMOD

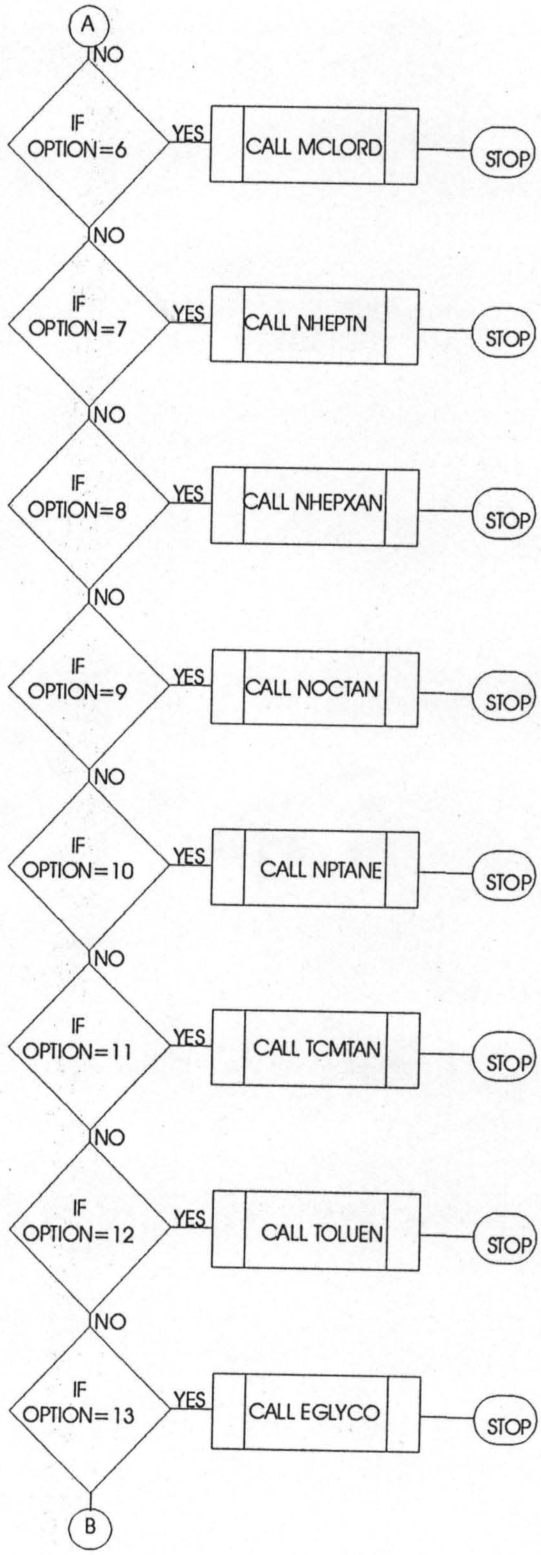


Figure 3.1: Continued

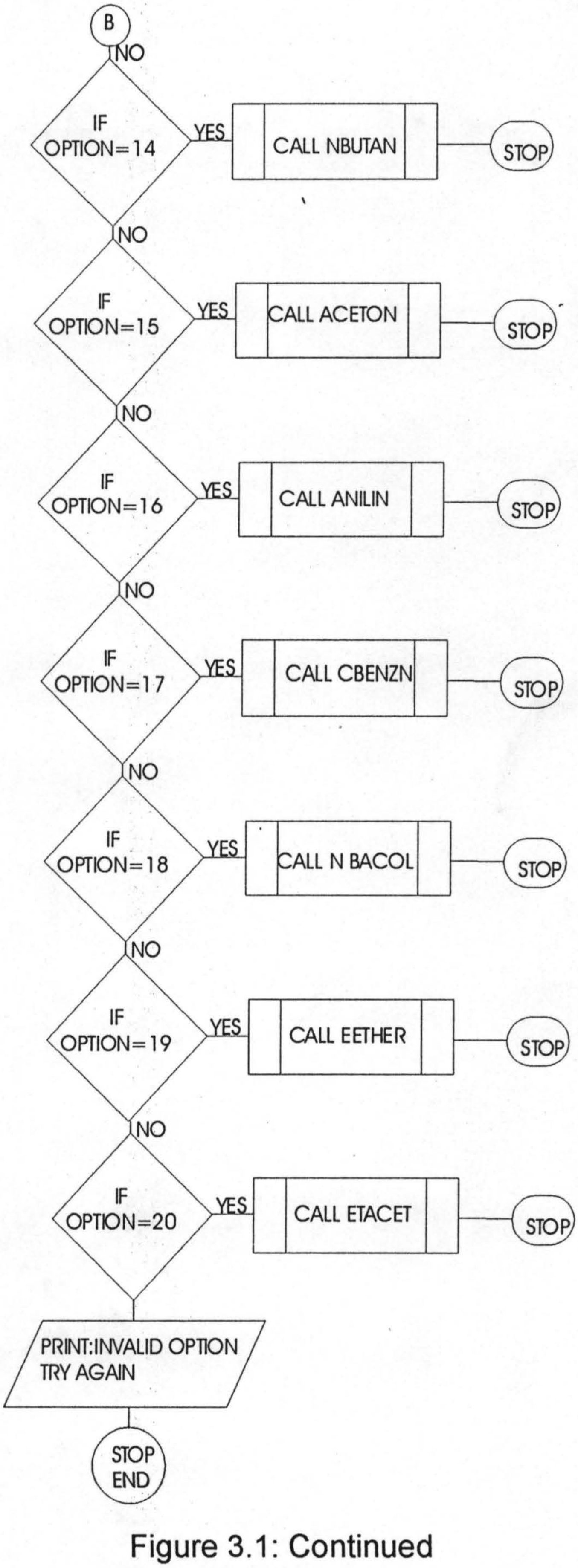


Figure 3.1: Continued

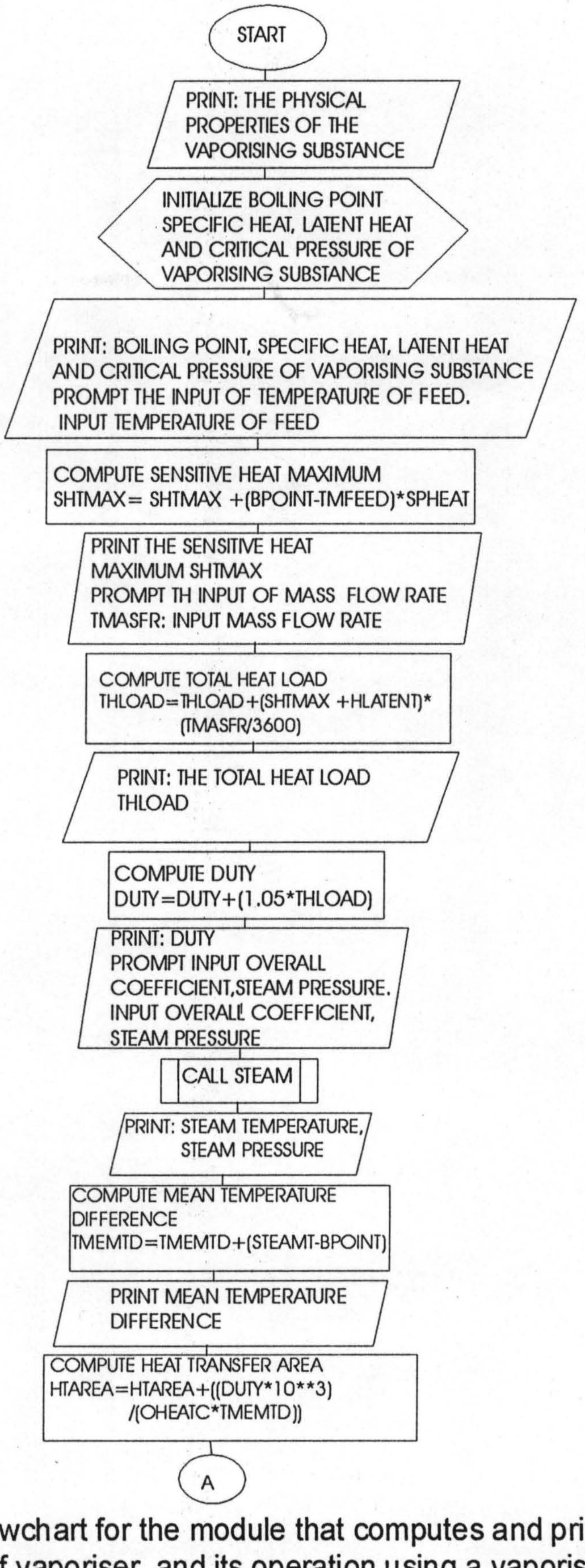


Figure 3.2: Flowchart for the module that computes and print the Total annual variable cost of vaporiser and its operation using a vaporising substance

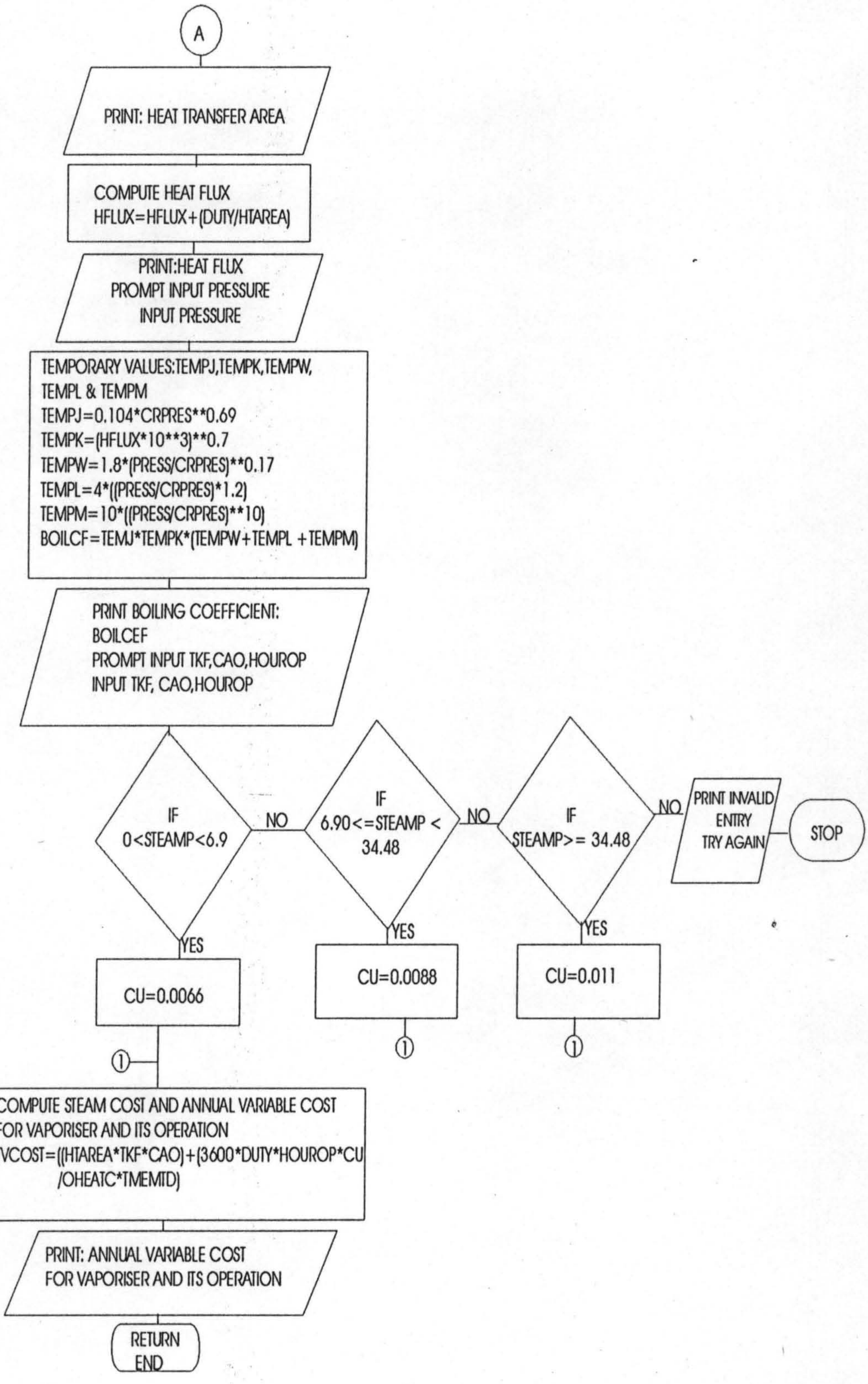


Figure 3.2: Continued

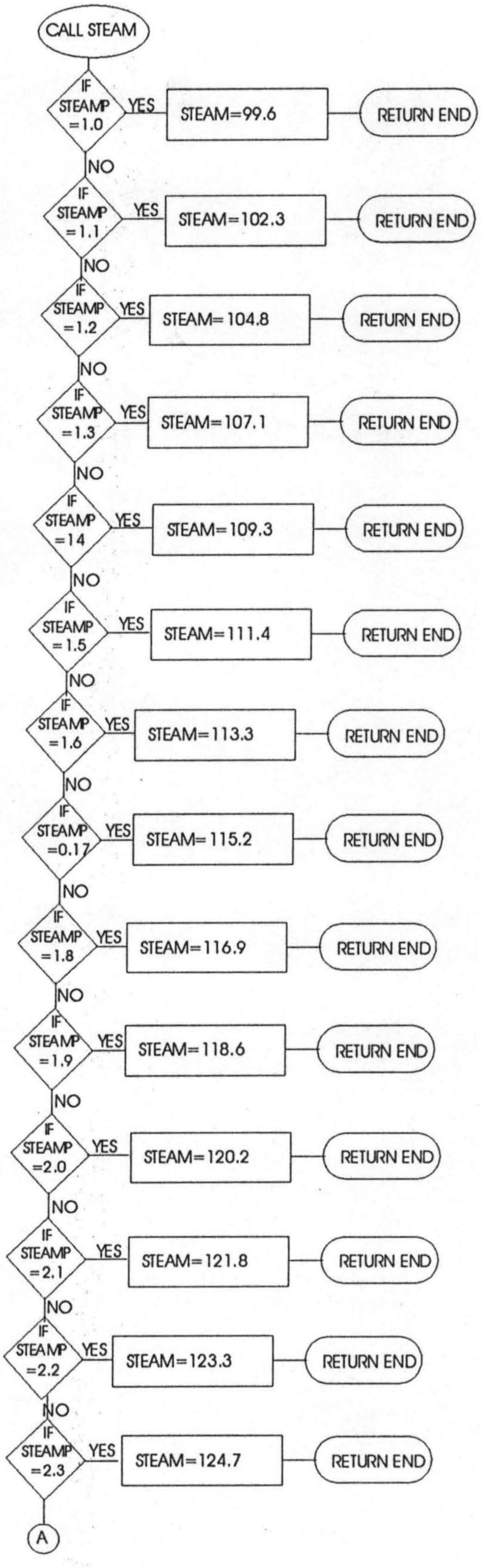


Figure 3.3: Flowchart for subroutine steam that determines steam temperature given the steam pressure.

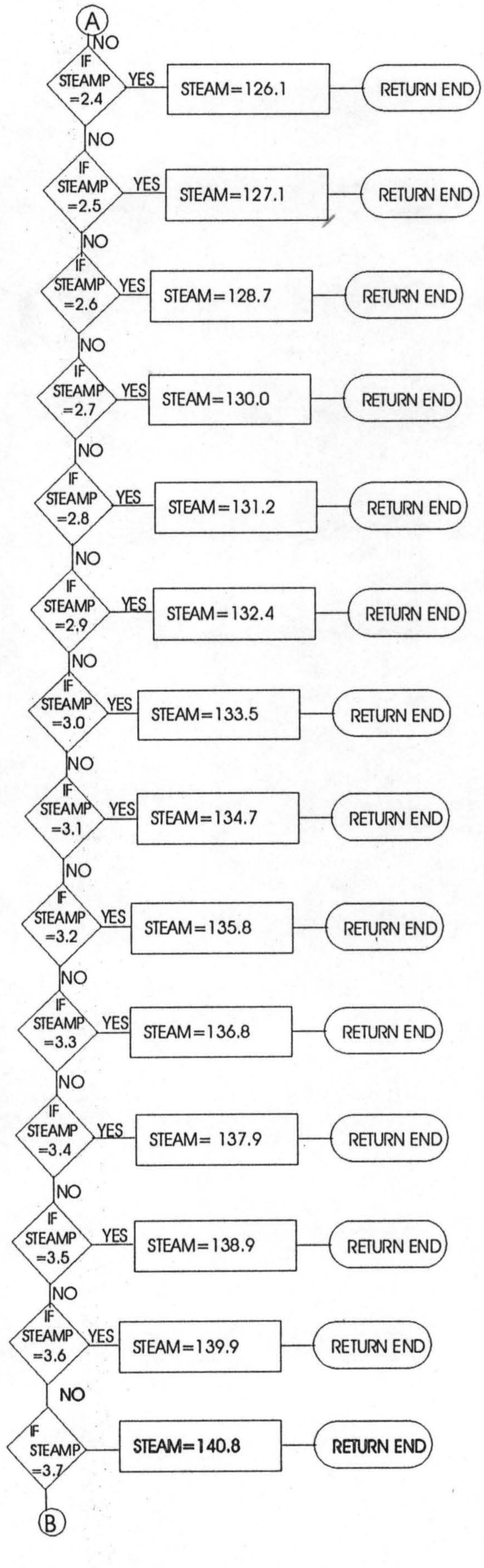


Figure 3.3: Continued

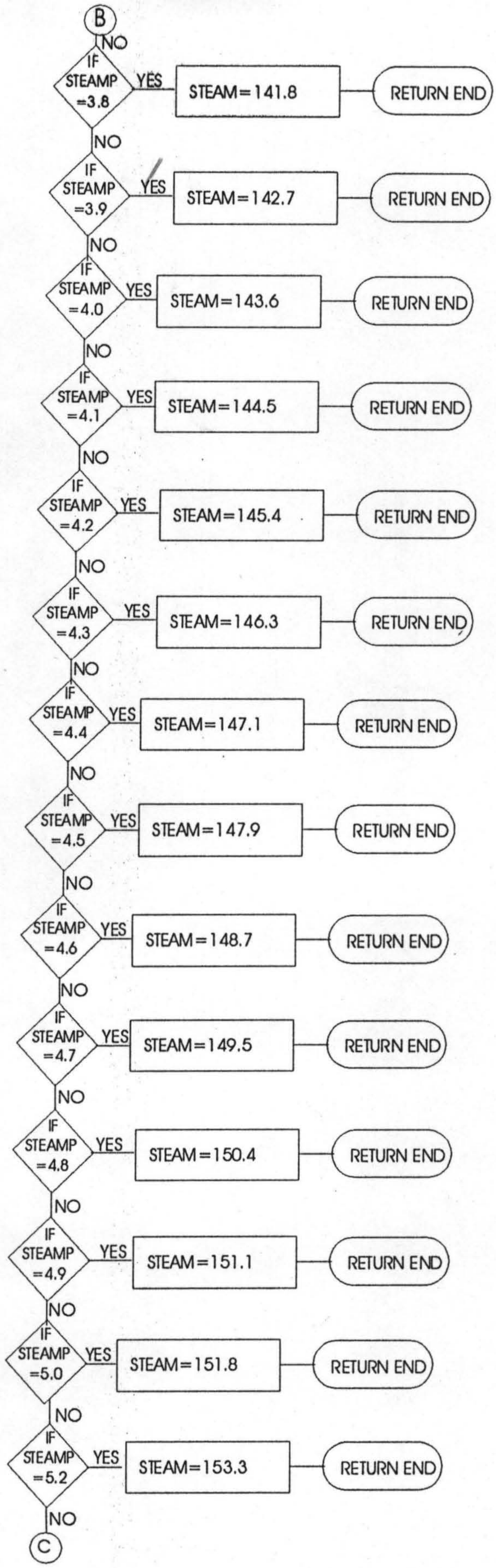


Figure 3.3: Continued

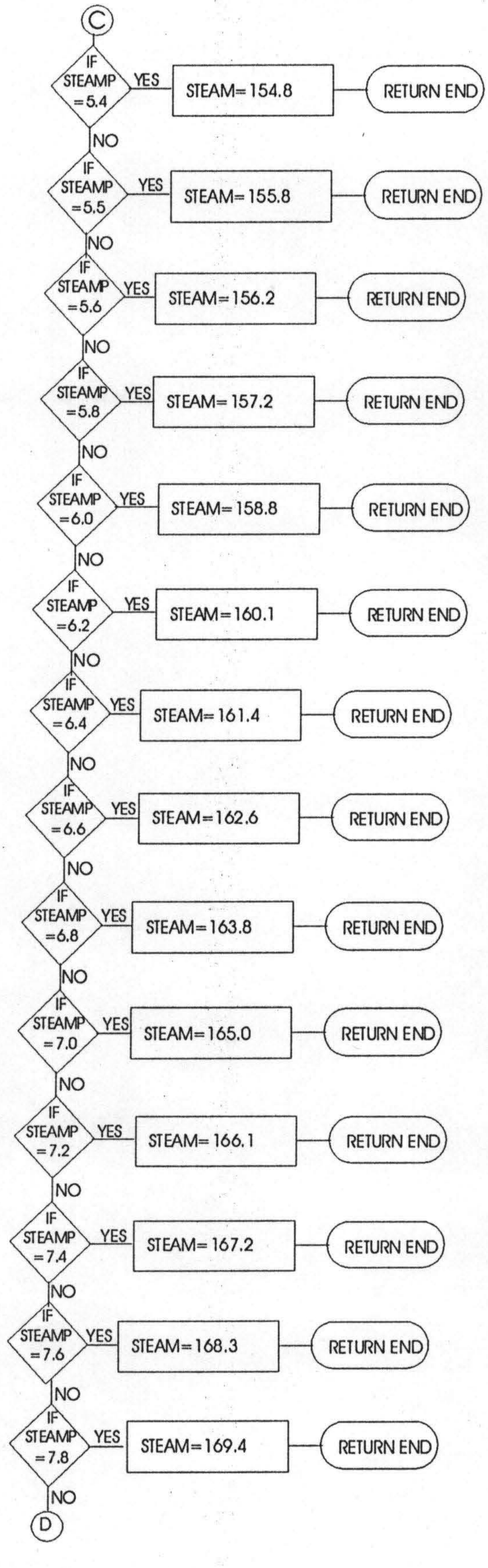


Figure 3.3: Continued

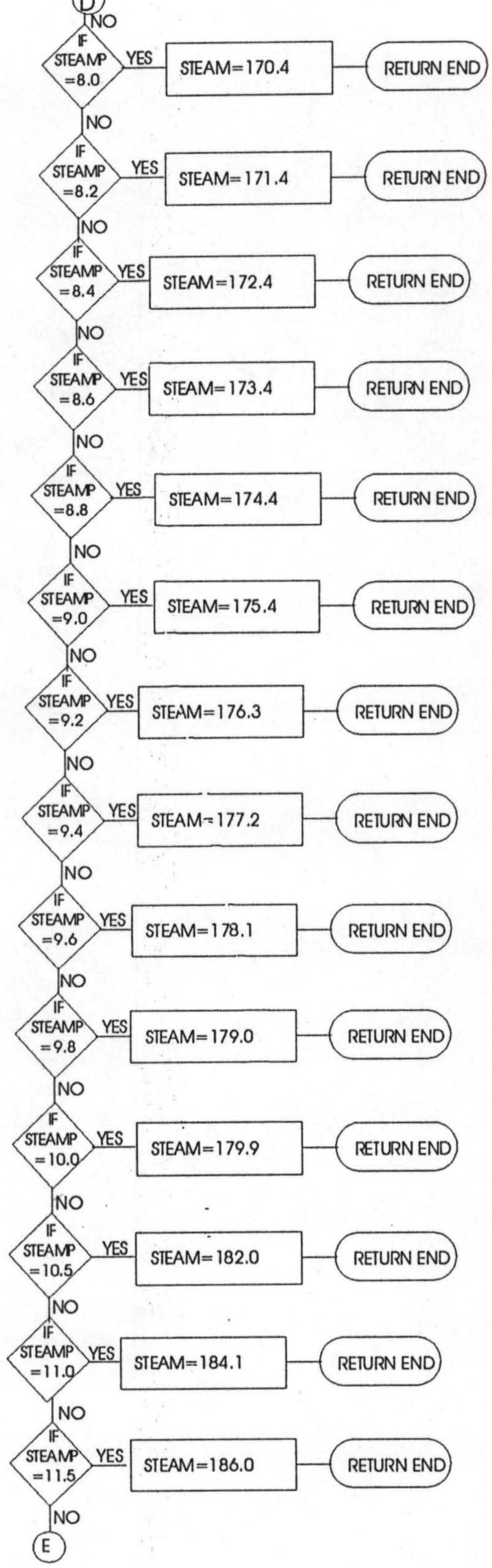


Figure 3.3: Continued

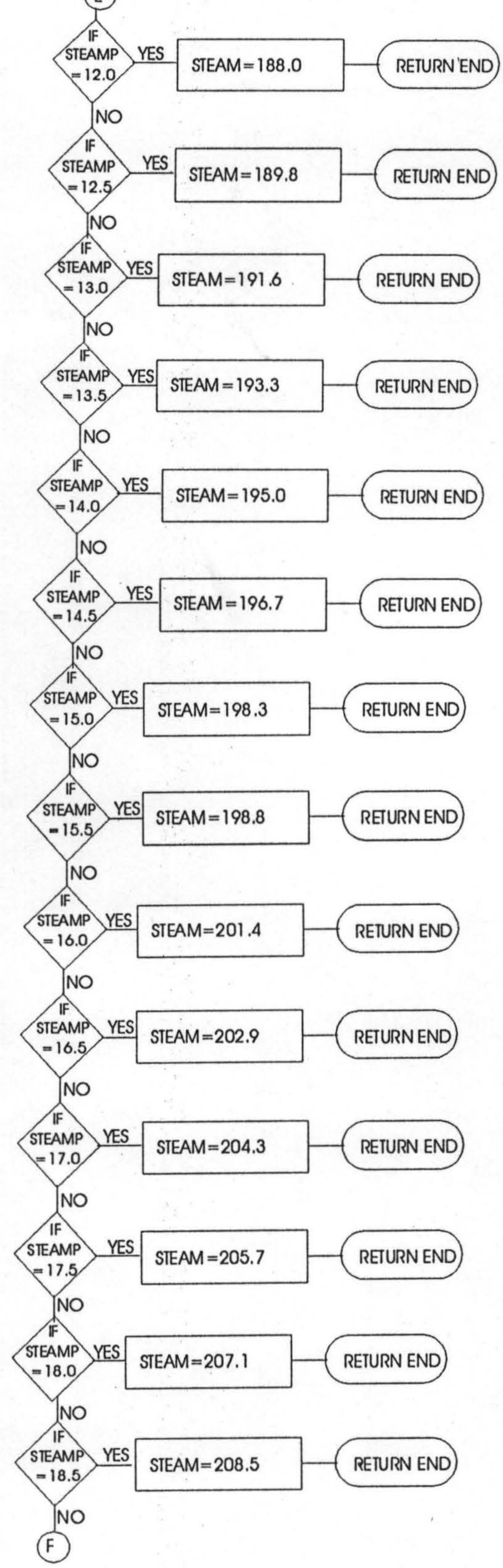
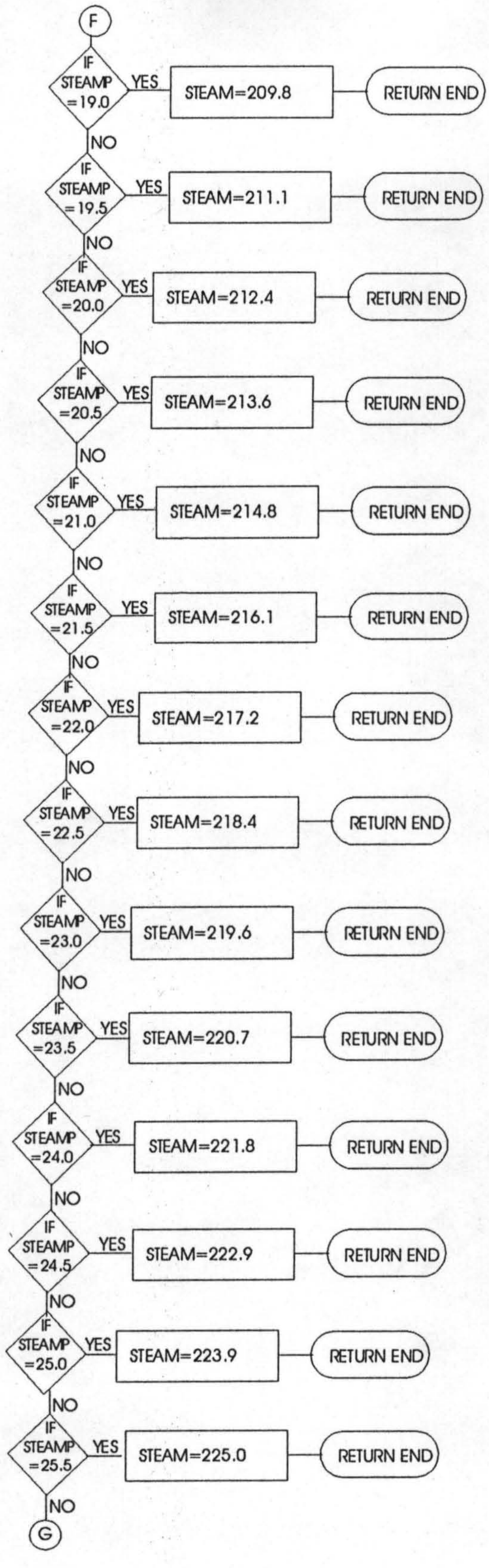


Figure 3.3: Continued



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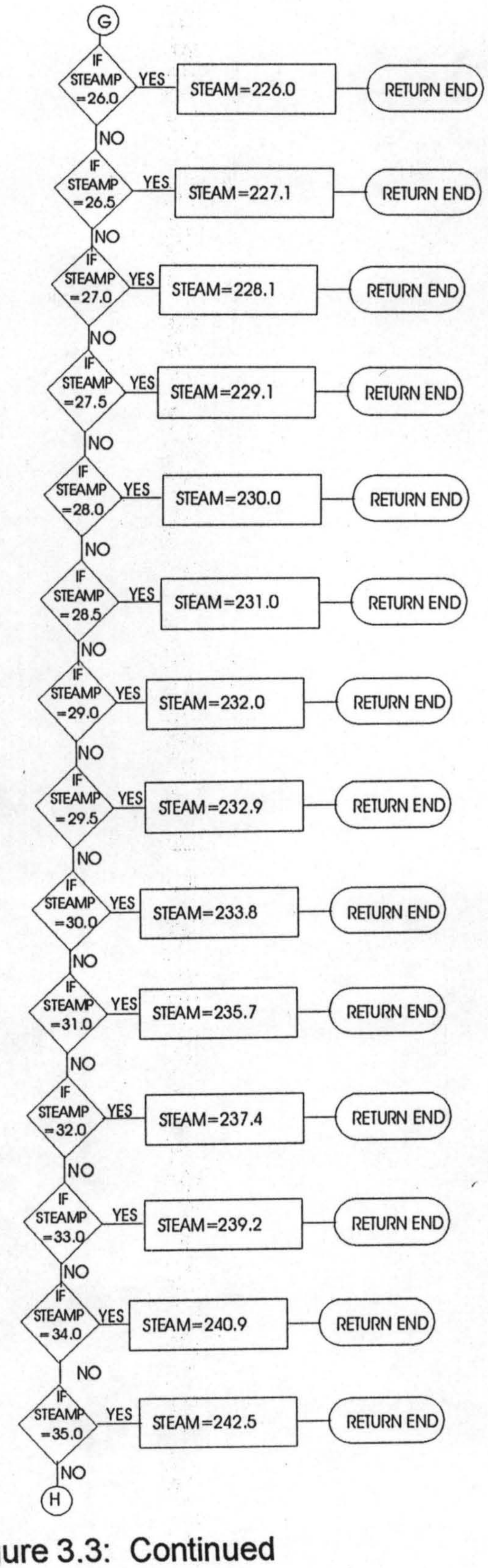

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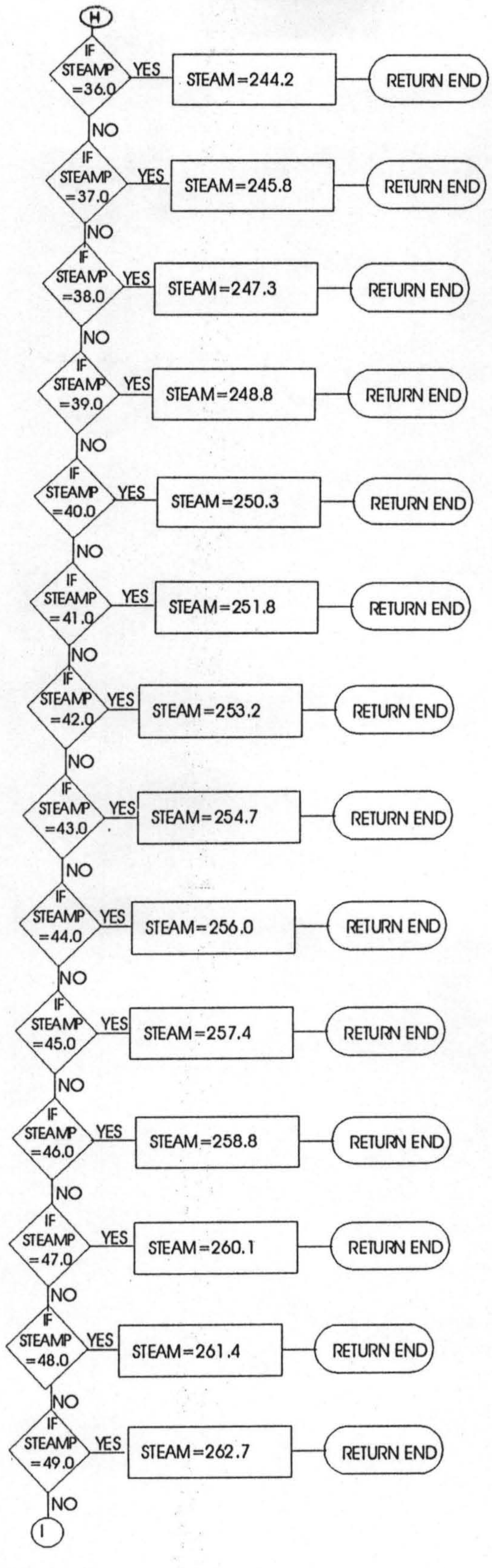

Figure 3.3: Continued

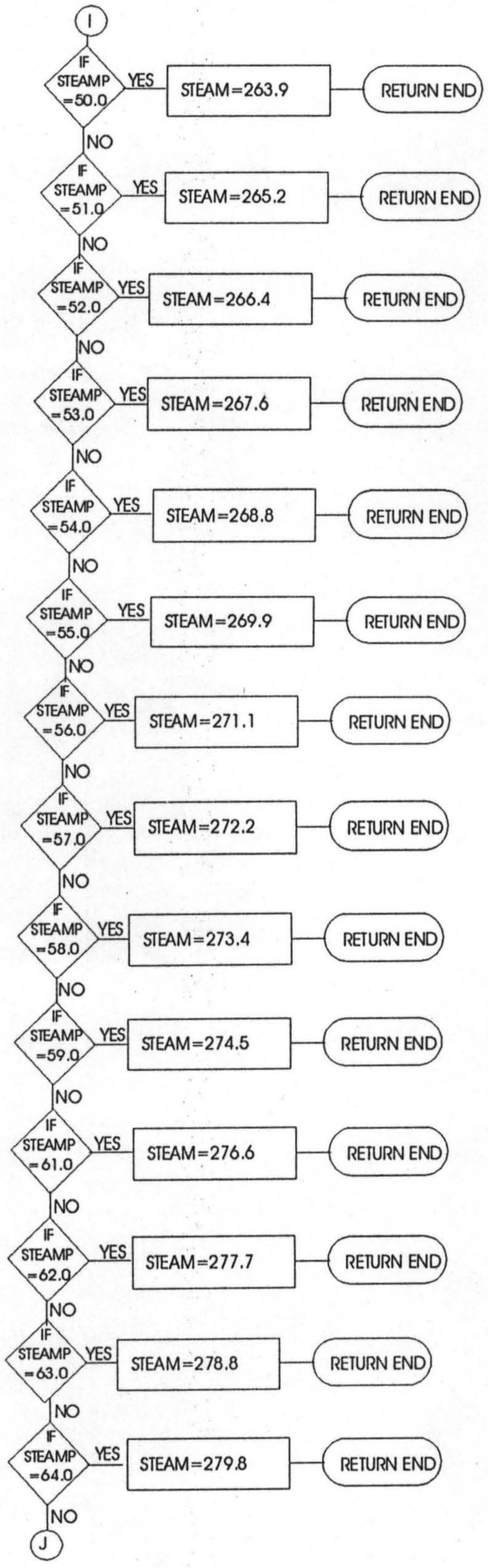

Figure 3.3: Continued

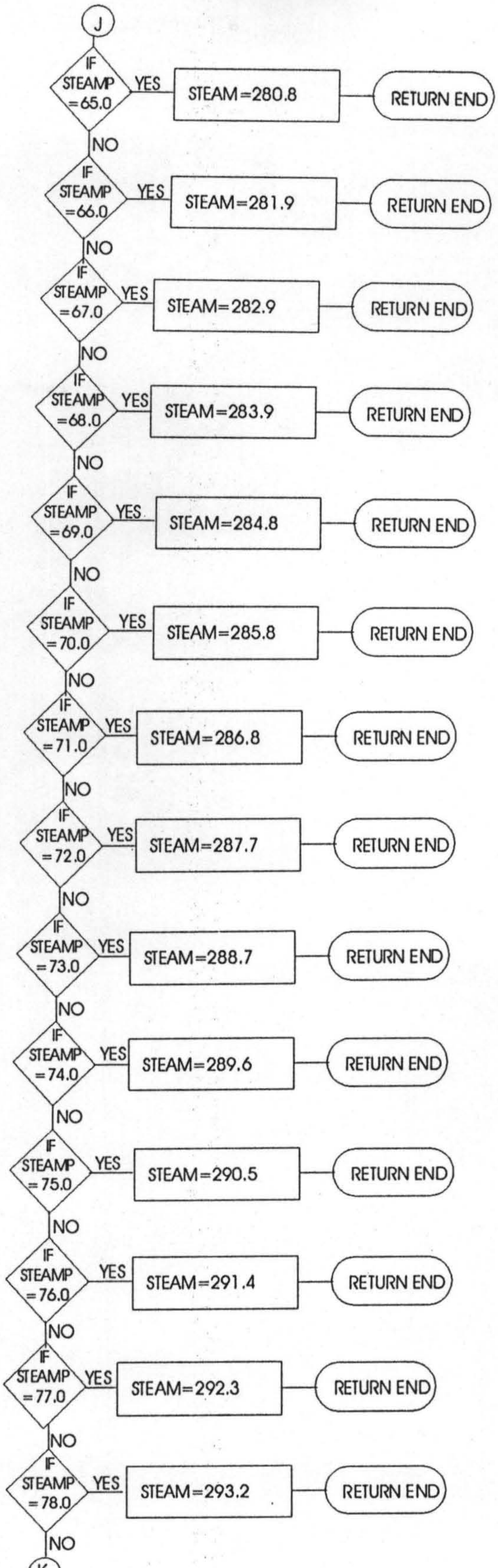

Figure 3.3: Continued

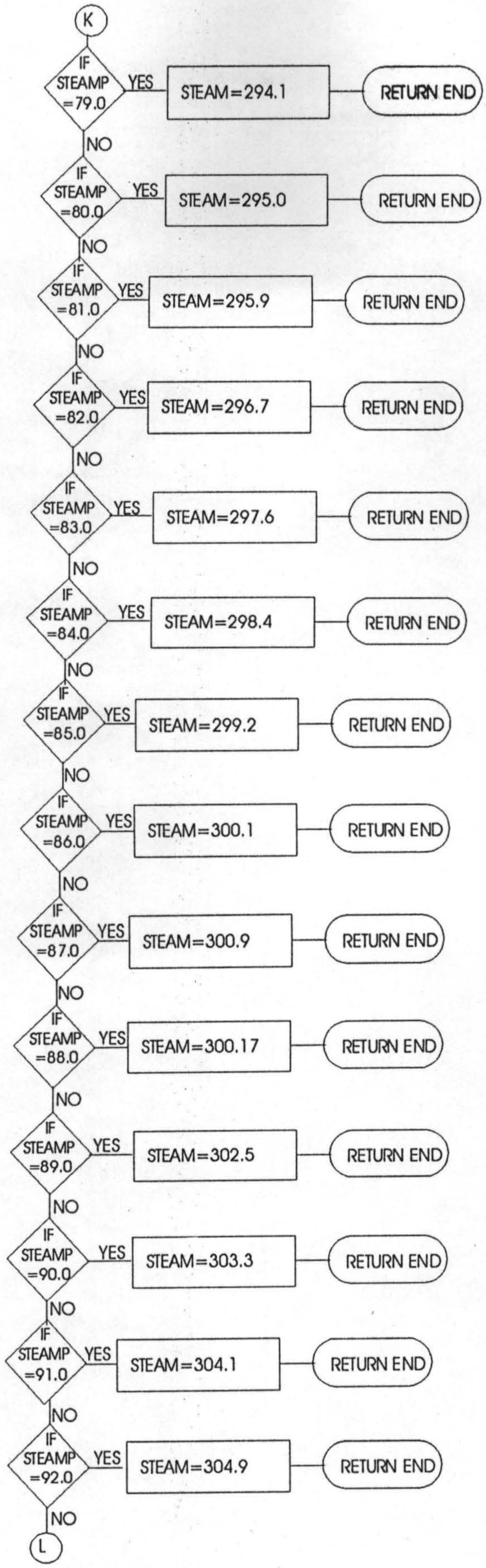

Figure 3.3: Continued

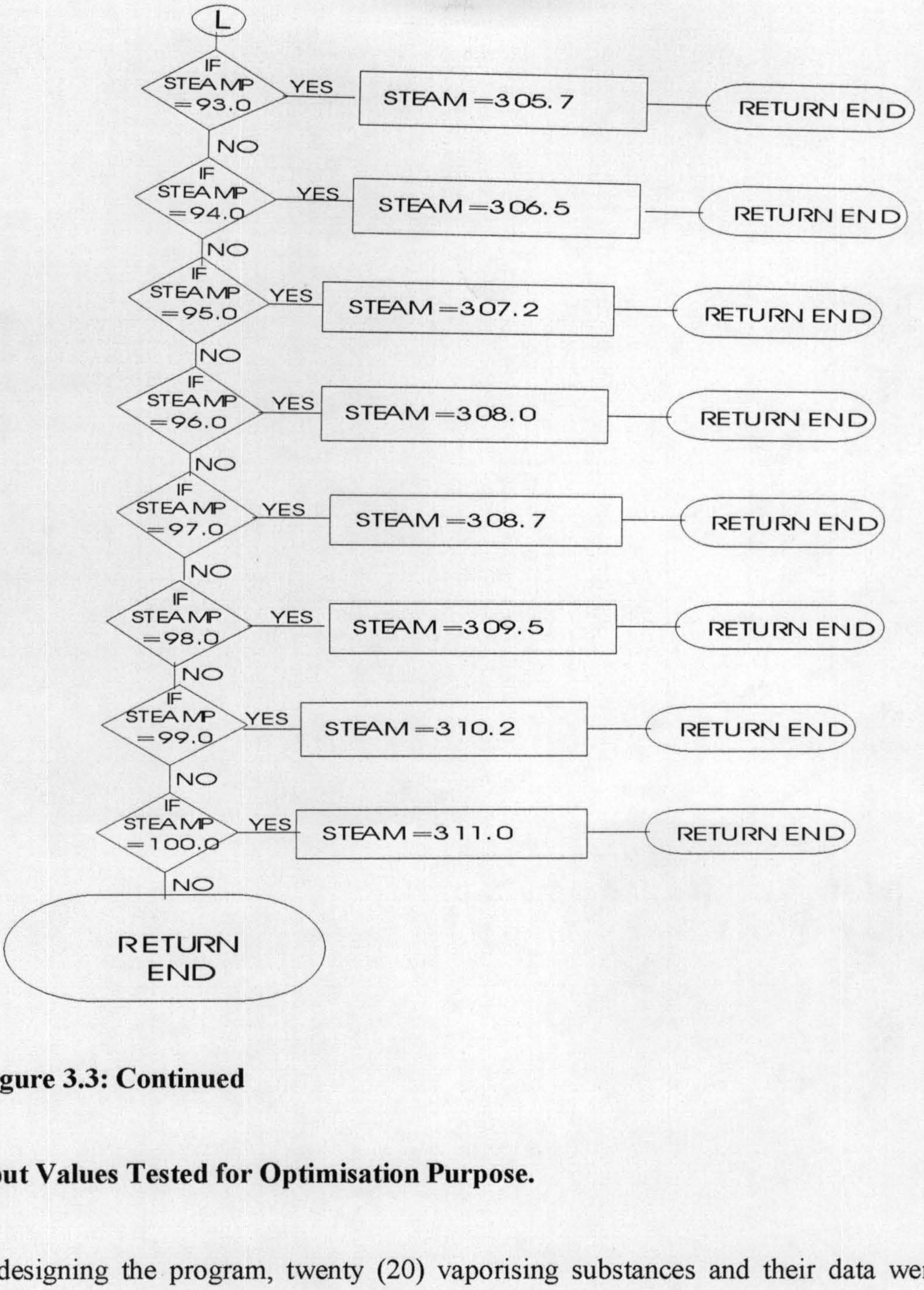

Figure 3.3: Continued

3.6 Input Values Tested for Optimisation Purpose.

In designing the program, twenty (20) vaporising substances and their data were considered. To use this program for optimising design, two sets of variables were chosen for each vaporising substances.

These input variables are shown in Table 3.3

Table 3.3; **Input Values Tested for Optimisation Purpose.**

SUBSTANCE TO BE VAPORISD	MINIMUM TEMP. OF FEED (°C)	MASS FLOW RATE (Kg/hr)	ASSUMED OVERALL HEAT TRASFER COEFFICIENT (W/M² °C)	STEAM PRESSURE (BAR)	OPERATING PRESSURE (BAR)	TKF, CAO, HOURP
E BENZE	0	5000	1000	8.00	58	1.15 180 7200
	0	5000	1200	8.00	58	1.15 180 7200
CH FORM	0	7000	1200	3.40	58	1.15 180 7200
	0	7000	900	3.40	58	1.15 1807200
E ALCOHOL	0	5000	700	8.00	58	1.15 180 7200
	0	5000	900	8.00	58	1.15 180 7200
E BENZENE	0	7000	900	20.00	58	1.15 180 7200
	0	7000	600	20.00	58	1.15 180 7200
E BROMIDE	0	5000	1500	4.00	58	1.15 180 7200
	0	5000	1000	4.00	58	1.15 180 7200
M CHLORIDE	0	7000	1000	2.60	58	1.15 180 7200
	0	7000	1200	2.60	58	1.15 180 7200
n-HEPTANE	0	5000	600	2.60	58	1.15 180 7200
	0	5000	900	2.60	58	1.15 1807200
n-HEXANE	0	7000	800	2.60	58	1.15 180 7200
	0	7000	600	2.60	58	1.15 180 7200
n-OCTANE	0	5000	900	6.00	58	1.15 180 7200
	0	5000	600	6.00	58	1.15 180 7200
n-PENTANE	0	5000	1000	1.70	58	1.15 180 7200
	0	5000	1200	1.70	58	1.15 180 7200
TC-METHANE	0	7000	1000	3.60	58	1.15 180 7200
	0	7000	1200	3.60	58	1.15 180 7200
TOULENE	0	5000	900	35.00	58	1.15 180 7200
	0	5000	600	35.00	58	1.15 180 7200
E GLYCOL	0	7000	700	38.00	58	1.15 180 7200
	0	7000	900	38.00	58	1.15 180 7200
n-BUTANE	0	5000	1000	1.70	58	1.15 180 7200
	0	5000	1000	2.40	58	1.15 180 7200
ACE TONE	0	7000	1000	3.00	58	1.15 180 7200
	0	5000	1000	3.00	58	1.15 180 7200
ANILINE	0	5000	700	40.00	58	1.15 180 7200
	0	7000	700	40.00	58	1.15 180 7200
C BENZENE	0	7000	600	20.00	58	1.15 180 7200
	0	7000	600	36.00	58	1.15 180 7200
n-BUTYL ALCOHOL	0	5000	600	36.00	58	1.15 180 7200
	0	7000	600	36.00	58	1.15 180 7200
n-ETHYL ETHER	0	7000	1500	4.00	58	1.15 180 7200
	0	7000	1500	8.00	58	1.15 180 7200
ETHYL ACETATE	0	5000	900	12.00	58	1.15 180 7200
	0	5000	700	12.00	58	1.15 180 7200

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results

The results of manual calculations and CAD program for both the problem statement and optimisation are considered.

4.1.1 Results from Manual Calculations and CAD Program for Problem Statement

The manual calculations of the problem statement are shown in Appendix A. The results of these calculations and those from CAD program are shown in Table 4.1

Table 4.1; **Results from manual calculations and CAD Program for problem statement**

Design parameters	**Manual Calculation**	**CAD program**
Sensitive heat maximum (kJ/kg)	140.80	140.8110
Total heat load (kw)	648.30	648.3486
Duty (Kw)	681.00	680.7660
Steam temperature (^{O}C)	115.20	115.2000
Mean temperature difference (^{O}C)	59.10	59.1000
Heat transfer Area (m^2)	11.50	11.5189
Heat Flux (Kw/m^2)	59.20	59.1000
Boiling coefficient (w/m^{2O}C)	4855.00	4849.6333
Total annual variable cost($/year)	473968.00	473809.90

Correlation coefficient = 0.9999 or 1

4.1.2 **Results of Optimisation**

The results obtained in testing the optimisation potential of the CAD program using the sets of variables in Table 3.3 are shown in Tables 4.2 to 4.21

TABLE 4.2: Results of optimisation of assumed overall heat coefficient (U) for benzene

Design parameters	**CAD program**	
	U (w/m$^{2\,o}$C)	
	1000	1200
Duty (kw)	785.8547	785.8547
Heat transfer area (m^2)	8.7027	7.2523
Heat flux (kw/m^2)	90.3000	108.3600
Boiling coefficient (w/m^{2o}C)	6922.8540	7865.2410
Total annual variable cost ($/year)	476654.82	476354.08

An increase in the assumed overall heat transfer coefficient (u) leads to decrease in the total annual variable cost and heat transfer area and gives a corresponding increase in the boiling coefficient and heat flux.

Table 4.3: Results of optimisation of assumed overall heat coefficient (U) for chloroform

Design parameters	CAD program	
	U (w/m$^{2\,O}$C)	
	1200	900
Duty (kw)	625.1611	625.1611
Heat transfer area (m^2)	6.7923	9.0564
Heat flux (kw/m^2)	92.0400	69.0300
Boiling coefficient (w/m^{2o}C)	7324.8290	5988.8080
Total annual variable cost ($/year)	334985.40	335454.10

A decrease in the value of the assumed overall heat transfer coefficient brings about an increase in total annual variable cost and heat transfer area and leads to a decrease in boiling coefficient and heat flux. The duty of the vaporiser remain constant in this optimisation.

Table 4.4 ; Results of optimisation of assumed overall heat transfer coefficient (U) for ethyl alcohol

Design parameters	CAD program	
	U(w/m$^{2\,0}$C)	
	700	900
Duty (kw)	1509.2990	1509.2990
Heat transfer area(m^2)	23.4109	18.2085
Heat flux (kw/m^2)	64.4700	82.8900
Boiling coefficient (w/m^{2o}C)	5984.1840	7135.1990
Total annual variable($/year)	8990092.40	898015.40

Table 4.5 ; Results of optimisation of assumed overall heat transfer coefficient (U) ethyl benzene

Design parameters	CAD program	
	U (w/m^2 °C)	
	900	600
duty (kw)	1170.3600	1170.3600
heat transfer area (m^2)	16.8883	25.3325
heat flux (kw/m^2)	69.3000	46.2000
boiling coefficient (w/m^{2o}C)	5381.1620	4051.4650
total annual variable cost ($/year)	832907.60	834655.50

Table 4.6 ; Results of optimisation of assumed overall heat transfer coefficient (U) for ethyl bromide

Design parameters	CAD program	
	U(w/m2oC)	
	1500	1000
Duty (KW)	415.5690	415.5690
Heat transfer area (m^2)	2.6335	3.9503
Heat flux (kw/m^2)	157.8000	105.2000
Boiling coefficient(w/m^{2o}C)	11103.5600	8359.8480
Total annual variable cost ($/year)	162215.30	162487.90

Table 4.7; Results of optimisation of assumed overall heat transfer coefficient (U) for methylene chloride

Design parameters	CAD program	
	U(W/M^{2O}C)	
	1000	1200
Duty (kw)	774.4388	774.4388
Heat transfer area (M^2)	8.7310	7.2758
Heat flux (kw/m^2)	88.7000	106.4400
Boiling coefficient (w/m^{2o}C)	8979.5420	10200.7600
Total annual variable cost ($ /year)	359134.60	358833.30

Table 4.8; Results of optimisation of assumed overall heat transfer coefficient (U) for n-heptane

Design parameters	CAD program	
	U (w/m^{2O}C)	
	600	900
Duty (Kw)	782.4637	782.4637
Heat transfer Area (m^2)	43.0398	23.6932
Heat flux (Kw/m^2)	18.1800	27.2700
Boiling coefficient (w/m^{2O}C)	1946.5360	2585.3910
Total annual variable cost ($/year)	1065786.00	1062816.00

Table 4.9; Results of optimisation of assumed overall heat transfer coefficient (U) for n- hexane

Design parameters	CAD program	
	U(W/M^{2O}C)	
	800	600
Duty (Kw)	939.8577	939.8577
Heat transfer Area (m^2)	19.6065	26.1420
Heat flux (Kw/m^2)	47.6065	35.9520
Boiling coefficient (w/m^{2O}C)	3917.9480	3203.3290
Total annual variable cost ($/year)	645996.40	647349.20

Table 4.10; Results of optimisation of assumed overall heat transfer coefficient (U) for n-octane.

Design parameters	CAD program	
	U (W/M$^{2\,O}$C)	
	900	600
Duty (Kw)	709.7604	709.7604
Heat transfer Area (m^2)	23.8255	35,7382
Heat flux (Kw/m^2)	29.7900	19.8600
Boiling coefficient (w/m^{2O}C)	2707.9190	2038.7870
Total annual variable cost ($/year	882511.10	884977.10

Table 4.11; Results of optimisation of assumed overall heat transfer coefficient (U) for n-pentane

Design parameters	CAD program	
	U (W/M^2 ^{o}C)	
	1000	1200
Duty (Kw)	633.5986	633-5986
Heat transfer Area (m^2)	8.0101	6.6751
Heat flux (Kw/m^2)	79.1000	94.9200
Boiling coefficient (w/m^{2O}C)	5693.1550	6468.1470
Total annual variable cost ($/year)	329481.80	329205.50

Table 4.12; Results of optimisation of assumed overall heat transfer coefficient (U) for tetrachloro methane.

Design parameter	CAD program	
	U(w/m^{2o}C)	
	1000	1200
Duty (kw)	745.1787	745.1787
Heat transfer area (m^2)	11.7536	9.7947
Heat flux (kw/m^2)	63.4000	76.0800
Boiling coefficient (w/m^{2o}C)	5352.3190	6080.9140
Total annual variable cost ($/year)	483464.90	483059.40

Table 4.13; Results of optimisation of assumed overall heat transfer coefficient (U) for toluene

Design parameters	CAD program	
	U(W/M^{2o}C)	
	900	600
Duty (kw)	789.3965	789.3965
Heat transfer area (m^2)	6.6548	9.9823
Heat flux (kw/m^2)	118.6200	79.0800
Boiling coefficient (w/m^{2o}C)	8026.5210	6043.1510
Total annual variable cost ($/year)	409914.30	410603.10

Table 4.14; Results of optimisation of assumed overall heat transfer coefficient (U) for ethylene glycol

Design parameters	CAD program	
	U(w/m^2 °C)	
	700	900
Duty (kw)	2616.6900	2616.6900
Heat transfer area (m^2)	74.3167	57.8018
Heat flux (kw/m^2)	35.2100	45.2700
Boiling coefficient (w/m^2 °C)	3581.8940	4270.8440
Total annual variable cost ($/year)	3563809.00	3560391.00

Table 4.15; Results of optimisation of steam pressure (SP) for n-butane

Design parameters	CAD program	
	SP (bar)	
	1.70	2.40
Duty (kw)	680.7660	680.7660
Heat transfer area (M^2)	11.5189	9.7252
Heat flux (kw/m^2)	59.1000	70.000
Boiling coefficient ($w/m^{2o}C$)	4835.6300	5443.9040
Total annual variable cost ($/year)	43809.90	400030.90

An increase in steam pressure for this vaporising substance decreases the total annual variable cost and heat transfer area whereas boiling coefficient and heat flux are increased. The duty of the vaporiser for this vaporising substance remain constant.

Table 4.16; Results of optimisation of mass flow rate (MF) for acetone

Design parameters	CAD program	
	MF (Kg/hr)	
	7000	5000
Duty (kw)	1315.9070	939.9337
Heat transfer area (M^2)	17.0014	12.1438
Heat flux (kw/m^2)	77.4000	77.4000
Boiling coefficient ($w/m^2\,^oC$)	6666.6750	6666.6750
Total annual variable cost ($/year)	699323.40	499516.70

A change in mass flow rate affects the total annual variable cost, heat transfer area and duty of the vaporiser but maintaining constant values of boiling coefficient and heat flux.

Table 4.17; Results of optimisation of mass flow rate (MF) for aniline

Design parameters	**CAD program**	
	MF (Kg/hr)	
	5000	7000
Duty (kw)	1207.1560	1690.0180
Heat transfer area (M^2)	26.0107	36.4150
Heat flux (kw/m^2)	46.4100	46.4100
Boiling coefficient ($w/m^2\,^{o}C$)	4483.8340	4483.8340
Total annual variable cost ($/year)	1247326.00	1746256.00

Table 4.18; Results for optimisation of steam pressure (SP) for chlorobenzene

Design parameters	**CAD program**	
	MF (Kg/hr)	
	20.00	36.00
Duty (kw)	1013.1400	1013.1400
Heat transfer area (M^2)	21.0021	15.0496
Heat flux (kw/m^2)	48.2400	67.3200
Boiling coefficient ($w/m^2\,^{o}C$)	4365.5330	5512.5560
Total annual variable cost ($/year)	691977.70	619040.70

Table 4.19; Results of optimisation of mass flow rate (MF) for n-butyl alcohol

Design parameter	CAD program	
	MF (Kg/hr)	
	5000	7000
Duty (kw)	1264.6970	1770.5760
Heat transfer area (M^2)	16.5710	23.1994
Heat flux (kw/m^2)	76.3200	76.3200
Boiling coefficient ($w/m^2\,^oC$)	6169.6650	6169.6640
Total annual variable cost ($/year)	681619.40	954167.10

Table 4.20; Results of optimisation of steam pressure (MF) for n- ethyl ether

Design parameters	CAD program	
	SP(Bar)	
	4.00	8.00
Duty (kw)	776.5161	776.5161
Heat transfer area (M^2)	4.7441	3.8087
Heat flux (kw/m^2)	163.6800	203.8800
Boiling coefficient ($w/m^2\,^oC$)	9697.7790	11309.3500
Total annual variable cost ($/year)	292220.50	312539.90

Table 4.21; Results of optimisation pf assumed overall heat transfer coefficient (U) for ethyl acetate

Design parameters	CAD program	
	U(w/m^2 ^{o}C)	
	900	700
Duty (kw)	763.3047	763.3047
Heat transfer area (M^2)	7.6476	9.8326
Heat flux (kw/m^2)	99.8100	77.6300
Boiling coefficient (w/m^2 ^{o}C)	6940.8470	5821.1850
Total annual variable cost ($/year)	377167.70	377619.90

4.2 DISCUSSION

The discussion will focus on the comparison between the manual calculations and the CAD program for problem statement and optimisation of design variables.

4.2.1 Comparison between Manual Calculations and CAD Program for Problem Statement.

From Table 4.1, it can be seen from the statistical correlation coefficient, which is 0.9999 that results obtained from manual calculations agree with those obtained from CAD program.

This shows that the programming of the tables, graphs, correlations using appropriate numerical methods and software are accurate. Thus the tedious calculations, iterations, reading of graphs and tables are now eliminated so that quicker and more accurate results can be obtained (Peters and Timmerhaus, 1991). For instance, in order to design a thermosyphon reboiler, using hand calculations would be tedious and time-consuming. The iterative nature of the procedure leads itself to solution by computers (Richardson and Coulson, 1991). Sarmal et al. (1973) discuss the development of a computer program for vertical thermosyphon reboiler design and give the algorithms and design equations in which the programs are available. Adebola (1998) developed a computer aided-design module of a vaporiser and found that the time taken for the running of the software is far less compare with that obtained with manual calculations. The physical properties of these vaporising substances provide an enabling environment for the program accuracy (Yaws, 2004).

4.2.2 Discussion of Optimisation Results

The five design parameters considered in the optimisation of this design were the duty of the vaporiser, heat transfer area, heat flux, boiling heat coefficient and the total annual variable cost of the vaporiser and its operation.

In Tables 4.2- 4.14 and 4.21, variable changed for the purpose of optimisation is the assumed overall heat transfer coefficient. For instance, in Tables 4.2 for benzene, an increase in the assumed overall heat transfer coefficient decreases the heat transfer area and the total annual variable cost and increases the heat flux and the boiling heat coefficient (Adebola, 1998). In Tables 4.3 for chloroform, a decrease in assumed overall heat transfer coefficient increases the heat transfer area and the total annual variable cost of vaporiser and its operation and decreases the heat flux and the boiling coefficient. In both cases the duty of the vaporiser remained unchanged. For benzene, the decrease in the total annual variable cost ensures that optimal cost is attained at a very low assumed overall heat transfer coefficient, since this is a function of the heat transfer area, duty and the mean temperature difference (Peters and Timmerhaus, 1991). For chloroform, a decrease in heat flux and boiling coefficient is an indication that the critical heat flux is not exceeded at a high assumed overall heat transfer coefficient (Richardson and coulson, 1997). This variation is applicable to other tables considered above for the purpose of this optimisation.

In Tables 4.15, 4.18 and 4.20, the variables changed for the purpose of optimisation is the steam pressure. For instance, Table 4.15 for n-butane, an increase in steam pressure increases the heat flux and the boiling coefficient and decreases the heat transfer area (Adebola, 1998) and the total annual variable cost for the vaporiser and its operation. The duty of the vaporiser is unaffected by the steam pressure (Richardson and Coulson 1991). The reason being that the boiling coefficient is a function of the physical properties, pressure and the mean temperature difference between the fluids (Kern, 1950).

In Tables 4.16, 4.17 and 4.19, the variables changed for the purpose of optimisation is the mass flow rate. For instance, Table 4.16 for acetone, a decrease in mass flow rate decreases the duty of the vaporiser, the heat transfer area and the total annual variable cost of the vaporiser. In tables 4.17 for aniline, an increase in mass flow rate increases the duty of the vaporiser, heat transfer area and the total annual variable cost of vaporiser and its operation. In both cases, the heat flux and boiling coefficient remain unchanged. The variation in the duty is as a result of its functionality over the mass flow rate , sensitive heat maximum, latent heat and the specific heat capacity of the substances which is itself together with the heat transfer area and mean temperature difference are functions of the total annual variable cost for vaporiser and its operation (Peters and Timmerhaus, 1991). The unchanging nature of heat flux and boiling coefficient create room for vast increase in mass flow rate and heat transfer area which may not be economically viable as a result of high rate of recycle (Kern, 1950).

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

A CAD module was developed for implementing the optimisation of a Computer Aided-Design module of a vaporiser. The program was tested with a design problem and the result of the manual and CAD program agree reasonably well as confirmed by the correlation coefficient which was approximately equal to 1.

The program can thus be used for hundreds of design specifications and accurate results obtained within small processing time.

The CAD program was also used in optimising the design by varying the values of certain design parameters such as for 20 vaporising substances.

The results obtained agreed with the expected values in the parameters optimised especially the cost such as the annual operating cost and annual fixed cost. This shows that these parameters could be adjusted to obtain optimal cost for the design of a vaporiser for a given vaporising substance.

5.2 Recommendation

The module could be extended to handle more vaporising substances.

An equation should be developed to relate the steam pressure and steam saturation temperature so that insignificant values, like numbers to more than two decimal places could be handled.

REFERENCES

1. Ayoade, K. (1994) Optimisation Techniques for Engineers and Management Scientists. NAWA publishers, Uniport Choba Port Harcourt, pp1-4, 26.

2. Richardson, J.F. and Coulson, J.M. (1997) Chemical Engineering Vol. 1, 4th edition, Pergamon Press, Oxford England, pp315-316.

3. Peters, M.S. and Timmerhaus, K.D. (1991) Plant Design and Economics for Chemical Engineers, 4th edition, McGraw-Hill Chemical Engineering Series, New York. pp625-939.

4. Richardson, J.F. and Coulson, J.M. (1991) Chemical Engineering Vol. 6, 2nd edition New York, pp22-24, 234-286, 590-609.

5. Kirk, R.E. and Orthman, D.F. (Eds.) (1977) Encyclopedia of Chemical Technology, 3rd edition (Willey).

   In: Richardson, J.F. and Coulson, J.M. (1991) Chemical Engineering Vol.6, 2nd edition, New York, pp270.

6. Faith, W.L., Keyes, W.L. and Clark, R.E. (1965) Industrial Chemicals, 3rd edition (Willey).

   In: Richardson, J.F. and Coulson, J.M. (1991) Chemical Engineering Vol. 6, 2nd edition, New York, pp270.

7. Kern, D.Q. (1950) Process Heat Transfer, McGraw-Hill, New York, pp1-3; 453-460.

8. Edgar, T.F. and Himmerblau, D.M. (1989) Optimisation Chemical Processes, International edition pp4; 107.

9. Stephenson, R.M. (1966) Introduction to Chemical Process Industries (Reinhold).

In: Richardson, J.F. and Coulson, J.M. (1991) Chemical Engineering Vol.6, 2nd edition New York, pp271.

10. Groggins, p. (1958) Unit Processes in Organic Synthesis, 5th ed. (McGraw-Hill).
In: Richardson, J.F. and Coulson, J.M. (1991) Chemical Engineering Vol.6, 2nd edition New York, pp270.

11. Ulrich, G.D. (1998) A Guide to Chemical Engineering Plant Design and Economics, McGraw-Hill publishers, New York, pp95-96.

12. Meyers, R.A. (1992) Encyclopedia of Physical Science and Technology, Vol.4, 2nd edition Academic Press, Inc. London, pp525- 527.

13. Okike, E.U. (1998) A Simple Guide to FORTRAN77 Programming, pp1-3.

14. Weissermal, K. and Arpe, H. (1978) Industrial Organic Chemistry (verlag chemic).
In: Richardson, J.F and Coulson, J.M. (1991) Chemical Engineering Vol.6, 2nd edition New York, pp271.

15. Forster, K. and Zuber, N. (1955) AICHEJ 1, pp531. Dynamics of Vapour Bubbles and Boiling Transfer.
In: Richardson, J.F. and Coulson, J.M. (1991) Chemical Engineering Vol.6, 2nd edition New York, pp616.

16. Mostinski, I.L. (1963) Tephloenergetika 4, 66; English abstract in Brit. Chem. Eng. 8, 580 (1963), Calculation of Boiling Heat Transfer Coefficients, based on the law of corresponding states.
In: Richardson, J.F. and Coulson, J.M. (1991) Chemical Engineering Vol.6, 2nd edition New York, pp617.

17. Adebola, D.F. (1998) Computer Aided-Design Module of a Vaporiser. B.ENG.Thesis submitted to the department of Chemical Engineering, FUT Minna, 37pp.

18. Reid, R.C., Sherwood, T.K. and Prausnitz, J.M.(1977) Properties of Gases and Liquids, 3rd edition (McGraw-Hill).

In: Richardson, J.F. and Coulson, J.M. (1991) Chemical Engineering Vol.6, 2nd edition, New York, pp617.

19. Kobe, K.A. and Associates (1949-1958) Thermo-chemistry of Petrochemicals, printed from Petroleum Refiner, Houston; Gulf Publishing Company.

20. Yaws, C.L. (2004) Yaws Handbook of Thermodynamics and Physical Properties of Chemical Compounds, copy @ 2004 Knovel corporation New York, 779pp.

21. Lange, N.A. (1979) Handbook of Chemistry, 12th edition, McGraw-Hill New York.

22. Ali, B. and Onkar, B.S. (1996) FORTRAN77 SYNTAX; copyright @ 1996 in the United States of America, pp9-17.

23. Palen, J.W. and Taborek, J. (1962) Refinery Kettle Reboiler. Chem. Eng. Prog. 58 (July) 39.

In: Richardson, J.F. and Coulson, J.M. (1991) Chemical Engineering Vol.6, 2nd edition New York, pp617.

24. Zuber, N., Tribus, M. and Westwater, J.M. (1961) The Hydrodynamic Crisis in Pool Boiling of saturated and Subcooled Liquids. Second International Heat Transfer Conference, paper 27, p230. Am. Soc. Mech. Eng.

In: Richardson, J.F. and Coulson, J.M. (1991) Chemical Engineering Vol.6, 2nd edition New York, pp618.

25. Simeon, O.F. (1993) Fundamentals of FORTRAN77 Programming, ADA + JANES Press Nigeria Limited, pp59.

26. Weast, R.C. (1979) Handbook of Chemistry and Physics, 59th edition, Boca Raton FL: CRC Press.

27. Sarma, N.V.L.S., Reddy, P.J. and Murti, P.S. (1973) A Computer Design Method for Vertical Thermosyphon Reboiler. Industrial Engineering Process Design Development 12, 278.

In: Richardson, J.F. and Coulson, J.M. (1991) Chemical Engineering Vol.6, 2nd edition New York, pp617.

28. Touloukian, Y.S. (Ed.) (1970-1977) Thermo-physical properties of matter. TPRC Data Services (plenum press).

In: Richardson, J.F. and Coulson, J.M. (1991) Chemical Engineering Vol.6, 2nd edition New York, pp271.

29. Maxwell, J.B. (1950) Data book on Hydrocarbons, Van Nostrand Reinhold, New York.

30. Perry, R.H. and Chilton, C.H. (Eds.) (1973) Chemical Engineers Handbook, 5th edition, McGraw-Hill Publishers New York U.S.A.

31. Mullin, J.W. (1967) S.I. Units in Chemical Engineering. The chemical Engineer No. 211, 176.

In: Richardson, J.F. and Coulson, J.M. (1997) Chemical Engineering Vol.1 4th edition, Pergamon Press, Oxford England, pp625.

APPENDIX A

MANUAL CALCULATION FOR PROBLEM STATEMENT

Mass flow rate = 5000 Kg/hr

Operating pressure = 5.84 bar

Minimum temperature of the feed = O ^{O}C

Steam pressure = 1.7 Bar

Physical properties of n-butane at 5.84 bar

Boiling point = 56.1°C

Latent heat = 326 kJ/kg

Mean specific heat, liquid = 2.51 kJ/kg°C

Critical pressure (PC) = 38 bar

Heat loads:

Sensitive heat (maximum) = $Cp\Delta T$ = (56.1- 0) * 2.51 = 140.8 kJ/kg

Total heat load = (140.8 + 326)*5000/3600 = 648.3 kw

Add 5% due to heat losses;

Maximum heat load (duty) = 1.05 X 648.3 = 681 kw

Assume U = 1000 $W/M^{2o}C$

Mean temperature difference both side isothermal

Steam saturation temperature at 1.7 bar = 115.2 ° C

$K_F = 1.15$; $H_Y = 7200$ hrs/year; $\Delta T_M = 59.1\ ^oC$; $C_{pu} = 4.18\ kJ/Kg^OC$

$$CT = A_O K_F C_{AO} + \frac{(q1\ H_Y\ C_u)\ 3600}{C_{PU}\ \Delta T_M}$$

$$= 11.5 \times 1.15 \times 180 + \frac{681 \times 7200 \times 0.0066 \times 3600}{4.18 \times 59.1}$$

$$= 2380.5 + 471587.50 = \$473968.00/year$$

$$C_T = \$473968.00/year$$

$\Delta T = 115.2 - 56.1 = 59.1\ ^{o}C$

Outside area required (Ao) = $681 \times 10^3/1000 \times 59.1 = 11.5\ m^2$

Boiling coefficient:

Use mostinski's equation, heat flux based on estimated area.

$q = q^{'}/A_o = 681/\ 11.5 = 59.2\ kw/m^2$

$$h_{nb} = 0.104(PC)^{0.69}\ (q)0.7 \left[1.8(P/PC)^{0.17} + (P/PC)^{1.2} + 10\ (P/PC)^{10}\right]$$

$$h_{nb} = 0.104(38)^{0.69}(59.2X10^3)^{0.7}\left[1.8\left(\frac{5.84}{38}\right)^{0.17} + 4\left(\frac{5.84}{38}\right)^{1.2} + 10\left(\frac{5.84}{38}\right)^{10}\right]$$

h_{nb} = 4855 $w/m^{2\,o}C$

Costing;

Duty of vaporiser,q' = 681 kw

Area Ao = $11.5m^2$

Assume cost of steam for pressure of 1.7 bar

C_u = \$0.0066/kg

Assume cost of vaporiser per square meter

C_{AO} = \$180/m^2

Assume annual fixed charges including maintenance, expressed as a fraction of initial cost for completely installed vaporiser, to be 15%.

APPENDIX B

```
      PROGRAM CADMOD
C  AUTHOR:          ADEJOH ADU ZAKARIAH
C  MAT. NO.:        M. ENG./SEET/749/2001/2002
C  COURSE TITLE:    M.ENG PROJECT WORK
C  COURSE CODE:     CEE 623
C  PROJECT TITLE:   OPTIMISATION OF COMPUTER AIDED DESIGN MODULE OF A
                    VAPORISER
C
C  SUPERVISOR:      DR. K.R.ONIFADE
C  LANGUAGE:        FORTRAN 77
C  DATE:            5 MAY, 2004

C                   DEFINATION OF VARIABLES
C
C INPUT VARIABLE                                                    TYPE
C
C      BPOINT      BOILING POINT OF SUBSTANCE                       REAL
C      SPHEAT      SPECIFIC HEAT OF SUBSTANCE                       REAL
C      HLATEN      LATENT HEAT OF SUBSTANCE                         REAL
C      CRPRES      CRITICAL PRESSURE OF SUBSTANCE                   REAL
C      TMFEED      MINIMUM FEED TEMPERATURE                         REAL
C      TMASFR      MASS FLOW RATE                                   REAL
C      OHEATC      OVERALL HEAT TRANSFER COEFFICIENT                REAL
C      STEAMP      STEAM PRESSURE                                   REAL
C      SHTCST      SPECIFIC HEAT CAPACITY OF STEAM                  REAL
C      TKF         PERCENTAGE ANNUAL FIXED CHARGES FOR
C                  COMPLETELY INSTALLED VAPORISER                   REAL
C      CAO         COST OF VAPORISER PER SQUARE METRE               REAL
C  HOUROP      ANNUAL HOURS OF OPERATION                            REAL
C      CU          COST OF STEAM PER KILOGRAM                       REAL
C
C  OUTPUT VARIABLE                                                  TYPE
C
C      SHTMAX      SENSITIVE HEAT MAXIMUM                           REAL
C      THLOAD      TOTAL HEAT LOAD                                  REAL
C      DUTY        DUTY OF VAPORISER                                REAL
C      STEAMT      STEAM TEMPERATURE                                REAL
C      TMEMTD      MEAN TEMPERATURE DIFFERENCE                      REAL
C      HTAREA      HEAT TRANSFER AREA                               REAL
C      HTFLUX      HEAT FLUX                                        REAL
C      TEMPJ       TEMPORARY STORAGE FOR COMPUTATION OF BOILCF REAL
C      TEMPK       TEMPORARY STORAGE FOR COMPUTATION OF BOILCF REAL
C      TEMPW       TEMPORARY STORAGE FOR COMPUTATION OF BOILCF REAL
C      TEMPL       TEMPORARY STORAGE FOR COMPUTATION OF BOILCF REAL
C      TEMPM       TEMPORARY STORAGE FOR COMPUTATION OF BOILCF REAL
C      BOILCF      BOILING COEFFICIENT                              REAL
C      TVCOST      TOTAL ANNUAL VARIABLE COST FOR VAPORISER
C                  AND ITS OPERATION                                REAL
C
C
C    DEFINATION OF SUBROUTINES
C    SUBROUTINE        DEFINATION
C
C    BENZEN   COMPUTES THE PHYSICAL PROPERTIES OF BENZENE & TVCOST
C    CLFORM   COMPUTES THE PHYSICAL PROPERTIES OF CHLOROFORM & TVCOST
```

APPENDIX B

```
C       ETANOL   COMPUTES THE PHYSICAL PROPERTIES OF ETHYL ALCOHOL &
        TVCOST
C       EBENZN   COMPUTES THE PHYSICAL PROPERTIES OF ETHYL BENZENE &
        TVCOST
C       EBROMD   COMPUTES THE PHYSICAL PROPERTIES OF ETHYL BROMIDE &
        TVCOST
C       MCLORD   COMPUTES THE PHYSICAL PROPERTIES OF METHYLENE CHLORIDE &
        TVCOST
C       NHEPTN   COMPUTES THE PHYSICAL PROPERTIES OF n-HEPTANE & TVCOST
C       NHEXAN   COMPUTES THE PHYSICAL PROPERTIES OF n-HEXANE & TVCOST
C       NOCTAN   COMPUTES THE PHYSICAL PROPERTIES OF n-OCTANE & TVCOST
C       NPTANE   COMPUTES THE PHYSICAL PROPERTIES OF n-PENTANE ALCOHOL &
        TVCOST
C       TMCTAN   COMPUTES THE PHYSICAL PROPERTIES OF TETRACHLOROMETHANE &
        TVCOST
C       TOLUEN   COMPUTES THE PHYSICAL PROPERTIES OF TOLUENE & TVCOST
C       EGLYCO   COMPUTES THE PHYSICAL PROPERTIES OF ETHYLENE GLYCOL &
        TVCOST
C       NBUTAN   COMPUTES THE PHYSICAL PROPERTIES OF n-BUTANE & TVCOST
C       ACETON   COMPUTES THE PHYSICAL PROPERTIES OF ACETON & TVCOST
C       ANILIN   COMPUTES THE PHYSICAL PROPERTIES OF ANILINE & TVCOST
C       CBENZN   COMPUTES THE PHYSICAL PROPERTIES OF CHLOROBENZENE &
        TVCOST
C       NBACOL   COMPUTES THE PHYSICAL PROPERTIES OF n-BUTYL ALCOHOL &
        TVCOST
C       EETHER   COMPUTES THE PHYSICAL PROPERTIES OF ETHYL ETHER & TVCOST
C       ETACET   COMPUTES THE PHYSICAL PROPERTIES OF ETHYLENE ACETATE &
        TVCOST
C       STEAM    DETERMINATION OF STEAM TEMPERATURE GIVEN STEAM PRESSURE
C
        REAL BPOINT, SPHEAT, HLATEN, CRPRES, TMFEED, OHEATC, STEAMP
        REAL STEAMT, SHTMAX, TMASFR, THLOAD, DUTY, TMEMTD, HTAREA, HFLUX,
        PRESS
        REAL TEMPJ, TEMPK, TEMPW, TEMPL, TEMPM, BOILCF, TVCOST, TKF, CAO
        REAL HOUROP, CU
        COMMON BPOINT, SPHEAT, HLATEN, CRPRES, TMFEED, OHEATC, STEAMP,
       $STEAMT, SHTMAX, TMASFR, THLOAD, DUTY, TMEMTD, HTAREA, HFLUX,
        PRESS,
       $TVCOST, TKF, CAO, HOUROP, CU, SHTCST
        INTEGER OPTION
C       OPENNING A RESULT FILE (ADEJO.RES)
        OPEN (2, FILE='ADEJO.RES')
        REWIND (2)
        WRITE (*, 10)'THE MENU'
     10 FORMATS (1X, A8)
        WRITE (*, 12)'COMPUTER AIDED DESIGN OF VAPORISER'
     12 FORMATS (1X, A)
C       SELECTS A NUMBER BETWEEN 1 AND 20 INCLUSIVE AS SHOWN BELOW,
C       WHERE EACH NUMBER SELECTED REPRESENTS THE ORGANIC COMPOUND
C       WHOSE PHYSICAL PROPERTIES YOU WANT TO KNOW.
        PRINT*,'SELECT AN OPTION FROM THE LIST BELOW'
        PRINT*,'1 BENZENE'
        PRINT*,'2 CHLOROFORM'
        PRINT*,'3 ETHYL ALCOHOL'
```

APPENDIX B

```
      PRINT*,'4 ETHYL BENZENE'
      PRINT*,'5 ETHYL BROMIDE'
      PRINT*,'6 METHYLENE CHLORIDE'
      PRINT*,'7 n-HEPTANE'
      PRINT*,'8 n-HEXANE'
      PRINT*,'9 n-OCTANE'
      PRINT*,'10 n-PENTANE'
      PRINT*,'11 TETRACHLOROMETHANE'
      PRINT*,'12 TOLUENE'
      PRINT*,'13 ETHYL GLYCOL'
      PRINT*,'14 n-BUTANE'
      PRINT*,'15 ACETON'
      PRINT*,'16 ANILINE'
      PRINT*,'17 CLOROBENZENE'
      PRINT*,'18 n-BUTHYL ALCHOHOL'
      PRINT*,'19 ETHYL ETHER'
      PRINT*,'10 ETHYLENE ACETATE'
      PRINT*,'INPUT SELECTED OPTION'
      READ (*,*) OPTION
C
      IF (OPTION.EQ.1) THEN
         CALL BENZEN (BPOINT, SPHEAT, HLATEN, CRPRES, TMFEED, OHEATC,
     $   STEAMP, STEAMT, SHTMAX, TMASFR, THLOAD, DUTY, TMEMTD, HTAREA,
         HFLUX,
     $   PRESS,TEMPJ,TEMPK,TEMPW,TEMPL,TEMPM,BOILCF,TVCOST,TKF,CAO,CU,
     $   HOUROP, SHTCST)
         STOP
      ELSEIF (OPTION.EQ.2) THEN
         CALL CLFORM (BPOINT, SPHEAT, HLATEN, CRPRES, TMFEED, OHEATC,
     $   STEAMP, STEAMT, SHTMAX,TMASFR,THLOAD,DUTY,TMEMTD,HTAREA,HFLUX,
     $   PRESS,TEMPJ,TEMPK,TEMPW,TEMPL,TEMPM,BOILCF,TVCOST,TKF,CAO,CU,
     $   HOUROP,SHTCST)
         STOP
      ELSEIF(OPTION.EQ.3)THEN
         CALL ETANOL(BPOINT,SPHEAT,HLATEN,CRPRES,TMFEED,OHEATC,
     $   STEAMP,STEAMT,SHTMAX,TMASFR,THLOAD,DUTY,TMEMTD,HTAREA,HFLUX,
     $   PRESS,TEMPJ,TEMPK,TEMPW,TEMPL,TEMPM,BOILCF,TVCOST,TKF,CAO,CU,
     $   HOUROP,SHTCST)
         STOP
      ELSEIF(OPTION.EQ.4)THEN
         CALL EBENZN(BPOINT,SPHEAT,HLATEN,CRPRES,TMFEED,OHEATC,
     $   STEAMP,STEAMT,SHTMAX,TMASFR,THLOAD,DUTY,TMEMTD,HTAREA,HFLUX,
     $   PRESS,TEMPJ,TEMPK,TEMPW,TEMPL,TEMPM,BOILCF,TVCOST,TKF,CAO,CU,
     $   HOUROP,SHTCST)
         STOP
      ELSEIF(OPTION.EQ.5)THEN
         CALL EBROMD(BPOINT,SPHEAT,HLATEN,CRPRES,TMFEED,OHEATC,
     $   STEAMP,STEAMT,SHTMAX,TMASFR,THLOAD,DUTY,TMEMTD,HTAREA,HFLUX,
     $   PRESS,TEMPJ,TEMPK,TEMPW,TEMPL,TEMPM,BOILCF,TVCOST,TKF,CAO,CU,
     $   HOUROP,SHTCST)
         STOP
      ELSEIF(OPTION.EQ.6)THEN
         CALL MCLORD(BPOINT,SPHEAT,HLATEN,CRPRES,TMFEED,OHEATC,
     $   STEAMP,STEAMT,SHTMAX,TMASFR,THLOAD,DUTY,TMEMTD,HTAREA,HFLUX,
     $   PRESS,TEMPJ,TEMPK,TEMPW,TEMPL,TEMPM,BOILCF,TVCOST,TKF,CAO,CU,
```

```
$    HOUROP,SHTCST)
     STOP
 ELSEIF(OPTION.EQ.7)THEN
     CALL NHEPTN(BPOINT,SPHEAT,HLATEN,CRPRES,TMFEED,OHEATC,
$    STEAMP,STEAMT,SHTMAX,TMASFR,THLOAD,DUTY,TMEMTD,HTAREA,HFLUX,
$    PRESS,TEMPJ,TEMPK,TEMPW,TEMPL,TEMPM,BOILCF,TVCOST,TKF,CAO,CU,
$    HOUROP,SHTCST)
     STOP
 ELSEIF(OPTION.EQ.8)THEN
     CALL NHEXAN(BPOINT,SPHEAT,HLATEN,CRPRES,TMFEED,OHEATC,
$    STEAMP,STEAMT,SHTMAX,TMASFR,THLOAD,DUTY,TMEMTD,HTAREA,HFLUX,
$    PRESS,TEMPJ,TEMPK,TEMPW,TEMPL,TEMPM,BOILCF,TVCOST,TKF,CAO,CU,
$    HOUROP,SHTCST)
     STOP
 ELSEIF(OPTION.EQ.9)THEN
     CALL NOCTAN(BPOINT,SPHEAT,HLATEN,CRPRES,TMFEED,OHEATC,
$    STEAMP,STEAMT,SHTMAX,TMASFR,THLOAD,DUTY,TMEMTD,HTAREA,HFLUX,
$    PRESS,TEMPJ,TEMPK,TEMPW,TEMPL,TEMPM,BOILCF,TVCOST,TKF,CAO,CU,
$    HOUROP,SHTCST)
     STOP
 ELSEIF(OPTION.EQ.10)THEN
     CALL NPTANE(BPOINT,SPHEAT,HLATEN,CRPRES,TMFEED,OHEATC,
$    STEAMP,STEAMT,SHTMAX,TMASFR,THLOAD,DUTY,TMEMTD,HTAREA,HFLUX,
$    PRESS,TEMPJ,TEMPK,TEMPW,TEMPL,TEMPM,BOILCF,TVCOST,TKF,CAO,CU,
$    HOUROP,SHTCST)
     STOP
 ELSEIF(OPTION.EQ.11)THEN
     CALL TCMTAN(BPOINT,SPHEAT,HLATEN,CRPRES,TMFEED,OHEATC,
$    STEAMP,STEAMT,SHTMAX,TMASFR,THLOAD,DUTY,TMEMTD,HTAREA,HFLUX,
$    PRESS,TEMPJ,TEMPK,TEMPW,TEMPL,TEMPM,BOILCF,TVCOST,TKF,CAO,CU,
$    HOUROP,SHTCST)
     STOP
 ELSEIF(OPTION.EQ.12)THEN
     CALL TOLUEN(BPOINT,SPHEAT,HLATEN,CRPRES,TMFEED,OHEATC,
$    STEAMP,STEAMT,SHTMAX,TMASFR,THLOAD,DUTY,TMEMTD,HTAREA,HFLUX,
$    PRESS,TEMPJ,TEMPK,TEMPW,TEMPL,TEMPM,BOILCF,TVCOST,TKF,CAO,CU,
$    HOUROP,SHTCST)
     STOP
 ELSEIF(OPTION.EQ.13)THEN
     CALL EGLYCO(BPOINT,SPHEAT,HLATEN,CRPRES,TMFEED,OHEATC,
$    STEAMP,STEAMT,SHTMAX,TMASFR,THLOAD,DUTY,TMEMTD,HTAREA,HFLUX,
$    PRESS,TEMPJ,TEMPK,TEMPW,TEMPL,TEMPM,BOILCF,TVCOST,TKF,CAO,CU,
$    HOUROP,SHTCST)
     STOP
 ELSEIF(OPTION.EQ.14)THEN
     CALL NBUTAN(BPOINT,SPHEAT,HLATEN,CRPRES,TMFEED,OHEATC,
$    STEAMP,STEAMT,SHTMAX,TMASFR,THLOAD,DUTY,TMEMTD,HTAREA,HFLUX,
$    PRESS,TEMPJ,TEMPK,TEMPW,TEMPL,TEMPM,BOILCF,TVCOST,TKF,CAO,CU,
$    HOUROP,SHTCST)
     STOP
 ELSEIF(OPTION.EQ.15)THEN
     CALL ACETON(BPOINT,SPHEAT,HLATEN,CRPRES,TMFEED,OHEATC,
$    STEAMP,STEAMT,SHTMAX,TMASFR,THLOAD,DUTY,TMEMTD,HTAREA,HFLUX,
$    PRESS,TEMPJ,TEMPK,TEMPW,TEMPL,TEMPM,BOILCF,TVCOST,TKF,CAO,CU,
$    HOUROP,SHTCST)
```

```
        STOP
      ELSEIF(OPTION.EQ.16)THEN
        CALL ANILIN(BPOINT,SPHEAT,HLATEN,CRPRES,TMFEED,OHEATC,
     $  STEAMP,STEAMT,SHTMAX,TMASFR,THLOAD,DUTY,TMEMTD,HTAREA,HFLUX,
     $  PRESS,TEMPJ,TEMPK,TEMPW,TEMPL,TEMPM,BOILCF,TVCOST,TKF,CAO,CU,
     $  HOUROP,SHTCST)
        STOP
      ELSEIF(OPTION.EQ.17)THEN
        CALL CBENZN(BPOINT,SPHEAT,HLATEN,CRPRES,TMFEED,OHEATC,
     $  STEAMP,STEAMT,SHTMAX,TMASFR,THLOAD,DUTY,TMEMTD,HTAREA,HFLUX,
     $  PRESS,TEMPJ,TEMPK,TEMPW,TEMPL,TEMPM,BOILCF,TVCOST,TKF,CAO,CU,
     $  HOUROP,SHTCST)
        STOP
      ELSEIF(OPTION.EQ.18)THEN
        CALL NBACOL(BPOINT,SPHEAT,HLATEN,CRPRES,TMFEED,OHEATC,
     $  STEAMP,STEAMT,SHTMAX,TMASFR,THLOAD,DUTY,TMEMTD,HTAREA,HFLUX,
     $  PRESS,TEMPJ,TEMPK,TEMPW,TEMPL,TEMPM,BOILCF,TVCOST,TKF,CAO,CU,
     $  HOUROP,SHTCST)
        STOP
      ELSEIF(OPTION.EQ.19)THEN
        CALL EETHER(BPOINT,SPHEAT,HLATEN,CRPRES,TMFEED,OHEATC,
     $  STEAMP,STEAMT,SHTMAX,TMASFR,THLOAD,DUTY,TMEMTD,HTAREA,HFLUX,
     $  PRESS,TEMPJ,TEMPK,TEMPW,TEMPL,TEMPM,BOILCF,TVCOST,TKF,CAO,CU,
     $  HOUROP,SHTCST)
        STOP
      ELSEIF(OPTION.EQ.20)THEN
        CALL ETACET(BPOINT,SPHEAT,HLATEN,CRPRES,TMFEED,OHEATC,
     $  STEAMP,STEAMT,SHTMAX,TMASFR,THLOAD,DUTY,TMEMTD,HTAREA,HFLUX,
     $  PRESS,TEMPJ,TEMPK,TEMPW,TEMPL,TEMPM,BOILCF,TVCOST,TKF,CAO,CU,
     $  HOUROP,SHTCST)
        STOP
      ELSE
         WRITE(*,16)'INVALID ENTRY',OPTION,'TRY AGAIN'
   16 FORMAT(1X,A,1X,F10.4,1X,A)
      ENDIF
      STOP
      END

C   SECTION FOR SUBROUTINES

      SUBROUTINE  BENZEN(BPOINT,SPHEAT,HLATEN,CRPRES,TMFEED,OHEATC,
     $STEAMP,STEAMT,SHTMAX,TMASFR,THLOAD,DUTY,TMEMTD,HTAREA,HFLUX,
     $PRESS,TEMPJ,TEMPK,TEMPW,TEMPL,TEMPM,BOILCF,TVCOST,TKF,CAO,CU,
     $HOUROP,SHTCST)
      WRITE(*,18)'PHYSICAL PROPERTIES OF BENZENE'
      WRITE(2,18)'PHYSICAL PROPERTIES OF BENZENE'
   18 FORMAT(//,15X,A)
      SHTCST = 4.18
      BPOINT=80.1
      SPHEAT=1.788
      HLATEN=395.653
      CRPRES=47.07
      WRITE(*,20)'BOILING POINT',BPOINT,'C'
      WRITE(2,20)'BOILING POINT',BPOINT,'C'
   20 FORMAT(//,10X,A,T48,F10.4,1X,A)
      WRITE(*,22)'SPECIFIC HEAT',SPHEAT,'KJ/KgC'
```

APPENDIX B

```
      WRITE(2,22)'SPECIFIC HEAT',SPHEAT,'KJ/KgC'
   22 FORMAT(//,10X,A,T48,F10.4,1X,A)
      WRITE(*,24)'CRITICAL PRESSURE',CRPRES,'Bar'
      WRITE(2,24)'CRITICAL PRESSURE',CRPRES,'Bar'
   24 FORMAT(//,10X,A,T48,F10.4,1X,A)
      WRITE(*,26)'LATENT HEAT',HLATEN,'KJ/Kg'
      WRITE(2,26)'LATENT HEAT',HLATEN,'KJ/Kg'
   26 FORMAT(//,10X,A,T48,F10.4,1X,A)
      PRINT*,'INPUT MINIMUM TEMPERATURE OF THE FEED ','C'
      READ(*,*)TMFEED
C  COMPUTATION OF SENSITIVE HEAT MAXIMUM
      SHTMAX = (BPOINT-TMFEED)*SPHEAT
      WRITE(*,28)'SENSITIVE HEAT MAXIMUM',SHTMAX,'KJ/Kg'
      WRITE(2,28)'SENSITIVE HEAT MAXIMUM',SHTMAX,'KJ/Kg'
   28 FORMAT(//,10X,A,T48,F10.4,1X,A)
      PRINT*,'INPUT MASSFLOW RATE ','Kg/hr'
      READ(*,*)TMASFR
C    COMPUTATION OF THE TOTAL HEAT LOAD
      THLOAD = (SHTMAX + HLATEN)*(TMASFR/3600)
      WRITE(*,30)'TOTAL HEAT LOAD',THLOAD,'KW'
      WRITE(2,30)'TOTAL HEAT LOAD',THLOAD,'KW'
   30 FORMAT(//,10X,A,T48,F10.4,1X,A)
C    COMPUTATION OF DUTY
      DUTY = 1.05*THLOAD
      WRITE(*,31)'DUTY',DUTY,'KW'
      WRITE(2,31)'DUTY',DUTY,'KW'
   31 FORMAT(//,10X,A,T48,F10.4,1X,A)
      PRINT*,'INPUT OVERALL COEFFICIENT(BETWEEN 1000 - 1500)','W/SQ.MC'
      READ(*,*)OHEATC
C     VALIDATION OF OVERALL HEAT COEFFICIENT
      IF(OHEATC .LT.1000 .AND. OHEATC .GT.1500) THEN
         PRINT*,'INVALID ENTRY',OHEATC,'PROGRAM WILL BE TERMINATED'
      ELSE
         PRINT*,'INPUT STEAM PRESSURE ','Bar'
         READ(*,*)STEAMP
      ENDIF
      CALL STEAM(STEAMP,STEAMT)
      WRITE(*,32)'STEAM TEMPERATURE',STEAMT,'C'
      WRITE(2,32)'STEAM TEMPERATURE',STEAMT,'C'
   32 FORMAT(//,10X,A,T48,F10.4,1X,A)
C     COMPUTATION OF MEAN TEMPERATURE DIFFERENCE
      TMEMTD = STEAMT - BPOINT
      WRITE(*,34)'MEAN TEMPERATURE DIFFERENCE',TMEMTD,'C'
      WRITE(2,34)'MEAN TEMPERATURE DIFFERENCE',TMEMTD,'C'
   34 FORMAT(//,10X,A,T48,F10.4,1X,A)
C     COMPUTATION OF HEAT TRANSFER AREA
      HTAREA = (DUTY*(10**3))/(OHEATC*TMEMTD)
      WRITE(*,36)'HEAT TRANSFER AREA',HTAREA,'SQ.m'
      WRITE(2,36)'HEAT TRANSFER AREA',HTAREA,'SQ.m'
   36 FORMAT(//,10X,A,T48,F10.4,1X,A)
C     COMPUTATION OF HEAT FLUX
      HFLUX = DUTY/HTAREA
      WRITE(*,38)'HEAT FLUX',HFLUX,'KW/SQ.m'
      WRITE(2,38)'HEAT FLUX',HFLUX,'KW/SQ.m'
   38 FORMAT(//,10X,A,T48,F10.4,1X,A)
      PRINT*,'INPUT OPERATING PRESSURE ','Bar'
```

APPENDIX B

```
      READ(*,*)PRESS
C     COMPUTATION OF TEMPORAL VALUE USED FOR
C    THE COMPUTATION OF BOILING COEFFICIENT
      TEMPJ = .104*CRPRES**.69
      TEMPK = (HFLUX*10**3)**.7
      TEMPW = 1.8*(PRESS/CRPRES)**0.17
      TEMPL = 4*((PRESS/CRPRES)**1.2)
      TEMPM = 10*((PRESS/CRPRES)**10)
C     COMPUTATION OF BOILING COEFFICIENT
      BOILCF = TEMPJ*TEMPK*(TEMPW+TEMPL+TEMPM)
      WRITE(*,40)'BOILING COEFFICIENT',BOILCF,'W/SQ.m c'
      WRITE (2, 40)'BOILING COEFFICIENT', BOILCF,'W/SQ.m c'
   40 FORMAT(//,10X,A,T48,F10.4,1X,A)
      PRINT*,'ENTER THE VALUES OF TKF,CAO,HOUROP'
      READ(*,*)TKF,CAO,HOUROP
C     DETERMINATION OF STEAM COST
      IF(STEAMP.GT.0 .AND. STEAMP .LT. 6.90)THEN
             CU = 0.0066
      ELSEIF(STEAMP.GE.6.90. AND. STEAMP .LT. 34.48)THEN
             CU = 0.0088
      ELSEIF(STEAMP.GE.34.48)THEN
             CU = 0.011
      ELSE
             PRINT*,'INVALID ENTRY',STEAMP,'TRY AGAIN'
      ENDIF
C     COMPUTATION OF TOTAL ANNUAL VARIABLE COST
      TVCOST=((HTAREA*TKF*CAO)+((3600*DUTY*HOUROP*CU)/(SHTCST*TMEMTD)))
      WRITE(*,42)'TOTAL ANNUAL VARIABLE COST'
      WRITE(2,42)'TOTAL ANNUAL VARIABLE COST'
   42 FORMAT(//,10X,A)
      WRITE(2,44)'FOR VAPORISER AND ITS OPERATION',TVCOST,'$/YEAR'
      WRITE(*,44)'FOR VAPORISER AND ITS OPERATION',TVCOST,'$/YEAR'
   44 FORMAT(//,10X,A,T48,F15.4,1X,A)
      RETURN
      END

      SUBROUTINE  CLFORM(BPOINT,SPHEAT,HLATEN,CRPRES,TMFEED,OHEATC,
     $STEAMP,STEAMT,SHTMAX,TMASFR,THLOAD,DUTY,TMEMTD,HTAREA,HFLUX,
     $PRESS,TEMPJ,TEMPK,TEMPW,TEMPL,TEMPM,BOILCF,TVCOST,TKF,CAO,CU,
     $HOUROP,SHTCST)
      WRITE(*,18)'PHYSICAL PROPERTIES OF CHLOROFORM'
      WRITE(2,18)'PHYSICAL PROPERTIES OF CHLOROFORM'
   18 FORMAT(//,15X,A)
      PRINT*
C  INITIALIZATION OF VARIABLES
      SHTCST = 4.18
      BPOINT=61.2
      SPHEAT=0.967
      HLATEN=247.021
      CRPRES=53.84
      WRITE(*,20)'BOILING POINT',BPOINT,'C'
      WRITE(2,20)'BOILING POINT',BPOINT,'C'
   20 FORMAT(//,10X,A,T48,F10.4,1X,A)
      WRITE(*,22)'SPECIFIC HEAT',SPHEAT,'KJ/KgC'
      WRITE(2,22)'SPECIFIC HEAT',SPHEAT,'KJ/KgC'
   22 FORMAT(//,10X,A,T48,F10.4,1X,A)
```

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```
      WRITE(*,24)'CRITICAL PRESSURE',CRPRES,'Bar'
      WRITE(2,24)'CRITICAL PRESSURE ',CRPRES,'Bar'
   24 FORMAT(//,10X,A,T48,F10.4,1X,A)
      WRITE(*,26)'LATENT HEAT',HLATEN,'KJ/Kg'
      WRITE(2,26)'LATENT HEAT',HLATEN,'KJ/Kg'
   26 FORMAT(//,10X,A,T48,F10.4,1X,A)
      PRINT*,'INPUT MINIMUM TEMPERATURE OF THE FEED ','C'
      READ(*,*)TMFEED
C  COMPUTATION OF SENSITIVE HEAT MAXIMUM
      SHTMAX = (BPOINT-TMFEED)*SPHEAT
      WRITE(*,28)'SENSITIVE HEAT MAXIMUM',SHTMAX,'KJ/Kg'
      WRITE(2,28)'SENSITIVE HEAT MAXIMUM',SHTMAX,'KJ/Kg'
   28 FORMAT(//,10X,A,T48,F10.4,1X,A)
      PRINT*,'INPUT MASS FLOW RATE ','Kg/hr'
      READ(*,*)TMASFR
C    COMPUTATION OF THE TOTAL HEAT LOAD
      THLOAD = (SHTMAX + HLATEN)*(TMASFR/3600)
      WRITE(*,30)'TOTAL HEAT LOAD',THLOAD,'KW'
      WRITE(2,30)'TOTAL HEAT LOAD',THLOAD,'KW'
   30 FORMAT(//,10X,A,T48,F10.4,1X,A)
C    COMPUTATION OF DUTY
      DUTY = 1.05*THLOAD
      WRITE(*,31)'DUTY',DUTY,'KW'
      WRITE(2,31)'DUTY',DUTY,'KW'
   31 FORMAT(//,10X,A,T48,F10.4,1X,A)
      PRINT*,'INPUT OVERALL COEFFICIENT(BETWEEN 900 - 1200)','W/SQ.MC'
      READ(*,*)OHEATC
C     VALIDATION OF OVERALL HEAT COEFFICIENT
      IF(OHEATC .LT.900 .AND. OHEATC .GT.1200) THEN
         PRINT*,'INVALID ENTRY',OHEATC,'PROGRAM WILL BE TERMINATED'
      ELSE
         PRINT*,'INPUT STEAM PRESSURE ','Bar'
         READ(*,*)STEAMP
      ENDIF
      CALL STEAM(STEAMP,STEAMT)
      WRITE(*,32)'STEAM TEMPERATURE',STEAMT,'C'
      WRITE(2,32)'STEAM TEMPERATURE',STEAMT,'C'
   32 FORMAT(//,10X,A,T48,F10.4,1X,A)
C     COMPUTATION OF MEAN TEMPERATURE DIFFERENCE
      TMEMTD = STEAMT - BPOINT
      WRITE(*,34)'MEAN TEMPERATURE DIFFERENCE',TMEMTD,'C'
      WRITE(2,34)'MEAN TEMPERATURE DIFFERENCE',TMEMTD,'C'
   34 FORMAT(//,10X,A,T48,F10.4,1X,A)
C     COMPUTATION OF HEAT TRANSFER AREA
      HTAREA = (DUTY*(10**3))/(OHEATC*TMEMTD)
      WRITE(*,36)'HEAT TRANSFER AREA',HTAREA,'SQ.m'
      WRITE(2,36)'HEAT TRANSFER AREA',HTAREA,'SQ.m'
   36 FORMAT(//,10X,A,T48,F10.4,1X,A)
C     COMPUTATION OF HEAT FLUX
      HFLUX = DUTY/HTAREA
      WRITE(*,38)'HEAT FLUX',HFLUX,'KW/SQ.m'
      WRITE(2,38)'HEAT FLUX',HFLUX,'KW/SQ.m'
   38 FORMAT(//,10X,A,T48,F10.4,1X,A)
      PRINT*,'INPUT OPERATING PRESSURE ','Bar'
      READ(*,*)PRESS
C     COMPUTATION OF TEMPORAL VALUES USED FOR THE COMPUTAION
```

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```
C      OF THE BOILING COEFFIENT
       TEMPJ = .104*CRPRES**.69
       TEMPK = (HFLUX*10**3)**0.7
       TEMPW = 1.8*(PRESS/CRPRES)**0.17
       TEMPL = 4*((PRESS/CRPRES)**1.2)
       TEMPM = 10*((PRESS/CRPRES)**10)
C      COMPUTATION OF BOILING COEFFICIENT
       BOILCF = TEMPJ*TEMPK*(TEMPW+TEMPL+TEMPM)
       WRITE(*,40)'BOILING COEFFICIENT = ',BOILCF,'W/SQ.m c'
       WRITE(2,40)'BOILING COEFFICIENT = ',BOILCF,'W/SQ.m c'
   40  FORMAT(//,10X,A,T48,F10.4,1X,A)
       PRINT*,'ENTER THE VALUES OF TKF,CAO,HOUROP'
       READ(*,*)TKF,CAO,HOUROP
C      DETERMINATION OF STEAM COST
       IF(STEAMP.GT.0 .AND. STEAMP .LT. 6.90)THEN
             CU = 0.0066
       ELSEIF(STEAMP.GE.6.90 .AND. STEAMP .LT. 34.48)THEN
             CU = 0.0088
       ELSEIF(STEAMP.GE.34.48)THEN
             CU = 0.011
       ELSE
             PRINT*,'INVALID ENTRY',STEAMP,'TRY AGAIN'
       ENDIF
C      COMPUTATION OF TOTAL ANNUAL VARIABLE COST
       TVCOST=((HTAREA*TKF*CAO)+((3600*DUTY*HOUROP*CU)/(SHTCST*TMEMTD)))
       WRITE(*,42)'TOTAL ANNUAL VARIABLE COST'
       WRITE(2,42)'TOTAL ANNUAL VARIABLE COST'
   42  FORMAT(//,10X,A)
       WRITE(2,44)'FOR VAPORISER AND ITS OPERATION',TVCOST,'$/YEAR'
       WRITE(*,44)'FOR VAPORISER AND ITS OPERATION',TVCOST,'$/YEAR'
   44  FORMAT(/,10X,A,T45,F13.4,1X,A)
       RETURN
       END

       SUBROUTINE  ETANOL(BPOINT,SPHEAT,HLATEN,CRPRES,TMFEED,OHEATC,
      $STEAMP,STEAMT,SHTMAX,TMASFR,THLOAD,DUTY,TMEMTD,HTAREA,HFLUX,
      $PRESS,TEMPJ,TEMPK,TEMPW,TEMPL,TEMPM,BOILCF,TVCOST,TKF,CAO,CU,
      $HOUROP,SHTCST)
       WRITE(*,18)'PHYSICAL PROPERTIES OF ETHYL ALCOHOL'
       WRITE(2,18)'PHYSICAL PROPERTIES OF ETHYL ALCOHOL'
   18  FORMAT(//,15X,A)
       PRINT*
C    INITIALIZATION OF VARIABLES
       SHTCST = 4.18
       BPOINT=78.3
       SPHEAT=2.47
       HLATEN=841.547
       CRPRES=61.78
       WRITE(*,20)'BOILING POINT = ',BPOINT,'C'
       WRITE(2,20)'BOILING POINT = ',BPOINT,'C'
   20  FORMAT(//,10X,A,T48,F10.4,1X,A)
       WRITE(*,22)'SPECIFIC HEAT = ',SPHEAT,'KJ/KgC'
       WRITE(2,22)'SPECIFIC HEAT = ',SPHEAT,'KJ/KgC'
   22  FORMAT(//,10X,A,T48,F10.4,1X,A)
       WRITE(*,24)'CRITICAL PRESSURE = ',CRPRES,'Bar'
       WRITE(2,24)'CRITICAL PRESSURE = ',CRPRES,'Bar'
```

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```
   24 FORMAT(//,10X,A,T48,F10.4,1X,A)
      WRITE(*,26)'LATENT HEAT = ',HLATEN,'KJ/Kg'
      WRITE(2,26)'LATENT HEAT = ',HLATEN,'KJ/Kg'
   26 FORMAT(//,10X,A,T48,F10.4,1X,A)
      PRINT*,'INPUT MINIMUM TEMPERATURE OF THE FEED ','C'
      READ(*,*)TMFEED
C COMPUTATION OF SENSITIVE HEAT MAXIMUM
      SHTMAX = (BPOINT-TMFEED)*SPHEAT
      WRITE(*,28)'SENSITIVE HEAT MAXIMUM = ',SHTMAX,'KJ/Kg'
      WRITE(2,28)'SENSITIVE HEAT MAXIMUM = ',SHTMAX,'KJ/Kg'
   28 FORMAT(//,10X,A,T48,F10.4,1X,A)
      PRINT*,'INPUT MASS FLOW RATE ','Kg/hr'
      READ(*,*)TMASFR
C    COMPUTATION OF THE TOTAL HEAT LOAD
      THLOAD = (SHTMAX + HLATEN)*(TMASFR/3600)
      WRITE(*,30)'TOTAL HEAT LOAD = ',THLOAD,'KW'
      WRITE(2,30)'TOTAL HEAT LOAD = ',THLOAD,'KW'
   30 FORMAT(//,10X,A,T48,F10.4,1X,A)
C    COMPUTATION OF DUTY
      DUTY = 1.05*THLOAD
      WRITE(*,31)'DUTY',DUTY,'KW'
      WRITE(2,31)'DUTY',DUTY,'KW'
   31 FORMAT(//,10X,A,T48,F10.4,1X,A)
      PRINT*,'INPUT OVERALL COEFFICIENT(BETWEEN 600 - 900)','W/SQ.MC'
      READ(*,*)OHEATC
C      VALIDATION OF OVERALL HEAT COEFFICIENT
      IF(OHEATC .LT.900 .AND. OHEATC .GT.1200) THEN
         PRINT*,'INVALID ENTRY',OHEATC,'PROGRAM WILL BE TERMINATED'
      ELSE
         PRINT*,'INPUT STEAM PRESSURE ','Bar'
         READ(*,*)STEAMP
      ENDIF
      CALL STEAM(STEAMP,STEAMT)
      WRITE(*,32)'STEAM TEMPERATURE = ',STEAMT,'C'
      WRITE(2,32)'STEAM TEMPERATURE = ',STEAMT,'C'
   32 FORMAT(//,10X,A,T48,F10.4,1X,A)
C     COMPUTATION OF MEAN TEMPERATURE DIFFERENCE
      TMEMTD = STEAMT - BPOINT
      WRITE(*,34)'MEAND TEMPERATURE DIFFERENCE = ',TMEMTD,'C'
      WRITE(2,34)'MEAND TEMPERATURE DIFFERENCE = ',TMEMTD,'C'
   34 FORMAT(//,10X,A,T48,F10.4,1X,A)
C     COMPUTATION OF HEAT TRANSFER AREA
      HTAREA = (DUTY*(10**3))/(OHEATC*TMEMTD)
      WRITE(*,36)'HEAT TRANSFER AREA = ',HTAREA,'SQ.m'
      WRITE(2,36)'HEAT TRANSFER AREA = ',HTAREA,'SQ.m'
   36 FORMAT(//,10X,A,T48,F10.4,1X,A)
C     COMPUTATION OF HEAT FLUX
      HFLUX = DUTY/HTAREA
      WRITE(*,38)'HEAT FLUX = ',HFLUX,'KW/SQ.m'
      WRITE(2,38)'HEAT FLUX = ',HFLUX,'KW/SQ.m'
   38 FORMAT(//,10X,A,T48,F10.4,1X,A)
      PRINT*,'INPUT OPERATING PRESSURE ','Bar'
      READ(*,*)PRESS
C     COMPUTATION OF TEMPORAL VALUES USED FOR
C     THE COMPUTAION OF THE BOILING COEFFIENT
      TEMPJ = .104*CRPRES**.69
```

APPENDIX B

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      TEMPK = (HFLUX*10**3)**0.7
      TEMPW = 1.8*(PRESS/CRPRES)**0.17
      TEMPL = 4*((PRESS/CRPRES)**1.2)
      TEMPM = 10*((PRESS/CRPRES)**10)
C     COMPUTATION OF BOILING COEFFICIENT
      BOILCF = TEMPJ*TEMPK*(TEMPW+TEMPL+TEMPM)
      WRITE(*,40)'BOILING COEFFICIENT = ',BOILCF,'W/SQ.m c'
      WRITE(2,40)'BOILING COEFFICIENT = ',BOILCF,'W/SQ.m c'
   40 FORMAT(//,10X,A,T48,F10.4,1X,A)
      PRINT*,'ENTER THE VALUES OF TKF,CAO,HOUROP'
      READ(*,*)TKF,CAO,HOUROP
C     DETERMINATION OF STEAM COST
      IF(STEAMP.GT.0 .AND. STEAMP .LT. 6.90)THEN
            CU = 0.0066
      ELSEIF(STEAMP.GE.6.90 .AND. STEAMP .LT. 34.48)THEN
            CU = 0.0088
      ELSEIF(STEAMP.GE.34.48)THEN
            CU = 0.011
      ELSE
            PRINT*,'INVALID ENTRY',STEAMP,'TRY AGAIN'
      ENDIF
C     COMPUTATION OF TOTAL ANNUAL VARIABLE COST
      TVCOST=((HTAREA*TKF*CAO)+((3600*DUTY*HOUROP*CU)/(SHTCST*TMEMTD)))
      WRITE(*,42)'TOTAL ANNUAL VARIABLE COST'
      WRITE(2,42)'TOTAL ANNUAL VARIABLE COST'
   42 FORMAT(//,10X,A)
      WRITE(2,44)'FOR VAPORISER AND ITS OPERATION',TVCOST,'$/YEAR'
      WRITE(*,44)'FOR VAPORISER AND ITS OPERATION',TVCOST,'$/YEAR'
   44 FORMAT(/,10X,A,T45,F13.4,1X,A)
      RETURN
      END

      SUBROUTINE  EBENZN(BPOINT,SPHEAT,HLATEN,CRPRES,TMFEED,OHEATC,
     $STEAMP,STEAMT,SHTMAX,TMASFR,THLOAD,DUTY,TMEMTD,HTAREA,HFLUX,
     $PRESS,TEMPJ,TEMPK,TEMPW,TEMPL,TEMPM,BOILCF,TVCOST,TKF,CAO,CU,
     $HOUROP,SHTCST)
      WRITE(*,18)'PHYSICAL PROPERTIES OF ETHYL BENZENE'
      WRITE(2,18)'PHYSICAL PROPERTIES OF ETHYL BENZENE'
   18 FORMAT(//,15X,A)
C  INITIALIZATION OF VARIABLES
      PRINT*
      SHTCST = 4.18
      BPOINT=135.4
      SPHEAT=1.729
      HLATEN=339.131
      CRPRES=37.36
      WRITE(*,20)'BOILING POINT',BPOINT,'C'
      WRITE(2,20)'BOILING POINT',BPOINT,'C'
   20 FORMAT(//,10X,A,T48,F10.4,1X,A)
      WRITE(*,22)'SPECIFIC HEAT',SPHEAT,'KJ/KgC'
      WRITE(2,22)'SPECIFIC HEAT',SPHEAT,'KJ/KgC'
   22 FORMAT(//,10X,A,T48,F10.4,1X,A)
      WRITE(*,24)'CRITICAL PRESSURE',CRPRES,'Bar'
      WRITE(2,24)'CRITICAL PRESSURE',CRPRES,'Bar'
   24 FORMAT(//,10X,A,T48,F10.4,1X,A)
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      WRITE(*,26)'LATENT HEAT',HLATEN,'KJ/Kg'
      WRITE(2,26)'LATENT HEAT',HLATEN,'KJ/Kg'
   26 FORMAT(//,10X,A,T48,F10.4,1X,A)
      PRINT*,'INPUT MINIMUM TEMPERATURE OF THE FEED ','C'
      READ(*,*)TMFEED
C   COMPUTATION OF SENSITIVE HEAT MAXIMUM
      SHTMAX = (BPOINT-TMFEED)*SPHEAT
      WRITE(*,28)'SENSITIVE HEAT MAXIMUM',SHTMAX,'KJ/Kg'
      WRITE(2,28)'SENSITIVE HEAT MAXIMUM',SHTMAX,'KJ/Kg'
   28 FORMAT(//,10X,A,T48,F10.4,1X,A)
      PRINT*,'INPUT MASS FLOW RATE ','Kg/hr'
      READ(*,*)TMASFR
C    COMPUTATION OF THE TOTAL HEAT LOAD
      THLOAD = (SHTMAX + HLATEN)*(TMASFR/3600)
      WRITE(*,30)'TOTAL HEAT LOAD',THLOAD,'KW'
      WRITE(2,30)'TOTAL HEAT LOAD',THLOAD,'KW'
   30 FORMAT(//,10X,A,T48,F10.4,1X,A)
C    COMPUTATION OF DUTY
      DUTY = 1.05*THLOAD
      WRITE(*,31)'DUTY',DUTY,'KW'
      WRITE(2,31)'DUTY',DUTY,'KW'
   31 FORMAT(//,10X,A,T48,F10.4,1X,A)
      PRINT*,'INPUT OVERALL COEFFICIENT(BETWEEN 600 - 900)','W/SQ.MC'
      READ(*,*)OHEATC
C     VALIDATION OF OVERALL HEAT COEFFIENT
      IF(OHEATC .LT.900 .AND. OHEATC .GT.1200) THEN
         PRINT*,'INVALID ENTRY',OHEATC,'PROGRAM WILL BE TERMINATED'
      ELSE
         PRINT*,'INPUT STEAM PRESSURE', 'Bar'
         READ(*,*)STEAMP
      ENDIF
      CALL STEAM(STEAMP,STEAMT)
      WRITE(*,32)'STEAM TEMPERATURE',STEAMT,'C'
      WRITE(2,32)'STEAM TEMPERATURE',STEAMT,'C'
   32 FORMAT(//,10X,A,T48,F10.4,1X,A)
C     COMPUTATION OF MEAN TEMPERATURE DIFFERENCE
      TMEMTD = STEAMT - BPOINT
      WRITE(*,34)'MEAND TEMPERATURE DIFFERENCE',TMEMTD,'C'
      WRITE(2,34)'MEAND TEMPERATURE DIFFERENCE',TMEMTD,'C'
   34 FORMAT(//,10X,A,T48,F10.4,1X,A)
C     COMPUTATION OF HEAT TRANSFER AREA
      HTAREA = (DUTY*(10**3))/(OHEATC*TMEMTD)
      WRITE(*,36)'HEAT TRANSFER AREA',HTAREA,'SQ.m'
      WRITE(2,36)'HEAT TRANSFER AREA',HTAREA,'SQ.m'
   36 FORMAT(//,10X,A,T48,F10.4,1X,A)
C     COMPUTATION OF HEAT FLUX
      HFLUX = DUTY/HTAREA
      WRITE(*,38)'HEAT FLUX',HFLUX,'KW/SQ.m'
      WRITE(2,38)'HEAT FLUX',HFLUX,'KW/SQ.m'
   38 FORMAT(//,10X,A,T48,F10.4,1X,A)
      PRINT*,'INPUT OPERATING PRESSURE ','Bar'
      READ(*,*)PRESS
C     COMPUTATION OF TEMPORAL VALUES USED FOR
C     THE COMPUTAION OF THE BOILING COEFFICIENT
      TEMPJ = .104*CRPRES**.69
```

APPENDIX B

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      TEMPK = (HFLUX*10**3)**0.7
      TEMPW = 1.8*(PRESS/CRPRES)**0.17
      TEMPL = 4*((PRESS/CRPRES)**1.2)
      TEMPM = 10*((PRESS/CRPRES)**10)
C     COMPUTATION OF BOILING COEFFICIENT
      BOILCF = TEMPJ*TEMPK*(TEMPW+TEMPL+TEMPM)
      WRITE(*,40)'BOILING COEFFICIENT',BOILCF,'W/SQ.m c'
      WRITE(2,40)'BOILING COEFFICIENT',BOILCF,'W/SQ.m c'
   40 FORMAT(//,10X,A,T48,F10.4,1X,A)
      PRINT*,'ENTER THE VALUES OF TKF,CAO,HOUROP'
      READ(*,*)TKF,CAO,HOUROP
C     DETERMINATION OF STEAM COST
      IF(STEAMP.GT.0 .AND. STEAMP .LT. 6.90)THEN
             CU = 0.0066
      ELSEIF(STEAMP.GE.6.90 .AND. STEAMP .LT. 34.48)THEN
             CU = 0.0088
      ELSEIF(STEAMP.GE.34.48)THEN
             CU = 0.011
      ELSE
             PRINT*,'INVALID ENTRY',STEAMP,'TRY AGAIN'
      ENDIF
C     COMPUTATION OF TOTAL ANNUAL VARIABLE COST
      TVCOST=((HTAREA*TKF*CAO)+((3600*DUTY*HOUROP*CU)/(SHTCST*TMEMTD)))
      WRITE(*,42)'TOTAL ANNUAL VARIABLE COST'
      WRITE(2,42)'TOTAL ANNUAL VARIABLE COST'
   42 FORMAT(//,10X,A)
      WRITE(2,44)'FOR VAPORISER AND ITS OPERATION',TVCOST,'$/YEAR'
      WRITE(*,44)'FOR VAPORISER AND ITS OPERATION',TVCOST,'$/YEAR'
   44 FORMAT(/,10X,A,T45,F13.4,1X,A)
      RETURN
      END

      SUBROUTINE  EBROMD(BPOINT,SPHEAT,HLATEN,CRPRES,TMFEED,OHEATC,
     $STEAMP,STEAMT,SHTMAX,TMASFR,THLOAD,DUTY,TMEMTD,HTAREA,HFLUX,
     $PRESS,TEMPJ,TEMPK,TEMPW,TEMPL,TEMPM,BOILCF,TVCOST,TKF,CAO,CU,
     $HOUROP,SHTCST)
      WRITE(*,18)'PHYSICAL PROPERTIES OF ETHYL BROMIDE'
      WRITE(2,18)'PHYSICAL PROPERTIES OF ETHYL BROMIDE'
   18 FORMAT(//,15X,A)
      PRINT*
C INITIALIZATION OF VARIABLES
      SHTCST = 4.18
      BPOINT=38.4
      SPHEAT=0.879
      HLATEN=251.208
      CRPRES=60.31
      WRITE(*,20)'BOILING POINT',BPOINT,'C'
      WRITE(2,20)'BOILING POINT',BPOINT,'C'
   20 FORMAT(//,10X,A,T48,F10.4,1X,A)
      WRITE(*,22)'SPECIFIC HEAT',SPHEAT,'KJ/KgC'
      WRITE(2,22)'SPECIFIC HEAT',SPHEAT,'KJ/KgC'
   22 FORMAT(//,10X,A,T48,F10.4,1X,A)
      WRITE(*,24)'CRITICAL PRESSURE',CRPRES,'Bar'
      WRITE(2,24)'CRITICAL PRESSURE',CRPRES,'Bar'
   24 FORMAT(//,10X,A,T48,F10.4,1X,A)
```

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```
      WRITE(*,26)'LATENT HEAT',HLATEN,'KJ/Kg'
      WRITE(2,26)'LATENT HEAT',HLATEN,'KJ/Kg'
   26 FORMAT(//,10X,A,T48,F10.4,1X,A)
      PRINT*,'INPUT MINIMUM TEMPERATURE OF THE FEED ','C'
      READ(*,*)TMFEED
C  COMPUTATION OF SENSITIVE HEAT MAXIMUM
      SHTMAX = (BPOINT-TMFEED)*SPHEAT
      WRITE(*,28)'SENSITIVE HEAT MAXIMUM',SHTMAX,'KJ/Kg'
      WRITE(2,28)'SENSITIVE HEAT MAXIMUM',SHTMAX,'KJ/Kg'
   28 FORMAT(//,10X,A,T48,F10.4,1X,A)
      PRINT*,'INPUT MASS FLOW RATE ','Kg/hr'
      READ(*,*)TMASFR
C    COMPUTATION OF THE TOTAL HEAT LOAD
      THLOAD = (SHTMAX + HLATEN)*(TMASFR/3600)
      WRITE(*,30)'TOTAL HEAT LOAD',THLOAD,'KW'
      WRITE(2,30)'TOTAL HEAT LOAD',THLOAD,'KW'
   30 FORMAT(//,10X,A,T48,F10.4,1X,A)
C    COMPUTATION OF DUTY
      DUTY = 1.05*THLOAD
      WRITE(*,31)'DUTY',DUTY,'KW'
      WRITE(2,31)'DUTY',DUTY,'KW'
   31 FORMAT(//,10X,A,T48,F10.4,1X,A)
      PRINT*,'INPUT OVERALL COEFFICIENT(BETWEEN 1000 - 1500)','W/SQ.MC'
      READ(*,*)OHEATC
C      VALIDATION OF OVERALL HEAT COEFFICIENT
      IF(OHEATC .LT.1000 .AND. OHEATC .GT.1500) THEN
         PRINT*,'INVALID ENTRY',OHEATC,'PROGRAM WILL BE TERMINATED'
      ELSE
         PRINT*,'INPUT STEAM PRESSURE ','Bar'
         READ(*,*)STEAMP
      ENDIF
      CALL STEAM(STEAMP,STEAMT)
      WRITE(*,32)'STEAM TEMPERATURE',STEAMT,'C'
      WRITE(2,32)'STEAM TEMPERATURE',STEAMT,'C'
   32 FORMAT(//,10X,A,T48,F10.4,1X,A)
C     COMPUTATION OF MEAN TEMPERATURE DIFERENCE
      TMEMTD = STEAMT - BPOINT
      WRITE(*,34)'MEAND TEMPERATURE DIFFERENCE',TMEMTD,'C'
      WRITE(2,34)'MEAND TEMPERATURE DIFFERENCE',TMEMTD,'C'
   34 FORMAT(//,10X,A,T48,F10.4,1X,A)
C     COMPUTATION OF HEAT TRANSFER AREA
      HTAREA = (DUTY*(10**3))/(OHEATC*TMEMTD)
      WRITE(*,36)'HEAT TRANSFER AREA',HTAREA,'SQ.m'
      WRITE(2,36)'HEAT TRANSFER AREA',HTAREA,'SQ.m'
   36 FORMAT(//,10X,A,T48,F10.4,1X,A)
C     COMPUTATION OF HEAT FLUX
      HFLUX = DUTY/HTAREA
      WRITE(*,38)'HEAT FLUX',HFLUX,'KW/SQ.m'
      WRITE(2,38)'HEAT FLUX',HFLUX,'KW/SQ.m'
   38 FORMAT(//,10X,A,T48,F10.4,1X,A)
      PRINT*,'INPUT OPERATING PRESSURE ','Bar'
      READ(*,*)PRESS
C     COMPUTATION OF TEMPORAL VALUES USED FOR
C     THE COMPUTAION OF THE BOILING COEFFICIENT
      TEMPJ = .104*CRPRES**.69
```

APPENDIX B

```
      TEMPK = (HFLUX*10**3)**0.7
      TEMPW = 1.8*(PRESS/CRPRES)**0.17
      TEMPL = 4*((PRESS/CRPRES)**1.2)
      TEMPM = 10*((PRESS/CRPRES)**10)
C     COMPUTATION OF BOILING COEFFICIENT
      BOILCF = TEMPJ*TEMPK*(TEMPW+TEMPL+TEMPM)
      WRITE(*,40)'BOILING COEFFICIENT',BOILCF,'W/SQ.m c'
      WRITE(2,40)'BOILING COEFFICIENT',BOILCF,'W/SQ.m c'
   40 FORMAT(//,10X,A,T48,F10.4,1X,A)
      PRINT*,'ENTER THE VALUES OF TKF,CAO,HOUROP'
      READ(*,*)TKF,CAO,HOUROP
C     DETERMINATION OF STEAM COST
      IF(STEAMP.GT.0 .AND. STEAMP .LT. 6.90)THEN
            CU = 0.0066
      ELSEIF(STEAMP.GE.6.90 .AND. STEAMP .LT. 34.48)THEN
            CU = 0.0088
      ELSEIF(STEAMP.GE.34.48)THEN
            CU = 0.011
      ELSE
            PRINT*,'INVALID ENTRY',STEAMP,'TRY AGAIN'
      ENDIF
C     COMPUTATION OF TOTAL ANNUAL VARIABLE COST
      TVCOST=((HTAREA*TKF*CAO)+((3600*DUTY*HOUROP*CU)/(SHTCST*TMEMTD)))
      WRITE(*,42)'TOTAL ANNUAL VARIABLE COST'
      WRITE(2,42)'TOTAL ANNUAL VARIABLE COST'
   42 FORMAT(//,10X,A)
      WRITE(2,44)'FOR VAPORISER AND ITS OPERATION',TVCOST,'$/YEAR'
      WRITE(*,44)'FOR VAPORISER AND ITS OPERATION',TVCOST,'$/YEAR'
   44 FORMAT(/,10X,A,T45,F13.4,1X,A)
      RETURN
      END

      SUBROUTINE  MCLORD(BPOINT,SPHEAT,HLATEN,CRPRES,TMFEED,OHEATC,
     $STEAMP,STEAMT,SHTMAX,TMASFR,THLOAD,DUTY,TMEMTD,HTAREA,HFLUX,
     $PRESS,TEMPJ,TEMPK,TEMPW,TEMPL,TEMPM,BOILCF,TVCOST,TKF,CAO,CU,
     $HOUROP,SHTCST)
      WRITE(*,18)'PHYSICAL PROPERTIES OF METHYLENE CHLORIDE'
      WRITE(2,18)'PHYSICAL PROPERTIES OF METHYLENE CHLORIDE'
   18 FORMAT(//,15X,A)
      PRINT*
C  INITIALIZATION OF VARIABLES
      SHTCST = 4.18
      BPOINT=40
      SPHEAT=1.214
      HLATEN=330.757
      CRPRES=99.44
      WRITE(*,20)'BOILING POINT',BPOINT,'C'
      WRITE(2,20)'BOILING POINT',BPOINT,'C'
   20 FORMAT(//,10X,A,T48,F10.4,1X,A)
      WRITE(*,22)'SPECIFIC HEAT',SPHEAT,'KJ/KgC'
      WRITE(2,22)'SPECIFIC HEAT',SPHEAT,'KJ/KgC'
   22 FORMAT(//,10X,A,T48,F10.4,1X,A)
      WRITE(*,24)'CRITICAL PRESSURE',CRPRES,'Bar'
      WRITE(2,24)'CRITICAL PRESSURE',CRPRES,'Bar'
   24 FORMAT(//,10X,A,T48,F10.4,1X,A)
```

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```
      WRITE(*,26)'LATENT HEAT',HLATEN,'KJ/Kg'
      WRITE(2,26)'LATENT HEAT',HLATEN,'KJ/Kg'
   26 FORMAT(//,10X,A,T48,F10.4,1X,A)
      PRINT*,'INPUT MINIMUM TEMPERATURE OF THE FEED ','C'
      READ(*,*)TMFEED
C  COMPUTATION OF SENSITIVE HEAT MAXIMUM
      SHTMAX = (BPOINT-TMFEED)*SPHEAT
      WRITE(*,28)'SENSITIVE HEAT MAXIMUM',SHTMAX,'KJ/Kg'
      WRITE(2,28)'SENSITIVE HEAT MAXIMUM',SHTMAX,'KJ/Kg'
   28 FORMAT(//,10X,A,T48,F10.4,1X,A)
      PRINT*,'INPUT MASS FLOW RATE ','Kg/hr'
      READ(*,*)TMASFR
C    COMPUTATION OF THE TOTAL HEAT LOAD
      THLOAD = (SHTMAX + HLATEN)*(TMASFR/3600)
      WRITE(*,30)'TOTAL HEAT LOAD',THLOAD,'KW'
      WRITE(2,30)'TOTAL HEAT LOAD',THLOAD,'KW'
   30 FORMAT(//,10X,A,T48,F10.4,1X,A)
C    COMPUTATION OF DUTY
      DUTY = 1.05*THLOAD
      WRITE(*,31)'DUTY',DUTY,'KW'
      WRITE(2,31)'DUTY',DUTY,'KW'
   31 FORMAT(//,10X,A,T48,F10.4,1X,A)
      PRINT*,'INPUT OVERALL COEFFICIENT(BETWEEN 1000 - 1500)','W/SQ.MC'
      READ(*,*)OHEATC
C     VALIDATION OF OVERALL HEAT COEFFICIENT
      IF(OHEATC .LT.1000 .AND. OHEATC .GT.1500) THEN
         PRINT*,'INVALID ENTRY',OHEATC,'PROGRAM WILL BE TERMINATED'
      ELSE
         PRINT*,'INPUT STEAM PRESSURE', 'Bar'
         READ(*,*)STEAMP
      ENDIF
      CALL STEAM(STEAMP,STEAMT)
      WRITE(*,32)'STEAM TEMPERATURE',STEAMT,'C'
      WRITE(2,32)'STEAM TEMPERATURE',STEAMT,'C'
   32 FORMAT(//,10X,A,T48,F10.4,1X,A)
C     COMPUTATION OF MEAN TEMPERATURE DIFFERENCE
      TMEMTD = STEAMT - BPOINT
      WRITE(*,34)'MEAND TEMPERATURE DIFFERENCE',TMEMTD,'C'
      WRITE(2,34)'MEAND TEMPERATURE DIFFERENCE',TMEMTD,'C'
   34 FORMAT(//,10X,A,T48,F10.4,1X,A)
C     COMPUTATION OF HEAT TRANSFER AREA
      HTAREA = (DUTY*(10**3))/(OHEATC*TMEMTD)
      WRITE(*,36)'HEAT TRANSFER AREA',HTAREA,'SQ.m'
      WRITE(2,36)'HEAT TRANSFER AREA',HTAREA,'SQ.m'
   36 FORMAT(//,10X,A,T48,F10.4,1X,A)
C     COMPUTATION OF HEAT FLUX
      HFLUX = DUTY/HTAREA
      WRITE(*,38)'HEAT FLUX',HFLUX,'KW/SQ.m'
      WRITE(2,38)'HEAT FLUX',HFLUX,'KW/SQ.m'
   38 FORMAT(//,10X,A,T48,F10.4,1X,A)
      PRINT*,'INPUT OPERATING PRESSURE ', 'Bar'
      READ(*,*)PRESS
C     COMPUTATION OF TEMPORAL VALUES USED FOR
C     THE COMPUTAION OF THE BOILING COEFFICIENT
      TEMPJ = .104*CRPRES**.69
```

APPENDIX B

```
      TEMPK = (HFLUX*10**3)**0.7
      TEMPW = 1.8*(PRESS/CRPRES)**0.17
      TEMPL = 4*((PRESS/CRPRES)**1.2)
      TEMPM = 10*((PRESS/CRPRES)**10)
C     COMPUTATION OF BOILING COEFFICIENT
      BOILCF = TEMPJ*TEMPK*(TEMPW+TEMPL+TEMPM)
      WRITE(*,40)'BOILING COEFFICIENT',BOILCF,'W/SQ.m c'
      WRITE(2,40)'BOILING COEFFICIENT',BOILCF,'W/SQ.m c'
   40 FORMAT(//,10X,A,T48,F10.4,1X,A)
      PRINT*,'ENTER THE VALUES OF TKF,CAO,HOUROP'
      READ(*,*)TKF,CAO,HOUROP
C     DETERMINATION OF STEAM COST
      IF(STEAMP.GT.0 .AND. STEAMP .LT. 6.90)THEN
            CU = 0.0066
      ELSEIF(STEAMP.GE.6.90 .AND. STEAMP .LT. 34.48)THEN
            CU = 0.0088
      ELSEIF(STEAMP.GE.34.48)THEN
            CU = 0.011
      ELSE
            PRINT*,'INVALID ENTRY',STEAMP,'TRY AGAIN'
      ENDIF
C     COMPUTATION OF TOTAL ANNUAL VARIABLE COST
      TVCOST=((HTAREA*TKF*CAO)+((3600*DUTY*HOUROP*CU)/(SHTCST*TMEMTD)))
      WRITE(*,42)'TOTAL ANNUAL VARIABLE COST'
      WRITE(2,42)'TOTAL ANNUAL VARIABLE COST'
   42 FORMAT(//,10X,A)
      WRITE(2,44)'FOR VAPORISER AND ITS OPERATION',TVCOST,'$/YEAR'
      WRITE(*,44)'FOR VAPORISER AND ITS OPERATION',TVCOST,'$/YEAR'
   44 FORMAT(/,10X,A,T45,F13.4,1X,A)
      RETURN
      END

      SUBROUTINE  NHEPTN(BPOINT,SPHEAT,HLATEN,CRPRES,TMFEED,OHEATC,
     $STEAMP,STEAMT,SHTMAX,TMASFR,THLOAD,DUTY,TMEMTD,HTAREA,HFLUX,
     $PRESS,TEMPJ,TEMPK,TEMPW,TEMPL,TEMPM,BOILCF,TVCOST,TKF,CAO,CU,
     $HOUROP,SHTCST)
      WRITE(*,18)'PHYSICAL PROPERTIES OF n-HEPTANE'
      WRITE(2,18)'PHYSICAL PROPERTIES OF n-HEPTANE'
   18 FORMAT(//,15X,A)
      PRINT*
C  INITIALIZATION OF VARIABLES
      SHTCST = 4.18
      BPOINT=98.4
      SPHEAT=2.219
      HLATEN=318.197
      CRPRES=26.38
      WRITE(*,20)'BOILING POINT',BPOINT,'C'
      WRITE(2,20)'BOILING POINT',BPOINT,'C'
   20 FORMAT(//,10X,A,T48,F10.4,1X,A)
      WRITE(*,22)'SPECIFIC HEAT',SPHEAT,'KJ/KgC'
      WRITE(2,22)'SPECIFIC HEAT',SPHEAT,'KJ/KgC'
   22 FORMAT(//,10X,A,T48,F10.4,1X,A)
      WRITE(*,24)'CRITICAL PRESSURE',CRPRES,'Bar'
      WRITE(2,24)'CRITICAL PRESSURE',CRPRES,'Bar'
   24 FORMAT(//,10X,A,T48,F10.4,1X,A)
```

APPENDIX B

```
      WRITE(*,26)'LATENT HEAT',HLATEN,'KJ/Kg'
      WRITE(2,26)'LATENT HEAT',HLATEN,'KJ/Kg'
   26 FORMAT(//,10X,A,T48,F10.4,1X,A)
      PRINT*,'INPUT MINIMUM TEMPERATURE OF THE FEED ','C'
      READ(*,*)TMFEED
C   COMPUTATION OF SENSITIVE HEAT MAXIMUM
      SHTMAX = (BPOINT-TMFEED)*SPHEAT
      WRITE(*,28)'SENSITIVE HEAT MAXIMUM',SHTMAX,'KJ/Kg'
      WRITE(2,28)'SENSITIVE HEAT MAXIMUM',SHTMAX,'KJ/Kg'
   28 FORMAT(//,10X,A,T48,F10.4,1X,A)
      PRINT*,'INPUT MASS FLOW RATE ','Kg/hr'
      READ(*,*)TMASFR
C     COMPUTATION OF THE TOTAL HEAT LOAD
      THLOAD = (SHTMAX + HLATEN)*(TMASFR/3600)
      WRITE(*,30)'TOTAL HEAT LOAD',THLOAD,'KW'
      WRITE(2,30)'TOTAL HEAT LOAD',THLOAD,'KW'
   30 FORMAT(//,10X,A,T48,F10.4,1X,A)
C     COMPUTATION OF DUTY
      DUTY = 1.05*THLOAD
      WRITE(*,31)'DUTY',DUTY,'KW'
      WRITE(2,31)'DUTY',DUTY,'KW'
   31 FORMAT(//,10X,A,T48,F10.4,1X,A)
      PRINT*,'INPUT OVERALL COEFFICIENT(BETWEEN 600 - 900)','W/SQ.MC'
      READ(*,*)OHEATC
C       VALIDATION OF OVERALL HEAT COEFFICIENT
      IF(OHEATC .LT.900 .AND. OHEATC .GT.1200) THEN
         PRINT*,'INVALID ENTRY',OHEATC,'PROGRAM WILL BE TERMINATED'
      ELSE
         PRINT*,'INPUT STEAM PRESSURE ','Bar'
         READ(*,*)STEAMP
      ENDIF
      CALL STEAM(STEAMP,STEAMT)
      WRITE(*,32)'STEAM TEMPERATURE',STEAMT,'C'
      WRITE(2,32)'STEAM TEMPERATURE',STEAMT,'C'
   32 FORMAT(//,10X,A,T48,F10.4,1X,A)
C     COMPUTATION OF MEAN TEMPERATURE DIFFERENCE
      TMEMTD = STEAMT - BPOINT
      WRITE(*,34)'MEAND TEMPERATURE DIFFERENCE',TMEMTD,'C'
      WRITE(2,34)'MEAND TEMPERATURE DIFFERENCE',TMEMTD,'C'
   34 FORMAT(//,10X,A,T48,F10.4,1X,A)
C     COMPUTATION OF HEAT TRANSFER AREA
      HTAREA = (DUTY*(10**3))/(OHEATC*TMEMTD)
      WRITE(*,36)'HEAT TRANSFER AREA',HTAREA,'SQ.m'
      WRITE(2,36)'HEAT TRANSFER AREA',HTAREA,'SQ.m'
   36 FORMAT(//,10X,A,T48,F10.4,1X,A)
C     COMPUTATION OF HEAT FLUX
      HFLUX = DUTY/HTAREA
      WRITE(*,38)'HEAT FLUX',HFLUX,'KW/SQ.m'
      WRITE(2,38)'HEAT FLUX',HFLUX,'KW/SQ.m'
   38 FORMAT(//,10X,A,T48,F10.4,1X,A)
      PRINT*,'INPUT OPERATING PRESSURE ','Bar'
      READ(*,*)PRESS
C     COMPUTATION OF TEMPORAL VALUES USED FOR
C     THE COMPUTAION OF THE BOILING COEFFICIENT
      TEMPJ = .104*CRPRES**.69
```

APPENDIX B

```
      TEMPK = (HFLUX*10**3)**0.7
      TEMPW = 1.8*(PRESS/CRPRES)**0.17
      TEMPL = 4*((PRESS/CRPRES)**1.2)
      TEMPM = 10*((PRESS/CRPRES)**10)
C     COMPUTATION OF BOILING COEFFICIENT
      BOILCF = TEMPJ*TEMPK*(TEMPW+TEMPL+TEMPM)
      WRITE(*,40)'BOILING COEFFICIENT',BOILCF,'W/SQ.m c'
      WRITE(2,40)'BOILING COEFFICIENT',BOILCF,'W/SQ.m c'
   40 FORMAT(//,10X,A,T48,F10.4,1X,A)
      PRINT*,'ENTER THE VALUES OF TKF,CAO,HOUROP'
      READ(*,*)TKF,CAO,HOUROP
C     DETERMINATION OF STEAM COST
      IF(STEAMP.GT.0 .AND. STEAMP .LT. 6.90)THEN
             CU = 0.0066
      ELSEIF(STEAMP.GE.6.90 .AND. STEAMP .LT. 34.48)THEN
             CU = 0.0088
      ELSEIF(STEAMP.GE.34.48)THEN
             CU = 0.011
      ELSE
             PRINT*,'INVALID ENTRY',STEAMP,'TRY AGAIN'
      ENDIF
C     COMPUTATION OF TOTAL ANNUAL VARIABLE COST
      TVCOST=((HTAREA*TKF*CAO)+((3600*DUTY*HOUROP*CU)/(SHTCST*TMEMTD)))
      WRITE(*,42)' TOTAL ANNUAL VARIABLE COST FOR '
      WRITE(2,42)' TOTAL ANNUAL VARIABLE COST FOR '
   42 FORMAT(//,10X,A)
      WRITE(2,44)'VAPORISER AND ITS OPERATION',TVCOST,'$/YEAR'
      WRITE(*,44)'VAPORISER AND ITS OPERATION',TVCOST,'$/YEAR'
   44 FORMAT(//,10X,A,T48,F15.4,1X,A)
      RETURN
      END

      SUBROUTINE  NHEXAN(BPOINT,SPHEAT,HLATEN,CRPRES,TMFEED,OHEATC,
     $STEAMP,STEAMT,SHTMAX,TMASFR,THLOAD,DUTY,TMEMTD,HTAREA,HFLUX,
     $PRESS,TEMPJ,TEMPK,TEMPW,TEMPL,TEMPM,BOILCF,TVCOST,TKF,CAO,CU,
     $HOUROP,SHTCST)
      WRITE(*,18)'PHYSICAL PROPERTIES OF n-HEXANE'
      WRITE(2,18)'PHYSICAL PROPERTIES OF n-HEXANE'
   18 FORMAT(//,15X,A)
      PRINT*
C  INITIALIZATION OF VARIABLES
      SHTCST = 4.18
      BPOINT=68.78
      SPHEAT=1.884
      HLATEN=330.757
      CRPRES=29.22
      WRITE(*,20)'BOILING POINT',BPOINT,'C'
      WRITE(2,20)'BOILING POINT',BPOINT,'C'
   20 FORMAT(//,10X,A,T48,F10.4,1X,A)
      WRITE(*,22)'SPECIFIC HEAT',SPHEAT,'KJ/KgC'
      WRITE(2,22)'SPECIFIC HEAT',SPHEAT,'KJ/KgC'
   22 FORMAT(//,10X,A,T48,F10.4,1X,A)
      WRITE(2,24)'CRITICAL PRESSURE',CRPRES,'Bar'
   24 FORMAT(//,10X,A,T48,F10.4,1X,A)
      WRITE(*,26)'LATENT HEAT',HLATEN,'KJ/Kg'
```

APPENDIX B

```
      WRITE(2,26)'LATENT HEAT',HLATEN,'KJ/Kg'
   26 FORMAT(//,10X,A,T48,F10.4,1X,A)
      PRINT*,'INPUT MINIMUM TEMPERATURE OF THE FEED ','C'
      READ(*,*)TMFEED
C   COMPUTATION OF SENSITIVE HEAT MAXIMUM
      SHTMAX = (BPOINT-TMFEED)*SPHEAT
      WRITE(*,28)'SENSITIVE HEAT MAXIMUM',SHTMAX,'KJ/Kg'
      WRITE(2,28)'SENSITIVE HEAT MAXIMUM',SHTMAX,'KJ/Kg'
   28 FORMAT(//,10X,A,T48,F10.4,1X,A)
      PRINT*,'INPUT MASS FLOW RATE ','Kg/hr'
      READ(*,*)TMASFR
C     COMPUTATION OF THE TOTAL HEAT LOAD
      THLOAD = (SHTMAX + HLATEN)*(TMASFR/3600)
      WRITE(2,30)'TOTAL HEAT LOAD',THLOAD,'KW'
   30 FORMAT(//,10X,A,T48,F10.4,1X,A)
C     COMPUTATION OF DUTY
      DUTY = 1.05*THLOAD
      WRITE(*,31)'DUTY',DUTY,'KW'
      WRITE(2,31)'DUTY',DUTY,'KW'
   31 FORMAT(//,10X,A,T48,F10.4,1X,A)
      PRINT*,'INPUT OVERALL COEFFICIENT(BETWEEN 600 - 900)','W/SQ.MC'
      READ(*,*)OHEATC
C       VALIDATION OF OVERALL HEAT COEFFICIENT
      IF(OHEATC .LT.900 .AND. OHEATC .GT.1200) THEN
         PRINT*,'INVALID ENTRY',OHEATC,'PROGRAM WILL BE TERMINATED'
      ELSE
         PRINT*,'INPUT STEAM PRESSURE ','Bar'
         READ(*,*)STEAMP
      ENDIF
      CALL STEAM(STEAMP,STEAMT)
      WRITE(*,32)'STEAM TEMPERATURE',STEAMT,'C'
      WRITE(2,32)'STEAM TEMPERATURE',STEAMT,'C'
   32 FORMAT(//,10X,A,T48,F10.4,1X,A)
C     COMPUTATION OF MEAN TEMPERATURE DIFFERENCE
      TMEMTD = STEAMT - BPOINT
      WRITE(*,34)'MEAND TEMPERATURE DIFFERENCE',TMEMTD,'C'
      WRITE(2,34)'MEAND TEMPERATURE DIFFERENCE',TMEMTD,'C'
   34 FORMAT(//,10X,A,T48,F10.4,1X,A)
C     COMPUTATION OF HEAT TRANSFER AREA
      HTAREA = (DUTY*(10**3))/(OHEATC*TMEMTD)
      WRITE(*,36)'HEAT TRANSFER AREA',HTAREA,'SQ.m'
      WRITE(2,36)'HEAT TRANSFER AREA',HTAREA,'SQ.m'
   36 FORMAT(//,10X,A,T48,F10.4,1X,A)
C     COMPUTATION OF HEAT FLUX
      HFLUX = DUTY/HTAREA
      WRITE(*,38)'HEAT FLUX',HFLUX,'KW/SQ.m'
      WRITE(2,38)'HEAT FLUX',HFLUX,'KW/SQ.m'
   38 FORMAT(//,10X,A,T48,F10.4,1X,A)
      PRINT*,'INPUT OPERATING PRESSURE ','Bar'
      READ(*,*)PRESS
C     COMPUTATION OF TEMPORAL VALUES USED FOR
C     THE COMPUTAION OF THE BOILING COEFFICIENT
      TEMPJ = .104*CRPRES**.69
      TEMPK = (HFLUX*10**3)**0.7
      TEMPW = 1.8*(PRESS/CRPRES)**0.17
```

```
      TEMPL = 4*((PRESS/CRPRES)**1.2)
      TEMPM = 10*((PRESS/CRPRES)**10)
C     COMPUTATION OF BOILING COEFFICIENT
      BOILCF = TEMPJ*TEMPK*(TEMPW+TEMPL+TEMPM)
      WRITE(*,40)'BOILING COEFFICIENT',BOILCF,'W/SQ.m c'
      WRITE(2,40)'BOILING COEFFICIENT',BOILCF,'W/SQ.m c'
   40 FORMAT(//,10X,A,T48,F10.4;1X,A)
      PRINT*,'ENTER THE VALUES OF TKF,CAO,HOUROP'
      READ(*,*)TKF,CAO,HOUROP
C     DETERMINATION OF STEAM COST
      IF(STEAMP.GT.0 .AND. STEAMP .LT. 6.90)THEN
             CU = 0.0066
      ELSEIF(STEAMP.GE.6.90 .AND. STEAMP .LT. 34.48)THEN
             CU = 0.0088
      ELSEIF(STEAMP.GE.34.48)THEN
             CU = 0.011
      ELSE
             PRINT*,'INVALID ENTRY',STEAMP,'TRY AGAIN'
      ENDIF
C     COMPUTATION OF TOTAL ANNUAL VARIABLE COST
      TVCOST=((HTAREA*TKF*CAO)+((3600*DUTY*HOUROP*CU)/(SHTCST*TMEMTD)))
      WRITE(*,42)'TOTAL ANNUAL VARIABLE COST'
      WRITE(2,42)'TOTAL ANNUAL VARIABLE COST'
   42 FORMAT(//,10X,A)
      WRITE(2,44)'FOR VAPORISER AND ITS OPERATION',TVCOST,'$/YEAR'
      WRITE(*,44)'FOR VAPORISER AND ITS OPERATION',TVCOST,'$/YEAR'
   44 FORMAT(//,10X,A,T48,F15.4,1X,A)
      RETURN
      END

      SUBROUTINE  NOCTAN(BPOINT,SPHEAT,HLATEN,CRPRES,TMFEED,OHEATC,
     $STEAMP,STEAMT,SHTMAX,TMASFR,THLOAD,DUTY,TMEMTD,HTAREA,HFLUX,
     $PRESS,TEMPJ,TEMPK,TEMPW,TEMPL,TEMPM,BOILCF,TVCOST,TKF,CAO,CU,
     $HOUROP,SHTCST)
      WRITE(*,18)'PHYSICAL PROPERTIES OF n-OCTANE'
      WRITE(2,18)'PHYSICAL PROPERTIES OF n-OCTANE'
   18 FORMAT(//,15X,A)
      PRINT*
C  INITIALIZATION OF VARIABLES
      SHTCST = 4.18
      BPOINT=125.7
      SPHEAT=1.507
      HLATEN=297.263
      CRPRES=24.22
      WRITE(*,20)'BOILING POINT',BPOINT,'C'
      WRITE(2,20)'BOILING POINT',BPOINT,'C'
   20 FORMAT(//,10X,A,T48,F10.4,1X,A)
      WRITE(*,22)'SPECIFIC HEAT',SPHEAT,'KJ/KgC'
      WRITE(2,22)'SPECIFIC HEAT',SPHEAT,'KJ/KgC'
   22 FORMAT(//,10X,A,T48,F10.4,1X,A)
      WRITE(*,24)'CRITICAL PRESSURE',CRPRES,'Bar'
      WRITE(2,24)'CRITICAL PRESSURE',CRPRES,'Bar'
   24 FORMAT(//,10X,A,T48,F10.4,1X,A)
      WRITE(*,26)'LATENT HEAT',HLATEN,'KJ/Kg'
      WRITE(2,26)'LATENT HEAT',HLATEN,'KJ/Kg'
```

APPENDIX B

```
   26 FORMAT(//,10X,A,T48,F10.4,1X,A)
      PRINT*,'INPUT MINIMUM TEMPERATURE OF THE FEED ','C'
      READ(*,*)TMFEED
C  COMPUTATION OF SENSITIVE HEAT MAXIMUM
      SHTMAX = (BPOINT-TMFEED)*SPHEAT
      WRITE(*,26)'LATENT HEAT',HLATEN,'KJ/Kg'
      WRITE(2,26)'LATENT HEAT',HLATEN,'KJ/Kg'
   28 FORMAT(//,10X,A,T48,F10.4,1X,A)
      PRINT*,'INPUT MASS FLOW RATE ','Kg/hr'
      READ(*,*)TMASFR
C    COMPUTATION OF THE TOTAL HEAT LOAD
      THLOAD = (SHTMAX + HLATEN)*(TMASFR/3600)
      WRITE(*,30)'TOTAL HEAT LOAD',THLOAD,'KW'
      WRITE(2,30)'TOTAL HEAT LOAD',THLOAD,'KW'
   30 FORMAT(//,10X,A,T48,F10.4,1X,A)
C    COMPUTATION OF DUTY
      DUTY = 1.05*THLOAD
      WRITE(*,31)'DUTY',DUTY,'KW'
      WRITE(2,31)'DUTY',DUTY,'KW'
   31 FORMAT(//,10X,A,T48,F10.4,1X,A)
      PRINT*,'INPUT OVERALL COEFFICIENT(BETWEEN 600 - 900)','W/SQ.MC'
      READ(*,*)OHEATC
C      VALIDATION OF OVERALL HEAT COEFFICIENT
      IF(OHEATC .LT.900 .AND. OHEATC .GT.1200) THEN
         PRINT*,'INVALID ENTRY',OHEATC,'PROGRAM WILL BE TERMINATED'
      ELSE
         PRINT*,'INPUT STEAM PRESSURE ','Bar'
         READ(*,*)STEAMP
      ENDIF
      CALL STEAM(STEAMP,STEAMT)
      WRITE(*,32)'STEAM TEMPERATURE',STEAMT,'C'
      WRITE(2,32)'STEAM TEMPERATURE',STEAMT,'C'
   32 FORMAT(//,10X,A,T48,F10.4,1X,A)
C     COMPUTATION OF MEAN TEMPERATURE DIFFERENCE
      TMEMTD = STEAMT - BPOINT
      WRITE(*,34)'MEAND TEMPERATURE DIFFERENCE',TMEMTD,'C'
      WRITE(2,34)'MEAND TEMPERATURE DIFFERENCE',TMEMTD,'C'
   34 FORMAT(//,10X,A,T48,F10.4,1X,A)
C     COMPUTATION OF HEAT TRANSFER AREA
      HTAREA = (DUTY*(10**3))/(OHEATC*TMEMTD)
      WRITE(*,36)'HEAT TRANSFER AREA',HTAREA,'SQ.m'
      WRITE(2,36)'HEAT TRANSFER AREA',HTAREA,'SQ.m'
   36 FORMAT(//,10X,A,T48,F10.4,1X,A)
C     COMPUTATION OF HEAT FLUX
      HFLUX = DUTY/HTAREA
      WRITE(*,38)'HEAT FLUX',HFLUX,'KW/SQ.m'
      WRITE(2,38)'HEAT FLUX',HFLUX,'KW/SQ.m'
   38 FORMAT(//,10X,A,T48,F10.4,1X,A)
      PRINT*,'INPUT OPERATING PRESSURE ','Bar'
      READ(*,*)PRESS
C     COMPUTATION OF TEMPORAL VALUES USED FOR
C     THE COMPUTAION OF THE BOILING COEFFICIENT
      TEMPJ = .104*CRPRES**.69
      TEMPK = (HFLUX*10**3)**0.7
      TEMPW = 1.8*(PRESS/CRPRES)**0.17
```

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```
      TEMPL = 4*((PRESS/CRPRES)**1.2)
      TEMPM = 10*((PRESS/CRPRES)**10)
C     COMPUTATION OF BOILING COEFFICIENT
      BOILCF = TEMPJ*TEMPK*(TEMPW+TEMPL+TEMPM)
      WRITE(*,40)'BOILING COEFFICIENT',BOILCF,'W/SQ.m c'
      WRITE(2,40)'BOILING COEFFICIENT',BOILCF,'W/SQ.m c'
   40 FORMAT(//,10X,A,T48,F10.4,1X,A)
      PRINT*,'ENTER THE VALUES OF TKF,CAO,HOUROP'
      READ(*,*)TKF,CAO,HOUROP
C     DETERMINATION OF STEAM COST
      IF(STEAMP.GT.0 .AND. STEAMP .LT. 6.90)THEN
              CU = 0.0066
      ELSEIF(STEAMP.GE.6.90 .AND. STEAMP .LT. 34.48)THEN
              CU = 0.0088
      ELSEIF(STEAMP.GE.34.48)THEN
              CU = 0.011
      ELSE
              PRINT*,'INVALID ENTRY',STEAMP,'TRY AGAIN'
      ENDIF
C     COMPUTATION OF TOTAL ANNUAL VARIABLE COST
      TVCOST=((HTAREA*TKF*CAO)+((3600*DUTY*HOUROP*CU)/(SHTCST*TMEMTD)))
      WRITE(*,42)'TOTAL ANNUAL VARIABLE COST'
      WRITE(2,42)'TOTAL ANNUAL VARIABLE COST'
   42 FORMAT(//,10X,A)
      WRITE(2,44)'FOR VAPORISER AND ITS OPERATION',TVCOST,'$/YEAR'
      WRITE(*,44)'FOR VAPORISER AND ITS OPERATION',TVCOST,'$/YEAR'
   44 FORMAT(//,10X,A,T48,F15.4,1X,A)
      RETURN
      END

      SUBROUTINE  NPTANE(BPOINT,SPHEAT,HLATEN,CRPRES,TMFEED,OHEATC,
     $STEAMP,STEAMT,SHTMAX,TMASFR,THLOAD,DUTY,TMEMTD,HTAREA,HFLUX,
     $PRESS,TEMPJ,TEMPK,TEMPW,TEMPL,TEMPM,BOILCF,TVCOST,TKF,CAO,CU,
     $HOUROP,SHTCST)
      WRITE(*,18)'PHYSICAL PROPERTIES OF n-PENTANE'
      WRITE(2,18)'PHYSICAL PROPERTIES OF n-PENTANE'
   18 FORMAT(//,15X,A)
      PRINT*
C  INITIALIZATION OF VARIABLES
      SHTCST = 4.18
      BPOINT=36.1
      SPHEAT=2.177
      HLATEN=355.878
      CRPRES=32.36
      WRITE(*,20)'BOILING POINT',BPOINT,'C'
      WRITE(2,20)'BOILING POINT',BPOINT,'C'
   20 FORMAT(//,10X,A,T48,F10.4,1X,A)
      WRITE(*,22)'SPECIFIC HEAT',SPHEAT,'KJ/KgC'
      WRITE(2,22)'SPECIFIC HEAT',SPHEAT,'KJ/KgC'
   22 FORMAT(//,10X,A,T48,F10.4,1X,A)
      WRITE(*,24)'CRITICAL PRESSURE',CRPRES,'Bar'
      WRITE(2,24)'CRITICAL PRESSURE',CRPRES,'Bar'
   24 FORMAT(//,10X,A,T48,F10.4,1X,A)
      WRITE(*,26)'LATENT HEAT',HLATEN,'KJ/Kg'
      WRITE(2,26)'LATENT HEAT',HLATEN,'KJ/Kg'
```

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```
   26 FORMAT(//,10X,A,T48,F10.4,1X,A)
      PRINT*,'INPUT MINIMUM TEMPERATURE OF THE FEED ','C'
      READ(*,*)TMFEED
C  COMPUTATION OF SENSITIVE HEAT MAXIMUM
      SHTMAX = (BPOINT-TMFEED)*SPHEAT
      WRITE(*,28)'SENSITIVE HEAT MAXIMUM',SHTMAX,'KJ/Kg'
      WRITE(2,28)'SENSITIVE HEAT MAXIMUM',SHTMAX,'KJ/Kg'
   28 FORMAT(//,10X,A,T48,F10.4;1X,A)
      PRINT*,'INPUT MASS FLOW RATE ','Kg/hr'
      READ(*,*)TMASFR
C    COMPUTATION OF THE TOTAL HEAT LOAD
      THLOAD = (SHTMAX + HLATEN)*(TMASFR/3600)
      WRITE(*,30)'TOTAL HEAT LOAD',THLOAD,'KW'
      WRITE(2,30)'TOTAL HEAT LOAD',THLOAD,'KW'
   30 FORMAT(//,10X,A,T48,F10.4,1X,A)
C    COMPUTATION OF DUTY
      DUTY = 1.05*THLOAD
      WRITE(*,31)'DUTY',DUTY,'KW'
      WRITE(2,31)'DUTY',DUTY,'KW'
   31 FORMAT(//,10X,A,T48,F10.4,1X,A)
      PRINT*,'INPUT OVERALL COEFFICIENT(BETWEEN 1000 - 1500)','W/SQ.MC'
      READ(*,*)OHEATC
C   VALIDATION OF OVERALL HEAT COEFFICIENT
      IF(OHEATC .LT.1000 .AND. OHEATC .GT.1500) THEN
         PRINT*,'INVALID ENTRY',OHEATC,'PROGRAM WILL BE TERMINATED'
      ELSE
         PRINT*,'INPUT STEAM PRESSURE ','Bar'
         READ(*,*)STEAMP
      ENDIF
      CALL STEAM(STEAMP,STEAMT)
      WRITE(*,32)'STEAM TEMPERATURE',STEAMT,'C'
      WRITE(2,32)'STEAM TEMPERATURE',STEAMT,'C'
   32 FORMAT(//,10X,A,T48,F10.4,1X,A)
C     COMPUTATION OF MEAN TEMPERATURE DIFFERENCE
      TMEMTD = STEAMT - BPOINT
      WRITE(*,34)'MEAND TEMPERATURE DIFFERENCE',TMEMTD,'C'
      WRITE(2,34)'MEAND TEMPERATURE DIFFERENCE',TMEMTD,'C'
   34 FORMAT(//,10X,A,T48,F10.4,1X,A)
C     COMPUTATION OF HEAT TRANSFER AREA
      HTAREA = (DUTY*(10**3))/(OHEATC*TMEMTD)
      WRITE(*,36)'HEAT TRANSFER AREA',HTAREA,'SQ.m'
      WRITE(2,36)'HEAT TRANSFER AREA',HTAREA,'SQ.m'
   36 FORMAT(//,10X,A,T48,F10.4,1X,A)
C     COMPUTATION OF HEAT FLUX
      HFLUX = DUTY/HTAREA
      WRITE(*,38)'HEAT FLUX',HFLUX,'KW/SQ.m'
      WRITE(2,38)'HEAT FLUX',HFLUX,'KW/SQ.m'
   38 FORMAT(//,10X,A,T48,F10.4,1X,A)
      PRINT*,'INPUT OPERATING PRESSURE ','Bar'
      READ(*,*)PRESS
C     COMPUTATION OF TEMPORAL VALUES USED FOR
C     THE COMPUTAION OF THE BOILING COEFFICIENT
      TEMPJ = .104*CRPRES**.69
      TEMPK = (HFLUX*10**3)**0.7
      TEMPW = 1.8*(PRESS/CRPRES)**0.17
```

APPENDIX B

```
      TEMPL = 4*((PRESS/CRPRES)**1.2)
      TEMPM = 10*((PRESS/CRPRES)**10)
C     COMPUTATION OF BOILING COEFFICIENT
      BOILCF = TEMPJ*TEMPK*(TEMPW+TEMPL+TEMPM)
      WRITE(*,40)'BOILING COEFFICIENT',BOILCF,'W/SQ.m c'
      WRITE(2,40)'BOILING COEFFICIENT',BOILCF,'W/SQ.m c'
   40 FORMAT(//,10X,A,T48,F10.4,1X,A)
      PRINT*,'ENTER THE VALUES OF TKF,CAO,HOUROP'
      READ(*,*)TKF,CAO,HOUROP
C     DETERMINATION OF STEAM COST
      IF(STEAMP.GT.0 .AND. STEAMP .LT. 6.90)THEN
             CU = 0.0066
      ELSEIF(STEAMP.GE.6.90 .AND. STEAMP .LT. 34.48)THEN
             CU = 0.0088
      ELSEIF(STEAMP.GE.34.48)THEN
             CU = 0.011
      ELSE
             PRINT*,'INVALID ENTRY',STEAMP,'TRY AGAIN'
      ENDIF
C     COMPUTATION OF TOTAL ANNUAL VARIABLE COST
      TVCOST=((HTAREA*TKF*CAO)+((3600*DUTY*HOUROP*CU)/(SHTCST*TMEMTD)))
      WRITE(*,42)'TOTAL ANNUAL VARIABLE COST'
      WRITE(2,42)'TOTAL ANNUAL VARIABLE COST'
   42 FORMAT(//,10X,A)
      WRITE(2,44)'FOR VAPORISER AND ITS OPERATION',TVCOST,'$/YEAR'
      WRITE(*,44)'FOR VAPORISER AND ITS OPERATION',TVCOST,'$/YEAR'
   44 FORMAT(//,10X,A,T48,F15.4,1X,A)
      RETURN
      END
      SUBROUTINE  TCMTAN(BPOINT,SPHEAT,HLATEN,CRPRES,TMFEED,OHEATC,
     $STEAMP,STEAMT,SHTMAX,TMASFR,THLOAD,DUTY,TMEMTD,HTAREA,HFLUX,
     $PRESS,TEMPJ,TEMPK,TEMPW,TEMPL,TEMPM,BOILCF,TVCOST,TKF,CAO,CU,
     $HOUROP,SHTCST)
      WRITE(*,18)'PHYSICAL PROPERTIES OF TETRACHLOROMETHANE'
      WRITE(2,18)'PHYSICAL PROPERTIES OF TETRACHLOROMETHANE'
   18 FORMAT(//,15X,A)
      SHTCST = 4.18
      BPOINT=76.5
      SPHEAT=0.847
      HLATEN=300.19
      CRPRES=45.6
      WRITE(*,20)'BOILING POINT',BPOINT,'C'
      WRITE(2,20)'BOILING POINT',BPOINT,'C'
   20 FORMAT(//,10X,A,T54,F10.4,1X,A)
      WRITE(*,22)'SPECIFIC HEAT',SPHEAT,'KJ/KgC'
      WRITE(2,22)'SPECIFIC HEAT',SPHEAT,'KJ/KgC'
   22 FORMAT(//,10X,A,T54,F10.4,1X,A)
      WRITE(*,24)'CRITICAL PRESSURE',CRPRES,'Bar'
      WRITE(2,24)'CRITICAL PRESSURE',CRPRES,'Bar'
   24 FORMAT(//,10X,A,T54,F10.4,1X,A)
      WRITE(*,26)'LATENT HEAT',HLATEN,'KJ/Kg'
      WRITE(2,26)'LATENT HEAT',HLATEN,'KJ/Kg'
   26 FORMAT(//,10X,A,T54,F10.4,1X,A)
      PRINT*,'INPUT MINIMUM TEMPERATURE OF THE FEED ','C'
```

APPENDIX B

```
      READ(*,*)TMFEED
C   COMPUTATION OF SENSITIVE HEAT MAXIMUM
      SHTMAX = (BPOINT-TMFEED)*SPHEAT
      WRITE(*,28)'SENSITIVE HEAT MAXIMUM',SHTMAX,'KJ/Kg'
      WRITE(2,28)'SENSITIVE HEAT MAXIMUM',SHTMAX,'KJ/Kg'
   28 FORMAT(//,10X,A,T54,F10.4,1X,A)
      PRINT*,'INPUT MASS FLOW RATE ','Kg/hr'
      READ(*,*)TMASFR
C     COMPUTATION OF THE TOTAL HEAT LOAD
      THLOAD = (SHTMAX + HLATEN)*(TMASFR/3600)
      WRITE(*,30)'TOTAL HEAT LOAD',THLOAD,'KW'
      WRITE(2,30)'TOTAL HEAT LOAD',THLOAD,'KW'
   30 FORMAT(//,10X,A,T54,F10.4,1X,A)
C     COMPUTATION OF DUTY
      DUTY = 1.05*THLOAD
      WRITE(*,31)'DUTY',DUTY,'KW'
      WRITE(2,31)'DUTY',DUTY,'KW'
   31 FORMAT(//,10X,A,T54,F10.4,1X,A)
      PRINT*,'INPUT OVERALL COEFFICIENT(BETWEEN 1000 - 1500)', 'W/SQ.MC'
      READ(*,*)OHEATC
C     VALIDATION OF OVERALL HEAT COEFFICIENT
      IF(OHEATC .LT.1000 .AND. OHEATC .GT.1500) THEN
         PRINT*,'INVALID ENTRY',OHEATC,'PROGRAM WILL BE TERMINATED'
      ELSE
         PRINT*,'INPUT STEAM PRESSURE' ,'Bar'
         READ(*,*)STEAMP
      ENDIF
      CALL STEAM(STEAMP,STEAMT)
      WRITE(*,32)'STEAM TEMPERATURE',STEAMT,'C'
      WRITE(2,32)'STEAM TEMPERATURE',STEAMT,'C'
   32 FORMAT(//,10X,A,T54,F10.2,1X,A)
C     COMPUTATION OF MEAN TEMPERATURE DIFFERENCE
      TMEMTD = STEAMT - BPOINT
      WRITE(*,34)'MEAN TEMPERATURE DIFFERENCE',TMEMTD,'C'
      WRITE(2,34)'MEAN TEMPERATURE DIFFERENCE',TMEMTD,'C'
   34 FORMAT(//,10X,A,T54,F10.4,1X,A)
C     COMPUTATION OF HEAT TRANSFER AREA
      HTAREA = (DUTY*(10**3))/(OHEATC*TMEMTD)
      WRITE(*,36)'HEAT TRANSFER AREA',HTAREA,'SQ.m'
      WRITE(2,36)'HEAT TRANSFER AREA',HTAREA,'SQ.m'
   36 FORMAT(//,10X,A,T54,F10.4,1X,A)
C     COMPUTATION OF HEAT FLUX
      HFLUX = DUTY/HTAREA
      WRITE(*,38)'HEAT FLUX',HFLUX,'KW/SQ.m'
      WRITE(2,38)'HEAT FLUX',HFLUX,'KW/SQ.m'
   38 FORMAT(//,10X,A,T54,F10.4,1X,A)
      PRINT*,'INPUT OPERATING PRESSURE ' ,'Bar'
      READ(*,*)PRESS
C     COMPUTATION OF TEMPORAL VALUE USED FOR
C    THE COMPUTATION OF BOILING COEFFICIENT
      TEMPJ = .104*CRPRES**.69
      TEMPK = (HFLUX*10**3)**.7
      TEMPW = 1.8*(PRESS/CRPRES)**0.17
      TEMPL = 4*((PRESS/CRPRES)**1.2)
```

```
      TEMPM = 10*((PRESS/CRPRES)**10)
C     COMPUTATION OF BOILING COEFFICIENT
      BOILCF = TEMPJ*TEMPK*(TEMPW+TEMPL+TEMPM)
      WRITE(*,40)'BOILING COEFFICIENT',BOILCF,'W/SQ.m c'
      WRITE(2,40)'BOILING COEFFICIENT',BOILCF,'W/SQ.m c'
   40 FORMAT(//,10X,A,T54,F10.4,1X,A)
      PRINT*,'ENTER THE VALUES OF TKF,CAO,HOUROP'
      READ(*,*)TKF,CAO,HOUROP
C     DETERMINATION OF STEAM COST
      IF(STEAMP.GT.0 .OR. STEAMP .LT. 6.90)THEN
             CU = 0.0066
      ELSEIF(STEAMP.GE.6.90. AND. STEAMP .LT. 34.48)THEN
             CU = 0.0088
      ELSEIF(STEAMP.GE.34.48)THEN
             CU = 0.011
      ELSE
             PRINT*,'INVALID ENTRY',STEAMP,'TRY AGAIN'
      ENDIF
C     COMPUTATION OF TOTAL ANNUAL VARIABLE COST
      TVCOST=((HTAREA*TKF*CAO)+((3600*DUTY*HOUROP*CU)/(SHTCST*TMEMTD)))
      WRITE(*,42)'TOTAL ANNUAL VARIABLE COST'
      WRITE(2,42)'TOTAL ANNUAL VARIABLE COST'
   42 FORMAT(/,10X,A)
      WRITE(2,44)'FOR VAPORISER AND ITS OPERATION',TVCOST,'$/YEAR'
      WRITE(*,44)'FOR VAPORISER AND ITS OPERATION',TVCOST,'$/YEAR'
   44 FORMAT(/,10X,A,T45,F13.4,1X,A)
      RETURN
      END

      SUBROUTINE  TOLUEN(BPOINT,SPHEAT,HLATEN,CRPRES,TMFEED,OHEATC,
     $STEAMP,STEAMT,SHTMAX,TMASFR,THLOAD,DUTY,TMEMTD,HTAREA,HFLUX,
     $PRESS,TEMPJ,TEMPK,TEMPW,TEMPL,TEMPM,BOILCF,TVCOST,TKF,CAO,CU,
     $HOUROP,SHTCST)
      WRITE(*,18)'PHYSICAL PROPERTIES OF TOLUENE'
      WRITE(2,18)'PHYSICAL PROPERTIES OF TOLUENE'
   18 FORMAT(//,15X,A)
      PRINT*
C   INITIALIZATION OF VARIABLES
      SHTCST = 4.18
      BPOINT=110.7
      SPHEAT=1.675
      HLATEN=355.878
      CRPRES=40.71
      WRITE(*,20)'BOILING POINT',BPOINT,'C'
      WRITE(2,20)'BOILING POINT',BPOINT,'C'
   20 FORMAT(//,10X,A,T54,F10.4,1X,A)
      WRITE(*,22)'SPECIFIC HEAT',SPHEAT,'KJ/KgC'
      WRITE(2,22)'SPECIFIC HEAT',SPHEAT,'KJ/KgC'
   22 FORMAT(//,10X,A,T54,F10.4,1X,A)
      WRITE(*,24)'CRITICAL PRESSURE',CRPRES,'Bar'
      WRITE(2,24)'CRITICAL PRESSURE ',CRPRES,'Bar'
   24 FORMAT(//,10X,A,T54,F10.4,1X,A)
      WRITE(*,26)'LATENT HEAT',HLATEN,'KJ/Kg'
      WRITE(2,26)'LATENT HEAT',HLATEN,'KJ/Kg'
   26 FORMAT(//,10X,A,T54,F10.4,1X,A)
```

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```
      PRINT*,'INPUT MINIMUM TEMPERATURE OF THE FEED ','C'
      READ(*,*)TMFEED
C   COMPUTATION OF SENSITIVE HEAT MAXIMUM
      SHTMAX = (BPOINT-TMFEED)*SPHEAT
      WRITE(*,28)'SENSITIVE HEAT MAXIMUM',SHTMAX,'KJ/Kg'
      WRITE(2,28)'SENSITIVE HEAT MAXIMUM',SHTMAX,'KJ/Kg'
   28 FORMAT(//,10X,A,T54,F10.4,1X,A)
      PRINT*,'INPUT MASS FLOW RATE ','Kg/hr'
      READ(*,*)TMASFR
C     COMPUTATION OF THE TOTAL HEAT LOAD
      THLOAD = (SHTMAX + HLATEN)*(TMASFR/3600)
      WRITE(*,30)'TOTAL HEAT LOAD',THLOAD,'KW'
      WRITE(2,30)'TOTAL HEAT LOAD',THLOAD,'KW'
   30 FORMAT(//,10X,A,T54,F10.4,1X,A)
C     COMPUTATION OF DUTY
      DUTY = 1.05*THLOAD
      WRITE(*,31)'DUTY',DUTY,'KW'
      WRITE(2,31)'DUTY',DUTY,'KW'
   31 FORMAT(//,10X,A,T54,F10.4,1X,A)
      PRINT*,'INPUT OVERALL COEFFICIENT(BETWEEN 600 - 900)','W/SQ.MC'
      READ(*,*)OHEATC
C     VALIDATION OF OVERALL HEAT COEFFICIENT
      IF(OHEATC .LT.900 .AND. OHEATC .GT.1200) THEN
         PRINT*,'INVALID ENTRY',OHEATC,'PROGRAM WILL BE TERMINATED'
      ELSE
         PRINT*,'INPUT STEAM PRESSURE ','Bar'
         READ(*,*)STEAMP
      ENDIF
      CALL STEAM(STEAMP,STEAMT)
      WRITE(*,32)'STEAM TEMPERATURE',STEAMT,'C'
      WRITE(2,32)'STEAM TEMPERATURE',STEAMT,'C'
   32 FORMAT(//,10X,A,T54,F10.4,1X,A)
C     COMPUTATION OF MEAN TEMPERATURE DIFFERENCE
      TMEMTD = STEAMT - BPOINT
      WRITE(*,34)'MEAN TEMPERATURE DIFFERENCE',TMEMTD,'C'
      WRITE(2,34)'MEAN TEMPERATURE DIFFERENCE',TMEMTD,'C'
   34 FORMAT(//,10X,A,T54,F10.4,1X,A)
C     COMPUTATION OF HEAT TRANSFER AREA
      HTAREA = (DUTY*(10**3))/(OHEATC*TMEMTD)
      WRITE(*,36)'HEAT TRANSFER AREA',HTAREA,'SQ.m'
      WRITE(2,36)'HEAT TRANSFER AREA',HTAREA,'SQ.m'
   36 FORMAT(//,10X,A,T54,F10.4,1X,A)
C     COMPUTATION OF HEAT FLUX
      HFLUX = DUTY/HTAREA
      WRITE(*,38)'HEAT FLUX',HFLUX,'KW/SQ.m'
      WRITE(2,38)'HEAT FLUX',HFLUX,'KW/SQ.m'
   38 FORMAT(//,10X,A,T54,F10.4,1X,A)
      PRINT*,'INPUT OPERATING PRESSURE ','Bar'
      READ(*,*)PRESS
C     COMPUTATION OF TEMPORAL VALUES USED FOR THE COMPUTAION
C     OF THE BOILING COEFFIENT
      TEMPJ = .104*CRPRES**.69
      TEMPK = (HFLUX*10**3)**0.7
      TEMPW = 1.8*(PRESS/CRPRES)**0.17
      TEMPL = 4*((PRESS/CRPRES)**1.2)
```

APPENDIX B

```
      TEMPM = 10*((PRESS/CRPRES)**10)
C     COMPUTATION OF BOILING COEFFICIENT
      BOILCF = TEMPJ*TEMPK*(TEMPW+TEMPL+TEMPM)
      WRITE(*,40)'BOILING COEFFICIENT = ',BOILCF,'W/SQ.m c'
      WRITE(2,40)'BOILING COEFFICIENT = ',BOILCF,'W/SQ.m c'
   40 FORMAT(//,10X,A,T54,F10.4,1X,A)
      PRINT*,'ENTER THE VALUES OF TKF,CAO,HOUROP'
      READ(*,*)TKF,CAO,HOUROP
C     DETERMINATION OF STEAM COST
      IF(STEAMP.GT.0 .AND. STEAMP .LT. 6.90)THEN
             CU = 0.0066
      ELSEIF(STEAMP.GE.6.90 .AND. STEAMP .LT. 34.48)THEN
             CU = 0.0088
      ELSEIF(STEAMP.GE.34.48)THEN
             CU = 0.011
      ELSE
             PRINT*,'INVALID ENTRY',STEAMP,'TRY AGAIN'
      ENDIF
C     COMPUTATION OF TOTAL ANNUAL VARIABLE COST
      TVCOST=((HTAREA*TKF*CAO)+((3600*DUTY*HOUROP*CU)/(SHTCST*TMEMTD)))
      WRITE(*,42)'TOTAL ANNUAL VARIABLE COST'
      WRITE(2,42)'TOTAL ANNUAL VARIABLE COST'
   42 FORMAT(/,10X,A)
      WRITE(2,44)'FOR VAPORISER AND ITS OPERATION',TVCOST,'$/YEAR'
      WRITE(*,44)'FOR VAPORISER AND ITS OPERATION',TVCOST,'$/YEAR'
   44 FORMAT(/,10X,A,T48,F13.4,1X,A)
      RETURN
      END

      SUBROUTINE  EGLYCO(BPOINT,SPHEAT,HLATEN,CRPRES,TMFEED,OHEATC,
     $STEAMP,STEAMT,SHTMAX,TMASFR,THLOAD,DUTY,TMEMTD,HTAREA,HFLUX,
     $PRESS,TEMPJ,TEMPK,TEMPW,TEMPL,TEMPM,BOILCF,TVCOST,TKF,CAO,CU,
     $HOUROP,SHTCST)
      WRITE(*,18)'PHYSICAL PROPERTIES OF EHTYLENE GLYCOL'
      WRITE(2,18)'PHYSICAL PROPERTIES OF EHTYLENE GLYCOL'
   18 FORMAT(//,15X,A)
      PRINT*
C  INITIALIZATION OF VARIABLES
      SHTCST = 4.18
      BPOINT=197
      SPHEAT=2.382
      HLATEN=812.39
      CRPRES=47.12
      WRITE(*,20)'BOILING POINT = ',BPOINT,'C'
      WRITE(2,20)'BOILING POINT = ',BPOINT,'C'
   20 FORMAT(//,10X,A,T54,F10.4,1X,A)
      WRITE(*,22)'SPECIFIC HEAT = ',SPHEAT,'KJ/KgC'
      WRITE(2,22)'SPECIFIC HEAT = ',SPHEAT,'KJ/KgC'
   22 FORMAT(//,10X,A,T54,F10.4,1X,A)
      WRITE(*,24)'CRITICAL PRESSURE = ',CRPRES,'Bar'
      WRITE(2,24)'CRITICAL PRESSURE = ',CRPRES,'Bar'
   24 FORMAT(//,10X,A,T54,F10.4,1X,A)
      WRITE(*,26)'LATENT HEAT = ',HLATEN,'KJ/Kg'
      WRITE(2,26)'LATENT HEAT = ',HLATEN,'KJ/Kg'
   26 FORMAT(//,10X,A,T54,F10.4,1X,A)
```

APPENDIX B

```
      PRINT*,'INPUT MINIMUM TEMPERATURE OF THE FEED ','C'
      READ(*,*)TMFEED
C   COMPUTATION OF SENSITIVE HEAT MAXIMUM
      SHTMAX = (BPOINT-TMFEED)*SPHEAT
      WRITE(2,28)'SENSITIVE HEAT MAXIMUM = ',SHTMAX,'KJ/Kg'
      WRITE(2,28)'SENSITIVE HEAT MAXIMUM = ',SHTMAX,'KJ/Kg'
   28 FORMAT(//,10X,A,T54,F10.4,1X,A)
      PRINT*,'INPUT MASS FLOW RATE ','Kg/hr'
      READ(*,*)TMASFR
C     COMPUTATION OF THE TOTAL HEAT LOAD
      THLOAD = (SHTMAX + HLATEN)*(TMASFR/3600)
      WRITE(*,30)'TOTAL HEAT LOAD = ',THLOAD,'KW'
      WRITE(2,30)'TOTAL HEAT LOAD = ',THLOAD,'KW'
   30 FORMAT(//,10X,A,T54,F10.4,1X,A)
C     COMPUTATION OF DUTY
      DUTY = 1.05*THLOAD
      WRITE(*,31)'DUTY',DUTY,'KW'
      WRITE(2,31)'DUTY',DUTY,'KW'
   31 FORMAT(//,10X,A,T54,F10.4,1X,A)
      PRINT*,'INPUT OVERALL COEFFICIENT(BETWEEN 600 - 900)','W/SQ.MC'
      READ(*,*)OHEATC
C     VALIDATION OF OVERALL HEAT TRANSFER COEFFICIENT COEFFICIENT
      IF(OHEATC .LT.900 .AND. OHEATC .GT.1200) THEN
         PRINT*,'INVALID ENTRY',OHEATC,'PROGRAM WILL BE TERMINATED'
      ELSE
         PRINT*,'INPUT STEAM PRESSURE ','Bar'
         READ(*,*)STEAMP
      ENDIF
      CALL STEAM(STEAMP,STEAMT)
      WRITE(*,32)'STEAM TEMPERATURE = ',STEAMT,'C'
      WRITE(2,32)'STEAM TEMPERATURE = ',STEAMT,'C'
   32 FORMAT(//,10X,A,T54,F10.4,1X,A)
C     COMPUTATION OF MEAN TEMPERATURE DIFFERENCE
      TMEMTD = STEAMT - BPOINT
      WRITE(*,34)'MEAND TEMPERATURE DIFFERENCE = ',TMEMTD,'C'
      WRITE(2,34)'MEAND TEMPERATURE DIFFERENCE = ',TMEMTD,'C'
   34 FORMAT(//,10X,A,T54,F10.4,1X,A)
C     COMPUTATION OF HEAT TRANSFER AREA
      HTAREA = (DUTY*(10**3))/(OHEATC*TMEMTD)
      WRITE(*,36)'HEAT TRANSFER AREA = ',HTAREA,'SQ.m'
      WRITE(2,36)'HEAT TRANSFER AREA = ',HTAREA,'SQ.m'
   36 FORMAT(//,10X,A,T54,F10.4,1X,A)
C     COMPUTATION OF HEAT FLUX
      HFLUX = DUTY/HTAREA
      WRITE(*,38)'HEAT FLUX = ',HFLUX,'KW/SQ.m'
      WRITE(2,38)'HEAT FLUX = ',HFLUX,'KW/SQ.m'
   38 FORMAT(//,10X,A,T54,F10.4,1X,A)
      PRINT*,'INPUT OPERATING PRESSURE ','Bar'
      READ(*,*)PRESS
C     COMPUTATION OF TEMPORAL VALUES USED FOR
C     THE COMPUTAION OF THE BOILING COEFFIENT
      TEMPJ = .104*CRPRES**.69
      TEMPK = (HFLUX*10**3)**0.7
      TEMPW = 1.8*(PRESS/CRPRES)**0.17
      TEMPL = 4*((PRESS/CRPRES)**1.2)
```

```
      TEMPM = 10*((PRESS/CRPRES)**10)
C     COMPUTATION OF BOILING COEFFICIENT
      BOILCF = TEMPJ*TEMPK*(TEMPW+TEMPL+TEMPM)
      WRITE(*,40)'BOILING COEFFICIENT = ',BOILCF,'W/SQ.m c'
      WRITE(2,40)'BOILING COEFFICIENT = ',BOILCF,'W/SQ.m c'
   40 FORMAT(//,10X,A,T54,F10.4,1X,A)
      PRINT*,'ENTER THE VALUES OF TKF,CAO,HOUROP'
      READ(*,*)TKF,CAO,HOUROP
C     DETERMINATION OF STEAM COST
      IF(STEAMP.GT.0 .AND. STEAMP .LT. 6.90)THEN
            CU = 0.0066
      ELSEIF(STEAMP.GE.6.90 .AND. STEAMP .LT. 34.48)THEN
            CU = 0.0088
      ELSEIF(STEAMP.GE.34.48)THEN
            CU = 0.011
      ELSE
            PRINT*,'INVALID ENTRY',STEAMP,'TRY AGAIN'
      ENDIF
C     COMPUTATION OF TOTAL ANNUAL VARIABLE COST
      TVCOST=((HTAREA*TKF*CAO)+((3600*DUTY*HOUROP*CU)/(SHTCST*TMEMTD)))
      WRITE(*,42)'TOTAL ANNUAL VARIABLE COST'
      WRITE(2,42)'TOTAL ANNUAL VARIABLE COST'
   42 FORMAT(/,10X,A)
      WRITE(2,44)'FOR VAPORISER AND ITS OPERATION',TVCOST,'$/YEAR'
      WRITE(*,44)'FOR VAPORISER AND ITS OPERATION',TVCOST,'$/YEAR'
   44 FORMAT(/,10X,A,T48,F13.4,1X,A)
      RETURN
      END

      SUBROUTINE  NBUTAN(BPOINT,SPHEAT,HLATEN,CRPRES,TMFEED,OHEATC,
     $STEAMP,STEAMT,SHTMAX,TMASFR,THLOAD,DUTY,TMEMTD,HTAREA,HFLUX,
     $PRESS,TEMPJ,TEMPK,TEMPW,TEMPL,TEMPM,BOILCF,TVCOST,TKF,CAO,CU,
     $HOUROP,SHTCST)
      WRITE(*,18)'PHYSICAL PROPERTIES OF n-BUTANE'
      WRITE(2,18)'PHYSICAL PROPERTIES OF n-BUTANE'
   18 FORMAT(//,15X,A)
C  INITIALIZATION OF VARIABLES
      PRINT*
      SHTCST = 4.18
      BPOINT=56.1
      SPHEAT=2.51
      HLATEN=326
      CRPRES=38
      WRITE(*,20)'BOILING POINT',BPOINT,'C'
      WRITE(2,20)'BOILING POINT',BPOINT,'C'
   20 FORMAT(//,10X,A,T54,F10.4,1X,A)
      WRITE(*,22)'SPECIFIC HEAT',SPHEAT,'KJ/KgC'
      WRITE(2,22)'SPECIFIC HEAT',SPHEAT,'KJ/KgC'
   22 FORMAT(//,10X,A,T54,F10.4,1X,A)
      WRITE(*,24)'CRITICAL PRESSURE',CRPRES,'Bar'
      WRITE(2,24)'CRITICAL PRESSURE',CRPRES,'Bar'
   24 FORMAT(//,10X,A,T54,F10.4,1X,A)
      WRITE(*,26)'LATENT HEAT',HLATEN,'KJ/Kg'
      WRITE(2,26)'LATENT HEAT',HLATEN,'KJ/Kg'
   26 FORMAT(//,10X,A,T54,F10.4,1X,A)
```

APPENDIX B

```
      PRINT*,'INPUT MINIMUM TEMPERATURE OF THE FEED ','C'
      READ(*,*)TMFEED
C    COMPUTATION OF SENSITIVE HEAT MAXIMUM
      SHTMAX = (BPOINT-TMFEED)*SPHEAT
      WRITE(*,28)'SENSITIVE HEAT MAXIMUM',SHTMAX,'KJ/Kg'
      WRITE(2,28)'SENSITIVE HEAT MAXIMUM',SHTMAX,'KJ/Kg'
   28 FORMAT(//,10X,A,T54,F10.4;1X,A)
      PRINT*,'INPUT MASS FLOW RATE ','Kg/hr'
      READ(*,*)TMASFR
C     COMPUTATION OF THE TOTAL HEAT LOAD
      THLOAD = (SHTMAX + HLATEN)*(TMASFR/3600)
      WRITE(*,30)'TOTAL HEAT LOAD',THLOAD,'KW'
      WRITE(2,30)'TOTAL HEAT LOAD',THLOAD,'KW'
   30 FORMAT(//,10X,A,T54,F10.4,1X,A)
C     COMPUTATION OF DUTY
      DUTY = 1.05*THLOAD
      WRITE(*,31)'DUTY',DUTY,'KW'
      WRITE(2,31)'DUTY',DUTY,'KW'
   31 FORMAT(//,10X,A,T54,F10.4,1X,A)
      PRINT*,'INPUT OVERALL COEFFICIENT(BETWEEN 1000 - 1500)','W/SQ.MC'
      READ(*,*)OHEATC
C       VALIDATION OF OVERALL HEAT COEFFIENT
      IF(OHEATC .LT.900 .AND. OHEATC .GT.1200) THEN
         PRINT*,'INVALID ENTRY',OHEATC,'PROGRAM WILL BE TERMINATED'
      ELSE
         PRINT*,'INPUT STEAM PRESSURE ','Bar'
         READ(*,*)STEAMP
      ENDIF
      CALL STEAM(STEAMP,STEAMT)
      WRITE(*,32)'STEAM TEMPERATURE',STEAMT,'C'
      WRITE(2,32)'STEAM TEMPERATURE',STEAMT,'C'
   32 FORMAT(//,10X,A,T54,F10.4,1X,A)
C     COMPUTATION OF MEAN TEMPERATURE DIFFERENCE
      TMEMTD = STEAMT - BPOINT
      WRITE(*,34)'MEAND TEMPERATURE DIFFERENCE',TMEMTD,'C'
      WRITE(2,34)'MEAND TEMPERATURE DIFFERENCE',TMEMTD,'C'
   34 FORMAT(//,10X,A,T54,F10.4,1X,A)
C     COMPUTATION OF HEAT TRANSFER AREA
      HTAREA = (DUTY*(10**3))/(OHEATC*TMEMTD)
      WRITE(*,36)'HEAT TRANSFER AREA',HTAREA,'SQ.m'
      WRITE(2,36)'HEAT TRANSFER AREA',HTAREA,'SQ.m'
   36 FORMAT(//,10X,A,T54,F10.4,1X,A)
C     COMPUTATION OF HEAT FLUX
      HFLUX = DUTY/HTAREA
      WRITE(*,38)'HEAT FLUX',HFLUX,'KW/SQ.m'
      WRITE(2,38)'HEAT FLUX',HFLUX,'KW/SQ.m'
   38 FORMAT(//,10X,A,T54,F10.4,1X,A)
      PRINT*,'INPUT OPERATING PRESSURE ','Bar'
      READ(*,*)PRESS
C     COMPUTATION OF TEMPORAL VALUES USED FOR
C     THE COMPUTAION OF THE BOILING COEFFICIENT
      TEMPJ = .104*CRPRES**.69
      TEMPK = (HFLUX*10**3)**0.7
      TEMPW = 1.8*(PRESS/CRPRES)**0.17
      TEMPL = 4*((PRESS/CRPRES)**1.2)
```

APPENDIX B

```
      TEMPM = 10*((PRESS/CRPRES)**10)
C     COMPUTATION OF BOILING COEFFICIENT
      BOILCF = TEMPJ*TEMPK*(TEMPW+TEMPL+TEMPM)
      WRITE(*,40)'BOILING COEFFICIENT',BOILCF,'W/SQ.m c'
      WRITE(2,40)'BOILING COEFFICIENT',BOILCF,'W/SQ.m c'
   40 FORMAT(//,10X,A,T54,F10.4,1X,A)
      PRINT*,'ENTER THE VALUES OF TKF,CAO,HOUROP'
      READ(*,*)TKF,CAO,HOUROP
C     DETERMINATION OF STEAM COST
      IF(STEAMP.GT.0 .AND. STEAMP .LT. 6.90)THEN
            CU = 0.0066
      ELSEIF(STEAMP.GE.6.90 .AND. STEAMP .LT. 34.48)THEN
            CU = 0.0088
      ELSEIF(STEAMP.GE.34.48)THEN
            CU = 0.011
      ELSE
            PRINT*,'INVALID ENTRY',STEAMP,'TRY AGAIN'
      ENDIF
C     COMPUTATION OF TOTAL ANNUAL VARIABLE COST
      TVCOST=((HTAREA*TKF*CAO)+((3600*DUTY*HOUROP*CU)/(SHTCST*TMEMTD)))
      WRITE(*,42)'TOTAL ANNUAL VARIABLE COST'
      WRITE(2,42)'TOTAL ANNUAL VARIABLE COST'
   42 FORMAT(/,10X,A)
      WRITE(2,44)'FOR VAPORISER AND ITS OPERATION',TVCOST,'$/YEAR'
      WRITE(*,44)'FOR VAPORISER AND ITS OPERATION',TVCOST,'$/YEAR'
   44 FORMAT(/,10X,A,T48,F13.4,1X,A)
      RETURN
      END

      SUBROUTINE  ACETON(BPOINT,SPHEAT,HLATEN,CRPRES,TMFEED,OHEATC,
     $STEAMP,STEAMT,SHTMAX,TMASFR,THLOAD,DUTY,TMEMTD,HTAREA,HFLUX,
     $PRESS,TEMPJ,TEMPK,TEMPW,TEMPL,TEMPM,BOILCF,TVCOST,TKF,CAO,CU,
     $HOUROP,SHTCST)
      WRITE(*,18)'PHYSICAL PROPERTIES OF ACETONE'
      WRITE(2,18)'PHYSICAL PROPERTIES OF ACETONE'
   18 FORMAT(//,15X,A)
      PRINT*
C   INITIALIZATION OF VARIABLES
      SHTCST = 4.18
      BPOINT=56.1
      SPHEAT=2.16
      HLATEN=523.35
      CRPRES=58.34
      WRITE(*,20)'BOILING POINT',BPOINT,'C'
      WRITE(2,20)'BOILING POINT',BPOINT,'C'
   20 FORMAT(//,10X,A,T54,F10.4,1X,A)
      WRITE(*,22)'SPECIFIC HEAT',SPHEAT,'KJ/KgC'
      WRITE(2,22)'SPECIFIC HEAT',SPHEAT,'KJ/KgC'
   22 FORMAT(//,10X,A,T54,F10.4,1X,A)
      WRITE(*,24)'CRITICAL PRESSURE',CRPRES,'Bar'
      WRITE(2,24)'CRITICAL PRESSURE',CRPRES,'Bar'
   24 FORMAT(//,10X,A,T54,F10.4,1X,A)
      WRITE(*,26)'LATENT HEAT',HLATEN,'KJ/Kg'
      WRITE(2,26)'LATENT HEAT',HLATEN,'KJ/Kg'
   26 FORMAT(//,10X,A,T54,F10.4,1X,A)
```

APPENDIX B

```
      PRINT*,'INPUT MINIMUM TEMPERATURE OF THE FEED ','C'
      READ(*,*)TMFEED
C  COMPUTATION OF SENSITIVE HEAT MAXIMUM
      SHTMAX = (BPOINT-TMFEED)*SPHEAT
      WRITE(*,28)'SENSITIVE HEAT MAXIMUM',SHTMAX,'KJ/Kg'
      WRITE(2,28)'SENSITIVE HEAT MAXIMUM',SHTMAX,'KJ/Kg'
   28 FORMAT(//,10X,A,T54,F10.4,1X,A)
      PRINT*,'INPUT MASS FLOW RATE ','Kg/hr'
      READ(*,*)TMASFR
C     COMPUTATION OF THE TOTAL HEAT LOAD
      THLOAD = (SHTMAX + HLATEN)*(TMASFR/3600)
      WRITE(*,30)'TOTAL HEAT LOAD',THLOAD,'KW'
      WRITE(2,30)'TOTAL HEAT LOAD',THLOAD,'KW'
   30 FORMAT(//,10X,A,T54,F10.4,1X,A)
C     COMPUTATION OF DUTY
      DUTY = 1.05*THLOAD
      WRITE(*,31)'DUTY',DUTY,'KW'
      WRITE(2,31)'DUTY',DUTY,'KW'
   31 FORMAT(//,10X,A,T54,F10.4,1X,A)
      PRINT*,'INPUT OVERALL COEFFICIENT(BETWEEN 1000 - 1500)','W/SQ.MC'
      READ(*,*)OHEATC
C      VALIDATION OF OVERALL HEAT COEFFICIENT
      IF(OHEATC .LT.1000 .AND. OHEATC .GT.1500) THEN
         PRINT*,'INVALID ENTRY',OHEATC,'PROGRAM WILL BE TERMINATED'
      ELSE
         PRINT*,'INPUT STEAM PRESSURE ','Bar'
         READ(*,*)STEAMP
      ENDIF
      CALL STEAM(STEAMP,STEAMT)
      WRITE(*,32)'STEAM TEMPERATURE',STEAMT,'C'
      WRITE(2,32)'STEAM TEMPERATURE',STEAMT,'C'
   32 FORMAT(//,10X,A,T54,F10.4,1X,A)
C     COMPUTATION OF MEAN TEMPERATURE DIFFERENCE
      TMEMTD = STEAMT - BPOINT
      WRITE(*,34)'MEAND TEMPERATURE DIFFERENCE',TMEMTD,'C'
      WRITE(2,34)'MEAND TEMPERATURE DIFFERENCE',TMEMTD,'C'
   34 FORMAT(//,10X,A,T54,F10.4,1X,A)
C     COMPUTATION OF HEAT TRANSFER AREA
      HTAREA = (DUTY*(10**3))/(OHEATC*TMEMTD)
      WRITE(*,36)'HEAT TRANSFER AREA',HTAREA,'SQ.m'
      WRITE(2,36)'HEAT TRANSFER AREA',HTAREA,'SQ.m'
   36 FORMAT(//,10X,A,T54,F10.4,1X,A)
C     COMPUTATION OF HEAT FLUX
      HFLUX = DUTY/HTAREA
      WRITE(*,38)'HEAT FLUX',HFLUX,'KW/SQ.m'
      WRITE(2,38)'HEAT FLUX',HFLUX,'KW/SQ.m'
   38 FORMAT(//,10X,A,T54,F10.4,1X,A)
      PRINT*,'INPUT OPERATING PRESSURE ','Bar'
      READ(*,*)PRESS
C     COMPUTATION OF TEMPORAL VALUES USED FOR
C     THE COMPUTAION OF THE BOILING COEFFICIENT
      TEMPJ = .104*CRPRES**.69
      TEMPK = (HFLUX*10**3)**0.7
      TEMPW = 1.8*(PRESS/CRPRES)**0.17
      TEMPL = 4*((PRESS/CRPRES)**1.2)
```

```
      TEMPM = 10*((PRESS/CRPRES)**10)
C     COMPUTATION OF BOILING COEFFICIENT
      BOILCF = TEMPJ*TEMPK*(TEMPW+TEMPL+TEMPM)
      WRITE(*,40)'BOILING COEFFICIENT',BOILCF,'W/SQ.m c'
      WRITE(2,40)'BOILING COEFFICIENT',BOILCF,'W/SQ.m c'
   40 FORMAT(//,10X,A,T54,F10.4,1X,A)
      PRINT*,'ENTER THE VALUES OF TKF,CAO,HOUROP'
      READ(*,*)TKF,CAO,HOUROP
C     DETERMINATION OF STEAM COST
      IF(STEAMP.GT.0 .AND. STEAMP .LT. 6.90)THEN
              CU = 0.0066
      ELSEIF(STEAMP.GE.6.90 .AND. STEAMP .LT. 34.48)THEN
              CU = 0.0088
      ELSEIF(STEAMP.GE.34.48)THEN
              CU = 0.011
      ELSE
              PRINT*,'INVALID ENTRY',STEAMP,'TRY AGAIN'
      ENDIF
C     COMPUTATION OF TOTAL ANNUAL VARIABLE COST
      TVCOST=((HTAREA*TKF*CAO)+((3600*DUTY*HOUROP*CU)/(SHTCST*TMEMTD)))
      WRITE(*,42)'TOTAL ANNUAL VARIABLE COST'
      WRITE(2,42)'TOTAL ANNUAL VARIABLE COST'
   42 FORMAT(/,10X,A)
      WRITE(2,44)'FOR VAPORISER AND ITS OPERATION',TVCOST,'$/YEAR'
      WRITE(*,44)'FOR VAPORISER AND ITS OPERATION',TVCOST,'$/YEAR'
   44 FORMAT(/,10X,A,T48,F13.4,1X,A)
      RETURN
      END

      SUBROUTINE  ANILIN(BPOINT,SPHEAT,HLATEN,CRPRES,TMFEED,OHEATC,
     $STEAMP,STEAMT,SHTMAX,TMASFR,THLOAD,DUTY,TMEMTD,HTAREA,HFLUX,
     $PRESS,TEMPJ,TEMPK,TEMPW,TEMPL,TEMPM,BOILCF,TVCOST,TKF,CAO,CU,
     $HOUROP,SHTCST)
      WRITE(*,18)'PHYSICAL PROPERTIES OF ANILINE'
      WRITE(2,18)'PHYSICAL PROPERTIES OF ANILINE'
   18 FORMAT(//,15X,A)
      PRINT*
C   INITIALIZATION OF VARIABLES
      SHTCST = 4.18
      BPOINT=184
      SPHEAT=2.064
      HLATEN=447.988
      CRPRES=51.99
      WRITE(*,20)'BOILING POINT',BPOINT,'C'
      WRITE(2,20)'BOILING POINT',BPOINT,'C'
   20 FORMAT(//,10X,A,T54,F10.4,1X,A)
      WRITE(*,22)'SPECIFIC HEAT',SPHEAT,'KJ/KgC'
      WRITE(2,22)'SPECIFIC HEAT',SPHEAT,'KJ/KgC'
   22 FORMAT(//,10X,A,T54,F10.4,1X,A)
      WRITE(*,24)'CRITICAL PRESSURE',CRPRES,'Bar'
      WRITE(2,24)'CRITICAL PRESSURE',CRPRES,'Bar'
   24 FORMAT(//,10X,A,T54,F10.4,1X,A)
      WRITE(*,26)'LATENT HEAT',HLATEN,'KJ/Kg'
      WRITE(2,26)'LATENT HEAT',HLATEN,'KJ/Kg'
   26 FORMAT(//,10X,A,T54,F10.4,1X,A)
```

APPENDIX B

```
      PRINT*,'INPUT MINIMUM TEMPERATURE OF THE FEED ','C'
      READ(*,*)TMFEED
C  COMPUTATION OF SENSITIVE HEAT MAXIMUM
      SHTMAX = (BPOINT-TMFEED)*SPHEAT
      WRITE(*,28)'SENSITIVE HEAT MAXIMUM',SHTMAX,'KJ/Kg'
      WRITE(2,28)'SENSITIVE HEAT MAXIMUM',SHTMAX,'KJ/Kg'
   28 FORMAT(//,10X,A,T54,F10.4,1X,A)
      PRINT*,'INPUT MASS FLOW RATE ','Kg/hr'
      READ(*,*)TMASFR
C    COMPUTATION OF THE TOTAL HEAT LOAD
      THLOAD = (SHTMAX + HLATEN)*(TMASFR/3600)
      WRITE(*,30)'TOTAL HEAT LOAD',THLOAD,'KW'
      WRITE(2,30)'TOTAL HEAT LOAD',THLOAD,'KW'
   30 FORMAT(//,10X,A,T54,F10.4,1X,A)
C    COMPUTATION OF DUTY
      DUTY = 1.05*THLOAD
      WRITE(*,31)'DUTY',DUTY,'KW'
      WRITE(2,31)'DUTY',DUTY,'KW'
   31 FORMAT(//,10X,A,T54,F10.4,1X,A)
      PRINT*,'INPUT OVERALL COEFFICIENT(BETWEEN 600 - 900)','W/SQ.MC'
      READ(*,*)OHEATC
C     VALIDATION OF OVERALL HEAT COEFFICIENT
      IF(OHEATC .LT.1000 .AND. OHEATC .GT.1500) THEN
         PRINT*,'INVALID ENTRY',OHEATC,'PROGRAM WILL BE TERMINATED'
      ELSE
         PRINT*,'INPUT STEAM PRESSURE ','Bar'
         READ(*,*)STEAMP
      ENDIF
      CALL STEAM(STEAMP,STEAMT)
      WRITE(*,32)'STEAM TEMPERATURE',STEAMT,'C'
      WRITE(2,32)'STEAM TEMPERATURE',STEAMT,'C'
   32 FORMAT(//,10X,A,T54,F10.4,1X,A)
C     COMPUTATION OF MEAN TEMPERATURE DIFFERENCE
      TMEMTD = STEAMT - BPOINT
      WRITE(*,34)'MEAND TEMPERATURE DIFFERENCE',TMEMTD,'C'
      WRITE(2,34)'MEAND TEMPERATURE DIFFERENCE',TMEMTD,'C'
   34 FORMAT(//,10X,A,T54,F10.4,1X,A)
C     COMPUTATION OF HEAT TRANSFER AREA
      HTAREA = (DUTY*(10**3))/(OHEATC*TMEMTD)
      WRITE(*,36)'HEAT TRANSFER AREA',HTAREA,'SQ.m'
      WRITE(2,36)'HEAT TRANSFER AREA',HTAREA,'SQ.m'
   36 FORMAT(//,10X,A,T54,F10.4,1X,A)
C     COMPUTATION OF HEAT FLUX
      HFLUX = DUTY/HTAREA
      WRITE(*,38)'HEAT FLUX',HFLUX,'KW/SQ.m'
      WRITE(2,38)'HEAT FLUX',HFLUX,'KW/SQ.m'
   38 FORMAT(//,10X,A,T54,F10.4,1X,A)
      PRINT*,'INPUT OPERATING PRESSURE ','Bar'
      READ(*,*)PRESS
C     COMPUTATION OF TEMPORAL VALUES USED FOR
C     THE COMPUTAION OF THE BOILING COEFFICIENT
      TEMPJ = .104*CRPRES**.69
      TEMPK = (HFLUX*10**3)**0.7
      TEMPW = 1.8*(PRESS/CRPRES)**0.17
      TEMPL = 4*((PRESS/CRPRES)**1.2)
```

APPENDIX B

```
      TEMPM = 10*((PRESS/CRPRES)**10)
C     COMPUTATION OF BOILING COEFFICIENT
      BOILCF = TEMPJ*TEMPK*(TEMPW+TEMPL+TEMPM)
      WRITE(*,40)'BOILING COEFFICIENT',BOILCF,'W/SQ.m c'
      WRITE(2,40)'BOILING COEFFICIENT',BOILCF,'W/SQ.m c'
   40 FORMAT(//,10X,A,T54,F10.4,1X,A)
      PRINT*,'ENTER THE VALUES OF TKF,CAO,HOUROP'
      READ(*,*)TKF,CAO,HOUROP
C     DETERMINATION OF STEAM COST
      IF(STEAMP.GT.0 .AND. STEAMP .LT. 6.90)THEN
             CU = 0.0066
      ELSEIF(STEAMP.GE.6.90 .AND. STEAMP .LT. 34.48)THEN
             CU = 0.0088
      ELSEIF(STEAMP.GE.34.48)THEN
             CU = 0.011
      ELSE
             PRINT*,'INVALID ENTRY',STEAMP,'TRY AGAIN'
      ENDIF
C     COMPUTATION OF TOTAL ANNUAL VARIABLE COST
      TVCOST=((HTAREA*TKF*CAO)+((3600*DUTY*HOUROP*CU)/(SHTCST*TMEMTD)))
      WRITE(*,42)'TOTAL ANNUAL VARIABLE COST'
      WRITE(2,42)'TOTAL ANNUAL VARIABLE COST'
   42 FORMAT(/,10X,A)
      WRITE(2,44)'FOR VAPORISER AND ITS OPERATION',TVCOST,'$/YEAR'
      WRITE(*,44)'FOR VAPORISER AND ITS OPERATION',TVCOST,'$/YEAR'
   44 FORMAT(/,10X,A,T48,F13.4,1X,A)
      RETURN
      END

      SUBROUTINE  CBENZN(BPOINT,SPHEAT,HLATEN,CRPRES,TMFEED,OHEATC,
     $STEAMP,STEAMT,SHTMAX,TMASFR,THLOAD,DUTY,TMEMTD,HTAREA,HFLUX,
     $PRESS,TEMPJ,TEMPK,TEMPW,TEMPL,TEMPM,BOILCF,TVCOST,TKF,CAO,CU,
     $HOUROP,SHTCST)
      WRITE(*,18)'PHYSICAL PROPERTIES OF CHLOROBENZENE'
      WRITE(2,18)'PHYSICAL PROPERTIES OF CHLOROBENZENE'
   18 FORMAT(//,15X,A)
      PRINT*
C  INITIALIZATION OF VARIABLES
      SHTCST = 4.18
      BPOINT=132
      SPHEAT=1.298
      HLATEN=324.896
      CRPRES=43.74
      WRITE(*,20)'BOILING POINT',BPOINT,'C'
      WRITE(2,20)'BOILING POINT',BPOINT,'C'
   20 FORMAT(//,10X,A,T54,F10.4,1X,A)
      WRITE(*,22)'SPECIFIC HEAT',SPHEAT,'KJ/KgC'
      WRITE(2,22)'SPECIFIC HEAT',SPHEAT,'KJ/KgC'
   22 FORMAT(//,10X,A,T54,F10.4,1X,A)
      WRITE(*,24)'CRITICAL PRESSURE',CRPRES,'Bar'
      WRITE(2,24)'CRITICAL PRESSURE',CRPRES,'Bar'
   24 FORMAT(//,10X,A,T54,F10.4,1X,A)
      WRITE(*,26)'LATENT HEAT',HLATEN,'KJ/Kg'
      WRITE(2,26)'LATENT HEAT',HLATEN,'KJ/Kg'
   26 FORMAT(//,10X,A,T54,F10.4,1X,A)
```

APPENDIX B

```
      PRINT*,'INPUT MINIMUM TEMPERATURE OF THE FEED ','C'
      READ(*,*)TMFEED
C  COMPUTATION OF SENSITIVE HEAT MAXIMUM
      SHTMAX = (BPOINT-TMFEED)*SPHEAT
      WRITE(*,28)'SENSITIVE HEAT MAXIMUM',SHTMAX,'KJ/Kg'
      WRITE(2,28)'SENSITIVE HEAT MAXIMUM',SHTMAX,'KJ/Kg'
   28 FORMAT(//,10X,A,T54,F10.4,1X,A)
      PRINT*,'INPUT MASS FLOW RATE ','Kg/hr'
      READ(*,*)TMASFR
C     COMPUTATION OF THE TOTAL HEAT LOAD
      THLOAD = (SHTMAX + HLATEN)*(TMASFR/3600)
      WRITE(*,30)'TOTAL HEAT LOAD',THLOAD,'KW'
      WRITE(2,30)'TOTAL HEAT LOAD',THLOAD,'KW'
   30 FORMAT(//,10X,A,T54,F10.4,1X,A)
C     COMPUTATION OF DUTY
      DUTY = 1.05*THLOAD
      WRITE(*,31)'DUTY',DUTY,'KW'
      WRITE(2,31)'DUTY',DUTY,'KW'
   31 FORMAT(//,10X,A,T54,F10.4,1X,A)
      PRINT*,'INPUT OVERALL COEFFICIENT(BETWEEN 600 - 900)','W/SQ.MC'
      READ(*,*)OHEATC
C      VALIDATION OF OVERALL HEAT COEFFICIENT
      IF(OHEATC .LT.900 .AND. OHEATC .GT.1200) THEN
         PRINT*,'INVALID ENTRY',OHEATC,'PROGRAM WILL BE TERMINATED'
      ELSE
         PRINT*,'INPUT STEAM PRESSURE ','Bar'
         READ(*,*)STEAMP
      ENDIF
      CALL STEAM(STEAMP,STEAMT)
      WRITE(*,32)'STEAM TEMPERATURE',STEAMT,'C'
      WRITE(2,32)'STEAM TEMPERATURE',STEAMT,'C'
   32 FORMAT(//,10X,A,T54,F10.4,1X,A)
C     COMPUTATION OF MEAN TEMPERATURE DIFFERENCE
      TMEMTD = STEAMT - BPOINT
      WRITE(*,34)'MEAND TEMPERATURE DIFFERENCE',TMEMTD,'C'
      WRITE(2,34)'MEAND TEMPERATURE DIFFERENCE',TMEMTD,'C'
   34 FORMAT(//,10X,A,T54,F10.4,1X,A)
C     COMPUTATION OF HEAT TRANSFER AREA
      HTAREA = (DUTY*(10**3))/(OHEATC*TMEMTD)
      WRITE(*,36)'HEAT TRANSFER AREA',HTAREA,'SQ.m'
      WRITE(2,36)'HEAT TRANSFER AREA',HTAREA,'SQ.m'
   36 FORMAT(//,10X,A,T54,F10.4,1X,A)
C     COMPUTATION OF HEAT FLUX
      HFLUX = DUTY/HTAREA
      WRITE(*,38)'HEAT FLUX',HFLUX,'KW/SQ.m'
      WRITE(2,38)'HEAT FLUX',HFLUX,'KW/SQ.m'
   38 FORMAT(//,10X,A,T54,F10.4,1X,A)
      PRINT*,'INPUT OPERATING PRESSURE ','Bar'
      READ(*,*)PRESS
C     COMPUTATION OF TEMPORAL VALUES USED FOR
C     THE COMPUTAION OF THE BOILING COEFFICIENT
      TEMPJ = .104*CRPRES**.69
      TEMPK = (HFLUX*10**3)**0.7
      TEMPW = 1.8*(PRESS/CRPRES)**0.17
      TEMPL = 4*((PRESS/CRPRES)**1.2)
```

```
      TEMPM = 10*((PRESS/CRPRES)**10)
C     COMPUTATION OF BOILING COEFFICIENT
      BOILCF = TEMPJ*TEMPK*(TEMPW+TEMPL+TEMPM)
      WRITE(*,40)'BOILING COEFFICIENT',BOILCF,'W/SQ.m c'
      WRITE(2,40)'BOILING COEFFICIENT',BOILCF,'W/SQ.m c'
   40 FORMAT(//,10X,A,T54,F10.4,1X,A)
      PRINT*,'ENTER THE VALUES OF TKF,CAO,HOUROP'
      READ(*,*)TKF,CAO,HOUROP
C     DETERMINATION OF STEAM COST
      IF(STEAMP.GT.0 .AND. STEAMP .LT. 6.90)THEN
             CU = 0.0066
      ELSEIF(STEAMP.GE.6.90 .AND. STEAMP .LT. 34.48)THEN
             CU = 0.0088
      ELSEIF(STEAMP.GE.34.48)THEN
             CU = 0.011
      ELSE
             PRINT*,'INVALID ENTRY',STEAMP,'TRY AGAIN'
      ENDIF
C     COMPUTATION OF TOTAL ANNUAL VARIABLE COST
      TVCOST=((HTAREA*TKF*CAO)+((3600*DUTY*HOUROP*CU)/(SHTCST*TMEMTD)))
      WRITE(*,42)'TOTAL ANNUAL VARIABLE COST'
      WRITE(2,42)'TOTAL ANNUAL VARIABLE COST'
   42 FORMAT(/,10X,A)
      WRITE(2,44)'FOR VAPORISER AND ITS OPERATION',TVCOST,'$/YEAR'
      WRITE(*,44)'FOR VAPORISER AND ITS OPERATION',TVCOST,'$/YEAR'
   44 FORMAT(/,10X,A,T48,F13.4,1X,A)
      RETURN
      END

      SUBROUTINE  NBACOL(BPOINT,SPHEAT,HLATEN,CRPRES,TMFEED,OHEATC,
     $STEAMP,STEAMT,SHTMAX,TMASFR,THLOAD,DUTY,TMEMTD,HTAREA,HFLUX,
     $PRESS,TEMPJ,TEMPK,TEMPW,TEMPL,TEMPM,BOILCF,TVCOST,TKF,CAO,CU,
     $HOUROP,SHTCST)
      WRITE(*,18)'PHYSICAL PROPERTIES OF n-BUTHYL ALCOHOL'
      WRITE(2,18)'PHYSICAL PROPERTIES OF n-BUTHYL ALCOHOL'
   18 FORMAT(//,15X,A)
      PRINT*
C  INITIALIZATION OF VARIABLES
      SHTCST = 4.18
      BPOINT=117
      SPHEAT=2.366
      HLATEN=590.399
      CRPRES=47.46
      WRITE(*,20)'BOILING POINT',BPOINT,'C'
      WRITE(2,20)'BOILING POINT',BPOINT,'C'
   20 FORMAT(//,10X,A,T54,F10.4,1X,A)
      WRITE(*,22)'SPECIFIC HEAT',SPHEAT,'KJ/KgC'
      WRITE(2,22)'SPECIFIC HEAT',SPHEAT,'KJ/KgC'
   22 FORMAT(//,10X,A,T54,F10.4,1X,A)
      WRITE(2,24)'CRITICAL PRESSURE',CRPRES,'Bar'
   24 FORMAT(//,10X,A,T54,F10.4,1X,A)
      WRITE(*,26)'LATENT HEAT',HLATEN,'KJ/Kg'
      WRITE(2,26)'LATENT HEAT',HLATEN,'KJ/Kg'
   26 FORMAT(//,10X,A,T54,F10.4,1X,A)
      PRINT*,'INPUT MINIMUM TEMPERATURE OF THE FEED ','C'
```

APPENDIX B

```
      READ(*,*)TMFEED
C   COMPUTATION OF SENSITIVE HEAT MAXIMUM
      SHTMAX = (BPOINT-TMFEED)*SPHEAT
      WRITE(*,28)'SENSITIVE HEAT MAXIMUM',SHTMAX,'KJ/Kg'
      WRITE(2,28)'SENSITIVE HEAT MAXIMUM',SHTMAX,'KJ/Kg'
   28 FORMAT(//,10X,A,T54,F10.4,1X,A)
      PRINT*,'INPUT MASS FLOW RATE ','Kg/hr'
      READ(*,*)TMASFR
C     COMPUTATION OF THE TOTAL HEAT LOAD
      THLOAD = (SHTMAX + HLATEN)*(TMASFR/3600)
      WRITE(2,30)'TOTAL HEAT LOAD',THLOAD,'KW'
   30 FORMAT(//,10X,A,T54,F10.4,1X,A)
C     COMPUTATION OF DUTY
      DUTY = 1.05*THLOAD
      WRITE(*,31)'DUTY',DUTY,'KW'
      WRITE(2,31)'DUTY',DUTY,'KW'
   31 FORMAT(//,10X,A,T54,F10.4,1X,A)
      PRINT*,'INPUT OVERALL COEFFICIENT(BETWEEN 600 - 900)','W/SQ.MC'
      READ(*,*)OHEATC
C      VALIDATION OF OVERALL HEAT COEFFICIENT
      IF(OHEATC .LT.900 .AND. OHEATC .GT.1200) THEN
         PRINT*,'INVALID ENTRY',OHEATC,'PROGRAM WILL BE TERMINATED'
      ELSE
         PRINT*,'INPUT STEAM PRESSURE ','Bar'
         READ(*,*)STEAMP
      ENDIF
      CALL STEAM(STEAMP,STEAMT)
      WRITE(*,32)'STEAM TEMPERATURE',STEAMT,'C'
      WRITE(2,32)'STEAM TEMPERATURE',STEAMT,'C'
   32 FORMAT(//,10X,A,T54,F10.4,1X,A)
C     COMPUTATION OF MEAN TEMPERATURE DIFFERENCE
      TMEMTD = STEAMT - BPOINT
      WRITE(*,34)'MEAND TEMPERATURE DIFFERENCE',TMEMTD,'C'
      WRITE(2,34)'MEAND TEMPERATURE DIFFERENCE',TMEMTD,'C'
   34 FORMAT(//,10X,A,T54,F10.4,1X,A)
C     COMPUTATION OF HEAT TRANSFER AREA
      HTAREA = (DUTY*(10**3))/(OHEATC*TMEMTD)
      WRITE(*,36)'HEAT TRANSFER AREA',HTAREA,'SQ.m'
      WRITE(2,36)'HEAT TRANSFER AREA',HTAREA,'SQ.m'
   36 FORMAT(//,10X,A,T54,F10.4,1X,A)
C     COMPUTATION OF HEAT FLUX
      HFLUX = DUTY/HTAREA
      WRITE(*,38)'HEAT FLUX',HFLUX,'KW/SQ.m'
      WRITE(2,38)'HEAT FLUX',HFLUX,'KW/SQ.m'
   38 FORMAT(//,10X,A,T54,F10.4,1X,A)
      PRINT*,'INPUT OPERATING PRESSURE ','Bar'
      READ(*,*)PRESS
C     COMPUTATION OF TEMPORAL VALUES USED FOR
C     THE COMPUTAION OF THE BOILING COEFFICIENT
      TEMPJ = .104*CRPRES**.69
      TEMPK = (HFLUX*10**3)**0.7
      TEMPW = 1.8*(PRESS/CRPRES)**0.17
      TEMPL = 4*((PRESS/CRPRES)**1.2)
      TEMPM = 10*((PRESS/CRPRES)**10)
C     COMPUTATION OF BOILING COEFFICIENT
```

```
      BOILCF = TEMPJ*TEMPK*(TEMPW+TEMPL+TEMPM)
      WRITE(*,40)'BOILING COEFFICIENT',BOILCF,'W/SQ.m c'
      WRITE(2,40)'BOILING COEFFICIENT',BOILCF,'W/SQ.m c'
   40 FORMAT(//,10X,A,T54,F10.4,1X,A)
      PRINT*,'ENTER THE VALUES OF TKF,CAO,HOUROP'
      READ(*,*)TKF,CAO,HOUROP
C     DETERMINATION OF STEAM COST
      IF(STEAMP.GT.0 .AND. STEAMP .LT. 6.90)THEN
              CU = 0.0066
      ELSEIF(STEAMP.GE.6.90 .AND. STEAMP .LT. 34.48)THEN
              CU = 0.0088
      ELSEIF(STEAMP.GE.34.48)THEN
              CU = 0.011
      ELSE
              PRINT*,'INVALID ENTRY',STEAMP,'TRY AGAIN'
      ENDIF
C     COMPUTATION OF TOTAL ANNUAL VARIABLE COST
      TVCOST=((HTAREA*TKF*CAO)+((3600*DUTY*HOUROP*CU)/(SHTCST*TMEMTD)))
      WRITE(*,42)'TOTAL ANNUAL VARIABLE COST'
      WRITE(2,42)'TOTAL ANNUAL VARIABLE COST'
   42 FORMAT(/,10X,A)
      WRITE(2,44)'FOR VAPORISER AND ITS OPERATION',TVCOST,'$/YEAR'
      WRITE(*,44)'FOR VAPORISER AND ITS OPERATION',TVCOST,'$/YEAR'
   44 FORMAT(/,10X,A,T48,F13.4,1X,A)
      RETURN
      END

      SUBROUTINE  EETHER(BPOINT,SPHEAT,HLATEN,CRPRES,TMFEED,OHEATC,
     $STEAMP,STEAMT,SHTMAX,TMASFR,THLOAD,DUTY,TMEMTD,HTAREA,HFLUX,
     $PRESS,TEMPJ,TEMPK,TEMPW,TEMPL,TEMPM,BOILCF,TVCOST,TKF,CAO,CU,
     $HOUROP,SHTCST)
      WRITE(*,18)'PHYSICAL PROPERTIES OF ETHYL ETHER'
      WRITE(2,18)'PHYSICAL PROPERTIES OF ETHYL ETHER'
   18 FORMAT(//,15X,A)
      PRINT*
C  INITIALIZATION OF VARIABLES
      SHTCST = 4.18
      BPOINT=34.48
      SPHEAT=2.328
      HLATEN=300.065
      CRPRES=35.6
      WRITE(*,20)'BOILING POINT',BPOINT,'C'
      WRITE(2,20)'BOILING POINT',BPOINT,'C'
   20 FORMAT(//,10X,A,T54,F10.4,1X,A)
      WRITE(*,22)'SPECIFIC HEAT',SPHEAT,'KJ/KgC'
      WRITE(2,22)'SPECIFIC HEAT',SPHEAT,'KJ/KgC'
   22 FORMAT(//,10X,A,T54,F10.4,1X,A)
      WRITE(*,24)'CRITICAL PRESSURE',CRPRES,'Bar'
      WRITE(2,24)'CRITICAL PRESSURE',CRPRES,'Bar'
   24 FORMAT(//,10X,A,T54,F10.4,1X,A)
      WRITE(*,26)'LATENT HEAT',HLATEN,'KJ/Kg'
      WRITE(2,26)'LATENT HEAT',HLATEN,'KJ/Kg'
   26 FORMAT(//,10X,A,T54,F10.4,1X,A)
      PRINT*,'INPUT MINIMUM TEMPERATURE OF THE FEED ','C'
      READ(*,*)TMFEED
```

APPENDIX B

```
C  COMPUTATION OF SENSITIVE HEAT MAXIMUM
      SHTMAX = (BPOINT-TMFEED)*SPHEAT
      WRITE(*,26)'LATENT HEAT',HLATEN,'KJ/Kg'
      WRITE(2,26)'LATENT HEAT',HLATEN,'KJ/Kg'
   28 FORMAT(//,10X,A,T54,F10.4,1X,A)
      PRINT*,'INPUT MASS FLOW RATE ','Kg/hr'
      READ(*,*)TMASFR
C    COMPUTATION OF THE TOTAL HEAT LOAD
      THLOAD = (SHTMAX + HLATEN)*(TMASFR/3600)
      WRITE(*,30)'TOTAL HEAT LOAD',THLOAD,'KW'
      WRITE(2,30)'TOTAL HEAT LOAD',THLOAD,'KW'
   30 FORMAT(//,10X,A,T54,F10.4,1X,A)
C    COMPUTATION OF DUTY
      DUTY = 1.05*THLOAD
      WRITE(*,31)'DUTY',DUTY,'KW'
      WRITE(2,31)'DUTY',DUTY,'KW'
   31 FORMAT(//,10X,A,T54,F10.4,1X,A)
      PRINT*,'INPUT OVERALL COEFFICIENT(BETWEEN 1000 - 1500)','W/SQ.MC'
      READ(*,*)OHEATC
C     VALIDATION OF OVERALL HEAT COEFFICIENT
      IF(OHEATC .LT.900 .AND. OHEATC .GT.1200) THEN
         PRINT*,'INVALID ENTRY',OHEATC,'PROGRAM WILL BE TERMINATED'
      ELSE
         PRINT*,'INPUT STEAM PRESSURE ','Bar'
         READ(*,*)STEAMP
      ENDIF
      CALL STEAM(STEAMP,STEAMT)
      WRITE(*,32)'STEAM TEMPERATURE',STEAMT,'C'
      WRITE(2,32)'STEAM TEMPERATURE',STEAMT,'C'
   32 FORMAT(//,10X,A,T54,F10.4,1X,A)
C     COMPUTATION OF MEAN TEMPERATURE DIFFERENCE
      TMEMTD = STEAMT - BPOINT
      WRITE(*,34)'MEAND TEMPERATURE DIFFERENCE',TMEMTD,'C'
      WRITE(2,34)'MEAND TEMPERATURE DIFFERENCE',TMEMTD,'C'
   34 FORMAT(//,10X,A,T54,F10.4,1X,A)
C     COMPUTATION OF HEAT TRANSFER AREA
      HTAREA = (DUTY*(10**3))/(OHEATC*TMEMTD)
      WRITE(*,36)'HEAT TRANSFER AREA',HTAREA,'SQ.m'
      WRITE(2,36)'HEAT TRANSFER AREA',HTAREA,'SQ.m'
   36 FORMAT(//,10X,A,T54,F10.4,1X,A)
C     COMPUTATION OF HEAT FLUX
      HFLUX = DUTY/HTAREA
      WRITE(*,38)'HEAT FLUX',HFLUX,'KW/SQ.m'
      WRITE(2,38)'HEAT FLUX',HFLUX,'KW/SQ.m'
   38 FORMAT(//,10X,A,T54,F10.4,1X,A)
      PRINT*,'INPUT OPERATING PRESSURE ','Bar'
      READ(*,*)PRESS
C     COMPUTATION OF TEMPORAL VALUES USED FOR
C     THE COMPUTAION OF THE BOILING COEFFICIENT
      TEMPJ = .104*CRPRES**.69
      TEMPK = (HFLUX*10**3)**0.7
      TEMPW = 1.8*(PRESS/CRPRES)**0.17
      TEMPL = 4*((PRESS/CRPRES)**1.2)
      TEMPM = 10*((PRESS/CRPRES)**10)
C     COMPUTATION OF BOILING COEFFICIENT
```

APPENDIX B

```
      BOILCF = TEMPJ*TEMPK*(TEMPW+TEMPL+TEMPM)
      WRITE(*,40)'BOILING COEFFICIENT',BOILCF,'W/SQ.m c'
      WRITE(2,40)'BOILING COEFFICIENT',BOILCF,'W/SQ.m c'
   40 FORMAT(//,10X,A,T54,F10.4,1X,A)
      PRINT*,'ENTER THE VALUES OF TKF,CAO,HOUROP'
      READ(*,*)TKF,CAO,HOUROP
C     DETERMINATION OF STEAM COST
      IF(STEAMP.GT.0 .AND. STEAMP .LT. 6.90)THEN
            CU = 0.0066
      ELSEIF(STEAMP.GE.6.90 .AND. STEAMP .LT. 34.48)THEN
            CU = 0.0088
      ELSEIF(STEAMP.GE.34.48)THEN
            CU = 0.011
      ELSE
            PRINT*,'INVALID ENTRY',STEAMP,'TRY AGAIN'
      ENDIF
C     COMPUTATION OF TOTAL ANNUAL VARIABLE COST
      TVCOST=((HTAREA*TKF*CAO)+((3600*DUTY*HOUROP*CU)/(SHTCST*TMEMTD)))
      WRITE(*,42)'TOTAL ANNUAL VARIABLE COST'
      WRITE(2,42)'TOTAL ANNUAL VARIABLE COST'
   42 FORMAT(/,10X,A)
      WRITE(2,44)'FOR VAPORISER AND ITS OPERATION',TVCOST,'$/YEAR'
      WRITE(*,44)'FOR VAPORISER AND ITS OPERATION',TVCOST,'$/YEAR'
   44 FORMAT(/,10X,A,T48,F13.4,1X,A)
      RETURN
      END

      SUBROUTINE  ETACET(BPOINT,SPHEAT,HLATEN,CRPRES,TMFEED,OHEATC,
     $STEAMP,STEAMT,SHTMAX,TMASFR,THLOAD,DUTY,TMEMTD,HTAREA,HFLUX,
     $PRESS,TEMPJ,TEMPK,TEMPW,TEMPL,TEMPM,BOILCF,TVCOST,TKF,CAO,CU,
     $HOUROP,SHTCST)
      WRITE(*,18)'PHYSICAL PROPERTIES OF ETHYL ACETATE'
      WRITE(2,18)'PHYSICAL PROPERTIES OF ETHYL ACETATE'
   18 FORMAT(//,15X,A)
      PRINT*
C  INITIALIZATION OF VARIABLES
      SHTCST = 4.18
      BPOINT=77.1
      SPHEAT=2.01
      HLATEN=368.438
      CRPRES=37.24
      WRITE(*,20)'BOILING POINT',BPOINT,'C'
      WRITE(2,20)'BOILING POINT',BPOINT,'C'
   20 FORMAT(//,10X,A,T54,F10.4,1X,A)
      WRITE(*,22)'SPECIFIC HEAT',SPHEAT,'KJ/KgC'
      WRITE(2,22)'SPECIFIC HEAT',SPHEAT,'KJ/KgC'
   22 FORMAT(//,10X,A,T54,F10.4,1X,A)
      WRITE(*,24)'CRITICAL PRESSURE',CRPRES,'Bar'
      WRITE(2,24)'CRITICAL PRESSURE',CRPRES,'Bar'
   24 FORMAT(//,10X,A,T54,F10.4,1X,A)
      WRITE(*,26)'LATENT HEAT',HLATEN,'KJ/Kg'
      WRITE(2,26)'LATENT HEAT',HLATEN,'KJ/Kg'
   26 FORMAT(//,10X,A,T54,F10.4,1X,A)
      PRINT*,'INPUT MINIMUM TEMPERATURE OF THE FEED ','C'
      READ(*,*)TMFEED
```

APPENDIX B

```
C  COMPUTATION OF SENSITIVE HEAT MAXIMUM
      SHTMAX = (BPOINT-TMFEED)*SPHEAT
      WRITE(*,28)'SENSITIVE HEAT MAXIMUM',SHTMAX,'KJ/Kg'
      WRITE(2,28)'SENSITIVE HEAT MAXIMUM',SHTMAX,'KJ/Kg'
   28 FORMAT(//,10X,A,T54,F10.4,1X,A)
      PRINT*,'INPUT MASS FLOW RATE ','Kg/hr'
      READ(*,*)TMASFR
C     COMPUTATION OF THE TOTAL HEAT LOAD
      THLOAD = (SHTMAX + HLATEN)*(TMASFR/3600)
      WRITE(*,30)'TOTAL HEAT LOAD',THLOAD,'KW'
      WRITE(2,30)'TOTAL HEAT LOAD',THLOAD,'KW'
   30 FORMAT(//,10X,A,T54,F10.4,1X,A)
C     COMPUTATION OF DUTY
      DUTY = 1.05*THLOAD
      WRITE(*,31)'DUTY',DUTY,'KW'
      WRITE(2,31)'DUTY',DUTY,'KW'
   31 FORMAT(//,10X,A,T54,F10.4,1X,A)
      PRINT*,'INPUT OVERALL COEFFICIENT(BETWEEN 600 - 900)','W/SQ.MC'
      READ(*,*)OHEATC
C   VALIDATION OF OVERALL HEAT COEFFICIENT
      IF(OHEATC .LT.1000 .AND. OHEATC .GT.1500) THEN
         PRINT*,'INVALID ENTRY',OHEATC,'PROGRAM WILL BE TERMINATED'
      ELSE
         PRINT*,'INPUT STEAM PRESSURE ','Bar'
         READ(*,*)STEAMP
      ENDIF
      CALL STEAM(STEAMP,STEAMT)
      WRITE(*,32)'STEAM TEMPERATURE',STEAMT,'C'
      WRITE(2,32)'STEAM TEMPERATURE',STEAMT,'C'
   32 FORMAT(//,10X,A,T54,F10.4,1X,A)
C     COMPUTATION OF MEAN TEMPERATURE DIFFERENCE
      TMEMTD = STEAMT - BPOINT
      WRITE(*,34)'MEAND TEMPERATURE DIFFERENCE',TMEMTD,'C'
      WRITE(2,34)'MEAND TEMPERATURE DIFFERENCE',TMEMTD,'C'
   34 FORMAT(//,10X,A,T54,F10.4,1X,A)
C     COMPUTATION OF HEAT TRANSFER AREA
      HTAREA = (DUTY*(10**3))/(OHEATC*TMEMTD)
      WRITE(*,36)'HEAT TRANSFER AREA',HTAREA,'SQ.m'
      WRITE(2,36)'HEAT TRANSFER AREA',HTAREA,'SQ.m'
   36 FORMAT(//,10X,A,T54,F10.4,1X,A)
C     COMPUTATION OF HEAT FLUX
      HFLUX = DUTY/HTAREA
      WRITE(*,38)'HEAT FLUX',HFLUX,'KW/SQ.m'
      WRITE(2,38)'HEAT FLUX',HFLUX,'KW/SQ.m'
   38 FORMAT(//,10X,A,T54,F10.4,1X,A)
      PRINT*,'INPUT OPERATING PRESSURE ','Bar'
      READ(*,*)PRESS
C     COMPUTATION OF TEMPORAL VALUES USED FOR
C     THE COMPUTAION OF THE BOILING COEFFICIENT
      TEMPJ = .104*CRPRES**.69
      TEMPK = (HFLUX*10**3)**0.7
      TEMPW = 1.8*(PRESS/CRPRES)**0.17
      TEMPL = 4*((PRESS/CRPRES)**1.2)
      TEMPM = 10*((PRESS/CRPRES)**10)
C     COMPUTATION OF BOILING COEFFICIENT
```

APPENDIX B

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      BOILCF = TEMPJ*TEMPK*(TEMPW+TEMPL+TEMPM)
      WRITE(*,40)'BOILING COEFFICIENT',BOILCF,'W/SQ.m c'
      WRITE(2,40)'BOILING COEFFICIENT',BOILCF,'W/SQ.m c'
   40 FORMAT(//,10X,A,T54,F10.4,1X,A)
      PRINT*,'ENTER THE VALUES OF TKF,CAO,HOUROP'
      READ(*,*)TKF,CAO,HOUROP
C     DETERMINATION OF STEAM COST
      IF(STEAMP.GT.0 .AND. STEAMP .LT. 6.90)THEN
            CU = 0.0066
      ELSEIF(STEAMP.GE.6.90 .AND. STEAMP .LT. 34.48)THEN
            CU = 0.0088
      ELSEIF(STEAMP.GE.34.48)THEN
            CU = 0.011
      ELSE
            PRINT*,'INVALID ENTRY',STEAMP,'TRY AGAIN'
      ENDIF
C     COMPUTATION OF TOTAL ANNUAL VARIABLE COST
      TVCOST=((HTAREA*TKF*CAO)+((3600*DUTY*HOUROP*CU)/(SHTCST*TMEMTD)))
      WRITE(*,42)'TOTAL ANNUAL VARIABLE COST'
      WRITE(2,42)'TOTAL ANNUAL VARIABLE COST'
   42 FORMAT(/,10X,A)
      WRITE(2,44)'FOR VAPORISER AND ITS OPERATION',TVCOST,'$/YEAR'
      WRITE(*,44)'FOR VAPORISER AND ITS OPERATION',TVCOST,'$/YEAR'
   44 FORMAT(/,10X,A,T48,F13.4,1X,A)
      RETURN
      END
C SUBROUTINE 'STEAM'DETERMINES THE STEAM TEMPERATURE GIVEN THE STEAM
PRESSURE
      SUBROUTINE STEAM(STEAMP,STEAMT)
      IF(STEAMP.EQ.1.0) STEAMT = 99.6
      IF(STEAMP.EQ.1.1) STEAMT = 102.3
      IF(STEAMP.EQ.1.2) STEAMT = 104.8
      IF(STEAMP.EQ.1.3) STEAMT = 107.1
      IF(STEAMP.EQ.1.4) STEAMT = 109.3
      IF(STEAMP.EQ.1.5) STEAMT = 111.4
      IF(STEAMP.EQ.1.6) STEAMT = 113.3
      IF(STEAMP.EQ.1.7) STEAMT = 115.2
      IF(STEAMP.EQ.1.8) STEAMT = 116.9
      IF(STEAMP.EQ.1.9) STEAMT = 118.6
      IF(STEAMP.EQ.2.0) STEAMT = 120.2
      IF(STEAMP.EQ.2.1) STEAMT = 121.8
      IF(STEAMP.EQ.2.2) STEAMT = 123.3
      IF(STEAMP.EQ.2.3) STEAMT = 124.7
      IF(STEAMP.EQ.2.4) STEAMT = 126.1
      IF(STEAMP.EQ.2.5) STEAMT = 127.1
      IF(STEAMP.EQ.2.6) STEAMT = 128.7
      IF(STEAMP.EQ.2.7) STEAMT = 130.0
      IF(STEAMP.EQ.2.8) STEAMT = 131.2
      IF(STEAMP.EQ.2.9) STEAMT = 132.4
      IF(STEAMP.EQ.3.0) STEAMT = 133.5
      IF(STEAMP.EQ.3.1) STEAMT = 134.7
      IF(STEAMP.EQ.3.2) STEAMT = 135.8
      IF(STEAMP.EQ.3.3) STEAMT = 136.8
      IF(STEAMP.EQ.3.4) STEAMT = 137.9
      IF(STEAMP.EQ.3.5) STEAMT = 138.9
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APPENDIX B

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IF(STEAMP.EQ.3.6) STEAMT = 139.9
IF(STEAMP.EQ.3.7) STEAMT = 140.8
IF(STEAMP.EQ.3.8) STEAMT = 141.8
IF(STEAMP.EQ.3.9) STEAMT = 142.7
IF(STEAMP.EQ.4.0) STEAMT = 143.6
IF(STEAMP.EQ.4.1) STEAMT = 144.5
IF(STEAMP.EQ.4.2) STEAMT = 145.4
IF(STEAMP.EQ.4.3) STEAMT = 146.3
IF(STEAMP.EQ.4.4) STEAMT = 147.1
IF(STEAMP.EQ.4.5) STEAMT = 147.9
IF(STEAMP.EQ.4.6) STEAMT = 148.7
IF(STEAMP.EQ.4.7) STEAMT = 149.5
IF(STEAMP.EQ.4.8) STEAMT = 150.4
IF(STEAMP.EQ.4.9) STEAMT = 151.1
IF(STEAMP.EQ.5.0) STEAMT = 151.8
IF(STEAMP.EQ.5.2) STEAMT = 153.3
IF(STEAMP.EQ.5.4) STEAMT = 154.8
IF(STEAMP.EQ.5.5) STEAMT = 155.8
IF(STEAMP.EQ.5.6) STEAMT = 156.2
IF(STEAMP.EQ.5.8) STEAMT = 157.2
IF(STEAMP.EQ.6.0) STEAMT = 158.8
IF(STEAMP.EQ.6.2) STEAMT = 160.1
IF(STEAMP.EQ.6.4) STEAMT = 161.4
IF(STEAMP.EQ.6.6) STEAMT = 162.6
IF(STEAMP.EQ.6.8) STEAMT = 163.8
IF(STEAMP.EQ.7.0) STEAMT = 165.0
IF(STEAMP.EQ.7.2) STEAMT = 166.1
IF(STEAMP.EQ.7.4) STEAMT = 167.2
IF(STEAMP.EQ.7.6) STEAMT = 168.3
IF(STEAMP.EQ.7.8) STEAMT = 169.4
IF(STEAMP.EQ.8.0) STEAMT = 170.4
IF(STEAMP.EQ.8.2) STEAMT = 171.4
IF(STEAMP.EQ.8.4) STEAMT = 172.4
IF(STEAMP.EQ.8.6) STEAMT = 173.4
IF(STEAMP.EQ.8.8) STEAMT = 174.4
IF(STEAMP.EQ.9.0) STEAMT = 175.4
IF(STEAMP.EQ.9.2) STEAMT = 176.3
IF(STEAMP.EQ.9.4) STEAMT = 177.2
IF(STEAMP.EQ.9.6) STEAMT = 178.1
IF(STEAMP.EQ.9.8) STEAMT = 179.0
IF(STEAMP.EQ.10.0) STEAMT = 179.9
IF(STEAMP.EQ.10.5) STEAMT = 182.0
IF(STEAMP.EQ.11.0) STEAMT = 184.1
IF(STEAMP.EQ.11.5) STEAMT = 186.0
IF(STEAMP.EQ.12.0) STEAMT = 188.0
IF(STEAMP.EQ.12.5) STEAMT = 189.8
IF(STEAMP.EQ.13.0) STEAMT = 191.6
IF(STEAMP.EQ.13.5) STEAMT = 193.3
IF(STEAMP.EQ.14.0) STEAMT = 195.0
IF(STEAMP.EQ.14.5) STEAMT = 196.7
IF(STEAMP.EQ.15.0) STEAMT = 198.3
IF(STEAMP.EQ.15.5) STEAMT = 198.8
IF(STEAMP.EQ.16.0) STEAMT = 201.4
IF(STEAMP.EQ.16.5) STEAMT = 202.9
IF(STEAMP.EQ.17.0) STEAMT = 204.3
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PPENDIX B

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IF(STEAMP.EQ.17.5) STEAMT = 205.7
IF(STEAMP.EQ.18.0) STEAMT = 207.1
IF(STEAMP.EQ.18.5) STEAMT = 208.5
IF(STEAMP.EQ.19.0) STEAMT = 209.8
IF(STEAMP.EQ.19.5) STEAMT = 211.1
IF(STEAMP.EQ.20.0) STEAMT = 212.4
IF(STEAMP.EQ.20.5) STEAMT = 213.6
IF(STEAMP.EQ.21.0) STEAMT = 214.8
IF(STEAMP.EQ.21.5) STEAMT = 216.1
IF(STEAMP.EQ.22.0) STEAMT = 217.2
IF(STEAMP.EQ.22.5) STEAMT = 218.4
IF(STEAMP.EQ.23.0) STEAMT = 219.6
IF(STEAMP.EQ.23.5) STEAMT = 220.7
IF(STEAMP.EQ.24.0) STEAMT = 221.8
IF(STEAMP.EQ.24.5) STEAMT = 222.9
IF(STEAMP.EQ.25.0) STEAMT = 223.9
IF(STEAMP.EQ.25.5) STEAMT = 225.0
IF(STEAMP.EQ.26.0) STEAMT = 226.0
IF(STEAMP.EQ.26.5) STEAMT = 227.1
IF(STEAMP.EQ.27.0) STEAMT = 228.1
IF(STEAMP.EQ.27.5) STEAMT = 229.1
IF(STEAMP.EQ.28.0) STEAMT = 230.0
IF(STEAMP.EQ.28.5) STEAMT = 231.0
IF(STEAMP.EQ.29.0) STEAMT = 232.0
IF(STEAMP.EQ.29.5) STEAMT = 232.9
IF(STEAMP.EQ.30.0) STEAMT = 233.8
IF(STEAMP.EQ.31.0) STEAMT = 235.7
IF(STEAMP.EQ.32.0) STEAMT = 237.4
IF(STEAMP.EQ.33.0) STEAMT = 239.2
IF(STEAMP.EQ.34.0) STEAMT = 240.9
IF(STEAMP.EQ.35.0) STEAMT = 242.5
IF(STEAMP.EQ.36.0) STEAMT = 244.2
IF(STEAMP.EQ.37.0) STEAMT = 245.8
IF(STEAMP.EQ.38.0) STEAMT = 247.3
IF(STEAMP.EQ.39.0) STEAMT = 248.8
IF(STEAMP.EQ.40.0) STEAMT = 250.3
IF(STEAMP.EQ.41.0) STEAMT = 251.8
IF(STEAMP.EQ.42.0) STEAMT = 253.2
IF(STEAMP.EQ.43.0) STEAMT = 254.7
IF(STEAMP.EQ.44.0) STEAMT = 256.0
IF(STEAMP.EQ.45.0) STEAMT = 257.4
IF(STEAMP.EQ.46.0) STEAMT = 258.8
IF(STEAMP.EQ.47.0) STEAMT = 260.1
IF(STEAMP.EQ.48.0) STEAMT = 261.4
IF(STEAMP.EQ.49.0) STEAMT = 262.7
IF(STEAMP.EQ.50.0) STEAMT = 263.9
IF(STEAMP.EQ.51.0) STEAMT = 265.2
IF(STEAMP.EQ.52.0) STEAMT = 266.4
IF(STEAMP.EQ.53.0) STEAMT = 267.6
IF(STEAMP.EQ.54.0) STEAMT = 268.8
IF(STEAMP.EQ.55.0) STEAMT = 269.9
IF(STEAMP.EQ.56.0) STEAMT = 271.1
IF(STEAMP.EQ.57.0) STEAMT = 272.2
IF(STEAMP.EQ.58.0) STEAMT = 273.4
IF(STEAMP.EQ.59.0) STEAMT = 274.5
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APPENDIX B

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IF(STEAMP.EQ.60.0) STEAMT = 275.6
IF(STEAMP.EQ.61.0) STEAMT = 276.6
IF(STEAMP.EQ.62.0) STEAMT = 277.7
IF(STEAMP.EQ.63.0) STEAMT = 278.8
IF(STEAMP.EQ.64.0) STEAMT = 279.8
IF(STEAMP.EQ.65.0) STEAMT = 280.8
IF(STEAMP.EQ.66.0) STEAMT = 281.9
IF(STEAMP.EQ.67.0) STEAMT = 282.9
IF(STEAMP.EQ.68.0) STEAMT = 283.9
IF(STEAMP.EQ.69.0) STEAMT = 284.8
IF(STEAMP.EQ.70.0) STEAMT = 285.8
IF(STEAMP.EQ.71.0) STEAMT = 286.8
IF(STEAMP.EQ.72.0) STEAMT = 287.7
IF(STEAMP.EQ.73.0) STEAMT = 288.7
IF(STEAMP.EQ.74.0) STEAMT = 289.6
IF(STEAMP.EQ.75.0) STEAMT = 290.5
IF(STEAMP.EQ.76.0) STEAMT = 291.4
IF(STEAMP.EQ.77.0) STEAMT = 292.3
IF(STEAMP.EQ.78.0) STEAMT = 293.2
IF(STEAMP.EQ.79.0) STEAMT = 294.1
IF(STEAMP.EQ.80.0) STEAMT = 295.0
IF(STEAMP.EQ.81.0) STEAMT = 295.9
IF(STEAMP.EQ.82.0) STEAMT = 296.7
IF(STEAMP.EQ.83.0) STEAMT = 297.6
IF(STEAMP.EQ.84.0) STEAMT = 298.4
IF(STEAMP.EQ.85.0) STEAMT = 299.2
IF(STEAMP.EQ.86.0) STEAMT = 300.1
IF(STEAMP.EQ.87.0) STEAMT = 300.9
IF(STEAMP.EQ.88.0) STEAMT = 301.7
IF(STEAMP.EQ.89.0) STEAMT = 302.5
IF(STEAMP.EQ.90.0) STEAMT = 303.3
IF(STEAMP.EQ.91.0) STEAMT = 304.1
IF(STEAMP.EQ.92.0) STEAMT = 304.9
IF(STEAMP.EQ.93.0) STEAMT = 305.7
IF(STEAMP.EQ.94.0) STEAMT = 306.5
IF(STEAMP.EQ.95.0) STEAMT = 307.2
IF(STEAMP.EQ.96.0) STEAMT = 308.0
IF(STEAMP.EQ.97.0) STEAMT = 308.7
IF(STEAMP.EQ.98.0) STEAMT = 309.5
IF(STEAMP.EQ.99.0) STEAMT = 310.2
IF(STEAMP.EQ.100.0) STEAMT = 311.0
RETURN
END
```

APPENDIX C

PHYSICAL PROPERTIES OF BENZENE

BOILING POINT	80.1000 C
SPECIFIC HEAT	1.7880 KJ/KgC
CRITICAL PRESSURE	47.0700 Bar
LATENT HEAT	395.6530 KJ/Kg
SENSITIVE HEAT MAXIMUM	143.2188 KJ/Kg
TOTAL HEAT LOAD	1047.8060 KW
DUTY	1100.1970 KW
STEAM TEMPERATURE	161.4000 C
MEAN TEMPERATURE DIFFERENCE	81.3000 C
HEAT TRANSFER AREA	11.2771 SQ.m
HEAT FLUX	97.5600 KW/SQ.m
BOILING COEFFICIENT	7307.9230 W/SQ.m c
TOTAL ANNUAL VARIABLE COST	
FOR VAPORISER AND ITS OP	556171.9000 $/YEAR

APPENDIX C

PHYSICAL PROPERTIES OF METHYLENE CHLORIDE

BOILING POINT	40.0000 C
SPECIFIC HEAT	1.2140 KJ/KgC
CRITICAL PRESSURE	99.4400 Bar
LATENT HEAT	330.7570 KJ/Kg
SENSITIVE HEAT MAXIMUM	48.5600 KJ/Kg
TOTAL HEAT LOAD	737.5608 KW
DUTY	774.4388 KW
STEAM TEMPERATURE	128.7000 C
MEAND TEMPERATURE DIFFERENCE	88.7000 C
HEAT TRANSFER AREA	7.2758 SQ.m
HEAT FLUX	106.4400 KW/SQ.m
BOILING COEFFICIENT	10200.7600 W/SQ.m c
TOTAL ANNUAL VARIABLE COST FOR VAPORISER AND ITS OPERATION	358833.3000 $/YEAR

APPENDIX C

PHYSICAL PROPERTIES OF n-HEPTANE

BOILING POINT	98.4000 C
SPECIFIC HEAT	2.2190 KJ/KgC
CRITICAL PRESSURE	26.3800 Bar
LATENT HEAT	318.1970 KJ/Kg
SENSITIVE HEAT MAXIMUM	218.3496 KJ/Kg
TOTAL HEAT LOAD	745.2036 KW
DUTY	782.4637 KW
STEAM TEMPERATURE	128.7000 C
MEAND TEMPERATURE DIFFERENCE	30.3000 C
HEAT TRANSFER AREA	28.6932 SQ.m
HEAT FLUX	27.2700 KW/SQ.m
BOILING COEFFICIENT	2585.3910 W/SQ.m c
TOTAL ANNUAL VARIABLE COST FOR	
VAPORISER AND ITS OPERATION	1062816.0000 $/YEAR

APPENDIX C

PHYSICAL PROPERTIES OF n-OCTANE

BOILING POINT	125.7000 C
SPECIFIC HEAT	1.5070 KJ/KgC
CRITICAL PRESSURE	24.2200 Bar
LATENT HEAT	297.2630 KJ/Kg
LATENT HEAT	297.2630 KJ/Kg
TOTAL HEAT LOAD	675.9623 KW
DUTY	709.7604 KW
STEAM TEMPERATURE	158.8000 C
MEAND TEMPERATURE DIFFERENCE	33.1000 C
HEAT TRANSFER AREA	35.7382 SQ.m
HEAT FLUX	19.8600 KW/SQ.m
BOILING COEFFICIENT	2038.7870 W/SQ.m c
TOTAL ANNUAL VARIABLE COST	
FOR VAPORISER AND ITS OPERATION	884977.1000 $/YEAR

APPENDIX C

PHYSICAL PROPERTIES OF n-PENTANE

BOILING POINT	36.1000 C
SPECIFIC HEAT	2.1770 KJ/KgC
CRITICAL PRESSURE	32.3600 Bar
LATENT HEAT	355.8780 KJ/Kg
SENSITIVE HEAT MAXIMUM	78.5897 KJ/Kg
TOTAL HEAT LOAD	603.4273 KW
DUTY	633.5986 KW
STEAM TEMPERATURE	115.2000 C
MEAND TEMPERATURE DIFFERENCE	79.1000 C
HEAT TRANSFER AREA	8.0101 SQ.m
HEAT FLUX	79.1000 KW/SQ.m
BOILING COEFFICIENT	5693.1550 W/SQ.m c
TOTAL ANNUAL VARIABLE COST	
FOR VAPORISER AND ITS OPERATION	329481.8000 $/YEAR

APPENDIX C

PHYSICAL PROPERTIES OF TETRACHLOROMETHANE

BOILING POINT	76.5000 C
SPECIFIC HEAT	0.8470 KJ/KgC
CRITICAL PRESSURE	45.6000 Bar
LATENT HEAT	300.1900 KJ/Kg
SENSITIVE HEAT MAXIMUM	64.7955 KJ/Kg
TOTAL HEAT LOAD	506.9243 KW
DUTY	532.2704 KW
STEAM TEMPERATURE	133.50 C
MEAN TEMPERATURE DIFFERENCE	57.0000 C
HEAT TRANSFER AREA	9.3381 SQ.m
HEAT FLUX	57.0000 KW/SQ.m
BOILING COEFFICIENT	4968.1190 W/SQ.m c
TOTAL ANNUAL VARIABLE COST FOR VAPORISER AND ITS OPERATION	384106.1000 $/YEAR

APPENDIX C

PHYSICAL PROPERTIES OF EHTYLENE GLYCOL

BOILING POINT =	197.0000 C
SPECIFIC HEAT =	2.3820 KJ/KgC
CRITICAL PRESSURE =	47.1200 Bar
LATENT HEAT =	812.3900 KJ/Kg
SENSITIVE HEAT MAXIMUM =	469.2540 KJ/Kg
SENSITIVE HEAT MAXIMUM =	469.2540 KJ/Kg
TOTAL HEAT LOAD =	1780.0610 KW
DUTY	1869.0640 KW
STEAM TEMPERATURE =	201.4000 C
MEAND TEMPERATURE DIFFERENCE =	4.4000 C
HEAT TRANSFER AREA =	606.8398 SQ.m
HEAT FLUX =	3.0800 KW/SQ.m
BOILING COEFFICIENT =	650.7759 W/SQ.m c
TOTAL ANNUAL VARIABLE COST FOR VAPORISER AND ITS OPERATION	23305620.0000 $/YEAR

APPENDIX C

PHYSICAL PROPERTIES OF ANILINE

BOILING POINT	184.0000 C
SPECIFIC HEAT	2.0640 KJ/KgC
CRITICAL PRESSURE	51.9900 Bar
LATENT HEAT	447.9880 KJ/Kg
SENSITIVE HEAT MAXIMUM	379.7760 KJ/Kg
TOTAL HEAT LOAD	1149.6720 KW
DUTY	1207.1560 KW
STEAM TEMPERATURE	247.3000 C
MEAND TEMPERATURE DIFFERENCE	63.3000 C
HEAT TRANSFER AREA	27.2434 SQ.m
HEAT FLUX	44.3100 KW/SQ.m
BOILING COEFFICIENT	4340.8300 W/SQ.m c
TOTAL ANNUAL VARIABLE COST FOR VAPORISER AND ITS OPERATION	1306441.0000 $/YEAR

APPENDIX C

PHYSICAL PROPERTIES OF ACETONE

BOILING POINT	56.1000 C
SPECIFIC HEAT	2.1600 KJ/KgC
CRITICAL PRESSURE	58.3400 Bar
LATENT HEAT	523.3500 KJ/Kg
SENSITIVE HEAT MAXIMUM	121.1760 KJ/Kg
TOTAL HEAT LOAD	1253.2450 KW
DUTY	1315.9070 KW
STEAM TEMPERATURE	131.2000 C
MEAND TEMPERATURE DIFFERENCE	75.1000 C
HEAT TRANSFER AREA	17.5221 SQ.m
HEAT FLUX	75.1000 KW/SQ.m
BOILING COEFFICIENT	6527.3750 W/SQ.m c
TOTAL ANNUAL VARIABLE COST FOR VAPORISER AND ITS OPERATION	720740.7000 $/YEAR

APPENDIX C

PHYSICAL PROPERTIES OF n-BUTANE

BOILING POINT	56.1000 C
SPECIFIC HEAT	2.5100 KJ/KgC
CRITICAL PRESSURE	38.0000 Bar
LATENT HEAT	326.0000 KJ/Kg
SENSITIVE HEAT MAXIMUM	140.8110 KJ/Kg
TOTAL HEAT LOAD	648.3486 KW
DUTY	680.7660 KW
STEAM TEMPERATURE	126.1000 C
MEAND TEMPERATURE DIFFERENCE	70.0000 C
HEAT TRANSFER AREA	9.7252 SQ.m
HEAT FLUX	70.0000 KW/SQ.m
BOILING COEFFICIENT	5443.9040 W/SQ.m c
TOTAL ANNUAL VARIABLE COST FOR VAPORISER AND ITS OPERATION	400030.9000 $/YEAR

APPENDIX D

1. **Calculations for Converting Pressure from Psig to Bar.**

(a) Calculations for high pressure steam (HPS)

Pressure in psig = 500 psig

Pressure in bar = pressure in psig/14.503 = 500/14.503

Pressure in bar = 34.48 bar.

For high pressure steam, steam pressure is greater or equal to 34. 48 bar (Steam pressure $\geq$ 34.48 bar)

(b) Calculations for medium pressure steam (MPS)

Pressure in psig = 100psig

Pressure in bar = 100/14.503 = 6.90 bar

For medium pressure steam, steam pressure is greater or equal to 100 bar but less than 34.48 bar (6.90 Steam pressure $\leq$ 34.48)

(c) Calculations for low pressure steam (LPS) or Exhaust.

Pressure in psig = 0 psig

Pressure in bar= 0 psig

For Exhaust or low pressure steam, steam pressure is greater than 0 but less than 100 bar.

2. Calculations for Converting Mass from Pounds to Kilogram

Mass in pounds = 1000 1b

Mass in kilogram = mass in pounds x 0.454

Mass in kilogram = 1000 x 0.454 = 454 kg.

3. Calculations for the Cost of Steam per Kilogram (C_u):

(a) For high pressure steam, range for cost of steam is

7.00 - 5.00/454kg

Therefore, cost of steam per kilogram (C_U) will be

$$\frac{3.00}{454} - \frac{4.00}{454} = 0.0088 - 0.011/kg$$

(b) for medium pressure steam range for cost of steam is

3.00 – 4.00/454kg

Therefore, cost of steam per kilogram (C_U) will be

$$\frac{3.00}{454} - \frac{4.00}{454} = 0.0066 - 0.0088/kg$$

(c) For Exhaust or low pressure steam, range for cost of steam is 2.00 – 3.00/454kg

Therefore, cost of steam per kilogram (C_U) will be

$$\frac{2.00}{454} - \frac{3.00}{454}$$

= 0.0044 – 0.0066/kg

Conversion Factors for Some Common S.I. Units:

An asterisk (*) denotes an exact relationship.

Time:

*	1 min	-	60 secs
*	I hr	-	3.6ks
*	1day	-	86.4ks
*	1year	-	31.5ms

Power (Heat Flow)

1 hp (British) - 745.70 w

1 hp (metric) - 735.50 w

1 erg/s - 10^{-7}w

1ft lbf/s - 1.3558 w

1Btu/h - 0.29307w

1ton of Refrigeration - 3516.9 w

Area:

*1lin^2 - 45.16 mm^2

1ft^2 - 0.092903m^2

1yd - 0.83613 m^2

1acre - 4046.9 m^2

1mile^2 - 2.590km^2

Heat Flux:

1Btu/hft^2 - 3.1546w/m^2

1kcal/hm^2 - 1.163 w/m^2

Heat Transfers Coefficient

1Btu/hft^{2o}f - 5.6783 w/m^{2}c

Mass:

10^7	-	28.352g
*1lb	-	0.45359239kg
1cut	-	50.8023kg
1ton	-	1016.06kg

Latent Heat:

* 1Btu/lb - 2.326 kg

Specific Heat Capacity:

* 1Btu/lb$_f$ - 4.1868kJ/kg^{o}c

Pressure:

1lbf/in^2	-	6.8948 K/m^2
1tonf/in^2	-	15.444 MN/m^2
1lbf/ft^2	-	47.880 N/m^2
*1atm	-	101.325KN/m^2
1kgf/cm2	-	98.0665KN/m^2
*bar	-	105 N/m^2
1psig	-	6895. 1252 N/m^2
1ft water	-	2.9791 KN/m^2
1 in. water	-	249.09 KN/m^2
1in. Hg	-	3.3864 KN/m^2
1mm Hg (1torr)	-	133.32 N/m^2

APPENDIX E

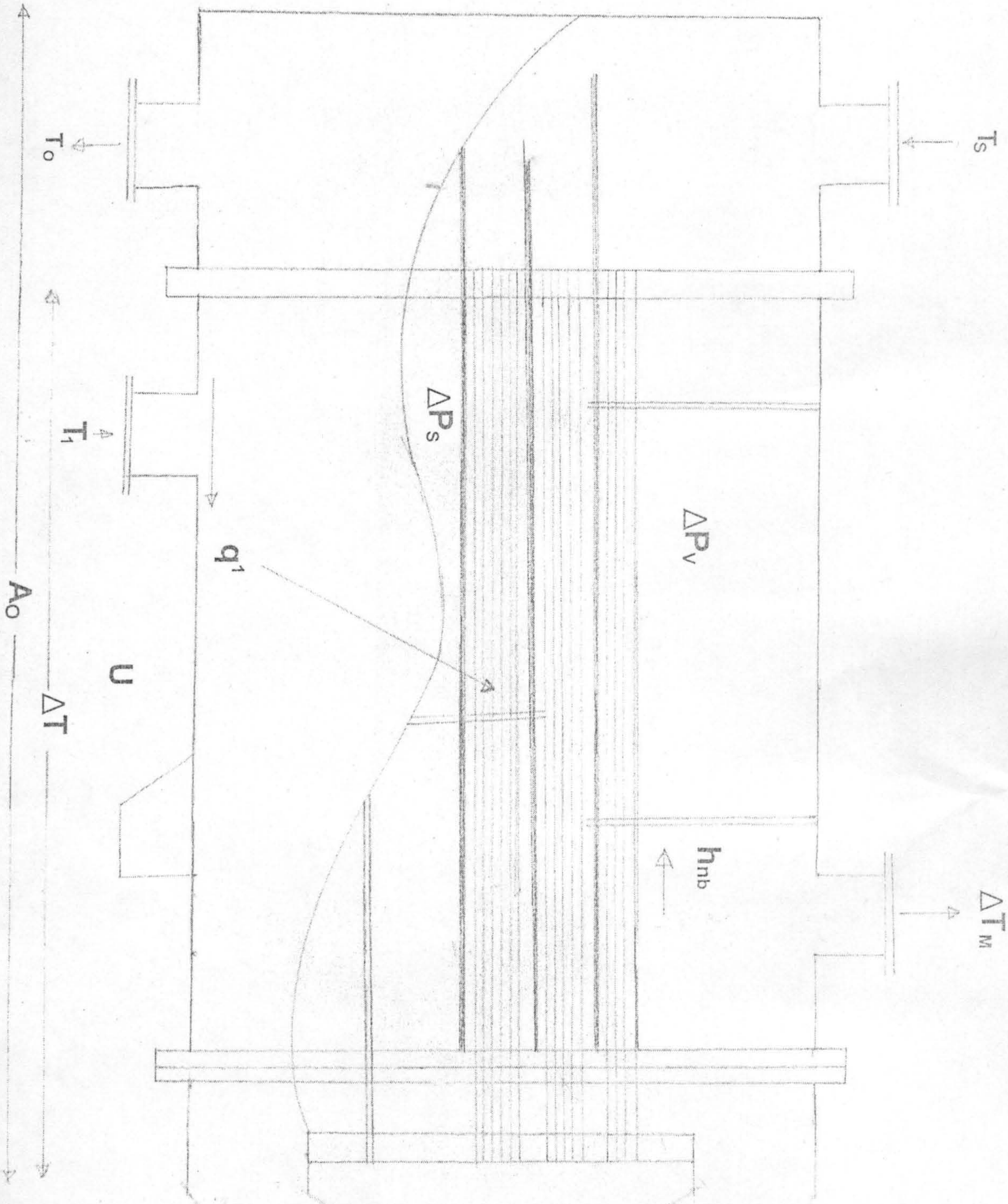

FIG E : DIAGRAM OF VAPORISER