DESIGN OF A PLANT TO PRODUCE 10,000 LITERS PER DAY OF CASHEW KERNEL OIL

BY

AKO EDACHE HUBERT

2000/9532EH

DEPARMENT OF CHEMICAL ENGINEERING

FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA

OCTOBER, 2006

DESIGN OF A PLANT TO PRODUCE 10,000 LITERS PER DAY OF CASHEW KERNEL OIL

BY

AKO EDACHE HUBERT

2000/9532EH

A RESEARCH PROJECT SUBMITTED TO THE DEPARTMENT OF CHEMICAL ENGINEERING, SCHOOL OF ENGINEERING AND ENGINEERING TECHNOLOGY, FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGER STATE, NIGERIA.

IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF BACHELOR OF ENGINEERING (B.ENG.) DEGREE IN CHEMICAL ENGINEERING

OCTOBER, 2006

DECLARATION

I hereby declare that this project work was carried out by me under the supervision of Engr. (Mrs.) E.J. Eterigho of the Department of Chemical Engineering.

This project is a record of my own personal research work and all the information from the published and unpublished work of others is duly acknowledged by way of references.

.... 02/11/06

Ako Edache Hubert Date

CERTIFICATION

This is to certify that this research project titled" Design of a plant to produce 10,000 liter per day of cashew kernel.oil" was carried out by Ako Edache Hubert and submitted to the Department of Chemical Engineering, School of Engineering and Engineering Technology, Federal University of Technology, Minna, Niger State, in Partial fulfillment of the requirement for the award of Bachelor of Engineering (B. Eng) Degree in Chemical Engineering.

Engr. E. J. Eterigho (Mrs)	05/11/08
(Project Supervisor)	Date
Dr. M.O. Edoga	
(Head of Department)	Date
External Supervisor	Date

DEDICATION

This project is dedicated to Victoria, for whom that name and word was made and who gave mw my first chance in life.

ACKNOWLEDGMENT

All glory is to God for he is the author and finisher of my life.

My supervisor, Engineer (Mrs) Elizabeth Eterigho, you are more than a lecturer to me. You are a mother, a motivator and an inspiration; an Angel, in disguise, sent to this world to show people what it means to be good.

I want to thank every member of my family for their support and prayers throughout my stay in school, especially my mother. Ma, words can not describe my gratitude to you. To my uncles- Matthew, Hilary, Tony and Emmanuel- I say a big thank you. Calista, thanks for all the criticism. Rose, Dick, Ladi, Christie, Blessing and Aunt Pauline- I love you all.

To all my friends- where do I start from.......? Jude, Abdul, Philip, Chux, S.A, Andrew (Dr. Dre), Heinrich, Linda, Yinka, I.J (m'lv), Afoma, Ooja, Vincent, Egah, Gaby suzuki, Brother, Dee, Jummai .... I am sorry I can't mention all your names because if I try to, I won't finish writing.

Finally, to all my class mates and lecturers, especially Engr. Abdulwahab Giwa A.K.A Alpha, thank you for all the times you have helped me out in the pursuit of the Golden Fleece.

ABSTRACT

The design of the plant to produce 10,000liters/day of cashew kernel oil was carried out using computer spread sheet for the material balance and MathCAD for the energy balance, equipment specification and the economic analysis of the plant. 270,888 kg/day of cashew kernels yielded the desired 10,000 liters/day of cashew kernel oil. The plant has an over all energy requirement of 758,700 kJ/h. The height and diameter of the conical crusher was found to be 6.113m and 3.057m. The height and diameter of the cylindrical extractor was found to be 9.491m and 4.745m respectively. The height and diameter of the cylindrical desolventiser was found to be 4.165m and 2.082m respectively. The height and diameter of the cylindrical column was found to be 5.56m and 2.78m respectively. From the economic analysis, the plant was estimated to have a rate of return and pay back period of approximately 50% and 2 years respectively.

TABLE OF CONTENTS

CHAPTER ONE

1.0 INTRODUCTION

With the recent trends in governmental policies, Nigeria is gradually moving towards diversification of its revenue base from a solely crude oil based economy to one where other sectors play a central role. Also there is a sharp reduction in the importation of foreign goods which was the case some years ago.

This trend has necessitated the development of the non oil sectors of the economy paripasu with the establishment of industries for the production of goods that were here-to-fore imported and any move towards this direction is welcomed by the government as being evidenced by the rapid growth of small and medium scale manufacturing enterprises. This is the motivation for this work.

Nigeria is the third largest producer of cashew nuts in the world and since research has shown that the cashew kernel oil (CKO) is edible and can be used in the pharmaceutical and cosmetics industries, this abundant raw material can be exploited to produce oil which can compete favorably with the imported oil brands.

No evidence of the commercial production of CKO has been found in the world and by this, the proposed plant could be the sole producer of CKO in the world making it a very lucrative venture since demand will be high due to the lower cost as compared to other oil brands. This low price is as a result of a cut in the cost of production which stems from the fact that the raw material (cashew nuts) occurs abundantly in the country, is easy to harvest and the cashew tree does not need too much care, all these facts as compared to the raw materials for producing groundnut oil, soyabean oil e.t.c which will require that it be planted every year, weeded, fertilized and harvested by either intensive labour or mechanically, all these leading to a high cost of production.

This work aims at designing a plant that will break even in a very short time (maximum of 3 years), there by ensuring that investors into such a project start making profit from the project in no time.

1.1 Aim and Objectives

This project work is aimed at designing a plant to produce cashew kernel oil with a very short pay back period (maximum of 3 years). Such a plant when built and running will:

I. Provide employment for labor in the country.

II. Reduce dependability on imported oil by increasing local production.

III. Diversification of the revenue base of the government.

IV. Cut the cost of production of vegetable oil due to the abundant and more easily sourced raw material.

V. Increase the supply of vegetable oil in the market which will translate to a cut in the selling price.

1.2 Approach

This design work will be carried out using a spread sheet for the material balance and MathCAD for the energy balance, equipments selection and specification, the costing of individual equipments and the economic analysis of the plant.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Cashew (Anarcadium occidenta L.)

The cashew is a member of the anacardiaceae family, allied with mango, pistachio, poison ivy, poison oak e.t.c. The anacardiaceae is known for having resinous back and often caustic oils in leaves, bark and fruits.

The cashew industry had to overcome severe limitation posed by caustic oils in the nut shell. But today, the caustic oil that made the plant domestication difficult has become a valuable byproduct of cashew nut production.

Cashew is a native of northeastern Brazil in the area between the Atlantic and the amazon rain forest. The vegetation of the area is dry forest savanna woodland or thorn scrubs, and includes the almost desert like Caatinga. Cashew is sometimes referred to as a rain forest specie and nuts are found in products that have a rain forest friendly label or connotation. Although the trees will grow in tropical wet forest, they rarely produce many nuts and production is far greater in areas with distinct wet and dry season, such as its native range in Brazil, India and east Africa (FAO, 2002).

The Portuguese introduced cashew into the west coast of India and the east coast of Africa in the 16th century shortly after its discovery in 1578. It was planted in India initially to reduce erosion and uses for the nut and pseudo fruit, the cashew apple, were developed much later. The trees were adapted to the region and became naturalized in Central America and the Caribbean islands. Natural domestication predated the arrival of the Europeans, although international nut trade did not occur until the 1920s. Native South Americans discovered that roasting nut in the fire wood would remove the caustic oil allowing the nut to be cracked and eaten without any ill effects. The roasting technique was either not known or not appreciated outside the native range so the cashew apple was the first product to be consumed, with the nut being discarded. Natives also knew of many medicinal uses for the apple juice, bark and caustic seed oil which were later exploited by the Europeans. (greencottage, 2000.)

India developed a more refined means of removing the caustic oil and this country is now being given credited for developing the modern nut industry. India led the world for many years in nut production until recently when production in Vietnam surged about three fold in a few years. In its native Brazil cashew production ranks in the top five of the world, and virtually all cashew apple juice products come from this country. Preliminary data suggests that cashew production surpassed almond in 2003, and thus, cashew now claims the title of the number one nut crop in the world.

1,870,284 million tonnes of cashew was produced commercially in 32 countries (FAO, 2002). World production doubled in 1994, with most countries experiencing a substantial increase, particularly Vietnam.

The top ten countries in the world based on cashew production is shown in the table below:

Table 2.1: Top ten countries in the world based on cashew production. (FAO, 2002).

Country	Percentage production
1. Vietnam	28
2. India	25
3. Nigeria	10
4. Brazil	8
5. Tanzania	5
6. Indonesia	4
7. Guinea-Bissau	4
8. Coted'ivore	4
9. Mozambique	3
10. Benin	2

The true botanical fruit is nut about 1 inch long shaped like a small boxing glove, hanging below a fleshy, swollen peduncle called the cashew apple or pseudo fruit The cashew apple resembles a pear in shape and size, is juicy, fibrous and astringent tasting. It has thin skin of either yellow or light red color, and yellow flesh fruit are borne singly or in small clusters and mature in 60-90 days. The nut develops first, followed by the rapid swelling of the cashew in the last few weeks of its growth.

The nut shell has an inner and outer wall separated by a honeycomb tissue infused with caustic oil. Cracking the nuts fresh results in the oil contaminating the kernel, so nuts are roasted to drive off the oil before shelling. The nuts are about 22-30% kernel by weight and kernels are difficult to extract whole compared to other tree nuts.

The composition of the cashew kernel is shown in the table below:

Table 2.2: Composition of cashew kernel. (Weiss, 2000)

Component	Percentage
1. water	3-7
2. protein	18-22
3. fats	46
4. carbohydrate	27
5. crude fiber	1.1

2.2 Cashew Kernel Oil (CKO)

The cashew kernel oil (CKO) is brownish, sweet oil whose property can be conveniently divided into physical and chemical properties.

Tables of the physical and chemical properties of CKO are shown below:

Table 2.3: Physical properties of CKO.(Weiss, 2000)

Properties	Value/Remarks
1. color	brown
2. odor	sweet
3. specific gravity	0.803
4. boiling point	125°C
5. ref. Index at 29°C	1.433
6. density	820kg/m^3
7. viscosity at 29°C	0.00359kg/ms

Table 2.4: Chemical properties of CKO (Weiss, 2000)

Properties	Values
1. acid value	3.37
2. saponification value	192.15
3. iodine	71.06
4. pH	5.6

2.3 Uses of Cashew Kernel Oil

From research studies carried out, it has been discovered that CKO is edible when fortified with vitamin A. (Oladele, 2005). Cashew kernel oil can be utilized in the pharmaceutical industries in lowering cholesterol level in blood, in helping cure diabetes and kidney, in relieving rheumatism and for curing skin diseases like eczema (FAO, 2002).

It can also be used as a carrier for ligaments, as an anesthetic in leprosy and psoriasis and for blisters, warts, corns and ulcers.

The CKO has a delicate and pleasant hazelnut smell which does not persist when incorporated in formulations. Its natural richness in vitamin E protects it against oxidation and gives the formulated product a free radical scavenging activity. As all unsaturated vegetable oils, it can be used for skin care products, hand cream, massage oils, sun and after sun products and lip balms. (Greencottage, 2004).

2.4 Production Techniques

CKO is produced using cashew kernel as raw material. The kernel is extracted from the shell by cleaning the cashew nut, soaking in water, roasting, shelling, and extraction of the kernel, drying, peeling, grading and packaging.

The CKO can then be extracted from the nut either by the use of hydraulic press, screw press or solvent extraction. Solvent extraction of the oil from the kernel is preferred because about 98% extraction can be achieved as compared to 80% and 90% for the hydraulic and screw presses respectively. (Shreve's, 1984).

CHAPTER THREE

3.0 PROCESS DESCRIPTION

The CKO will be processed via solvent extraction using hexane as the solvent. The main operations involved in the extraction of the CKO from the kernels involves the extraction of the oil using hexane and then recovery of hexane from the cake and miscella,(mixture of oil and solvent), leaving the extractor. A detailed description of the process is given below.

3.1 Crushing of The Cashew Kernels

The raw materials for the process are cashew kernels which are fed into a crusher at room temperature. This operation is carried out to reduce the size of the cashew kernels and hence provide a large surface area for solvent action. Due to the energy of crushing, there is a 20°C rise in the temperature of the cashew kernels. Crusher rollers are used because the crusher can be set to give any convenient size of product.

3.2 Extraction Of Oil From The Cashew Kernels

The crushed kernels are fed into an extractor where extraction takes place using hexane as a solvent which is fed into the extractor at room temperature. After extraction the miscella leaves the extractor at 39°C and since the heat gained by the hexane stream is equal that lost by the kernel stream, the cake leaves the extractor at 37°C. The miscella is made up of 25% oil and 10% of the oil is entrained in the cake. Equal amount of hexane and cashew kernels are used for the extraction.

A counter current flow of the streams is favored and hence a Bollman's extractor is employed since the rotation of its perforated baskets containing the kernels allows the solvent to permeate through hence allowing for continuous extraction.

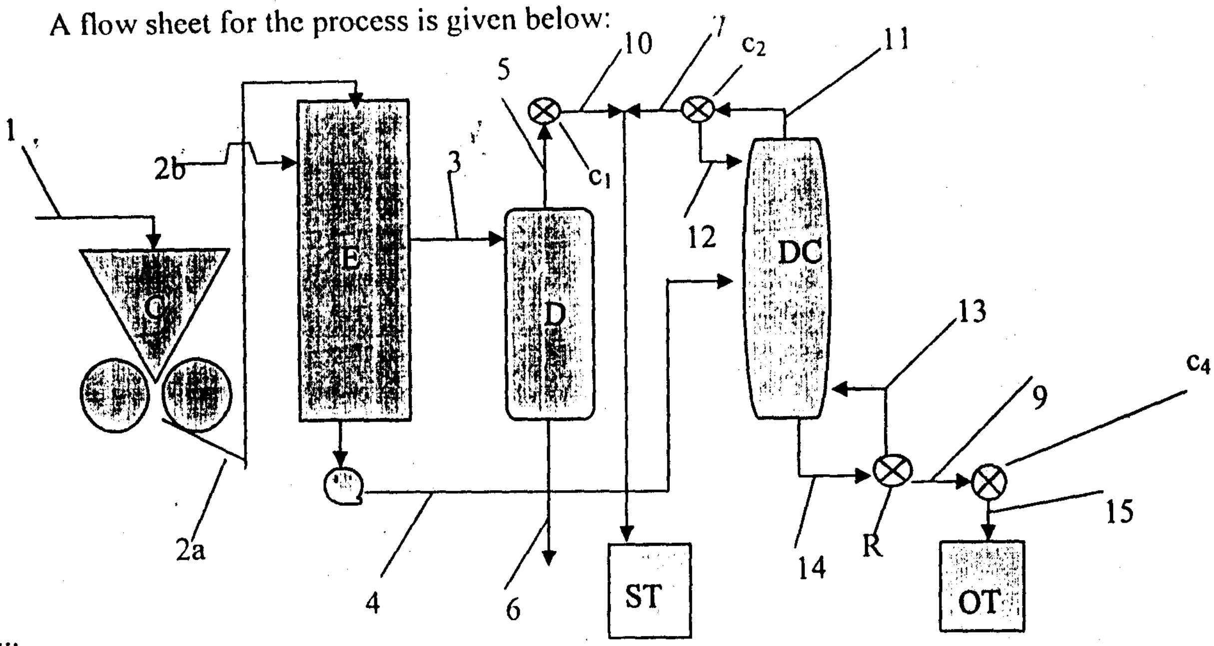
3.3 Desolventising The Cake

The desolventiser is an evaporator which contains plates with scrapers on each plate. As the mixture of cashew kernels and hexane is fed into the top of the desolventiser, the scrapers on each plate scrape the cake to a lower plate while hexane evaporates. The desolventiser is operated at atmospheric pressure and at 70°C.

3.4 Solvent Recovery From Miscella

The miscella from the evaporator is pumped to a distillation column operated at atmospheric pressure and at reflux of 3. The oil comes out of the bottom at a100°C and is cooled to room temperature and stored. The column condenser cools the recovered hexane to 25°C and the hexane is sent to storage.

A flow sheet for the process is given below:



Key:

Stream	Description
1	cashew kernels
2a	crushed cashew kernels
3	cashew cake and entrained solvent
4	miscella
5	recovered hexane from cake
6	cake to dryer, toaster and storage
7	cooled hexane from column
9	oil from column reboiler
10	cooled hexane from desolventiser
11	vapor from column
12	reflux to column
13	reboiler vapor
14	bottom from column into reboiler
15	cooled oil from reboiler
2b	hexane to extractor

Symbol	Name
C	crusher
E	extractor
D	desolventiser
DC	distillation column
ST	solvent tank
OT	oil tank
c1	condenser 01
c2	condenser 02
c4	condenser 04
R	reboiler

CHAPTER FOUR

4.0 EQUIPMENT DESIGN AND PLANT ECONOMIC ANALYSIS

The Equipment design involves the material and energy balances across the major equipments and also the selection and specification of these equipments. The Economic analysis covers the purchased equipment costs, total capital investment required for the plant and also the total production cost. It also estimates the income of the plant and gives the estimated rate of return and pay back period.

4.1 Equipment Design

Overall material balance

For a system without accumulation, the overall material balance is given as

INPUT = OUTPUT..4.1

cashew kernels = cashew cake + cashew kernel oil

The design specifies that 66% of the fat be extracted and since 10,000liters/day of CKO is specified, the the starting mass of cashew can be obtained.

$\rho_{oil} := 820 \frac{kg}{m^3}$ $\qquad vol_{oil} := 10 \frac{m^3}{day}$

$mass_{oil} := \rho_{oil} \cdot vol_{oil}$ $\qquad mass_{oil} = 8.2 \times 10^3 \frac{kg}{day}$

$mass\_cash\_kern := \frac{mass_{oil}}{46\% \cdot (66\%)}$ $\qquad mass\_cash\_kern = 2.701 \times 10^4 \frac{kg}{day}$

From the overall material balance

$mass\_cake := mass\_cash\_kern - mass_{oil}$ $\qquad mass\_cake = 1.881 \times 10^4 \frac{kg}{day}$

Overall energy balance

An overall energy balance of the plant is given as

ENTHALPY OF INPUTS + HEAT LOAD = ENTHALPY OF OUTPUTS.........................4.2

enthalpy of cashew kernels + heat load = enthalpy of cashew cake + enthalpy of oil

The cashew kernels enter the system at 25°C. The CKO and cashew cake leave at 25°C and 70°C respectively. The refrence temperature is taken to be 25°C. This implies that

$\Delta H_{cash\_kern} := 0 \frac{kJ}{h}$ $\qquad \Delta H_{CKO} := 0 \frac{kJ}{h}$

$\Delta H_{cake} := 7.587 \times 10^4 \frac{kJ}{h}$

From equation 4.2, the heat load for the system is given as

$heat\_load := \Delta H_{cake} + \Delta H_{CKO} - \Delta H_{cash\_kern}$ $\qquad heat\_load = 7.587 \times 10^4 \frac{kJ}{h}$

4.1.1 Crusher design

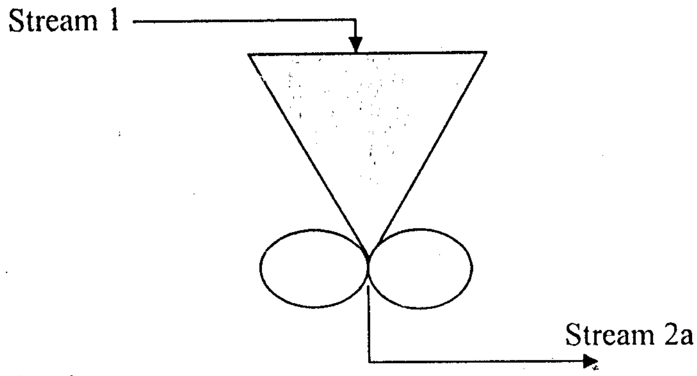


Fig. 4.1: Crusher.

I. Material balance

Assumption: 100% recovery						
		Input			Output	
		Stream 1			Stream 2	
Component	kg/day	Kg%	kg/day*scale up	kg/day	Kg%	kg/day*scale up
Water	3.9000	0.0390	44.0193	3.9000	0.0390	44.0193
Protein	22.0000	0.2200	248.3140	22.0000	0.2200	248.3140
Fat	46.0000	0.4600	519.2020	46.0000	0.4600	519.2020
Carbohydrate	27.0000	0.2700	304.7490	27.0000	0.2700	304.7490
Crudefibre	1.1000	0.0110	12.4157	1.1000	0.0110	12.4157
Hexane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	100.0000	1.0000	1128.7000	100.0000	1.0000	1128.7000

II. Energy balance

Assumption: There is a 20°C rise in temperature

Enthalpy of inputs

$$m := \begin{pmatrix} 44.0193 \\ 248.3140 \\ 519.2020 \\ 304.7490 \\ 12.4157 \\ 0.0000 \end{pmatrix} \frac{kg}{h} \qquad T := \left[\begin{pmatrix} 25 \\ 25 \\ 25 \\ 25 \\ 25 \\ 25 \end{pmatrix} + 273\right] K \qquad \begin{pmatrix} \text{water} \\ \text{protein} \\ \text{fat} \\ \text{carbohydrate} \\ \text{crudefiber} \\ \text{hexane} \end{pmatrix}$$

$T_{ref} := 298K$

Enthalpy of water

$T_0 = 298\,K$ $\qquad m_0 = 44.019\,\frac{kg}{h}$

$a_0 := 18.2964\,\frac{kJ}{kg \cdot K}$ $\quad b_0 := 1.095 \cdot 10^{-2}\,\frac{kJ}{kg \cdot K^2}$ $\quad c_0 := -4.891 \cdot 10^{-5}\,\frac{kJ}{kg \cdot K^3}$ $\quad d_0 := 0$

$$c_p := \frac{\left[a_0 + b_0 \cdot T_0 + c_0 \cdot (T_0)^2 + d_0 \cdot (T_0)^3\right]}{18} \qquad c_p = 0.956\,\frac{kJ}{kg \cdot K}$$

$\Delta T := T_0 - T_{ref}$ $\qquad \Delta T = 0\,K$

$\Delta H_{water} := m_0 \cdot c_p \cdot \Delta T$ $\qquad \Delta H_{water} = 0\,\frac{kJ}{h}$

Enthalpy of proteins

$T_1 = 298\,K$ $\qquad m_1 = 248.314\,\frac{kg}{h}$

$c_p := 1.7\,\frac{kJ}{kg \cdot K}$

$\Delta T := T_1 - T_{ref}$ $\qquad \Delta T = 0\,K$

$\Delta H_{protein} := m_1 \cdot c_p \cdot \Delta T$ $\qquad \Delta H_{protein} = 0\,\frac{kJ}{h}$

Enthalpy of fats

$T_2 = 298\,K$ $\qquad$ $m_2 = 519.202\,\frac{kg}{h}$

$c_p := 8.100\,\frac{kJ}{kg \cdot K}$

$\Delta T := T_2 - T_{ref}$ $\qquad$ $\Delta T = 0\,K$

$\Delta H_{fats} := m_2 \cdot c_p \cdot \Delta T$ $\qquad$ $\Delta H_{fats} = 0\,\frac{kJ}{h}$

Enthalpy of carbohydrate

$T_3 = 298\,K$ $\qquad$ $m_3 = 304.749\,\frac{kg}{h}$

$c_p := 1.344\,\frac{kJ}{kg \cdot K}$

$\Delta T := T_3 - T_{ref}$ $\qquad$ $\Delta T = 0\,K$

$\Delta H_{carb} := m_3 \cdot c_p \cdot \Delta T$ $\qquad$ $\Delta H_{carb} = 0\,\frac{kJ}{h}$

Enthalpy of crude fiber

$T_4 = 298\,K$ $\qquad$ $m_4 = 12.416\,\frac{kg}{h}$

$c_p := 0.98\,\frac{kJ}{kg \cdot K}$

$\Delta T := T_4 - T_{ref}$ $\qquad$ $\Delta T = 0\,K$

$\Delta H_{crudefiber} := m_4 \cdot c_p \cdot \Delta T$ $\qquad$ $\Delta H_{crudefiber} = 0\,\frac{kJ}{h}$

Enthalpy of hexane

$T_5 = 298\,K$ $\qquad$ $m_5 = 0\,\frac{kg}{h}$

$a_5 := 1.7212 \cdot 10^5\,\frac{kJ}{kg \cdot K}$ $\qquad$ $b_5 := -1.8378 \cdot 10^2\,\frac{kJ}{kg \cdot K^2}$ $\qquad$ $c_5 := 8.8734 \cdot 10^{-1}\,\frac{kJ}{kg \cdot K^3}$ $\qquad$ $d_5 := 0$

$$c_p := \frac{\left[a_5 + b_5 \cdot T_5 + c_5 \cdot (T_5)^2 + d_5 \cdot (T_5)^3\right]}{86.177 \cdot 1000} \qquad c_p = 2.276\,\frac{kJ}{kg \cdot K}$$

$\Delta T := T_5 - T_{ref}$ $\qquad$ $\Delta T = 0\,K$

$\Delta H_{hexane} := m_5 \cdot c_p \cdot \Delta T$ $\qquad$ $\Delta H_{hexane} = 0\,\frac{kJ}{h}$

Total enthalpy in

$\Delta H_{IN} := \Delta H_{water} + \Delta H_{protein} + \Delta H_{fats} + \Delta H_{carb} + \Delta H_{crudefiber} + \Delta H_{hexane}$

$\Delta H_{IN} = 0 \frac{kJ}{kg \cdot K}$

Enthalpy of outputs

$$m := \begin{pmatrix} 44.0193 \\ 248.3140 \\ 519.2020 \\ 304.7490 \\ 12.4157 \\ 0.0000 \end{pmatrix} \frac{kg}{h} \qquad T := \left[\begin{pmatrix} 45 \\ 45 \\ 45 \\ 45 \\ 45 \\ 45 \end{pmatrix} + 273 \right] K \qquad \begin{pmatrix} \text{water} \\ \text{protein} \\ \text{fat} \\ \text{carbohydrate} \\ \text{crudefiber} \\ \text{hexane} \end{pmatrix}$$

$T_{ref} := 298K$

Enthalpy of water

$T_0 = 318 K$ $\qquad m_0 = 44.019 \frac{kg}{h}$

$a_0 := 18.2964 \frac{kJ}{kg \cdot K}$ $\quad b_0 := 1.095 \cdot 10^{-2} \frac{kJ}{kg \cdot K^2}$ $\quad c_0 := -4.891 \cdot 10^{-5} \frac{kJ}{kg \cdot K^3}$ $\quad d_0 := 0$

$c_p := \frac{\left[a_0 + b_0 \cdot T_0 + c_0 \cdot (T_0)^2 + d_0 \cdot (T_0)^3\right]}{18}$ $\qquad c_p = 2.276 \frac{kJ}{kg \cdot K}$

$\Delta T := T_0 - T_{ref}$ $\qquad \Delta T = 20 K$

$\Delta H_{water} := m_0 \cdot c_p \cdot \Delta T$ $\qquad \Delta H_{water} = 823.284 \frac{kJ}{h}$

Enthalpy of proteins

$T_1 = 318 K$ $\qquad m_1 = 248.314 \frac{kg}{h}$

$c_p := 1.7 \frac{kJ}{kg \cdot K}$

$\Delta T := T_1 - T_{ref}$ $\qquad \Delta T = 20 K$

$\Delta H_{protein} := m_1 \cdot c_p \cdot \Delta T$ $\qquad \Delta H_{protein} = 8.443 \times 10^3 \frac{kJ}{h}$

Enthalpy of fats

$T_2 = 298\,K$ $\qquad m_2 = 519.202\,\frac{kg}{h}$

$c_p := 8.100\,\frac{kJ}{kg\cdot K}$

$\Delta T := T_2 - T_{ref}$ $\qquad \Delta T = 0\,K$

$\Delta H_{fats} := m_2\cdot c_p\cdot \Delta T$ $\qquad \Delta H_{fats} = 0\,\frac{kJ}{h}$

Enthalpy of carbohydrate

$T_3 = 298\,K$ $\qquad m_3 = 304.749\,\frac{kg}{h}$

$c_p := 1.344\,\frac{kJ}{kg\cdot K}$

$\Delta T := T_3 - T_{ref}$ $\qquad \Delta T = 0\,K$

$\Delta H_{carb} := m_3\cdot c_p\cdot \Delta T$ $\qquad \Delta H_{carb} = 0\,\frac{kJ}{h}$

Enthalpy of crude fiber

$T_4 = 298\,K$ $\qquad m_4 = 12.416\,\frac{kg}{h}$

$c_p := 0.98\,\frac{kJ}{kg\cdot K}$

$\Delta T := T_4 - T_{ref}$ $\qquad \Delta T = 0\,K$

$\Delta H_{crudefiber} := m_4\cdot c_p\cdot \Delta T$ $\qquad \Delta H_{crudefiber} = 0\,\frac{kJ}{h}$

Enthalpy of hexane

$T_5 = 298\,K$ $\qquad m_5 = 0\,\frac{kg}{h}$

$a_5 := 1.7212\cdot 10^5\,\frac{kJ}{kg\cdot K}$ $\qquad b_5 := -1.8378\cdot 10^2\,\frac{kJ}{kg\cdot K^2}$ $\qquad c_5 := 8.8734\cdot 10^{-1}\,\frac{kJ}{kg\cdot K}$ $\qquad d_5 := 0$

$$c_p := \frac{\left[a_5 + b_5\cdot T_5 + c_5\cdot (T_5)^2 + d_5\cdot (T_5)^3\right]}{86.177\cdot 1000}$$ $\qquad c_p = 2.36\,\frac{kJ}{kg\cdot K}$

$\Delta T := T_5 - T_{ref}$ $\qquad \Delta T = 20\,K$

$\Delta H_{hexane} := m_5\cdot c_p\cdot \Delta T$ $\qquad \Delta H_{hexane} = 0\,\frac{kJ}{h}$

Total enthalpy out

$$\Delta H_{OUT} := \Delta H_{water} + \Delta H_{protein} + \Delta H_{fats} + \Delta H_{carb} + \Delta H_{crudefiber} + \Delta H_{hexane}$$

$\Delta H_{OUT} = 1.018\times 10^6\,\frac{kJ}{kg\cdot K}$

Heat load of crusher

$Q_{CRUSHER} := \Delta H_{OUT} - \Delta H_{IN}$ $\qquad Q_{CRUSHER} = 1.018\times 10^6\,\frac{kJ}{h}$

III. Crusher selection and specification

Type:crusher roles
Material: carbon steel
Assumptions:
1.The void volume is 10% of the volume.
2.The crusher is assumed to be conical.
3.The thickness of the carbon steel is assumed to be 0.01

$$mass := \begin{pmatrix} 44.0193 \\ 248.3140 \\ 519.2020 \\ 304.7490 \\ 12.4157 \\ 0.0000 \end{pmatrix} \frac{kg}{h} \quad x := \begin{pmatrix} 0.0390 \\ 0.2200 \\ 0.4600 \\ 0.2700 \\ 0.0110 \\ 0.0000 \end{pmatrix} \quad d := \begin{pmatrix} 1000 \\ 530 \\ 910 \\ 680 \\ 420 \\ 236.9 \end{pmatrix} \frac{kg}{m^3} \quad \begin{pmatrix} water \\ protein \\ fats \\ carbohydrate \\ crudefiber \\ hexane \end{pmatrix}$$

$$averagedensity := x_0 \cdot d_0 + x_1 \cdot d_1 + x_2 \cdot d_2 + x_3 \cdot d_3 + x_4 \cdot d_4 + x_5 \cdot d_5$$

$$averagedensity = 762.42 \frac{kg}{m^3}$$

$$volume_{comp} := \frac{(mass_0 + mass_1 + mass_2 + mass_3 + mass_4 + mass_5)}{averagedensity}$$

$$volume_{comp} = 1.48\,m^3$$

$$volume_{void} := 0.01 \cdot volume_{comp}$$

$$volume_{void} = 0.015\,m^3$$

$$volume_{crusher} := volume_{comp} + volume_{void}$$

$$volume_{crusher} = 1.495\,m^3$$

$$D_{crusher} := \left(6 \cdot \frac{volume_{crusher}}{\pi}\right)^{\frac{1}{3}}$$

$$D_{crusher} = 1.419\,m$$

The height of the crusher is given as

$$H_{crusher} := 2D_{crusher}$$

$$H_{crusher} = 2.837\,m$$

The internal radius of the crusher is given as

$$R_{internal} := \frac{D_{crusher}}{2}$$

$$R_{internal} = 0.709\,m$$

The external radius is given as

$R_{external} := R_{internal} + 0.01$

$R_{external} = 0.719\,m$

The lenght of the slope is L and calculated as

$L := \sqrt{\left(R_{external}^{2} + H_{crusher}^{2}\right)}$

$L = 2.927\,m$

The total surface area is then given as

$A_{crusher} := \pi R_{external} \cdot L$

$A_{crusher} = 6.615\,m^2$

IV. Crusher cost

The surface area of the crusher is

$A_{crusher} := 6.615m^2$

cost of carbon steel of thickness 0.01m and area 2.977m^2 is

$A_{pan} := 2.997m^2$ $cost_{pan} := 46000 Naira$ (Obitex, 2006.)

The cost of the carbon steel required for the crusher

$cost_{cs} := \frac{\left(A_{crusher} \cdot cost_{pan}\right)}{A_{pan}}$ $cost_{cs} = 1.015 \times 10^5\,Naira$

the cost of the crusher motor is estimated to be 15% of the cost of the carbon steel

$cost_{motor} := 15\% \cdot cost_{cs}$ $cost_{motor} = 1.523 \times 10^4\,Naira$

the cost of construction is estimated to be 10% of the cost of the carbon steel

$cost_{con} := 10\% \cdot cost_{cs}$ $cost_{con} = 1.015 \times 10^4\,Naira$

the estimated cost of the crusher is given as

$cost_{crusher} := cost_{cs} + cost_{motor} + cost_{con}$ $cost_{crusher} = 1.269 \times 10^5\,Naira$

4.1.2 Extractor design

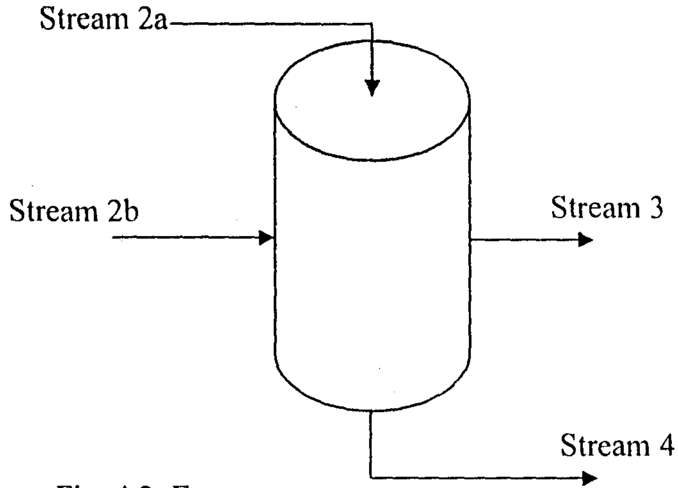


Fig. 4.2: Extractor

I. Material balance

Assumption:	66% of the fats is removed and 10 % of the solvent is entrained in the cake. 100kg/day of hexane is added								
		Input			Output				
		Stream 2			Stream 3			Stream 4	
Component	kg/day	Kg%	kg/day*scale up	kg/day	Kg%	kg/day*scale up	kg/day	Kg%	kg/day*scaleup
Water	3.9000	0.0195	44.0193	3.9000	0.0490	44.0193	0.0000	0.0000	0.0000
Protein	22.0000	0.1100	248.3140	22.0000	0.2762	248.3140	0.0000	0.0000	0.0000
Fat	46.0000	0.2300	519.2020	15.6400	0.1964	176.5287	30.3600	0.2522	342.6733
Carbohydrate	27.0000	0.1350	304.7490	27.0000	0.3390	304.7490	0.0000	0.0000	0.0000
Crudefibre	1.1000	0.0055	12.4157	1.1000	0.0138	12.4157	0.0000	0.0000	0.0000
Hexane	100.0000	0.5000	1128.7000	10.0000	0.1256	112.8700	90.0000	0.7478	1015.8300
Total	200.0000	1.0000	2257.4000	79.6400	1.0000	898.8967	120.3600	1.0000	1358.5033

II. Energy balance

Work is not done on or by the system but heat is transferred from the cashew kernel stream to the hexane stream.

Equipment selection and specification

Type: Bollman's extractor.
Material: Carbon steel.
Assumptions:
1. The void volume is 10% of the volume.
2. The extractor is assumed to be cylinderical.
3. The thickness of the carbon steel is assumed to be 0.01m.
4. Contains 15 cylinderical carbon steel perforated baskets each 0.005m thick .

$$\text{mass} := \begin{pmatrix} 44.01930 \\ 248.31400 \\ 519.20200 \\ 304.74900 \\ 12.41570 \\ 1128.70000 \end{pmatrix} \frac{kg}{h} \quad x := \begin{pmatrix} 0.0195 \\ 0.1100 \\ 0.2300 \\ 0.1350 \\ 0.0055 \\ 0.5000 \end{pmatrix} \quad d := \begin{pmatrix} 1000 \\ 530 \\ 910 \\ 680 \\ 420 \\ 236.9 \end{pmatrix} \frac{kg}{m^3} \quad \begin{pmatrix} \text{water} \\ \text{protein} \\ \text{fats} \\ \text{carbohydrate} \\ \text{crudefiber} \\ \text{hexane} \end{pmatrix}$$

$$\text{averagedensity} := x_0 \cdot d_0 + x_1 \cdot d_1 + x_2 \cdot d_2 + x_3 \cdot d_3 + x_4 \cdot d_4 + x_5 \cdot d_5$$

$$\text{averagedensity} = 499.66 \frac{kg}{m^3}$$

the volume of one basket is given below

$$\text{volume}_{comp} := \frac{\frac{(\text{mass}_0 + \text{mass}_1 + \text{mass}_2 + \text{mass}_3 + \text{mass}_4 + \text{mass}_5)}{15}}{\text{averagedensity}}$$

$$\text{volume}_{comp} = 0.301\, m^3$$

$$\text{volume}_{void} := 0.01 \cdot \text{volume}_{comp}$$

$$\text{volume}_{void} = 3.012 \times 10^{-3}\, m^3$$

$$\text{volume}_{basket} := \text{volume}_{comp} + \text{volume}_{void}$$

$$\text{volume}_{basket} = 0.304\, m^3$$

$$D_{basket} := \left(2 \cdot \frac{volume_{basket}}{\pi}\right)^{\frac{1}{3}}$$

$$D_{basket} = 0.579\,m$$

The height of the basket is given as

$$H_{basket} := 2D_{basket}$$

$$H_{basket} = 1.157\,m$$

The internal radius of the crusher is given as

$$R_{internal} := \frac{D_{basket}}{2}$$

$$R_{internal} = 0.289\,m$$

The external radius is given as

$$R_{external} := R_{internal} + 0.005$$

$$R_{external} = 0.294\,m$$

The total surface area is then given as

$$A_{basket} := \pi R_{external}^{2} + 2\pi R_{external} \cdot H_{basket}$$

$$A_{basket} = 2.412\,m^2$$

the total basket area is

$$total_{area} := 15 \cdot A_{basket}$$

$$total_{area} = 36.174\,m^2$$

the extractor's volume, thus, is

$$volume_{void} := 0.01 \cdot total_{area}$$

$$volume_{void} = 0.362\,m^3$$

$$volume_{ext} := total_{area} + volume_{void}$$

$$volume_{ext} = 36.536\,m^3$$

$$D_{ext} := \left(2 \cdot \frac{volume_{ext}}{\pi}\right)^{\frac{1}{3}}$$

$$D_{ext} = 2.855\,m$$

The height of the extractor is given as

$$H_{ext} := 2D_{ext}$$

$$H_{ext} = 5.709\,m$$

The internal radius of the extractor is given as

$$R_{internal} := \frac{D_{ext}}{2}$$

$$R_{internal} = 1.427\,m$$

The external radius is given as

$$R_{external} := R_{internal} + 0.005$$

$$R_{external} = 1.432\,m$$

The total surface area is then given as

$$A_{ext} := 2\pi R_{external}^{2} + 2\pi R_{external} \cdot H_{ext}$$

$$A_{ext} = 64.265\,m^{2}$$

IV. Extractor cost

The surface area of the extractor is

$$A_{exractor} := 64.265m^{2}$$

cost of carbon steel of thickness 0.01m and area 2.977m^2 is

$A_{pan} := 2.997m^{2}$ $\quad$ $cost_{pan} := 46000\,Naira$ $\quad$ (Obitex, 2006.)

The cost of the carbon steel required for the bare body of the extractor

$$cost_{cs1} := \frac{(A_{extractor} \cdot cost_{pan})}{A_{pan}} \qquad cost_{cs1} = 9.864 \times 10^{5}\ \text{Naira}$$

the extractor contains 15 perforated carbon steel baskets each of thickness 0.005m and area $11.08m^2$ respectively.

$$A_{basket} := 2.412m^2$$

cost of carbon steel of thickness 0.005m and area $2.977m^2$ is

$$A_{pan} := 2.997m^2 \qquad cost_{pan} := 23000\text{Naira}$$ (Obitex, 2006.)

The cost of the carbon steel required for the basket

$$cost_{cs2} := \frac{(A_{basket} \cdot cost_{pan})}{A_{pan}} \qquad cost_{cs2} = 1.851 \times 10^{4}\ \text{Naira}$$

the total cost of carbon steel is given as

$$cost_{cs} := cost_{cs1} + cost_{cs2} \qquad cost_{cs} = 1.005 \times 10^{6}\ \text{Naira}$$

the cost of construction is estimated to be 10% of the cost of the carbon steel

$$cost_{con} := 10\% \cdot cost_{cs} \qquad cost_{con} = 1.005 \times 10^{5}\ \text{Naira}$$

the cost of extractor is estimated to be

$$cost_{ext} := cost_{cs} + cost_{con} \qquad cost_{ext} = 1.105 \times 10^{6}\ \text{Naira}$$

4.1.3 Desolventiser design

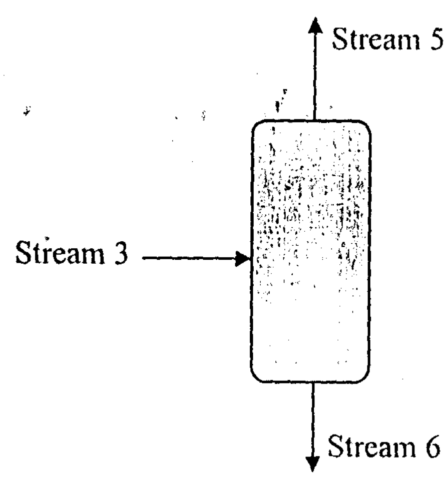


Fig 4.3: Desolventiser

I. Material balance

Assumption: 100% recovery of hexane									
		Input			Output				
		Stream 3			Stream 5			Stream 6	
Component	kg/day	Kg%	kg/day*scale up	kg/day	Kg%	kg/day*scale up	kg/day	Kg%	kg/day*scaleup
Water	3.9000	0.0490	44.0193	0.0000	0.0000	0.0000	3.9000	0.0560	44.0193
Protein	22.0000	0.2762	248.3140	0.0000	0.0000	0.0000	22.0000	0.3159	248.3140
Fat	15.6400	0.1964	176.5287	0.0000	0.0000	0.0000	15.6400	0.2246	176.5287
Carbohydrate	27.0000	0.3390	304.7490	0.0000	0.0000	0.0000	27.0000	0.3877	304.7490
Crudefibre	1.1000	0.0138	12.4157	0.0000	0.0000	0.0000	1.1000	0.0158	12.4157
Hexane	10.0000	0.1256	112.8700	10.0000	1.0000	112.8700	0.0000	0.0000	0.0000
Total	79.6400	1.0000	898.8967	10.0000	1.0000	112.8700	69.6400	1.0000	786.0267

II. Energy balance

Assumption: The desolventiser operates at 70°C

Enthalpy of inputs

$$m := \begin{pmatrix} 44.0193 \\ 248.3140 \\ 176.5287 \\ 304.7490 \\ 12.4157 \\ 112.8700 \end{pmatrix} \frac{kg}{day} \qquad T := \left[\begin{pmatrix} 37 \\ 37 \\ 37 \\ 37 \\ 37 \\ 37 \end{pmatrix} + 273\right] K \qquad \begin{pmatrix} water \\ protein \\ fat \\ carbohydrate \\ crudefiber \\ hexane \end{pmatrix}$$

$$T_{ref} := 298K$$

Enthalpy of water

$T_0 = 310K$ $\qquad m_0 = 44.019 \frac{kg}{h}$

$a_0 := 18.2964 \frac{kJ}{kg \cdot K}$ $\qquad b_0 := 1.095 \cdot 10^{-2} \frac{kJ}{kg \cdot K^2}$ $\qquad c_0 := -4.891 \cdot 10^{-5} \frac{kJ}{kg \cdot K^3}$ $\qquad d_0 := 0$

$$c_p := \frac{\left[a_0 + b_0 \cdot T_0 + c_0 \cdot (T_0)^2 + d_0 \cdot (T_0)^3\right]}{18} \qquad c_p = 0.944 \frac{kJ}{kg \cdot K}$$

$\Delta T := T_0 - T_{ref}$ $\qquad \Delta T = 12K$

$\Delta H_{water} := m_0 \cdot c_p \cdot \Delta T$ $\qquad \Delta H_{water} = 498.611 \frac{kJ}{h}$

Enthalpy of proteins

$T_1 = 310K$ $m_1 = 248.314\frac{kg}{h}$

$c_p := 1.7\frac{kJ}{kg \cdot K}$

$\Delta T := T_1 - T_{ref}$ $\Delta T = 12K$

$\Delta H_{protein} := m_1 \cdot c_p \cdot \Delta T$ $\Delta H_{protein} = 5.066 \times 10^3 \frac{kJ}{h}$

Enthalpy of fats

$T_2 = 310K$ $m_2 = 176.529\frac{kg}{h}$

$c_p := 8.100\frac{kJ}{kg \cdot K}$

$\Delta T := T_2 - T_{ref}$ $\Delta T = 12K$

$\Delta H_{fats} := m_2 \cdot c_p \cdot \Delta T$ $\Delta H_{fats} = 1.716 \times 10^4 \frac{kJ}{h}$

Enthalpy of carbohydrate

$T_3 = 310K$ $m_3 = 304.749\frac{kg}{h}$

$c_p := 1.344\frac{kJ}{kg \cdot K}$

$\Delta T := T_3 - T_{ref}$ $\Delta T = 12K$

$\Delta H_{carb} := m_3 \cdot c_p \cdot \Delta T$ $\Delta H_{carb} = 4.915 \times 10^3 \frac{kJ}{h}$

Enthalpy of crude fiber

$T_4 = 310K$ $m_4 = 12.416\frac{kg}{h}$

$c_p := 0.98\frac{kJ}{kg \cdot K}$

$\Delta T := T_4 - T_{ref}$ $\Delta T = 12K$

$\Delta H_{crudefiber} := m_4 \cdot c_p \cdot \Delta T$ $\Delta H_{crudefiber} = 146.009\frac{kJ}{h}$

Enthalpy of hexane

$T_5 = 310\,K$ $\quad m_5 = 112.87\,\frac{kg}{h}$

$a_5 := 1.7212 \cdot 10^5$ $\quad b_5 := -1.8378 \cdot 10^2$ $\quad c_5 := 8.8734 \cdot 10^{-1}$ $\quad d_5 := 0$

$$c_p := \frac{\left[a_5 + b_5 \cdot T_5 + c_5 \cdot (T_5)^2 + d_5 \cdot (T_5)^3\right]}{86.177 \cdot 1000} \qquad c_p = 2.326\,\frac{kJ}{kg \cdot K}$$

$\Delta T := T_5 - T_{ref}$ $\quad \Delta T = 12\,K$

$\Delta H_{hexane} := m_5 \cdot c_p \cdot \Delta T$ $\quad \Delta H_{hexane} = 3.15 \times 10^3\,\frac{kJ}{h}$

Total enthalpy in

$$\Delta H_{IN} := \Delta H_{water} + \Delta H_{protein} + \Delta H_{fats} + \Delta H_{carb} + \Delta H_{crudefiber} + \Delta H_{hexane}$$

$$\Delta H_{IN} = 3.093 \times 10^4\,\frac{kJ}{h}$$

Enthalpy of outputs

$$m := \begin{pmatrix} 44.0193 \\ 248.3140 \\ 176.5287 \\ 304.7490 \\ 12.4157 \\ 112.8700 \end{pmatrix} \frac{kg}{h} \qquad T := \left[\begin{pmatrix} 70 \\ 70 \\ 70 \\ 70 \\ 70 \\ 69 \end{pmatrix} + 273\right] K \qquad \begin{pmatrix} \text{water} \\ \text{protein} \\ \text{fat} \\ \text{carbohydrate} \\ \text{crudefiber} \\ \text{hexane} \end{pmatrix}$$

$T_{ref} := 298K$

Enthalpy of water

$T_0 = 343\,K$ $\quad m_0 = 44.019\,\frac{kg}{h}$

$a_0 := 18.2964$ $\quad b_0 := 1.095 \cdot 10^{-2}$ $\quad c_0 := -4.891 \cdot 10^{-5}$ $\quad d_0 := 0$

$$c_p := \frac{\left[a_0 + b_0 \cdot T_0 + c_0 \cdot (T_0)^2 + d_0 \cdot (T_0)^3\right]}{18} \qquad c_p = 0.905\,\frac{kJ}{kg \cdot K}$$

$\Delta T := T_0 - T_{ref}$ $\quad \Delta T = 45\,K$

$\Delta H_{water} := m_0 \cdot c_p \cdot \Delta T$ $\quad \Delta H_{water} = 1.794 \times 10^3\,\frac{kJ}{h}$

Enthalpy of proteins

$T_1 = 343\,K$ $\quad m_1 = 248.314\,\frac{kg}{h}$

$c_p := 1.7\,\frac{kJ}{kg \cdot K}$

$\Delta T := T_1 - T_{ref}$ $\quad \Delta T = 45\,K$

$\Delta H_{protein} := m_1 \cdot c_p \cdot \Delta T$ $\quad \Delta H_{protein} = 1.9 \times 10^4\,\frac{kJ}{h}$

Enthalpy of fats

$T_2 = 343\,K$ $\quad m_2 = 176.529\,\frac{kg}{h}$

$c_p := 8.100\,\frac{kJ}{kg \cdot K}$

$\Delta T := T_2 - T_{ref}$ $\quad \Delta T = 45\,K$

$\Delta H_{fats} := m_2 \cdot c_p \cdot \Delta T$ $\quad \Delta H_{fats} = 6.434 \times 10^4\,\frac{kJ}{h}$

Enthalpy of carbohydrate

$T_3 = 343\,K$ $\quad m_3 = 304.749\,\frac{kg}{h}$

$c_p := 1.344\,\frac{kJ}{kg \cdot K}$

$\Delta T := T_3 - T_{ref}$ $\quad \Delta T = 45\,K$

$\Delta H_{carb} := m_3 \cdot c_p \cdot \Delta T$ $\quad \Delta H_{carb} = 1.843 \times 10^4\,\frac{kJ}{h}$

Enthalpy of crude fiber

$T_4 = 343\,K$ $\quad m_4 = 12.416\,\frac{kg}{h}$

$c_p := 0.98\,\frac{kJ}{kg \cdot K}$

$\Delta T := T_4 - T_{ref}$ $\qquad \Delta T = 45\,K$

$\Delta H_{crudefiber} := m_4 \cdot c_p \cdot \Delta T$ $\qquad \Delta H_{crudefiber} = 547.532\,\frac{kJ}{h}$

Enthalpy of hexane

$T_5 = 342\,K$ $\quad m_5 = 112.87\,\frac{kg}{h}$

$a_5 := 1.7212 \cdot 10^5$ $\quad b_5 := -1.8378 \cdot 10^2$ $\quad c_5 := 8.8734 \cdot 10^{-1}$ $\quad d_5 := 0$

$$c_p := \frac{\left[a_5 + b_5 \cdot T_5 + c_5 \cdot (T_5)^2 + d_5 \cdot (T_5)^3\right]}{86177}$$ $\qquad c_p = 2.472\,\frac{kJ}{kg \cdot K}$

$a := 4.4544 \cdot 10^7$ $\quad b := 0.39002$ $\quad c := 0$ $\quad d := 0$

$T_c := 507.6K$ $\quad T_r := \frac{T_5}{T_c}$ $\quad T_r = 0.674\,K$

$$\Delta H_v := \frac{\left[a \cdot (1 - T_r)^{b + (c \cdot T_r) + d \cdot T_r \cdot T_r}\right]}{1000 \cdot 86.177}$$ $\qquad \Delta H_v = 333.94\,\frac{kJ}{kg}$

$\Delta T := T_5 - T_{ref}$ $\qquad \Delta T = 44\,K$

$\Delta H_{hexane} := m_5 \cdot (c_p \cdot \Delta T + \Delta H_v)$ $\qquad \Delta H_{hexane} = 4.997 \times 10^4\,\frac{kJ}{h}$

Total enthalpy out

$$\Delta H_{OUT} := \Delta H_{water} + \Delta H_{protein} + \Delta H_{fats} + \Delta H_{carb} + \Delta H_{crudefiber} + \Delta H_{hexane}$$

$$\Delta H_{OUT} = 1.541 \times 10^5\,\frac{kJ}{h}$$

Heat load of desolventiser

$Q_{DESOLVENTISER} := \Delta H_{OUT} - \Delta H_{IN}$ $\qquad Q_{DESOLVENTISER} = 1.231 \times 10^5 \frac{kJ}{h}$

The mass of steam required for the heating process is

$\Delta H_{vwater} := 2.26 \cdot 10^3 \frac{kJ}{kg}$

$m_{steam} := \frac{Q_{DESOLVENTISER}}{\Delta H_{vwater}}$ $\qquad m_{steam} = 54.491 \frac{kg}{h}$

III. Desolventiser selection and specification

Type:Vertical tube evaporator
Material: Carbon steel
Assumptions:
1.The void volume is 10% of the volume.
2.The desolventiser is assumed to be cylinderical.
3.The thickness of the carbon steel is assumed to be 0.01
4.It contains 9 plates and scrapers spaced at a distance of 0.5m.The plates are 0.01m thick carbon steel.

$$mass := \begin{pmatrix} 44.01930 \\ 248.31400 \\ 176.52868 \\ 304.74900 \\ 12.41570 \\ 112.87000 \end{pmatrix} \frac{kg}{h} \qquad x := \begin{pmatrix} 0.0490 \\ 0.2762 \\ 0.1964 \\ 0.3390 \\ 0.0138 \\ 0.1256 \end{pmatrix} \qquad d := \begin{pmatrix} 1000 \\ 530 \\ 910 \\ 680 \\ 420 \\ 236.9 \end{pmatrix} \frac{kg}{m^3} \qquad \begin{pmatrix} \text{water} \\ \text{protein} \\ \text{fats} \\ \text{carbohydrate} \\ \text{crudefiber} \\ \text{hexane} \end{pmatrix}$$

$averagedensity := x_0 \cdot d_0 + x_1 \cdot d_1 + x_2 \cdot d_2 + x_3 \cdot d_3 + x_4 \cdot d_4 + x_5 \cdot d_5$

$averagedensity = 640.181 \frac{kg}{m^3}$

$$volume_{comp} := \frac{(mass_0 + mass_1 + mass_2 + mass_3 + mass_4 + mass_5)}{averagedensity}$$

$$volume_{comp} = 1.404\,m^3$$

$$volume_{void} := 0.01 \cdot volume_{comp}$$

$$volume_{void} = 0.014\,m^3$$

$$volume_{desolventiser} := volume_{comp} + volume_{void}$$

$$volume_{desolventiser} = 1.418\,m^3$$

$$D_{desolventiser} := \left(2 \cdot \frac{volume_{desolventiser}}{\pi}\right)^{\frac{1}{3}}$$

$$D_{desolventiser} = 0.967\,m$$

The height of the desolventiser is given as

$$H_{desolventiser} := 2D_{desolventiser}$$

$$H_{desolventiser} = 1.933\,m$$

The internal radius of the desolventiser is given as

$$R_{internal} := \frac{D_{desolventiser}}{2}$$

$$R_{internal} = 0.483\,m$$

The external radius is given as

$$R_{external} := R_{internal} + 0.01$$

$$R_{external} = 0.493\,m$$

The total surface area is then given as

$$A_{desolventiser} := 2\pi R_{external}^{\;2} + 2\pi R_{external} \cdot H_{desolventiser}$$

$$A_{desolventiser} = 7.519\,m^2$$

The desolventiser is assumed to have plates on which there are scrapers spaced at an interval of 0.5m.

$\alpha := 0.5m$

The number of plates is thus given as

$$N_{plates} := \frac{H_{desolventiser}}{\alpha} \qquad N_{plates} = 3.866$$

The surface area of the plates is given as

$$A_{plates} := N_{plates} \cdot \left(\pi \frac{D_{desolventiser}^2}{2} + \pi \frac{D_{desolventiser}}{4} \cdot \alpha \right) \qquad A_{plates} = 7.14 m^2$$

IV. Desolventiser cost

The surface area of the desolventiser is

$A_{desolv} := 7.519 m^2$

cost of carbon steel of thickness 0.01m and area 2.977m² is

$A_{pan} := 2.997 m^2$ $\qquad cost_{pan} := 46000 Naira$ $\qquad$ (Obitex, 2006.)

The cost of the carbon steel required for the desolventiser

$$cost_{cs1} := \frac{(A_{desolv} \cdot cost_{pan})}{A_{pan}} \qquad cost_{cs1} = 1.154 \times 10^5 \, Naira$$

the cost of the desolventiser plates is estimated to be

$A_{plates} := 7.14 m^2$

cost of carbon steel of thickness 0.01m and area 2.977m² is

$A_{pan} := 2.997 m^2$ $\qquad cost_{pan} := 46000 Naira$ $\qquad$ (market price)

The cost of the carbon steel required for the 12 plates of the column

$$cost_{cs2} := \frac{(A_{plates} \cdot cost_{pan})}{A_{pan}} \qquad cost_{cs2} = 1.096 \times 10^5 \, Naira$$

The cost of scrapers is estimated to be 80% the cost of the plates

$cost_{cs3} := 80\% \cdot cost_{cs2}$ $\qquad$ $cost_{cs3} = 8.767 \times 10^4$ Naira

The cost of motor is estimated to be 15% of the cost of the scraper

$cost_{cs4} := 15\% \cdot cost_{cs3}$ $\qquad$ $cost_{cs4} = 1.315 \times 10^4$ Naira

The total cost of carbon steel required

$cost_{cs} := cost_{cs1} + cost_{cs2} + cost_{cs3} + cost_{cs4}$ $\qquad$ $cost_{cs} = 3.258 \times 10^5$ Naira

$cost_{con} := 10\% \cdot cost_{cs}$ $\qquad$ $cost_{con} = 3.258 \times 10^4$ Naira

the estimated cost of the desolventiser is given as

$cost_{desolventiser} := cost_{cs} + cost_{con}$ $\qquad$ $cost_{desolventiser} = 3.584 \times 10^5$ Naira

4.1.4 Distillation column design

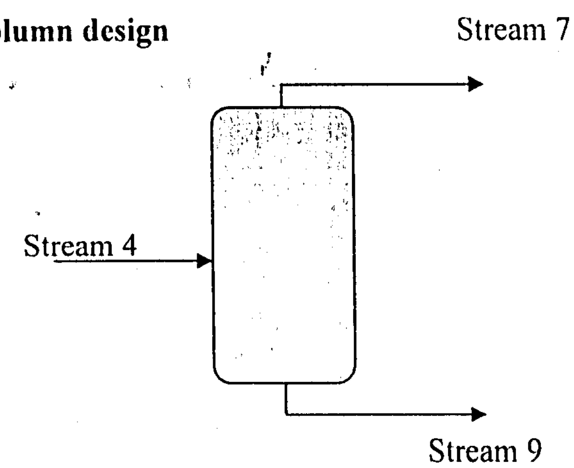


Fig.4.4: Distillation column

I. Material balance

ASSUMPTION: 99% hexane at the top and 0.01% at the bottom.										
		Input					Output			
		Stream 4				Stream 7			Stream 9	
Component	kg/h	Kg%	kg/h*scale up		kg/h	Kg%	kg/h*scale up	kg/h	Kg%	kg/h*scale up
Water	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Protein	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Fat	30.3600	0.2522	342.6733		0.0901	0.0010	1.0168	30.2699	1.0000	341.6565
Carbohydrate	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Crudefibre	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Hexane	90.0000	0.7478	1015.8300		89.9999	0.9990	1015.8290	0.0001	0.0000	0.0010
Total	120.3600	1.0000	1358.5033		90.0900	1.0000	1016.8458	30.2700	1.0000	341.6575

II. Column selection and specification

Type: Sieve tray column
Material: carbon steel
Assumptions:
1. The void volume is 10% of the volume.
2. The column is assumed to be cylinderical.
3. The thickness of the carbon steel is assumed to be 0.01.
4. It contains, 0.005mm thick, carbon steel plates spaced at 0.5m.

$$\text{mass} := \begin{pmatrix} 0.0000 \\ 0.0000 \\ 342.67332 \\ 0.0000 \\ 0.0000 \\ 1015.83000 \end{pmatrix} \frac{kg}{h} \quad x := \begin{pmatrix} 0.0000 \\ 0.0000 \\ 0.2522 \\ 0.0000 \\ 0.0000 \\ 0.7478 \end{pmatrix} \quad d := \begin{pmatrix} 1000 \\ 530 \\ 910 \\ 680 \\ 420 \\ 236.9 \end{pmatrix} \frac{kg}{m^3} \quad \begin{pmatrix} \text{water} \\ \text{protein} \\ \text{fats} \\ \text{carbohydrate} \\ \text{crudefiber} \\ \text{hexane} \end{pmatrix}$$

$$\text{averagedensity} := x_0 \cdot d_0 + x_1 \cdot d_1 + x_2 \cdot d_2 + x_3 \cdot d_3 + x_4 \cdot d_4 + x_5 \cdot d_5$$

$$\text{averagedensity} = 406.656 \frac{kg}{m^3}$$

$$\text{volume}_{comp} := \frac{(\text{mass}_0 + \text{mass}_1 + \text{mass}_2 + \text{mass}_3 + \text{mass}_4 + \text{mass}_5)}{\text{averagedensity}}$$

$$\text{volume}_{comp} = 3.341\, m^3$$

$$\text{volume}_{void} := 0.01 \cdot \text{volume}_{comp}$$

$$\text{volume}_{void} = 0.033\, m^3$$

$$\text{volume}_{column} := \text{volume}_{comp} + \text{volume}_{void}$$

$$\text{volume}_{column} = 3.374\, m^3$$

$$D_{column} := \left(2 \cdot \frac{volume_{column}}{\pi}\right)^{\frac{1}{3}}$$

$$D_{column} = 1.29\,m$$

The height of the column is given as

$$H_{column} := 2D_{column}$$

$$H_{column} = 2.581\,m$$

The internal radius of the column is given as

$$R_{internal} := \frac{D_{column}}{2}$$

$$R_{internal} = 0.645\,m$$

The external radius is given as

$$R_{external} := R_{internal} + 0.01$$

$$R_{external} = 0.655\,m$$

The total surface area is then given as

$$A_{column} := 2\pi R_{external}^{2} + 2\pi R_{external} \cdot H_{column}$$

$$A_{column} = 13.319\,m^2$$

the spacing between the plates is assumed to be

$$\alpha := 0.5$$

the no. of plates in the column is then given as

$$N_{plate} := \frac{H_{column}}{\alpha} \qquad N_{plate} = 5.161$$

The surface area of the plates are

$$A_{plates} := N_{plates} \cdot \left(\pi \frac{D_{column}}{2}^{2} + \pi \frac{D_{column}}{4} \cdot \alpha\right) \qquad A_{plates} = 12.069\,m^2$$

III. Column cost

The surface area of the column is

$A_{col} := 13.319m^2$

cost of carbon steel of thickness 0.01m and area 2.977m² is

$A_{pan} := 2.997m^2$ $\quad cost_{pan} := 46000Naira$ (Obitex, 2006.)

The cost of the carbon steel required for the bare body of the column

$$cost_{cs1} := \frac{(A_{col} \cdot cost_{pan})}{A_{pan}} \qquad cost_{cs1} = 2.044 \times 10^5 \text{ Naira}$$

The cost of plates installation is estimated as

$A_{plates} := 12.069m^2$

cost of carbon steel of thickness 0.005m and area 2.977m² is

$A_{pan} := 2.997m^2$ $\quad cost_{pan} := 23000Naira$ (Obitex, 2006.)

The cost of the carbon steel required for the 12 plates of the column

$$cost_{cs2} := \frac{(A_{plates} \cdot cost_{pan})}{A_{pan}} \qquad cost_{cs2} = 9.262 \times 10^4 \text{ Naira}$$

The total cost of carbon steel is given as

$$cost_{cs} := cost_{cs1} + cost_{cs2} \qquad cost_{cs} = 2.971 \times 10^5 \text{ Naira}$$

$$cost_{con} := 10\% \cdot (cost_{cs}) \qquad cost_{con} = 2.971 \times 10^4 \text{ Naira}$$

$$cost_{col} := cost_{cs} + cost_{con} \qquad cost_{col} = 3.268 \times 10^5 \text{ Naira}$$

4.1.5 Condenser 01 design

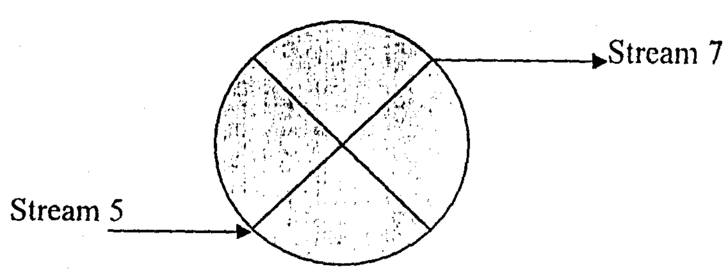


Fig. 4.5: Condenser 01

I. Material balance

Assumption: No material is lost							
		Input				Output	
		Stream 5				Stream 10	
Component	kg/h	Kg%	kg/h*scale up		kg/h	Kg%	kg/h*scale up
Water	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000
Protein	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000
Fat	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000
Carbohydrate	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000
Crudefibre	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000
Hexane	10.0000	1.0000	112.8700		10.0000	1.0000	112.8700
Total	10.0000	1.0000	112.8700		10.0000	1.0000	112.8700

II. Energy balance

Assumptions :1. Hexane is cooled to 25^{0}C

2. There is a 30^{o}C rise in the temperature of cooling water

Enthalpy of inputs

$$m := \begin{pmatrix} 0.0000 \\ 0.0000 \\ 0.0000 \\ 0.0000 \\ 0.0000 \\ 112.8700 \end{pmatrix} \frac{kg}{h} \qquad T := \left[\begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 69 \end{pmatrix} + 273\right] K \qquad \begin{pmatrix} \text{water} \\ \text{protein} \\ \text{fat} \\ \text{carbohydrate} \\ \text{crudefiber} \\ \text{hexane} \end{pmatrix}$$

$$T_{ref} := 298K$$

Enthalpy of water

$T_0 = 273\,K$ $\quad m_0 = 0\,\frac{kg}{h}$

$a_0 := 18.2964\,\frac{kJ}{kg \cdot K}$ $\quad b_0 := 1.095 \cdot 10^{-2}\,\frac{kJ}{kg \cdot K^2}$ $\quad c_0 := -4.891 \cdot 10^{-5}\,\frac{kJ}{kg \cdot K^3}$ $\quad d_0 := 0$

$$c_p := \frac{\left[a_0 + b_0 \cdot T_0 + c_0 \cdot (T_0)^2 + d_0 \cdot (T_0)^3\right]}{18} \qquad c_p = 0.98\,\frac{kJ}{kg \cdot K}$$

$\Delta T := T_0 - T_{ref}$ $\quad \Delta T = -25\,K$

$\Delta H_{water} := m_0 \cdot c_p \cdot \Delta T$ $\quad \Delta H_{water} = 0\,\frac{kJ}{h}$

Enthalpy of proteins

$T_1 = 273\,K$ $\quad m_1 = 0\,\frac{kg}{h}$

$c_p := 1.7\,\frac{kJ}{kg \cdot K}$

$\Delta T := T_1 - T_{ref}$ $\quad \Delta T = -25\,K$

$\Delta H_{protein} := m_1 \cdot c_p \cdot \Delta T$ $\quad \Delta H_{protein} = 0\,\frac{kJ}{h}$

Enthalpy of fats

$T_2 = 273\,K$ $\quad m_2 = 0\,\frac{kg}{h}$

$c_p := 8.100\,\frac{kJ}{kg \cdot K}$

$\Delta T := T_2 - T_{ref}$ $\quad \Delta T = -25\,K$

$\Delta H_{fats} := m_2 \cdot c_p \cdot \Delta T$ $\quad \Delta H_{fats} = 0\,s\,\frac{kJ}{day}$

Enthalpy of carbohydrate

$T_3 = 273\,K$ $\quad m_3 = 0\,\frac{kg}{h}$

$c_p := 1.344\,\frac{kJ}{kg \cdot K}$

$\Delta T := T_3 - T_{ref}$ $\quad \Delta T = -25\,K$

$\Delta H_{carb} := m_3 \cdot c_p \cdot \Delta T$ $\quad \Delta H_{carb} = 0\,\frac{kJ}{h}$

Enthalpy of crude fiber

$T_4 = 273\,K$ $\quad m_4 = 0\,\frac{kg}{h}$

$c_p := 0.98\,\frac{kJ}{kg \cdot K}$

$\Delta T := T_4 - T_{ref}$ $\quad \Delta T = -25\,K$

$\Delta H_{crudefiber} := m_4 \cdot c_p \cdot \Delta T$ $\quad \Delta H_{crudefiber} = 0\,\frac{kJ}{h}$

Enthalpy of hexane

$T_5 = 342\,K$ $\quad m_5 = 112.87\,\frac{kg}{h}$

$a_5 := 1.7212 \cdot 10^5\,\frac{kJ}{kg \cdot K}$ $\quad b_5 := -1.8378 \cdot 10^2\,\frac{kJ}{kg \cdot K^2}$ $\quad c_5 := 8.8734 \cdot 10^{-1}\,\frac{kJ}{kg \cdot K^3}$ $\quad d_5 := 0$

$$c_p := \frac{\left[a_5 + b_5 \cdot T_5 + c_5 \cdot (T_5)^2 + d_5 \cdot (T_5)^3\right]}{86177} \qquad c_p = 2.472\,\frac{kJ}{kg \cdot K}$$

$a := 4.4544 \cdot 10^7$ $\quad b := 0.39002$ $\quad c := 0$ $\quad d := 0$

$T_c := 507.6K$ $\quad T_r := \frac{T_5}{T_c}$ $\quad T_r = 0.674\,K$

$$\Delta H_v := \frac{\left[a \cdot (1 - T_r)^{b + (c \cdot T_r) + d \cdot T_r \cdot T_r}\right]}{1000 \cdot 86.177} \qquad \Delta H_v = 333.94\,\frac{kJ}{kg}$$

$\Delta T := T_5 - T_{ref}$ $\quad \Delta T = 44\,K$

$\Delta H_{hexane} := m_5 \cdot (c_p \cdot \Delta T + \Delta H_v)$ $\quad \Delta H_{hexane} = 4.997 \times 10^4\,\frac{kJ}{h}$

Total enthalpy in

$$\Delta H_{IN} := \Delta H_{water} + \Delta H_{protein} + \Delta H_{fats} + \Delta H_{carb} + \Delta H_{crudefiber} + \Delta H_{hexane}$$

$\Delta H_{IN} = 4.997 \times 10^4\,\frac{kJ}{h}$

Enthalpy of outputs

$$m := \begin{pmatrix} 0.0000 \\ 0.0000 \\ 0.0000 \\ 0.0000 \\ 0.0000 \\ 112.8700 \end{pmatrix} \frac{kg}{h} \qquad T := \left[\begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 25 \end{pmatrix} + 273\right] K \qquad \begin{pmatrix} \text{water} \\ \text{protein} \\ \text{fat} \\ \text{carbohydrate} \\ \text{crudefiber} \\ \text{hexane} \end{pmatrix}$$

$T_{ref} := 298K$

Enthalpy of water

$T_0 = 273\,K$ $\qquad m_0 = 0\,\frac{kg}{h}$

$a_0 := 18.2964\,\frac{kJ}{kg \cdot K}$ $\quad b_0 := 1.095 \cdot 10^{-2}\,\frac{kJ}{kg \cdot K^2}$ $\quad c_0 := -4.891 \cdot 10^{-5}\,\frac{kJ}{kg \cdot K^3}$ $\quad d_0 := 0$

$$c_p := \frac{\left[a_0 + b_0 \cdot T_0 + c_0 \cdot (T_0)^2 + d_0 \cdot (T_0)^3\right]}{18} \qquad c_p = 0.98\,\frac{kJ}{kg \cdot K}$$

$\Delta T := T_0 - T_{ref}$ $\qquad \Delta T = -25\,K$

$\Delta H_{water} := m_0 \cdot c_p \cdot \Delta T$ $\qquad \Delta H_{water} = 0\,\frac{kJ}{h}$

Enthalpy of proteins

$T_1 = 273\,K$ $\qquad m_1 = 0\,\frac{kg}{h}$

$c_p := 1.7\,\frac{kJ}{kg \cdot K}$

$\Delta T := T_1 - T_{ref}$ $\qquad \Delta T = -25\,K$

$\Delta H_{protein} := m_1 \cdot c_p \cdot \Delta T$ $\qquad \Delta H_{protein} = 0\,\frac{kJ}{h}$

Enthalpy of fats

$T_2 = 273\,K$ $\qquad m_2 = 0\,\frac{kg}{h}$

$c_p := 8.100\,\frac{kJ}{kg \cdot K}$

$\Delta T := T_2 - T_{ref}$ $\qquad \Delta T = -25\,K$

$\Delta H_{fats} := m_2 \cdot c_p \cdot \Delta T$ $\qquad \Delta H_{fats} = 0\,\frac{kJ}{h}$

Enthalpy of carbohydrate

$T_3 = 273\,K$ $\quad m_3 = 0\,\frac{kg}{h}$

$c_p := 1.344\,\frac{kJ}{kg \cdot K}$

$\Delta T := T_3 - T_{ref}$ $\qquad \Delta T = -25\,K$

$\Delta H_{carb} := m_3 \cdot c_p \cdot \Delta T$ $\qquad \Delta H_{carb} = 0\,\frac{kJ}{h}$

Enthalpy of crude fiber

$T_4 = 273\,K$ $\quad m_4 = 0\,\frac{kg}{h}$

$c_p := 0.98\,\frac{kJ}{kg \cdot K}$

$\Delta T := T_4 - T_{ref}$ $\qquad \Delta T = -25\,K$

$\Delta H_{crudefiber} := m_4 \cdot c_p \cdot \Delta T$ $\qquad \Delta H_{crudefiber} = 0\,\frac{kJ}{h}$

Enthalpy of hexane

$T_5 = 298\,K$ $\quad m_5 = 112.87\,\frac{kg}{h}$

$a_5 := 1.7212 \cdot 10^5\,\frac{kJ}{kg \cdot K}$ $\quad b_5 := -1.8378 \cdot 10^2\,\frac{kJ}{kg \cdot K^2}$ $\quad c_5 := 8.8734 \cdot 10^{-1}\,\frac{kJ}{kg \cdot K^3}$ $\quad d_5 := 0$

$c_p := \frac{\left[a_5 + b_5 \cdot T_5 + c_5 \cdot (T_5)^2 + d_5 \cdot (T_5)^3\right]}{86177}$ $\qquad c_p = 2.276\,\frac{kJ}{kg \cdot K}$

$\Delta T := T_5 - T_{ref}$ $\qquad \Delta T = 0\,K$

$\Delta H_{hexane} := m_5 \cdot (c_p \cdot \Delta T)$ $\qquad \Delta H_{hexane} = 0\,\frac{kJ}{h}$

Total enthalpy out

$\Delta H_{OUT} := \Delta H_{water} + \Delta H_{protein} + \Delta H_{fats} + \Delta H_{carb} + \Delta H_{crudefiber} + \Delta H_{hexane}$

$\Delta H_{OUT} = 0\,\frac{kJ}{kg \cdot K}$

Heat load of condenser 01

$Q_{CONDENSER01} := \Delta H_{OUT} - \Delta H_{IN}$ $\qquad Q_{CONDENSER01} = -4.997 \times 10^4 \frac{kJ}{h}$

The mass of cooling water required is given as

$c_{pwater} := 4.187 \frac{kJ}{kg \cdot K}$ $\qquad \Delta T_{water} := (30 + 273)$

$$m_{coolingwater} := \frac{-Q_{CONDENSER01}}{c_{pwater} \cdot \Delta T_{water}} \qquad m_{coolingwater} = 39.388 \frac{kg}{h}$$

III. Condenser 01 selection and specification

Type: Shell and tube heat exchanger-Horizontal shell-side.
Material: Carbon steel
Assumptions:
1. The void volume is 10% of the volume.
2. The condenser is assumed to be cylinderical.
3. The thickness of the carbon steel shell is 0.01m.
4. The carbon steel tubes of thickness 0.005m have a diameter of 0.08m.

$$mass := \begin{pmatrix} 0.0000 \\ 0.0000 \\ 0.0000 \\ 0.0000 \\ 0.0000 \\ 112.87000 \end{pmatrix} \frac{kg}{h} \quad x := \begin{pmatrix} 0.0000 \\ 0.0000 \\ 0.0000 \\ 0.0000 \\ 0.0000 \\ 1.0000 \end{pmatrix} \quad d := \begin{pmatrix} 1000 \\ 530 \\ 910 \\ 680 \\ 420 \\ 236.9 \end{pmatrix} \frac{kg}{m^3} \quad \begin{pmatrix} water \\ protein \\ fats \\ carbohydrate \\ crudefiber \\ hexane \end{pmatrix}$$

$$averagedensity := x_0 \cdot d_0 + x_1 \cdot d_1 + x_2 \cdot d_2 + x_3 \cdot d_3 + x_4 \cdot d_4 + x_5 \cdot d_5$$

$$averagedensity = 236.9 \frac{kg}{m^3}$$

$$volume_{comp} := \frac{(mass_0 + mass_1 + mass_2 + mass_3 + mass_4 + mass_5)}{averagedensity}$$

$$volume_{comp} = 0.476\, m^3$$

$$volume_{void} := 0.01 \cdot volume_{comp}$$

$$volume_{void} = 4.764 \times 10^{-3} \, m^3$$

$$volume_{cond01} := volume_{comp} + volume_{void}$$

$$volume_{cond01} = 0.481 \, m^3$$

$$D_{cond01} := \left(\frac{8}{3} \cdot \frac{volume_{cond01}}{\pi} \right)^{\frac{1}{3}}$$

$$D_{cond01} = 0.742 \, m$$

The length of the condenser is given as

$$L_{cond01} := 1.5 D_{cond01}$$

$$L_{cond01} = 1.113 \, m$$

The internal radius of the condenser is given as

$$R_{internal} := \frac{D_{cond01}}{2}$$

$$R_{internal} = 0.371 \, m$$

The external radius is given as

$$R_{external} := R_{internal} + 0.01$$

$$R_{external} = 0.381 \, m$$

The total surface area is then given as

$$A_{cond01} := 2\pi R_{external}^2 + 2\pi R_{external} \cdot L_{cond01}$$

$$A_{cond01} = 3.576 \, m^2$$

The number of tubes required to fill the volume of the shell is given as

$\alpha := 0.005\text{m}$ $\qquad D_{inter} := 0.08\text{m}$ $\qquad D_{tubes} := D_{inter} + \alpha$

$D_{tubes} = 0.085\,\text{m}$

$$N_{tubes} := \frac{\left(\pi \cdot \frac{D_{cond01}^{2}}{4}\right)}{\pi \frac{D_{tubes}^{2}}{4}} \qquad N_{tubes} = 76.196$$

The lenght of the tubes is estimated as 3/4 the lenght of the shell

$$L_{tube} := \frac{3}{4} \cdot L_{cond01} \qquad L_{tube} = 0.835\,\text{m}$$

The area of the tubes is given as

$$A_{tubes} := N_{tubes} \cdot 2\pi \cdot \frac{D_{tubes}}{4} \cdot L_{tube} \qquad A_{tubes} = 8.492\,\text{m}^2$$

IV. Condenser 01 cost

The surface area of condenser 01 is

$A_{cond01} := 3.576\text{m}^2$

cost of carbon steel of thickness 0.01m and area 2.977m^2 is

$A_{pan} := 2.997\text{m}^2$ $\qquad cost_{pan} := 46000\text{Naira}$ (Obitex, 2006.)

The cost of the carbon steel required for the condenser

$$cost_{cs} := \frac{\left(A_{cond01} \cdot cost_{pan}\right)}{A_{pan}} \qquad cost_{cs} = 5.489 \times 10^4\,\text{Naira}$$

The cost of the tubes is estimated below

$N_{tubes} := 76.196$ $\qquad L_{tube} := 0.835\text{m}$

cost of carbon steel tube of diameter 0.08m and length 6m is

$L_{tube1} := 6\text{m}$ $\qquad cost_{tube1} := 3850\text{Naira}$ (Obitex, 2006.)

The cost of the carbon steel required for the condenser

$$cost_{tubes} := \frac{N_{tubes} \cdot \left(L_{tube} \cdot cost_{tubel}\right)}{L_{tubel}} \qquad cost_{tubes} = 4.083 \times 10^{4} \text{ Naira}$$

the cost of construction is estimated to be 10% of the cost of the carbon steel

$$cost_{con} := 10\% \cdot cost_{cs} \qquad cost_{con} = 5.489 \times 10^{3} \text{ Naira}$$

the estimated cost of the condenser is given as

$$cost_{cond01} := cost_{cs} + cost_{tubes} + cost_{con} \qquad cost_{cond01} = 1.012 \times 10^{5} \text{ Naira}$$

4.1.6 Condenser 02 design

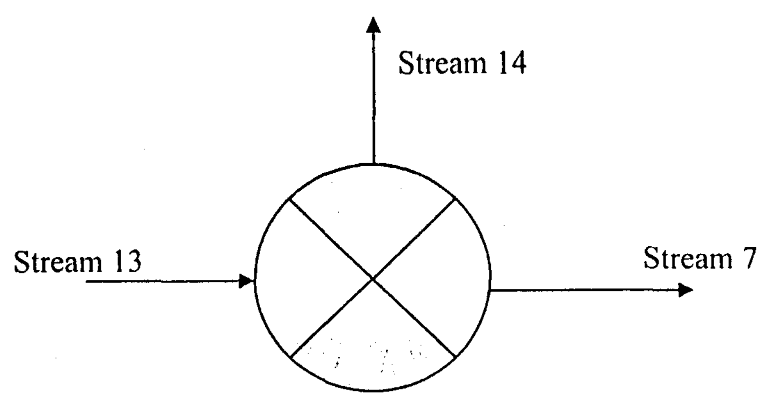


Fig 4.6: Condenser 02

I. Material balance

Assumption:no material is lost and reflux ratio is 3										
R =	3.0000									
		input					Output			
		Stream 11				Stream 7			Stream 12	
Component	kg/h	Kg%	kg/h*scale up		kg/h	Kg%	kg/h*scale up	kg/h	Kg%	kg/h*scale up
Water	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Protein	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Fat	0.0901	0.0010	1.0168		0.0225	0.0010	0.2542	0.0676	0.0010	0.7626
Carbohydrate	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Crudefibre	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Hexane	89.9999	0.9990	1015.8290		22.5000	0.9990	253.9572	67.4999	0.9990	761.8717
Total	90.0900	1.0000	1016.8458		22.5225	1.0000	254.2115	67.5675	1.0000	762.6344

II. Energy balance

Assumption :Vapour from column is cooled to 25⁰C

Enthalpy of inputs

$$m := \begin{pmatrix} 0.0000 \\ 0.0000 \\ 1.0168 \\ 0.0000 \\ 0.0000 \\ 1015.8290 \end{pmatrix} \frac{kg}{h} \qquad T := \left[\begin{pmatrix} 0 \\ 0 \\ 69 \\ 0 \\ 0 \\ 69 \end{pmatrix} + 273\right] K \qquad \begin{pmatrix} \text{water} \\ \text{protein} \\ \text{fat} \\ \text{carbohydrate} \\ \text{crudefiber} \\ \text{hexane} \end{pmatrix}$$

$$T_{ref} := 298K$$

Enthalpy of water

$T_0 = 273\,K \qquad m_0 = 0\,\frac{kg}{h}$

$a_0 := 18.2964\,\frac{kJ}{kg \cdot K} \qquad b_0 := 1.095 \cdot 10^{-2}\,\frac{kJ}{kg \cdot K^2} \qquad c_0 := -4.891 \cdot 10^{-5}\,\frac{kJ}{kg \cdot K^3} \qquad d_0 := 0$

$$c_p := \frac{\left[a_0 + b_0 \cdot T_0 + c_0 \cdot (T_0)^2 + d_0 \cdot (T_0)^3\right]}{18} \qquad c_p = 0.98\,\frac{kJ}{kg \cdot K}$$

$$\Delta T := T_0 - T_{ref} \qquad \Delta T = -25\,K$$

$$\Delta H_{water} := m_0 \cdot c_p \cdot \Delta T \qquad \Delta H_{water} = 0\,\frac{kJ}{h}$$

Enthalpy of proteins

$T_1 = 273\,K \qquad m_1 = 0\,\frac{kg}{h}$

$c_p := 1.7\,\frac{kJ}{kg \cdot K}$

$$\Delta T := T_1 - T_{ref} \qquad \Delta T = -25\,K$$

$$\Delta H_{protein} := m_1 \cdot c_p \cdot \Delta T \qquad \Delta H_{protein} = 0\,\frac{kJ}{h}$$

Enthalpy of fats

$T_2 = 342\,K$ $\quad m_2 = 1.017\,\frac{kg}{h}$

$c_p := 8.100\,\frac{kJ}{kg \cdot K}$

$\Delta H_v := 36.6675\,\frac{kJ}{K}$

$\Delta T := T_2 - T_{ref}$ $\quad \Delta T = 44\,K$

$\Delta H_{fats} := m_2 \cdot \left(c_p \cdot \Delta T + \Delta H_v\right)$ $\quad \Delta H_{fats} = 399.671\,\frac{kJ}{h}$

Enthalpy of carbohydrate

$T_3 = 273\,K$ $\quad m_3 = 0\,\frac{kg}{h}$

$c_p := 1.344\,\frac{kJ}{kg \cdot K}$

$\Delta T := T_3 - T_{ref}$ $\quad \Delta T = -25\,K$

$\Delta H_{carb} := m_3 \cdot c_p \cdot \Delta T$ $\quad \Delta H_{carb} = 0\,\frac{kJ}{h}$

Enthalpy of crude fiber

$T_4 = 273\,K$ $\quad m_4 = 0\,\frac{kg}{h}$

$c_p := 0.98\,\frac{kJ}{kg \cdot K}$

$\Delta T := T_4 - T_{ref}$ $\quad \Delta T = -25\,K$

$\Delta H_{crudefiber} := m_4 \cdot c_p \cdot \Delta T$ $\quad \Delta H_{crudefiber} = 0\,\frac{kJ}{h}$

Enthalpy of hexane

$T_5 = 342\,K$ $\quad m_5 = 1.016 \times 10^3\,\frac{kg}{h}$

$a_5 := 1.7212 \cdot 10^5\,\frac{kJ}{kg \cdot K}$ $\quad b_5 := -1.8378 \cdot 10^2\,\frac{kJ}{kg \cdot K^2}$ $\quad c_5 := 8.8734 \cdot 10^{-1}\,\frac{kJ}{kg \cdot K^3}$ $\quad d_5 := 0$

$$c_p := \frac{\left[a_5 + b_5 \cdot T_5 + c_5 \cdot (T_5)^2 + d_5 \cdot (T_5)^3\right]}{86177} \qquad c_p = 2.472\,\frac{kJ}{kg \cdot K}$$

$a := 4.4544 \cdot 10^7$ $\quad b := 0.39002$ $\quad c := 0$ $\quad d := 0$

$T_c := 507.6K$ $\quad T_r := \frac{T_5}{T_c}$ $\quad T_r = 0.674\,K$

$$\Delta H_v := \frac{\left[a \cdot (1 - T_r)^{b+(c \cdot T_r)+d \cdot T_r \cdot T_r}\right]}{1000 \cdot 86.177} \qquad \Delta H_v = 333.94\,\frac{kJ}{K}$$

$\Delta T := T_5 - T_{ref}$ $\quad \Delta T = 44\,K$

$\Delta H_{hexane} := m_5 \cdot (c_p \cdot \Delta T + \Delta H_v)$ $\quad \Delta H_{hexane} = 4.497 \times 10^5\,\frac{kJ}{h}$

Total enthalpy in

$$\Delta H_{IN} := \Delta H_{water} + \Delta H_{protein} + \Delta H_{fats} + \Delta H_{carb} + \Delta H_{crudefiber} + \Delta H_{hexane}$$

$$\Delta H_{IN} = 4.501 \times 10^5\,\frac{kJ}{h}$$

Enthalpy of outputs

$$m := \begin{pmatrix} 0.0000 \\ 0.0000 \\ 1.0168 \\ 0.0000 \\ 0.0000 \\ 1015.8290 \end{pmatrix} \frac{kg}{h} \qquad T := \left[\begin{pmatrix} 0 \\ 0 \\ 25 \\ 0 \\ 0 \\ 25 \end{pmatrix} + 273\right]K \qquad \begin{pmatrix} \text{water} \\ \text{protein} \\ \text{fat} \\ \text{carbohydrate} \\ \text{crudefiber} \\ \text{hexane} \end{pmatrix}$$

$T_{ref} := 298K$

Enthalpy of water

$T_0 = 273\,K$ $\quad m_0 = 0\,\frac{kg}{h}$

$a_0 := 18.2964\,\frac{kJ}{kg \cdot K}$ $\quad b_0 := 1.095 \cdot 10^{-2}\,\frac{kJ}{kg \cdot K^2}$ $\quad c_0 := -4.891 \cdot 10^{-5}\,\frac{kJ}{kg \cdot K^3}$ $\quad d_0 := 0$

$$c_p := \frac{\left[a_0 + b_0 \cdot T_0 + c_0 \cdot (T_0)^2 + d_0 \cdot (T_0)^3\right]}{18} \qquad c_p = 0.98\,\frac{kJ}{kg \cdot K}$$

$\Delta T := T_0 - T_{ref}$ $\Delta T = -25\,K$

$\Delta H_{water} := m_0 \cdot c_p \cdot \Delta T$ $\Delta H_{water} = 0\,\frac{kJ}{h}$

Enthalpy of proteins

$T_1 = 273\,K$ $m_1 = 0\,\frac{kg}{h}$

$c_p := 1.7\,\frac{kJ}{kg \cdot K}$

$\Delta T := T_1 - T_{ref}$ $\Delta T = -25\,K$

$\Delta H_{protein} := m_1 \cdot c_p \cdot \Delta T$ $\Delta H_{protein} = 0\,s\,\frac{kJ}{day}$

Enthalpy of fats

$T_2 = 298\,K$ $m_2 = 1.017\,\frac{kg}{h}$

$c_p := 8.100\,\frac{kJ}{kg \cdot K}$

$\Delta T := T_2 - T_{ref}$ $\Delta T = 0\,K$

$\Delta H_{fats} := m_2 \cdot c_p \cdot \Delta T$ $\Delta H_{fats} = 0\,\frac{kJ}{h}$

Enthalpy of carbohydrate

$T_3 = 273\,K$ $m_3 = 0\,\frac{kg}{h}$

$c_p := 1.344\,\frac{kJ}{kg \cdot K}$

$\Delta T := T_3 - T_{ref}$ $\Delta T = -25\,K$

$\Delta H_{carb} := m_3 \cdot c_p \cdot \Delta T$ $\Delta H_{carb} = 0\,\frac{kJ}{h}$

Enthalpy of crude fiber

$T_4 = 273\,K$ $m_4 = 0\,\frac{kg}{h}$

$c_p := 0.98\,\frac{kJ}{kg \cdot K}$

$\Delta T := T_4 - T_{ref}$ $\Delta T = -25\,K$

$\Delta H_{crudefiber} := m_4 \cdot c_p \cdot \Delta T$ $\Delta H_{crudefiber} = 0\,\frac{kJ}{h}$

Enthalpy of hexane

$T_5 = 298\,\text{K}$ $m_5 = 1.016 \times 10^3 \frac{\text{kg}}{\text{h}}$

$a_5 := 1.7212 \cdot 10^5 \frac{\text{kJ}}{\text{kg} \cdot \text{K}}$ $b_5 := -1.8378 \cdot 10^2 \frac{\text{kJ}}{\text{kg} \cdot \text{K}^2}$ $c_5 := 8.8734 \cdot 10^{-1} \frac{\text{kJ}}{\text{kg} \cdot \text{K}^3}$ $d_5 := 0$

$$c_p := \frac{\left[a_5 + b_5 \cdot T_5 + c_5 \cdot (T_5)^2 + d_5 \cdot (T_5)^3\right]}{86177}$$ $c_p = 2.276 \frac{\text{kJ}}{\text{kg} \cdot \text{K}}$

$\Delta T := T_5 - T_{ref}$ $\Delta T = 0\,\text{K}$

$\Delta H_{hexane} := m_5 \cdot (c_p \cdot \Delta T)$ $\Delta H_{hexane} = 0 \frac{\text{kJ}}{\text{h}}$

Total enthalpy out

$$\Delta H_{OUT} := \Delta H_{water} + \Delta H_{protein} + \Delta H_{fats} + \Delta H_{carb} + \Delta H_{crudefiber} + \Delta H_{hexane}$$

$\Delta H_{OUT} = 0 \frac{\text{kJ}}{\text{h}}$

Heat load of condenser 02

$Q_{CONDENSER02} := \Delta H_{OUT} - \Delta H_{IN}$ $Q_{CONDENSER02} = -4.501 \times 10^5 \frac{\text{kJ}}{\text{h}}$

The mass of cooling water required is given as

$c_{pwater} := 4.187 \frac{\text{kJ}}{\text{kg} \cdot \text{K}}$ $\Delta T_{water} := (30 + 273)$

$$m_{coolingwater} := \frac{-Q_{CONDENSER02}}{c_{pwater} \cdot \Delta T_{water}}$$ $m_{coolingwater} = 354.805 \frac{\text{kg}}{\text{h}}$

III. Condenser 02 selection and specification

Type: Shell and tube heat exchanger-Horizontal shell-side.
Material: Carbon steel
Assumptions:
1. The void volume is 10% of the volume.
2. The condenser is assumed to be cylindrical.
3. The thickness of the carbon steel shell is 0.01m.
4. The carbon steel tubes of thickness 0.005m have a diameter of 0.08m.

$$\text{mass} := \begin{pmatrix} 0.0000 \\ 0.0000 \\ 1.01685 \\ 0.0000 \\ 0.0000 \\ 1015.82898 \end{pmatrix} \frac{kg}{h} \quad x := \begin{pmatrix} 0.0000 \\ 0.0000 \\ 0.0010 \\ 0.0000 \\ 0.0000 \\ 0.9990 \end{pmatrix} \quad d := \begin{pmatrix} 1000 \\ 530 \\ 910 \\ 680 \\ 420 \\ 236.9 \end{pmatrix} \frac{kg}{m^3} \quad \begin{pmatrix} \text{water} \\ \text{protein} \\ \text{fats} \\ \text{carbohydrate} \\ \text{crudefiber} \\ \text{hexane} \end{pmatrix}$$

$$\text{averagedensity} := x_0 \cdot d_0 + x_1 \cdot d_1 + x_2 \cdot d_2 + x_3 \cdot d_3 + x_4 \cdot d_4 + x_5 \cdot d_5$$

$$\text{averagedensity} = 237.573 \frac{kg}{m^3}$$

$$\text{volume}_{comp} := \frac{(\text{mass}_0 + \text{mass}_1 + \text{mass}_2 + \text{mass}_3 + \text{mass}_4 + \text{mass}_5)}{\text{averagedensity}}$$

$$\text{volume}_{comp} = 4.28\,m^3$$

$$\text{volume}_{void} := 0.01 \cdot \text{volume}_{comp}$$

$$\text{volume}_{void} = 0.043\,m^3$$

$$\text{volume}_{cond02} := \text{volume}_{comp} + \text{volume}_{void}$$

$$\text{volume}_{cond02} = 4.323\,m^3$$

$$D_{cond02} := \left(\frac{8}{3} \cdot \frac{\text{volume}_{cond02}}{\pi}\right)^{\frac{1}{3}}$$

$$D_{cond02} = 1.542\,m$$

The length of the condenser is given as

$$L_{cond02} := 1.5D_{cond02}$$

$$L_{cond02} = 2.314\,m$$

The internal radius of the condenser is given as

$$R_{internal} := \frac{D_{cond02}}{2}$$

$$R_{internal} = 0.771\,m$$

The external radius is given as

$$R_{external} := R_{internal} + 0.01$$

$$R_{external} = 0.781\,m$$

The total surface area is then given as

$$A_{cond02} := 2\pi R_{external}^2 + 2\pi R_{external} \cdot L_{cond02}$$

$$A_{cond02} = 15.191\,m^2$$

The number of tubes required to fill the volume of the shell is given as

$\alpha := 0.005m$ $\quad D_{inter} := 0.08m$ $\quad D_{tubes} := D_{inter} + \alpha$

$$D_{tubes} = 0.085\,m$$

$$N_{tubes} := \frac{\left(\pi \cdot \frac{D_{cond02}^2}{4}\right)}{\pi \frac{D_{tubes}^2}{4}} \qquad N_{tubes} = 329.277$$

The lenght of the tubes is estimated as 3/4 the lenght of the shell

$$L_{tube} := \frac{3}{4} \cdot L_{cond02} \qquad L_{tube} = 1.735\,m$$

The area of the tubes is given as

$$A_{tubes} := N_{tubes} \cdot 2\pi \cdot \frac{D_{tubes}}{4} \cdot L_{tube} \qquad A_{tubes} = 76.287\,m^2$$

IV. Condenser 02 cost

The surface area of condenser 02 is

$$A_{cond02} := 15.191m^2$$

cost of carbon steel of thickness 0.01m and area 2.977m^2 is

$A_{pan} := 2.997m^2$ $\quad cost_{pan} := 46000Naira$ $\quad$ (Obitex, 2006.)

4.1.7 Condenser 04 design

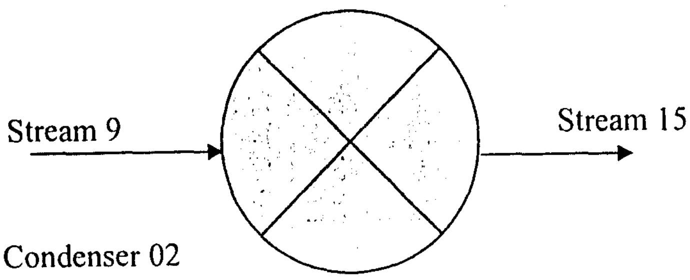


Fig. 4.7: Condenser 02

I. Material balance

Assumption: No material is lost		Input Stream 9		Output Stream 15		
Component	kg/h	Kg%	kg/h*scale up	kg/h	Kg%	kg/h*scale up
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Protein	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Fat	30.2699	1.0000	341.6565	30.2699	1.0000	341.6565
Carbohydrate	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Crudefibre	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Hexane	0.0001	0.0000	0.0010	0.0001	0.0000	0.0010
Total	30.2700	1.0000	341.6575	30.2700	1.0000	341.6575

II. Energy balance

Assumption :Bottom from column is cooled to 25°C

Enthalpy of inputs

$$m := \begin{pmatrix} 0.0000 \\ 0.0000 \\ 341.6565 \\ 0.0000 \\ 0.0000 \\ 0.0010 \end{pmatrix} \frac{kg}{h} \qquad T := \left[\begin{pmatrix} 0 \\ 0 \\ 100 \\ 0 \\ 0 \\ 100 \end{pmatrix} + 273\right] K \qquad \begin{pmatrix} \text{water} \\ \text{protein} \\ \text{fat} \\ \text{carbohydrate} \\ \text{crudefiber} \\ \text{hexane} \end{pmatrix}$$

$$T_{ref} := 298K$$

Enthalpy of water

$T_0 = 273\,K$ $\qquad m_0 = 0\,\frac{kg}{h}$

$a_0 := 18.2964\,\frac{kJ}{kg \cdot K}$ $\quad b_0 := 1.095 \cdot 10^{-2}\,\frac{kJ}{kg \cdot K^2}$ $\quad c_0 := -4.891 \cdot 10^{-5}\,\frac{kJ}{kg \cdot K^3}$ $\quad d_0 := 0$

$$c_p := \frac{\left[a_0 + b_0 \cdot T_0 + c_0 \cdot (T_0)^2 + d_0 \cdot (T_0)^3\right]}{18} \qquad c_p = 0.98\,\frac{kJ}{kg \cdot K}$$

$\Delta T := T_0 - T_{ref}$ $\qquad \Delta T = -25\,K$

$\Delta H_{water} := m_0 \cdot c_p \cdot \Delta T$ $\qquad \Delta H_{water} = 0\,\frac{kJ}{h}$

Enthalpy of proteins

$T_1 = 273\,K$ $\qquad m_1 = 0\,\frac{kg}{h}$

$c_p := 1.7\,\frac{kJ}{kg \cdot K}$

$\Delta T := T_1 - T_{ref}$ $\qquad \Delta T = -25\,K$

$\Delta H_{protein} := m_1 \cdot c_p \cdot \Delta T$ $\qquad \Delta H_{protein} = 0\,\frac{kJ}{h}$

Enthalpy of fats

$T_2 = 373\,K$ $\qquad m_2 = 341.656\,\frac{kg}{h}$

$c_p := 8.100\,\frac{kJ}{kg \cdot K}$

$\Delta T := T_2 - T_{ref}$ $\qquad \Delta T = 75\,K$

$\Delta H_{fats} := m_2 \cdot (c_p \cdot \Delta T)$ $\qquad \Delta H_{fats} = 2.076 \times 10^5 \frac{kJ}{h}$

Enthalpy of carbohydrate

$T_3 = 273\,K \qquad m_3 = 0 \frac{kg}{h}$

$c_p := 1.344 \frac{kJ}{kg \cdot K}$

$\Delta T := T_3 - T_{ref}$ $\qquad \Delta T = -25\,K$

$\Delta H_{carb} := m_3 \cdot c_p \cdot \Delta T$ $\qquad \Delta H_{carb} = 0 \frac{kJ}{h}$

Enthalpy of crude fiber

$T_4 = 273\,K \qquad m_4 = 0 \frac{kg}{h}$

$c_p := 0.98 \frac{kJ}{kg \cdot K}$

$\Delta T := T_4 - T_{ref}$ $\qquad \Delta T = -25\,K$

$\Delta H_{crudefiber} := m_4 \cdot c_p \cdot \Delta T$ $\qquad \Delta H_{crudefiber} = 0 \frac{kJ}{h}$

Enthalpy of hexane

$T_5 = 373\,K \qquad m_5 = 1 \times 10^{-3} \frac{kg}{h}$

$a_5 := 1.7212 \cdot 10^5 \frac{kJ}{kg \cdot K} \qquad b_5 := -1.8378 \cdot 10^2 \frac{kJ}{kg \cdot K^2} \qquad c_5 := 8.8734 \cdot 10^{-1} \frac{kJ}{kg \cdot K^3} \qquad d_5 := 0$

$c_p := \frac{\left[a_5 + b_5 \cdot T_5 + c_5 \cdot (T_5)^2 + d_5 \cdot (T_5)^3\right]}{86177}$ $\qquad c_p = 2.634 \frac{kJ}{kg \cdot K}$

$a := 4.4544 \cdot 10^7 \frac{kJ}{K} \qquad b := 0.39002 \qquad c := 0 \qquad d := 0$

$T_c := 507.6K \qquad T_r := \frac{T_5}{T_c} \qquad T_r = 0.735\,K$

$\Delta H_v := a \cdot (1 - T_r)^{b + (c \cdot T_r) + d \cdot T_r \cdot T_r}$ $\qquad \Delta H_v = 2.654 \times 10^7 \frac{kJ}{K}$

$\Delta T := T_5 - T_{ref}$ $\Delta T = 75\,K$

$\Delta H_{hexane} := m_5 \cdot (c_p \cdot \Delta T + \Delta H_v)$ $\Delta H_{hexane} = 2.654 \times 10^4 \frac{kJ}{h}$

Total enthalpy in

$$\Delta H_{IN} := \Delta H_{water} + \Delta H_{protein} + \Delta H_{fats} + \Delta H_{carb} + \Delta H_{crudefiber} + \Delta H_{hexane}$$

$$\Delta H_{IN} = 2.341 \times 10^5 \frac{kJ}{h}$$

Enthalpy of outputs

$$m := \begin{pmatrix} 0.0000 \\ 0.0000 \\ 341.6565 \\ 0.0000 \\ 0.0000 \\ 0.0010 \end{pmatrix} \frac{kg}{h} \qquad T := \left[\begin{pmatrix} 0 \\ 0 \\ 25 \\ 0 \\ 0 \\ 25 \end{pmatrix} + 273\right] K \qquad \begin{pmatrix} \text{water} \\ \text{protein} \\ \text{fat} \\ \text{carbohydrate} \\ \text{crudefiber} \\ \text{hexane} \end{pmatrix}$$

$T_{ref} := 298K$

Enthalpy of water

$T_0 = 273\,K$ $m_0 = 0 \frac{kg}{h}$

$a_0 := 18.2964 \frac{kJ}{kg \cdot K}$ $b_0 := 1.095 \cdot 10^{-2} \frac{kJ}{kg \cdot K^2}$ $c_0 := -4.891 \cdot 10^{-5} \frac{kJ}{kg \cdot K^3}$ $d_0 := 0$

$c_p := \frac{\left[a_0 + b_0 \cdot T_0 + c_0 \cdot (T_0)^2 + d_0 \cdot (T_0)^3\right]}{18}$ $c_p = 0.98 \frac{kJ}{kg \cdot K}$

$\Delta T := T_0 - T_{ref}$ $\Delta T = -25\,K$

$\Delta H_{water} := m_0 \cdot c_p \cdot \Delta T$ $\Delta H_{water} = 0 \frac{kJ}{h}$

Enthalpy of proteins

$T_1 = 273\,K$ $m_1 = 0 \frac{kg}{h}$

$c_p := 1.7 \frac{kJ}{kg \cdot K}$

$\Delta T := T_1 - T_{ref}$ $\Delta T = -25\,K$

$\Delta H_{protein} := m_1 \cdot c_p \cdot \Delta T$ $\Delta H_{protein} = 0 \frac{kJ}{h}$

Enthalpy of fats

$T_2 = 298\,K$ $\quad m_2 = 341.656\,\frac{kg}{h}$

$c_p := 8.100\,\frac{kJ}{kg \cdot K}$

$\Delta T := T_2 - T_{ref}$ $\quad \Delta T = 0\,K$

$\Delta H_{fats} := m_2 \cdot c_p \cdot \Delta T$ $\quad \Delta H_{fats} = 0\,\frac{kJ}{h}$

Enthalpy of carbohydrate

$T_3 = 273\,K$ $\quad m_3 = 0\,\frac{kg}{h}$

$c_p := 1.344\,\frac{kJ}{kg \cdot K}$

$\Delta T := T_3 - T_{ref}$ $\quad \Delta T = -25\,K$

$\Delta H_{carb} := m_3 \cdot c_p \cdot \Delta T$ $\quad \Delta H_{carb} = 0\,\frac{kJ}{h}$

Enthalpy of crude fiber

$T_4 = 273\,K$ $\quad m_4 = 0\,\frac{kg}{h}$

$c_p := 0.98\,\frac{kJ}{kg \cdot K}$

$\Delta T := T_4 - T_{ref}$ $\quad \Delta T = -25\,K$

$\Delta H_{crudefiber} := m_4 \cdot c_p \cdot \Delta T$ $\quad \Delta H_{crudefiber} = 0\,\frac{kJ}{h}$

Enthalpy of hexane

$T_5 = 298\,K$ $\quad m_5 = 1 \times 10^{-3}\,\frac{kg}{h}$

$a_5 := 1.7212 \cdot 10^5\,\frac{kJ}{kg \cdot K}$ $\quad b_5 := -1.8378 \cdot 10^2\,\frac{kJ}{kg \cdot K^2}$ $\quad c_5 := 8.8734 \cdot 10^{-1}\,\frac{kJ}{kg \cdot K^3}$ $\quad d_5 := 0$

$c_p := \frac{\left[a_5 + b_5 \cdot T_5 + c_5 \cdot (T_5)^2 + d_5 \cdot (T_5)^3\right]}{86177}$ $\quad c_p = 2.276\,\frac{kJ}{kg \cdot K}$

$\Delta T := T_5 - T_{ref}$ $\Delta T = 0\,K$

$\Delta H_{hexane} := m_5 \cdot \left(c_p \cdot \Delta T\right)$ $\Delta H_{hexane} = 0\,\frac{kJ}{h}$

Total enthalpy out

$\Delta H_{OUT} := \Delta H_{water} + \Delta H_{protein} + \Delta H_{fats} + \Delta H_{carb} + \Delta H_{crudefiber} + \Delta H_{hexane}$

$\Delta H_{OUT} = 0\,\frac{kJ}{h}$

Heat load of condenser 04

$Q_{CONDENSER04} := \Delta H_{OUT} - \Delta H_{IN}$ $Q_{CONDENSER04} = -2.341 \times 10^{5}\,\frac{kJ}{h}$

The mass of cooling water required is given as

$c_{pwater} := 4.187\,\frac{kJ}{kg \cdot K}$ $\Delta T_{water} := (30 + 273)$

$m_{coolingwater} := \frac{-Q_{CONDENSER04}}{c_{pwater} \cdot \Delta T_{water}}$ $m_{coolingwater} = 184.525\,\frac{kg}{h}$

III. Condenser 04 selection and specification

Type:Shell and tube heat exchanger-Horizontal shell-side.
Material: Carbon steel
Assumptions:
1.The void volume is 10% of the volume.
2.The condenser is assumed to be cylinderical.
3.The thickness of the carbon steel shell is 0.01m.
4.The carbon steel tubes of thickness 0.005m have a diameter of 0.08m.

$$mass := \begin{pmatrix} 0.0000 \\ 0.0000 \\ 341.65647 \\ 0.0000 \\ 0.0000 \\ 0.00102 \end{pmatrix} \frac{kg}{h} \quad x := \begin{pmatrix} 0.0000 \\ 0.0000 \\ 1.0000 \\ 0.0000 \\ 0.0000 \\ 0.0000 \end{pmatrix} \quad d := \begin{pmatrix} 1000 \\ 530 \\ 910 \\ 680 \\ 420 \\ 236.9 \end{pmatrix} \frac{kg}{m^3} \quad \begin{pmatrix} \text{water} \\ \text{protein} \\ \text{fats} \\ \text{carbohydrate} \\ \text{crudefiber} \\ \text{hexane} \end{pmatrix}$$

$$averagedensity := x_0 \cdot d_0 + x_1 \cdot d_1 + x_2 \cdot d_2 + x_3 \cdot d_3 + x_4 \cdot d_4 + x_5 \cdot d_5$$

$$averagedensity = 910 \frac{kg}{m^3}$$

$$volume_{comp} := \frac{(mass_0 + mass_1 + mass_2 + mass_3 + mass_4 + mass_5)}{averagedensity}$$

$$volume_{comp} = 0.375\,m^3$$

$$volume_{void} := 0.01 \cdot volume_{comp}$$

$$volume_{void} = 3.754 \times 10^{-3}\,m^3$$

$$volume_{cond04} := volume_{comp} + volume_{void}$$

$$volume_{cond04} = 0.379\,m^3$$

$$D_{cond04} := \left(\frac{8}{3} \cdot \frac{volume_{cond04}}{\pi}\right)^{\frac{1}{3}}$$

$$D_{cond04} = 0.685\,m$$

The length of the condenser is given as

$$L_{cond04} := 1.5D_{cond04}$$

$$L_{cond04} = 1.028\,m$$

The internal radius of the condenser is given as

$$R_{internal} := \frac{D_{cond04}}{2}$$

$$R_{internal} = 0.343\,m$$

The external radius is given as

$$R_{external} := R_{internal} + 0.01$$

$$R_{external} = 0.353\,m$$

The total surface area is then given as

$$A_{cond04} := 2\pi R_{external}^2 + 2\pi R_{external} \cdot L_{cond04}$$

$$A_{cond04} = 3.059\,m^2$$

The number of tubes required to fill the volume of the shell is given as

$\alpha := 0.005m$ $D_{inter} := 0.08m$ $D_{tubes} := D_{inter} + \alpha$

$$D_{tubes} = 0.085\,m$$

$$N_{tubes} := \frac{\left(\pi \cdot \frac{D_{cond04}^2}{4}\right)}{\pi \frac{D_{tubes}^2}{4}} \qquad N_{tubes} = 65.006$$

The lenght of the tubes is estimated as 3/4 the lenght of the shell

$$L_{tube} := \frac{3}{4} \cdot L_{cond04} \qquad L_{tube} = 0.771\,m$$

The area of the tubes is given as

$$A_{tubes} := N_{tubes} \cdot 2\pi \cdot \frac{D_{tubes}}{4} \cdot L_{tube} \qquad A_{tubes} = 6.692\,m^2$$

IV. Condenser 04 cost

The surface area of condenser 04 is

$$A_{cond04} := 3.059m^2$$

cost of carbon steel of thickness 0.01m and area 2.977m^2 is

$A_{pan} := 2.997m^2$ $cost_{pan} := 46000 Naira$ (Obitex, 2006.)

The cost of the carbon steel required for the condenser

$$cost_{cs} := \frac{\left(A_{cond04} \cdot cost_{pan}\right)}{A_{pan}} \qquad cost_{cs} = 4.695 \times 10^4\ Naira$$

The cost of the tubes is estimated below

$N_{tubes} := 65.006$ $\qquad$ $L_{tube} := 0.771\text{m}$

cost of carbon steel tube of diameter 0.08m and length 6m is

$L_{tube1} := 6\text{m}$ $\qquad$ $cost_{tube1} := 3850\text{Naira}$ $\qquad$ (Obitex, 2006.)

The cost of the tubes is

$$cost_{tubes} := \frac{N_{tubes} \cdot \left(L_{tube} \cdot cost_{tube1}\right)}{L_{tube1}} \qquad cost_{tubes} = 3.216 \times 10^{4}\ \text{Naira}$$

the cost of construction is estimated to be 10% of the cost of the carbon steel

$$cost_{con} := 10\% \cdot cost_{cs} \qquad cost_{con} = 4.695 \times 10^{3}\ \text{Naira}$$

the estimated cost of the condenser is given as

$$cost_{cond04} := cost_{cs} + cost_{tubes} + cost_{con} \qquad cost_{cond04} = 8.381 \times 10^{4}\ \text{Naira}$$

4.1.8 Reboiler design

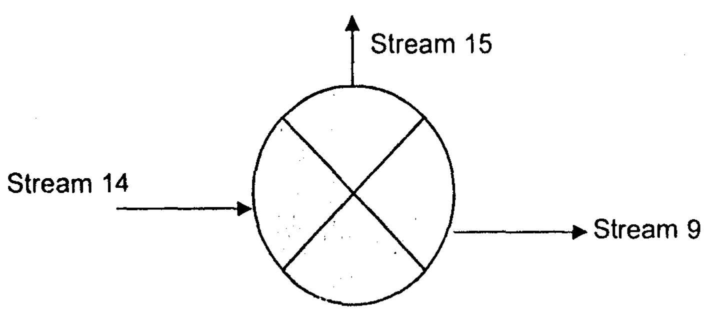


Fig. 4.8: Reboiler.

I. Material balance

Assumption:No material is lost and q is 1.01									
Q =	1.0100								
		Input				Output			
		Stream 14			Stream 9			Stream 13	
Component	kg/h	Kg%	kg/h*scale up	kg/h	Kg%	kg/h*scale up	kg/h	Kg%	kg/h*scale up
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Protein	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Fat	189.1305	1.0000	2134.7164	30.2699	1.0000	341.6565	158.8606	1.0000	1793.0599
Carbohydrate	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Crudefibre	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Hexane	0.0006	0.0000	0.0063	0.0001	0.0000	0.0010	0.0005	0.0000	0.0053
Total	189.1311	1.0000	2134.7227	30.2700	1.0000	341.6575	158.8611	1.0000	1793.0652

I. Energy balance

The energy required by the reboiler is determined from a balance around the column

Enthalpy of feed Into the column

$T := (39 + 273)K$

$x_{fat} := 0.2522$ $\qquad$ $x_{hex} := 0.7478$

$c_{pfat} := 8.1 \frac{kJ}{kg \cdot K}$

$a_5 := 1.7212 \cdot 10^5 \frac{kJ}{kg \cdot K}$ $\qquad$ $b_5 := -1.8378 \cdot 10^2 \frac{kJ}{kg \cdot K^2}$ $\qquad$ $c_5 := 8.8734 \cdot 10^{-1} \frac{kJ}{kg \cdot K^3}$ $\qquad$ $d_5 := 0$

$c_{phex} := \frac{\left[a_5 + b_5 \cdot T + c_5 \cdot (T)^2 + d_5 \cdot (T)^3\right]}{86177}$ $\qquad$ $c_{phex} = 2.334 \frac{kJ}{kg \cdot K}$

$c_{pfeed} := x_{fat} \cdot c_{pfat} + x_{hex} \cdot c_{phex}$ $\qquad$ $c_{pfeed} = 3.788 \frac{kJ}{kg \cdot K}$

$m_{feed} := 1358.5033 \frac{kg}{h}$

$\Delta H_{feed} := m_{feed} \cdot c_{pfeed} \cdot (T - 298)$ $\qquad$ $\Delta H_{feed} = 7.205 \times 10^4 \frac{kJ}{h}$

Enthalpy of products out of condenser 02

$\Delta H_{OUT} = 0 \frac{kJ}{h}$

Enthalpy of product out of the reboiler

$T := (100 + 273)K$

$x_{fat} := 1$ $\qquad$ $x_{hex} := 0$

$c_{pfat} := 8.1 \frac{kJ}{kg \cdot K}$

$a_5 := 1.7212 \cdot 10^5 \frac{kJ}{kg \cdot K}$ $\qquad$ $b_5 := -1.8378 \cdot 10^2 \frac{kJ}{kg \cdot K^2}$ $\qquad$ $c_5 := 8.8734 \cdot 10^{-1} \frac{kJ}{kg \cdot K^3}$ $\qquad$ $d_5 := 0$

$c_{phex} := \frac{\left[a_5 + b_5 \cdot T + c_5 \cdot (T)^2 + d_5 \cdot (T)^3\right]}{86177}$ $\qquad$ $c_{phex} = 2.634 \frac{kJ}{kg \cdot K}$

$c_{preb} := x_{fat} \cdot c_{pfat} + x_{hex} \cdot c_{phex}$ $\qquad$ $c_{preb} = 8.1 \frac{kJ}{kg \cdot K}$

kg · K

$m_{reb} := 341.6575 \frac{kg}{h}$

$\Delta H_{reb} := m_{reb} \cdot c_{preb} \cdot (T - T_{ref})$ $\Delta H_{reb} = 2.076 \times 10^5 \frac{kJ}{h}$

Heat load of condenser 02

$Q_{CONDENSER02} = -4.501 \times 10^5 \frac{kJ}{h}$

Heat load of reboiler

$Q_{REBOILER} := -(Q_{CONDENSER02}) + \Delta H_{reb} + \Delta H_{OUT} - \Delta H_{feed}$

$Q_{REBOILER} = 5.856 \times 10^5 \frac{kJ}{h}$

The mass of steam required for the heating process is

$\Delta H_{vwater} := 2.26 \cdot 10^3 \frac{kJ}{kg}$

$m_{steam} := \frac{Q_{REBOILER}}{\Delta H_{vwater}}$ $m_{steam} = 259.13 \frac{kg}{h}$

III. Reboiler selection and specification

Type: Shell and tube heat exchanger-Horizontal shell-side.
Material: Carbon steel
Assumptions:
1. The void volume is 10% of the volume.
2. The condenser is assumed to be cylinderical.
3. The thickness of the carbon steel shell is 0.01m.
4. The carbon steel tubes of thickness 0.005m have a diameter of 0.08m.

$$\text{mass} := \begin{pmatrix} 0.0000 \\ 0.0000 \\ 2134.7164 \\ 0.0000 \\ 0.0000 \\ 0.0063 \end{pmatrix} \frac{kg}{h} \quad x := \begin{pmatrix} 0.0000 \\ 0.0000 \\ 1.0000 \\ 0.0000 \\ 0.0000 \\ 0.0000 \end{pmatrix} \quad d := \begin{pmatrix} 1000 \\ 530 \\ 910 \\ 680 \\ 420 \\ 236.9 \end{pmatrix} \frac{kg}{m^3} \quad \begin{pmatrix} \text{water} \\ \text{protein} \\ \text{fats} \\ \text{carbohydrate} \\ \text{crudefiber} \\ \text{hexane} \end{pmatrix}$$

$$averagedensity := x_0 \cdot d_0 + x_1 \cdot d_1 + x_2 \cdot d_2 + x_3 \cdot d_3 + x_4 \cdot d_4 + x_5 \cdot d_5$$

$$averagedensity = 910 \frac{kg}{m^3}$$

$$volume_{comp} := \frac{(mass_0 + mass_1 + mass_2 + mass_3 + mass_4 + mass_5)}{averagedensity}$$

$$volume_{comp} = 2.346\,m^3$$

$$volume_{void} := 0.01 \cdot volume_{comp}$$

$$volume_{void} = 0.023\,m^3$$

$$volume_{reb} := volume_{comp} + volume_{void}$$

$$volume_{reb} = 2.369\,m^3$$

$$D_{reb} := \left(\frac{8}{3} \cdot \frac{volume_{reb}}{\pi}\right)^{\frac{1}{3}}$$

$$D_{reb} = 1.262\,m$$

The length of the reboiler is given as

$$L_{reb} := 1.5D_{reb}$$

$$L_{reb} = 1.893\,m$$

The internal radius of the reboiler is given as

$$R_{internal} := \frac{D_{reb}}{2}$$

$$R_{internal} = 0.631\,m$$

The external radius is given as

$$R_{external} := R_{internal} + 0.01$$

$$R_{external} = 0.641\,m$$

The total surface area is then given as

$$A_{reb} := 2\pi R_{external}^2 + 2\pi R_{external} \cdot L_{reb}$$

$$A_{reb} = 10.21\,m^2$$

The number of tubes required to fill the volume of the shell is given as

$\alpha := 0.005m$ $\quad D_{inter} := 0.08m$ $\quad D_{tubes} := D_{inter} + \alpha$

$$D_{tubes} = 0.085\,m$$

$$N_{tubes} := \frac{\left(\pi \cdot \frac{D_{reb}^2}{4}\right)}{\pi \cdot \frac{D_{tubes}^2}{4}} \qquad N_{tubes} = 220.524$$

The lenght of the tubes is estimated as 3/4 the lenght of the shell

$$L_{tube} := \frac{3}{4} \cdot L_{reb} \qquad L_{tube} = 1.42\,m$$

The area of the tubes is given as

$$A_{tubes} := N_{tubes} \cdot 2\pi \cdot \frac{D_{tubes}}{4} \cdot L_{tube} \qquad A_{tubes} = 41.811\,m^2$$

IV. Reboiler cost

The surface area of reboiler is

$$A_{reb} := 10.21m^2$$

cost of carbon steel of thickness 0.01m and area 2.977m² is

$A_{pan} := 2.997m^2$ $\quad cost_{pan} := 46000Naira$ $\quad$ (Obitex, 2006.)

The cost of the carbon steel required for the condenser

$$cost_{cs} := \frac{\left(A_{reb} \cdot cost_{pan}\right)}{A_{pan}} \qquad cost_{cs} = 1.567 \times 10^5\,Naira$$

The cost of the tubes is estimated below

$N_{tubes} := 220.524$ $\qquad$ $L_{tube} := 1.42m$

cost of carbon steel tube of diameter 0.08m and length 6m is

$L_{tube1} := 6m$ $\qquad$ $cost_{tube1} := 3850 Naira$ $\qquad$ (Obitex, 2006.)

The cost of the tubes is

$$cost_{tubes} := \frac{N_{tubes} \cdot (L_{tube} \cdot cost_{tube1})}{L_{tube1}} \qquad cost_{tubes} = 2.009 \times 10^5 \ Naira$$

the cost of construction is estimated to be 10% of the cost of the carbon steel

$$cost_{con} := 10\% \cdot cost_{cs} \qquad cost_{con} = 1.567 \times 10^4 \ Naira$$

the estimated cost of the condenser is given as

$$cost_{reb} := cost_{cs} + cost_{tubes} + cost_{con} \qquad cost_{reb} = 3.733 \times 10^5 \ Naira$$

4.2 Economic Analysis of The Plant

All percentages are obtained from Sinnot, 1999.

4.2.1 Purchased equipment cost

$$cost_e := \begin{pmatrix} cost_{crusher} \\ cost_{ext} \\ cost_{desolventiser} \\ cost_{col} \\ cost_{cond01} \\ cost_{cond02} \\ cost_{cond04} \\ cost_{reb} \end{pmatrix} Naira \qquad \begin{pmatrix} crusher \\ extractor \\ desolventiser \\ column \\ condenser01 \\ condenser02 \\ condenser04 \\ reboiler \end{pmatrix}$$

The purchased equipment cost PCE is given as

$$PCE := cost_{e_0} + cost_{e_1} + cost_{e_2} + cost_{e_3} + \left(cost_{e_4} + cost_{e_5} + cost_{e_6} + cost_{e_7}\right)$$

$$PCE = 3.099 \times 10^6 \ Naira$$

4.2.2 Total capital investment

i. Physical plant cost

f is the fraction of the PCE that the item it is estimated for is.

$$f := \begin{pmatrix} 0.45 \\ 0.45 \\ 0.15 \\ 0.10 \\ 0.10 \\ 0.45 \\ 0.20 \\ 0.05 \\ 0.05 \end{pmatrix} \qquad \begin{pmatrix} \text{equipment\_erection} \\ \text{piping} \\ \text{instrumentation} \\ \text{electrical} \\ \text{buildings} \\ \text{utilities} \\ \text{storages} \\ \text{site\_developement} \\ \text{auxillary\_bildings} \end{pmatrix}$$

(Sinnot, 1999)

Total physical plant cost PPC is given as

$$PPC := PCE \cdot (1 + f_0 + f_1 + f_2 + f_3 + f_4 + f_5 + f_6 + f_7 + f_8)$$

$PPC = 9.297 \times 10^6$ Naira

ii. Fixed capital

$$f := \begin{pmatrix} 0.25 \\ 0.05 \\ 0.10 \end{pmatrix} \qquad \begin{pmatrix} \text{design\_and\_engineering} \\ \text{contractors\_fee} \\ \text{contigency} \end{pmatrix}$$

(Sinnot, 1999)

The plant fixed capital FC cost is given as

$FC := PPC \cdot (1 + f_0 + f_1 + f_2)$ $\qquad FC = 1.302 \times 10^7$ Naira

iii. Working capital

This is estimated to be 5% of the fixed capital cost. Therefore, working capital WC given as

$WC := 5\% \cdot FC$ $\qquad WC = 6.508 \times 10^5$ Naira

The total capital investment of the plant, therefore is

$TCI := FC + WC$ $\qquad TCI = 1.367 \times 10^7$ Naira

4.2.3 Annual operating costs

The plant operates for 24 hours in a day and 350 days in a year.

i Variable costs

1. Raw materials

$attain := \frac{24h}{day} \cdot 350 \frac{day}{yr}$ $\qquad$ $attain = 1.26 \times 10^{4} \frac{h}{yr}$

$m_{cashew} := 1128.7 \frac{kg}{h} \cdot attain$ $\qquad$ $m_{cashew} = 1.422 \times 10^{7} \frac{kg}{yr}$

$cost_{cashew} := 11 \frac{Naira}{kg}$

$cost_{RM} := m_{cashew} \cdot cost_{cashew}$

$cost_{RM} = 1.564 \times 10^{8} \frac{Naira}{yr}$

2. Miscellaneous material: 10% of maintainance.

$cost_{M} := 10\% \cdot 5\% \cdot FC$ $\qquad$ $cost_{M} = 6.508 \times 10^{4} \frac{Naira}{yr}$

3. Utilities

$m_{cooling\_water} := 578.718 \frac{kg}{h} \cdot attain$ $\qquad$ $m_{cooling\_water} = 7.292 \times 10^{6} \frac{kg}{yr}$

$vol_{cw} := \frac{m_{cooling\_water}}{1000 \frac{kg}{m^{3}}}$ $\qquad$ $vol_{cw} = 7.292 \times 10^{3} \frac{m^{3}}{yr}$

$vol_{cw} = 7.292 \times 10^{6} \frac{liter}{yr}$

$cost_{cw} := 0.5 \frac{Naira}{liter}$

$m_{steam} := 259.13 \frac{kg}{h} \cdot attain$ $\qquad$ $m_{steam} = 3.265 \times 10^{6} \frac{kg}{yr}$

$cost_{steam} := 1.61 \frac{Naira}{kg}$ (Sinnot, 1999)

$cost_{utilities} := vol_{cw} \cdot cost_{cw} + m_{steam} \cdot cost_{steam}$

$cost_{utilities} = 8.903 \times 10^{6} \frac{Naira}{yr}$

The variable operational costs is given as

$$VOC := cost_{RM} + cost_{M} + cost_{utilities}$$

$$VOC = 1.654 \times 10^{8} \frac{Naira}{yr}$$

ii. Fixed costs

1. Maintainance: 5% of FC

$$cost_{main} := 5\% \cdot FC \qquad cost_{main} = 6.508 \times 10^{5} \frac{Naira}{yr}$$

2. Operating labour: Four unskilled workers are needed to mount each 8-hour shift with a supervising engineer for each shift. The administration staff is made up of the manager, accountant, personnel manager, store keeper, two drivers and a security man. They are paid according to their skills.

$$n_{skill} := 6 \qquad cost_{skill} := 1440000 \frac{Naira}{yr}$$

$$n_{unskill} := 12 \qquad cost_{unskill} := 432000 \frac{Naira}{yr}$$

$$n_{semiskill} := 4 \qquad cost_{semiskill} := 480000 \frac{Naira}{yr}$$

$$cost_{labor} := n_{skill} \cdot cost_{skill} + n_{unskill} \cdot cost_{unskill} + n_{semiskill} \cdot cost_{semiskill}$$

$$cost_{labor} = 1.574 \times 10^{7} \frac{Naira}{yr}$$

3. Plant overheads: 50% of operating labour.

$$cost_{po} := 50\% \cdot cost_{labor} \qquad cost_{po} = 7.872 \times 10^{6} \frac{Naira}{yr}$$

4. Laboratory: 30% of operating labour.

$$cost_{lab} := 30\% \cdot cost_{labor} \qquad cost_{lab} = 4.723 \times 10^{6} \frac{Naira}{yr}$$

5. Capital charges: 10% of FC.

$$cost_{cc} := 10\% \cdot FC \qquad cost_{cc} = 1.302 \times 10^{6} \frac{Naira}{yr}$$

6. Insurance: 1% of FC.

$$cost_{ins} := 1\% \cdot FC \qquad cost_{ins} = 1.302 \times 10^{5} \frac{Naira}{yr}$$

7. Local taxes: 1% of FC.

$$cost_{LT} := 1\% \cdot FC \qquad cost_{LT} = 1.302 \times 10^{5} \frac{Naira}{yr}$$

The fixed operational cost is

$$FOC := cost_{main} + cost_{labor} + cost_{po} + cost_{lab} + cost_{cc} + cost_{ins} + cost_{LT}$$

$$FOC = 3.055 \times 10^{7} \frac{Naira}{yr}$$

iv. Direct production cost.

$$DPC := VOC + FOC \qquad DPC = 1.96 \times 10^{8} \frac{Naira}{yr}$$

iii. Company's costs; These include general overheads, sales expense, research and development costs and company's reserves. Their value is 20% of DPC.

$$cost_{company} := 20\% \cdot DPC \qquad cost_{company} = 3.919 \times 10^{7} \frac{Naira}{yr}$$

The total annual operating costs is

$$AOC := DPC + cost_{company} \qquad AOC = 2.351 \times 10^{8} \frac{Naira}{yr}$$

4.2.4 Gross earnings

The selling price of cashew kernel oil is N45 per liter

$$SP_{OIL} := 56 \frac{Naira}{liter}$$

$$vol_{oil} := 10000 \frac{liter}{day} \qquad attainment := 350 \frac{day}{yr}$$

$$income_{oil} := vol_{oil} \cdot SP_{OIL} \cdot attainment \qquad income_{oil} = 1.96 \times 10^{8} \frac{Naira}{yr}$$

The selling price of the cashew cake is N2 per kg

$$SP_{cake} := 7 \cdot \frac{Naira}{kg}$$

$$mass_{cake} := 786.02668 \frac{kg}{h} \qquad attain := 24 \cdot 350 \cdot \frac{h}{yr}$$

$$income_{cake} := SP_{cake} \cdot mass_{cake} \cdot attain \qquad income_{cake} = 4.622 \times 10^{7} \frac{Naira}{yr}$$

Total income is

$$TI := income_{oil} + income_{cake} \qquad TI = 2.422 \times 10^{8} \frac{Naira}{yr}$$

Therefore,

$GROSS_{income} := TI - AOC$ $\qquad GROSS_{income} = 7.07 \times 10^{6} \frac{Naira}{yr}$

4.2.5 Net profit: Assuming a tax rate of 13%

$TAX := 16\% \cdot GROSS_{income}$ $\qquad TAX = 1.131 \times 10^{6}\ Naira$

$NP := GROSS_{income} - TAX$ $\qquad NP = 5.938 \times 10^{6}\ Naira$

4.2.6 Rate of return

$ROR := \left(\frac{NP}{TCI}\right) \cdot 100\%$ $\qquad ROR = 43.455\%$

4.2.7. Pay back period

$PB := \frac{1}{ROR}$ $\qquad PB = 2.301\ yr$

CHAPTER FIVE

5.0 RESULTS AND DISCUSSION OF RESULTS

5.1 Results

The summary of the results obtained from the calculation of this project is as presented in table 5.1 to 5.5.

The results of the material balance are shown below:

Table 5.1: The material balance for each equipment.

Equipment	input kg/h	output kg/h
Crusher	1128.700	1128.700
Extractor	2257.400	2257.400
desolventiser	898.897	898.897
Distillation column	1358.503	1358.503
Condenser 01	112.870	112.870
Condenser 02	1016.846	1016.846
Condenser 04	341.657	341.657
reboiler	2134.723	2134.723

The results of the energy balances are shown below:

Table 5.2: The energy balance for each equipment.

Equipment	Heat load (kJ/h)
crusher	101,800.0
extractor	0
desolventiser	1231000.0
Distillation column	0
Condenser 01	-4,9970.0
Condenser 02	-3,998.0
Condenser 04	-234,600.0
reboiler	13,9500.0
Total	7,5870.0

The results of the equipments selection and specification is given below:

Table 5.3: The equipment selection and specification.

Equipment	Type	Height(m)	Diameter(m)	Area(m^2)	volume(m^3)
crusher	crusher rolls	2.84	1.42	6.62	14.95
extractor	Bollman's extractor	5.71	2.86	64.27	36.54
desolventiser	vertical tube	1.993	0.97	7.52	1.42
column	sieve plate	2.58	1.29	13.32	3.37
condenser01	horizontal shell side	1.11	0.74	3.58	1.11
condenser02	horizontal shell side	0.77	1.54	15.19	4.32
condenser04	horizontal shell side	1.03	0.69	3.06	0.38
reboiler	horizontal shell side	1.89	1.262	10.21	2.37

The results of the economic analysis is shown in table 5.4 and 5.5 below:

.Table 5.4: The equipment cost.

Equipment	Cost(Naira)
crusher	126,900
extractor	1,105,000
desolventiser	326,800
distillation column	326,800
condenser 01	101,200
condenser 02	621,000
condenser 04	83,810
reboiler	373,300
total	3,099,000

Table 5.5: The Economic description of the plant.

Economic description	Value
PCE	₦ 9,297,000
FC	₦13,020,000
WC	₦650,800
TCI	₦13,670,000
ROR	50%
PBP	approximately 2 years

5.2 Discussion of Results

The design problem states a 10000liters/day of cashew kernel oil (CKO). A 24- hour day and a 350-day year assumed to be the plant attainment. The overall material balance shows that 27010kg/day of cashew kernels was required as feed. The overall energy balance shows that the plant requires 75780kJ/h

It is observed that all the material entering each equipment comes out as output. This implies that accumulation does not occur in the system and the system can be assumed to operate at a steady state.

The energy balance around the equipment show that energy is added to the system in the crusher, desolventiser and reboiler while heat is removed from the system at the condensers via cooling. No energy is added or removed from the system in the extractor but there is a transfer of heat from the higher energy cashew kernels to the lower energy hexane stream. Due to the relatively large amount of material being handled, the heat load was also relatively high e.g, 123,100 kJ/h for desolventiser and 450,100 kJ/h for condenser 02.

The equipment selection was done bearing in mind the heat load and nature of the raw materials and product from the plant. Since the heat load is relatively high, steel was chosen as the material for construction of all of the equipment and since hexane, the cashew kernels and the cashew kernel oil are not corrosive, carbon steel is employed to reduce the cost of material for construction.

The sizing of these equipment was approximately done and the Extractor was found to be the largest equipment with an area, height and diameter of $64.265m^2$, 5.709m and 2.855m respectively. This size was due to the fact that a large amount of material is passed through it per hour.

Economic analysis carried out on the plant shows that the total purchased equipment cost (PCE) and the plant fixed cost (FC) were found to be ₦3,099,000 and ₦13,020,000 respectively. Thus, the Total capital investment (TCI) and the Annual operational cost (AOC) per annum were found to be ₦13,670,000 and ₦233,100,000 respectively. The plant yields an annual profit after tax of ₦5,938,000. A rate of return (ROR) of approximately 50% and the plant pay back period (PBR) of approximately 2 years were estimated for the plant.

From these results, it can be seen that the proposed plant is economically viable since only 2 years is required for the plant to break-even, even at a selling price of the products that is lesser than the selling price of the conventional oil brands.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATION

6.1 Conclusion

The result of this research work shows that for a plant to produce 10,000 liters/day of cashew kernel oil, the Purchased equipment cost is ₦3,099,000, the Total capital investment is ₦13,670,000 and the Annual operating cost per annum is ₦233,100,000 .

Finally, the plant was found to be economically viable as it yields a net profit of 5,938,000 Naira with a pay back period of 2 years.

6.2 Recommendation

Haven designed a plant for the production of cashew kernel oil, it is recommended that a cashew nut shell liquid (CNSL) plant be sited close to this plant so that the by product from the CNSL plant, cashew kernels, can be used as the raw material for the CKO plant. For a better quality product, a process of refining the oil should also be added to the proposed plant. It is also recommended that the plant be sited in the middle belt of Nigeria as cashew trees grow abundantly in this part of the country e.g. Kogi and Benue states.

More importantly, this work is just a conceptual design work. So, before construction is contemplated, a more detailed design of the plant has to be carried out with detailed research and development. Also, a refining process for the produced oil should be included in future designs.

REFERENCES

- Arinze, H. A. (2005); Design Of A Plant To Produce 100liters/Day Of Cashew Nut Shell Liquid, An Un Published Work Of The Department Of Chemical Engineering, F.U.T. Minna
- Austin, G. J. (1984); Shreve's Chemical Process Industries, 5th Edition, McGraw Hill, Singapore.
- Oladele, K. K. (2005); Extraction and Characterization of Cashew Kernel Oil, an Unpublished Work of the Department Of Chemical Engineering, F. U. T. Minna.
- Norman, A. A. (1989); Advanced Chemistry, 3rd Edition, Heinemann, Oxford, U.K.
- Odu Geoffrey N. (2005); Design of plant to produce 1000 tonnes of Glycerol Per Annum Using Saponification Process, Department of Chemical Engineering, F.U.T. Minna -unpublished work.
- Okoronkwo, C.O & son's enterprise, no. 16, Idris Kuta road, Minna, Niger State.
- Perry, R. F. and Green D. W. (1998); Perry's Chemical Engineer's handbook, 7th Edition,

  McGraw-Hill Book Company, New-York, U.S.A.
- Sinnot, R.K. (1999), Coulson and Richardson's Chemical Engineering, Vol.6, 3rd Edition, Butterworth, Heinemann, Oxford, U.K
- Weis, E. A. (2004) "Oil Seed Crops" 2nd edition, World Agricultural Series, Black Well Science Publication, U.K.
- Nashkoiv, K.B. (2002) "Tropical trees" www.fao.org.
- Polbosky, J. M. (2002) "The Medicinal Value of Cashew Bark" www.fao.org.
- Roberts, N.N. (2004) "The Economic Value of the Cashew Tree" www.greencottage.com.