In the name of Allah the most mercifull

Sudan University Of Science and Technology
Faculty of Graduate Studies

Bioethanol production from sorghum grains

إنتاج الايثانول من حبوب الذرة

A Thesis Submitted to Sudan University for Science and Technology college of Graduate Studies in Partial Fulfillment of the Requirements for the Degree of Master of Science In Chemical Engineering

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بسم الله الرحمن الرحيم

قال تعالى:

(وقل اعملوا فسيرى الله عملكم ورسوله والمؤمنون وستردون إلى عالم الغيب والشهادة فينبئكم بِما كُنتُم تَعمَلون)

صدق الله العظيم

سورة التوبة

الاية 105

Dedication

I dedicate this research with much love and appreciation to:

Whom proudly my name followed with his,

Who words are not enough for him,

Whom supported me and was next to me at the past,

Whom I ever missed and will never forget,

My dear father's soul mate

To whom paradise under her feet,

Who gave me from her soul, love, and persistence,

Whom her duaa is the secret of my success,

May Allah provide her with health and long life,

The mean of love, kind and optimism my life angle,

My beloved mother

To whom prefer me on their selves and educate me life science,

Who show me which is more beautiful of life,

Whom we shared our mother's hug and I get my strength and resolve from,

My brother and sister who mean the world to me,

To Whom I grow up, and am valuable with and I adopt on, and supporting me,

Whom I gain power and love by her existence, whom I know mean of life with her,

Whom I hope all success, progress, health and long life,

Who have good heart and good intentions,

My dear beloved sister

To my friends, family, all relatives, my uncles, aunt, all dears I missed and my teachers past and present

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All symbols are defined in the text when they are first used.

A_a	Active, or bubbling, area	(m^2)
A	Total column cross-sectional area	(m^2)
A_{dc}	Cross-sectional area of domncomer	(m^2)
A_h	Hole area, the total area of all the active holes	(m^2)
A_n	Net area available for vapor liquid disengagement,	(m^2)
C_D	Discharge coefficient.	
D	Rate of distilled.	(kmol/h)
DDGs	Dried Distilled Grains	
Dc	Column diameter.	(m)
F_{LV}	Flow parameter.	
F	Rate of feed.	(kmol/h)
H	Column height.	(m)
h_w	Weir Height.	(m)
h_d	Hole diameter.	(m)
k_2, k1	Constant.	
L_w	Mass flow rate of liquid.	(kg/h)
M.wt /v	Molecular weight of vapor .	(kg/kmol)
M.wt /L	Molecular weight of liquid.	
N_a	Actual number of plates.	
N_{min}	Minimum number of plates	
Nr	Number of plates on rectifying section.	
Ns	Number of plates on stripping section.	
R_{min}	Minimum reflux ratio.	

R	Actual reflux ratio.	
U_f	Flooding velocity.	(m/s)
U_v	Vapour velocity.	(m/s)
W	Rate of waste.	(kmol/h)
x_F	Mole fraction of feed.	
x_D	Mole fraction of distilled.	
x_W	Mole fraction of waste.	
x_{Lk}	Mole fraction of light key component.	
x_{Hk}	Mole fraction of heavy key component.	

Abstract

A biofuel is a fuel that produced through contemporary biological processes such as agriculture and anaerobic digestion, rather than a fuel produced by geological processes. It can be derived directly from plants or indirectly from agriculture or industrial waste. Bioethanol is an alcohol made by fermentation, it is produced from sugar or starch crops such as corn, sugar cane or sweet sorghum. Biodiesel and ethanol can be used as fuel for vehicles in its pure form but it is usually used as gasoline additive. Sorghum is a fast- growing crop that can be harvested twice a year and that can produce both food (grain) and energy. In this study, sorghum juice, which mostly consists of readily fermentable sugars, were converted to bio-ethanol. Ethanol is a renewable source of energy and it is potentially cleaner alternative to fossil fuels. Production of ethanol is growing day by day at a great extent for its versatile application and demand. Fermentation is a biological process in which sugars are converted to cellular energy then produce ethanol.

The objective of this study is to enhance the production of ethanol from sorghum using fermentation and simple distillation. An amount of grain sorghum flour was mixed with water, and yeast was added and the fermentation was conducted for different periods of time at room temperature and at closed container with small pipe for CO_2 removal. The results showed that (69%v/v) ethanol could be obtained from sorghum at specific conditions. The fermented liquid was filtered and introduce to simple distillation device to obtain ethanol. The ethanol was collected and its concentration was measured by refractometer. The design of a distillation column was done where the minimum number of stages were 18 and actual number of stages were 35 with a reflux ratio of 12.6, column diameter 2.5m and hight 22m , in a sieve tray column

المستخلص :

الوقود الحيوي هو وقود ينتج من عمليات حيوية مثل الزراعية ويمكن اشتقاقه من المخلفات الزراعية والصناعية. الايثانول الحيوي هو وقود ينتج بتخمير السكر و النشا في المواد الكروهيدريتية مثل الذرة وقصب السكر وغيرها ويستخدم كوقود للمركبات في صورته النقية .الايثانول الحيوي هو الاكثر استخداماً ويقلل من التلوث.الذرة هي من الحبوب الاساسية المستخدمة في السودان وفي دول اخرى وتستخدم ايضا للطاقة الحيوية.الايثانول هو من مصادر الطاقة المتجددة بديل للـوقـود الاحفوري. انتاج الايثانول متزايد حيوية يتحول فيها السكريات الي ايثانول .كل فترة واخرى نسبة لاستخداماته المتعددة .التخمير هو عملية باستخدام حفاز كالخميرة.

الهدف من هذه الدراسة هو تعزيز امكانية انتاج الايثانول من الذرة لتغطية الحوجة عبر تخمير الذرة .وزنت كمية محددة من الذرة ثم طحنت واضيفت اليها الماء تم التخمير في فترات زمنية مختلفة في وعاء زجاجي مغلق مع وجود انبوب تنفيس ل ثاني اوكسيد الكربون وعند درجة حرارة الغرفة.تم تصفية المحلول المخمر ثم وضعه في جهاز تقطير وتجميعه وقياس التراكيز له بجهاز الانكسار الضوئي.

تم الحصول علي ايثانول69%.تظهر النتائج انه يمكن انتاج الايثانول من الذرة عند ظروف محددة.

Chapter One

Introduction

1.1 Overview:

The increasing problem of the CO_2 emissions besides some energy security concerns has strengthened the interest in alternative, nonpetroleum-based sources of energy. Biomass is the only suitable and renewable primary energy resource than can provide alternative transportation fuels such as bioethanol or biodiesel in the short-term. Current production of bioethanol relies on ethanol from starch and sugars but there has been considerable debate about its sustainability (P. Alvira, 2010).

In this context, some of the most important factors to reduce ethanol production cost are: an efficient utilization of the raw material to obtain high ethanol yields, high productivity, high ethanol concentration in the distillation feed. A large number of pretreatment approaches have been investigated on a wide variety of feedstock's types and there are several recent review articles which provide a general overview of the field Besides being considered a crucial step in the biological conversion to ethanol, biomass pretreatment represents one of the main economic costs in the process(P. Alvira, 2010).

1.2 Biofuel and ethanol:

A biofuel is a fuel that produced through contemporary biological processes such as agriculture and anaerobic digestion, rather than a fuel produced by geological processes. It can be derived directly from plants or indirectly from agriculture or industrial waste. **Bioethanol** is an alcohol made by fermentation it produced in sugar or starch crops such as corn, sugar cane or sweet sorghum. Biodiesel and **ethanol** can be used as fuel for vehicles in its pure form but it is usually used as gasoline additiv(http://en.m.wikipedia.org/wiki/biofuel02072018101540).

Unlike other renewable energy sources, biomass can be converted directly into liquid fuels - biofuels – for our transportation needs (cars, trucks buses , airplanes and trains). The two most common types of biofuels are ethanol and biodiesel (http://en.m.wikipedia.org/wiki/biofuel02072018101540).

Ethanol also called ethyl alcohol is a chemical compound with chemical formula C_2H_5OH or CH_3-CH_2-OH (an ethyl group linked to hydroxyl group) abbreviated as EtOH. It is volatile flammable colorless liquid and it found in alcoholic drinks.

Ethanol is an alcohol, the same found in beer and wine. it is made by fermentation of any biomass that high in carbohydrates (starch in wheat or corn , sugar or celluloses) through process similar to brewing beer. Fuel ethanol which is sometimes referred to as "gasohol" has been distilled and dehydrated to create a high-octane, water-free alcohol (http://en.m.wikipedia.org/wiki/ethanol02072018101840).

1.3 Bio-Ethanol:

1.3.1Ethanol:

Ethyl alcohol (CH_3CH_2OH), or ethanol, is an inflammable volatile liquid produced by the fermentation of sugars by yeast according to the following equation:

$$C_6H_{12}O_6 \longrightarrow 2C_2H_5OH+2CO_2 \qquad (1.1)$$

The raw materials used in the synthesis of ethanol are ethylene and natural gas (The major source of ethylene is from refining of petroleum spirit) *(http://en.m.wikipedia.org/wiki/ethanol02072018101840)*.

Essentially the process involved is hydration of ethylene using sulfuric acid catalyst. The main reaction is:

$$C_2H_4+ H_2SO_4 \rightarrow C_2H_5HSO_4+H_2O \rightarrow C_2H_5OH+ H_2SO_4 \qquad (1.2)$$

Table (1.1) Properties of ethanol.

Formula	C_2H_6O
Density	789 kg/cm^3
Viscosity	0.0012 pa.s
Boiling point	78.37C°
Melting point	-114C°
Color	Colorless

1.3.2 Characteristics of ethanol:

Pure ethanol is a polar solvent that is water –soluble and has a 55 flash point. Ethanol has a vapor density of 1.59 which indicates that it is heavier than air, consequently, ethanol vapors do not rise, similar to vapors from gasoline, which seek lower altitudes. Ethanol's specific gravity is 0.79, which indicates that it is lighter than water but since it is water-soluble it be considered hydrophilic. It will thoroughly mix with water *(http://en.m.wikipedia.org/wiki/ethanol02072018101840).*

1.3.3Uses of ethanol:

Ethyl alcohol is used in intoxicating beverages and, as a fuel and solvent; it is also frequently used as a hand wash, small amounts of green soap, perfumes or other disinfectants mixed in. ethanol produced industrially is used as rectified spirit, as a solvent and in toilet preparations, and also as

- Chemical solvent and in industries.
- Clean burning fuel source.
- In medical application as antiseptic and disinfectant and medicinal solvent.

- Used as engine fuel (the largest use).
- Feedstock in industrials such as ethyl halides ethyl esters.
- Low temperature liquid and cooling bath.

1.3.4 Advantages of using ethanol as fuel:-

Ethanol has many positive features as an alternative liquid fuel

- Ethanol is renewable, relatively safe fuel that can be used with few engine modifications.
- Adding ethanol to gasoline raises the octane number* of the fuel blend, thus guarding against engine knock (premature ignition), which can be damage the engine. Ethanol is thus able to replace more costly octane-boosting components such as alkylate.
- Because ethanol contains oxygen, ethanol containing gasoline burns more cleanly and reduces the amount of harmful emission of carbon monoxide (CO).
- It can improve agricultural economies by providing farmers with stable market for certain crops.
- Using ethanol increases national energy security because some use of foreign petroleum.

*octane number is a value used to indicate the resistance of motor fuel to knock in sport-ignition internal combustion engines. Octane numbers are based on a scale on which is octane is 100(minimal knock) and heptanes is 0 (bad knock).

1.3.5 Disadvantages off ethanol fuel:

A major concern regarding about the use of ethanol as transportation fuel is its corrosive and regarding effect on fuel systems and fuel storage facilities. The most notable problems are as follows:

- Degradation of some rubber and plastic materials. This occurs because of the solvent –like nature of ethanol, ethanol molecules being absorbed into the material, causing them to soften and swell.
- Degradation of metal due to the acidic or galvanic nature of ethanol although anhydrous ethanol in itself is only slightly.
- Corrosive of metals the hygroscopic nature of ethanol, one of the main reasons being corrosive contaminants in the water such as sodium chloride and organic acid.
- Fuel line clogging due to ethanol 'stripping of' fuel system deposit.

1.4 Ethanol in Sudan:

Ethanol had been formally recognized as a fuel in Sudan, and the product was named Nile Ultra E-10, in reference to the River Nile (personal contact).

Sudan had started using 10% ethanol mixed into petrol. Kenana is a pioneer in the production of ethanol on a commercial scale in the country and has plans to expand its production considerably. The company plans to increase the production from 65 million liters to 200 million liters per year (personal contact kenana company , Ahmed Horbkanin).

1.5 Aim of study:

The aim of this study is to produce ethanol by using fermented sorghum grain to be used as bio-fuel.

1.6: Objectives:

There are many objectives for this study:

- To determine the optimum ethanol yield that can obtain from sorghum juice.
- To design a distillation unit to separate ethanol-water mixture.

Chapter Two

Literature Review

2.1 Previous Studies:

In a general survey of the relevant literatures, a lot of work and references have been observed. Experimental work on similar sorghum was used to produce ethanol, from the previous studies and published work the conditions of the reactions will be cited and investigation.

Ethanol demand is increasing drastically in the present time due to its blending in automotive fuels, which is desirable for getting clean exhaust and fuel sufficiency. The higher cost of cultivation of sorghum/sugarcane highly sensitive molasses rates and ultimately instabilities in the price of ethanol have created grounds to search on ethanol production. Ethanol can be fermented from many sources of starch, including corn, wheat, grain sorghum, barley, and potatoes, and from sugar crops such as sugar cane and sweet sorghum. Because there has been an abundant supply of corn, most of the ethanol made in the United States is from corn. Most of the ethanol is produced in the Midwest and Upper Midwest Where ethanol plants are close to and have a consistent supply of corn, access to water resources, and have livestock production nearby. A by-product of ethanol production is distiller's grains, which can be fed to livestock either wet or dried. Ethanol can be produced from sorghum and sweet sorghum.(du Preez et al., 1985).

Who developed the art of distillation during the Abbasid caliphate, the most notable of whom was Al-Razi. The writings attributed to Jabir Ibn Hayyan (Geber) (721-815) mention the flammable vapors of boiled wine. Al-Kind (801-873) unambiguously described the distillation of wine(Khalil et al., 2015).

Distillation of ethanol from water yields a product that is at most 96% ethanol, because ethanol from an azeotrope with water. Absolute ethanol was first obtained in 1796 by Johann Tobias Lowitz, by filtering distilled ethanol through charcoal(Khalil et al., 2015).

In 1998, world total ethanol production was 31.2 billion liters (8.3 billion gallons). Only 7% of the total corresponded to synthetic alcohol (derived from gas or coal), the remainder being obtained by fermentation. Fuel ethanol accounts for approximately two-thirds of the total production. In terms of regional production, the Americas produced, in billions of liters, 20.3, Asia 5.5, Europe 4.7, Africa 0.5, and Oceania 0.2. Brazil was the largest producer in the world (13.5 billion liters) the USA attained 6.4 billion liters. Brazilian bioethanol was totally channeled into the fuel sector, whereas in the USA approximately 3.9 billion liters was used for the domestic fuel mix. In the European Union, more than 2 billion liters of ethanol were produced, but only 5% of this was used as fuel. Thirty percent of the production (120 million liters) corresponded to France, 18% to the United Kingdom, 17% to Germany, and 9% to Italy.

Ethanol has been used by humans since prehistory as the intoxicating ingredient in alcoholic beverages. Dried residues on 900-year-old pottery found in northern china imply the use of alcoholic beverages even among Neolithic people .Its isolation as a relatively pure compound was first achieved by Islamic alchemists

2.2 Sweet sorghum:-

Sweet sorghum is any of the many varieties of the sorghum grass whose stalks have high sugar content more than 70%. It thrives better under drier and wormer conditions than many other crops. In many states it called molasses it refers to sweet syrup made as byproduct of sugarcane or sugar beet (Ratnavathi et al., 2011).

Synthetic alcohol predominates in Germany and the United Kingdom. Sweden used 12 million liters of fuel ethanol, which corresponds to about 0.22% of the 5.5 billion liters of gasoline consumed. It is expected that the demand for ethanol for transportation will increase dramatically until 2010. In August 1999 an executive order was signed in the USA that specified the goal of tripling “biogases products and bioenergy” by the year 2010, which is projected to reduce the import of almost 4 billion barrels of oil.

2.3 Sorghum:

Plantae kingdom, its scientific name is sorghum (bicolor L. moench) commonly called sorghum, and also great millet, durra, is a grass species cultivated for its grain which is used for food for human, animal food and ethanol production. Sorghum is the fifth most important cereal crops after rice, wheat, maize, and barely. It grows in clumps reach over 4m high. The grain is small 2-4mm diameter. Sorghum grows in a wide range of temperature, the species can be used as ethanol fuel feedstock may be better than sugarcane, it can grow under harsher conditions, it has protein levels around 9% (http://www.sciencedirect.com/topics/food_science/sorghum08072018092350).

Our mechanistic hypothesis is that cross-linking of sorghum proteins during cooking, and the formation of a web-like protein matrix, restricts the accessibility of hydrolyzing enzymes to the starches within the protein matrix.

Research is being conducted to develop a genetic cross that will make the plant more tolerant to colder temperatures, sorghum can be used as replacement of corn silage in the diet for dairy cattle. Another research application of sorghum is biofuel can be turned into ethanol, the biomass can be burned and turned into charcoal, syn-gas, and bio-oil (http://en.m.wikipedia.org/wiki/sorghum_bicolor05072018050441).

Figure (2.1) sorghum plant

(http://en.m.wikipedia.org/wiki/sorghum_bicolor05072018050441)

Sorghum is a genus of flowering plants is also called sorghum bicolor native to Africa with many cultivated forms now is an important crop worldwide used for food , animal fodder , the production of alcoholic beverages and biofuels .some species of sorghum can contain levels of hydrogen cyanide and nitrates. Sorghum is efficient in converting solar energy to chemical energy, biofuel using sweet sorghum as high sugar content for ethanol production is being developed with biomass which can be turned into charcoal, syngas and bio-oil.

Sorghum is a major cereal crop in many countries it had been underutilized as renewable feedstock for bioenergy. In general ethanol yield increase as starch content increase.

A 100-gram amount of raw sorghum provides 329 calories 72% carbohydrates. 4% fat and 11% protein. Sorghum supplies numerous essential nutrients in rich content, including protein, fiber and vitamin B .It doesn't contain gluten which makes it useful for gluten-free diets(du Preez et al., 1985).

Table (2.1): Characteristics of typical raw sorghum juice(Laopaiboon*etal*., 2009)

Characteristics	Value
pH	4.9
Total sugar(g/L)	173.02
Fermentable nitrogen(mg/L)	626.38
Ammonium ions(ppm)	21.4
Nitrite ions (ppm)	4.4
Total potassium (ppm)	1790
Total calcium (ppm)	166
Total zinc (ppm)	1.4
Total copper (ppm)	0.3

It is possible that sorghum samples with high protein digestibility provided more free-amino acid for yeast growth during fermentation. However, it is more probable that the starch–protein interaction had a major effect on conversion efficiency and fermentation yield. Small starch granules may be embedded in the protein matrix during grain development and remained ungelitanized during cooking, and some starch may remain embedded in the protein matrix due to protein denaturation during cooking . It appears that the embedded starch granules are inaccessible to hydrolytic enzyme degradation and, consequently, are not converted into glucose for yeast fermentation. In addition, the relatively low digestibility of the sorghum protein matrix will contribute to this effect (http://www.sciencedirect.com/topics/food_science/sorghum08072018092350).

2.4 Sorghum in Sudan:

Sorghum has always been closely associated with the culture of Sudan. As a basic nutrition of Sudanese, traditions of people of this country.

Signs of presence of sorghum were found in different excavation, in kuwa (dongola) a signal of its importance. In contemporary Sudan the sorghum farming operations are marked with several rituals. Sorghum is reach in fibers that help reduce cholesterol in the blood, yellow type is reach in vitamin A while white is less reach. Sorghum of different varieties is of tremendous economic value. In addition to its value as food its byproducts are important, it is also gaining increasing demand with the turn towards the production of bio-fuel, sorghum grows in several regions e.g. Gedarif, Nuba mountain, Blue Nile, and other.

The increasing cost of energy and finite oil and gas reserves has created a need to develop alternative fuels from renewable sources, and for several reasons it is expected that sorghum will be one of new sources, because it is highly productive, drought tolerant (http://www.sciencedirect.com/topics/food_science/sorghum08072018092350).

Sorghum has attracted strong interest because of its many good characteristics such as rapid growth and high sugar accumulation, high biomass production potential, excellent nitrogen usage efficiency, wide adaptability, drought resistance, and water lodging tolerance and salinity resistance. The ability to withstand severe drought conditions and its high water usage efficiency make sorghum a good renewable feedstock suitable for cultivation in arid regions, such as the southern US and many areas in Africa and Asia. Sorghum varieties include grain sorghum, sweet sorghum, forage sorghum and high-tonnage (energy) sorghum. There have been several reviews written on the use of sorghum as a potential renewable feedstock. Most of these reviews focused almost exclusively on production of ethanol and did not cover works on the use of sorghum-derived sugars for production of industrial chemicals in sufficient detail. In this report, we review the studies that have been reported in the literature and at conferences on the use of sorghum as feedstock for production of fuels and industrial chemicals in biochemical conversion processes.(Appiah-Nkansah et al., 2018).

Grain sorghum and sweet sorghum juice are considered separately whereas sweet sorghum bagasse, forage sorghum and high-tonnage sorghum are considered together under the topic of sorghum biomass since they all contain cellulosic materials (cellulose and hemicellulose) as the major sources of fermentable sugars for conversion to useful products(Nhuan P. Nghiem 2016).

Most of the research on the use of grain sorghum as a feedstock for production of fuels and chemicals has been focused on ethanol fermentation. There have been only a small number of published reports on the use of grain sorghum for production of chemicals.

Zhan et al. investigated the production of lactic acid from extrusion-cooked grain sorghum using *Rhizopus oryzae*. In a 5-liter bioreactor with pH and temperature control using a simple salt medium and grain sorghum substrate at 15 wt%, the final lactic acid concentration obtained at 72 hours was 42.3 g/L. Fang and Hanna studied the production of levulinic acid using whole kernel sorghum grains blended with 2%, 5% and 8% aqueous solutions of sulfuric acid. The maximum yield of levulinic acid was achieved at 200 C, 8% sulfuric acid and 10% substrate loading. Valuable products can also be obtained from the Dried Distillers Grains (DDGS) co-product of grain ethanol fermentation, for example, extraction of kafirin (main storage proteins in sorghum) with acetic acid, HCl-ethanol and NaOH-ethanol mixtures under reducing conditions(Nhuan P. Nghiem 2016).

2.5 Factors Impacting Ethanol Production from Grain Sorghum:

- **Genotype (G)**: Concentration and amount of ethanol obtained from juice fermentation were influenced by all three investigated factors due to a higher ethanol concentration in the intermediate and late harvest. Given a very similar amount of juice in the two genotypes (Lorenzo Capecchi and Barbanti, 2017).
- **Soil moisture (SM)**: Soil moisture strongly influenced both concentration and amount of EtOH. In particular, high soil moisture determined a 21% increase of ethanol concentration in the average of the three harvests. In combination with the wide differences in juice quantity (Lorenzo Capecchi and Barbanti, 2017) .
- **Harvest (H)**: In late vs. early harvest and high vs. low soil moisture, bagasse showed a decrease of extractives and concurrent increase in all fiber components, which are the premises for lower glucose yield in enzymatic hydrolysis. However, the amounts of both juice- and bagasse-derived ethanol were greatly enhanced by late harvest and high soil moisture, due to a strong increase of sugar concentration, juice, and bagasse amounts offsetting lower ethanol concentration in fermentation.
- Water use efficiency referred to the combined ethanol production portrayed the combination of sweet sorghum, late harvest, and low soil moisture, as

that fetching a reasonable efficiency in exchange for a remarkable saving (59%) in the amount of water, compared to high soil moisture. These findings translate into a variable amount of land and water needed (Lorenzo Capecchi and Barbanti, 2017).

- **Fermentation rate** plays an important role in the production capacity of an ethanol plant and therefore affects profit. Among the tested sorghum samples, fermentation of most samples was complete within 60-66 hr after inoculation. The fermentation of some samples proceeded much faster, however, increased concentrations of free amino nitrogen facilitated yeast fermentation of sugar to ethanol (O'Connor-Cox1991). The fermentation process could be shortened by 5-10 thereby increasing the addition of a yeast extract from 0.30 to 0.40% .
- Major factors adversely affecting the bioconversion efficiency of grain sorghum also include high viscosity, low protein digestibility, protein and starch interaction, and the amount of amylose-lipid complexes. Waxy genotypes had higher average conversion efficiency and brown sorghums had the lowest conversion efficiency(X. Wu, 2007).

The fermentation of sugar into ethanol is one of the earliest biotechnologies by humans. The intoxicating effects of ethanol consumption have been known since ancient times. The Arab chemist AL-kindi unambiguously described the distillation of wine. The process later spread from Middle East to Italy. production of alcohol from distilled wine was later recorded by the school of salemo alchemists in 12 century(Olsson, 2001).

Ethanol was first prepared synthetically in 1825 by Michael Faraday. He found that sulfuric acid could absorb large volumes of coal gas. He gave the resulting solution to another chemist who found sulphovinic acid convert to ethanol which can produced from ethylene by acid catalyst similar to current ethanol synthesis. Ethanol was used as lamp fuel and automotive fuel.

Production of bio-ethanol from bio-mass is one way to reduce both consumption of crude oil and environmental pollution. Using bio-ethanol blended gasoline fuel for automobile can significantly reduce petroleum use and exhaust green house gas emission. Bio-ethanol can be produced from different kinds of raw materials simple sugars, starch, and lignocelluloses. Bio-ethanol from sugar cane produced under proper condition is essentially a clean fuel and has several advantages over petroleum derived gasoline. Conversion technologies for producing ethanol from cellulose biomass resources such as forest materials and urban wastes are under development.(Balat and Balat, 2009).

2.6 Natural accurance and production:

Ethanol is a byproduct of the metabolic process of yeast so it can be found in overripe fruit it also produce during the germination of many plants , minute amount of it found in breath of some volunteer .

Ethanol is produce both as petrochemical through the hydration of ethylene and via biological process by fermenting sugars with yeast which is more economical from

- Ethylene hydration with sulfuric acid as catalyst.
- From carbon dioxide
- Cellulose
- Fermentation

Fermentation is process of culturing yeast under thermal condition then higer concentration obtained by distillation. Ethanol can be produced from mixtures of sweet sorghum juice and sorghum starch using very high gravity fermentation with urea supplementation. Biofuel processing technologies capable of increasing ethanol production, cost-effectiveness, energy saving, and water efficiency in the current dry-grind ethanol processes would significantly contribute to meeting the growing demand for fuel in commercial transportation.(Appiah-Nkansah et al., 2018).

It is estimated that vehicles in the USA alone consume about 450 billion liters of fuel per year (1998), which has a great impact on the environment. Bioethanol and biodiesel have emerged as alternatives for fossil fuels.

2.7 Performance.

Ethanol has a higher octane (ability to resist compression) rating than gasoline, enabling combustion engines to run at a higher compression ratio and thus giving a superior net performance (Wyman 1996). Additionally, the vapor pressure of alcohol is greater and the heat of vaporization is higher than that of gasoline, which is primarily responsible for the increased power outputs using alcohol. However, 1 gallon (3.78 l) of pure ethanol, due to its oxygen content, has 33% less energy than gasoline (Kosaric 1996).

Ethanol has been known for a long time, being perhaps the oldest product obtained through traditional biotechnology. Its current applications include potable, chemical, and fuel ethanol. Cars fueled by ethanol were already planned by Henry Ford in the 1880s, when he designed early models that ran on “farm ethanol” made from corn. Early in the twentieth century, however, petroleum derived fuels (fossil fuels) began to appear and quickly dominated the market(Sikarwar et al., 2017).

Ethanol (EtOH) production in the USA was expected to grow to about 3125 million liters in 1986 from an estimated 2841 million liters in 1985 (II). This growth in EtOH production is principally the result of increased demand for an octane enhancer in regular and unleaded gasoline. The EPA upper limits for lead content in gasoline have been reduced to 26 mg L- I effective 1 Jan. 1986, and complete elimination of lead from gasoline has been proposed for 1988. Although

EtOH can be manufactured from a large number of commodities, the chief product used in the USA is maize (Zea mays L.). In Brazil, the world's largest EtOH producer, sugar from sugarcane (Saccharum spp.) is used to produce EtOH(Laopaiboon et al., 2007).

Sugar crops are of special interest in EtOH production because these renewable resources achieve high yields, grow in many countries, and can be converted into EtOH by application of relatively simple technology. In addition, EtOH production from sugar crops would provide an alternative market for low-cost agricultural commodities. Sweet sorghum [Sorghum bicolor (L.) Moench] is a coarse grass herbaceous annual that in the tropics can be rationed to produce successive crops. Sweet sorghum is currently grown for syrup, forage, and silage(Laopaiboon et al., 2007).

For ordinary multi component distillation, determination of feasible distillation sequences, as well as column design and optimization, is relatively straightforward. In contrast, determining and optimizing enhanced-distillation sequences are considerably more difficult. Rigorous calculations frequently fail because of liquid-solution non idealities and/or the difficulty of specifying feasible separations.

2.8 Food versus fuel

A common objection to biomass energy production is that it could divert agricultural away from crops in a hungry world even leading to mass starvation in the poor countries. There are two opinions with this fact one with and the other against:

The first one says that the world already grows more than enough food to feed every one. About a billion people now don’t have enough food to meet basic daily needs, but that’s not because there is not enough food.

There's more food per capita now than there's ever been before enough to make every one fat. There is enough to provide at least 4.3 pounds of food per person a day. People starve because they are victims of an inequitable economic system, not because they are victim of scarcity and over population. Another reason is that energy costs as they impact on consumer food costs as they impact every single food product on the shelf. The third reason is that increasing petroleum prices have about twice the impact on consumer food prices.

The second opinion says that any attempt to grow fuel for general use would require a massive increase in crop yields at a time it is unable to feed everyone. Present food shortages through the world call attention to the importance of continuing S us exports of corn and sorghum to reduce starvation. Expanding ethanol production could entail diverting essential crop land from producing sorghum needed to sustain human life to producing sorghum for ethanol factories.

2.9 Methods for ethanol production:

1. Ethylene hydration.
2. Cellulosic ethanol.
3. *Fermentation.*

Alcoholic fermentation is a complex of biochemical process during which yeasts convert sugars to ethanol , carbon dioxide and other byproducts(Buratti and Benedetti, 2016).

Alcoholic fermentation of grains and fruits to produce alcoholic beverages for human consumption is universal, the best known drinking alcohol include wine brandy and pisco from grapes, sake from rice vodka from potatoes and beer whisky from grain. Alcoholism has replaced dietry shortages as the most common cause of thiamine deficiency include prolonged fasting and feeding after fasting(Román, 2013).

Ethanol fermentation is one of the oldest and most important processes used in biotechnology industry. In the U.S. alone about 4.5 billion gallons of ethanol are produced annually from plants sources like corn sorghum and sweet sorghum, used as transportation fuel .the annual production is expected to grow more than 7.5 gallons in next few years. Many microorganisms including bacteria and yeasts can produce ethanol as major fermentation product from carbohydrates. Current industrial ethanol fermentation is mainly carried out with the yeast *saccharomyce cerevisiae* because of its hardiness (low pH and high ethanol tolerance). since the metabolic fermentation takes place after the alcoholic fermentation vigorous carbon dioxide production can stimulate a secondary fermentation(Yang et al., 2007).

When fermentation occurs within normality with good performance the bubbles formed are regular and with certain grow , keeping the same pattern throughout the surface of the fermentation environment and are easily broken by pressure exerted by the carbon dioxide released Carbon dioxide is a major co-product in the fermentation process. When there is contamination the bubbles become bigger and irregular in shape.(de Vasconcelos, 2015).

For the production of industrial alcohol, fermentation is usually complete in 50hr. or less, depending on the temperature, sugar concentration, and other factors.

For ethanol production by *Saccharomyces cerevisiae* from blackstrap molasses, the sugar concentration 17%, temperature 30 C, pH 4.5 and incubation period of 72 hours, were the optimal conditions for producing.(de Vasconcelos, 2015).

Production of ethanol from sorghum juice

After extraction, sorghum juice can be readily fermented into ethanol using yeasts or bacteria. Figure 2.2 shows the simplified diagram for ethanol production using sorghum juice.

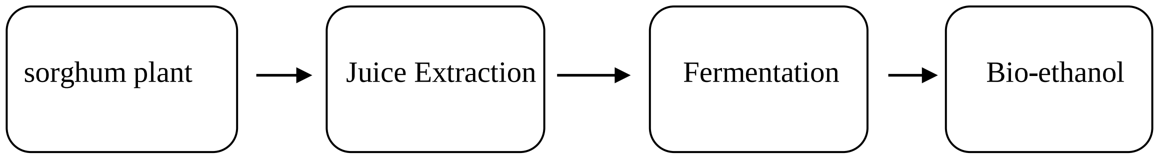


Figure (2.2) Simplified diagram for production of ethanol from sorghum juice

2.10 Microorganisms Used

Underkofler and Hickey (1954) reported that the main producers of fermentation are the yeasts especially Saccharomyces spp. which have rapid growth, high alcohol sugar tolerance and efficiency in the conversions of carbohydrates in molasses to alcohol.

The optimum temperature for multiplication of most yeast species lied between 25 C° to 28 C°, although some yeasts could grow better at 37 C or at 20 C°.26.

On the fermentation of chopped sweet sorghum to ethanol, the influence of various process parameters, such as temperature, yeast cell concentration and moisture content, on the rate and extent of ethanol fermentation was investigated. Optimal values of these parameters were 35ºC, 7(10)8 cells/g raw sorghum and 70% moisture level, respectively. Dombek and Ingram (1986) reported that Saccharomyces cerevisiae is capable of very rapid rates of glycolsis and ethanol production under optimal conditions, producing over 50mmoles of ethanol per hour per gram of cells protein *(http://scholar.google.com/scholar/ethanol_production_from_sorghum)*.

The optimum fermentation temperature of the yeasts was 25 C and the highest ethanol concentration in the mash (8.5v/v) was reached when the initial sugar concentration was 30%. The test also showed that the inoculums size was of minor importance in the fermentation process.

Yeasts serve many purposes. The selection of the most appropriate species, strains and varieties for specific purposes, from the multiplicity available has been going on for a long time. Weakly respiring, largely fermenting yeast, so-called' bottom yeasts ', are used in the brewing of beer. The yeasts used for ethanol production and wine-making, as well as baker's yeasts, are largely ' top yeasts'.

Ethanol is almost found in mixture of ethanol-water mixture and it is mostly separated by distillation process.

2.11 Types of distillation:

- **Extractive distillation** is used to separate azeotropes and close-boiling mixtures. If the feed is a minimum-boiling azeotrope, a solvent, with a lower volatility than the key components of the feed mixture, is added to a tray just a few trays below the top of the column so that the solvent is present in the down-flowing liquid, and little solvent is stripped and lost to the overhead vapor e.g. Acetone and Chloroform.
- **Salt distillation**, water, as a solvent in the extractive distillation of acetone and methanol has the disadvantages that a large amount is required to adequately alter and, even though the solvent is introduced into the column several trays below the top, enough water is stripped into the distillate to reduce the acetone purity to 95.6 mol%. The water vapor pressure can be lowered, and thus the purity of acetone distillate increased, by using an aqueous inorganic-salt solution as the solvent. Salt distillation is accompanied by several problems. First and foremost is corrosion, particularly with aqueous chloride-salt solutions, which may require stainless steel or a more expensive corrosion-resistant material. Feeding and dissolving a salt into the reflux poses problems.

- **Pressure-swing distillation** if a binary azeotrope disappears at some pressure, or changes composition by 5 mol% or more over a moderate range of pressure, consideration should be given to using two ordinary distillation columns operating in series at different pressures. This process is referred to as pressure-swing distillation e.g. separations of the minimum-boiling azeotrope of tetrahydrofuran–water.
- **Reactive Distillation**: A chemical that reacts selectively and reversibly with one or more feed constituents is added, and the reaction product is then distilled from the nonreacting components. The reaction is later reversed to recover the separating agent and reacting component.
- **Homogeneous Azeotropic Distillation.**
- **Heterogeneous Azeotropic Distillation.**

  (Coulson and Richardson ,chemical engineering volume.6, 1983, Huang and Hodson, 1958 chapter 11.)

2.12 Limitations on bio-ethanol production

Bio-ethanol production generally utilizes derivatives from food crops such as corn grain and sugar cane, but the limited supply of these crops can lead to competition between their use in bio-ethanol production and food provision.

Currently, a large amount of studies regarding the utilization of lignocellulosic biomass as a feedstock for producing fuel ethanol is being carried out worldwide. For countries where the cultivation of energy crops is difficult, lignocellulosic materials are an attractive option for the production of bio-fuels. Lignocellulosic materials serve as a cheap and abundant feedstock, which is required to produce fuel ethanol from renewable resources at reasonable costs. Producing bio-ethanol from lignocellulosic materials may allay many of the environmental and food-versus-fuel concerns that are drawbacks of producing bio-ethanol from food crops like sugar or corn.

2.13 The future of ethanol production

Groundbreaking technologies have been introduced to the domestic food industry through the history of modern society. The past century alone our society and more specifically the domestic food industry has been introduced to countless innovation. Where would the food industry be right now if families at home were still gathering ice and snow? critic said that growing crops for biofuels is energy intensive. Ethanol industry is facing difficult economic times, more than 20 ethanol plants had filed for bankruptcy in recent months (http://www.stewart.com/the_future_of_ethanol_production/19072018051624/).

There are many factors determine the future of ethanol industry such as…

- The energy policy of countries.
- The emerging technology and competitive position.
- The availability of plant resources.

The potential change this developing technology could have on industry is at its worst devastating to those who grow crops utilized in current production of ethanol and on the same time for food manufacturing instead of corn syrup.

Corn or sorghum may not be the ideal raw material for ethanol production cause the process may need enzymes and more additives.

Scientists say they have developed a new way to make liquid ethanol efficiently without using corn or other crops needed in the conventional method for producing the biofuel. The new technique may be more environmentally friendly than current method. It is by turning carbon monoxide gas into liquid ethanol by using electrode made of copper.

Chapter Three
Materials and Methods

3.1 Introduction:

This chapter contains information about the type of materials used in this research, also the methods for determining the ratio of converting sorghum to ethanol and information of the design.

All samples were prepared on laboratories of University of Khartoum collected after that chemical analysis were done.

3.2 Micro-organism:

Commercially bought dried baker's yeast (*Saccharomyces cerevisiae*) was used as micro-organisms in the fermentations process. Prior to being added to the juice, the dried cells were revived in a small amount of the juice to reduce lag time in the fermentation broth.

3.3 Fermentation of sweet sorghum juice to ethanol:

The fermentation of sorghum juice is much simpler and easier to perform than starch fermentation since the juice contains soluble sugars ready for fermentation.

Figure (3.1) shows the experimental steps for the fermentation of sorghum juice to ethanol.

Sorghum

fermentation

Distillation

Figure (3.1): experimental procedure followed

3.4 Materials:

- Sorghum.
- Yeast.
- Distilled water

3.5 Equipment and Apparatus:

- Beakers and measuring cylinders.
- Simple distillation device.

Fig (3.5.1) Simple distillation device

Consists of:

- German heater with maximum temperature 450C

- Condenser

- Pyrex round bottom flask (500 ml)

- Digital balance

Figure (3.5.2):Digital balance

Adam Equipment

Version AE446L512

Maximum weight 4.5kg

- Containers

Fig (3.5.3) 20Litre fermentation container

- Refractometer

Fig (3.5.4) Refractometer

ZEISS (west Germany)

Version 134797

- Plastic filters , funnel and filter papers

Figure (3.5.5): Funnel and filtering paper

3.6: Methodology :

Fermentation of sorghum was conducted by using a fermentor and a simple method was used which involved:

1- Adding distilled water to sorghum.

2- Inoculation with yeast.

3- Fermentation was run at ambient temperature (30 ± 2 C) in 10liter conical flask. Samples were taken at intervals and then distillation by simple device was done until required for analysis.

4- Distillation was done by using a simple distillator at a temperature of 100 C then a Refractometer was used to determine the concentration of ethyl alcohol. After that a rectifying column was used to produce rectified (92%) alcohol.

After first distillation the distilled concentration was 40% then it pass through a second distillation and pure ethanol was added to increase the concentration.

3.6.1 Optimum Time of Fermentation:

- Fermentation of sorghum was carried out in 10 liter conical flask and the flasks were inoculated with a 48 hours culture. For distillation and determination of ethyl alcohol.
- Ethanol was estimated by distillation followed by measurement of ethanol quantity in milliliter and ethanol concentrations were measured by refractometer which was formulated by the unit operation Laboratory Department of Chemical Engineering, Faculty of Engineering, University of Khartoum.
- An amount of sorghum weighted by balance and yeast, then water added and put at close glass container with tube to pass CO_2 to outside the container then closed well till fermentation take place, then after that distillation started .

- At first 300 ml of mixture took and then filtered by different diameter sieves then 200 ml of mixture put at round bottom flask and heated by heater connected with condenser in simple distillation apparatus, connected with thermometer to show temperature of mixture.
- Ethanol has lower boiling point than water so it evaporated first, the ethanol vapour then cooled and condensed to form pure liquid. Filtrating, heating, evaporating, cooling, then condensing. Concentration of liquid at any stages (feed distilled and waste) was recorded in different periods and measured by refractometer.

After distillation ethanol mixture passed through molecular thieves contained of charcoal to reduce the amount of water.

3.7 Process Description

Distillation is a separation process based on different on boiling points or volatilities obtained by repeated vaporization and condensation. It is a physical process used to separate chemicals from a mixture by the difference in how easily they vaporized, as the mixture is heated the temperature rises until it reaches the temperature of lowest boiling point substance in the mixture. The resultant hot vapor passes into condenser and is converted to the liquid which is then collected to receiver flask (Seader et al , Separation process Principles Chemical and Biochemical Operations third edition Chapter 7).

Distillation can consume more than 50% of a plant’s operating energy cost. A way to improve an existing plant’s operating cost is to improve their efficiency and operations by process optimization and control. This cannot be achieved without firstly understanding of distillation principles and design.

In distillation (fractionation), a feed mixture of two or more components is separated into two or more products, including, and often limited to, an overhead distillate and a bottoms product, whose compositions differ from that of the feed. Most often, the feed is a liquid or a vapor–liquid mixture. The bottoms product is almost always a liquid, but the distillate may be a liquid, a vapor, or both. Multistage distillation is the most widely used industrial method for separating chemical mixtures. (Seader et al Separation process Principles Chemical and Biochemical Operations third edition Chapter 7*).*

Towers can be classified into two main classifications based on how they are operated. These two classes are Batch Distillation and Continuous Distillation. There are many types of trays and Sieve tray was chosen in this study.

Vapor flows up the column and liquid down the column there are a condenser at the top and reboiler at bottom part of condensate returned to the top as reflux and part of liquid from the base of column is vaporized and returned to provide the vapor flow. The sections below feed know as stripping section and above it is rectifying section.

Chapter Four

Results and Discussions

4.1: Design of the distillation unit:

To carry out the design calculation the design must specify values for a certain number of independent variable to define the column completely. *(Seader et al Separation process Principles Chemical and Biochemical Operations third edition Chapter 7)*.

There are many factors that influence the design or analysis of operation includes:

- Feed flow rate, composition, temperature, pressure, and phase condition.
- Desired degree of component separation.
- Operating pressure (which must be below the critical pressure of the mixture).
- Pressure drop, particularly for vacuum operation.
- Minimum reflux ratio and actual reflux ratio.
- Minimum number of equilibrium stages and actual number of equilibrium stages (stage efficiency).
-Type of condenser (total, partial, or mixed).
- Degrees of liquid reflux subcooling.
- Type of reboiler (partial or total).
- Type of trays or packing.
- Column height.
- Feed-entry stage.
- Column diameter.
- Column internals, and materials of construction.
- Heat liability and chemical reactivity of feed components.

4.2 Fermentation of sorghum grains:

Fermentation of sorghum was conducted by using a fermentor and a simple method was used which involved:

- Adding 4liter of distilled water to 300g of sorghum.
- Inoculation with yeast (2g/liter).
- Fermentation was run for 72 hours at ambient temperature (30 ± 2 C) in 10liter conical flask. Samples were taken at intervals and then distillation by simple device was done until required for analysis.
- Distillation was done by using a simple distillator at a temperature of 100 C then a Refractometer was used to determine the concentration of ethyl alcohol. After that a rectifying column was used to produce rectified (92%) alcohol.

An amount of sorghum 300grams weighted by balance and yeast, then 1.5 liters of water added and put at close glass container with tube to pass CO_2 to outside the container then closed well till fermentation take place, then after 3 days distillation started and then after 7 days .

Table (4.1) Experimental data of fermentation.

	2 days		4 days		7 days	
Feed (F)(ml)	200 ml	183.4gram	200 ml	182.5 gm	200 ml	180 gm
Distilled (D)(ml)	50 ml	53 gm	45 ml	47 gm	100 ml	92 gm
Waste((w, ml))	147 ml	128.2 gm	150 ml	135 gm	100 ml	88 gm
Refractor index(D)	1.30		1.32		1.35	
Concentration of distilled by refractometer(M)	5.8		7.99		12.1	

A standard solutions of ethanol were prepared and measured by refractometer to get the concentrations of x_D ,x_F and x_W shown in the next table.

Table (4.2): Ethanol concentrations according to refractometer reading

Refractive Index	Ethanol Concentration % (w/v)
1.363	99.99
1.361	80
1.341	60
1.332	40
1.272	20

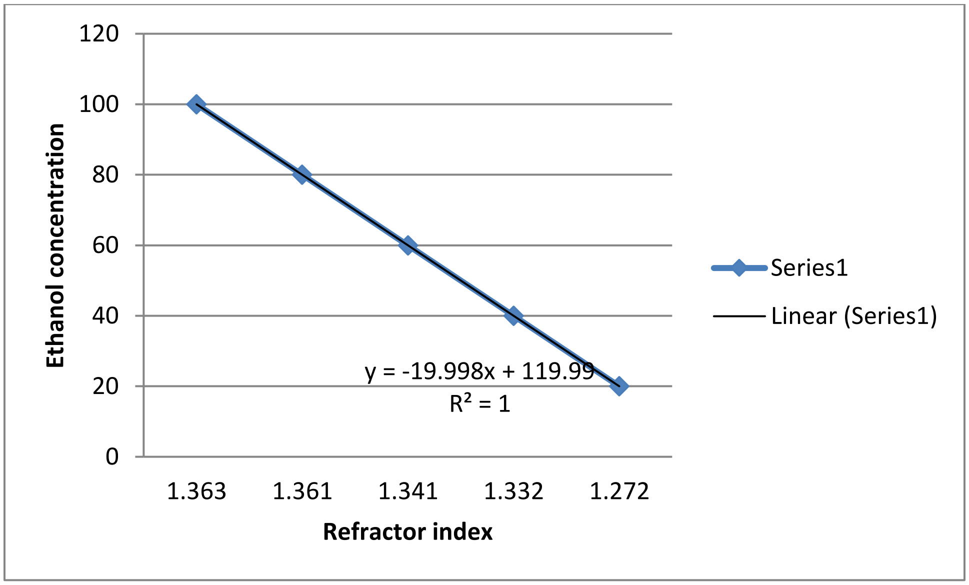


Figure (4.1) Relationship between ethanol concentrations % and refractor index.

Figure above explains the relation between ethanol concentrations % and refractor index. it shows that there is decreasing in refractor index with decreasing ethanol concentration. R^2 is the correlation.

*note that the concentration is increase by increasing the period of fermentation The (x_F , x_D , x_W in volume/volume is measured by preparing known concentrations solution).

The following discussion is limited to column equipped with sieve plate, stainless steel, operated at atmospheric pressure and treating binary system to calculate:

1. Reflux ratio "minimum – actual" R_{min} _ R.
2. Number of plates "minimum – actual" N_{min} _ N.
3. Feed plate location.

The precise location of the feed point will affect the number of stages required for a specified separation and the subsequent operation of the column. As a general rule, the feed should enter the column at the point that gives the best match between the feed composition (vapour and liquid if two phases) and the vapour and liquid streams in the column. In practice, it is wise to provide two or three feed-point nozzles located round the predicted feed point to allow for uncertainties in the design calculation and data, and possible changes in the feed composition after start-up.

3- Height and diameter of the tower.

4- areas of the tower :

- Total area.

- Active area.

- Net area.

5- Tray efficiency if complete mixing.

6- .Holes design:

-Hole diameter.

-Hole area.

-Number of holes.

7- Column efficiency

8- Weir height

By using given constants and data;-

Components are Ethanol and Water

Rate of feed F =10kmol/s and x_F = 0.3

Rate of distilled D =1.33kmol/s and x_D =0.92

Rate of waste W =8.667kmol/s and x_W = 0.08

At 70° C

Density of water ρ_{H2O} =1000kg/m^3

Density of Ethanol ρ_{Etoh} = 790 kg/m3

Viscosity of water = 8.9*10^{-4} pa.s

Viscosity of ethanol =.983*10^{-3} pa.s

Relative volatility of water (heavy key) = 0.5

Relative volatility of ethanol (light key) = 1.3

Plate spacing = 0.5m

- **And by using the following equations and figures ;**
  - Determination of Minimum Number of theoretical stages by using **Fenske's Equation: -**

$$N_m = \frac{\log([x_{LK}/x_{HK}]_D[x_{HK}/x_{LK}]_W)}{\log \alpha_{LK}} \quad (4.1)$$

Where N_m = Minimum Number of stages.

x_{lk} = composition of the light key.

x_{hk} = composition of the heavy key.

α_{LK} = average relative volatility for the light key component.

- Using **Underwood's Equations** to calculate minimum reflux ratio: -

$$\Sigma(\alpha_i x_{iD})/(\alpha_i - \Theta) = R_m + 1 \quad (4.2)$$

Where

R_m = minimum reflux ratio.

- Value of q was defined depends on the conditions of the feed.
- The values of Θ found by trial and error.

Feed Plate location by **Kirkbride's Equation**

$$\text{Log } Nr/Ns = 0.206\log[((W/D)(x_{HK}/x_{LK})F((x_{LKW}/x_{HKD}))^2] \quad (4.3)$$

Table (4.3) Compositions of ethanol at feed, distilled and waste stages

At feed x_{FEtoh}	0.3
At distilled x_{DEtoh}	0.92
At waste x_{WEtoh}	0.08

By applying equation (4.1)

Ethanol is the light key LK (1.3)

Water is the heavy key HK (0.9)

N_m= 18

For Minimum reflux ratio

Solve for by trial and error. For q=1 the feed is saturated liquid by applying equation (4.2)

For Θ = 0.8999

And the summation Σ =9.82 =R_m+1

Then R_m=8.8 and then R=9

The two most frequently used empirical methods for estimating the stage requirements for multicomponent distillations are the correlations published by Gilliland (1940) and by Erbar and Maddox (1961). These relate the number of ideal stages required for a given separation, at a given reflux ratio, to the number at total reflux (minimum possible) and the minimum reflux ratio (infinite number of stages). The Erbar-Maddox correlation is given in this section, as it is now generally considered. to give more reliable predictions. Their correlation is shown in Figure (A.1) which gives the ratio of number of stages required to the number at total reflux, as a function of the reflux ratio, with the minimum reflux ratio as a parameter. To use Figure (A.1) in appendix (A) estimates of the number of stages at total reflux and the minimum reflux ratio are needed.

And then for Erbar Maddox correlation and figure (A.1)

$R_m/(R_m+1)$=0.897 and $R/(R+1)$ =0.9

Then from the figure

Nm/N = 0.5

As Nm=18 then N = 18/0.5   N= 36

From the material balance….

F=D+W

$F.x_F = D.x_D + W.x_W$

F=10 kmole/s as basis

$x_F = 0.3$

$x_D = 0.92$

$x_W = 0.08$

D=2.62kmole/s

W=7.38kmole/s

- Feed Plate location by applying equation (4.3)

Substitute then

Log Nr/Ns=0.168 and Nr/Ns=1.48

Nr+Ns=36 and Ns=14 Nr=22

Feed location after 22 stages from top

Nr rectifying section   Ns stripping section

Number of stages and minimum reflux ratio According to McCabe–Thiele method

Y=α_I *x/(**1+(**α_I **-1)*x)** (4.4)

Table (4.4) Values of x and y

x	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**1**
y	**0.127**	**0.246**	**0.359**	**0.466**	**0.567**	**0.662**	**0.753**	**0.829**	**0.921**	**1**

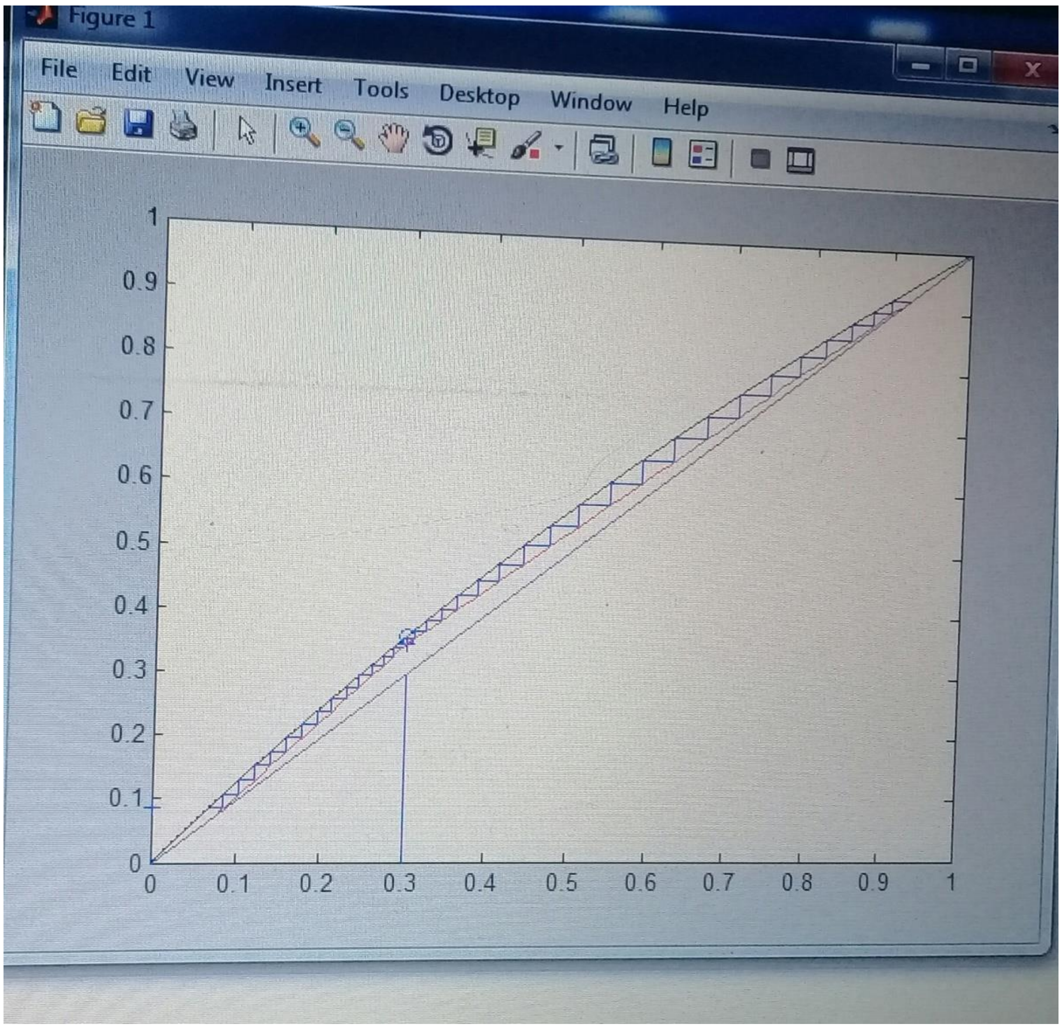


Figure (4.2) Number of stages by McCabe–Thiele method operating line for the rectifying section.

From figure (4.3)

N = 35

$C = x_d / R_m + 1 = 0.359$

$R_m = 9.7165$

$R = 1.3 * R_m$ $R = 12.63$

For feed location

$\grave{C} = x_d / R + 1 = 0.067$

From figure, Feed location after 21 stages from top.

To calculate column diameter;

The principal factor that determines the column diameter is the vapour flow-rate. The flooding condition fixes the upper limit of vapour velocity. A high vapour velocity is needed for high plate efficiencies, and the velocity will normally be between 70 to 90 per cent of flooding velocity.

- First calculate flow parameter from given data

$F_{LV} = (L_W/V_W)*(sqrt(\rho_v/\rho_L)$ (4.5)

Where

ρ_v = density of vapour phase kg/m3 ρ_L = density of liquid phase kg/m3

L_W = liquid mass flowrate kg/h V_W = liquid mass flowrate kg/h

$F_{LV}=(0.337/3)*(sqrt(790/1000))$

- $F_{LV} = 0.1$

The flooding velocity (U_f) can be estimated from the correlation given by Fair (1961):

- $U_f = k_1 * (sqrt(\rho_L - \rho_V) / \rho_V)$ (4.6)

K1— a constant obtained from Figure (A.2) in appendix (A)

Assuming plate spacing 0.5m

Then $k_1 = 9*10^{-2}$

$U_f = k_1 * (sqrt(\rho_L - \rho_V) / \rho_V)$

$U_f = 0.04638$m/s

Taking 80% flooding

$U_v = 0.0463 * 0.8 = 0.03711$m/s

And

The volumetric flow rate of vapour in tower V(m^3/s) =(mole flowrate * M . Wt /v)/ ρ_{Etoh}

$= V_w / \rho_v = 3*46/790 = 0.1746$m3/s

Net plate area A_n=V(m^3/s)/Uv(m/s) =4.707 m^2

Active area $A_c = A_n / .085 = 5.5345 m^2$

Molar flowrate of vapour = 3kmole/s

Mass flowrate = 3(kmol/s)*46(kg/kmol) = 138kg

And column diameter Dc= sqrt(Ac*4/ 3.14)

=2.6m

Column diameter Dc = 2.6m

Total column cross-sectional area A_c =(3.14/4)* D_c^2 = 3.14 m^2

Cross-sectional area of domncomer A_{dc} = 15%A_c =0.15 *3.1415= 0.471225m^2

Net area available for vapor liquid disengagement, normally equal to

$A_n = A_c - A_{dc}$ = 3.1415-0.471225= 2.6702m^2

- Active, or bubbling, area $A_a = A_c - 2A_{dc}$=3.1415-2*0.471225=2.199m2
- Hole area, the total area of all the active holes A_h = 10%A_a = 0.219m^2
- Weir Height (h_w) normally be between 100 to 40mm take it 75 mm.

A high weir will increase the plate efficiency but at the expense of a higher plate pressure drop.

- Hole (diameter) Size

For perforated trays the hole sizes used vary from 2.5 to 12 mm; 5mm is the preferred h_d =5 mm size.

- The plate thickness can be taken as equal to the perforation diameter 5mm
- area of a single hole: 1.964* 10^{-5} m^2
- The area of the perforations is 10% of the active area
- A_h = 10%A_a = 0.219m^2
- number of holes = : 0.219/1.964* 10^{-5} = 11197holes

The holes are distributed in triangular pitch

- Column efficiency E0 = N/NA O'Connell equation (4.7)

  =23/35 = 0.65

- **Plate Pressure Drop**

The pressure drop over the 4 plates is an important design consideration.

A simple additive model is normally used to predict the total pressure drop . The total is taken as the sum of the pressure drop calculated for the flow of . vapour through the dry plate (the dry plate drop(h_d); the head of clear liquid on the plate (h_w+h_{ow});and residual pressure drop.(Gil et al., 2008)

- The maximum vapour flow (U_{max}) through the plate perforations:

U_{max} = V/ A_h = 0.1746(m3)/0.219(m2/s)= 0.797 m/s

And as the ratio of the plate thickness to the hole diameter =1.0 and also as (10%)

C_D (discharge coefficient)=0.843

- h_d= 51((U_{max}/C_D)^2)*(ρ_V/ρ_L) (4.8)

=51*(0.797/0.843)^2*(790/1000)

= 0.706

The residual head is estimated from "Hunt et' a l :

- $h_r = 12.5*10^3/\rho_L$ = 12.5mm
- The total plate drop is::
- $h_t = h_d+(h_w+h_{ow})+h_r$

(h_w+h_{ow}) = 100mm obtained from figure and k2 is constant =31

Then

h_t =12.5+100+0.706 =113.206mm liquid.

- **column hight (H)**
  - The overall hight of the column will depend on the plate spacing from 0.15m to 1m is normally used. Close spacing is used with small column diameter.

H= (N_a-1)* plate spacing+ N_a/10 + 0.1Ht (4.9)

Ht =((N_a-1)* plate spacing+ N_a/10)/0.9

Ht =(35-1)*0.5+35/10)/0.9 = 22.77

Plate spacing= 0.5m H=22.77m

- **Overflow weir** I_w

The relationship between weir length and domncomer area that gives the relationship between the area of the domncomer and the weir length from the knowledge of the column diameter and x-sectional area:

$= A_{dc} / A_c = 0.471225/3.1415 = .15 = 15\%$

$I_w / D_C = 0.81$

$I_{w=}$ 2.025m

From figure (A.5) in appendix (A)

- **Plate type and Liquid-Flow Arrangement**

The choice of plate type (reverse, single-pass, or multiple-pass) will depend on the liquid flow rate and column diameter. Empirical correlations and plots are available, Liquid volumetric flow rate in the column:

- L= **The volumetric flow rate of vapor in tower** $L(m^3/s)$ =(mole (flowrate * M Wt /L)/ ρ_{water}

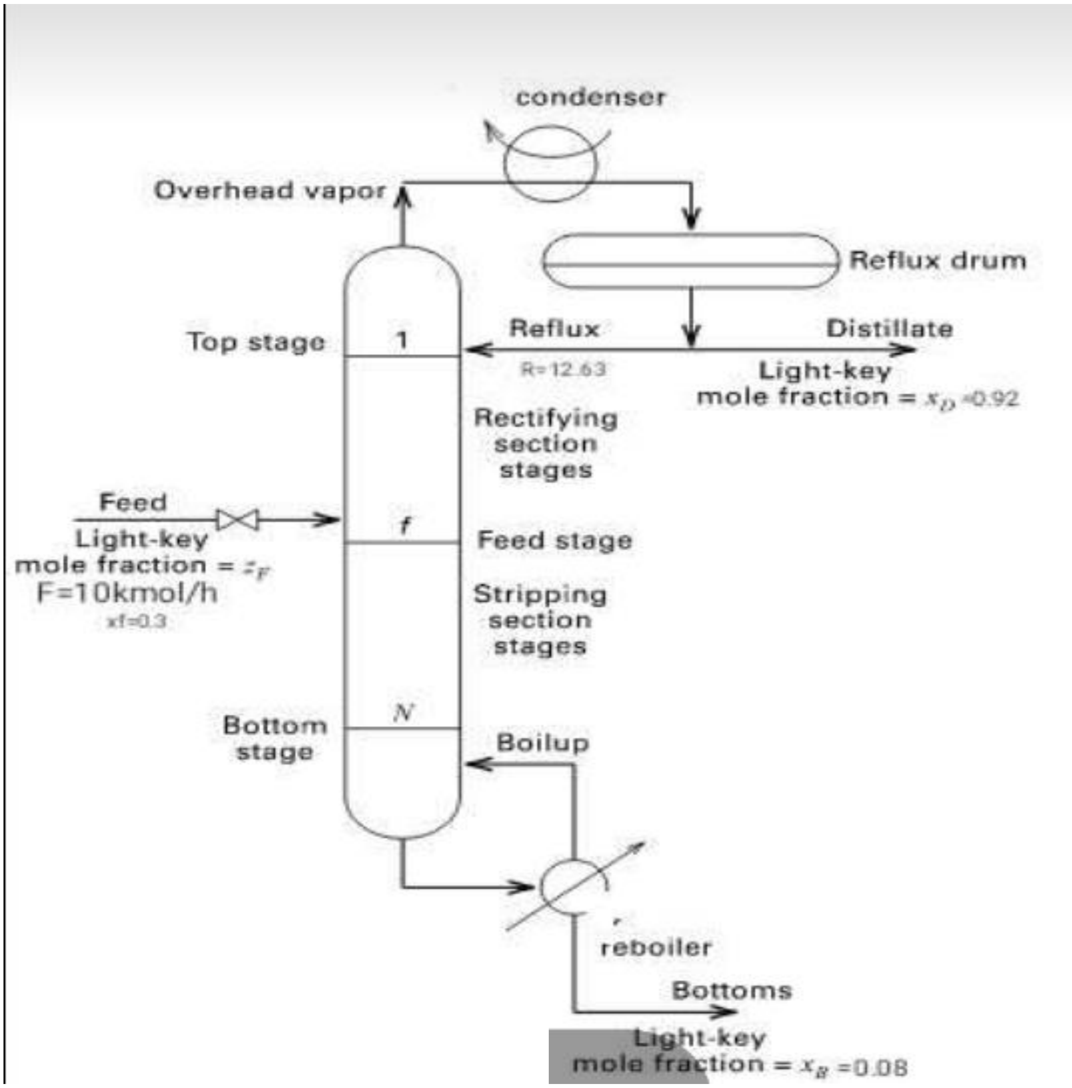
$=L_W/\rho_l = 1.33*18/1000 = 2.34*10^{-2} m3/s$

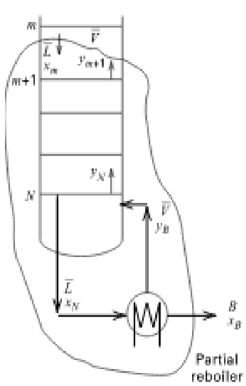
From Fig (A.6) in appendix (A) and for and D_c and L the suitable choice is: a single pass, cross flow plate flow arrangement.

Table (4.5) summary of design of sieve tray distillation column

N_m	18 stages
N_{actual}	35 stages
R_m	9.71
R	12.63
Feed location	After 21 stages from top
F_{LV}	0.1
Column diameter	2.5m
K1 (constant)	0.09
Plate spacing	0.5m
Volumetric flowrate	$0.174 m^3/s$
Mass flowrate	138kg/s
Molar flowrate	3kmole/s
A_C	$3.1415 m^2$
A_{dc}	$0.471 m^2$
A_n	$2.67 m^2$
h_w	75mm
Number of holes	11197 holes
Plate pressure drop	113.2 mm
Column height	22.77m

Design for the distillation column





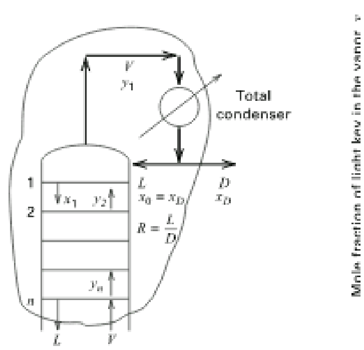


Figure (4.3) Design for the distillation column, stripping Section and rectifying section.

4.3: Discussions:-

The increasing populations of many nations have led to a new awareness of the importance of ethanol production. Significant technological advances have been made in recent years, which can lead to increased efficiency in ethanol production in many countries. Ethanol is used for flavorings and as a medium for chemical reaction and in recrystalizations. Some alcohol is used as a raw material for the synthesis of other chemicals and a little amount is used as fuel.

Industrial alcohol is largely derived from the distillation of fermented plant materials. The underlying economic problem of industrial alcohol production by fermentation is the cost of the raw material. Most of the industrial alcohol produced is derived from the fermentation of molasses. Today the scarcity and high price of this raw material has led the producer of industrial alcohol to be always in search of a cheaper usable raw. Material (Stainer and Ingram, 1976).

From the design equations and By using given constants and data Components are Ethanol and Water rate of feed (F) rate of distilled (D) rate of waste (W) at temperature of 70^{o} C , many design requirements calculated the most important were reflux ratio "minimum – actual" R_{min} _ R, number of plates "minimum actual" N_{min} _ N. feed plate location , Height and diameter (D) of the tower ,areas of the tower : (total area m^2 .active area (A_a m^2) , net area (A_n m^2)) Tray efficiency if complete mixing .column efficiency weir height. .Holes design -Hole diameter -Hole area A_h . -Number of holes.

Practical experiments by fermentation of sorghum for long period showed that 69% of ethanol obtained, sorghum fermented by adding yeast and distilled water then the mixture filtered and distilled in simple distillation device and concentration measured by refractometer.

Chapter Five

Conclusions and Recommendations

5.1 Conclusions:

Increase gasoline demand needs to increase the capacities of refineries to increase gasoline production and blending the gasoline with bioethanol to cover demand, as the blending of gasoline increases the octane number of fuel and allows full and clean combustion in order to contain oxygen also reduces emission of green house warming gases that effect the climate change.

Bio-fuels are being promoted in the transportation sector. Many research programs recently focus on the development of concepts such as renewable resources, sustainable development, green energy, eco-friendly process, etc., in the transportation sector.

Sorghum is a renewable resource suitable for use as a feedstock for production of fuels and chemicals. The majority of the research on sorghum bioconversion has focused on fuel ethanol but there also have been studies on production of industrial chemicals. To realize the full potential of sorghum as a renewable feedstock in the upcoming bio-based economy.

Carbon dioxide utilization: Large quantities of CO_2 are generated in ethanol production and also in aerobic fermentation processes. This important co-product can be used in many applications.

From the results outlined above, the following can easily be deduced:

- The project is feasible specially when it's compared with other sources for fermentation
- Steps of ethanol production from sorghum were explained clearly and also previous studies on ethanol production.
- Ethanol produced from sorghum grain instead of beer and other unbenifit alcohol.

- A design for distillation column was done and all considerations were calculated.
- For the chemical change during fermentation: pH, total sugar, reducing sugar and sucrose% decreased with time, but the amount of ethanol increased with time.
- According to the results of this study it is clear that it is possible to produce ethanol from sorghum in Sudan; the cost of production is reasonable and it can make good returns to producers. It is actually a good option beside or alternative for ethanol production from molasses.
- One major problem with bio-ethanol production is the availability of raw materials for the production. The availability of feedstock for bio-ethanol can vary considerably from season to season and depend on geographic locations. The price of the raw materials is also highly volatile, which can highly affect the production costs of the bioethanol.

5.2 Recommendations:

The study is recommended to make further studies on:

- Ethanol production from sorghum is less cost and easy to occure.
- According to increasing in demand of biofuel this will result in food versus fuel problem and it will come a time that crops planted will not be enough, so it is better to find another sources for biofuel production.
- More sugar bearing plants as recommended such as corn sugar beet sweet sorghum ….etc
- Increase refining capacities to produce more ethanol and gasoline.
- Expand kenana bioethanol plant.
- Benefit from the experiences of countries applied the system of blending bioethanol and gasoline.
- Also ethanol production from sweet sorghum more sugar content.

- It is better to find an alternative sources for biofuel production although biomass is good. But it is used as food.

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Appendix (A)

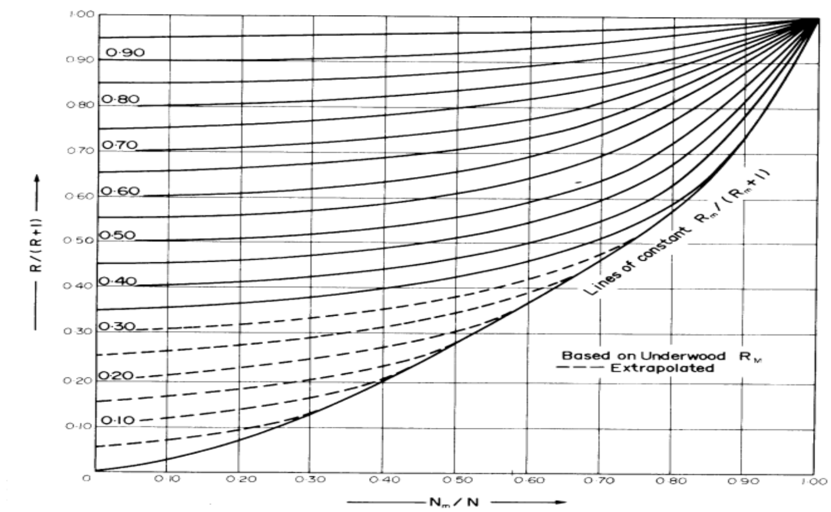


FIG. 11.11. Erbar–Maddox correlation (Erbar and Maddox, 1961)

Figure(A.1) Erbar -Maddox correlation

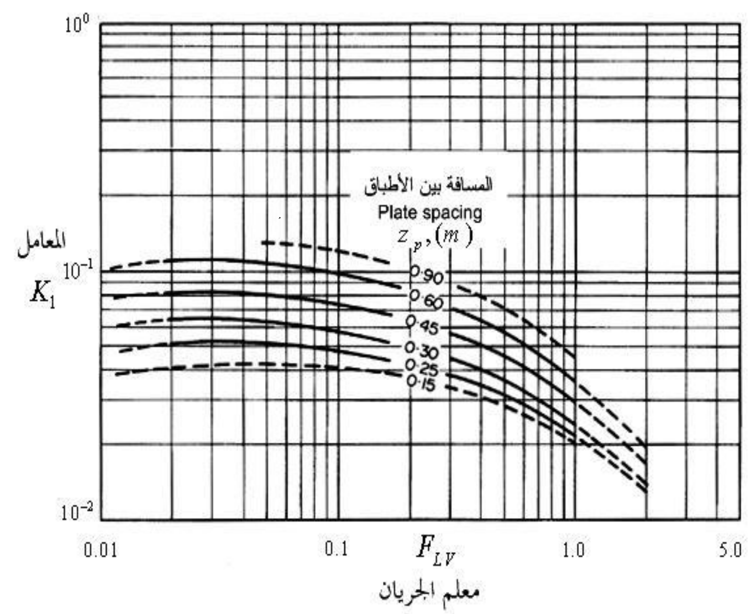
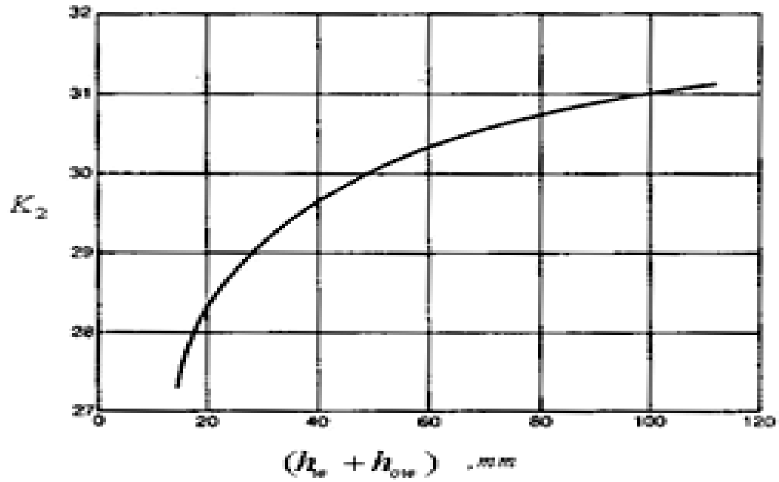


Figure (A.2): flooding velocity and K_1 (Fair,1961)



Fig(A.3): Weep-point correlation (Eduljee, 1959)

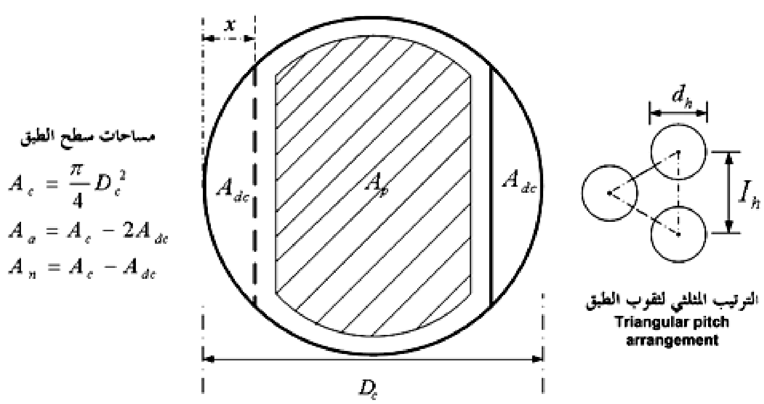


Fig (A.4): Areas and distances of the perforated tray

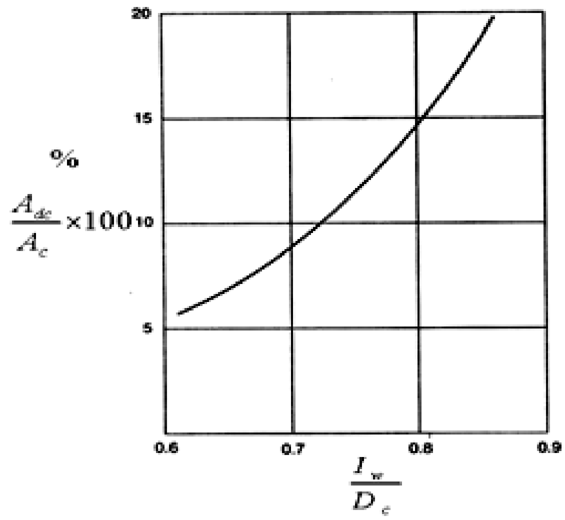


Fig: (A.5) Relation between domncomer area and weir length

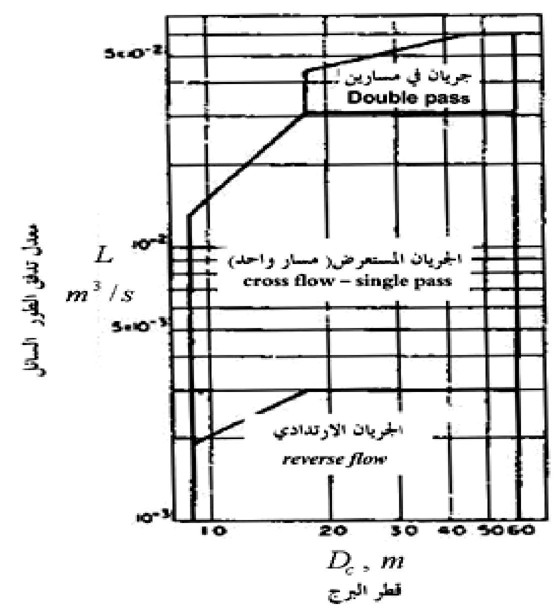
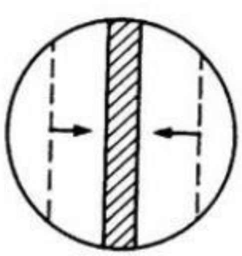
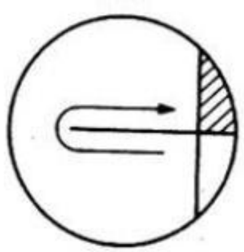


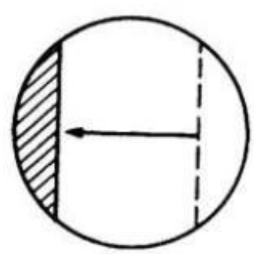
Fig (A.6) : Flow Arrangement on plate



double-pass flow



reverse flow



cross flow