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Design of an Ethanol Distillation Plant

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Abstract At present, ethanol has regained support for use in cars. It is used directly or blended with gasoline. In comparison to other alternate fuels, ethanol is renewable, produced domestically and provide economic benefits. Hence the interest in the design of an ethanol distillation plant in other to produce ethanol, which is environmental friendly fuel. Although, there has been a great resurgence in ethanol production and use as fuel, many challenges are still to be overcome before there is a wide spread, use and production of ethanol. In tropical region, such as Brazil, the viability of the use of ethanol as fuel is no longer a question because ethanol generates far more energy than needed to operate the ethanol plants. For countries like Brazil and U.S. who have promoted ethanol production, they have achieved greatly. Thus the need for the promotion in Nigeria. In this work, various local ethanol distillating plants were visited, workers interviewed, limitation of the examined plants discovered and worked on leading to the design of a better plant.

Keywords Design, Ethanol, Distillation Plant

1. Introduction

From time immemorial, ethanol has been in use contrary to popular belief; ethanol is not a new fuel. Its use dates back to the mid-1800s, in fact, it has been around as long as petroleum, but has faced significant challenges that petroleum did not face. Hence, its unpopularity as a source of fuel. In the late, 1850s, ethanol was a popular illuminates or lamps. In 1861, two significant events affected the use of ethanol as an illuminates. First, Kerosene came to the market and then, a $2.00081 gallon tax was imposed on alcohol (which affected ethanol) to assist in financing the Civil War in the U.S. Kerosene was quick to replace ethanol as the premier illuminates, due to its cheaper price. The tax on alcohol was lifted in 1906 d designed the car model to run on ethanol. Also, the use of ethanol during World War I perpetuated a further increase in ethanol production to 50 million gallons annually [1].

The use of ethanol declined again in 1919 because ethanol production was resisted and it could only be sold after it had been denatured (usually with petroleum). Consequently, in 1993, the use of ethanol rebounded when it was used during World War II for fuel and to make synthetic rubber. During this period about 600 million gallons of ethanol was produced annually in the U.S.A [1]. After the World War II, demand for ethanol reduced greatly due to importation of petroleum at cheap prices. Hence ethanol was not used on a large scale again for about forty years.

However, decades ago the versatility of ethanol was discovered. Its use as an ingredient in alcoholic beverages is well known. Medically, it is used as solvent for drugs, fluid in thermometers, and preservation of biological specimens and solutions with 70% ethanol are often used in laboratories for disinfecting work surfaces. In addition, ethanol is used as intermediates in the manufacturing of chemicals such as esters and halides. Some proportion of ethanol mixed with water or other solvents can be used as a solvent for paints and varnishes. It is also used in the manufacture of perfumes, paints, resins, dyes, soaps and tinctures.

Hence, the interest in the design of an ethanol distillation plant in order to produce ethanol, which is an environmentally friendly fuel.

In order to meet the wide varying applications of ethanol distillation plants, several methods were devised in the selection of materials to be used in the plant design. They are based on design and construction features, availability and cost of materials, physical state of the fluid and the chemical reaction between the fluid and the metals to be used.

2. Literature Review

2.1. Ethanol Distillation Plants

At present, ethanol has regained supports for use in cars. It is used as a fusil by itself or blended with gasoline (which is known as gasohol). In comparison to other alternative fuels, ethanol is renewable, produced domestically and provides economic benefits [2]. Many early ethanol plants were designed after distillery plants. Thus this led to insufficient and low-grade fuel ethanol production. Instead of focusing on optimizing yield and energy efficiency (which is important in fuel ethanol production). These plants can be classified into two categories namely traditional and modern industrial plants [3]. Increase in demand for fuel ethanol made technology for production of fuel ethanol critical and as a result of this, new plants were developed for large-scale production and improved efficiency. In this development, various factors were considered, which includes the ability of the plant to remain current for a long time without constant upgrading requirements, compatibility with current for a long time with current facilities, ability to handle a wide spectrum of raw materials and environmental friendliness [4].

The operation involves heating fermented solutions in the boiler to a temperature at which pure ethanol vapor is given off. The vapor passes through a pipe connected from the boiler to the condenser and the final product is collected at the receiver situated at the second reservoir.

Low proof ethanol is usually obtained, due to unregulated temperature (variation in temperature). Only the first product gotten is high quality ethanol (between 160 to 180 proof), which can be used as ethanol fuel because of its high flammability.

Improper condensation occurs when coolants becomes not due to no provision made for changing it during the process. Hence, the plant is labor and energy intensive and produces only a minute quantity of ethanol, which can be used as fuel. Therefore it does not meet the demand for ethanol as fuel but for human consumption.

2.2. Limitation of Existing Plants

Dehydration is carried out in the presence of benzene, this has a carcinogenic effect on human health. Insufficient thermal mass or internal surfaces to stabilize alcohol vapors, which create the turbulent up and down movement, also affects the condensing of ethanol and at the same time cooling and striping of the ethanol out of the upward moving vapors. In addition, the reflux column and condenser are permanently attached and thermally coupled to the boiler which means the only way to control the temperature is by raising or lowering the temperature of the boiler and this is only suitable for small scale production.

3. Materials and Methodology

In designing an economical, efficient and reliable plant, the following considerations were made.

3.1. Parameters for Consideration

Mechanical Properties	Chemical Properties	Materials
Tensile strength	Oxidation Resistance	Stainless Steel
Wear Resistance	Corrosion Resistance	Galvanized Sheets
Toughness	-	Copper Pipes and Tubes

3.2. Plant Description

This are the materials needed for a batch operation plant with a simple reflux column attached to a suitable boiler. Batch plants can be built with relative ease for small amount of money. Such plant comprises of the following major components.

Heat Source Design

The design was that heat will be provided from two heating elements. These heating elements are will be made of stainless steel. Electricity will be employed for heating, and the panels containing the heating elements will be placed directly in the boiler. Hence, the heat source will be internal. Electric Current passing through the wires and generates heat that radiates out of the heating element, which raises the temperature in the boiler. Boiler temperature will be controlled by the use of a thermostat to turn the current on and off as necessary. This is possible because both the thermostat and heating elements will be connected to the fuse box.

Although, the electric heating generally costs more than energy obtained from combustion of fuel, its use is justified for its convenience, cleanliness and compactness.

Boiler Design

This is mostly a chamber for heating water or generating steam above atmospheric pressure. In this case, the boiler was designed to have a conical – shaped top to prevent vapor from condensing at the top. The boiler will present the largest liquid surface area possible because vapor comes out of the liquid only at the surface. So the more the surface area, the greater the opportunity for the vapor to leave. In addition, there would be more area to apply the heat, thereby making a more efficient use of the heat source. Usually, boilers are vapor and liquid tight so as to prevent escape of vapor and liquid. This boiler is not an exception and the above will be achieved by lagging the boiler. Attached to the boiler will be a thermostat, which uses a feedback loop to control the boiler temperature. The thermostat will control the desired boiling temperature, and then sends appropriate instructions to the heating element.

By continually cycling through this feedback loop, the desired temperature will eventually be reached and maintained. With a thermometer in the liquid area of the boiler, the rise in temperature can be viewed.

Cylinder

This is the container used to collect the unwanted vapors emitted from the boiler

Reflux Column Design

This is a refinement of the existing types of plants. The column can be constructed from copper, iron, or stainless steel pipes and fittings. The use of certain types of rubbers, plastics, and metals that reacts chemically with the alcohol should be avoided e.g. aluminum.

A reflux column performs simultaneous distillations. Therefore it is more efficient than plants not having reflux columns. It produces in one run what ordinary plants may require three runs to do. The stripping section of the reflux column is packed with materials such as marbles, pebbles, broken glass, and short pieces of metal or glass tubing. Any material which would not rust or react with the alcohol can also be used. The purpose of packing is to provide as large an internal surface area as possible. Some sort of screen or retainer is needed at the base of the stripping section to hold the packing material in place. The efficiency of the reflux column is dependent upon the length and diameter of the column.

Transmission Channel Design

Transmission Channel from the boiler to the Cylinder is the first stage of the piping. The piping is done using copper tube, copper is chosen in preference to other metals because of its heat conductivity, malleability, resistance to corrosion and beauty. Ethanol vapor to be cooled is channeled through the tube from the top of the column to the condenser. Inside the condenser, the tube is coiled enabling maximum condensation by water flowing in the opposite direction around the tube. Moreover, the tube from the column to the inlets (tube inlet) of the condenser is lagged to prevent pre-condenser cooling. A slight downward slant from the column to the condenser will prevents the condensate from draining to the column.

Transmission channels are also employed to convey the cooling water from the reservoir to the overhead tank into the condenser and to convey the unwanted vapors to the cylinder.

Condenser Design

Heat must be removed from alcohol vapors by the condenser system. If the condenser does not remove enough heat, the alcohol vapor will be lost and no amount of reflux will be sufficient to liquefy the vapor. Obtaining high proof ethanol will not then be possible. The main thing is that the condenser designed is large enough to cool the entire vapor from the column.

Hydrometer Sump

There are several improvements which can be incorporated to the basic plant, of which the hydrometer sump is one. It is deigned to be constructed from ordinary pipes and fittings. In use, the product from the condenser is admitted at the bottom of the sump and it flows out of the top. The sump contains both a hydrometer and a thermometer which allows a constant check of the proof and temperature of the alcohol respectively. These instruments are held in place by a rubber cork.

Receiver

Metals such as steel cannot be used as receiver because ethanol is a bit corrosive and will rust steel. Rubber and plastic materials can also not be used since pure ethanol reacts with or dissolves certain rubber and plastic materials. However, glass can be used for the receiver in which the condensate is collected. Two receivers are needed, one for high proof product and the other for low proof product obtained.

Reservoir and Overhead Tank

The reservoir of this plant is cylindrical in shape. This component serves as a source of water supply. The cooling water is stored in the reservoir before it is taken by a tube to the overhead tank.

The overhead tank which is also cylindrical is raised above the ground level. It is a container used in holding the water pumped from the reservoir.

Water Pump

This is a machine used to raise water from the reservoir into the overhead tank and out of it to the condenser. The machine makes the cooling water flow in a particular direction due to pressure. It circulates the water from the reservoir to the overhead tank to the condenser and back to the reservoir.

Frame

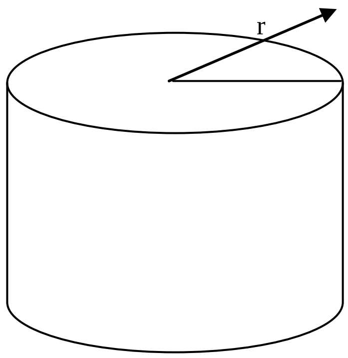
The main frame is the support for the entire plant. It accommodates other components of the plant and ensures adequate rigidity.

4.1. Design Calculations

Based on the following observations, considerations and identified limitations of existing ethanol distillation plants, this work made a design of an economical and easy to fabricate ethanol distillation plant that would be efficient. The following design calculations were made

4.1.1. Boiler Calculations

For a circular right cylinder of height h, and radius r, the lateral surface areas S, and Volume V is calculated as follows:



$S=2\pi rh$

$V=\pi r^2h$

Figure 4.1: Boiler Cylinder

Therefore, for this boiler cylinder of h = 250mm and r = 175mm,

$S = 2 \times \pi \times 175 \times 250 = 274889.36mm^2$

$V = \pi \times 175^2 \times 250 = 24052818.75mm3$

If the top and bottom caps of the boiler cylinder are added, the total surface area of the boiler cylinder is given by:

$T = 2\pi rh + 2 (\pi r^2) = 2\pi r (h + r)$

Therefore, T = 2 x π x 175 (250 + 175) = 1099.557429 x 425 = 467311.91mm^2

The boiler cap is a right circular frustum obtained from a right circular cone. For a right circular cone of height h and base radius r, the angle, is derived using

$\Phi = 2\tan^{-1}(r/h)$. Where r= 175mm and h=250mm

$\Phi = 2x \tan^{-1}(175/250) = 2 \times \tan^{-1} 0.7000 = 2 \times 34.9920202 = 69.98^0$

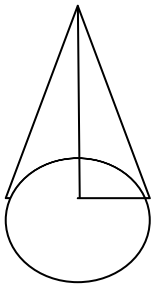
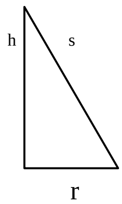


Figure 4.2: Right circular Cone

For this right circular cone, the slant height S is:

$S = \sqrt{(r^2 + h^2)}$



And the surface area (not including the base)

$S = \pi rs = \pi r \sqrt{(r^2 + h^2)}$

Where r =175mm and h= 250mm.

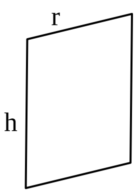
Therefore,

$S = \sqrt{(175^2 + 250^2)}$

$S = \sqrt{(30{,}625 + 62{,}500)} = \sqrt{93{,}125} = 305.16mm$

The above cone is dissected to get a frustum as shown below:

For a right circular frustum, let s be Slant height, R and r the base and Top radii respectively. And h the height. Where R = 175mm, r= 6.25mm and h= 200mm.



then,

$s = \sqrt{(R-r)^2 + h^2} = \sqrt{(175-6.25)^2 + 200^2}$

R $= \sqrt{28476.56 + 40000} = 261.68mm$

The surface area of the boiler cap (not including the top and bottom of the boiler cap) is:

$A = \pi (R+r) s = \pi (175 + 6.25) \times 261.68 = \pi \times 181.25 \times 261.68 = 149004.17mm^2$

Therefore, the total surface area of the boiler (not including the top of the boiler cap) is:

Total surface area of boiler= Total surface area of boiler cylinder + surface area of boiler cap

$= 467311.91mm^2 + 149004.17mm^2 = 616316.08mm^2$

The maximum amount of mash that this boiler can contain is 24 litres.

This was obtained as follows:

$1cm^3 = 1000\ mm^3$

$$1000cm^3 = \frac{1000mm^3 \times 1000cm^3}{1cm^3}$$

$1000cm^3 = 1{,}000{,}000\ mm^3$ But, $1000cm^3 = 1000ml$

Therefore, $1000{,}000\ mm^3 = 1000ml$

But, the boiler volume V is = $24052818.75mm^3$

$$24052818.75mm^3 = \frac{24052818.75mm^3 \times 1000ml}{1{,}000{,}000mm^3}$$

$24052818.8.75\ mm^3 = 24052.81875\ ml$

But, 1000 ml = 1itre

$$24052.81875\ ml = \frac{24052.81875\ ml \times 1\ liter}{1000\ ml} = 24.05\ liters\ =24\ liters$$

4.3. Reflux Calculation

The reflux column has 3 towers, each of height h= 100mm and r = 20mm. The curved surface area of each tower is calculated using the formula:

$$S = 2\,\pi\, r\, h$$

$$S = 2\pi \times 20 \times 100 = 2\pi \times 2000 = 12566.37mm^2$$

The curved surface area = the lateral surface area

Lateral surface area of each reflux tower is $12566.37mm^2$

Attached to each of the tower is a flange. This is a two-dimensional figure with four straight sides, whose four interior angles are right angles (90^o), and whose four sides are of equal length 80mm with thickness 4 mm. If the sides of the flange have a length s, the perimeter of the flange is simply four times the length of a side. This is represented algebraically by the formula: P = 4s . The area of the flange is determined by multiplying the length of a side by itself. i.e. $A = s^2$

$$P = 4 \times 80 = 320mm \text{ and } A = 80^2 = 6400mm^2$$

Hence, the specification of each of the reflux towers and flange are: Height, h = 100m, Radius, r = 20mm and Lateral surface area, S = $12566.37mm^2$

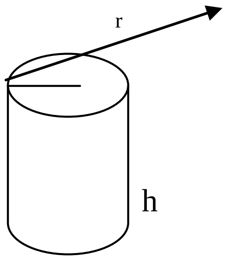


Figure 4.3: Reflux Tower

Flange length = 80mm, Flange thickness = 4mm and Flange area = 6400 mm^2

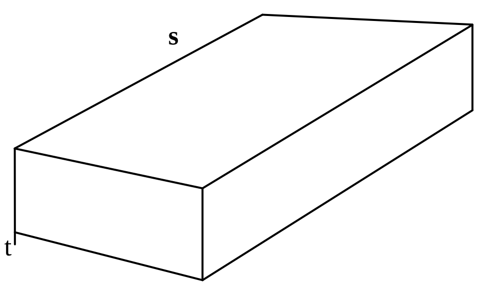


Figure 4.4: Reflux Flange

4.4 Condenser Calculations

With diameter d= 90mm and length l=310mm the total surface area of the condenser is obtained using T=π r 1+2 (πr). :. T 2 π r (r+l) =2π x 45 (45 + 310) =282.7433388x 355=100373.89mm^2

The volume of the condenser is obtained using $V = \pi\ r^2 1$. :. $V = \pi$ x 45^2x 310 = πx2025 x 310 =1972134.79 mm^3

The maximum amount of cooling water the condenser can contain is obtained as follow: 1000mm = 1 cm^3 .

$$1972134.79\ mm^3 = \frac{1972134.79\ mm^3 \text{ x } 1\ cm^3}{1000\ mm^3} = 1972.13\ cm^3$$

But, 1000 cm^3 = 1000ml :. 1972.13 cm^3 = 1972.13 ml. Recall: 1000 ml = 1 liter

$$:.\ 1972.13\ ml = \frac{1972.13\ ml \text{ x } 1\ liter}{1000\ ml} = 1.97\ litres \approx 2\ litres$$

Therefore, at any given time, the maximum amount of cooling water the condenser can contain is 2 litres. This makes room for the effective cooling of the vapors from the reflux column.

4.5. Hydrometer Sump Calculations

The cover of the sump is a circle with a small ring projection attached to it. The circle is such that all points on it are equidistant from a point in its plane called its center. The circumference of the circle was derived using the formula C = π d and its area is $A = \pi r^2$. The diameter d of the circle is 60mm. C= π x 60 = 188.50 mm, since =60mm, r=d/2. r= 60/2 = 30mm. A=π x 30^2 = π x 900 = 2827.43 mm^2

The hydrometer sump itself is a three-dimensional figure of height 200 mm and radius 30mm. its volume V is equal to πr^2 h and its total surface area is T= 2πr (h+ r). While its curved surface area C=: π r h. V =π x30^2 x 200 =π x 900 x 200 =π x 180000 =565486.68 mm^3

T = 2πx 30 x (200 + 30) = 188.50 x 230 = 43355 mm^2 and,

C = 2 π x 30 x 200 =2π x 6000=37699. 11 mm^2

4.6. Reservoir and Overhead Tank Calculations

Both the reservoir and overhead tank are three-dimensional geometric figures. These cylinders consist of two circular bases of equal area that are in parallel planes, and connected by a lateral surface that intersects the boundary of the bases. Since the line connecting the Centre of the two bases is perpendicular to those bases, these cylinders are right circular cylinders

And can be represented as shown below:

Figure 4.5: Reservoirs and Overhead Tank

As it can be seen from the diagram in the previous page, both the reservoir and overhead tank are of the same dimension with the height, h= 460 mm and radius, r = 155 mm. :. The volume of these containers is $V = \pi\ r^2 h$:. V= π x155^2 x 460 =π x 24025 x 460 = 347193111.21 mm^3

This quantity in litres is 347.19 litres. The lateral surface area of these containers is S = 2 π r h

:. S=2x π x 155 x460 =447991.11 mm^2

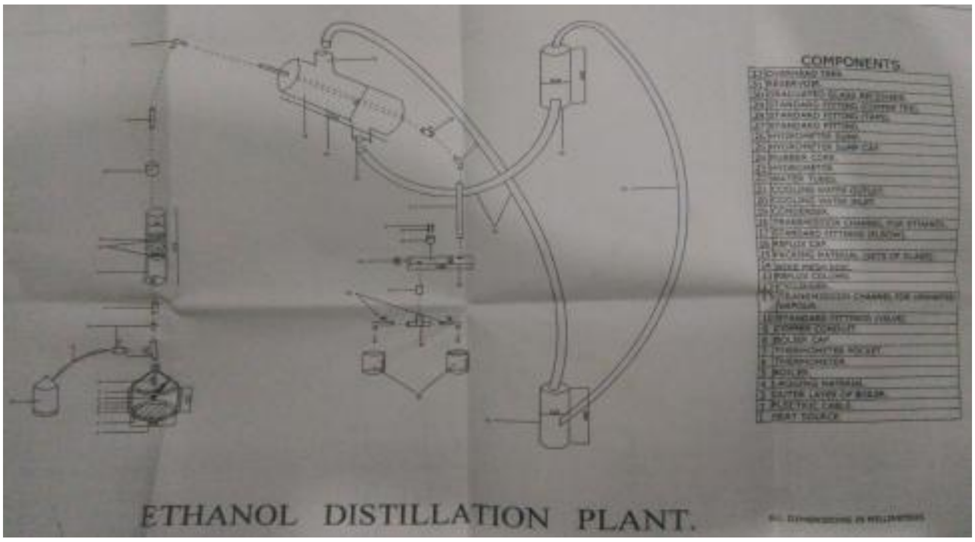
While the total surface area is A= 2π r (r + h)

A = 2 x π x 155 x (155 + 460) = 973.89 x 615 = 598942.35 mm^2

Therefore, this reservoir and overhead tank has the following specifications:

Height = 460mm, Radius = 155mm, Volume =347.19 litres, Lateral surface area =447991.11 mm^2

And Total surface area = 598942.35 mm^2



5. Conclusion

The safety of this plant which includes the physical work environment and the procedures followed in its operation cannot be underestimated. The work environment is controlled to avoid occupational hazards such as chemical, biological and physical hazards. Chemical hazards arise from the presence of poisonous gases and leakages. While source of contamination like bacteria transmitted by unclean equipment gives rise to biological hazards. Common physical hazards include ambient heat, burns and electric shock. In order to eliminate or reduce these hazards so as to have a good working condition, the deign considerations carefully takes care of each limitations identified. Equipment such as safety goggles, face masks, heat or radiant protection suits, boots and gloves are recommended. Effective working conditions are achieved since the protective equipment are appropriate, properly maintained and worn by the worker unlike in the local plants.

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