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Design of Carbon Dioxide Recovery Plant from Wort Fermentation for Preservation of Carbonated Drinks.

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ABSTRACT

This work presents the design of a plant to recover carbon dioxide from wort fermentation for preservation of carbonated drinks. The feed composition data was gotten from International Breweries Port Harcourt (Formally PABOD Breweries Plc) which has 95% CO_2, 4% Ethanol and 1% water. The material and Energy balance, Equipment sizing, costing and simulation was carried with the help of ASPEN HYSYS which gave 99.9% CO_2 purity that conforms with the standard for food beverage industries. The optimal process flow diagram for CO_2 recovery from wort fermentation was determined using HYSYS and this has economic advantage of reduction in the cost of production without adverse impact on the purity of CO_2. The plant designed with ASPEN HYSYS and simulated whose results when compared with manual results gave agreement. The design also involves unit operations (Gas separator, Gas washer, CO_2 Storage tank and stripper) in terms of cost, production rate and profit maximization at given conditions of the various unit operations. Also, material balance for Gas washer, Gas separator and stripper to develop the models for the design parameters for the recovery of CO_2 from wort fermentation was carried out using HYSYS.

KEYWORDS: Wort fermentation, Carbonated drinks, Carbon dioxide, Design, Aspen HYSYS, Costing.

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1. INTRODUCTION

In the production of quality beer, malt and soft drinks, breweries rely on many raw materials including water, barley, hops, yeast and carbon IV Oxide (CO_2). CO_2 has a large influence on not only the product's quality, but also the customer's acceptance of the product. CO_2 treatment, control and dosing are of fundamental importance and should be seen a total concept of which CO_2 Recovery plays a key role. The Installed Brewery capacity is 750 kg CO_2 per hour, designed to produce 1.5 M. hectoliter of beer per Year. The recovery process is composed of three parts: compression and purification processes, stripping and condensing process finally followed by a pressure storage and evaporation of the CO_2 for use in the production. A cooling facility is assisting the CO_2 plant.

Elshani (2018) observed that carbon dioxide does not support combustion and used as fire extinguishers. It reacts with water to produce the process by which CO_2 and alcohol are formed from the conversion of sugar by fermentation. The beer breweries can occur over time which involves many reactions. The breakdown of sugar into alcohol and carbon dioxide, if the quantity of sugar is known the volume of CO_2 that was formed would be known. Carbon dioxide can be compressed and used again for production and the environment is protected with cost saved in production of beer.

Berhanu *et al.* (2017) saccharomyces cerevisiae, isolated from "tella", may be potential strains for beer production. The objective was to isolate, identify and characterize potential yeast isolate from "tella" which can be used as beer yeast. We used biochemical test to identify and isolate "tella" yeast. The physicochemical

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characteristics of beer were determined. The degree of contaminant was analyzed, and six yeast were identified as 51, 52, 53, 54, 55 56, and 57. Yeast viability were analyzed in wort gravity of 12^0p and 14^0p (^{0}P= Degree Plato) and results were found to be 89%. Isolates 51, 53, 54, 55 and 56 grew in 100, 130 and 150 m/l of absolute ethanol. It was observed that the flocculation potential of isolate 53 and 54 were 85% and 82%. Isolates 53 and 54 are higher in concentration of alcohol than the other isolates. Isolates 51, 55 and 56 showed greater original extract than the control. The physicochemical parameters of bear produced from these isolates were compared with those of the commercials.

According to Charles (2008), Energy would be saved and recovered from the improvement required for implementation without effect on plant performance. Wort boiling is the main heat consuming process which means that brewing process involves intensive energy. Graham (2017) asserted that wort fermentation results in the production of products like Ethanol, carbon dioxide and glycerol. These products have little impact on beer and spirit flavor. These components are higher alcohols, ester, carbonyls and Sulphur compound. There are number of factors that can modify the balance which is the results.

According to Abass (2012), the brewing industry uses water and CO_2 for beer production. The technology used had improved over the last 20 years Energy consumption, water consumption; wastewater, solid waste, by-products and emissions to air remain major environmental challenges in the industry. The review was to create awareness of the impact of beer production on the environment and practices to reduce environmental impact.

The works reviewed presented key considerations in design of CO_2 recovery plant except the following:

i. Use of material balance to obtain the design parameters of separator, stripper column, gas separator etc.
ii. Use of energy balance to predict temperature distribution throughout the plant.
iii. The unit operations used for CO_2 recovery plant from wort fermentations in packed column, stripper column and absorber.
iv. The design constitutes the development of models for the functional parameters of packed column, stripper column and absorber.
v. Development of mechanical design for the packed column, stripper column and gas separator for the CO_2 recovery plant.
vi. Computes cost evaluations of the packed column, stripper column and gas separator needed to recover CO_2.
vii. Plant data from existing plant that will enable us computes the values for the functional parameters of the packed column, stripper column, and absorber.
viii. Design the plant using ASPEN HYSYS for simulation process.
ix. The comparisons of both simulation results from ASPEN HYSYS with manual design calculations were to enable standardization of design specifications of gas washer, stripper, and gas separator.

The aim of current study was to design a plant for CO_2 recovery from wort fermentation using the case study of international Breweries, Port Harcourt. The following objectives were carried out in order to achieve this aim:

i. To Study the unit operations and utilities in the plant for the CO_2 recovery from wort fermentation.
ii. The unit operations used to recover CO_2 from wort fermentation ingas washer, stripper and gas separator.
iii. Depict a process diagram and stripper showing all equipment and utilities used in the design and installation done.
iv. Plant data from existing plant that will enable us computes the values for the

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design parameters of the gas absorber, gas washer and stripper.

v. Design the plant using ASPEN HYSYS for simulation process

vi. Development of mechanical design for the gas absorber, gas washer and stripper for the CO_2 recovery from wort fermentation.

vii. The comparisons of both simulation results from ASPEN HYSYS with manual design are to enable standardization of design specifications of gas absorber, separator and stripper for the CO_2 recovery from wort fermentation.

2. Materials and Methods.

2.1 Materials

The materials used for this work includes carbon dioxide, process water (treated water for production), Aspen HYSYS, ammonia gas for cooling, Foam separator, gas balloon, compressor, carbon filter, dehydrator, reboiler, condenser, stripper, carbon dioxide storage tank, evaporator and data from International Breweries Port Harcourt, Rivers State.

2.2 Methods

The design of each units in the plant would use the materials balance principle as stated:

$$\begin{pmatrix} \text{Rate of accumulation of} \\ \text{material within the unit} \\ \text{operation} \end{pmatrix} = \begin{pmatrix} \text{Rate of inflow of} \\ \text{materials into the unit} \\ \text{operation} \end{pmatrix} - \begin{pmatrix} \text{rate of outflow} \\ \text{of materials from} \\ \text{unit operation} \end{pmatrix} \pm \begin{pmatrix} \text{Rate of deplection/generation of} \\ \text{materials due to chemical} \\ \text{reaction} \end{pmatrix} \quad (1)$$

The production of carbon dioxide from starch or sugar by oxidation can be represented by the equation.

$$C_6H_{12}O_6 \xrightarrow{\text{Yeast}} 2C_2H_5OH + 2CO_2 + \text{Heat Energy} \quad (2)$$

The carbon dioxide formed as a by- product of the main and additional fermentation of beer. CO_2 can be compressed and as such should be reused in the production.

2.3 Process Description

Figure 1 shows CO_2 recovered from wort fermentation and with a small overpressure it reaches the recovery plant first arriving in the foam trap which discards possible visible gas impurities such as foam generated during fermentation. Water soluble impurities (mainly alcohol) are removed in the water scrubber and the CO_2 is lead to the balloon as a buffer supplying the following two-step-compressors containing inter- and after cooler and dehumidifier. Here the CO_2 has reached a relatively high pressure close to 20bar. After the compression odours are removed in the carbon filters followed by drying the CO_2 to a dew point of -60C in the dehydrator. The carbon filters and dehydrators are regenerated by an electric heating element and by CO_2 purge gas or air.

The Stripping and liquefaction process ensure Purified CO_2 enters the reboiler for the stripping column in which it is precooled before liquefaction in the CO_2 condenser at temperature down to -25°C. Here the CO_2 is condensed to the reflux tank and inert gas is separated and discharged to the surroundings. Liquid CO_2 is pumped to the top of the stripping column, where further reduction of oxygen and inert gas is obtained. From the bottom of the column liquid CO_2 is partly pumped to the storage tank and partly circulated through the reboiler which heats the column and herby ensure continuous evaporation. For the simplest plant setup, the CO_2 is finally led through a steam heated evaporator before entering the production site, which means that the cooling potential is not utilized due to time constraints

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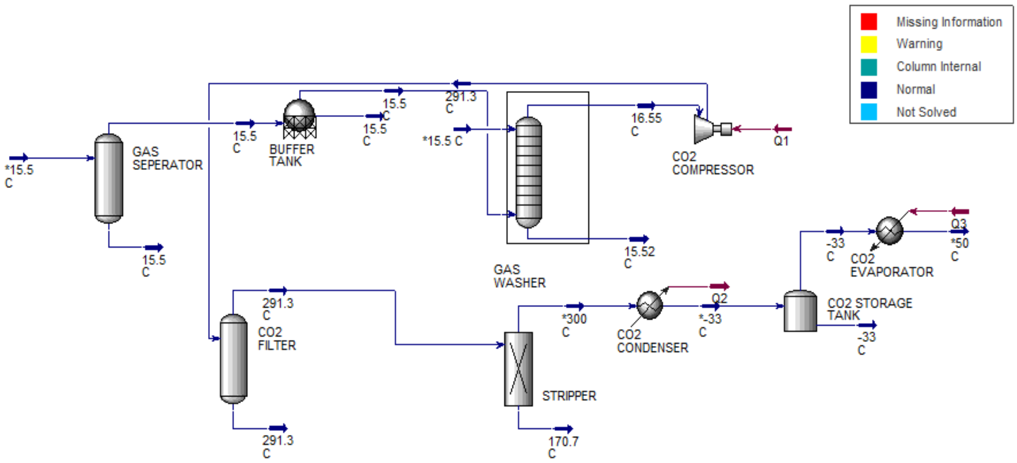

Figure 1: Process Flow Diagram of CO_2 Recovery Plant from Wort Fermentation

Table 1: Data from International Breweries

Parameters	Values
Feed Flowrate	1000kg/hr
CO_2	0.95
H_2O	0.01
C_2H_5OH	0.04
Fermentation Temperature	15.5 degree Celsius
Brew Length	365 Hectoliters
Unit tank Capacity	2555 Hectoliters (7 brews per Unit tank)
Annual Production capacity	1.5 million Hectoliters per Annum
CO_2 usage rate	8 Tons per day
CO_2 usage per Can/Bottle	2.5 - 2.7 v/v

3. Results and Discussion

3.1 Material Balance

Table 2 below shows the composition of material components balance for CO_2 recovery plant from wort fermentation at each stage. The feed composition as obtained from International Breweries Port Harcourt enters the Gas separator with 95% CO_2, 4% Ethanol and 1% water, the gas separator removes some of the impurities mostly in form of foam to concentrate carbon IV oxide giving output of 97.4% CO_2, 0.9% Ethanol and 1.65 water while the rest of the insignificant percentage composition are sent to drain.

The output from the Gas separator enters the Gas Washer and water is introduced from an external storage vessel to take out some left-over impurities from gas separator and the water goes to drain leaving 97.9% CO_2, 0.005% Ethanol and 2.0% water as output from gas washer.

The output from the gas washer becomes the input to the CO_2 activated carbon filter, after the components passed through the filter, the CO_2 became more concentrated with 99.97% CO_2, 0.0055% Ethanol and 0.0016% water.

The output of the filter enters the last stage of the purification process, the stripper where it is more purified to 99.999% CO_2 and this is the standard required CO_2 purity for food and beverage industries.

Table 2: Result of the Material Balance from HYSYS

Equipment	Parameters	Feed composition	Output Composition	Drain Composition
Gas Separator	CO_2	0.95	0.974104	0.000797
	Ethanol	0.04	0.009166	0.04833
	H_2O	0.01	0.01673	0.95637
Gas Washer	CO_2	0.974104	0.979617	0.000708
	Ethanol	0.009166	0.000005	0.013096
	H_2O	0.01673	0.020378	0.986196
CO_2 Filter	CO_2	0.979617	0.9997848	0
	Ethanol	0.000005	0.0000055	1
	H_2O	0.020378	0.0000166	0
Stripper	CO_2	0.9997848	0.99997	0.082069
	Ethanol	0.0000055	0.000004	0.006759
	H_2O	0.0000166	0.000026	0.911172

3.2 Energy Balance for the CO_2 Recovery from Wort Fermentation

Table 3 below shows the energy requirement of the CO_2 Recovery plant from wort fermentation. The heat flow as obtained from HYSYS show that the CO_2 evaporator requires the highest energy for operation with heat flow of 903356.8KJ/HR while CO_2 compressor requires the least with heat flow of 346510KJ/HR and the values conforms with standard when compared from literature.

The CO_2 compressor compresses the low-pressure CO_2 to approximately 18 bar as the pressure will be needed in the condenser-to-condenser CO_2 to -30 degree Celsius to -40 degree Celsius. The compression can be done in two stages base on the capacity of the plant, but we are only implementing one stage compression. For two stage compressors, a cooler is installed to remove heat of compression after each stage to avoid damage to the next compression stage.

The CO_2 evaporator double functions as a heat exchanger where at each part of the heat exchanger CO_2 is liquified and the other side CO_2 is evaporated. Liquid CO_2 from the storage tank is evaporated for use at the brewery or other consumers.

After the change of the packing type from Packed to trayed column, the Gas washer height reduced from 17.53 meters to 5.091 meters, diameter of 3.20 to 1.067 meters and Area of 8.044 to 0.8938 meters. CO_2 storage tank Height also reduced from 5.12 meters to 2.438 meters indicating that the equipment can be installed and maintained.

This change gave rise to the final Process Flow Diagram for effective CO_2 recovery with two CO_2 storage tanks for flexibility as one cannot recover and use from the same tank at the same time. The summary of the specifications per equipment is presented in the sections that follows.

3.3 Equipment Design Specification for CO_2 Recovery Plant from Wort Fermentation

The tables below show the design specifications for the equipment used in the recovery of CO_2 from wort fermentation, it started with specification for Gas Separator followed by Gas Washer, CO_2 filter, CO_2 stripper, CO_2 compressor, CO_2 condenser and CO_2 evaporator where the specifications are tabulated, and major function of each equipment stated.

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Table 3: Results of the Energy Balance of the above equipment

Equipment	Heat Flow value kJ/hr
CO_2 Compressor	3465140
CO_2 Condenser	4137366
CO_2 Evaporator	903356.8

Table 4: HYSYS Equipment sizing for CO_2 Recovery Plant from wort fermentation Using Trayed Column

Equipment	Diameter (m)	Height (m)	Area (m^2)
Gas Washer	1.067	5.098	0.8938
Gas Separator	3.962	6.142	1.050
CO_2 Storage tank	1.219	2.438	1.500

Table 5: Design Specification for Gas Separator

Gas Separator		
Column type	Trayed column	
Function	Separates CO_2 from foam and other impurities from wort fermentation to protect downstream system from pollution	
Medium	CO_2 gas	
Material Composition	**Inlet**	**Output**
CO_2	0.95	0.974104
Ethanol	0.04	0.009166
Water	0.01	0.01673
Operating Conditions		
Pressure	Min, 0 bar and Max 0.49 bar	
Temperature	Min, 5^0C and Max 80^0C	
Design Parameter		
Diameter	3.962 meters	
Height	6.142 meters	
Material	Stainless steel	
Power source	Electricity	
Purchase cost	18,400 USD	
Total direct cost	120,200 USD	

3.4 Equipment Design Specification for Gas Separator

Table 5. shows the design specification of Gas separator used in the recovery of CO_2 plant from wort fermentation. The Gas separator removes foam and other impurities from wort fermentation to protect downstream system from pollution. Trayed column was used, and medium is CO_2. CO_2 enters the column at 95% purity and leaves at 97.4% purity with water and ethanol going to drain. The maximum operational pressure of the equipment is estimated at 0.49 bar and maximum temperature of 80 degrees Celsius.

3.5 Equipment Design Specification for Gas Washer

Table 6 the design specification of Gas Washer used in the recovery of CO_2 plant from wort fermentation. The Gas washer uses water as medium to wash out soluble impurities out of the CO_2 gas. There is slight significant change in purity of the CO_2 at the output, the CO_2 enters at purity of 97.4% and leaves at purity of 97.9%. the equipment uses electricity as source of power and minimum operating pressure and temperature is as stated in Table 6.

3.6 Equipment Design Specification for CO_2 Filter

Table 7 shows the design specification of CO_2 Filter used in the recovery of CO_2 plant from wort fermentation. The CO_2 Filter removes the odours and not in water soluble impurities out of the CO_2 gas. It operates at pressure range of 16 to 20 bars and uses electricity as source of power with stainless steel as material of construction. The table below summarizes the input, output, diameter and height of the column.

Table 6: Design Specification for Gas Washer

Gas Washer		
Column type	Trayed column	
Function	To wash out soluble impurities out of the CO_2 gas	
Medium	CO_2 gas	
Material Composition	**Inlet**	**Output**
CO_2	0.974104	0.979617
Ethanol	0.009166	0.000005
Water	0.01673	0.020378
Operating Conditions		
Pressure	Min, -0.005 bar and Max, 0.015 bar	
Temperature	Min, 10^0C and Max 20^0C	
Design Parameter		
Diameter	1.067 meters	
Height	5.098 meters	
Material	Stainless steel	
Power source	Electricity	
Purchase cost	70,600 USD	
Total direct cost	231,200 USD	

3.7 Equipment Design Specification for CO_2 Stripper

Table 8 shows the design specification of CO_2Stripper used in the recovery of CO_2 plant from wort fermentation. The equipment stripes non-condensable gas from liquid CO_2 to purity of 99.99%. The column is constructed with stainless steel and is the final stage of the purification in the CO_2 recovery process.

3.8 Equipment Design Specification for CO_2 Compressor

Table 9 below shows the design specification of CO_2 Compressor used in the recovery of CO_2 plant from wort fermentation. This equipment made of carbon steel compress CO_2 free of foam, sugar and liquid of 90-100% purity. The inlet as well as the outlet flow rate is 980kg/hr. The power consumed by the equipment is 3465140KJ/HR, uses electricity as sources of power and observes 10 cycle stages. The table below summarizes the pressure and temperature demand of the equipment among other things.

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Table 7: Design Specification for CO_2 Filter

CO_2 Filter (Activated Carbon Filter)		
Column type	Trayed column	
Function	To filter out odors and not in water soluble impurities out of the CO_2 gas	
Medium	CO_2 gas	
Material Composition	**Inlet**	**Output**
CO_2	0.979617	0.99997848
Ethanol	0.000005	0.0000055
Water	0.020378	0.0000166
Operating Conditions		
Pressure	Min, 16 bar and Max, 20 bar	
Temperature	Min, 12^0C and Max, -40^0C	
Design Parameter		
Diameter	1.2001 meters	
Height	2.0134 meters	
Material	Stainless steel	
Power source	Electricity	
Purchase cost	17,000 USD	
Total direct cost	103,300 USD	

Table 8: Design Specification for CO_2 Stripper

CO_2 Stripper		
Column type	Trayed column	
Function	Stripping impurities (Non-condensable gas) from liquid CO_2 to purity of 99.99%	
Medium	CO_2 gas	
Material Composition	**Inlet**	**Output**
CO_2	0.9997848	0.99997
Ethanol	0.0000055	0.000004
Water	0.0000166	0.000026
Operating Conditions		
Pressure	Min, 16 bar and Max, 30 bar	
Temperature	Min, 12^0C and Max -40^0C	
Design Parameter		
Diameter	1.2001 meters	
Height	2.0134 meters	
Material	Stainless steel	
Power source	Electricity	
Purchase cost	17,000 USD	
Total direct cost	103,800 USD	

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4. CONCLUSION

The design of CO_2 recovery plant from wort fermentation using HYSYS proved that food grade CO_2 of 99.9% purity can be achieved as shown in preceding section. Results from the material balance shows significant improvement of the CO_2 as it passes through each unit of the process flow at the required temperature and pressure. The equipment design specification indicates that gas separator with 6.142 meters height is the equipment with highest height to be installed and others are within the range of 2-3 meters height. However, the CO_2 recovered from this project can be commercialized to generate more revenue for the company.

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