Design of Mechanically Agitated Fermenter for a Daily Ten Tons Ethanol Production from Cool-Feed Biomass

Fredrick B. Ugi, Benedict U. Ugi, and Gloria T.Tamunotonye

Abstract−This research designed a mechanically agitated fermenter that operates with the principles of heat exchanger, sustaining fermentation process in a conducive thermodynamic state which promotes product (ethanol) yield as well as its concentration (purity), with a target of achieving 10 tons per day ethanol from cool-feed biomass (palm wine). The design shows that the target was achieved at the fermenter vessel Area (A_0) of 15.5917 m^2 with the use of 1271.1646 kg/day coolant (water), operating at a conservative heat flow of 505262.484 J/day. MATLAB simulation was used to access the dynamic behavior of the agitated fermenter over a range of biomass and time. From the developed models, the result showed that the reaction rate of fermentation ((dC_L)/dt) was proportional to the overall mass transfer coefficient per unit volume of the biomass (K_L a) measured in per hours of the fermentation (hr^{-1}). This can be due to decrease in the feed mass of a fermenter due to biomass decay which increases the oxygen penetrability of the system. Decrease in the fermenter material (biomass) due to biomass decay was also observed. This implies promotion of the fermentation rate of the system as the rate of biomass fermentation ((dC_L)/dt) decreases with increase in feed value of biomass. The residence time of the system was also reduced which implies that there was an increase in the fermentation rate of the biomass hence, promoting satisfactory product yield and purity which is one of the target of this research.

Keywords− Fermentation, Ethanol, cool-feed, biomass, heat transfer

NOMENCLATURE

Authors might use unnumbered section to include the whole of abbreviations appeared in the manuscript. This section must be included before the Introduction. The abbreviations should be included as follows:

pH	Hydrogen Ion Concentration.
TDS	Total Dissolved Solids.
COD	Chemical Oxygen Demand.
BOD	Biochemical Oxygen Demand.
LTS	Low Temperature Steam..
LMTD	Logarithmic Mean Temperature.

I. INTRODUCTION

With increasing demands for GHG emission-free energy sources and ethanol (higher purity) having the ability to meet such demands, fermenters are being designed and researched mostly by various scientists and specialists [1-3] Fermenters have been known for their tremendous abilities of converting sugary substances into chemical products such as ethanol through microorganism interactions with biomass over periods of time [1-2] This has made fermentation a step to meet the demands for high-purity ethanol. Fermentation is classified among the oldest biotechnology processes, mostly applied in the food and medical processing industries. It is based on the application of biological enzymes (microorganisms') interactive abilities on organic matters to alcohol production from sugary substances [3]. Fermentation is a metabolic activity that takes place in starchy-like organic substances such as sugar or carbohydrates, converting them into economically important organic products like acids, gases, and alcohols by microbial activities over a period of time, either aerobically or anaerobically [1,3-5] . This process is carried out in an equipment known as a bioreactor or, more easily, a "fermenter", which provides a suitable and well-controlled environment for the growth of microorganisms or animal cells, aiming at obtaining these desirable products from sugar-active substances [5-6] In a fermenter, sterile nutrients and pure cultured microorganisms are mixed and left for the fermentation process to occur under aseptic and optimum conditions like pH, temperature, oxygen, etc. Fermentation takes place either as a batch, fed-batch, or continuous bioprocess [6-8]. Ethanol happened to be one of the most vital products obtained from fermentation all over the years, even as far back as the ancient centuries of man. Ethanol is a very important chemical (colorless and water-soluble with a boiling point of 78.37^o C) used for multi purposes such as alcoholic drink production, drugs, preservatives, organic solvents, and even as biofuel for automobile engines when of high purity [7-10]. The production of high purity level ethanol capable of use as fuel has kept researchers looking for means of attaining such a height of industrial requirements for a GHG-free energy source, and this high purity level ethanol is subject to the distillation temperature of the separating process from water, which is always known to be present with ethanol obtained from organic means. Ethanol with a boiling point of 78.37 ^{o}C has always been a headache to separate from water, whose boiling point tends to be nearer to that of the ethanol,

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catching the great interest of researchers all over the world [8-10]. So designing a fermenter that will aid the microbial growth in favor of the fast and satisfactory fermentation of bio-mass to generate high-purity ethanol at considerable temperature and other process variables or conditions is a great step towards a GHG-free automobile energy source. An effective fermenter provides a positive influence on the biological reaction and prevents foreign contamination [9-10] reported that the fermentation process requires proper mixing and monoseptic conditions to promote uniform shear rates. Aseptic environment is a well-defined defense means against unwanted microorganisms and contaminants of fermentation. This aseptic environment also prevents the escape of mixable cells from the process [3-6] . A higher degree of control over contamination should always be a considerable factor when designing fermenters for the sake of favorable product yield [9]. The design of the fermenter and its mode of operation depend greatly upon microorganisms' activities and interactions with biomass during the production process of ethanol. A good fermenter needs to have control over the pH, temperature, and oxygen tension of the system, as well as allow septic process operations, which are essential not only for control but also for future routine manufacturing [11] was able to design a batch-stirred bioreactor for ethanol production that uses yeast Saccharomyces cerevisiae as enzymes to improve the fermentation's performance. However, the fermenter designed had a fermentation time of 11.4 hrs with ethanol stripping of 69.1g and 12 hrs for 75.9g without stripping. The kinetic constants were 2.0kg, 97.9 kg, and 0.476 h, respectively. But the design was limited to only batch stirred bioreactors using yeast, and it is also a closed system culture technique. This work designs a mechanically agitated fermenter using heat transfer principles for the production of 10 tons per day of ethanol from cool feed. Biomass neglects the enzyme type as one of the major design criteria, making the design unique for all types of fermentation processes.

II. MATERIAL AND METHODS

A. Figures

Some of the materials used in this work were mainly to determine concentration before and after fermentation, with some other operating conditions such as pH and Temperature. These materials include;

- Palm wine
- Enzyme
- pH meter
- Thermocouple..

B. Design Methods

In this current research work, the basic methods used to ensure effectiveness of this research range from development of models using material and energy balances (considering thermodynamic constraints of the process and state variables required for the efficacy of the system), Numerical differential and integral method of solving, Data gathering via analytical method and Simulation validation methods using MATLAB-Simulink

C. Modeling Assumptions

These includes Steady-state operating condition, use of anaerobic (closed) system to ensure contamination free operation, negligible shaft work condition , adiabatic conditions, augmentation steam temperature of system which must not exceed 423k (⟦150⟧^o C), bottom jacket sidewalls fermenter for common hydrofoils, design is done with features supportive to process control over range of process variables, application of cylindrical traditional design techniques, use of mild steel for vessel surface design to reduce corrosion effects, the fermenter is made to have an external cooling jacket, to regulate / control the system temperature as shell side of a heating vessel., Due to the operation temperature and presents volatile compounds, the design is made considering the use of a sterilizable condenser required to prevent evaporation loss and to promote safety reasons.

D. Project Description

This work is based on the understanding that fermentation process involves the interactions of microorganisms with sugary biomass over a period of time, and these microorganisms exist in different forms and different properties. Some prokaryotic and others eukaryotic in nature, there metabolic pathways are with regards to their existence within surrounding factors which includes temperature, oxygen, moisture content, pH, Total Dissolved Solids (TDS), Chemical Oxygen Demand (COD) as well as their Biochemical Oxygen Demand (BOD), etc. Temperature is of great interest on this studies of obtaining pure ethanol, the purity and yield of ethanol from fermentation is subject to the temperature of the system. Hence some microorganisms in a fermentation system as shown in Figure 1 are mesophilic, some thermophilic and others Super thermophilic. This fermenter is designed to suit the existence of all the three types of fermentation favoring bacteria's via subjecting the fermenter to operate with a temperature range of T_f=298k=⟦25⟧^o C to T_s=423k=⟦150⟧^o C using a cooling jacket system which works with respect to the fundamental principles of shell and tube heat exchangers.

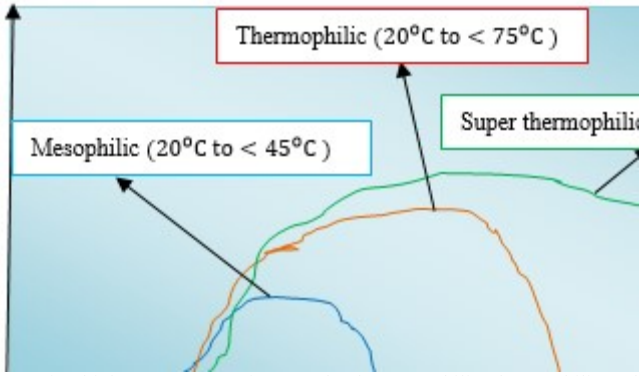

Fig. 1: Microbial temperature existence plot for Mesophilic, thermophilic and Super-thermophilic micro-organisms

Hence the feed used in this system (palm-wine) is a cool-feed, entering the fermenter at temperature below active operating microbial fermentation temperature range, the low temperature steam (LTS) is being injected with the feed to raise the system to instant fermentation, the feed is augmented using low temperature steam. The system designed also contains a cooling jacket carrying ambient water, used to control the heat duty / temperature of the system within the fermentation period.

E. Equipment (Agitated Fermenter) Design Calculations

The design of the agitated fermenter as done in this work applies the usage of step wise hand determination of some of the results as well as a dynamical simulation of the system

using MATLAB to access the system behavior over change in time and other process conditions such as feed mass.
Considering the fermenter system as stated;

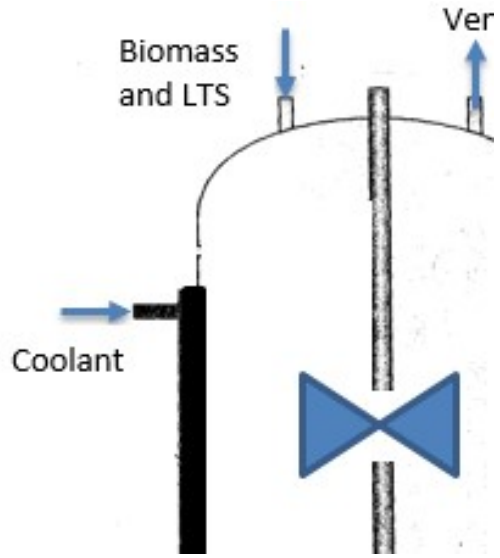

Fig. 2: Diagram of a Bottom Jacket agitated fermenter for microbial biomass production

F. Fermenter Material Balance

In every fermenter, there are specified enzymatic biochemical reactions taking place, leading to generation of diverse products, but in this design, the reaction favorable towards ethanol production from the biomass (palm wine) is considered for the fermenter, schematically describe as follows;

$$C_2H_5OH + Enzymes\ (\text{Yeast}) \xrightarrow[\text{Fementation}]{\text{Steam}} CH_3COOH + H_2O$$

Considering the 1st order chemical reaction with enzyme (yeast) describe as;

$$A + Enzymes \xrightarrow{k_1} \text{Produ}$$

Taking the material balance of the system (fermenter) as;

$$\left\{\begin{matrix}\text{total inpute rate}\\ of\ Biomass\\ fed\ into\ the\ fermenter\end{matrix}\right\} - \left\{\begin{matrix}\text{total output rate}\\ of\ Biomass\\ after\ fermentation\end{matrix}\right\} - \{r_A\}V_R = \left\{\begin{matrix}\text{accumulation}\\ in\ the\\ fermenter\end{matrix}\right\} \quad (1)$$

Where;
$-\{r_A\}$ =the consumption rate of substrate A in mol*l^{-1}s^{-1}

$$= k_1 C_{A,1} \quad (2)$$

Taken the reaction rate constant (K_1) of the fermentation to be of equivalent to the Overall mass transfer coefficient per unit volume biomass (K_La) measured in per hours of fermentation (hr^{-1})

$$\therefore -\{r_A\} = K_La(C^* - C_L) = OTR \quad (3)$$

$$K_La = \frac{\text{Amount of reactant}}{L \times t} \quad (4)$$

Hence the production is per day;

$$t = 24 \times 60 \times 60 = 86400\ \text{sec}$$

$$\therefore K_La = \frac{n}{86400L}$$

Considering the system operating at steady state;

$$V_oC_{A,o} - V_oC_{A,1} + K_La(C^* - C_L)V_R = 0 \quad (5)$$

So;

$$V_R = \frac{V_oC_{A,1} - V_oC_{A,o}}{K_La(C^* - C_L)} \quad (6)$$

Determining the time of the fermenting:

$$\tau = \frac{V_R}{V_o} = \frac{C_{A,1} - C_{A,o}}{K_La(C^* - C_L)} \quad (7)$$

G. Heat Balance of Agitated Fermenter

Hence the fermenter designed is a thermal subjective type, the biomass is been feed co-currently with low temperature steam ($\leq 70^oC$) into the fermenter, the essence of the lower temperate steam is to is to augment the microbial actions of the system, promoting fact enzymatic and biochemical reactions in the system, helping the process speedy start up actions, for better yielding. While the cooling jacket carrying cooling fluid is used to restrict the temperature from exceeding 105°C during the process period. This will enable the safe operations of the mesophilic, thermophilic and super thermophilic organisms that are needed for favorable fermentation of the biomass. During fermentation, temperature of the system may likely increases, so the cooling water is to control the system temperature so as to fall along the favorable range as desired by the microbes. So the heat or temperature of operation needs to be of great consideration for the design [12-14].
So taking the system energy balance is as follows:

$$\left[\frac{\text{Accumulation of heat system}}{\text{Time}}\right] = \left[\begin{matrix}\text{Rate of total}\\ \text{input of heat}\end{matrix}\right] - \left[\begin{matrix}\text{Rate of tatol output}\\ \text{of heat}\end{matrix}\right] + \left[\begin{matrix}\text{heat released}\\ \text{to environment}\end{matrix}\right] - \left[\begin{matrix}\text{shaft}\\ \text{work}\end{matrix}\right] \quad (8)$$

Defining each unit of equation (8) gives:

$$dH/dt = Q_{in} - Q_{out} + Q + W \quad (9)$$

At negligible shaft work conditions;

$$\therefore dH/dt = Q_{in} - Q_{out} + Q \quad (10)$$

At adiabatic conditions

$$Q_{in} = Q_{out} \quad (11)$$

Hence equation (10) becomes

$$dH/dt = Q \quad (12)$$

$$dH/dt = Q = mcp\Delta T \quad (13)$$

$$\therefore Q = mcpz \quad \textbf{(13b)}$$

Assuming the tube content will be ethanol and the coolant will be more viscous to the ethanol, so the tube will bear the biomass which produces the ethanol while the shell will carry the coolant

For the tube side;

$$Q_{tube} = m_t C_{p,t} dT \quad \textbf{(14)}$$

The tube holds the biomass and the augmentation steam, hence at a co-current flow of the coolant to the fermenter feed at steam injection bases, equation (14) above becomes:

$$= \frac{(m_{feed}+m_{steam})(Cp_{feed}+Cp_{steam})(T_f+T_s)-2T_2}{8} \quad \textbf{(15)}$$

Hence operating the reactor with parametric values, calculated to match efficiency of the fermenter with capacity of 10 tons/day;

$$M_{feed} = 10 \text{ Tons/day}$$

$$\text{If: } m_{feed} = M_{feed} \times 1000 = \frac{10{,}000\text{kg}}{\text{day}} \quad \textbf{(16)}$$

Taking the steam mass flow rate to be;

$$m_{steam} = 238 \text{ Tons/day}$$

Considering Ethanol as the substance (product) of the fermentation;

$$Cp_{feed} = C_{p_{biomass}} = 2.5\text{kj/kgK}$$

$$C_{p,steam} = 1.996\text{kj/kgK}$$

$$T_f = 298\text{k} = 25^oC$$

$$T_s = 423\text{k} = 150^oC \text{ (perry's et al 7th edition)}$$

$$T_2 = 213\text{k}$$

$$\therefore Q_{tube} = \frac{(10000-232)(2.57-1.996)(298+423)-2(213)}{8}$$
$$= 505262.484 \text{ J/day}$$

For the shell section;
Considering a heat conservative system:

$$Q_{shell} = Q_{tube} \quad \textbf{(17)}$$

$$\therefore Q_{shell} = m_s C_{p_s} \Delta T = m_s C_{p_s}(T_2 - T_1) \text{ of water using water as coolant} \quad \textbf{(18)}$$

$$505262.484 \text{ J/s} = m_s \times 4.18(383-288)$$

$$\therefore m_s = \frac{505262.484}{4.184 \times (T_2 = 383 - T_1 = 288)}$$

$$= 1271.1646\text{kg/day}$$

$$\therefore m_s = \text{mass flow rate of coolant (water)} = 1271.1646\text{kg/day of coolent (water)}$$

Hence, determining the system logarithmic mean temperature (LMTD), from the above equations we have:

$$\text{LMTD} = \frac{T_F+T_s-2T_2-2t_1+2t_2}{2\text{In}\left[\frac{T_F+T_s-2T_2}{2t_1+2t_2}\right]} \quad \textbf{(19)}$$
$$= \frac{298+423-2(213)-2(288)+2(383)}{2\text{In}\left[\frac{298+423-2(213)}{-2(285)+2(383)}\right]}$$
$$= \frac{485}{2\text{In}\left(\frac{295}{196}\right)} = \frac{485}{2(0.4089)}$$
$$= 593.0545\text{K}$$

$$\text{If: } \Delta T_m = F_t \times \text{LMTD} \quad \textbf{(20)}$$

$$\text{Where: } \sqrt{\frac{\left(\frac{\partial_t}{\partial_i}\right)^*\left(\frac{H_2}{\partial_2}\right)^*}{\left(\frac{\partial_t}{\partial_i}\right)\left(\frac{H_2}{\partial_i}\right)}} = F_t \quad \textbf{(21)}$$

$$F_t = \sqrt{\frac{\left(4/1.3\right)\left(7.5/1.3\right)}{\left(5.5/2.3\right)\left(8.5/2.3\right)}}$$
$$= \sqrt{\frac{17.7515}{8.8374}}$$
$$= 1.4173$$

Where;

$d_t = 5.5,\ d_i = 2.3,\ H_2 = 8.5,\ d_t^* = 4.0,\ D_i^* = 41.3$ and $H_L^* = 7.5$

$$\therefore \Delta T_m = F_t \times \text{LMTD}$$
$$= 1.4173 \times 593.0545$$
$$= 840.5235\text{K}$$

Hence the fermenter tube will be the bearer of the biomass to generate ethanol, the design will focus more on the tube, considering the dimensionless values of the system as follows;

Taken;
Tube specific heat capacity = $C_{p_{ethanol}} = 2.5$ kj/kgK
Tube internal diameter = di = 4.58m
Tube outside diameter = do = 7.5m
Ethanol thermal conductivity = $K_t = 0.519\ w/m^oC$
Tube side dynamic viscosity = $\mu = 8.90 \times 10^{-3}$mNs/m^2
Tube side density = $\rho = 1026.6636$ kg/m^3= feed (biomass) density

$$\text{Tube side velocity} = u = \frac{mass\ velocity\ (G')}{tube\ side\ density\ (\rho)} \quad \textbf{(22)}$$

$$= 8.1523\ m/day$$

i. $$\text{Prandtlnumber: } P_r = \frac{C_p \mu}{K_t} \quad \textbf{(23)}$$

$$= \frac{(2.5 \times 10^3) \times (8.90 \times 10^{-3})}{0.519}$$
$$= 4.29$$

ii. $$\text{Reynolds number: } R_e = \frac{\rho d_i u}{\mu} \quad \textbf{(24)}$$

$$\therefore R_e = \frac{8.1523 \times 4.58 \times 1026.6636}{8.90 \times 10^{-3}}$$

$$= 4.307088 \times 10^6$$

H. Determining the heat Transfer Coefficient of the Fermenter (h):

Hence the calculated Reynolds number (R_e) is greater than 2100, the heat transfer coefficient will be;

$h_o = j_{h,s}\frac{K_s}{d_i}R_eP_r^{0.33}\left[\frac{\mu}{\mu_w}\right]^{0.14}$ = shell side fluid heat coefficient **(25)**

$h_i = j_{h,t}\frac{K_t}{d_i}R_eP_r^{0.33}\left[\frac{\mu}{\mu_w}\right]^{0.14}$ =Tube side fluid heat coefficient **(26)**

Where:

$j_{h,t}$ = Heat transfer factor for the tube side

$j_{h,s}$ = Heat transfer factor for the shell side

μ_w = Tube side viscosity at tube temperature

Neglecting the viscosity correction term, the equations for heat transfer coefficient becomes;

$$h_o = j_{h,s}\frac{K_s}{d_i}R_eP_r^{0.33} \quad \textbf{(27)}$$

$$h_i = j_{h,t}\frac{K_t}{d_i}R_eP_r^{0.33} \quad \textbf{(28)}$$

For the tube, using the calculated Reynolds number (R_e), from the Figure 3 plot, $j_{h,t}$ is 2.1×10^{-3}

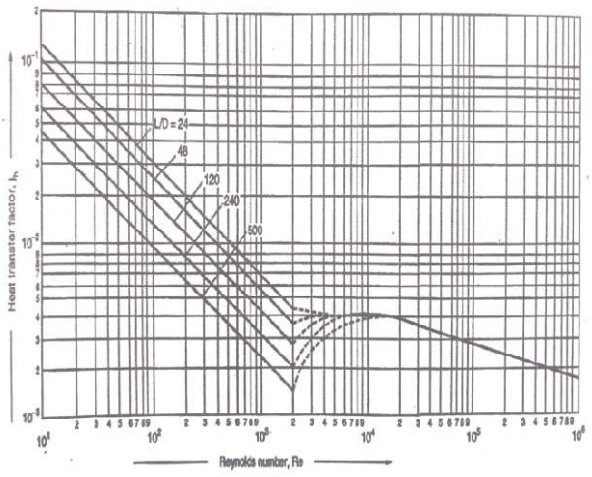

Fig. 3: Heat transfer plot on Reynold number bases

So;

$$h_i = j_{h,t}\frac{K_t}{d_i}R_eP_r^{0.33}$$
$$= (2.1 \times 10^{-3})\left(\frac{0.519}{4.58}\right)(4.307088 \times 10^6)(4.29)^{0.33} = 1657.3561 w/m^2K$$

I. Determining the Overall heat transfer coefficient of the Fermenter (Uo):

$$\frac{1}{U_o} = \frac{1}{h_s} + \frac{1}{f_s} + \frac{d_o \ln\left(\frac{d_o}{d_i}\right)}{2K_m} + \frac{d_o}{d_i f_i} + \frac{d_o}{d_i h_i} \quad \textbf{(29)}$$

Where**:**

f_i and f_s = Tube and shell side fouling coefficient or factor

Considering ethanol been a lighter hydrocarbon and the water been used as the coolant, the tube side fouling factor will be $f_i = 5000\, w/m^oC$ while that of the shell side will be $f_s = 3000\, w/m^oC$, also using copper with thermal conductivity of $K_m = 80 w/m^oC$

So Overall heat transfer will be,

$$\frac{1}{U_o} = \frac{1}{h_s} + \frac{1}{3000} + \frac{(7.5) \times \ln\left(\frac{7.5}{4.58}\right)}{2 \times 80} + \frac{7.5}{4.58 \times 5000} + \frac{7.5}{4.58 \times 1657.3561}$$

Assume $h_s = 855\, w/m^2K$

$$\therefore U_o = 38.5543\, wm^2K$$

Determining the Fermenter Area (A_o)

$$A_o = \frac{Q_s}{U_o \Delta T_m} \quad \textbf{(30)}$$

$$= \frac{505262}{38.5543 \times 840.5232} = 15.5917 m^2$$

Determining the system heat duty (Q_{Duty}):

$$Q_{Duty} = UA_o\Delta T_m \textbf{(31)}$$

Fermenter Diameter (D_R):

$$D_R = \frac{V_R}{A_o} \textbf{(32)}$$
$$= \frac{V_oC_{A,1} - V_oC_{A,o}}{A_oK_La(C^* - C_L)}$$

Fermenter Length (L):

$$L = \frac{Q}{U_o \pi D_R \Delta Tm} \quad \textbf{(33)}$$

Height of the fermenter:

$$h = \frac{4V_R}{\pi \emptyset^2} \quad \textbf{(34)}$$

Where;

$\emptyset$ = diameter of the sparger base plate

Number of stirring blades:

$$n = \frac{h}{\text{Aspect ratio of the famenter} \times \text{radius of the fermenter}} \quad \textbf{(35)}$$

$$= \frac{h}{3r} \quad \textbf{(36)}$$

Impellers spacing:

$$S = \frac{h}{2n} \quad \textbf{(37)}$$

Determining the wall/vessel thickness:

$$T = e + \text{corrosion allaawance} \textbf{(38)}$$
$$= \frac{Pd_i}{2SE - P} + C(\text{ASME code}) \quad \textbf{(39)}$$

$$\text{thickness} = \frac{1 \times 0.46}{(2 \times 5 \times 1) - 1} + 2$$
$$= 2.05\text{cm}$$

Where;

P = Operating pressure

d_i = External diameter

S = Design stress

E = Welding joint efficiency

C =Corrosion clearance

J. Costing of Fermenter Design

Given that a fermenter has the following factors;

Material of design = stainless steel

Reactor diameter = 4.6m

Operating pressure = 1 bar/1 atm

Impellers spacing = 5n/m

Bioreactor thickness = 2.05cm

Vessel type = cylindrical vessel

Number of blades = 20 of blades

Height of reactor = 6.65m

Calculating the total cost of the reactor:

Total cost of reactor = vessel cost + cost of packing, but

Vessel cost = bare vessel cost x material factor x pressure factor.

Therefore, for stainless steel

$$C_u = (\$\,6000 \times 2 \times 5)$$
$$= \$\,60{,}000$$

Maintenance cost = 2% of the vessel cost

$$= 0.2 \times \$60{,}000$$
$$\therefore C_M = \$\,12{,}000 \text{ per year}$$

Cost of packing = 16319.2481×20
$$= \$\,326.38$$

Total cost of reactor = vessel cost + cost of $= 60{,}000 + 326.38$
$$= \$\,60,.32$$

III. RESULT AND DISCUSSION

The simulation is based at variant mass bases of the system from M_{feed}=10 kg to M_{feed}=100kg according to Table 1.

Table. I

GROUPED DATA FOR MODEL SIMULATION

Data	Value/Source	Data	Value/Source
$\mathbf{t_1}$	**288k**(Gregory, 2007)	C_L	0.003mmL^{-1}(Gregory, 2007)
t_2	**383k**(Gregory, 2007)	$C_{A,o}$	**124.7 moldm^{-3}**(Analysis)
$\mathbf{T_F}$	**298 k**(Gregory, 2007)	Air flow rate throw spagger	0.4vvm(Ghasen,et al.,, 2007)
$\mathbf{T_s}$	**423 k**(Gregory, 2007)	$\mathbf{V_o}$	**54.5dm^{3}min^{-1}**(Assumed)
$\mathbf{T_2}$	**213 k**	M	8.90×10^{-3}mNs/m^2
$\mathbf{K_s}$	**0.919jm^{-1}s^{-1o}C^{-1}**(CEP April 2019)	$\mathbf{C}^*$	6.8mmL^{-1}(Gregory, 2007)
$\mathbf{j_{h,t}}$	86044.6 **w/m^{2}k** (Ghasen, et al.,, 2007)	$j_{h,s}$	**8.8**(Ghasen, et al.,, 2007)
K_t	0.519 w/m^oC(ethanol Conductivity)	$C_{A,1}$	**231.86 moldm^{-3}**(Analysis)
$C_{p_{ethanol}}$	2.5 kj/kgK	Di	4.58m(Assumed)
P	1026.6636 kg/m^3(Analysis)	do	7.5m(Assumed)

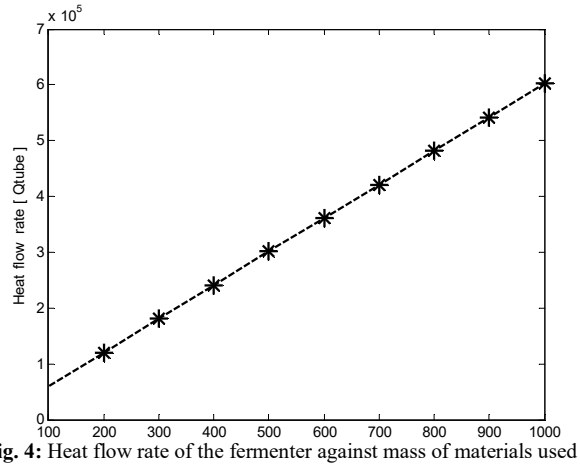

Fig. 4: Heat flow rate of the fermenter against mass of materials used

K. Heat flow rate of the fermenter against mass of materials used

Figures (except photographs) are often reduced to 7 cm × 7 cm. When preparing the figures, authors should pay attention to the widths of lines and similar details, as some (e.g. dotted or thin lines) may disappear after reduction. Figure 4 shows that the heat flow within an anaerobic fermenter during the fermentation period is proportional to the increase in the mass of the biomass set for digestion. So a digester operating with larger biomass feed requires heat or temperature control measures, either by using a cooling jacket or any other temperature-regulating approach, to promote microbial and yield efficiency of the [12, 15-18] as designed in this work using principles of heat transfer. A cooling jacket is required for large-scale fermenters to remove heat generated and is obligatory for the successful completion of the system [18-21]. Hence, the designed fermenter is in agreement with the accepted model which described temperature control measures as being of great relevance to every large-scale fermentation.

L. Volume of the fermenter against mass of materials used

Figure 5 shows variation of the volume of the fermenter against the mass of the feed sent into the reactor (M_{Feed}), hence from the graph there is a direct proportional increase in the system heat flow rate with respect to the increase in the feed value sent into the reactor implying that the system will require a greater amount heat to act on the feed in order to yield a satisfactory value or amount of the product [9, 13, 22-24]. Hence as M_{Feed} increases from 100to 1000, so V_R increases rapidly and proportionally perving way for a productive chemical process.

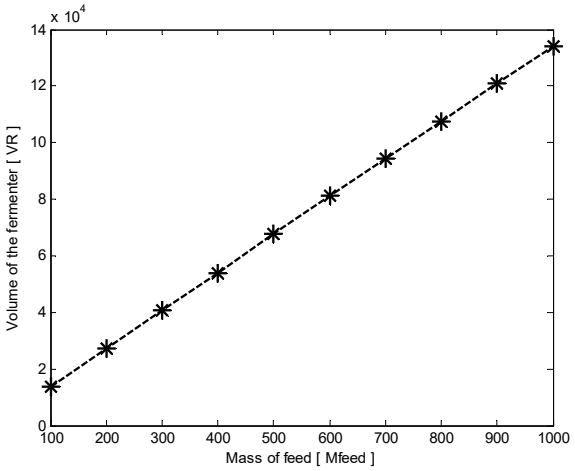

Fig. 5: Volume of the fermenter against mass of materials used

M. Mass of feed in the fermenter against Space time

Figure 6 shows variation of space time with mass of feed sent into the reactor (M_{Feed})**.** this was noticed to be exponentially in the increase as space time "X_A" increases. As the value of space time gradually increases towards $\tau = 2500$ sec, there was a gradual increase in the conversion process which followed a rapid conversion as the space time reach maximum. This project the designed reactor as effective for the production of 10 tons of ethanol per day under the space time and conversion rate.

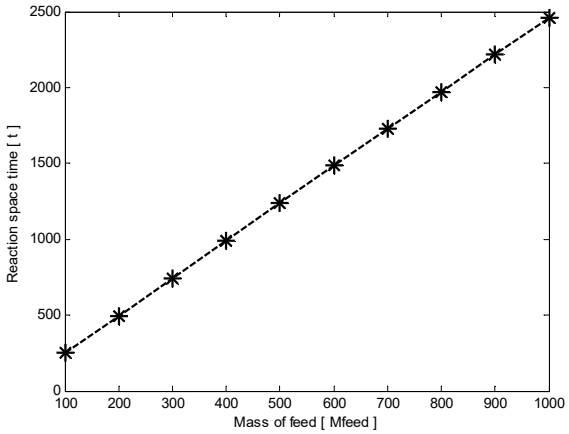

Fig. 6: Mass of feed in the fermenter against Space time

N. Rate of reaction in the fermenter against Mass of feed used

Figure 7 shows variation of the reaction rate in the reactor with respect to the change in process feeding value, from the plot it can be clearly stated that the rate of chemical reaction in the reactor all exponentially to the rapid increase in the feed value which is been sent into the reactor which stands a better chance of effecting the yielding rate

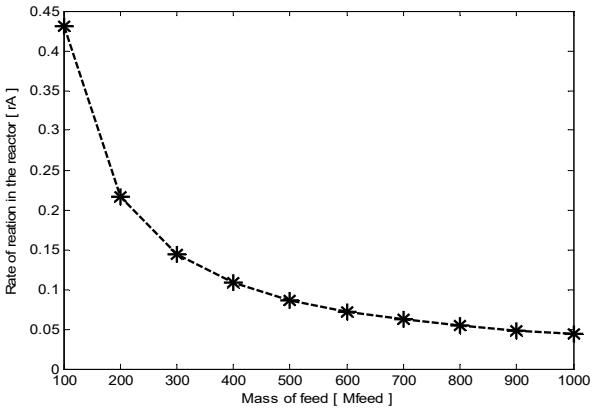

Fig. 7: Rate of reaction in the fermenter against Mass of feed used

O. Rate of reaction in the fermenter against Space time

Figure 8 shows variation of space time with respect to the reaction rate (r_A) which as it is reaction tends to be exponentially increasing, there is a corresponding fall on the system space time.

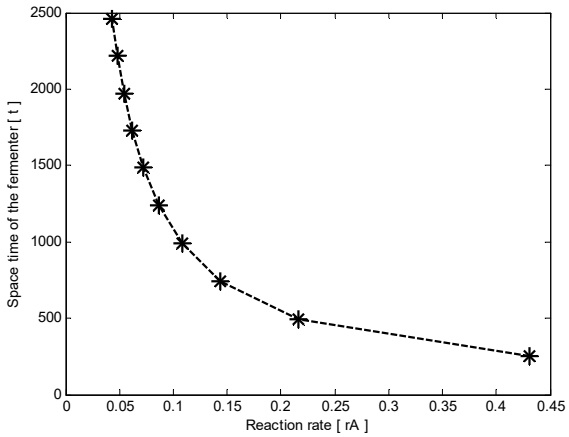

Fig. 8: Rate of reaction in the fermenter against Space time

P. Comparative graph of Rate of Oxygen transfer and Volume of the fermenter Vs mass of materials

Figure 9 shows variation of space time with fractional conversion (X_A) which is exponentially increasing as space time "X_A" increases**.** At maximum value of space time ranging from $\tau = 0.9$ hour and $\tau = 3.67$ hour the exponent level of the reaction tends to grow smoothly while after then there is a vast growth in the conversion process.

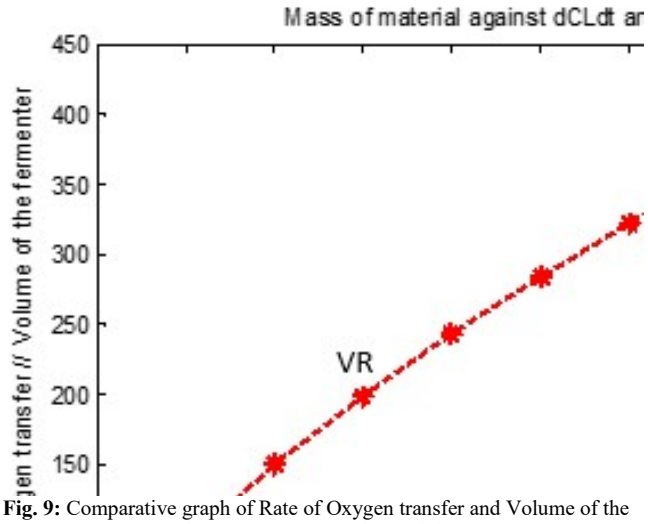

Fig. 9: Comparative graph of Rate of Oxygen transfer and Volume of the fermenter Vs mass of materials

Q. Rate of Oxygen Transfer Vs mass of Material in the fermenter

Figure 10 shows variation of space time with fractional conversion (X_A) which is exponentially increasing as space time "X_A" increases. At maximum value of space time ranging from $\tau = 0.9\ hour$ and $\tau = 3.67\ hour$ the exponent level of the reaction tends to grow smoothly while after then there is a vast growth in the conversion process. Increase in the biomass feed reduces the rate of oxygen transfer in the system hence subjecting the aerobic enzymes to dormant or death phase [25-26]. The plot shows that fermentation occurs most successfully within low mass feed rate, and that fermentation process is a factor of the feed mass.

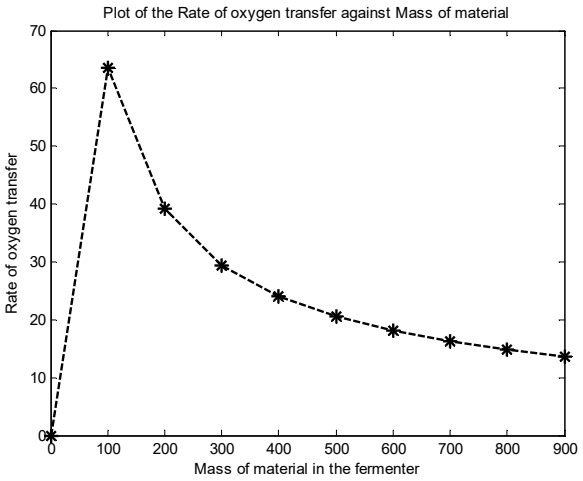

Fig. 10: Rate of Oxygen Transfer Vs mass of Material in the fermenter

IV. Conclusion

The design shows the target been achieved at the fermenter vessel Area of $(A_o) = 15.5917m^2$, with the use of $1271.1646kg/day$ coolent (water), with the system operating at conserved heat flow of $505262.484J/day$. MATLAB simulation is been used to access the dynamic behavior of the agitated fermenter over a range of biomass and time using the developed models, which shows that the reaction rate of fermentation $\left(\frac{dC_L}{dt}\right)$ is proportional to the Overall mass transfer coefficient per unit volume of the biomass (K_La) measured in per hours of the fermentation (hr^{-1}). So decrease in the feed mass of a fermenter due to biomass decay, increases the oxygen penetrability of the system, as shown in fig 9, and this effects promotes the Heat duty of the system over time which calls for the use of a cooling jacket designed fermenter, especially for large scale feeds. This decrease in the fermenter material (biomass) due to biomass decay promotes the fermentation rate of the system, as seen in fig 7 that the rate of biomass fermentation $\left(\frac{dC_L}{dt}\right)$ corresponding decreases with increase in feed value of biomass. The increase in the fermentation rate of the biomass reduces the resident time of the system as described in fig 8, promoting satisfactory product yielding and purity which is the one of the target of this work

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