Premier Journal of Engineering and Applied Sciences
Publication of Nigerian Society of Engineers, Ibadan Branch
P J E A S
Vol. 2, No. 1, 2021 ISSN:2734-3170

Thermodynamic Design of Kettle Boiler for the Distillation Unit of a Bioethanol Processing Plant

A. E. Adeleke[a*] and S. Oyelami[b]

[a]Department of Mechanical Engineering, Federal University Oye Ekiti, Nigeria.
[b]Department of Mechanical Engineering, Osun State University, Osogbo, Nigeria

Corresponding Author: *ademola.adeleke@fuoye.edu.ng*

ARTICLE INFO

Received: August, 2020
Accepted: January, 2021
Published: January, 2021

Keywords:
Kettle Boiler
Bioethanol
Distillation
Processing Plant

ABSTRACT

Heat exchanger in any bioethanol processing plant is a crucial energy transfer unit. The effective and efficient performance of a boiler depends on the thermodynamic design before manufacturing processes. This research focused on the design of a kettle boiler which will be used to generate vapour supplied to the distillation column for the separation of bioethanol from other components of fermented substrates. Conceptual design approach was executed to determine the optimum internal geometric parameters that will produce higher efficient boiler. The dimension and required number of internals of the boiler were determined using validated method from literature. The boiler designed specifications arrived at were; Boiler designed type: Kettle boiler (TEMA), Number of Tubes = 88 Tubes: U- Tube, 30 mm outside diameter laid on 45 mm square pitch. Shell diameter = 1010 mm; Free board = 410 mm, shell side pressure drop (0.22 kPa), tube side pressure drop (0.94kPa). The efficiency of the designed boiler was 0.72. The design specifications generated from this work provide a useful information and tool for the design and construction of the kettle boiler of a distillation unit of a bioethanol processing plant.

1. INTRODUCTION

The rapid depletion of fossil fuel, increase in population size and increase in energy demand with by-products that constitute environmental pollution necessitate the use of renewable energy source for driving the economy of a country (Oyelami and Adeboye, 2018). Production and the use of renewable energy fuels such as bioethanol and biodiesel may reduce the demand on fossil fuel resources and its effect on environment (Nisha and Nivedita, 2018; Walter *et al.,* 2008). Biofuels are liquid fuels produced from conversion of energy stored in biomass through different processes for either burning or transport purposes (Karin *et al.,* 2020; Narodoslawsky, 2010). They can be produced from the biodegradable portion of industrial and municipal waste, forest and agricultural products (Nisha and Nivedita, 2018). Bioethanol is a liquid produced during fermentation of sugars from sugar plants and cereal crops such as sugarcane, corn, wheat, beet, sorghum and cassava followed by distillation process.

Distillation is the separation of the constituent mixture of fermented mash enhanced by their difference in Relative Volatility (RV), or boiling points. Distillation is the most energy consuming process during bioethanol production. It is also said to be the most utilized method of separation of organic mixture to obtain high purity products (Moshen *et al.,* 2019; Vincent *et al.,* 2018; Adeleke *et al.,* 2013; Wahoho, 2007; Kim and Dale, 2005). Distillation unit of a bioethanol plant comprises of different part, each of which is used either to enhance material transfer or transfer heat energy. A typical distillation unit contains several major components which include a distillation column where the separation of liquid is carried out; trays/plates and /or packing inside the column which are used to help in component separations; a condenser to cool and condense the vapour leaving the top of the column; a reflux drum to hold the condensed vapour from the top of the column so that liquid (reflux) can be recycled back to the column, and the top product can be removed from the distillation; a reboiler to provide the necessary heat for vaporization of the bottom product for the distillation process. A schematic of a typical distillation unit with a single feed and two product streams is shown in Figure 1.

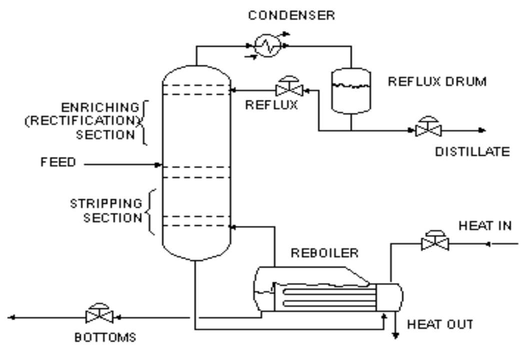

Figure 1: Main Components of Distillation Unit

Source: http://lorien.nd.ac.uk/ming/distil/distileqp.htm

Reboiler is a decisive component of the distillation unit of a bioethanol plant. It is a heat exchanger, located at the bottom of the distillation column where boiling of liquid takes place to generate vapour which are returned to the distillation column where separation of constituent mixture happen (Schack *et al.,* 2020).The various types of reboiler that are commonly used in any chemical industry are as follows;

Thermosyphon reboilers: These do not require pumping of the column bottoms liquid into the reboiler. Natural circulation is obtained by using the density difference between the reboiler inlet column bottoms liquid and the reboiler outlet liquid-vapor mixture to provide sufficient liquid head to deliver the tower bottoms into the reboiler. Thermosyphon reboilers (also known as Calandrias) are more complex than kettle reboilers and require more attention from the plant operators. There are many types of thermosyphon reboilers. They may be vertical or horizontal and they may also be once-through or recirculating. Some fluids being reboiled may be temperature-sensitive and, for example, subject to polymerization by contact with high temperature heat transfer tube walls. In such cases, it is best to have a high liquid recirculation rate to avoid having high tube wall temperatures which would cause polymerization and, hence, fouling of the tubes. Relative volatility of feed to reboiler must be considered before designing thermosyphon reboilers. The recirculation rate and pressure profile of the thermosyphon loop can also be calculated (Goedecke and Scholl, 2019).

Fired Reboiler: Fired heaters (furnaces) may be used as a distillation column reboiler. A pump is required to circulate the column bottoms through the heat transfer tubes in the furnace's convection and radiant sections. However, with some relatively minor changes inside the bottom section of the distillation column, a fired heater can also be used in once-through configuration. The heat source for the fired heater reboiler may be either fuel gas or fuel oil. Coal would rarely, if ever, be used as the fuel for a fired heater reboiler (Tahmineh *et al*., 2018).

Forced Circulation Reboilers: This type of reboiler uses a pump to circulate the column bottoms liquid through the reboilers. It should be noted that steam is not the only heat source that can be used. Any fluid stream at a high enough temperature could be used for any of the many shell and tube heat exchanger reboiler types (Alon, 2020).

Kettle Reboilers: The most critical element of reboiler design is the selection of the proper type of reboiler for a specific service. Most reboilers are of the shell and tube heat exchanger type and normally steam is used as the heat source in such reboilers. However, other heat transfer fluids like hot oil or Dowtherm may be used. Fuel-fired furnaces may also be used as reboilers in some cases (Tahmineh *et al*., 2018). The kettle reboiler (Figure 2) is a simple heat exchanger that has a tube bundle submerged in a liquid bath, with significant vapour disengaging space above the vapor. In this reboiler type, steam flows through the tube bundle and exits as condensate. Vapor and liquid are separated in the reboiler's disengaging space, so the return line carries essentially vapor. Kettle arrangements are once-through systems; reboiler effluent liquid does neither recirculate nor back-mix with bottom tray liquid. They may require pumping of the column bottoms liquid into the kettle, or there may be sufficient liquid head to deliver the liquid into the reboiler. The liquid from the bottom of the tower, commonly called the bottoms, flows through the shell side. There is a retaining wall or overflow weir separating the tube bundle from the reboiler section where the residual reboiled liquid (called the bottoms product) is withdrawn, so that the tube bundle is kept covered with liquid (Satish, 2017).

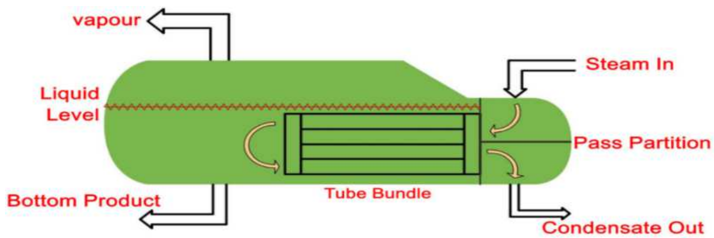

Figure 2. Kettle Reboiler (Source: Satish, 2017)

Proper reboiler operation is vital to effective distillation. In a typical classical distillation column, the entire vapor driving the separation comes from the reboiler. The reboiler receives a liquid stream from the column bottom and may partially or completely vaporize that stream. Steam usually provides the heat required for the vaporization. In the existing designs, much has not been found in the literature on the process design and mechanical design of the kettle reboiler of the distillation unit of a bioethanol plant. The aim of this work is to design a kettle reboiler for the distillation unit of a bioethanol plant.

2. METHODOLOGY

Operations

The distillation column is divided into a bottom (stripping) section and a top (enriching or rectification) section by the feed tray and the feed flows down the column where it is collected at the bottom in the reboiler. The liquid mixture to be processed is known as the feed and this is introduced somewhere near the middle of the column to a tray known as the feed tray. The boiler comprises of a combustion chamber featuring sand embedded fluidization.

The heat is supplied to the re-boiler to generate vapour and the source of heat input can be any suitable fluid; although in most chemical plants, this is normally high pressure steam. The boiler has the capability of producing steam at 15,000 kg/h and can hold feed water up to a maximum capacity of 20,900 l. The temperature of the combustion chamber is calculated to be between 800 °C and 1000 °C, while the produced steam has a mean temperature of 172 °C (Pambudi *et al.,* 2017). In refineries, the heating source may be the output streams of other columns. The vapour raised in the reboiler is re-introduced into the unit at the bottom of the column. The liquid removed from the reboiler is known as the bottom product or simply bottoms. The vapour moves up the column, and as it exits the top of the unit, it is cooled by a condenser. The condensed liquid is stored in a holding vessel known as reflux drum. Some of this liquid is recycled back to the top of the column and this is called the reflux. The condensed liquid that is removed from the system is known as the distillate or top product.

Design Theory of the Reboiler

A schematic diagram of distillation unit showing the material balance, modeled as a binary distillation column with one feed stage and two liquid products from the top and the bottom ends respectively are as shown in Figure 3. A similar column had been previously studied by Choe and Lubyen (1987) using dynamic model for the column design and a vapor hydraulic model to incorporate pressure dynamics in the simulation.

The model for the unsteady state is shown in equation 1, while the steady state is expressed in the form of equation 2. The steady state equation 2 was used to develop the dynamic simulator of the column in this study.

$$\frac{\partial}{\partial t}(M_B + M_D + Sum(M_{ni} * NT) = F - D - B \qquad (1)$$

Where F, D, and B are mass flowrates, M_B is the mass in the column base, M_D is the mass in the accumulator, Mn is the mass on tray n, and NT is the number of trays

$$F - D - B = 0 \qquad (2)$$

A boiler design is normally made in two steps; process design, followed by mechanical design. A process design includes a process flow sheet showing all pieces of equipment, instrumentation and control and the operating conditions of pressures, temperatures and flow rates. Also included in the process design are mass and energy balances on the overall process and on each unit in the process, as well as heat-exchange requirements. Determination of optimum operating conditions for the mass-transfer operations required for the separation and purification of the raw materials and products are also essential components. The purpose of mechanical design is to determine the dimension and the sizes of the boiler internals.

Assumptions made for the design.

The following assumptions were made in the design of the reboiler as suggested by Peters *et al.* (2004).

- Ideal gas behavior (low pressure system).
- Partial reboiler (operates as an equilibrium stage).
- Liquid in the reboiler is well mixed, i.e., the bottoms have the same composition as the liquid in the reboiler at any time.

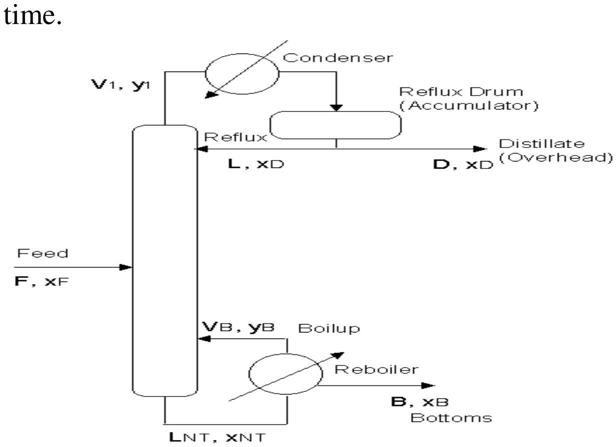

Figure 3: Schematic diagram of distillation unit showing the material balance

Premier Journal of Engineering and Applied Sciences
Publication of Nigerian Society of Engineers, Ibadan Branch
P J E A S
Vol. 2, No. 1, 2021 ISSN:2734-3170

Reboiler Loads

The heating loads in the reboiler are calculated from energy balances. Energy supplied by the reboiler is equal to the sum of the sensible heat needed to raise the liquid to its boiling point and the latent heat of vaporization (V_B *λ) must be added as shown in equation 3. The steady-state energy balance on the process side of the reboiler is then obtained.

$$Q_B = V_B\left[C_{mean}(T_B - T_1) + \lambda\right] \quad (3)$$

Where T_B is the temperature of vapour leaving the reboiler and T_1 is the temperature of liquid entering the reboiler.

The sensible heat transfer in a reboiler is relatively small, hence its heat load (Q_B) can be calculated from equation 4.

$$Q_B = V_B \lambda \quad (4)$$

The heating medium requirements (Q_R) can be calculated from an energy balance on the heating side of the reboiler to obtain equation 5. Saturated steam is taken as the heating medium.

$$Q_R = m_s \lambda_s \quad (5)$$

Where m_s the mass of saturated steam and λs is the latent heat of saturated steam

The steam rate (m_s) would then be obtained from equation 6 (neglecting thermal capacitance in the reboiler and heat losses)

$$m_s = {V_B \lambda}/{\lambda_s} \quad (6)$$

Similarly, if a liquid heat transfer fluid (e.g hot oil) is used, equations 7 and 8 are applicable.

$$m_f c_p (T_{htfs} - T_{htfr}) = V_B \lambda \quad (7)$$

$$UA \Delta T = V_B \lambda \quad (8)$$

Where m_f is the mass of the fluid in the reboiler, kg
C_p is the heat capacity of fluid in the reboiler at constant pressure, J/kg.K
T_{htfs} = Temperature of fluid supply, T_{htfr} = Temperature of fluid return, K
U is coefficient of heat transfer of reboiler material, W/m^2.K
A is the total surface area, m^2
Δ T is change in temperature between inlet and outlet of fluid flow.

Boiler efficiency = power out / power in = $\frac{Q(H_g - H_f)}{(qxGCV)} x100\%$ (9)

Q = rate of steam flow in kg/h
H_g = enthalpy of saturated steam in kcal/kg
H_f = enthalpy of feed water in kcal/kg
q = rate of fuel use in kg/h
GCV = gross calorific value in kcal/kg (e.g. pet coke 8200 kcal/kg)

Moreover, method for designing kettle reboiler for isothermal boiling is stated in the calculation of energy balance and the determination of the heat exchange in the reboiler, calculation of fluid property at the caloric temperature (or at arithmetic mean temperature) and pressure drop calculation, for example, tube side pressure drop (hot fluid) and shell side pressure drop (vaporizing liquid).

3. RESULTS AND DISCUSSION

The thermodynamic properties of the feed used and those obtained by utilising the thermal analysis equations are presented in Table 1. The reboiler is assumed to be operating at the same pressure as that of the column.

Table 1. Thermodynamic Properties of Feed used and those obtained from the thermal analysis equations

Properties	Value
Feed flowrate (kg/hr)	10238.8134
Quantity of liquid to be vaporized(kg/hr)	9414.9750
Feed Temperature (K)	433.83
Vaporization Temperature (K)	435.51
Average temperature (°C)	161.52
Latent heat of vaporization(at Average temperature) kJ/kg	550.2221
Specific heat capacity of feed at constant pressure, Cp (at average temperature) kgK	2.3298
Critical pressure((at average temperature) MPa	4.66

Design and Calculations
The following are determination of heat exchange, the design and calculations of geometry properties of a kettle reboiler for the distillation unit of a bioethanol processing plant.

Heat Loads

Maximum sensible heat = 2.3298 (435.51 - 433.83) = 3.9141 kJ/kg
Total Heat Load Q = 3.9141(10328.8134/3600) + 9414.9750/3699(550.2211)
= 1450.1094 kW
Adding 5 % losses, Maximum heat load (duty) Q_{max} = 1.05(1450.1094)
= 1522.6148 kW

Heat Balance and Number of Tubes

Assume U =1000 W/(m^{2}K)
Choose steam at 15.55 bar, T(sat) = 200 □C, λ□= 1938.6 kJ/kg
The LMTD was calculated from equation 10.

$$LMTD = \frac{\Delta T_2 - \Delta T_1}{Ln(\Delta T_2 / \Delta T_1)} \quad (10)$$

Where ΔT_1 is the temperature difference at inlet and ΔT_2 is the temperature difference at outlet. Substituting for ΔT_1 and ΔT_2

LMTD = [(200.160.68)-(200-162.36)]/ln[(200-160.68)-(200-162.36)]
= 38.47 □C

Area required = (1522.6148×1000)/(38.47×1000) = 39.58 m^2
Select 25 mm ID, 30 mm OD plain carbon U-tubes, L= 4.8 m

Premier Journal of Engineering and Applied Sciences
Publication of Nigerian Society of Engineers, Ibadan Branch
P J E A S
Vol. 2, No. 1, 2021 ISSN:2734-3170

No. of tubes = 88
Use square pitch, pt = 1.5(30) = 45 mm
Minimum bend radius = 3(OD) = 90 mm
From the tube layout, for 88 tubes, outer diameter limit = 502 mm
Heat Flux at saturated steam temperature q is given by equation 11.

$$q = \frac{Q_{\max}}{A_{req}} \quad (11)$$

Where Q_{max} is maximum heat load duty, 1522.61 kW and A_{req} is the required Area, 39.58 m^2

q = 1522.61/39.58
q = 38.47 kW/m^2

Maximum allowable heat flux
The maximum heat was calculated using equation 12 (Cengel, 2007)

$$q_{\max} = C_{cr} h_{fg} \left(\sigma g \rho_v^2 (\rho_l - \rho_v)\right)^{0.25} \quad (12)$$

Where, $C_{cr} h_{fg} = k\left(P_t/d\right)\left(\lambda/N^{0.5}\right)$

σ□= 48.4□10^{-3} N/m
ρ_L = 1062.5007 kg/m^3
ρ_V = 0.3830 kg/m^3
P_t = 1.25 inches = 25.4 mm
N = 88
K = 0.44

Substituting parameter values into equation 11, q_{max} is qiven as

q_{max} = 113.53 kW/m^2

Applying a factor of 0.7, maximum flux should not exceed 0.7×113.53 = 79.471 kW/m^2
q < q(max). Hence, the design is within permissible limits.

Velocity Check
The maximum allowable velocity is calculated from equation 13.

$$u_{\max} = 0.2\left[\frac{\rho_L - \rho_V}{\rho_V}\right]^{0.5} \quad (13)$$

Substituting parameter values

u_{max}= 11.826 m/s

while the vapor velocity at the surface is given by equation 14.

$$u = 0.2\left[\frac{\rho_L - \rho_V}{\rho_V}\right]^{0.5} \quad (14)$$

= 9414.9750/(3600×A×0.3038)
where A is the Surface area of liquid
For a Bundle diameter = 502 mm
D_S , shell diameter = 2(bundle diameter) ~1010 mm, liquid level as 600 mm from base
Free board = D_S – 600 = 1010-600 = 410 mm
Width at liquid level = 984.7 mm
Surface area of liquid (A) = 984.7□10^{-3}(4.8/2) = 2.3632 m^2
Substituting A into Equation 13, the vapor velocity is obtained.

u = 3.6427 m/s

Since u is less than u_{max}, the velocity is permissible.

Pressure drop in the tube side

The pressure drop in tube side (ΔPt) is given by Equation (15) (Kuppan, 2013)

$$\Delta P_t = N_p \left(8 j_h \left(\frac{L}{ID} \right) + 2.5 \right) \rho u_t^2 / 2 \quad (15)$$

Where

j_h is the friction factor, L is the length of tube, ID is the internal diameter of tube, N_p is the number of passes, u_t is the tube velocity and ρ is the density.

To determine the frictional factor, the Reynold's Number is calculated from Equation (16)

$$\mathrm{Re} = \frac{\rho u_t d}{\mu} \quad (16)$$

Re = $1.0\times0.36427\times25\times10^{-3}/(0.9\text{x}10^{-5})$

Re = 1012

Consequently the frictional factor was determined from Moody's Chart (Massey, 1989)

Friction factor, $j_h = 3.2\text{x}10^{-3}$

Therefore the pressure drop, ΔP_t was calculated from Equation (15)

ΔP_t = $2[8\times3.2\times10^{-3}\text{x}4.8/(25\times10^{-3}) + 2.5](1000\times 3.6427^2/2)$

ΔP_t =0.9839 kPa

Shell side pressure drop

The pressure drop in shell side (ΔPs) is given by Equation 17 (Kuppan, 2013),

$$\Delta P_s = 8 j_f \left(\frac{D_s}{d} \right) \left(\frac{L}{l_b} \right) \rho u_s^2 / 2 \quad (17)$$

Where

j_f is the frictional factor, D_s is shell diameter, *d* is shell equivalent diameter, L is the length of tube, U_s is the vapour velocity and ρ is the density and l_b is the baffle spacing.

For baffle spacing (l_b) = shell diameter (Ds), assuming baffles 45 % cut

For TEMA Pull-Through Floating Head Heat Exchanger

Clearance = 93 mm, Shell diameter = Ds = 823.2 mm, the cross flow area A_s is given by Equation (18)

$$A_s = \left(1 - \frac{D_O}{P_t} \right) D_s l_b \quad (18)$$

Where D_o is outer diameter in inches, P_t is pitch in inches

A_s = 0.1227 m^2

Equivalent diameter is obtained from Equation (19)

$$d = \left(\frac{1.27}{D_o} \right) \left(P_t^2 - 0.785 D_o^2 \right) \quad (19)$$

Substituting for all the parameters, the equivalent diameter is given by

d = 25.08 mm

The Reynold's Number was obtained from Equation 20 (Holman, 1989),

$$\mathrm{Re} = \frac{dG_s}{A_s \mu} \quad (20)$$

Where G_s is the mass flux obtained from Equation 2 (Holman, 1989),

$$G_s = {}^{w}\!/_{A_s} \quad (21)$$

Substituting for w and A_s
$G_s = (104.39/ 3600) / 0.1227$ kg/(m^{2}s)
$G_s = 0.236$ kg/m^{2}s
Substituting for all parameters in Equation 17
Re = $(25.08 \times 10^{-3} * 0.236) / (0.1227 * 0.9 \times 10^{-5}) = 5514$
From the correlation, friction factor
$j_f = 2.5 \times 10^{-3}$
Vapor velocity, U_s is obtained from Equation 22 by substitution of G_S and ρ_V

$$U_s = {}^{G_s}\!/_{\rho_v} \quad (22)$$

$= 0.236 / 0.0015$
$U_s = 157.3$ m/s
The pressure drop on the shell side was then calculated by substituting all calculated parameters in Equation (23)

$$\Delta P_s = 8 j_f \left(\frac{D_s}{d}\right)\left(\frac{L}{l_b}\right) \rho u_s^2 / 2 \quad (23)$$

$\Delta P_S = 0.22$ kPa
The maximum allowable pressure drop on the shell side for medium vacuum operation should be 10% of the absolute pressure which should be 1 kPa, but the value for ΔP_S (0.22kPa) was lower than 1 kPa. Hence, the condenser pressure drop is acceptable.

4. CONCLUSION

Distillation unit of a bioethanol plant is a crucial unit of the entire plant. Best grade ethanol is obtained with a well-designed reboiler. The Reboiler of the distillation unit of a bioethanol plant was designed in this study. The summary of the condenser designed is as follows; Type: Kettle boiler (TEMA), Number of tubes (88), U- Tube, 30 mm OD laid on 45 mm square pitch, Shell diameter (1010 mm), Free board (410 mm), Shell side pressure drop (0.22 kPa), Tube side pressure drop (0.94kPa). The design is hereby recommended for the construction of the boiler of the distillation unit of a bioethanol plant.

References

Adeleke, A. E., Aiyedun, P. O., Alamu, O. J., Dairo, O.U. and Olawale, S.O.A. (2013). Effect of Mole Fraction of the most Volatile Component in the Bottom on the Design of Distillation Column of a Bioethanol-Water System: A Simulation Study. *Annals of Science, Engineering and Technology,* 3(1):33-41.

Alon, D. (2020). CFD Simulation of Forced Recirculating Fired Heated Reboilers. *Processes* 8(2): 1-29.

Cengel, Y. A. (2007). Heat and Mass Transfer: A Practical Approach. Special Indian Edition. McGraw-Hill inc., New York.

Choe, Y. S. and Luyben, W. L. (1987). Rigorous Dynamic Models of Distillation Columns. *Industrial Engineering and Chemical Research,* 26(10): 2158-2161.

Goedecke, R. and Scholl, S. (2019). Modelling and Simulation of a Pillow Plate Thermosiphon Reboiler. *Heat Mass Transfer,* 55: 95–104.

Holman, J. P. (1989). Mechanical Engineering Series Heat Transfer. 8th Edition. McGraw- hill, Inc. New York.

Karin, A., Selma, B., Julia, H. and Maria, G. (2020). Criteria and Decision Support for a Sustainable Choice of Alternative Marine Fuels. *Sustainability,* 12: 1-23.

Kim, S. and Dale, B. E. (2005). Environmental Aspects of Ethanol from No-tilled Corn Grain: Non-renewable Energy Consumption and Greenhouse Gas Emissions. *Biomass and Bioenergy,* 28:475-489.

Kuppan, T. (2013). Heat Exchanger Design Handbook, Second Edition, CRC Press, Taylor & Francis Group. England.

Massey, B. S. (1989). Mechanics of Fluids. Six Edition, Chapman and Hall. pp. 578.

Mohsen, G., Paulo, E. S. M., Ismail, E., Jose, M. L., Amin, M. K. and Francisco, J. B. (2019). Emerging Techniques in Bioethanol Production: From Distillation to Waste Valorization. *Green Chemistry,* 21: 1171-1185.

Narodoslawsky, M. (2010). Structural Prospects and Challenges for Bio Commodity Processes. *Food Technology and Biotechnology,* 48(3): 270–275.

Nisha, S. and Nivedita, S. (2018). Second Generation Bio-ethanol Production from Lignocellulosic Waste and Its Future Perspectives: A review. *International Journal of Current Microbiology and Applied Sciences,* 7(5):1285-1290.

Oyelami, S. and Adeboye, B. (2018). Design of an Ethanol Distillation Plant. *Journal of Scientific and Engineering Research*, 5(5): 299-306

Peters, M. S., Timmerhaus, K. D. and West, R. E. (2004). Plant Design and Economics for Chemical Engineers, 5th ed. McGraw Hill, USA pp.769-782

Satish, P. (2017). Numerical Analysis of Vapour Velocity in the Kettle Reboiler at Different Entrainment Ratio. *International Journal of Scientific and Engineering Research,* 8(10): 1268-1273.

Schack, D., Jastram, A., Liesche, G. and Sundmacher, K. (2020). Energy-Efficient Distillation Processes by Additional Heat Transfer Derived from the FluMax Approach. *Frontiers in Energy Research*, 8(134): 1-13.

Tahmineh, A., Zohreh, R., Ali, C. and Ali J. (2018). Flame Failures and Recovery in Industrial Furnaces: A Neural Network Steady-State Model for the Firing Rate Set point Rearrangement. *International Journal of Chemical Engineering*, Article ID 3790849, 15 pp. https://doi.org/10.1155/2018/3790849

Vincent, G., Ivonne, R., Laszlo, H., Péter, L., Ferenc, D. and Xinqiang, Y. (2018). Review of Extractive Distillation. Process Design, Operation, Optimization and Control. *Chemical Engineering Research and Design*, 141:229-271.

Wahoho, S. (2007). Technology Development in Bioethanol Production in Indonesia. A power point presentation at the Asian Science and Technology Seminar, Japan Science and Technology Agency (JST) BPPT. Jakarta, March, 8th – 9th, 2007.

Walter, A. F., Rosillo-Calle, P., Dolzan, E., Piacente, K. Borges, D. (2008). Perspectives on Fuel Ethanol Consumption and Trade. *Biomass and Bioenergy* 32: 730-738.