# DESIGN OF BIOGAS COOLING PROCESSING FROM POME FOR (CSTR) CONTINUOUS STIRRED TANK REACTOR SYSTEM

## DESAIN SISTEM PENDINGIN PENGOLAHAN BIOGAS DARI POME UNTUK SISTEM (CSTR) CONTINUOUS STIRRED TANK REACTOR

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### Abstract

*POME (Palm Oil Mill Effluent) can be used as for biogas production, with the main content of (65%) methane gas ($CH_4$) and 35% Carbon Dioxide ($CO_2$), $H_2S$, and $H_2O$ gases. Apart from being a gas fuel and a source of electricity generation, biogas from POME waste as well as a waste processor becomes more environmentally friendly (according to quality standards). In order to support the process production of biogas from POME by using Continuous Stirred Tank Reactors (CSTR), it is necessary to decrease POME's temperature to meet the requirements of the reactor operating conditions. Cooling process by using a Cooling Tower through direct contact between fluids can be a good alternative to be used as a POME cooling method because of its effectiveness in heat exchange and smaller area needed than an open ponds. The type of cooling tower used is the Induced Draft Cooling Tower. In cooling tower design, the steps involved in determining the basic design, calculation of tower dimensions, basin, fan power, losses, and cooling air requirements. Based on the calculation, the tower dimensions determine a height of 5 m, length of 3.6 m, and width of 2.5 m, while the basin cooling tower dimensions determine a height of 2.7 m, length of 3.6 m, and width of 2.5 m, fan power of 5 hp. The cooling air requirement for the POME cooling process is 82,895.14 kg/hour.*

*Keywords : POME; Cooling Tower; CSTR; Fuel; Biogas*

### Abstrak

Limbah Cair Pabrik Kelapa Sawit (LCPKS) biasa disebut POME (*Palm Oil Mill Effluent*) dapat dimanfaatkan sebagai penghasil biogas dengan kandungan utama (65%) gas metana ($CH_4$) dan 35% gas Karbon Dioksida ($CO_2$), $H_2S$, dan $H_2O$. Selain sebagai bahan bakar gas dan sumber pembangkit listrik, biogas dari limbah POME sekaligus sebagai metode alternatif pengolah limbah POME menjadi lebih ramah lingkungan (sesuai baku mutu). Untuk mendukung proses produksi biogas dari POME dengan menggunakan *Continuous Stirred Tank Reactors* (CSTR), maka perlu dilakukan pendinginan POME agar memenuhi persyaratan kondisi operasi reaktor. Pendinginan dengan menggunakan *Cooling Tower* melalui kontak langsung antar fluida dapat menjadi alternatif yang baik untuk digunakan sebagai metode pendinginan POME karena pertukaran panas yang lebih efektif dan kebutuhan area yang lebih kecil dibandingkan kolam terbuka. Tipe menara pendingin yang digunakan adalah *Induced Draft Cooling Tower*. Pada desain cooling tower, tahapan yang dilakukan meliputi penentuan desain basis, kalkulasi dimensi menara, basin, daya fan, *losses*, dan kebutuhan udara pendingin. Dari hasil perhitungan diperoleh dimensi menara dengan tinggi 5 m, lebar 2,5 m, dan panjang 3,6 m, dimensi basin yaitu tinggi 2,7 m, lebar 3,6 m, dan panjang 2,5 m, daya fan sebesar 5 hp, dengan kebutuhan udara pendingin sebesar 82.895,14 kg/jam.

Kata Kunci : POME; *Cooling Tower*; CSTR; Bahan Bakar; Biogas

## INTRODUCTION

Over the past few decades, there has been a tremendous increase in the demand for palm oil all over the world. According to the FAO, this is due to the transition of many countries from the consumption of trans-fat to non-fatty food products. Similarly, Indonesia also experienced a significant increase in the palm oil sector with the development of approximately 850 additional Palm Oil Mills (PKS), thereby, increasing the production capacities from 30 to 90 tons per hour. In 2007, Indonesia's CPO production, which initially amounted to 17.5 MMT, increased to 38 MMT[1], Furthermore in 2018, it produced more than 40 MMT, and this was followed by an increase in palm oil mill effluent (POME) as the waste product of the PKS manufacturing process. This liquid waste consists of various organic components with a potential energy value that has not been fully utilized.

The transformation of Palm Oil Mill Effluent (POME) into energy can be a solution to overcome its negative impacts, such as the direct discharge into water bodies or the surrounding environment. POME can be processed into a biogas, which can be used as fuel for power plants (PLTBg) to create profits for industries. In biogas production, the reactor is used to convert the waste into organic gases by anaerobic process. It is conducted through a series of decomposition stages comprising of hydrolysis and acidification, acetogenesis, and methanogenesis. The main components are methane, carbon dioxide, and other associated gases such as $H_2S$ and ammonia[2]. The POME needs to be processed with appropriate and reliable technology in order to minimize the emergence of new undesirable by-products into the environment.

All biogas reactors have similar principles, with the creation of anaerobic conditions used to ease the inlet and outlet of raw materials and the adequacy of microorganisms in the reactor. One innovation reactor is the The Continuous-flow stirred-tank reactor (CSTR), which is used to produce an effective and optimal conversion process of POME into biogas. It used to handle liquid waste with high BOD and COD concentrations[3].

To optimize POME conversion and reactor efficiency, the pre-treatment process needs to be optimally prepared. The variables are a decrease in POME temperature and the removal of fiber content, solids, and other impurities from Cooling Ponds. The CSTR are susceptible to temperature changes due to the small reactor volume and the speed of the process compared to other technologies.

Biogas installations typically use mesophilic temperature ranges due to the ease of operation. An increase in POME temperature leads to a rise in the COD. Physical parameters such as viscosity and surface tension can change along with temperature. The POME feed obtained from Fat Pit with a temperature of 80 $^0C$[4] needs to be first lowered to 38 $^0C$ and fed to the CSTR. The cooling ensures the POME enters the reactor at an ideal temperature for bacteria and also converts COD waste into biogas. The temperature reduction is carried out using a Cooling Tower with air as a cooling medium. This process is considered more economical than the Heat Exchanger because it also does not need to be cooled again after use.

## METHODOLOGY

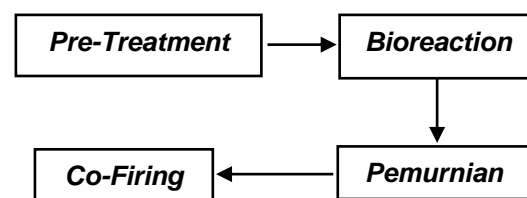The biogas production process from POME is generally described as follows:



Figure 1.
The Production Stages of Biogas from POME

a. **Pre-treatment of POME Raw Materials**

The raw materials are sourced from POME, in the form of liquid waste at a temperature of approximately 80 $^0C$ with the COD, and BOD composition obtained from the palm oil processing[4]. Based on the reactor type, the liquid waste specifications are adjusted within several parameters, namely temperature, acidity, and allowable solid content. Therefore, pre-treatment can be carried out physically or chemically, depending on the POME specifications from the mill.

b. **Biogas Production (Bioreaction)**

Crude Palm Oil liquid waste comprises of protein, carbohydrates, and glucose. It also contains carbon compounds capable of being processed by bacteria to produce biogas such as methane and carbon dioxide. The main component is methane gas ($CH_4$) formed from the liquid waste treatment through an anaerobic process[5].

In the initial stages, the polymer hydrolysis process is carried out in liquid waste, and this involves the use of lipase and protease enzymes to break down fat and hydrolysis in proteins to produce waste in dissolved compounds. The process of forming this acid solution is known as acidogenesis[6]. The availability of methane bacteria determines when the solution is ready to be processed to produce methane with carbon dioxide gas as a by-product. Methane bacteria are anaerobic bacteria that process food in acidic conditions; however, it is sensitive to high acid levels. Temperature is another influential parameter because it needs to be kept constant to achieve optimum methane gas production. The substrate in the liquid waste from the palm oil mill is in accordance with the requirements for the anaerobic production of methane gas with proper ratio of C (carbon) and N (nitrogen).

The POME treatment yields biogas containing high methane gas. The design capability and the reactor increases with tropical conditions, of the methane bacteria, and the raw materials in the form of liquid waste (POME)[7]. The design parameters refer to the methane bacteria type as well as the biogas operating pattern. Meanwhile, the pre-treatment process in the input reactor, solution temperature, acidity level, and homogenity factor is also considered. Furthermore, the methane gas produced needs to be maximized for the biogas quality to fulfil the requirements needed for fuel gas engine after undergoing purification.

It is important to determine the POME temperature in order to ascertain the use of a cooler. This is also used to ascertain the type of process and bacteria used in the reactor. The two temperature ranges commonly used in anaerobic digesters are mesophilic (25 - 40 $^0$C) and thermophilic (50 - 60 $^0$C). Biogas installations typically use mesophilic temperature ranges due to the ease of operation.

The reduction of the POME temperature before entering the reactor is very important and is related to the COD levels, viscosity, and surface tension. The reduction at the Pre-Treatment unit can be carried out with the heat transfer process using a Chiller, Cooler, and Cooling Tower.

In a related study, the POME temperature reduction process is conducted using the open pond system and Heat Exchanger method. Open ponds are limited to the use of a large land area, with a prolonged cooling process, and biogas formation. Furthermore, the methane gas is released into the air, thereby causing damage to the ozone layer.

In the cooling process, the disadvantages of using shell and tube and plate heat exchangers are the high construction and operating costs. Furthermore, an additional disadvantage of cooling with Heat Exchanger is frequent maintenance processes needed due to impurities from POME. The cooling process through direct contact between fluids using cooling towers is the best alternative to be used as a POME cooling method. By using the direct contact method, heat exchange is considered more effective because there is also an evaporation process that will maximize the POME cooling process. Cooling towers are also considered to be more economical than Heat Exchanger because in addition to using air conditioning media at ambient temperature, this cooling medium also does not need to be cooled again after used, and smaller area needed compared to settling ponds that are generally used in oil palm mills.

The biogas used the lagoon cover technology to obtain the optimum value of the POME cooling method. The POME is already at the technological readiness level of 7-8. Therefore this activity aims to utilize biogas as boiler fuel in palm oil processing mills. The current stage is referred to as the Pre-Treatment Unit construction stage with the use of the Mechanical Draft Cooling Tower[8]. Here, a fan is used to suck the air through the louver from the side into the Cooling Tower. This tool is relatively inexpensive and flexible because the wind speed is capable of being adjusted to the outside air and turbine load conditions.

At the top of the Cooling Tower, there are several fans driven by an electric motor through a series of gearboxes to reduce motor rotation. The hot POME enters the top header and sprays down to the splash type grid. Atmospheric air flows from the side through the fins due to fan suction and flows upwards, meeting with sprayed POME, enabling the cooling process. Hot air is then exhaled back to the atmosphere by the fan through the top of the Cooling Tower, and the cool POME is collected in a basin at the bottom of the Cooling Tower. Furthermore, the cold POME flows into CSTR. The working principle of the Cooling Tower used is shown in the following figure.
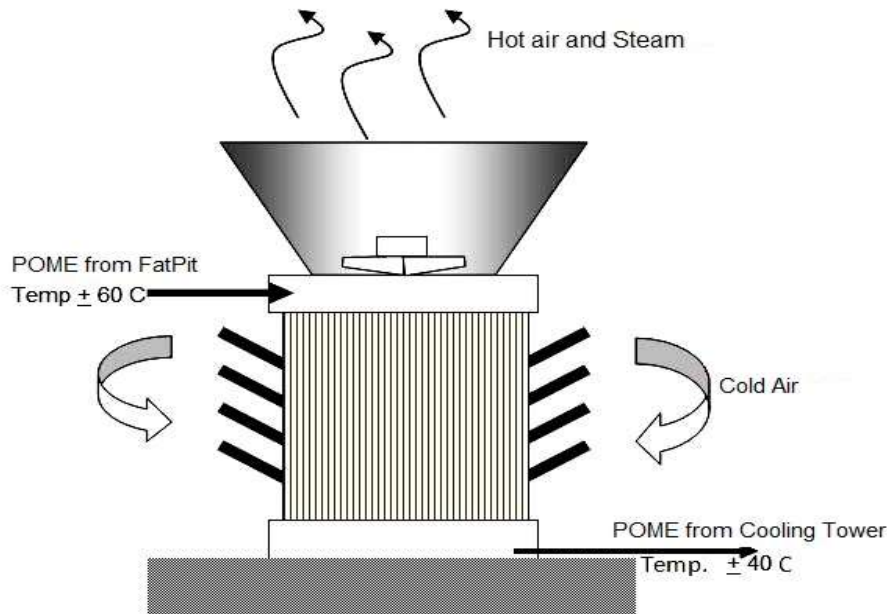
Figure 2
The Working Principle of Cooling Tower[9]

Cooling tower design calculations including the following step as follows :
1. Determination of design calculation basis
2. Calculate cooling tower dimensions: tower area, tower length and width
3. Calculation of the size of the cooling tower basin
4. Calculate the cooling tower fan motor power
5. Calculation of losses in cooling towers includes evaporation losses, drift losses, and blow down
6. Calculates the cycle of concentration (COC)
7. Calculate cooling air requirements

**DISCUSSION**

The cooling process is open, and POME coming from the Fat Pit is channeled to the Equilization Tank after being filtered with a Vibrator Screen to reduce the fiber content. Therefore, the open cooling system with the resulting of POME to the Buffer Tank fulfils the temperature requirements for CSTR feed.

Database design
POME volumetric rate, Q = 20 m$^3$/hour
Mass flow rate, W = 22,800 kg/hour
$\rho$ POME = 950 kg/m$^3$
Overdesign = 20%
Q POME = 24 m$^3$/hour
Q POME = 87.99 gal/min
T POME in, $T_{L1}$ = 80 $^o$C
T POME out, $T_{L2}$ = 38 $^0$C
T air dry bulb , $T_{db}$ = 30 $^0$C

T air wet bulb , $T_{wb}$ = 22.2 $^o$C
T approach = $T_{L2} - T_{wb}$ = 38 $^o$C – 22.2 $^o$C
= 15.8 $^o$C
$C_w$ [10] = 0.95 gal/min.ft$^2$

Calculating tower dimensions
Tower area, A = Q/Cw
= $\dfrac{87.99 \text{ gpm}}{0.95 \text{ gal/min.ft}^2}$
= 92.62 ft$^2$
= 8.61 m$^2$
A = L x W
where L = 1.5W
A = 1.5W$^2$
8,61 m$^2$ = 1.5W$^2$
L$^2$ = 5.74 m$^2$
L = 2.40 m
L = 3.59 m
Safety factor = 20%
Then, Cooling Tower dimensions:
Tower width,W = 2.40 m ≈ 2.5 m
Tower Lenght, L = 3.59 m ≈ 3.6 m
Tower height, H = 4.6 – 6.1 m[10]
= 5 m

Calculating Basin dimensions
Holding time = 1 hour
Basin Volume = Q x holding time
= 24 m$^3$
Basin height = V/(LxW)
= 24 m$^3$/(3.6 m x 2.5 m)
= 2.67 m ≈ 2.70 m
Basin lenght = 3.6 m
Basin width = 2.5 m

### Calculating Motor Drive Power of Fan Cooling Tower

HP fan = 0.031 hp/ft² (Fig. 12.15[10])

Power = A x 0.031 hp/ft²
= 92.62 ft² x 0.031 hp/ft²
= 4.79 hp

Assumed fan efficiency = 60%

Power fan = $\frac{1.72 \text{ hp}}{60\%}$
= 4.79 hp
= 5 hp

### Calculating Evaporation Losses (E)

Evaporation loss is calculated using the following equation [7]:

$$E = \frac{C \ x \ (T_i - T_o) x \ C_p}{\lambda} \qquad (1)$$

where:

C = circulating liquid
= 22,800 kg/hour

$T_i - T_o$ = n and out POME temperature differences

$i\Delta T$ = 42 °C

Cp = specific heat of liquid
(Cp value of water is taken because > 90% of POME content is water)
= 4.184 kJ/kg.oC

λ = Latent heat of water evaporation
= 2,260 kJ/kg

Therefore,

$$E = \frac{22,800 \ \frac{kg}{hour} x \ (42°C \ )x \ 4.184 kg/kgo_C}{2,260 \ kJ/kg} \qquad (2)$$

E = 1,772.83 kg/hour

### Calculating Drift Losses (D)

For the induced draft cooling tower type:

D = 0.1 – 0.3% of circulating liquid (C)

where :

D = 0.2% C

Then :

D = 0.2% C
= 0.2% x 22.800 kg/hour

D = 45.6 kg/hour

### Determining the Cycle of Concentration (COC)

The range of COC is generally from 3.0 to 7.0, where COC values are higher for power plants with large capacities [11]

Then, the COC = 5.0 was taken

### Calculating the Blow Down atau Draw Off (B)

Blow down is calculated by the following equation [11] :

$$B = \frac{E}{(COC - 1)}$$

Where:

E = Evaporation loss

COC = Cycle of concentration

then :

B = $\frac{1,773.83 \text{ kg/hour}}{(5-1)}$

B = 443.21 kg/hour

### Calculating the Total Losses (M)

M = D + E + B
= 45.6 kg/hour + 1,772.83 kg/hour + 443.21 kg/hour
= 2,261.64 kg/hour

This value is equivalent to 9.92% from circulating liquid (POME flow rate). Therefore, the total losses are 9.92% from the POME feed entering the Cooling Tower.

### Calculate cooling air requirements

T POME in, $T_{L1}$ = 80 °C
T POME out, $T_{L2}$ = 38 °C
T dry bulb udara, $T_{db}$ = 30 °C
T wet bulb udara, $T_{wb}$ = 22.2 °C
Cp POME = 4.184 kJ/kg. °C
POME mass flow rate = 22,800 kg/hour

Then, the heat needs to be absorbed as follows:

Q = m Cp ΔT
= 22,800 kg/hourx 4.184 kJ/kg. °C x (80 – 38) °C
= 4,006,598.40 kJ/hour

The cooling air requirement is calculated by,
m = Q / sensible heat of air.

Where enthalpy of dry air = sensible heat. Sensible heat values for air in certain Tdb and Twb conditions are searched using the Mollier Chart. To determine enthalpy dry air with the Mollier Chart, it is shown according to the arrow and the following number.

1. T air wet bulb , $T_{wb}$ = 22.2 °C
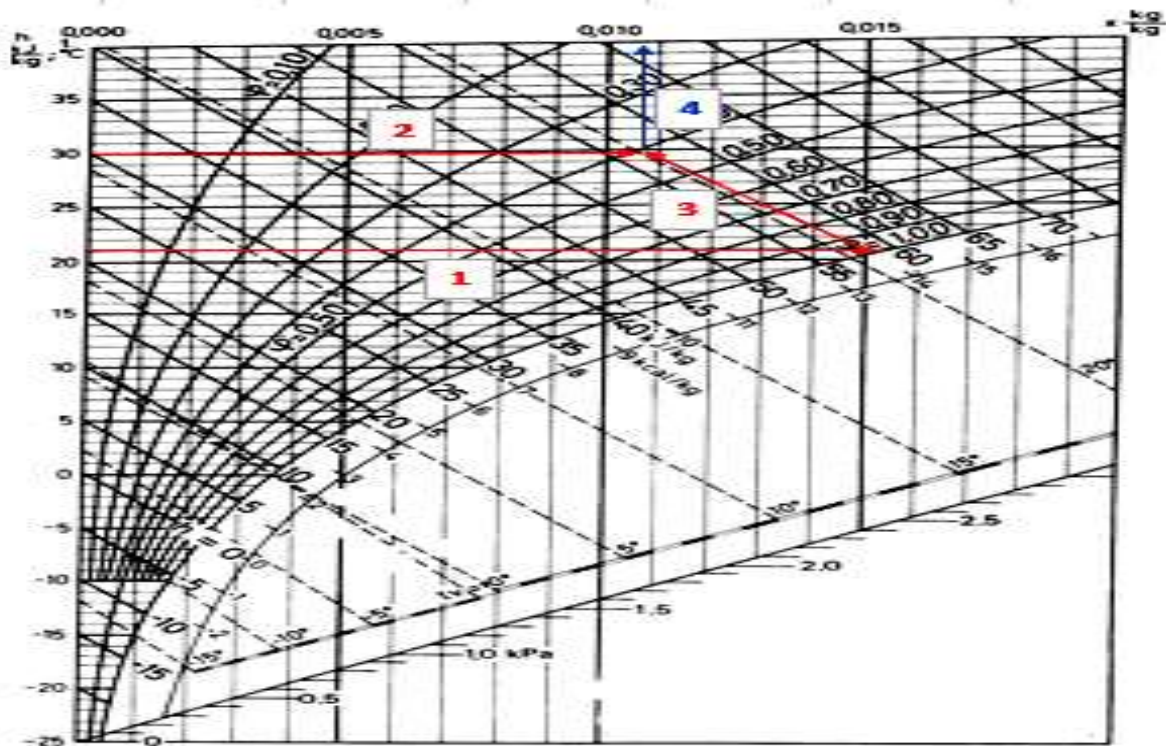2. T air dry bulb , $T_{db}$ = 30 °C

Figure 3.
*Mollier Chart*[12)]

From figure above :

*Enthalpy dry air* = 58 kJ/kg
with a specific humidity value of 0.0017 kg/kg

Furthermore, the cooling air requirement is calculated by dividing the amount of heat that needs to be absorbed by enthalpy dry air. Therefore, the amount of cooling air (m) needed in the POME cooling process is as follows:

m = $\dfrac{4,006,598.40 \text{ kJ/hour}}{58 \text{ kJ/kg}}$

= 69,079.28 kg/hour

*Safety factor* = 20%
Then m = 82,895.14 kg/hour

The cooling tower design calculations are shown in Table 1. Meanwhile, the mechanical drawing of the Cooling Tower is shown in Figure 4.

Table 1.
Results of Design Calculations *Cooling Tower*

| COOLING TOWER | | | | |
|---|---|---|---|---|
| **No.** | **Specification** | **Results** | | |
| 1 | Function | Cooling POME from Equalization Tank using air conditioner media as cooling | | |
| 2 | Type | Induced draft cooling tower | | |
| 3 | Capacity | 24 m³ | | |
| 4 | Tower Dimension | Height | 5.00 | m |
| | | Width | 2.50 | m |
| | | Length | 3.60 | m |
| 5 | Basin Dimension | Height | 2.70 | m |
| | | Width | 2.50 | m |
| | | Length | 3.60 | m |
| 6 | Power fan | 5 hp | | |
| 7 | Quantity | 1 unit | | |

*Source : Result of Data Processing*

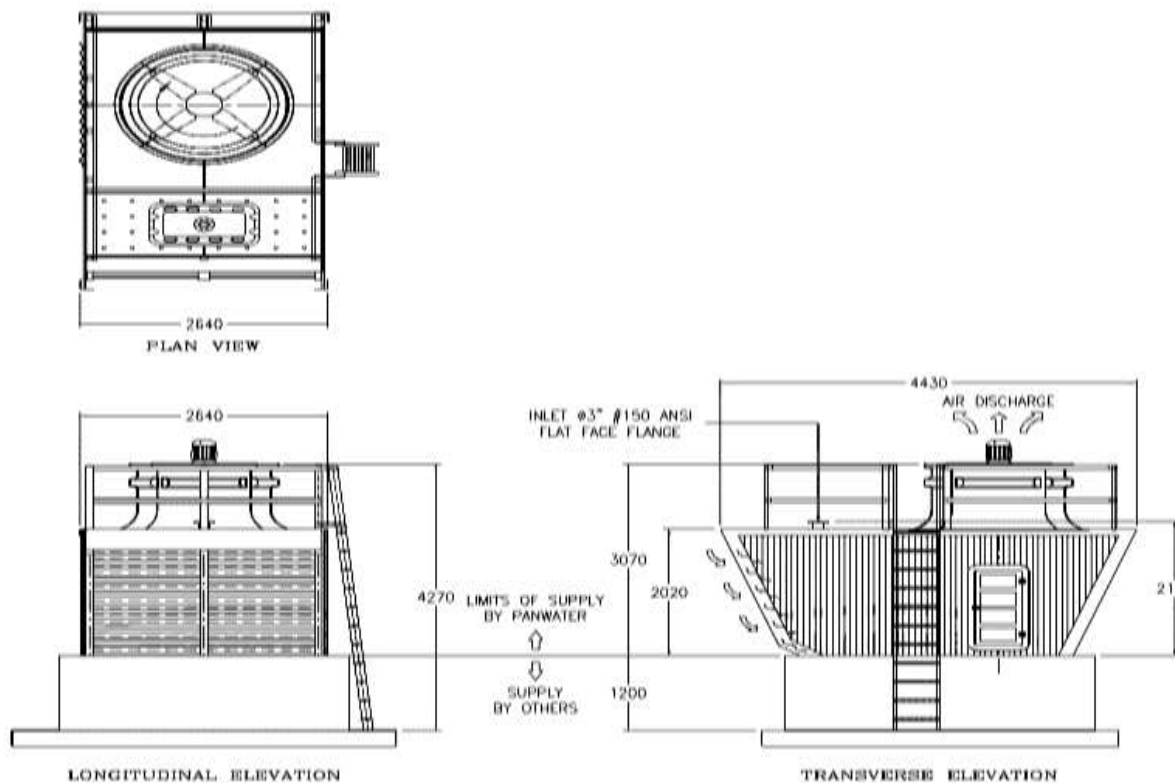Meanwhile, the mechanical drawing of the Cooling Tower is shown in the figure below.



Figure 4.
Cooling Tower Mechanical Drawing Design

## CONCLUSION

The reduction of the POME temperature before entering the CSTR is very important and is related to the COD levels, viscosity, and surface tension. The cooling process by using Cooling Tower through direct contact between fluids can be a good alternative to be used as a POME cooling method because its effectiveness in heat exchange process and smaller area needed compared to conventional settling ponds. Based on the calculation, the tower dimensions determine a height of 5 m, length of 3.6 m, and width of 2.5 m, while the basin cooling tower dimensions determine a height of 2.7 m, length of 3.6 m, and width of 2.5 m. The cooling air requirement for the POME cooling process is 82,895.14 kg/hour.

## ACKNOWLEDGEMENT

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