Design of Spent Metalworking Fluids Treatment Plant for Ibadan Municipal

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Abstract - Metalworking fluids (MWFs) are substances required in several industrial applications for lubrication of metallic parts and engines. Considering the large amount of these fluids consumed and disposed irresponsibly without prior treatment in Ibadan, Nigeria. Therefore, there is the need to design a spent metalworking fluid treatment plant for the city. With this view, a treatment plant with a retaining capacity of 0.1 million gallons influent per day was designed. The design was carried out using engineering principles with due consideration to cost, ease of operation, serviceability and durability. The plant consists of primary clarifier, aeration tank, sedimentation tank, chemical treatment tank, oxygen cylinders, sludge digester and the control panel. The proposed design aimed at ensuring a safe re-use of treated waste and recovered sludge for agricultural purposes. The characteristics of the influent and the expected effluent parameters are outlined.

Index Terms: Spent metalworking fluids, treatment plant, sludge, influent, effluent and digester.

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1 INTRODUCTION

Metalworking fluids (MWFs) are used in the metal cutting workshops as cooling and lubricating agents (Vesnal et al, 2013). They also have secondary functions, such as to reduce heat generation, provide flushing action in washing off the chips, to reduce friction and wear; and to protect the newly machined surface from environmental corrosion. MWFs also help to increase the tool life by reducing the cutting temperature during machining process.

MWFs provide numerous advantages but suffer from serious drawbacks of environmental problems. After utilization, the MWFs become less effective due to their thermal degradation and contamination by substances in suspension therefore they must be replaced periodically, generating a waste stream called spent cutting oil (Sulaymon and Thuaban, 2010). Generally, spent MWFs contain tramp oils (adulterant hydraulic and lubricating oil from the machine), greases, biocides, metal fines, other components of original

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emulsified oil and the products of their degradation. When irresponsibly and non-professionally handled, spent MWFs appear as environmentally hazardous waste oil (Vesnal et al, 2013).

In Ibadan (largest city in West African), spent MWFs are disposed from metal workshops without any prior treatment into rivers, storm drainages and landfills, where they are exposed to uncontrolled natural decomposition. However, the non-degradability of the oil fraction of MWFs makes natural decomposition difficult and impracticable. A field survey carried out among 103 metal workshops in Ibadan reported that 23 of the workshop operators dispose spent MWFs into storm drainage, 42 dispose as landfills, 13 dispose into the river (Kazeem et al, 2015). Spent MWFs are highly visible form of water pollution, land contaminations, health hazards and environmental degradation. When the spent fluids are disposed untreated even in small quantity in the environment or water, it can be concentrated by bio- magnification (Kilgore, 1999).

Regrettably, this condition characterizes the environmental culture of machine operators in Ibadan. It is important to note that endangered public health situation can curtails productivity and worsen urban condition of health. This ugly situation has persisted for several years and may continue to be because of high rate of illiteracy, ignorance, operators' inability to maintain a clean environment and reluctance of operators to cooperate with authority by disposing spent MWFs in illegal sites. Nigeria has a law banning the disposal of toxic substances such as the disposal of mineral oils. The pollution abatement

in industries and facilities generating waste regulation 5.1.9 of 1991 among other things imposes restrictions on the release of toxic substances and stipulates requirements for monitoring of pollution to ensure that permissible limits are not exceeded while unusual and accidental discharge contingency plans, generators liability and strategies for waste reduction the safety are put in place. Section (1) stipulates that 'No oil in any form shall be discharged into public drain, rivers, lakes, sea or underground injection without a permit issued by the agency or any organization designated by the Agency (Federal Ministry of Environment)' (Bamiro and Osibanjo, 2004).

Other factors that militate against descent disposal of spent MWFs in Ibadan include; uncontrolled number of increasing metal workshops, poor planning and lack of waste treatment plants for spent MWFs treatments.

The major objective of the study is to present a conceptual design of spent metalworking fluids treatment plant for Ibadan city. The design aims at achieving a safe re-use of treated waste and recovered sludge for agricultural purposes (such as irrigation and fertilizers production).

2 GENERAL DESIGN CRITERIA FOR A MUNICIPAL SPENT CUTTING FLUID TREATMENT PLANT

The objective of the spent metalworking fluids treatment plant is to ensure that spent MWFs collected from metal cutting workshops are properly collected, transported, treated to the required level and finally disposed of without causing any health or environmental problems. Prior to the design of a waste treatment plant, the following guidelines must be followed by the designer:

- The location of site for the waste treatment plants must be available. It is always advisable that the location of site should be far from water bodies, living environments, restaurants and shops. This will make future operations easy and reliable. In order to get a suitable location, the designer can liaise with the state council and environmental protection agency.
- The designer must be sure of the maximum number of metal cutting workshops and the quantity of spent MWFs disposed in each workshop weekly/monthly so as to determine the capacity of spent metalworking fluids

treatment plant to be designed. In determining the capacity of the reactor tanks, the designer must put into consideration the possibility of future extension of the treatment plant. Special factors causing influx of MWFs users should be foreseen to a possible extent.

- Reactor tanks should be provided with stainless steel ladders or step board for easy access to the tanks.
- Reactor tanks should be covered with a light material e.g. stainless steel and aluminum alloy open mesh flooring.
- Clean pipe borne water should be provided at a convenient location in the treatment site for pipes and hand washing.
- The material for air pipeline shall be steel with zinc coating.
- Air pipeline shall be installed above waste metalworking fluids level to prevent back flow of fluid into the pipeline.
- Valves shall be attached for check, flow adjustment, back flow prevention and waste air discharge.
- Reactor tanks should have drain pipe, catch basin and gutter on the side or bottom for drainage.
- Reactor tanks shall have foam removal equipment.
- Reactor tank shall have scum control equipment.
- The number of air compressors (blowers) shall be two or more. Capacity and number of air compressors shall be decided by plant start-up and future air in need considering diurnal variation within a day.

Further design shall be guided by following basic design considerations such as;
- Engineering (i.e. engineering drawing; design of part/components, flow rates)
- Treatment Processes

2.1 Working Principles of the Proposed Treatment Plant

The operation of the waste metalworking fluids plant is based on the fill-and-draw principle which consists of four main steps namely: Fill, React, Settle and Draw stages. The fill stage is known as the primary clarifier stage whereby the influent (untreated spent cutting fluid) passes through a screening where objects such as nylon, cans, bottles, rags and woods are being stopped from entering the aeration chamber. The primary clarifier stage is important because it ensures the mechanical components such as stirrer, pipes and pumps from getting damage. After partial treatment in this stage, the spent cutting fluid is transferred to the aeration tank (react stage) by means of a pump. Some sludge will remain in the primary clarifier. Figures 1 and 2 show the layout and conceptual designs of the proposed spent metalworking fluids treatment plant.
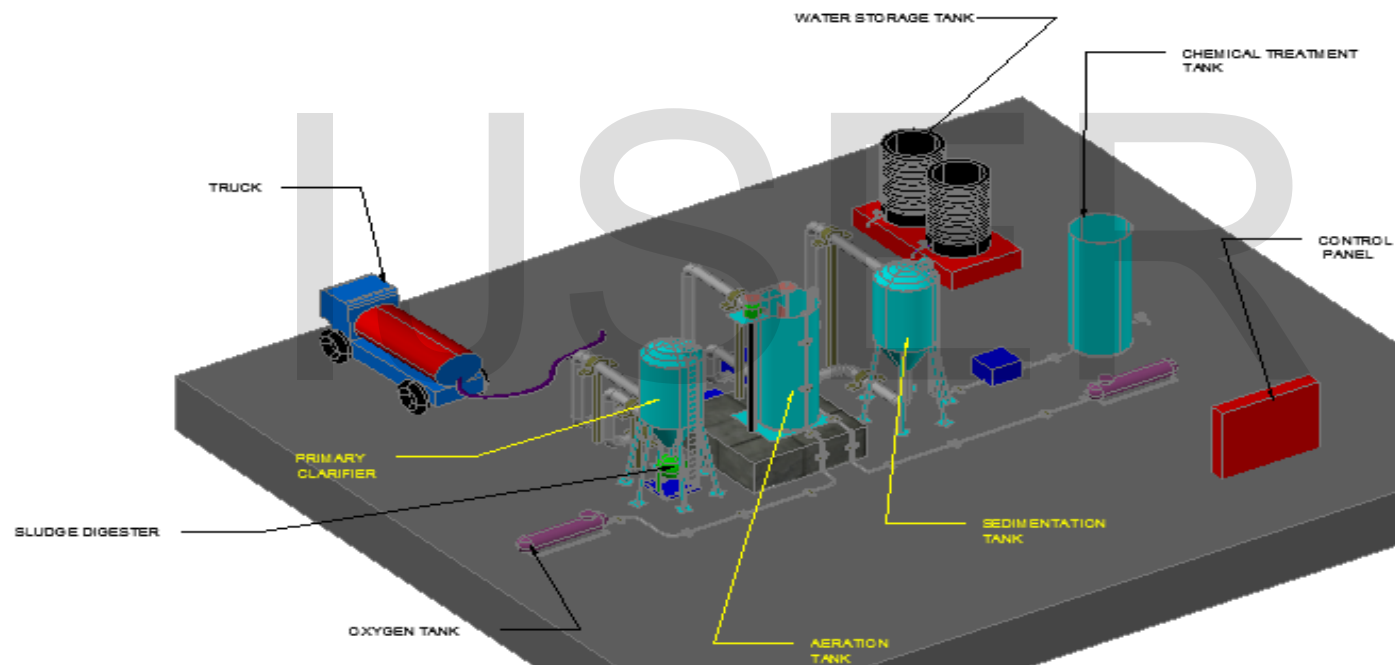

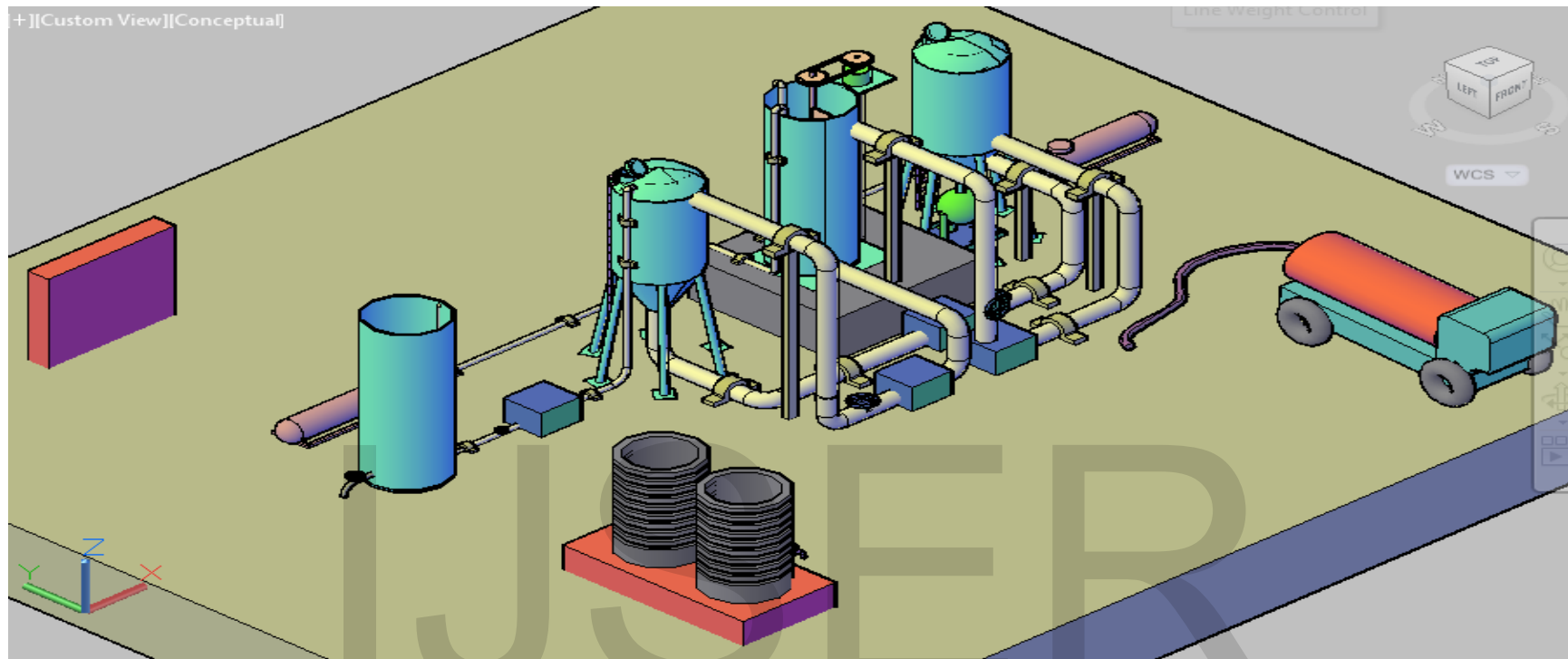Fig. 1: The layout of the proposed spent metworking fluids treatment plant

Fig. 2: The conceptual drawing of the spent metalworking fluids treatment plant.

As the spent cutting fluid enters the aeration tank, it mixes with the bacteria and other microorganisms known as mixed liquor or activated sludge. In the aeration chamber, the stirrer aerator has two functions: (1) It continuously puts oxygen from the air into the mixed liquor, oxygen which is necessary for the bacteria to live; and (2) Keeps the contents of the tank mixed and moving. While the waste cutting fluid flows into the aeration chamber, mixed liquor flows over the adjustable weir and out of the channel to the sedimentation tanks (also known as settle stage). The sedimentation tank is a specially designed tank which allows the mixed liquor solids (bacteria and inert inorganic material) settle to the bottom. When the solids settle, they leave a clarified liquid, (fluid floating on the surface) which will pass over the clarifier effluent weir. The cleared fluid from the sedimentation tank will be discharged to a tertiary treatment tank or a disinfecting chlorine contact chamber before discharging (draw stage) to the stream. The sludge which has settled to the bottom of the sedimentation tank will continuously be removed by pump for return into the primary clarifier to mix with new incoming waste metalworking fluids. As the sludge accumulates in the hopper base of the primary clarifier, it will be necessary from time to time to take excess activated sludge out of the process. The waste activated sludge will be removed by gravity to the sludge holding tank (digester) which is directly under the primary clarifier tank.

3 MATERIALS AND METHOD

The design was carried out using principles of engineering design with due consideration to cost, ease of operation, serviceability, durability and performance. The design of this treatment plant was separated into three distinct phases which include: (1) Design of machine components (such as tank volume, stirrer, pipes, electric power rating and belts designs), (2) Design of biological kinetics and (3) Design for fluid flow.

4 RESULTS

4.1 Design for Future Expansion of Metalworking Workshops

This section includes designing a municipal waste metalworking fluids treatment plant for Ibadan city, Nigeria for a projected period of 20years. A recently completed survey to metalworking workshops in Ibadan has showed that there are 103 operating metalworking workshops.

By considering future increase of the metalworking workshops, we can determine the possible number of workshops in 20 years as follows:

$$P = P_0 + (K t P_0) \tag{1}$$

Where,

P = Future number of metalworking workshops

$P_0 \Rightarrow$ Present number of metalworking workshops = 103

$t \Rightarrow$ Design period required for the plant = 20 years

$K \Rightarrow$ Constant = 0.03

P_{20} = 164.8

Therefore, the proposed waste metalworking fluids plant will be designed for approximately 165 metalworking workshops for a 20 years design period.

The waste treatment plant has been designed based upon the following design for reactor parameters:

TABLE 1
DESIGN PARAMETERS CONSIDERED FOR THE TREATMENT PLANT

Design Parameter	Range	Design
Average daily flow of waste metalworking fluids (Mg d)	-	0.1
Maximum Yield Coefficient (Y), lb VSS/lb BOD_5	0.4 – 0.8	0.6
Endogenous Decay Coefficient (kd), day^{-1}	0.025 – 0.075	0.06
Mixed Liquor Suspended Solids (X), mg/L	1,000 – 6,500	4,500
Volatile Suspended Solids Fraction (Xa)	0.5 – 0.8	0.8
Decay Fraction (fd)	0.78 – 0.82	0.8
Density of mild steel material considered (kg/m^3)	-	7,850
Acceleration due to gravity, g (m/s)	-	9.81
Sludge age in the reactor, θ_c (days)	5 – 15	8
Influent substrate, BOD_5 concentrate (S_o) [mg/L]	-	240
Effluent substrate (BOD_5) concentrate (S) [mg/L]	-	10
Concentration of sludge in return line, Xr (mg/L)	-	8,000
Concentration of solids in effluent, Xe (mg/L)	-	0
Peaking factor	-	2.5
Surface loading rate in settling tank ($gal/day/ft^3$)	-	400
Input waste sludge, (gal/day)	-	3300
Thickened waste activated sludge (%)	-	5.0
Minimum liquid temperature for aerobic digestion (^{o}C)	-	15
Maximum liquid temperature for aerobic digestion (^{o}C)	-	30
Sludge concentration in the digester (%)	-	70
Volatile fraction of digester suspended solids	-	0.8
Specific gravity of digester sludge	-	1.03
Density of water (kg/m^3)	-	994.6
Sludge cake solids	-	0.25
Sludge feed solids	-	0.05
Sludge centrate solids	-	0.003
Conversion factor from BOD^5 to BOD_L	-	0.68
Cake density (lb/ft^3)	-	60

The reactors have been calculated with several design parameters. The reactors will be provided with stirrer for mixing, oxygen delivery requirements and a digester for dewatering of sludge from the plant.

4.2 Designs for Machine Components

4.2.1 Reactor Tank Design

The reactor tank designed is a combination of two shapes: a cylinder with a conical hopper at its base to enable storage of spent metalworking fluids.

Volume of reactor =
$$[\text{Volume of cylinder} + \text{Volume of cone with a tip (frustum)}] \quad (2)$$

Where,
Volume of cone with a tip (frustum)
$$\Rightarrow \frac{\pi h}{3}[(R_1^2 + R_1r_1 + r_1^2) - (R_2^2 + R_2r_2 + r_2^2)] \quad (3)$$

Where $(R_1^2 + R_1r_1 + r_1^2) - (R_2^2 + R_2r_2 + r_2^2)$ is wall thickness of frustum

Let h be the height, R the radius of the upper base, and r the radius of the lower base of the frustum. Generally, volume, V, for a hollow cylinder is given by:
$$V = \text{Area} \times \text{height} = \pi(r_1^2 - r_2^2)h \quad (4)$$

Thickness of the cylindrical wall, t:
$$t = r_1 - r_2$$

Hence
Weight of reactor tank = Volume of reactor tank x Density of steel   (5)
Volume occupied by steel = Volume of the reactor
Density of material = 7850 kg/m^3
Mass of reactor tank = volume of reactor tank x Density of material to be considered
Weight of reactor tank = Mass of reactor tank x Acceleration due to gravity

4.2.2 Determination of Conical Hopper Outlet Diameter

The opening of the diameter for conical hoppers is given by (Jenike, 1964)
$$D = H(\theta)\frac{CAS}{\rho g/gc} \quad (6)$$
$$H(\theta) = 2 + \frac{\theta}{60} \quad (7)$$

Where gc is gravity constant conversion factors to convert the result from units of mass to units of

force $\frac{1kgm}{Ns^2}$. Typical value for H is about 2.4 (Jenike, 1964). Therefore θ semi included angle of the materials from equation (5) is $24°$. Figure 3 shows a conical hopper with semi included angle θ and outlet size D
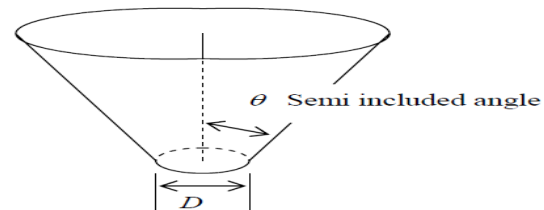

Fig 3: Conical Hopper with semi included angle and outlet diameter

As commonly practiced, the coefficient of friction is expressed as the angle of wall friction given by ϕ as;
$$\phi = \text{arc } \tan(\mu) \quad (8)$$

With known values of semi included angleθ, wall friction ϕ and the effective angle of internal friction, the flow factor (ff) can be determined from the Jenike published charts for conical hopers.
For flow: $\frac{\sigma c}{ff} > \sigma y$ (9)

Assuming σy and σc are related by the material flow function
$$\sigma y = \sigma c^{1.34}$$

Thus, the criterion for flow becomes
$$[\frac{\sigma y1/1.34}{ff}] > \sigma_y$$

And so the critical value of unconfined yield stress σ_{crit} is found when
$$[\frac{\sigma y1/1.34}{ff}] = \sigma_y \quad (10)$$

$ff = 1.54$ From the Jenike published chart for conical hoppers. The angle θ was reduced by $3°$ as a margin of safety (1964). Therefore θ used was $21°$ throughout. Hence solving for σy from equation (1) gives σ_{crit}

By applying law of indices we have,
$\sigma_y{}^{(-0.34/1.34)} = 1.54$

Therefore σy equals to σ_{crit} is 0.1823 kN/m2
And minimum diameter of circular outlet D is calculated to be 0.0495

4.2.3 Determination of Mass Flow Rate of Conical Hopper

The mass flow rate or discharge rate of a conical hopper was determined by the equation (Jenike, 1964):
$$\dot{m} = \rho^p A \sqrt{\frac{Dg}{2(m+1)Tan\theta}} \quad (11)$$

Where $A = \frac{\pi D^2}{4}$ (12)

For conical hopper m = 1

The stress action on the hopper wall is given by:

$$P_v = \frac{\rho^o g B}{4\mu K g c}\left(1 - \exp\left(-\frac{4 z \mu K}{D}\right)\right) \quad (13)$$

Where B is the hopper maximum diameter and z is the cylinder height

To estimate the normal stress on the hopper wall Jassen's assumption was applied

$$P_w = K P_v \quad\quad (14)$$

The material that can withstand the maximum stress acting on the wall of the hoppers should be selected.

4.2.4 Capacity Design for a Given Electric Motor Rating

The design for motor output power enables appropriate selection of a motor with enough power to start and run the machine at full load.

$$\text{Power} = F \times V \quad\quad\quad (15)$$

Where

P = Power in watts

F = Rotational force acting on the shaft in Newton (N)

V = Linear velocity of the shaft in meters/seconds

$$\text{But } F = ma \quad\quad\quad (16)$$

M = Mass of rotating shaft in kilogram (kg)

a = Angular acceleration of the motor in radian/seconds square (rad/s²)

$$a = w^2 r \quad\quad\quad (17)$$

w = angular velocity of the motor in radian/seconds

$$w = v/r$$

Therefore v = wr   (18)

By putting equation (17) into (16)

$$F = m w^2 r \quad\quad\quad (19)$$

By putting (18) and (19) into (20)

$$\text{But } w = \frac{2\pi N}{60} \quad (21)$$

Putting (21) into (20)

$$P = 8M\left(\frac{\pi N}{60}\right)^3 r^2 \quad (22)$$

4.2.5 Calculation of the Mass of Rotating Stirrer

$$D = \frac{M}{V} \quad (23)$$

Where D = Density of stirrer in kg/mm³

M = mass of stirrer in kg

V = volume of stirrer in mm³

But V = lbh   (24)

L = length of stirrer in mm

For horizontal component of the stirrer

Vhc = volume of horizontal component of the stirrer

$$V_{hc} = 4\,(lbh) \quad (25)$$

For the vertical component of the stirrer

Vvc = Volume of vertical component of the stirrer

$$V_{hc} = 4\,(lbh) \quad (26)$$

By adding the horizontal and vertical components, we obtain the volume of the stirrer. Density of stirrer is material dependent. For example, density of mild steel is 7.85 x 10⁶ kg/mm³

$$\text{Mass} = \text{density} \times \text{volume} \quad\quad (27)$$

The mass to be obtained from equation (27) will be substituted into equation (22) to get the electric power rating

$$P = 8M\left(\frac{\pi N}{60}\right)^3 r^2$$

P = electric motor power rating

M = mass of rotating stirrer

N = speed of the motor

r = radius of the motor pulley

4.2.6 Belt Selection and Design

There is need to select a belt that will surely transmit the motion as required under a reasonable tension without failure (cutting). Also the belt and the pulley must also be designed to allow the two to work together in harmony (to match each other and to hold firmly to each other). The speed of the driving pulley and the driven pulley can be expressed as

$$D_e N_e = D_s N_s \quad\quad\quad\quad (28)$$

De = Driving pulley diameters (mm)

Ne = Speed of driving pulley (rpm)

Ds = Driven pulley diameter (mm)

Ns = Speed of driven pulley (rpm)

The driving pulley can be determined from the electric motor to be considered. For instance, if the speed and diameter of the driving pulley are 600 rpm and 50 mm respectively, then to express the diameter of the driven pulley by considering speed input ratio 1:5, we transform equation (28).

$$D_s = \frac{D_e N_e}{N_s}$$

4.2.7 Center to Center Distance Design

The minimum distance between driving and driven pulleys for appropriate belt tension is obtained below

$$C = \frac{1}{2}(D_1 + D_2) + D_2 \quad\quad (29)$$

C = the minimum distance between the pulleys in meters

D_1 = Pitch diameter of the driving pulley (motor pulley) in meters.
D_2 = Pitch diameter of the driven pulley

4.2.8 Design for Belt Length

The design generally specifies the type of standard belt to be selected. Design length for belt is obtained from

$$L = 2C + \frac{\pi}{2}(D_2 + D_1) + \frac{(D_2 - D_1)^2}{4C} \qquad (30)$$

L = Belt length
C = Minimum distance between the pulleys
D_1 = Pitch diameter of the driving pulley (motor pulley) in meters
D_2 = Pitch diameter of the driven pulley

4.2.9 Tension in the Belt

The tension T_1 acting on the tight side of the belt and the tension T_2 acting on the slack side of the belt are calculated using the equation at Hall et al (1982).

$$\frac{T_1 - mV^2}{T_2 - mV^2} = e^{\frac{f\alpha}{\sin 0.5\theta}} \qquad (31)$$

Where m = mass of a unit length of the belt (kg)
V = linear velocity of belt (m/sec)
α = angle of wrap on pulley (rad)
f = coefficient of friction between belt & pulley.
T_1 = Tension in the tight side of belt (N)
T_2 = Tension in the slack side of (N)
θ = Groove angle for v – belt (degree).
The maximum tension in the tight side of the belt depends on the allowable stress of the material.
Linear velocity V is given by

$$V = \frac{\pi \times D_s \times N_s}{60} \qquad (32)$$

The angle of wrap between on the small and large pulleys for open belt is determined using Hall et al (1982).

$$\alpha^1 = 180° - 2\sin^{-1}\left[\frac{R - r}{C}\right] (33)$$

$$\alpha^2 = 180° + 2\sin^{-1}\left[\frac{R - r}{C}\right] (34)$$

α_1 = angle of wrap on small pulley
α_2 = angle of wrap on large pulley
R = radius of large pulley (m)
r = radius of small pulley (m)
C = center distance of shaft (m)

4.2.0 Pipe Design

Cross – sectional inside area of a pipe can be calculated as

$$A = \pi\left(\frac{di}{2}\right)^2 = \pi\left(\frac{di^2}{4}\right) \qquad (35)$$

Where
A = cross sectional inside area of pipe (mm²)
di = inside diameter of the pipe (mm²)
Similarly, the cross – sectional outside area of the pipe can be calculated as

$$A = \pi\left(\frac{do}{2}\right)^2 = \pi\left(\frac{do^2}{4}\right) \qquad (36)$$

Where
do = outside diameter (m)
Therefore, the cross-sectional wall area – or area of piping material can be calculated as

$$Am = \pi\left(\frac{do}{2}\right)^2 - \pi\left(\frac{di}{2}\right)^2$$

$$= \pi\left(\frac{do^2 - di^2}{4}\right) \qquad (37)$$

Where
Am = cross – sectional wall area of pipe (mm²)

4.2.0.1 Shaft Design

To determine the diameter of the shaft by neglecting bending moment we have:

$$T = \frac{60P}{2\pi N} \qquad (38)$$

Where
T = Torque transmitted by shaft
P = Power transmitted by the electric motor
N = Number of revolution of shaft per minute
Torque transmitted by the shaft can also be calculated in terms of the diameter of the shaft as:

$$T = \frac{\pi \times \tau \times d^3}{16} \qquad (39)$$

Where
τ = Allowable shear stress of the material
d = diameter of the shaft
The value of torque obtained in equation (38) can be substituted into (39)

4.3 Designs for Biological Kinetics
4.3.1 Volume of the Reactor

The volume of the reactor can be determined using the following equation derived from Monod kinetics:

$$Vr = \frac{\theta c Q Y (So - S)}{Xa (1 + Kd\theta c)} \qquad (40)$$

Where

Vr = Reactor volume (M gal) (m³)

θ_c = the average time that the sludge remains in the reactor (sludge age). θ_c ranges from 5 to 15days for a complete mix activated sludge process. The design of the reactor is based on θ_c on the assumption that substantially all the substrate (BOD) conversion occurs in the reactor.. A θ_c of 8 days will be assumed.

Q = Average daily influent flow rate (Mgd) = 0.1 Mgd.

Y = Maximum yield coefficient (mg VSS/mg BOD_5). For the activated sludge process for municipal treatment plant Y ranges from 0.4 to 0.8. A Y of 0.6mg VSS/mg BOD_5 will be assumed. Essentially, Y represents the maximum mg of cells produced per mg organic matter removed.

S_o = Influent substrate (BOD_5) concentration (mg/L) = 240 mg/L

S = Effluent substrate (BOD_5) concentration (mg/L) = 10mg/L

Xa = Concentration of microorganisms in reactor Mixed Liquor Volatile Suspended solids (MLVSS) in mgL. It is generally accepted that the ratio MLVSS/MLSS is 0.8, where MLSS is the Mixed Liquor Suspended Solids concentration in the reactor. MLSS represents the sum of volatile suspended solids (organics) and fixed suspended solids (inorganics). For a complete mix activated sludge process, MLSS ranges from 1,000 to 6,500 mg/L. An MLSS of 4,500 mg/L will be assumed.

Kd = Endogenous decay coefficient (d⁻¹) which is a coefficient representing the decrease of cell mass in the MLVSS. For the activated sludge process for municipal wastewater Kd ranges from 0.025 to 0.075 d⁻¹. A value of 0.06d⁻¹ will be assumed.

Therefore:

$$Vr = 0.021 \text{ M gal}$$

4.3.2 Determination of the Hydraulic Retention Time

The hydraulic retention time (θ) is given by:

$$\theta = \frac{Vr}{Q} \qquad (41)$$

Where

θ = hydraulic retention time

Vr = Volume of reactor

Q = Influent flow rate

θ = 0.21 M gal

4.3.3 Determination of the Quantity of Sludge Wasted

The observed cell yield

$$Yobs = \frac{Y}{1 + Kd\theta_c} \qquad (42)$$

Where, Yobs = Observed cell yield

Yobs= 0.41 mg/mg

Hence, 0.41 mg/mg represents the actual cell yield that would be observed. The observed cell yield is always less than the maximum cell yield (Y). the increase of MLVSS is calculated using the equation below:

$$Px = Yobs \, Q \, (S_o - S)(8.34 \text{ lb/Mgal/ mg/L}) \qquad (43)$$

Px is the quantity of the wasted sludge

Px = 78.65 lb/VSS/d

Therefore the increase in the mass of mixed liquor suspended solids (MLSS)

$$= Px(ss) = \frac{Px}{Xa} \qquad (44)$$

Px(ss) = 98.31 lb SS/d.

This is the total mass of sludge wasted from the system each day

4.3.4 Determination of Oxygen Requirement based on Ultimate Carbonaceous Oxygen Demand (BOD_L)

The theoretical oxygen requirements are determined using the BOD_5 of the wastewater and the amount of organisms (Px) wasted from the system each day. If all BOD_5 were converted to end products, the total oxygen demand would be computed by converting BOD_5 to ultimate BOD (BOD_L), using the appropriate conversion factor. Therefore the theoretical oxygen requirements for the removal of the carbonaceous organic matter in wastewater for an activated sludged system can be determined by the equation below:

LbO2/d=

$$\left(\text{total mass of } BOD_L \text{ utilized,} \frac{lb}{d}\right) -$$
$$1.42 \left(\text{mass of organisms wasted,} \frac{lb}{d}\right) \qquad (45)$$

For converting BOD_5 to BOD_L, a conversion factor, f is introduced. The most commonly used value of f is 0.68. Therefore, the theoretical oxygen required for the removal of the influent BOD_5 is calculated thus:

$$lb \, O_2/d = \frac{Q \, (S_o - S)(8.34) \; (lb/Mgal)/(mg/L))}{f} -$$
$$(1.42)(Px) \qquad (46)$$
$$lb \, O_2/d = \; 270.9 \; lb \, O_2 /d$$

It is recommended that the aeration equipment be designed with a safety factor of at least 2. Therefore, in sizing aeration equipment a value of (2) (270.9 lb O_2/d) = 541.9 lb O_2/d is to be used.

4.3.5 Computation of the Waste Activated Sludge (WAS) and Return Activated Sludge (RAS) Requirement

Control of activated sludge process is important to maintain high levels of treatment performance

under a wide range of operating conditions. The principle factors used in process control are (a) maintaining dissolve oxygen levels in the aeration tanks, (2) regulating the amount of return activated sludge (RAS), and (3) controlling the waste activated sludge (WAS). One of the methods of calculating the waste sludge flow rate is as shown below.

X = Mixed Liquor Suspended Solids (MLSS) = 4500 as earlier stated

Q = Return activated sludge pumping rate (Mgd)

Xr = Concentration of sludge in the return line $\left(\frac{mg}{L}\right)$.

When lacking site specific operational data a value commonly assumed is 8000 mg/L

Qe = Effluent flow are (Mgd)

Xe = Concentration of solids in effluent $\left(\frac{mg}{L}\right)$. When lacking sites specific operational data, this value is commonly assumed to be zero.

Qw = Waste activated sludge (WAS) pumping rate from the return line (Mgd). Therefore, the wasting rate is calculated using the following:

$$\theta c = \frac{VrX}{Qw'Xr + QeXe} \qquad (47)$$

Assuming the concentration of solids in the effluent from the settling tank is low, then the above equation reduces to:

$$\theta c = \frac{VrX}{Qw'Xr} \Rightarrow Qw' = \frac{VrX}{\theta cXr} \qquad (48)$$

$$Qw' = 0.0015 \text{ Mgd}$$

To determine the waste activated sludge (WAS) using this method, the solids concentration in both the aeration tanks and the return line must be known.

Assuming that the sludge blanket level in the settling tank remains constant and that the solids in the effluent from the settling tank (Xe) are negligible, a mass balance around the settling tank yields the following equation for RAS pumping rate:

$$Qr = \frac{XQ - XrQw'}{Xr - X} \qquad (49)$$

Using values defined previously, the RAS pumping rate is computed to be $Qr = 0.125 \text{ Mgd}$

The ratio of RAS pumping rate to influent flow rate, or recirculation ratio (α), may now be calculated:

$$\alpha = \frac{Qr}{Q} = 1.25 \Rightarrow OK \qquad (50)$$

Recirculation ratio can vary from 0.25 to 1.50 depending upon the type of activated sludge system used.

4.3.6 Calculation of the Growth of Biological Sludge

The growth of biological sludge over time period, Δt, mg/L is given by:

$$\frac{\Delta x}{\Delta t} = \frac{XVr}{\theta c} \qquad (51)$$

Growth of biological growth is 11.81 kg/day

4.3.7 Design the Circular Settling Tank

Municipal waste metalworking fluids with an average daily flow of 0.1 Mgd exists the aeration tanks of a standard activated sludge treatment process. Design of circular settling tank to separate the sludge from the effluent is to be designed. The settling tank will work in conjunction with the aeration tank. Assume a peaking factor of 2.5. The following are of paramount importance in the design of circular settling tank: (1) Determination of the peak flow (2) Determination of the settling tank surface area using surface loading criteria (3) Determination of the settling tank surface area using solids loading criteria (4) Determination of the number of settling tanks.

4.3.8 Calculation of the Peak Flow

Using a peaking factor of 2.5. The daily peak flow Qp is given by:

Qp = Peak flow x Average daily flow = 0.25 Mgd
        (52)

4.3.9 Calculation of the Settling Tank Surface Area Using Surface Loading Criteria

The recommended surface loading rates vary depending upon the type of activated sludge process used. However, surface loading rates ranging from 200 to 800 gal/day/ft² $(8.09 \text{ to } 32.4 \text{ L/m}^2.d)$ for average flow, and a maximum of $1,000 \text{ gal/day/ft}^2 \ (40.7 \text{ L/m}^2.d)$ for peak flow are accepted design values. For a Qp of 0.25 Mgd $\left(250,000 \frac{gal}{day}\right)$ and a design surface loading rate of 400 gal/day/ft^2 at peak flow the surface area (A) of a settling tank may be calculated:

$$\text{Surface loading rate (gal/day/ft}^2) = \frac{\text{Settling tank effluent flow (gal/day)}}{\text{Settling tank area (m}^2)} \qquad (53)$$

(53)

Therefore, A = 625ft²

4.3.0 Calculation of the Settling Tank Surface Area Using Solids Loading Criteria

The total solids load on a clarifier consists of contribution from both the influent and the return activated sludge (RAS).

Qr = RAS flow rate = 1.25 (Q) = 0.125 Mgd (54)

X = MLSS in aeration tank = 4500 mg/L

Therefore, the maximum solids loading occurs at peak flow and maximum RAS flow rate. The maximum solids entering the clarifier are calculated using:

Maximum solids (lb/d) =

$$(Qp + Qr)(X)(8.34\ lb.mg.Mgal) \quad (55)$$

Using values given above;

Maximum solids = $14{,}073.75\ lb/d$ = $586.41\ lb/h$ = of suspended solids

Therefore, using a solids loading rate of 2.0 lb/ft² at peak flow, the surface area of a settling tank may be calculated:

$$A = \frac{Maximum\ solids}{Solids\ loading\ rate} = 293.2 ft^2 \quad (56)$$

In this case, the solids loading dominate and dictate the required settling tank area.

4.4 Design of an Aerobic Digester

An aerobic digester is to be designed to treat the waste sludge produced by an activated sludge waste water treatment plant. The input waste sludge will be $3{,}300\ gal/d\left(5\frac{d}{wk}.only\right)$ of thickened waste activated sludge at 5.0 percent solids. The following assumptions will be considered:

(i) The minimum liquid temperature is 15°C and the maximum liquid temperature is 30°C.
(ii) The system must achieve a 35 percent volatile suspended solids (VSS) reduction
(iii) Sludge concentration in the digester is 70 percent of the incoming thickened sludge concentration.
(iv) The volatile fraction of digester suspended solids is 0.8.

Factors to be considered in designing aerobic digester include temperature, solids reduction, tank volume (hydraulic retention time), oxygen requirements and energy requirements for mixing. The total mass of solids processed by the digester will be 98.31 lb SS/d which is the total mass of solids wasted from the treatment facility. The total mass of VSS input to the digester is:

$$(0.8)\ Px(ss) = 78.65\ lb/d \quad (57)$$

VSS reduction = (0.35) (Total mass of VSS input to digester) = 27.53 lb VSS reduced/day (58)

Digested sludge leaving the digester =
(Px(ss) – VSS reduction) lb/d = 70.78 lb/d
(59)

4.4.1 Calculation of the Daily Volume of Sludge for Disposal

The volume of sludge to be disposed daily (Qi) is:

$$Qi = (3{,}300 gal/day)\left(\frac{5}{7}\right) = 2357 gal/day \quad (60)$$

4.4.2 Calculation of the Volume of Digested Sludge

The volume of digested sludge is:

$$V = \frac{Ws}{(\rho)(s.g)(\%\ solids)} \quad (61)$$

Where

V = sludge volume (ft³) (m³)

Ws = weight of sludge (70.78)(lb((kg)

ρ = density of water (62.4lb/ft³)

s.g. = specific gravity of digested sludge (assume s.g. = 1.03)

% solids = percent solids expressed as a decimal (incoming sludge: 5.0%)

Therefore, the volume of the digested sludge is:

V = 22.03ft³/d

4.4.3 Calculation of the Volume of the Aerobic Digester Volume

The volume of the aerobic digester is calculated using the equation below, assuming the digester is loaded with waste activated sludge only (Hicks, 2006).

$$V = \frac{QiXi}{X\ (KdPv + 1/\theta c)} \quad (62)$$

Where

V = Volume of aerobic digester, ft²/d (m³/d)

Qi = Influent average flow rate to the digester, ft³/d (m³/d)

Xi = Influent suspended solids, mg/L

Kd = Reaction rate constant d⁻¹, This may range from 0.05 d⁻¹ at 15°C to 0.14d⁻¹ at 25°C (assume 0.08 d⁻¹ at 15°C)

Pv = Volatile fraction of digester suspended solids (expressed as a decimal) = 0.8 (80%) as stated in the initial assumptions.

θc = Solids retention time (sludge age), d assuming 20.8 d

V = 30.041 ft³

4.4.4 Determination of the Sludge Feed Rate Required

Assuming the designed digester will be used to produce 1200 gal/d of aerobically digested sludge 5 h/d, 3 d/wk, then the sludge fed rate is:

$$\text{Sludge feed rate} = \frac{\text{Quantity of anerobic digested sludge}}{\text{Operating time of facility daily}}$$

(63)

Therefore, sludge feed rate $= \dfrac{1200 \text{ gal/day}}{[(5 \text{ h/d})(60 \text{ min/h})]}$

$= 4.0 \text{ gal/min}$

By considering a feed sludge specific gravity of 1.03, the sludge feed in lb/h is calculated using the equation below:

$$Ws = \frac{(V)(\rho)(s.g)(\% \text{ solids})(60 \text{ min/hr})}{7.48 \text{ gal/ft}^3} \qquad (64)$$

Where

Ws = Weight flow rate of sludge feed, lb/h $\left(\frac{kg}{h}\right)$

V = Volume flow rate of sludge feed, gal/min (L/s)

s.g. = Specific gravity of sludge

% solids = Percent solids expressed as a decimal

ρ = density of water (62.4lb/ft³)

By using the values obtained above, the sludge feed in lb/h is:

$Ws = 103.1 \text{ lb/h}$ of dry solids

4.4.5 Computation of the Solids Capture

A recovery formula is used to determine the solids capture, the equation for percentage solids recovery is given by:

$$R = 100 \left(\frac{Cs}{F}\right)\left[\frac{F - Cc}{Cs - Cc}\right] \qquad (65)$$

Where

R = Recovery, percent solids

Cs = Cake solids, percent solids (assuming 25%)

F = Feed solids, percent solids (assuming 5%)

Cc = Cenztrate solids, percent solids (assuming 0.3%)

Therefore, R = 95.14%

4.4.6 Calculation of the Dewatered Sludge Cake Discharged Rate

The dewatered sludge (cake) discharge rate is calculated using the following:

Cake discharge rate (lb/h) dry solids = (sludge federate, lb/h) (solids recovery)   (66)

Cake discharge rate = 98.09 lb/h dry cake

The wet cake discharge in (lb/h) is calculated using the following:

$$\text{Wet cake discharge (lb/h)} = \frac{\text{Cake discharge rate, lb/h}}{\text{Cake \% solids}}$$

(67)

Therefore, wet cake discharge = 392.lb/h wet cake

The volume of wet cake assuming a cake density of 60lb/ft³us calculated as follows:

$$\text{Volume of wet cake (ft}^3/\text{h}) = \frac{\text{Wet cake rate, lb/h}}{\text{Cake density, lb/ft}^3} \qquad (68)$$

$= 6.54 \text{ ft}^3/\text{h}$ wet cake

For a dewatering facility operation of 5 hr/day, the volume of dewatered sludge cake to be disposed of per day is:

$(6.54 \text{ ft}^3/\text{h})(5 \text{ hour/day}) = 32.7 \text{ ft}^3/\text{d} = 244.7 \text{ gal/day}$

4.4.7 Determination of the Percent Reduction in Sludge Volume

The percentage reduction is sludge volume is then calculated using the following:

$$\% \text{ Volume Reduction} = \frac{\text{Sludge volume in} - \text{Sludge volume out}}{\text{Sludge volume in}} \times 100\% \qquad (69)$$

$$= \frac{1200 \text{ gal/day} - 244.7 \text{ gal/day}}{1200 \text{ gal/day}} \times 100\%$$

$\% \text{ Volume Reduction} = 79.61\%$

4.4.8 Determination of the Flow rate required for Sludge Pump

The required flow rate for the sludge pump using 4 h.d, 7d/wk operation scheme is:

$$\text{Flow rate (gal/min)} = \frac{1200 \text{ gal/day}}{(5 \text{ h/d})(60 \text{ min/hr})} = 4 \text{ gal/min} \qquad (70)$$

The velocity of 4.0 gal/min in a 3 inch (76.3mm) diameter pipe is:

$$\text{Velocity} = \frac{4.0 \text{ gal/min}}{(7.48 \text{gal/ft})\left(\frac{\pi}{4}\right)(3 \text{ inch/12 inch/ft})^2(60 \text{s/min})} = 0.18 \text{ft/s} \qquad (71)$$

4.5 Designs for Fluid Flow
4.5.1 Detention Time

The theoretical (calculated) time required for a given amount of waste fluid to pass through a tank at a given rate of flow. The time required to fill a tank at a given flow. The detention time in hours can be calculated with the formula below:

$$\text{Detention Time} = \frac{(\text{Clarifier volume, gal})(24 \text{ hr/day})}{\text{Flow, gal/day}} \qquad (72)$$

Volume = 0.785 x Diameter of clarifier x Diameter of clarifier x Depth x 7.48 gal/ft³   (73)

4.5.2 Flow Rate of Waste Cutting Fluid Travelling through a Pipe

Flow rate, Q = Velocity x Transverse internal area of pipe A   (74)

Where

Velocity = rate of wastewater travelling through a pipe

Transverse internal area = 0.785 d_i^2

5.0 CONCLUSION

The design of a spent metalworking fluids treatment plant was carried out for Ibadan community, Nigeria. Plant capacity of 0.1 Mgd was designed using engineering principles. The designed treatment plant contained the major components such as reactors, mixers, aeration gas, and a digester (to dewater moisture content of sludge).

6.0 REFERENCES

[1] Fatima, H.A, Salah, F (2011). *Design of Wastewater Treatment Plant*. Republic of Iraq Ministry of Higher Education and Scientific Research. A B.Sc. Project submitted to to the Building & Construction Department of the University of Technology.

[2] Vigneswaran, S., Sundaravedivel, M and Chaudhary, *Sequencing Batch Reactors: Principles, Design/Operations and Case Studies D.S. Water and Wastewater Treatment Technologies..*

[3] Jenike A.W (1964), *Storage and Flow of Solids*, Bulletin No. 123, Utah Engineering Experiment Station, University of Utah, Salt Lake City, USA (Revised edition 1970)

[4] Khurmi R.S., Gupta J.K., *A textbook of machine design*. Paperback: 1230 pages Publisher.

[5] Fadare, D.A (2004). *Development of an Organo-mineral fertilizer processing plant.A Ph.D thesis*, Mechanical Engineering Department, University of Ibadan, Ibadan, Nigeria.

[6] Bamiro O.A and Osibanjo O (2004). *Pilot study of used oil in Nigeria*. Conducted by Basel convention regional coordinating center in Nigeria in collaboration with secretariat of Basel convention, Geneva.

[7] Vesna, B.L, Ivan, M. K, Miodrag, L.L, Dragiša, S. S, Dejan, U.S, Vlada, B.V. *Scaling up the chemical treatment of spent oil-in-water emulsions from a non-ferrous metal-processing plant*. SCIENTIFIC PAPER Hem.Ind. 67 (1) 59–68 (2013).

[8] Kilgore, M (1999), *Litter and Pollution* – Chintimini Wildlife Rehabilitation Center.
http: www.chintiminiwildlife.org/education

[9] Kazeem, R.A., Fadare, D.A., Ogundiran, M.B. (2015). *An Assessment of Metalworking Fluids Utilization and Management Practices of Machining Workshops in Ibadan*. University of Ibadan Technology Conference (UITECH) 2015, (2015).

[10] Tyler G, Hicks, P.E (2006). Handbook of Mechanical Engineering Calculations. Second Edition.

[11] Sulaymon, A.H, Thuaban, L.H (2010), *Demulsification of Cutting Fluid before Disposal to the Environment*. Journal of Engineering, 16(1), 4580- 4592

[12] Janssen, H.A (1985), Versucheüber, G, Verein, D, Zeitschrift, Pages 1045-1049

[13] Jenike, A.W., *Storage and Flow of Solids*, Bulletin 123, University of Utah Engineering Station, 1964 (revised, 1976).

ADDITIONAL DETAILS OF THE DESIGNED SPENT METALWORKING FLUIDS TREATMENT PLANT
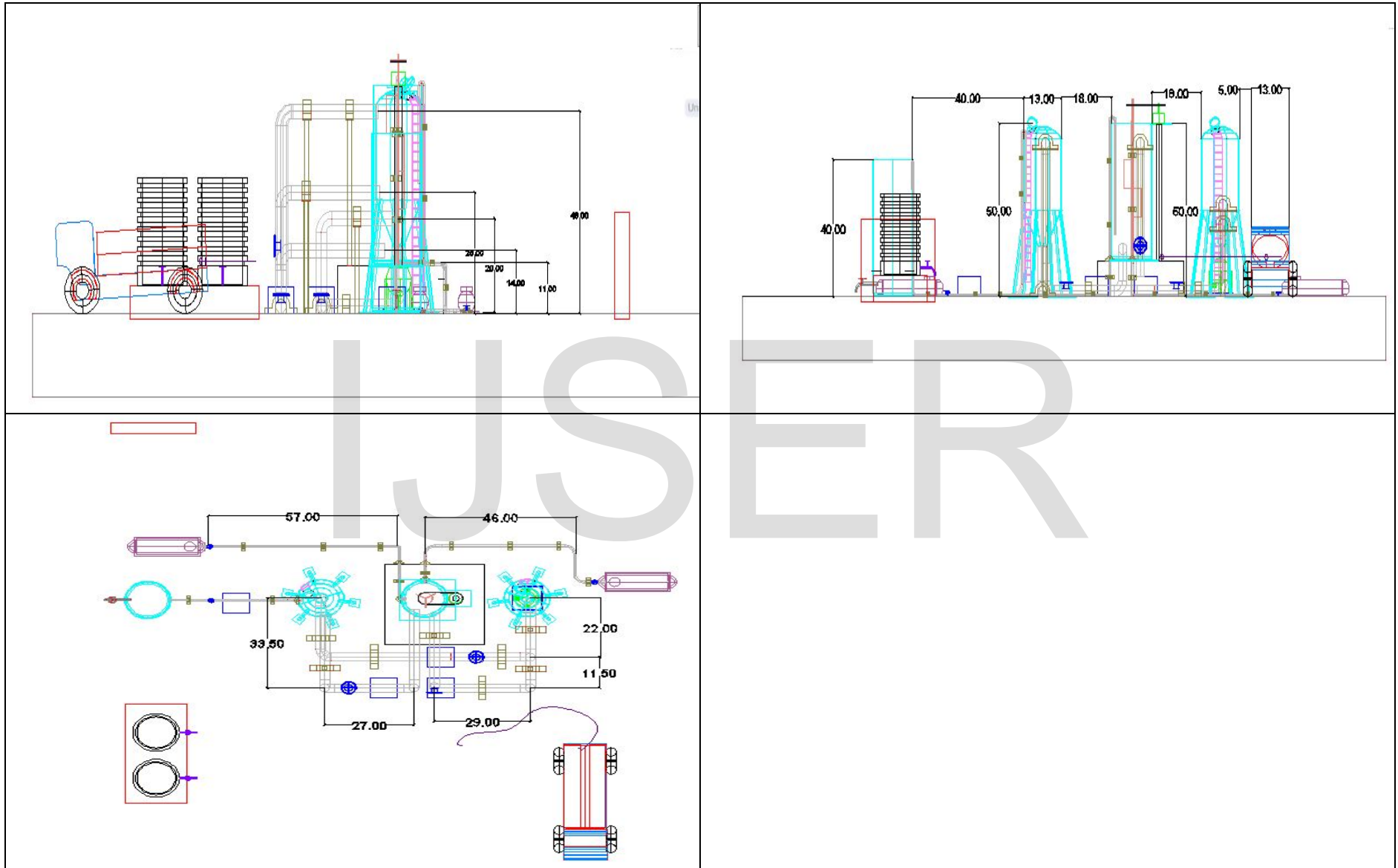

Fig.4. Shows the third angle projection of the designed spent metalworking fluids treatment plant.