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Design, Fabrication and Performance Evaluation of The Dewatering Machine for Bio-Digestate

by

Sujan Jojiju

A THESIS

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The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled "Design, Fabrication and Performance Evaluation of dewatering machine for bio digestate." submitted by Sujan Jojiju in partial fulfillment of the requirements for the degree of Master in Renewable Energy Engineering.

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ABSTRACT

The report entitled “DESIGN, FABRICATION AND TESTING OF DEWATERING MACHINE FOR BIODIGESTATE” is intended to modify the design of dewatering machine fabricated by Sherpa et al., 2017. and modify the design and fabricate and conduct performance evaluation.

In Nepal there is a huge need for the fertilizer and dewatering of the bio digested from the biogas could be an alternative for replacement of the imported chemical fertilizers with the organic fertilizer.

The dewatering machine is modified based on the literature review, recommendation from the previous studies and consultation with the experts. The design has been made in the “SOLIDWORKS” software. The modifications were fabricated at GRIT engineering works pvt ltd. The slurry for the testing was obtained from Organic farm house, Kapan. The major modifications were 5 Hp motor with 1440 rpm and gear with reduction of 1:40, spring assembly system at the end of the outlet and sieve.

The testing and performance analysis were carried out at different operating speeds i.e. 36, 25, 16, 12, 10 and 8 rpm with the help of Variable Frequency Drive (VFD).

The result shows that the capacity of the dewatering machine is 79.90 kg/hr. and the optimum operating speed for the dewatering process was to be 10 rpm. The liquid yield, extraction efficiency and extraction losses were found to be 90.77%, 71.64% and 26.30%. The installation cost of the dewatering machine is NRs 384000 and the payback period, internal rate of return and net present value is calculated as 2 years 6 month 4 days, 28.53% and Nrs 179006.35 respectively.

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LIST OF SYMBOLS

ρ_{sy}	Density of slurry (kg/m^3)
ρ_{ms}	Density of mild steel (kg/m^3)
NPV	Net Present Value
IRR	Internal Rate of Return
d_f	Diameter of flights (mm)
M_i	Initial Moisture content (%)
D_{sv}	Diameter of sieve (mm)
t_f	Thickness of flights (mm)
A_{sl}	Area of slots
L	Length of screw shaft (mm)
g	Acceleration due to gravity (m/s^2)
d_{min}	Minimum diameter of screw (mm)
d_{max}	Maximum diameter of screw (mm)
I_{int}	Interruptions length after each rotation (mm)
V_h	Capacity of hopper (ltrs)
T_m	Mean lead of screw (mm)
c	correction factor
F_{mt}	Material Factor per kW
P_o	Optimum pressure to separate slurry (MPa)
M	Mass (kg)
V	Volume
V_m	Mean peripheral velocity (m/s)

N	RPM of the screw
Q	Throughput Capacity (kg/hr)
N_{fr}	Normal frictional force (kN)
P	Power (kW)
μ	Coefficient of Friction
η	Efficiency
ψ	Filling coefficient
β	Tapered angle of screw shaft (°)
α	Taper angle of choking mechanism (°)

LIST OF ABBREVIATION

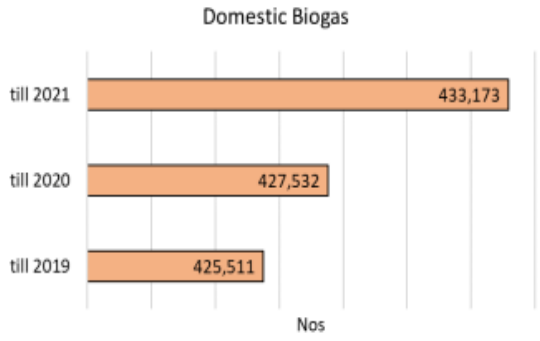
AEPC	Alternative Energy Promotion Center
C/N ratio	Carbon to Nitrogen ratio
CBS	Central Bureau of Statistics
DAME	Department of Mechanical and Aerospace Engineering
GI	Galvanized Iron
HP	Horse Power
IOE	Institute of Engineering
IRR	Internal Rate of Return
K	Potassium
Kg	Kilograms
MPa	Mega Pascal
N	Nitrogen
MoALD	Ministry of Agriculture and Livestock Development
MT	Metric Tonne
NRs	Nepalese Rupees
NPC	National Planning Commission
NPV	Net Present Value
P	Phosphorus
TSC	Total Solid Content
VFD	Variable Frequency Drive
WECS	Water and Energy Commission Secretariat

CHAPTER ONE: INTRODUCTION

1.1 Background

Biogas plants are based on the phenomenon of biological decomposition of organic materials in the absence of air. For biogas production, main inputs are manure and sewage, straw, households and industrial organic waste, maize and grass silage. The byproduct of the biogas plant is called slurry which can be used as a high nutrient fertilizer. Biogas slurry has high water content of almost 90%, which arises the concern of dewatering and drying before using in agriculture.

In case of Nepal, 433,173 domestic biogas plant and 343 large size biogas plant have been constructed in different parts of the country (WECS, 2021). As shown in the figure 1 Terai has the largest share of 51.99% of the installed domestic biogas plant and Bagmati province has highest installed share of 25.88%.



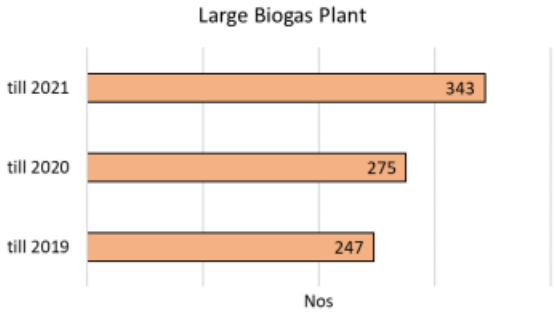
Province	Installed Share
Province 1	15.50%
Madhesh	6.30%
Bagmati	25.88%
Gandaki	18.88%
Lumbini	18.85%
Karnali	1.48%
Sudurpashchim	13.11%

Region	Installed Share
Terai	51.99%
Hill	46.05%
Mountain	1.96%

Figure 1 Installation of domestic biogas plant until 2021

Source: Energy Sector Synopsis Report 2021/22 (WECS, 2021)

Similarly, the installation of large biogas plant is prevalent in Terai (52%) and Hills (47%) with no significant installation in Mountain region as shown in figure 2. There has been commercial scale like in Pokhara, Nawalparasi and Syangja with 4,200 m^3 3,750 m^3 and 3,500 m^3 plant capacity respectively.



Province	Installed Share
Province 1	39%
Madhesh	6%
Bagmati	24%
Gandaki	24%
Lumbini	7%
Karnali	0%
Sudurpashchim	1%

Region	Installed Share
Terai	52%
Hill	47%
Mountain	1%

Figure 2 Installation of large biogas plant until 2021

Source: Energy Sector Synopsis Report 2021/22 (WECS, 2021)

Also, the fifteen periodic plans of the Government of Nepal have targeted to install further 200,000 domestic biogas plant and 500 large size biogas plant. (NPC, 2019). These biogas plants have high potential of slurry production. Slurry does not have any negative impact on environment. Use of slurry can also reduce financial transaction on imported fertilizers and hence profitably can be returned to the agricultural system. The utilization of slurry makes biogas technology a sustainable rural energy. It saves traditional fuel as well as fulfills the demand of chemical fertilizer.

Dewatering of slurry is a process to reduce the moisture content in the slurry output. Dewatered slurry can be managed as a solid material, rather than as a liquid material, and hence can be easily transported, stored, managed and used. Among various dewatering technologies such as centrifugal press, belt filter, screw press dewatering technology is widely used for high and low concentration sludge.

1.2 Research objective

The main objective of the study is to design, fabricate and conduct performance and financial evaluation of dewatering machine for drying of the biogas slurry.

The specific objectives are

i. To modify design and fabricate the dewatering machine.
ii. To conduct performance evaluation of the dewatering machine.
iii. To conduct financial assessment of the dewatering machine.

1.3 Problem statement

Slurry from biogas plant has a high moisture in nature and hence cause difficulty in handling, managing and transportation. Due to lack of dewatering technology, the handling and use of slurry is limited to nearby area where the biogas plant is located even then there is loss in quality. The traditional ways of dewatering of slurry takes more time and requires large storage space hence makes the slurry unviable for commercial uses.

The prototype manufactured by Department of Mechanical and Aerospace Engineering has problem with spillage due to clearance between screw and the sieve, which was more than 5mm. This also resulted in low compression pressure inside the screw. And although the liquid extraction efficiency was 80.177%, the number of tests carried out at different four rpm and result obtained is not enough for claiming the consistency of the dewatering machine. Moreover, the dewatering machine is mostly used for the dewatering of the biogas slurry and using the solid cake as well as liquid extracts as organic fertilizers.

1.4 Limitation

The study focuses on dewatering and slurry obtained from anaerobic digestion of organic waste. It does not consider the effect and segregation of inorganic waste like plastics, glass etc. in the biogas digester.

CHAPTER TWO: LITERATURE REVIEW

2.1 Biogas slurry

Biogas slurry is the final outcome of the anaerobic digestion in the biogas plant. This bio slurry has high organic content which is beneficial for use in agriculture as organic fertilizer. The slurry from the biogas plant contains around 93% and 7% water and dry matter respectively. Out of the dry matter, 4.5% is organic and 2.5% inorganic (Kumar et al., Biogas Slurry: Source of Nutrients for Eco-friendly Agriculture, 2015) And the biogas slurry contains phosphorus, potassium, zinc, iron, manganese and copper. The digested slurry contains 1.6%Nitrogen, 1.55% Phosphorous and 1.00% Potassium and slurry compost comprises of 0.75% of Nitrogen , 0.65% Phosphorous and 1.05% Potassium (Karki, 2006). If the slurry is mixed with organic fertilizers the combination becomes more effective. The combination increases the Carbon/Nitrogen (C/N) ratio and enhances the yield of cotton, wheat, maize and rice by 6.5%, 8.9%, 15.2% and 15.9% respectively (Kumar et al., Biogas Slurry: Source of Nutrients for Eco-friendly Agriculture, 2015).

Biogas slurry could be used as an organic fertilizer. It has the ability to produce a significant amount of macro and micro nutrients, as well as significant amounts of organic matter. In comparison to synthetic fertilizers, it has a low level of heavy metals and is rich in nutrients. Biogas slurry (Dry-DBGS & Wet-DBGS) is environmentally safe, has no hazardous or adverse consequences, and can effectively cut chemical fertilizer use by 15 to 25%.

As shown in figure 3, the Bio Gas Slurry (BGS) has various benefits such as for bio-pesticide activities, promotes growth of beneficial microbes, improve level of bio-chemical in plants, maintain physio-chemical properties of soil, source of macro/micro-nutrients. These overall improves the health of the plant.

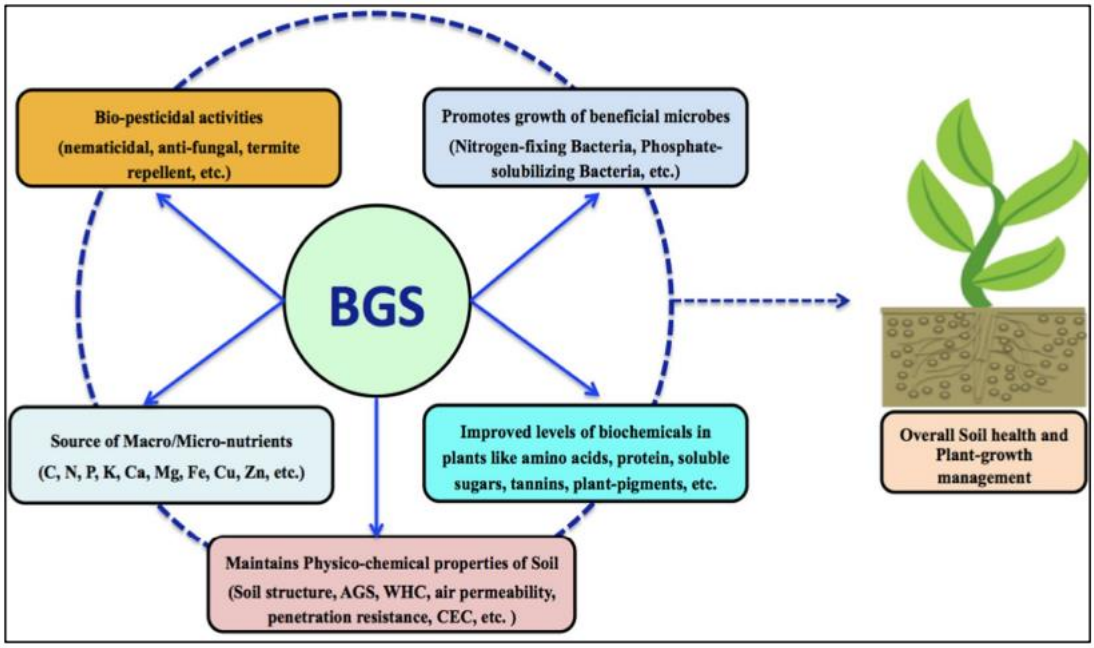


Figure 3 Various Benefits of Bio Gas Slurry (BGS)

Source: (Kumar et al., Overview on agricultural potentials of biogas slurry: applications, challenges, and solutions, 2021)

The use of biogas slurry is seen in the manure production as well. According to the Commercial Livestock Integrated Survey,2021, as shown in Figure 4, in total 258 farms are reported to produce manure from biogas slurry. The highest number of farms producing manure from biogas slurry was in Lumbini Province where as no farms in Karnali Province.

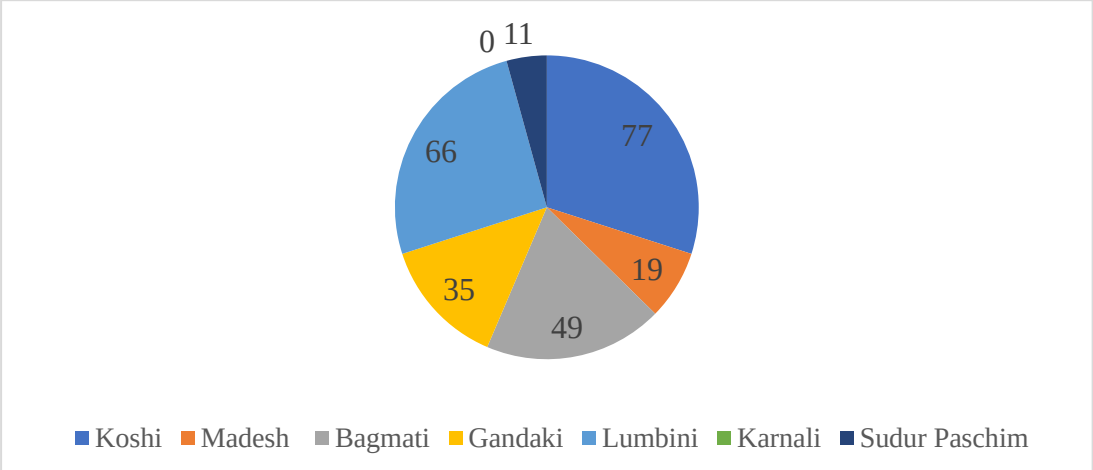


Figure 4 Number of Farm reporting manure production by biogas slurry in various provinces in Nepal

Source: Commercial Livestock Integrated Survey (CBS and MoALD, 2021)

2.2 Dewatering technology

Dewatering technology separates the moisture content in the slurry and hence improve the utilization of the bio slurry along with making it commercially viable as the organic fertilizer. The several advantages of the dewatering of the slurry are

- Decrease volume, and lowers storage and transportation cost
- Produces a material which helps in composting.
- Removes ponding and runoff
- Optimize air drying

2.3 Types of dewatering technology

There are several methods for drying the slurry rather than becoming fully dependent on the traditional solar drying methods. Some of the methods for dewatering of slurry are:

a. Centrifugal Press
b. Belt filter Press
c. Rotary Drum Filters

2.3.1 Centrifuge Press

Centrifugal Press uses force from rapid rotation of a cylindrical bowl in order to separate solids and liquid in waste. This action produces a non-liquid material called as “cake.” Centrifuges remove solids with the help of a scroll conveyor and remove liquid over the weir. The schematic diagram of the centrifuge is presented in Figure 5.

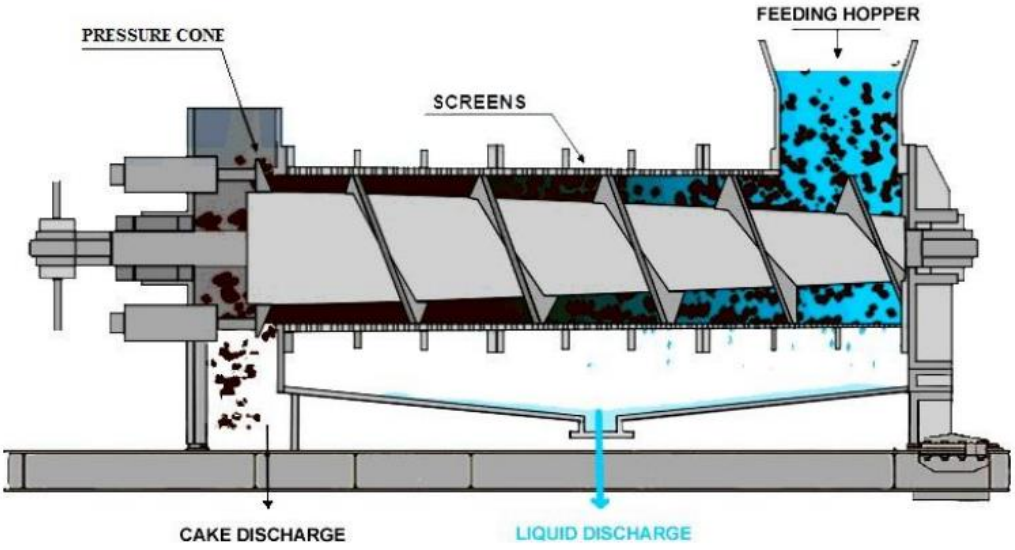


Figure 5: Schematic diagram of centrifugal press

Centrifuge press is one of the upcoming technologies for dewatering of waste water that can be implemented in biogas plant for drying of slurry. The major advantage of the centrifuge press over others are

- It has lower operation and maintenance costs
- It requires less space.
- It requires less attention of operator.
- It has low exposure to aerosols, pathogens and odors.
- It is easy to clean.
- It can manage high design loadings.
- It can achieve higher percent solids recovery.
- It is easy for maintenance.

2.3.2 Belt filter presses

The belt filter press is a type of machine that is used to dewater sludges, particularly in industries and waste water treatment plants. This process can be used to dewater biogas sludge as well. It consists of a cloth support, filtrate collector, and cake conveyor that moves in a continuous grooved rubber belt. The slurry may be put onto the filter at a constant rate as the belt is moving continually. It is common to direct this slurry flow

against the direction of belt travel in order to obtain a proper distribution of solids. The schematic diagram of the belt filter press is shown in Figure 6.

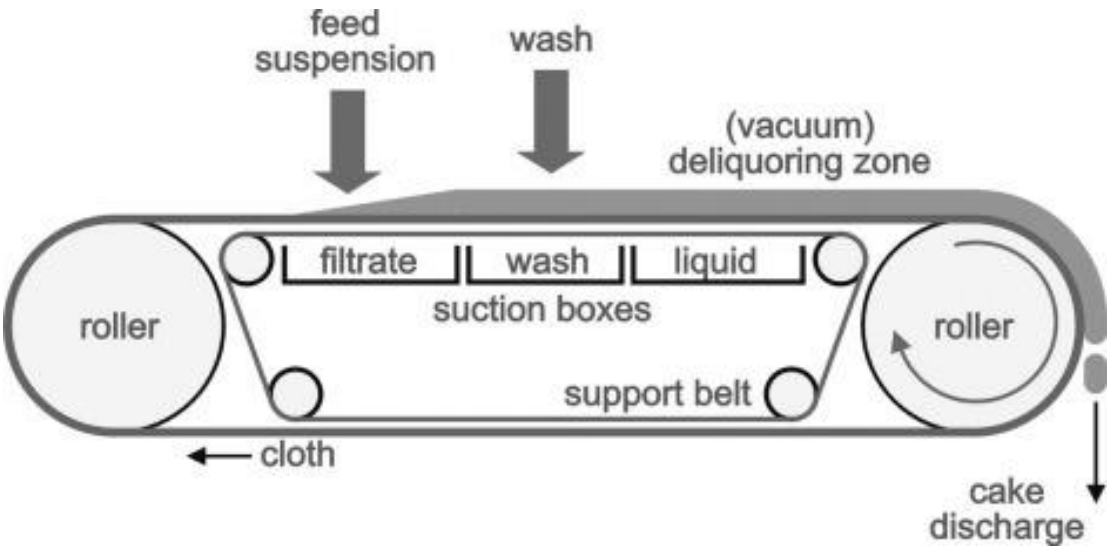


Figure 6: Schematic diagram of belt filter press

In filtered water the solid contents in wet slurry is around 6-10% which can be increased to 25% after dewatering from the belt press filter. The moisture content in case of belt press watering can reduce the moisture content up to 79%. The advantages of belt press filter are

- It is simple and reliable, requires low staffing, easy maintenance and a long life.
- It is designed to handle excess capacity and has high-capacity throughput.
- It has minimum initial costs and low energy operating cost.

2.3.3 Rotary drum filters

Rotary Vacuum Filter Drum is a cylindrical filter membrane, partly sub-merged in a slurry. With the rotation of the drum, the liquid is absorbed through the membrane. This results in separation of cake on the membrane surface. A blade is used to scrape the product from the surface. The schematic diagram of the rotary drum filter is shown in Figure 7.

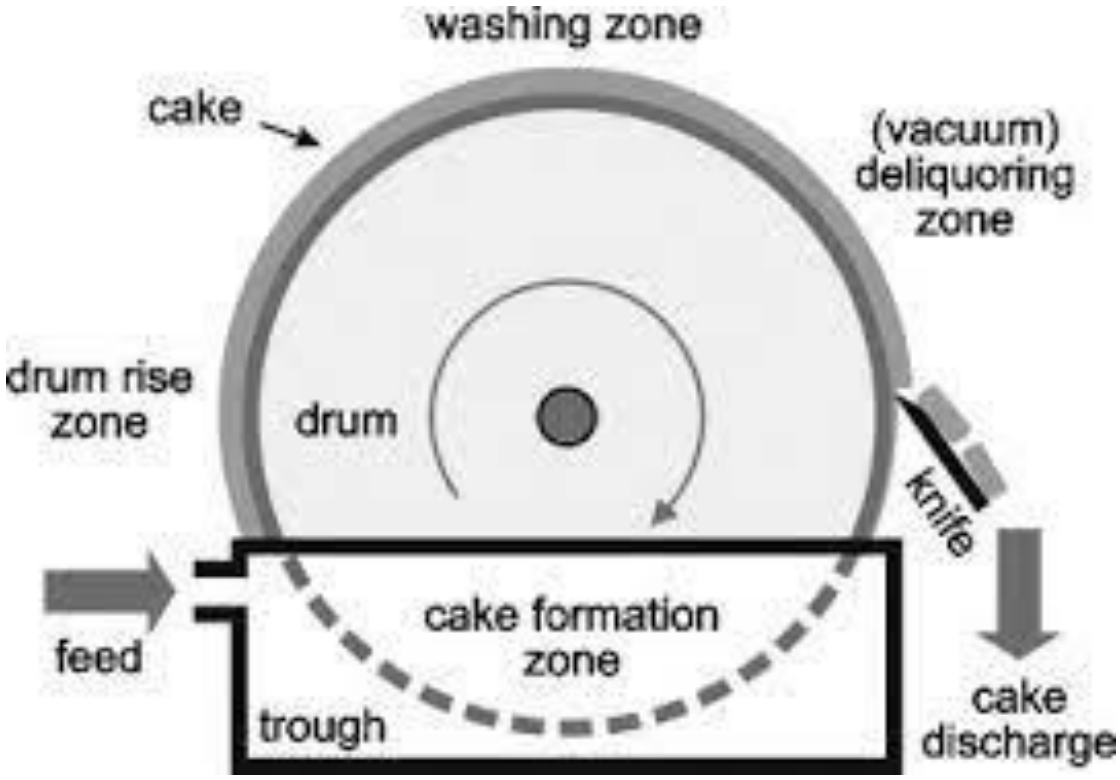


Figure 7: Schematic diagram of rotary drum filter

The positive aspect of rotary drum filter are

- It is a continuous operation and hence operating cost is low.
- It can control the thickness of cake with the variation of rotating speed of drum.
- Its' process can be easily modified.
- It produces relatively clean product.

2.3.4 Selection of Dewatering Technology

The characteristics of the dewatering technology varies according to different attributes such as cake dryness, solid recovery, drying time, operating cost, maintenance required and so on. The comparison of different dewatering technologies is mentioned in table 1 :-

Table 1 Comparison of different dewatering technologies

Type	Cake dryness	Solid Recovery	Process/Drying time	Operating Cost	Capital Cost	Chemical
	% solid	% solid capture	time (measurement)			usage
Vacuum Filters	16 - 45	85 – 95	Fast (minutes or hours)	High	Moderate	Moderate
Filter Presses	40 -60	80 – 95	Very fast (minutes or months)	High	High	High
Centrifuges	20 – 35	85 – 90	Fast (minutes or hour)	Moderate	Low	High
Drying Beds	25-60	90-100	Slow (weeks or months)	Very low	Low	Low
Sludge lagoons	20-40	90-100	Very slow (months or years)	None	Very Low	None
Gravity / Low Pressure	10-50	90-96	Moderate (days or weeks)	Low	Moderate	

Source: (Global Spec, 2023)

2.4 Performance evaluation

The performance evaluation of the dewatering machine is required. Various physical parameters like pH value, moisture content, solid content etc. along with chemical properties like nitrogen, phosphorous, potassium in slurry before and after dewatering etc, is required for better understanding.

While most of the parameters can be measured using various equipment's, some require mathematical formulas. Some of those parameters are

2.4.1 Moisture content

The moisture content in the sample shall be evaluated by comparing the weight of the slurry before and after drying. The loss of weight of the sample gives the moisture content. (Banik and Nandi, 2000). Mathematically,

$$\% \, moisture = \frac{B - C}{B - A} \, x \, 100$$

Where,

A= Wt. of container

B= Wt. of container + wt. of sample before dewatering

C= Wt. of container + wt. of sample after dewatering

2.4.2 Determination of total solid

$$Total \; Solid = \frac{C-A}{B-A} \, x \, 100$$ (Orhorhoro, 2017)

Where,

A= Wt. of container

B= Wt. of container + wt. of wet slurry

C= Wt. of container + wt. of oven dried slurry

2.4.3 Determination of volatile solid

$$\% \, volatile \; solid = \frac{B-C}{B-A} \, x \, 100$$ (Orhorhoro, 2017)

Where,

A= Wt. of silica crucible

B= Wt. of crucible + dry matter before ignition

C= Wt. of crucible + sample after ignition

2.4.4 Liquid Yield, Extraction efficiency and extraction loss

$L_y = \frac{100 \times W_{le}\%}{W_{le} + W_{rw}}$ (Olaniyan and Oje, 2011)

$L_e = \frac{100 \times W_{le}\%}{x \, W_{fs}}$ (Olaniyan and Oje, 2011)

$E_l = \frac{100 \times [W_{fs} - (W_{le} + W_{rw})]\%}{W_{fs}}$ (Olaniyan and Oje, 2011)

Where,

W_{le} = Liquid extracted (kg)

W_{rw} = Residual Liquid in output cake (kg)

W_{fs} = Feed sample (kg)

L_y = Liquid yield (%)

L_e = Extraction Efficiency (%)

E_l = Extraction loss (%)

The liquid constant is the ration of sum of liquid extracted and liquid in the cake output cake to the mass of slurry fed in.

$$x = \frac{W_{le} + W_{lc}}{W_{fs}}$$

2.5 Screw Press Dewatering Machine

Various screw press machines have been invented for various applications. For the dewatering of the biogas slurry from a cow dung, a study considering the output of the solid residues with Total Solid Content (TSC) 35 % and designed a screw press with 1.2 ton per hour, with 8 rpm and factor of safety 2.5. The optimal size of the perforation was found to be ϕ 3mm, optimum wire mesh size is 0.77 × 0.77 mm, and best screen hole size for filtering was found to be ϕ 3.00 mm with 40% solid waste collected. (Kataria, Hardik, & Pankit, 2018).

The dewatering parameters of the SP23 screw press machine such as rotational speed and counter pressure near the discharge end affects the dewatering efficiency. Also, the freeness of the feed stock and consistency are important parameters to be considered for a screw press performance. (Idrissi et al., 2019)

Similarly, the moisture content in a slurry and shaft speed of the screw is crucial for dewatering. The dewatering efficiency of 81.82% and dewatering rate of 49.38kg/hr, with separated solid fertilizer of 10.7% TSC, and liquid fertilizer with total solid content 4.07 were obtained. The maximum dewatering efficiency of 81.82% and moisture content 80-85% was obtained at speed of 40 rpm. Similarly, maximum dewatering rate of 49.38 kg per hour for 85-90% moisture content and 30 rpm shaft speed indicates moisture content and shaft speed as important indicators. (More, Agrawal, & Sharma, 2023)

The initial water content, back pressure, rotational speed is important for water removal. Similarly, rotational speed, back pressure and initial water content is important for screw press manufacturing. The optimal values were initial water content of 55%, speed of 30 rev/min and 5 kPa back pressure at the outlet. (Fu, Dou, Zhang, & Li, 2023)

The biogas slurry dewatering machine designed and fabricated by Department of Mechanical and Aerospace Engineering in 2017 has the following design specification and assumptions: -

Table 2 Design Specifications and Assumptions

S.No	Items	Conditions and Assumptions
1.	Slurry	Cow dung biogas plant effluent
2.	Slurry density, ρ_{sy} (kg/m^3)	1100
3.	Density of Mild Steel, ρ_{ms} (kg/m^3)	7850
4.	Thickness of flights, t_f (mm)	6
5.	Diameter of flight, d_f (mm)	160
6.	Initial moisture content, Mi (%) w.b	95.03%
7.	Diameter of sieve, d_{sv} (mm)	162
8.	Hole of sieve (mm)	0.7
9.	Total length of screw, L (mm)	920
10.	Minimum diameter of screw, d_{min} (mm)	80 (for tapered section)
11.	Maximum diameter of screw, d_{max}(mm)	160 for tapered section)
12.	Interruptions length after each rotation, l_i (mm)	20
13.	Taper angle of choking mechanism, α (°)	45

14.	Capacity of hopper, V_h (ltrs)	7
15.	Tapered angle of screw shaft, β (°)	2.973
16.	Mean lead of screw, T_m (mm)	69
17.	Acceleration due to gravity, g (m/s^2)	9.81
18.	Correction factor, c	0.7
19.	Filling coefficient of the screw cross section, ψ	0.125
20.	Material Factor per kW, F_{mt}	0.6
21.	Optimum pressure to separate slurry, P_o (Mpa)	1.74
22.	Coefficient of Friction, μ	0.0035

Source: (Sherpa, Sharma, & Panthi, 2017)

The dewatering machine designed, fabricated and tested for biogas plant effluent, powered by 1hp electric motor. (Figure 8). This machine has liquid yield and liquid extraction efficiency of 91.39% and 80.177% respectively at operating speed of 10 rpm. The production capacity of the developed dewatering machine was found to be about 16.4 kg/hr.

The recommendations were use of Stainless-Steel Screen for longer life, three phase electric motor instead of single-phase electric motor could be used, pre-thickening of the slurry will further improve the output obtained at outlet, decreasing the load on the machine. The dimensions of the components of machine-like screw were not accurate because of machining error. (Sherpa, Sharma, & Panthi, 2017)

Figure 8 Assembled Dewatering Machine

Source: (Sherpa, Sharma, & Panthi, 2017)

The dewatering machine manufactured by Sherpa, Sharma and Panthi in 2017 had problem with pressure build up, the supporting cage manufactured was not strong enough to hold the pressure developed, and bulging of the sieve was observed. Also, the motor 1 hp was not able to run the pulley system and slippage occurred during the

operation. The manufactured machine was in poor condition with no upper sieve and motor and rusted screw and other parts.

CHAPTER THREE: METHODOLOGY

3.1 Methodological Flowchart

The detailed methodology that shall be followed during the study "Design, Fabrication, and Performance Evaluation of the Dewatering Systems for Bio-Digestate" is shown in figure 9.

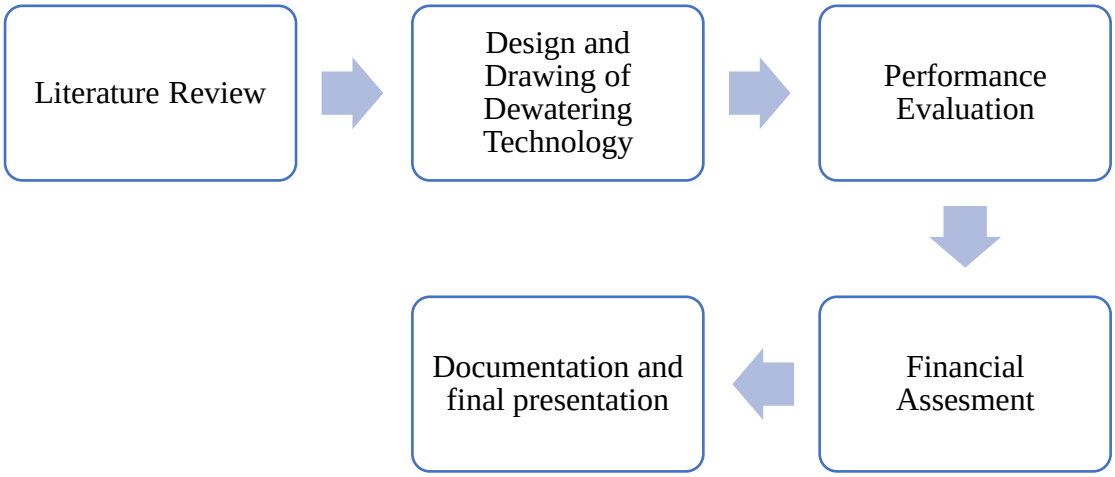


Figure 9 Methodological flowchart

The study shall begin with the literature review and will continue throughout the research. Various design parameter, guidelines for the design and installation of dewatering technology was studied.

3.2 Modeling and Design

3.2.1 Conceptual Design

The primary design with modifications was completed using the SOLIDWORKS design software. The figure 10 below shows the conceptual design:

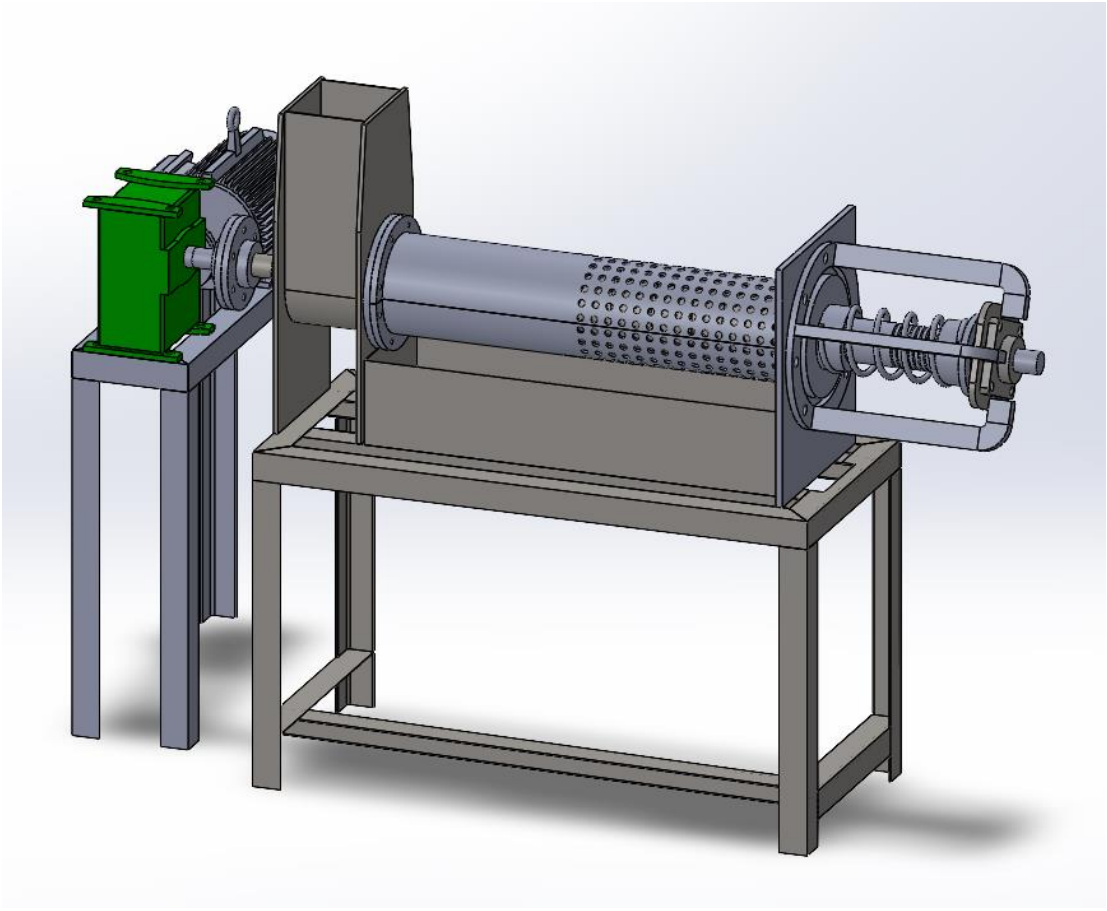


Figure 10 Conceptual design of dewatering machine

3.2.2 Visual inspection and review of performance of Biogas slurry dewatering machine

3.2.3 Frame Analysis and displacement

The stress analysis of the frame was carried by DMAE in 2017 and the maximum stress calculated was 1.134×10^8 N/m^2. And the maximum displacement in the frame is at the center of the angles and calculated as 0.6533 mm. (Sherpa, Sharma, & Panthi, 2017)

3.2.4 Detail Design modifications

3.2.4.1 Power requirement

The power required by the screw conveyor depends upon various frictions between materials such as: (Kataria, Hardik, & Pankit, 2018)

a. the casing and the transported material
b. the screw and the transported material
c. the intermediate and in the end bearing and hence on type of bearings installed.

d. In axial bearing owing to axial force
e. Additional resistance

As per Sherpa P. et al., 2017 the power requirement consideration calculated has considered the followings:

i. to overcome inertia of the shaft and screw
ii. to convey the slurry along length of the screw,
iii. to convey the slurry along length of the press,
iv. to press and separate liquid from the biogas effluent slurry, and
v. to compensate for friction and other losses.

3.2.4.1.1 Power required to overcome the inertia

The volume of Shaft; Volume, $V = \pi r^2 l$

For the 150mm length hollow cylinder section,

$$V_i = \pi \times 150 \times (40^2 - 34^2)\ mm^3$$

$$= 2.0923 \times 10^{-4}\ m^3$$

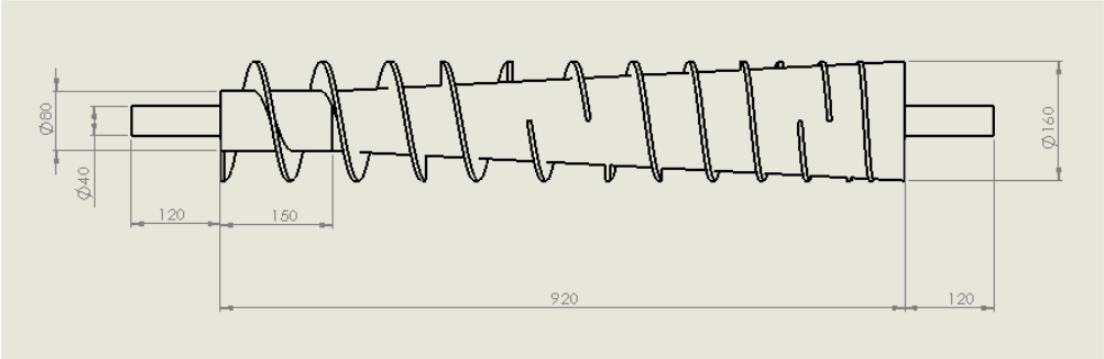


Figure 11 Drawing of screw

For the 770 mm hollow tapered cylinder section,

$$V_{ii} = \pi \times \frac{770}{3}\{(40^2 + 80^2 40 \times 80) - (34^2 + 74^2 + 34 \times 74)\}\ mm^3$$

$$= 1.65 \times 10^{-3}\ m^3$$

For the 40 mm shaft,

$V_{iii} = \pi \times 20^2 \times 1160\ mm^3$

$= 1.457 \times 10^{-3}\ m^3$

Now, Total Volume, $V = V_i + V_{ii} + V_{iii} = 3.317 \times 10^{-3}\ m^3$

Mass of the shaft, $M_s = 7850\ (\frac{kg}{m^3}) \times 3.137 \times 10^{-3}(m^3) = 26.036$ kg.

The screw press has 10 flights with a thickness of 6 mm. The flight has diameter of 160 mm. They are connected by hollow drive shaft with volume $3.317 \times 10^{-3}\ m^3$.

Net Vol of flight $V_{net} = (\pi \times 10 \times 0.006 \times 0.08^2 - 1.24 \times 10^{-4})\ mm^3$

$V_{net} = 1.082 \times 10^{-3}\ m^3$.

Mass of the flights, $M_T = 1.082 \times 10^{-3} \times 7850 = 8.49$ kg

Now, Mass of the flights and Mass of the shaft = 26.036 + 8.49 = 34.526 kg

Power = weight × Mean velocity(v_m)

$v_m = T_m \times N/60$

$= (0.069 \times 10) / 60 = 0.115 m/s$

Hence, Power required, **$P_1 = (34.526 \times 9.81) \times 0.0115 = 0.003895$ kW**

3.2.4.1.2 Power Required to convey the biogas effluent slurry

The throughput capacity of the screw press,

$Q = 15\ \pi\ d^2\ t_m\ N\ \psi\ \rho_{sl}\ c$ in kg/hr (Spirakovski and Dyachkov, 1983)

where,

d = screw diameter

t_m = lead of the screw

N = speed

C = correction factor

ψ = filling coefficient (0.125)

ρ_{sl} = 1100 kg/m^3

Thus, Q = 15 × π ×0.16^2 × 0.069 × 10 × 0.125 × 1100 × 0.7 = 79.907 kg/hr

Power required to convey the slurry,

$P_2 = Q\ L\ \rho_{sl}\ F_{mt} / 168547$

Where,

Q is the conveying capacity

L is the projected length of the screw conveyor (0.92m)

F_{mt} is the material factor per kW

P_2 = 79.907 × 0.92 × 1100 × 0.6 / 168547

= **0.28787 kW**

3.2.4.1.3 Power required to press and separate slurry

The optimum pressure to separate biogas effluent slurry into solid and liquid constituents is approximately 1.74 MPa (Mudryk,2016). Let the compression pressure is 60 % of optimum pressure = 1.74 * 0.4 = 0.696 MPa.

Power to separate, $P = F\ V_m$

Where,

F = Force required to separate the slurry

V_m = Mean velocity

But F = pressure × Total surface area

$V_m = t_m\ N/60$ where t_m is pitch of the screw

= (0.069 × 10)/60

= 0.0115 m/s

Curved Surface area of the drive shaft = 0.3277 m^2

Total area of flights are calculated as

Area of 1st flight = π × 0.08^2 – π × 0.04^2 = 0.0151 m^2

Area of 2nd flight = $\pi \times 0.08^2 - \pi \times 0.04^2 = 0.0151\ m^2$

Area of 3rd flight = $\pi \times 0.08^2 - \pi \times 0.04525^2 = 0.0137\ m^2$

Area of 4th flight = $\pi \times 0.08^2 - \pi \times 0.05095^2 = 0.01195\ m^2$

Area of 5th flight = $\pi \times 0.08^2 - \pi \times 0.005665^2 = 0.01\ m^2$

Area of 6th flight = $\pi \times 0.08^2 - \pi \times 0.06184^2 = 0.00809\ m^2$

Area of 7th flight = $\pi \times 0.08^2 - \pi \times 0.00665^2 = 0.000621\ m^2$

Area of 8th flight = $\pi \times 0.08^2 - \pi \times 0.0705^2 = 0.000449\ m^2$

Area of 9th flight = $\pi \times 0.08^2 - \pi \times 0.07425^2 = 0.00278\ m^2$

Area of 10th flight = $\pi \times 0.08^2 - \pi \times 0.0774^2 = 0.00128\ m^2$

Therefore, total area = sum of area of 10 flights

Total area of flights = $0.0891\ m^2$

Since, the effective area = total area / 2

Effective total area = 0.0891 /2 = $0.04455\ m^2$.

Total force required = pressure × total area

= 0.696 (MPa) × 0.04455 (m^2) = 31.0068 kN

Therefore, Power required to press and separate slurry = $F \times V_m$

= 31.0068 × 0.0115

P_3 = 0.3565782 kW

3.2.4.1.4 Power required to overcome friction and other losses

Frictional force = $\mu \times N_{fr}$ = 0.035 × 31.0068 × cos 30 = 0.93984 kN

Power Required to overcome friction P = 0.93984 × 0.0115 = 0.010808 kW

Considering other losses as 10% of frictional loss,

then P_4 = 0.006505 × 1.1 = 0.011889 kW

3.2.4.1.5 Overall Power required

$$P = P_1 + P_2 + P_3 + P_4$$

P = **0.003895 + 0.28787 + 0.3565782 + 0.011889**

= 0.7672332 kW

P = 1.02846 hp

Considering 10% on additional compensation

P = 1.02846 + 10% of 1.2846

P = 1.1313 hp

Therefore, the power of the motor shall be greater than 1.1313 hp ie 2 horse power electric motor is considered.

3.2.4.2 Sieve modification

When measured the gap between the screw and the sieve, it was found more than 5mm i.e around 6mm and leakage of the slurry through that gap was seen. This resulted in loss in compression pressure. Also, the frame of the sieve was very weak that it easily bulged out when the pressure developed inside the machine increased during dewatering.

The frame of the sieve was strengthened using lateral/ vertical members with proper bracings. The gap between the screw and sieve was reduced to a minimum value as the fabrication allows i.e., to 1mm. Also, another 120-mesh stainless steel sieve (125 microns wire mesh) is added above the existing 0.6mm sieve to retain the solid particles inside the machine. But during the dry test the 120 – mesh stainless steel sieve torn out as shown in fig 12.

Figure 12 Torn out 125 microns wire mesh

3.2.4.3 Spring Compression mechanism at outlet

Compression was not provided at the end of the screw causing low pressure build up inside the machine. This pressure was not enough to reduce the moisture content of the slurry.

The spring compression mechanism was added at the end of the screw in order to increase the pressure inside the machine to extract as much liquid as possible. The spring assembly is shown in fig 13 and the detail dimensions of the spring assembly are shown in fig 14.

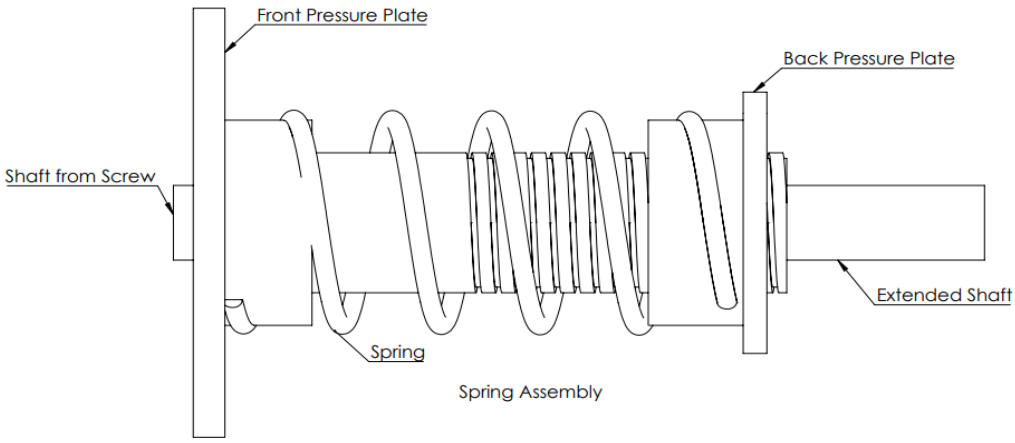


Figure 13 Spring assembly

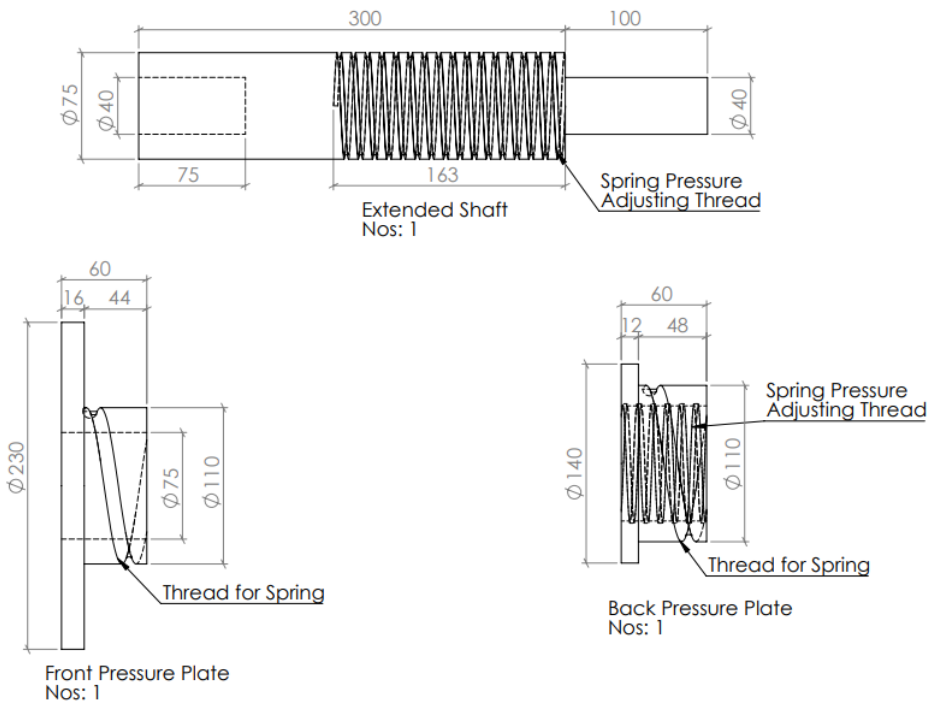


Figure 14 Detail dimension of spring

3.2.5 Drawing of dewatering machine

The detail design modification of the selected dewatering machine was considered in order to overcome the problem in existing machine. The schematic drawing indicating different parts of the dewatering machine and their specifications of old and modified design are shown in figure 15, figure 16 and figure 18respectively. The detail drawing of the 1st and 2nd modified dewatering machine are shown in figure 17 and figure 19 respectively.

The major parts of dewatering technology like feeding hooper (wet slurry entry point), cake discharge (dry slurry exit point), liquid discharge etc. shall be detailed out in the schematic diagram shown in figure 22.

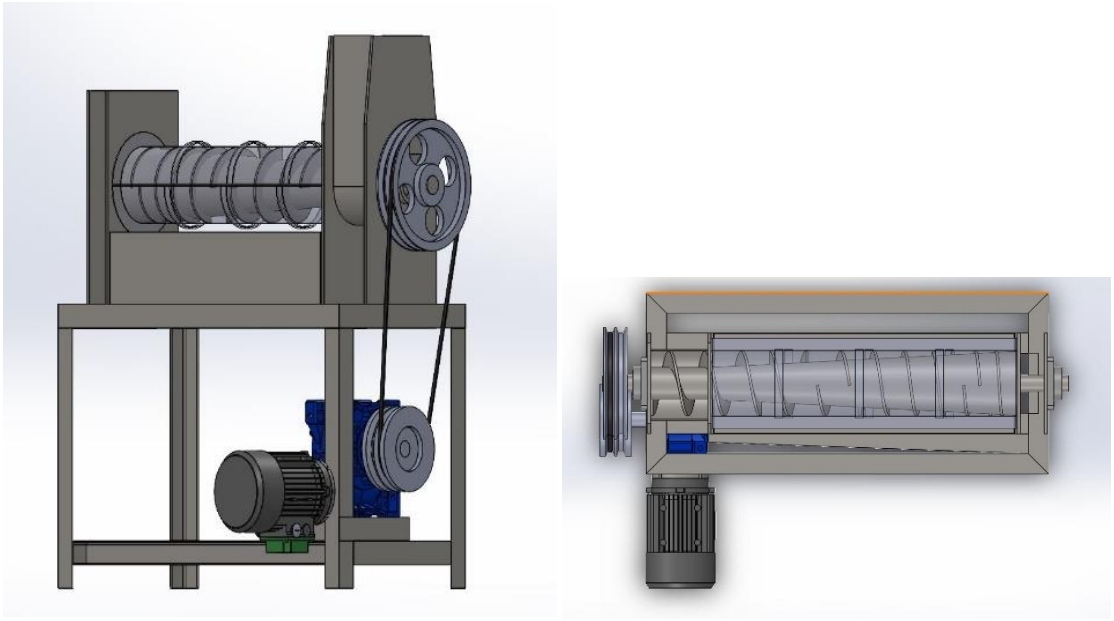


Figure 15 Old design of dewatering machine

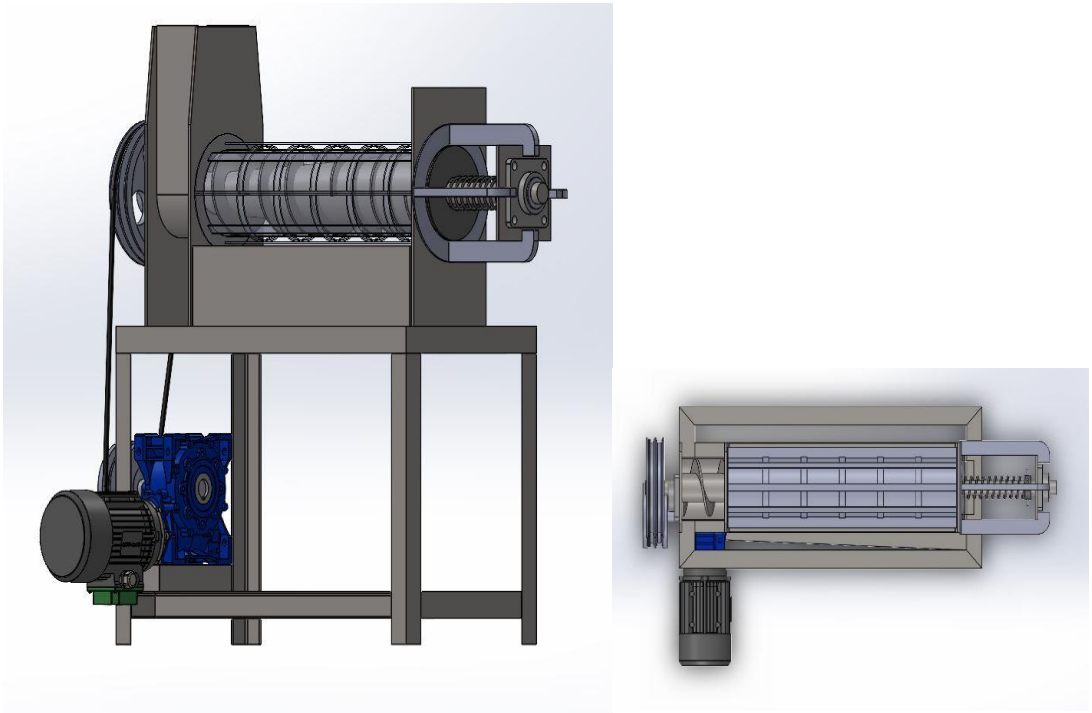


Figure 16 1st Modified Design of dewatering machine

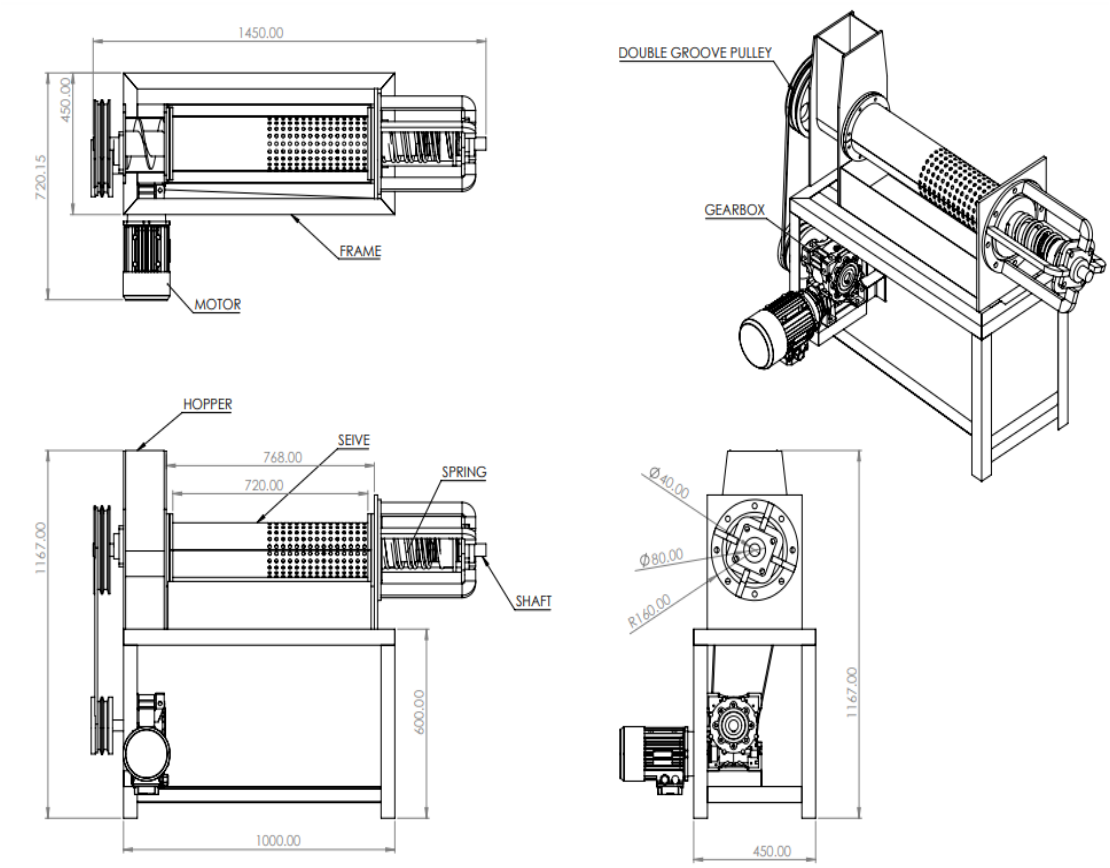


Figure 17 Detail drawing of 1st modified design

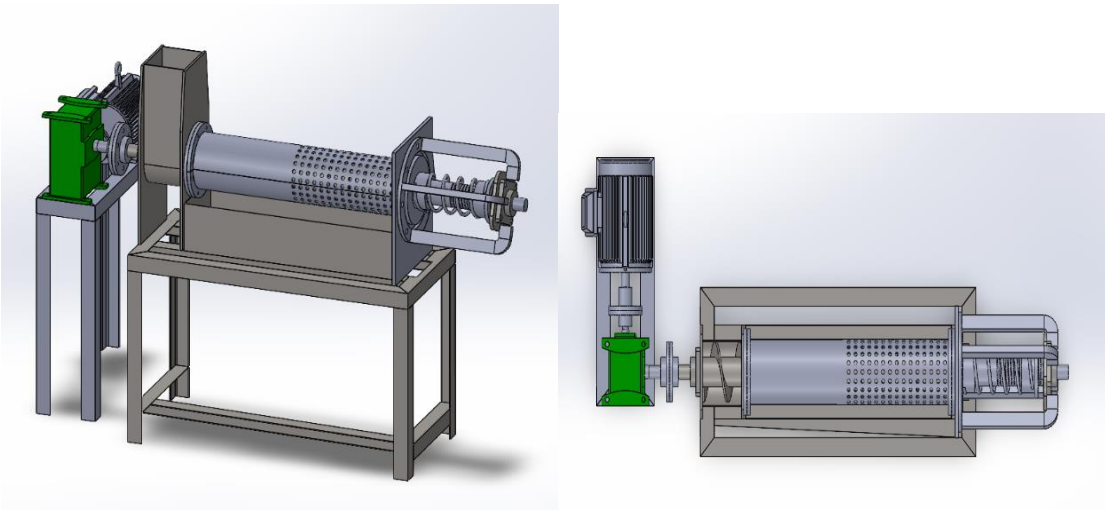


Figure 18 2nd Modified design of dewatering machine

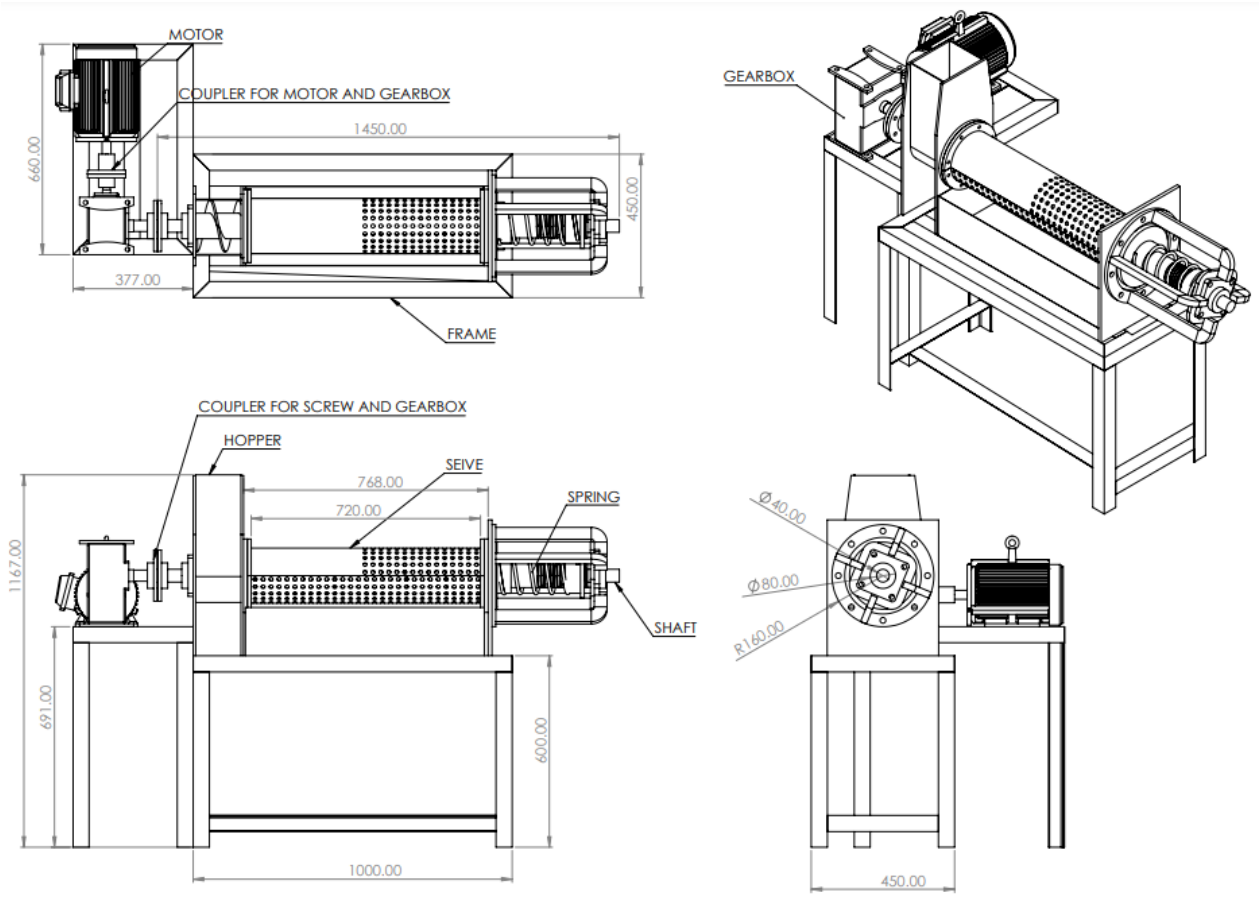


Figure 19 Detailed drawing of 2nf modified design

3.2.6 Components of the Dewatering Machine

3.2.6.1 Screw

The screw has 165 mm diameter with thickness of 6 mm. For tapered shaft of diameter 80 mm at the beginning and at the end have diameter of 160 mm. The tapered section was welded to a solid shaft having 40 mm diameter. In total 10 flights were welded to the tapered shaft. The pitch of the flights is in decreasing order from beginning to the end. The first three helixes were continuous having constant pitch of 90mm then the rest of helixes were welded at 20mm and an angle of 90 degree as shown in figure 20.

Figure 20 The Screw

3.2.6.2 Sieve

A stainless-steel net, GI net with holes of 0.7 mm and thickness of 1 mm was used. In order to withstand high pressure, a cage was manufactured to support the net. The clearance between the sieve and screw was about 1mm. The sieve and cage is shown in figure 21.

Figure 21 The Sieve and Cage

3.2.6.3 Frame

The frame was manufactured using 8 mm mild steel plates. Two bearings of 40 mm internal diameter were used for holding the screw. The total weight of the frame, hopper, pan and bearings is 41.4 kg, as shown in figure 22.

3.2.6.4 Hooper

Hooper was made for the inlet of the slurry. A 3mm mild steel plate was bend with the radius of 81mm such that no clearance between the screw and bottom of the hopper. As shown in figure 22.

3.2.6.5 Collecting Pan

A collecting pan was made using 1.5 mm mild steel sheet. A hole of 15mm is drilled in the pan so that the squeezed out from the slurry can be sent back to the inlet of the biogas plant, as shown in figure 22.

Figure 22 Dewatering machine assembly

3.3 Bill of Materials

Table 3 Bills of Material with cost

S.No	Items	Amount (Nrs)
1.	Motor (5 HP & 1440 rpm)	38000
2.	Gear box (1: 40)	70000
3.	Coupler	13000
4.	Frame	28000
5.	Screw	40000
6.	Sieve	15000
7.	Spring Assembly	30000
8.	Hopper	5000
9.	Nut, bolts, welding rod and other	20000
10.	Slurry Pump	75000
11.	Manufacturing cost	50000
	Total	**384000**

3.4 Testing of Dewatering machine

3.4.1 1st Modified dewatering machine

The testing of 1st modified dewatering machine with 2 hp motor and pulley system was done. The slurry was feed in the system through the hopper, the pulley and motor system got still. Even exerting the external force in pulley, the belt of the pulley slipped. The pressure developed by the screw is greater than the power to drive the system.

Figure 23 1st modification testing of dewatering machine

3.4.2 2nd modification of dewatering machine

The 2 hp motor and pulley system was replaced by the 5 HP motor and gear box system as shown in figure 18 and figure 19. The spring assembly system was installed at the outlet. The wire diameter of the spring is 10mm and total length is 110 mm having a material hard drawn ASTM A227. The spring constant is 19.809 N/mm and the maximum load is 2040.327 N. With the area of disc as 0.0616 m^2, the total back pressure from the spring assembly system is maximum 33.122 kPa.

3.4.2.1 Slurry Collection

The slurry was collected from the Organic farm house, Kapan. The slurry was collected from the pit, which was connected to the biogas plant of 30 MT. The biogas plant used cow dung and domestic organic food waste.

Figure 24 Slurry Collection

3.4.2.2 Testing

During the first phase of testing, there was a problem with clogging and the output from the machine was also not observed. The slurry inside the machine was rotating together with the screw with no pressure built up as shown in figure 25. Despite the dewatering taking place, the slurry could not perform efficiently as expected.

Figure 25 Clogging of material

The dry material was observed at the outlet but due to the taper of only 1mm the material inside was jammed and clogged. The tapered section was increased by grinding as shown in figure 26. The clearance measured before was 2.5mm, which was further increased to 3.5mm after the grinding.

Figure 26 Machining of tapered section

The output rotation of the motor and gear system was 16 rpm and the output of the dewatered machine was observed as shown in figure 27.

Figure 27 Output of dewatering machine

Afterwards, various speed undervariable frequency drive (VFD) of Emotron VS AC drive was used to conduct the tests. The results somehow indicated some changes in the dewatering, under low rpm. VFD setup used for the experimental setup can be observed from the figure 28.

Figure 28 VFD set up

3.5 Financial Assessment

The financial assessment of the dewatering machine is important for ensuring the feasibility and sustainability. The financial assessment shall be carried out by following methods.

i. Payback Period
ii. Net present value
iii. Internal rate of return

The total cost of the machine for the consumer is calculated based on the current market price of the machine components and current labor cost.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Test Results

The evaluation of the dewatering machine was carried out using the expressions given by Olaniyan and Oje (2011) which is

$$L_y = \frac{100 \times W_{le}\%}{W_{le} + W_{rw}}$$

$$L_e = \frac{100 \times W_{le}\%}{x\, W_{fs}}$$

$$E_l = \frac{100 \times [W_{fs} - (W_{le} + W_{rw})]\%}{W_{fs}}$$

Where,

W_{le} = Liquid extracted (kg)

W_{rw} = Residual Liquid in output cake (kg)

W_{fs} = Feed sample (kg)

L_y = Liquid yield (%)

L_e = Extraction Efficiency (%)

E_l = Extraction loss (%)

The liquid constant is the ration of sum of liquid extracted and liquid in the cake output cake to the mass of slurry fed in.

$$x = \frac{W_{le} + W_{lc}}{W_{fs}}$$

The results of the test carried out on the dewatering machine are shown in following table 4.

Table 4 Test results

Test No.	Feed Sample, W_{fs}(kg)	RPM	Weight of cake, W_c (kg)	Liquid Extracted W_{le}(kg)	Weight of Liquid in cake, W_{rw}(kg)
1	10	36	1.82	6.1	1.14
2	10	25	1.76	6.37	0.92
3	10	18	1.61	6.48	0.84
4	10	12	1.38	6.61	0.74
5	10	10	1.25	6.69	0.68
6	10	8	1.12	6.8	0.59

4.2 Performance results

The performance result of the dewatering machine is shown in table 5.

Table 5 Performance Result

Test No.	RPM	Liquid yield, L_y (%)	Extraction Efficiency,L_e(%)	Extraction Loss E_l(%)
1.	36	84.25	65.59	27.60
2.	25	87.38	68.49	27.10
3.	18	88.52	69.68	26.80
4.	12	89.93	71.08	26.50
5.	10	90.77	71.94	26.30
6.	8	92.02	73.12	26.10

4.3 Financial Analysis

S.No	Items	Amount (Nrs)
1.	Motor (5 HP & 1440 rpm)	38000
2.	Gear box (1: 40)	70000
3.	Coupler	13000
4.	Frame	28000
5.	Screw	40000
6.	Sieve	15000
7.	Spring Assembly	30000
8.	Hopper	5000
9.	Nut, bolts, welding rod and other	20000
10.	Slurry Pump	75000
	Total	**334000**

The cost of manufacturing in the GRIT Engineering Pvt ltd cost NRs 50000, therefore the total cost of the dewatering machine is NRs 384000.

4.4 Discussion

With the above performance test result obtained, the discussion of the liquid yield, extraction efficiency, extraction loss and financial analysis are discussed below:

4.4.1 Test and performance

At first the test results and performance of the dewatering machine in terms of liquid yield, extraction efficiency and extraction loss are discussed below:

4.4.1.1 Liquid Yield

The Liquid Yield decreased with the increase in the speed of the shaft, as shown in figure 29. The highest liquid yield was observed to be 92.16 % at 8 rpm whereas the lowest liquid yield was 87.02% at 36 rpm. The decrease in liquid yield with increase in rpm is due to the result of splashing liquid to the wall of the machine.

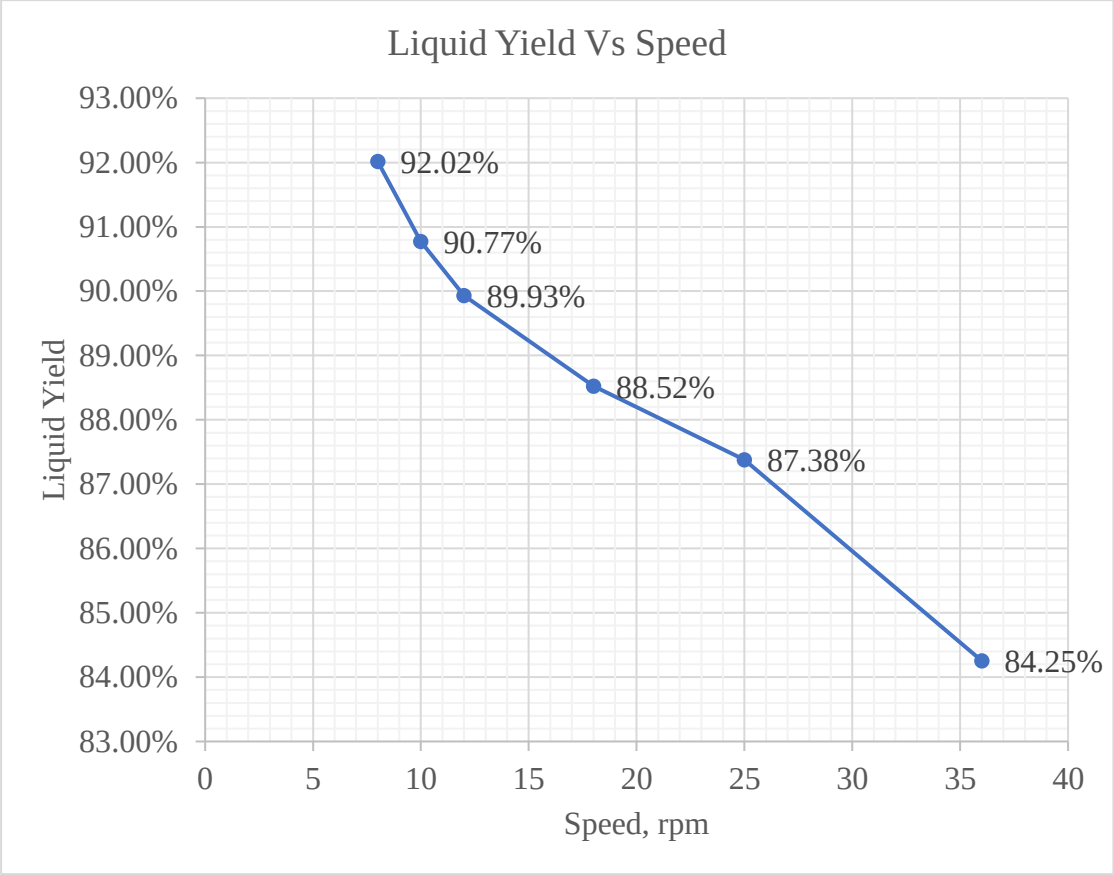


Figure 29 Liquid Yield Vs Speed

In comparison to the previous study by Sherpa et al., 2017, the liquid yield for the 20, 15, 10 and 8 rpm were calculated as 88.28%, 90.25%, 91.39% and 92.44% respectively. Similar trend of decrease in the liquid yield with increase in rpm was observed. A similar study by Kataria et.al (2018) showed that with Total Solid Content (TSC) 35 % and designed a screw press with 1.2 ton per hour, and 8 rpm with factor of safety 2.5.

However, in the study by Fu et. al (2023), the optimal parameters for dewatering machine was obtained in water content of 55%, at 30 rev/min and outlet back pressure of 5 kPa. The water removal rate was 48.9% and output rate was 234.2 kg/day. Hence,

it is seen that the optimum dewatering of the sludge depends on the moisture content, speed of the shaft and also on the total solid content.

4.4.1.2 Extraction Efficiency

The extraction efficiency of the dewatering machine decreased with the increase in the speed of the shaft. The highest extraction efficiency was observed to be 73.12% at 8 rpm whereas the lowest 65.59% was observed at 36 rpm as shown in figure 30.

In comparison to the previous study by Sherpa et al.,2017, the extraction efficiency at 20, 15, 10,8 rpm were calculated as 77.65%, 79.93%, 80.177% and 80.657% respectively. The difference in the extraction can be explained with the help of the initial moisture content in the slurry. The slurry they used had 91.38% of moisture content, however the slurry used had 95% moisture content due to collection in rainy season. Also, the collection of slurry at the top were with high moisture content was done from the pit. Also, the length of the shaft and screw designed and fabricated seems to be not sufficient for the extraction of the moisture content from the slurry.

Despite the extraction efficiency observed for the lower speed, it was observed that the dewatering of slurry from the sieve and screw was not taking place as illustrated in the literature. From the study, it was found that the extraction efficiency rises up for the lower speed of 12rpm compared to speed range of 15 to 36 rpm.

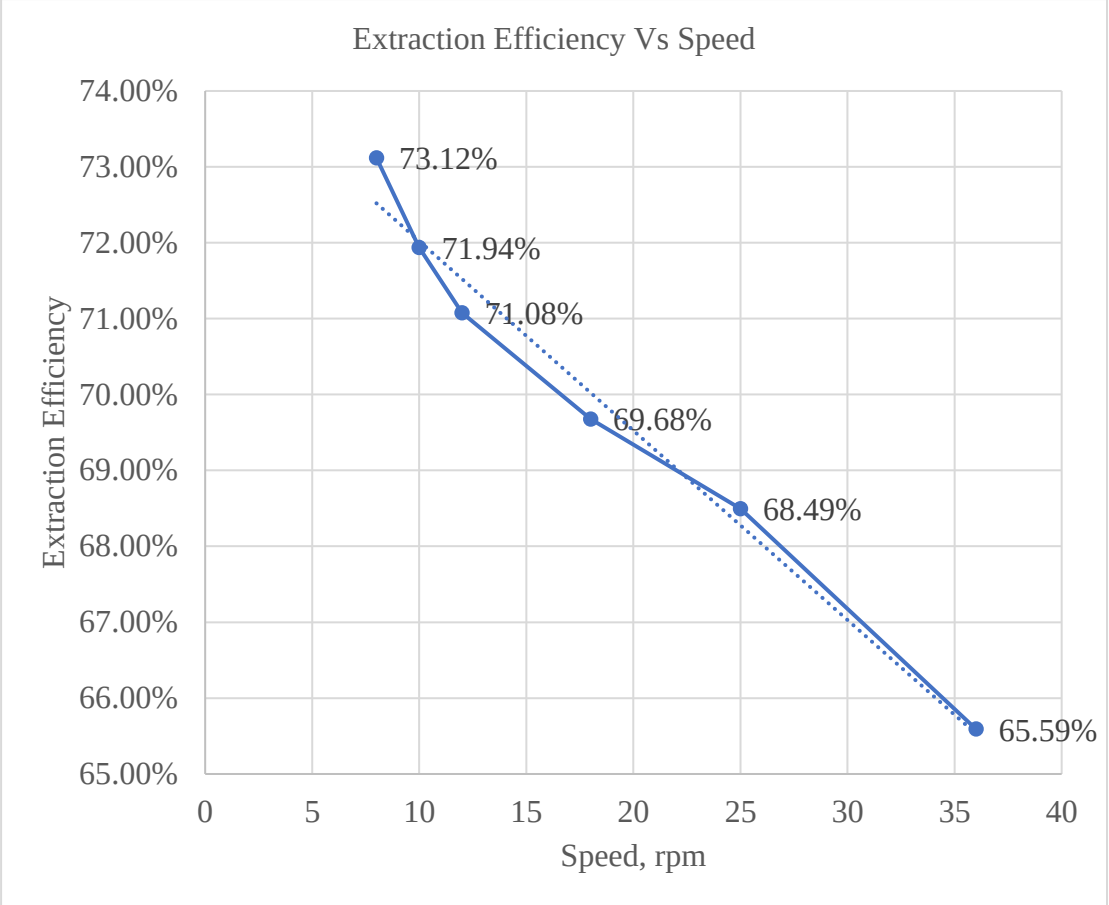


Figure 30 Extraction Efficiency Vs Speed

4.4.1.3 Extraction loss

The extraction loss has increased with the increase of speed. The highest loss was found to be 27.60% at 36 rpm whereas the lowest was 26.10% at 8 rpm. As presented in figure 31, and compared to figure 30 the efficient rpm for the operation of the dewatering system to have proper extraction efficiency and less extraction loss lies in the speed below the 12rpm.

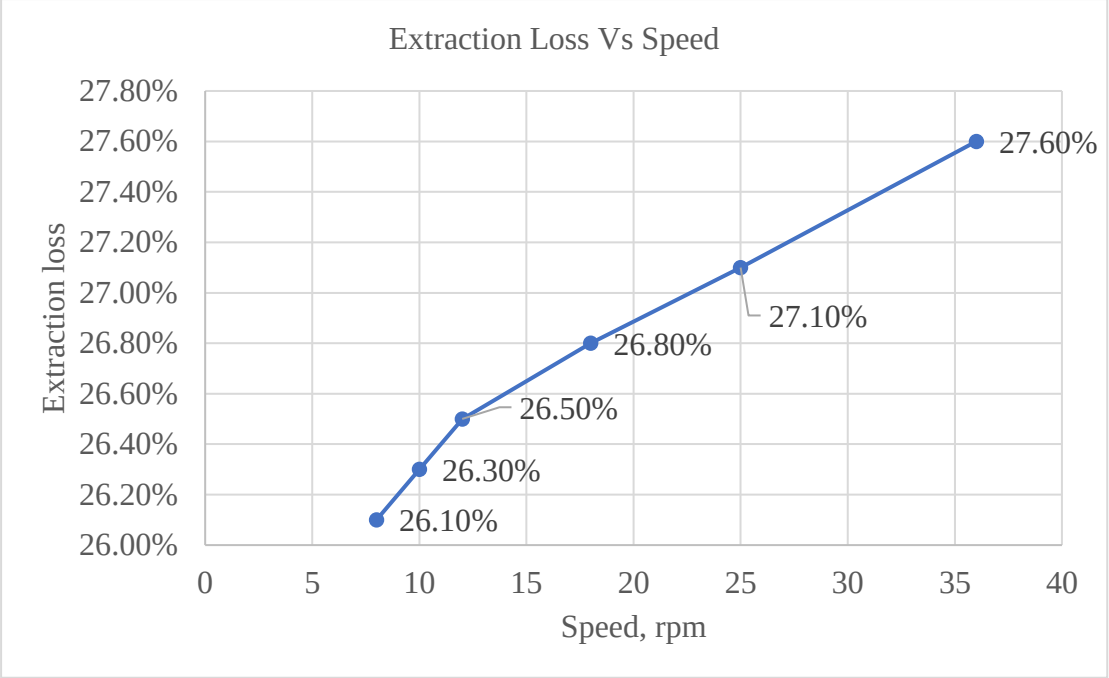


Figure 31 Extraction loss Vs Speed

In comparison with the previous study by Sherpa et al., 2017, the extraction loss at 20,15,10 and 8 rpm were calculated as 19.94%, 19.41%, 20.17% and 20.16% respectively. Similar trend is observed in this study as well.The extraction loss increased with the increase in speed, which indicates that once the speed increases, the slurry moves fast and vibration occurs.

4.4.2 Financial Analysis

The cost of the dewatering machine for the consumer will be NRs 3,84,000. Three labor will be required for operating a machine and packing the fertilizer. Assuming, the monthly wage of labor is NRs 19000 (salary and benefits included) which sum up the total annual labor cost as Nrs 6,84,000.

Assuming the dewatering machine be operated for 300 days annually.

For the cost for operation of the dewatering machine, a motor of 5 HP and a slurry pump of 1 hp. Machine operates 7 hrs/day. Then, the cost of the electricity would be Nrs 93958.2.

The annual maintenance cost of the dewatering machine is assumed 10% of total cost.

Annual maintenance cost is Nrs 38400.

Table 6 Cash flow

S.No	Cash flow (annual)	Amount (Nrs)
1.	Initial Cost	384000
2.	Operating Cost	93958.2
3.	Labor Cost	684000
4.	Maintenance Cost	38400
5.	Interest @ 10% annually	38400
6.	Income	10,08,000

If we consider a biogas plant of m^3, then the output of the plant would be 1200 kg/day. The compression ratio of the machine by weight is 7, then the output will be 171 kg per day. With the efficiency of 70% the output per day will be 120 kg per day. Market value of 1 kg organic fertilizer is Rs 25. Hence the annual income would be Nrs 10,08,000. The various cash flows are shown in table 6.

4.4.2.1 Payback Period

The payback period is the required number of years to gain the original capital. Annual income = 10,08,000

Annual expenses = operating cost + labor cost + maintenance cost + annual interest on investment

= 93958.2 + 684000+ 38400 + 38400

= 854758.2

Now, Net annual profit = Net annual income – Annual expenses

= 1008000 - 854758.2

= 153241.8

Therefore,

$$\text{Payback period} = \frac{Investment}{Annual\ profit}$$

$$= \frac{384000}{153241.8}$$

= 2.505844 years

= 2 years 6 month 2 days

In comparison to the study by Sherpa et al., 2017, the payback period was calculated as four month and two days. As the assumption of the price of the fertilizer obtained or the dry cake is assumed as NRs 50 which is much higher than actual market price. In this study the price of the dry cake is taken as Nrs 25. Also the total cost of the machine is Nrs 350000 in the study by Sherpa et al., 2017 were as this study shows the total cost of Nrs 384000 due to the price difference of the 1HP motor and 5HP motor gear system, also the price of the worker is adjusted to the monthly basis rather than daily wage.

4.4.2.2 Internal Rate of Return

Let us assume that the machine will function 5 years and it must be replaced completely.

Then,

Internal rate of return is a rate at which net present value of all cash flows equals to zero.

IRR = IRR(-384000, 153241.8, 153241.8, 153241.8, 153241.8, 153241.8) using excel command.

IRR = 28.53 %

The internal rate of return of the dewatering machine is calculated as 28.53%.

4.4.2.3 Net Present Value

This defines the net present value of the dewatering machine. Assuming it will last 5 years.

NPV = NPV(-384000, 153241.8, 153241.8, 153241.8, 153241.8, 153241.8) @ 10% using excel

NPV = NRs 179006.35

The net present value is calculated as one lakh seventy nine thousand and six rupees.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

A dewatering machine for the bio digestate was designed, fabricated and tested. With the obtained result and discussions, we can conclude that:

i. The dewatering machine was modified by replacing 2HP motor and Gearbox 1:30 by 5 hp three phase electric motor having 1440 rpm and gear box with the reduction of 1:40, sieve modified and spring assembly at the outlet.

ii. The performance evaluation of the dewatering machine shows the production capacity to be 79.9 kg/hr, with optimum speed being 10 rpm. The liquid yield, extraction efficiency and extraction loss were found to be 90.77%, 71.94% and 26.30% respectively.

iii. The financial evaluation of the dewatering machine shows that the total investment as NRs 384000. The payback period of the machine is calculated as 2year 6 month and 4 days with the internal rate of return as 28.53% and Net Present Value as NRs 179006.35 considering five-year lifetime of the machine.

5.2 Recommendation

The dewatering machine with modified design, fabricated and tested to conclude with the above three points. Though, there is always a room for improvement and innovation for better quality, efficiency and sustainability. Based on the experience with the design and manufacturing, following factors are recommended:

i. The stainless-steel screen shall be considered for longer life and prevent the problem of rusting.

ii. Pre-thickening of the slurry and mixing for consistency shall improve the output obtain and decrease the machine load as well.

iii. The screw of the machine shall be re-manufactured to accurate dimensions and profile in order to achieve desired pressure and appropriate motor selection.

iv. The moisture content, total suspended solid, volatile content and the nutrient content in the dry slurry, wet slurry and liquid shall be studied for optimal condition of dewatering machine.

v. The angle of the screw for this setup was in a horizontal layout, study for inclined setup could increase the efficiency of the setup, hence it is recommended for the modification and further study.

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Appendix A

Figure 32 Initial condition of Dewatering machine at workshop

Figure 33 Connection of 2HP motor and pulley system

Figure 34 Pipe for fixing Sieve

Figure 35 Pressure plate fabrication

Figure 36 Final modified Dewatering Machine Assembly