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Research article

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Design, Validation, and Examination on the Performance Improvement of Dewatering System Implemented for Biogas Slurry

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Abstract
The project addresses the pressing need for organic fertilizers in Nepal and explores an eco- friendly alternative to chemical fertilizers. By dewatering biogas residue, this research contributes to sustainable agriculture practices. The project's methodology involved a combination of research, literature recommendations, and guidance from experienced supervisors. SolidWorks was utilized for the design phase, while ANSYS facilitated simulation works. Subsequently, the testing of the dewatering machine was conducted. The biogas slurry used for testing and sun-drying was sourced from a prototype 1m3 capacity biogas plant. The machine's performance was evaluated at various operating speeds, with 8 rpm identified as the most efficient. Notable outcomes included a liquid yield of 52.51%, an extraction efficiency of 79.11%, and extraction losses amounting to 22.80%. To enhance the quality of the organic fertilizer, the slurry sample underwent sun-drying for different durations: 24, 48, and 72 hours. Nutrient concentrations (TS, N, P, K) were analyzed, that came with the 48-hour sun-drying period proving to be the most effective in reducing Total Solid contents. Comparatively, pre-treating the slurry sample for 24 and 48 hours prior to testing in the dewatering machine allowed for an assessment of the machine's efficiency, offering valuable insights to be contrasted with the sun-drying process. This research paves the way for a greener, more efficient method of dewatering biogas slurry, aligning with Nepal's agricultural and environmental sustainability goals.

Keywords: Organic Fertilizers, Biogas Slurry, Dewatering System, Solidworks, Ansys Simulation, Nutrient Concentrations, Sun-Drying, Payback Period, Npv, Irr

Chapter 1: Introduction

1.1 Background

Biogas plants play a crucial role in this context, offering a straightforward and cost- effective means of sustaining energy supply through the natural breakdown of organic matter, all without the need for air. However, a critical question arises regarding the treatment of biogas slurry. This slurry, rich in nutrients, has the potential to serve as a high- value fertilizer without adverse environmental impacts. Nepal has witnessed the proliferation of biogas plants, with 316 large-scale and 433,173 domestic units constructed across the nation [1]. The government's 15th periodic plan further underscores the commitment to expand these initiatives by installing an additional 200,000 home biogas plants and 500 larger biogas plants. So, to harness the full potential of the biogas slurry as an agricultural resource, it is essential to consider dewatering and drying methods. Dewatering, a critical physical process, reduces moisture content and volume, enhancing the sludge's dry substance content to around 40%. This not only makes it more manageable but also more cost- effective for transportation. Moreover, dewatering contributes to environmental benefits by reducing odors and increasing the calorific power of the sludge for energy generation. Drying of digested slurry is another viable option. It substantially reduces volume and weight, with relatively low construction costs for drying basins. However, it results in a significant loss of inorganic nitrogen. The drying process is influenced by various aspects, like heat source temperature, humidity, and sludge characteristics. Ultimately, the project aims to optimize the dewatering and drying of biogas slurry to maximize its agricultural and

environmental benefits. The choice of drying method and duration is crucial in preserving nutrient content and efficiency. This research aligns with Nepal's sustainability goals, offering a greener and more efficient approach to managing biogas slurry and contributing to the nation's agricultural and environmental well-being.

1.2 Problem Statement

The substantial moisture content in biogas plant slurry hampers efficient handling, management, and transport. The absence of effective dewatering technology restricts slurry utilization, impacting its quality even near the biogas plant. Long-term storage generates noxious odors and attracts pests. The conventional dewatering methods are time-consuming and demand excessive storage space, rendering them impractical for commercial purposes. Imported technologies are prohibitively expensive. Thus, the project aims to address these challenges by developing a locally available, cost-effective, and efficient solution for slurry treatment, enabling immediate use of slurry as fertilizer. This endeavor not only reduces the reliance on costly imported fertilizers but also promotes the sustainability of rural biogas systems. It conserves traditional fuel resources and diminishes the demand for chemical fertilizers, thereby addressing critical environmental and economic issues.

1.3 Objectives

To develop and assess a screw press-based dewatering system, comparing it to sun drying, for effective reduction of biogas slurry moisture, including comprehensive performance tests and financial viability analysis.

Specific Aims:

- Identify suitable dewatering technology through literature review.
- Design, simulate, and validate the primary components of the screw press dewatering system, ensuring efficiency.
- Evaluate the dewatering machine's performance by measuring reduced moisture content through sun drying.
- Conduct financial analysis for real- world applicability of the mechanical technology.

Chapter 2: Methods of Research

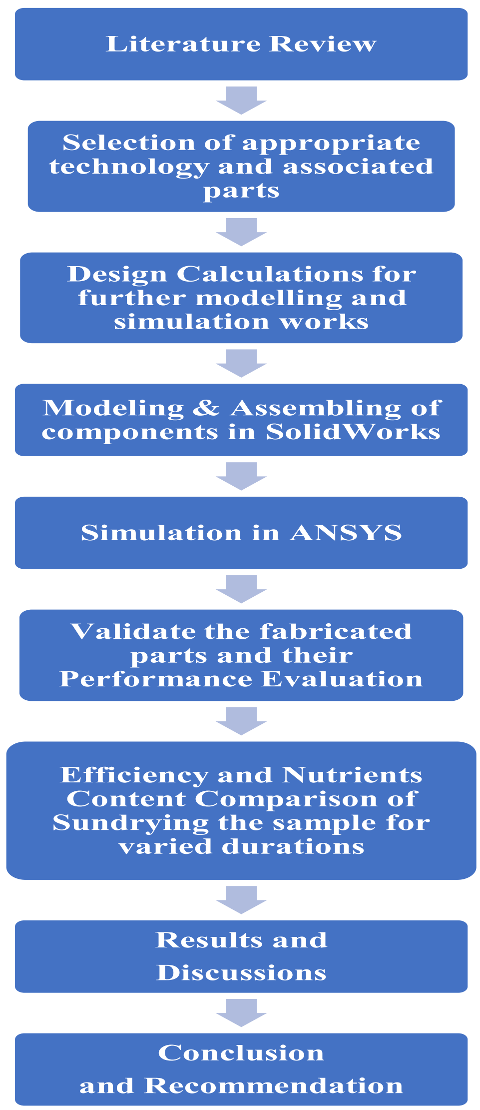

Figure 1: Methodology

2.1 Literature Review

Biogas production through anaerobic digestion generates nutrient-rich slurry, comprising over 90% water, with substantial plant nutrient contents like nitrogen (N), phosphorus (P), and potassium (K) [2]. This nutrient-rich slurry can enhance the quality and output of organic fertilizers and benefit plant growth [3]. Various research and studies have investigated dewatering technologies. Design improvements from single to twin screw presses have been found to enhance separation efficiency and product quality in agricultural and food processing industries [4]. Screw press dewatering machines, particularly those employing constant pitch screws with tapered shafts, have been considered energy-efficient and effective in nutrient retention [5]. It's crucial to select the right dewatering technology, considering factors like operator preferences, safety, and nutrient preservation [6].

The drying of digested slurry aims to reduce volume and weight. Sun drying and radiative drying using solar heat are common methods in South Asia [2]. However, drying may lead to nutrient loss, particularly nitrogen, if carried to an extreme [7]. For this project, Screw Press dewatering machines with constant pitch screws, particularly those with tapered shafts, have been identified as promising for nutrient preservation and solids separation. Sludge drying through radiative methods and acidification to reduce ammonia emissions are also relevant [8].

2.2 Design Calculations for Further Modeling and Simulation Works

Subsequent to the selection of technology, design calculations are carried out. These calculations are essential for establishing the parameters required for further modeling and simulation. The precision in these calculations is paramount as they influence

the subsequent steps of the project.

Design of hopper

The volume of hopper depends on density of slurry and mass of the slurry to be fed at a time.

Let, the mass of slurry to be fed at once, M=5kg

Density of slurry,

$$\rho_{slurry} = \frac{M}{V_i}$$

Volume of slurry, $V_i = 0.004545m^3$ (M=5kg, $\rho_{slurry} = 1100kg/m3$)

Hopper design is based on the volume of frustum of a pyramid. (Khurmi and Gupta, 2004)

$$V_h = \frac{\pi}{2}(R^2H - r^2h)$$

(R = 125mm; H = 200mm; r = 80mm; h = 50mm)

Volume of the hopper, V_h = $0.00406m^3$

Power needed to overcome the screw and shaft's motion The shaft is tapered & made hollow.

Volume of hollow tapered cylinder section,

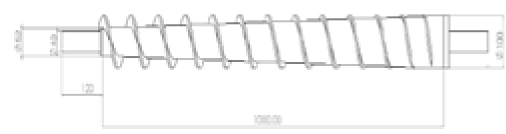

Figure 2: Drawing of screw

$V_1 = \frac{\pi * l}{3}[\sum r]^2 = 0.000688009m^3$ [since, (R=50mm, r=26mm, L=1000mm, R_s=40mm, t=6mm)]

Volume of 40mm shaft, (l=1.24m)

$V_2 = \pi {R_s}^2 l$ =$0.00155823m^3$

Total volume of shafts, V = V_1 + V_2= $0.002246239m^3$

For mass of shaft, Ms

$Ms = \rho_s * \text{V} = 17.63kg$ ($\rho_s for\ mild\ steel = 7850kg/m3$)

Radius of flights = r_f (50mm) (1)

So, Net Volume of flights, $V_f = 13 * \pi {r_f}^2 t$ = 0.00061261057m^3

Mass of the flight, $M_f = \rho_s * V_f$ = $5.178kg$

Total Mass, $M = Ms + M_f$= $22.81kg$

Total Weight, $W = M * g$ = $223.75N$

Hence, Power required,

$P_1 = W * v_m$ (Okafor, Basil E., 2015) (2)

Where,

$v_m = \frac{Tm*N}{60}$ = $0.01216m/s$

So, P_1 = 2.720*10^{-3} kW.

Power needed to convey the slurry

Firstly, the throughput capacity of the screw press is determined. i.e., the throughput capacity,

$$Q(\frac{kg}{hr}) = \frac{60\pi D^2 TmN\psi\rho_{slurry}c}{4}(\frac{TA_f}{2}))$$

(Okafor, Basil E., 2015)
Where,
c = correction factor (0.7),

ψ = filling coefficient (0.125 for high abrasive materials)

Q=33kg/hr

Power required to convey the slurry,

$$P_2 = \frac{QL\rho_{slurry}F_{mt}}{168547}$$

(Okafor, Basil E., 2015)

F_{mt} is the material factor per kW.

$P_2 = 0.123$kW

Power Required to Press and Separate Slurry

According to (*Mudryk*, 2016), the optimum pressure required to separate biogas effluent slurry into solid and liquid constituents is approximately 1.74 MPa.

The power required to press and separate slurry:

$P_3 = F * v_m$

Where, F = Force required to separate the slurry;

F = Squeezing pressure x TSA in contact with slurry
Total area of flights, TA_f; = Sum of Area of13 flights = $\Sigma[(\pi\times R^2) - (\pi\times r^2)] = 0.064251 m^2$

Force Required, F = Pressure $*A_f$ = 0.45 * 0.032126=14.45KN (Where, A_f=

$P_3 = F*v_m = 0.175712 KW$

Power Required to Overcome Friction

Frictional force, $F = \mu N_{fr} = 0.35 * 14.45 * cos30 = 4.3779 KN$
Frictional Power, $P_4 = F * Vm = 0.05325 kW$

Total Power required, $P = P_1 + P_2 + P_3 + P_4 = 0.3546828 kW$ (6)

Motor Selection

P_m = P+ (10%×P) = 0.390kW = 0.5229 hp. (say 10% losses)
So, 1hp, electric motor is selected.

2.3 Modeling & Assembling of Components in SolidWorks

With simulations completed, the focus shifts to modeling and assembling components using SolidWorks. A digital 3D model of the dewatering system is generated, providing a virtual representation of the assembled components and enabling the assessment of their interactions.

Fig. 3: Constant Pitch Screw (Straight shaft)

Fig. 4: Variable pitch screw (Straight shaft)

Fig. 5: Constant Pitch Screw (Tapered Shaft)

Fig.6: Variable Pitch Screw (Tapered Shaft)

Fig. 7: Motor with screw press (constant pitch & tapered shaft)

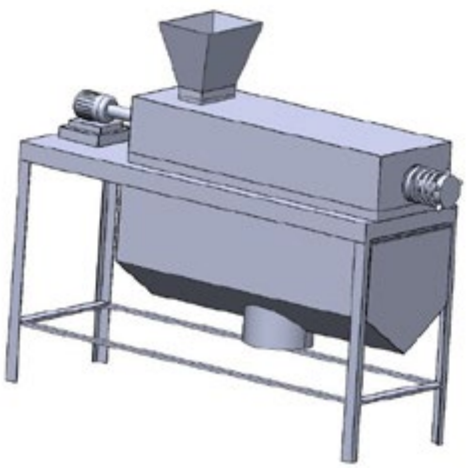

Fig. 8: Assembled model

2.4 Simulation in ANSYS

The designs and calculations are then taken forward into the simulation phase using ANSYS software. Simulations are conducted to predict the behavior and performance of the designed dewatering system. These simulations are instrumental in identifying potential design flaws before physical prototypes are created.

Fig. 9: Meshed Figure - Constant Pitch Screw (Tapered Shaft)

Fig. 10: Boundary Conditions - Constant Pitch Screw (Tapered Shaft)

Fig. 11: Fluid Domain - Constant Pitch Screw (Tapered Shaft)

Chapter 3: Results and Analysis

3.1 Results from ANSYS simulation

The analysis of four different types of screws and shafts, considering deformation, equivalent stress, and equivalent strain, has provided valuable insights for selecting the most suitable configuration. Among the options, the constant pitch screw with a tapered shaft exhibits the least deformation (0.17151 mm), suggesting its structural stability. In terms of equivalent stress, the constant pitch screw with a tapered shaft records the lowest stress 43.941MPa), indicating its capacity to endure pressure effectively. Furthermore, the equivalent strain values reveal that the constant pitch screw with a tapered shaft possesses the lowest equivalent strain (0.00022244 mm/mm), reflecting its robustness. In the context of pressure analysis, the constant pitch screw with a tapered shaft shows the most promising results, with a pressure difference of 90.165Pa, indicating efficient dewatering performance. Overall, considering the structural stability, lower equivalent stress, and higher-pressure difference, the constant pitch screw with a tapered shaft emerges as the optimal choice for the dewatering system.

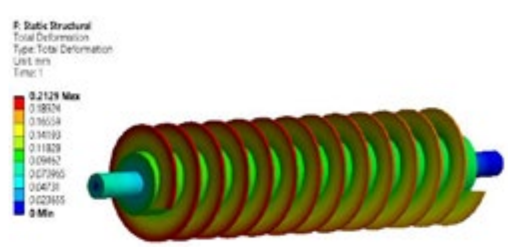

Fig. 12: Total Deformation - Constant Pitch Screw (Straight shaft)

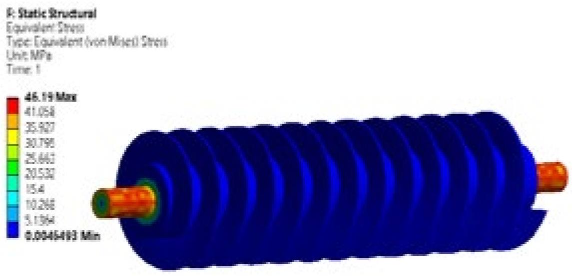

Fig 13: Equivalent Stress - Constant Pitch Screw (Straight shaft)

Fig. 14: Equivalent strain - Constant Pitch Screw (Straight shaft)

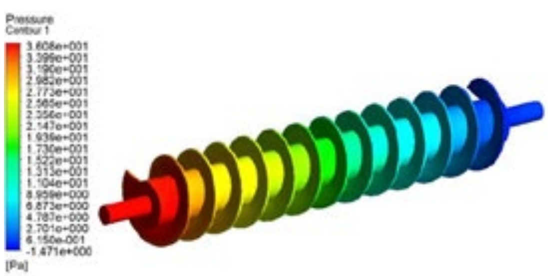

Fig. 15: Pressure Contour - Constant Pitch Screw (Straight shaft)

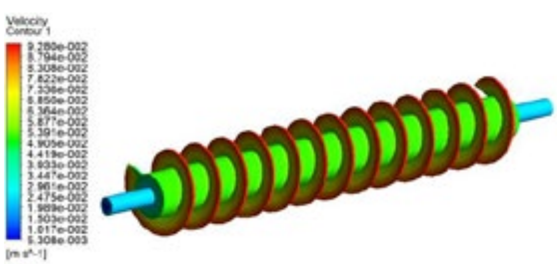

Fig. 16: Velocity Contour - Constant Pitch Screw (Straight shaft)

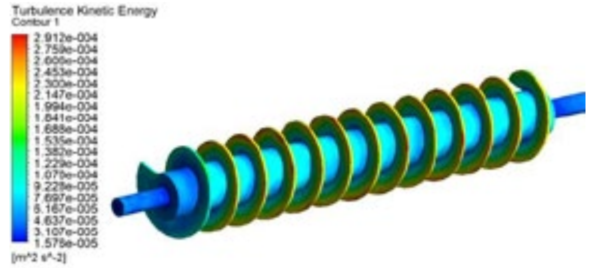

Fig. 17: TKE - Constant Pitch Screw (Straight shaft)

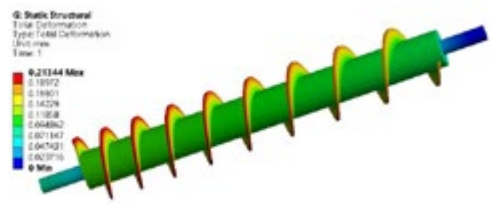

Fig. 18: Total Deformation - Variable pitch screw (Straight shaft)

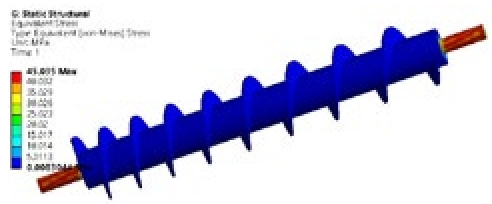

Fig. 19: Equivalent Stress - Variable pitch screw (Straight shaft)

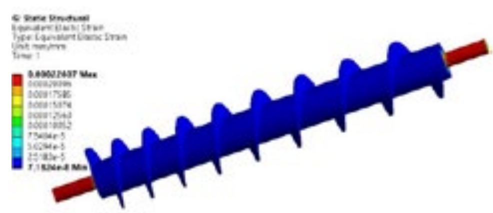

Fig. 20: Equivalent Strain - Variable pitch screw (Straight shaft)

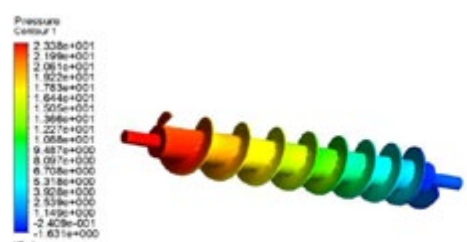

Fig. 21: Pressure Contour - Variable pitch screw (Straight shaft)

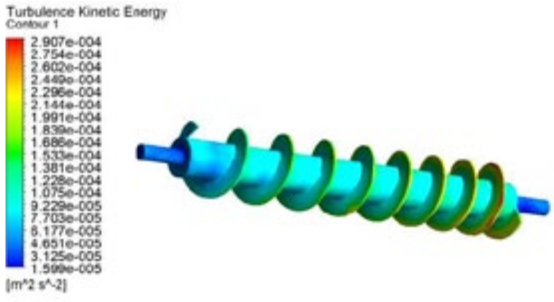

Fig. 22: TKE - Variable pitch screw (Straight shaft)

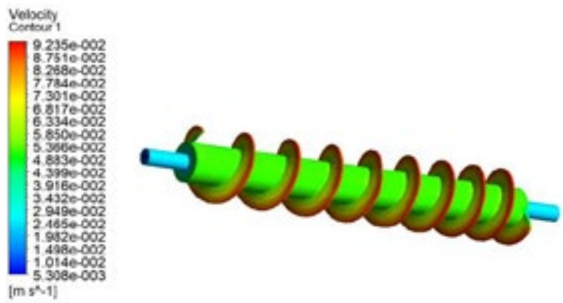

Fig. 23: Velocity Contour - Variable pitch screw (Straight shaft)

Fig. 24: Total deformation - Constant Pitch Screw (Tapered Shaft)

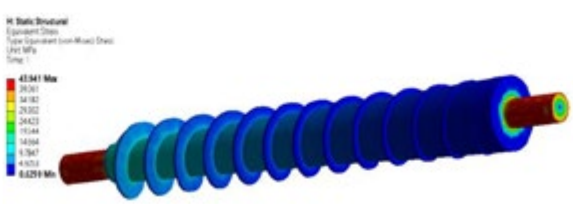

Fig. 25: Equivalent Stress - Constant Pitch Screw (Tapered Shaft)

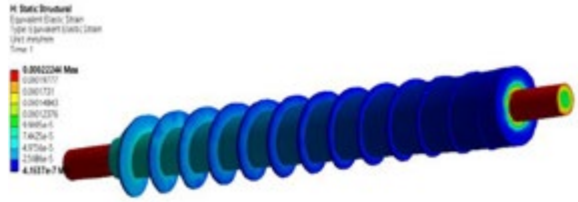

Fig. 26: Equivalent Strain - Constant Pitch Screw (Tapered Shaft)

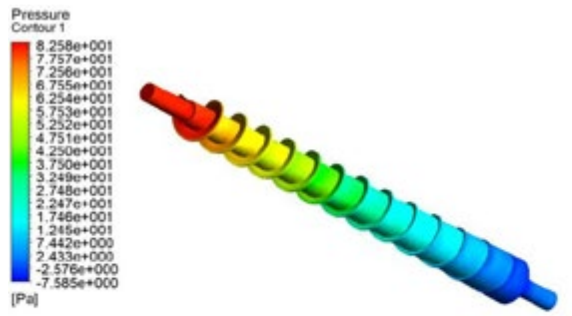

Fig. 27: Pressure Contour - Constant Pitch Screw (Tapered Shaft)

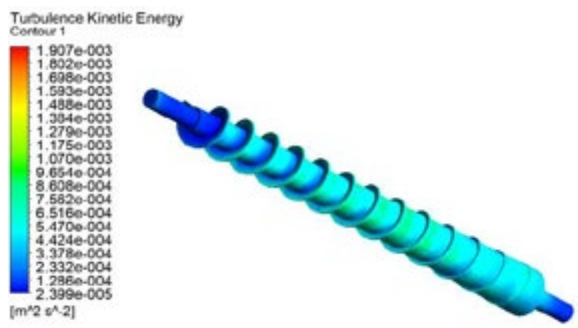

Fig. 28: T. Kinetic Energy - Constant Pitch Screw (Tapered Shaft)

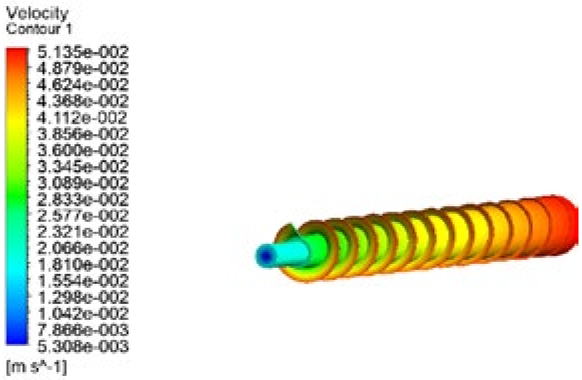

Fig. 29: Velocity Contour - Constant Pitch Screw (Tapered Shaft)

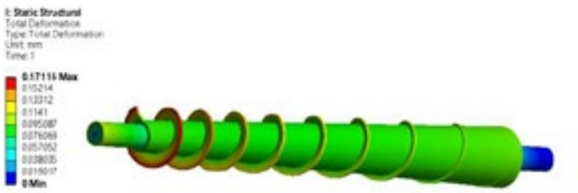

Fig. 30: Total Deformation - Variable Pitch Screw (Tapered Shaft)

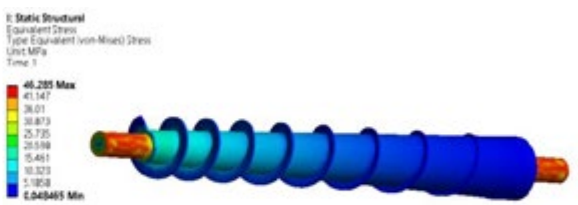

Fig. 31: Equivalent Stress - Variable Pitch Screw (Tapered Shaft)

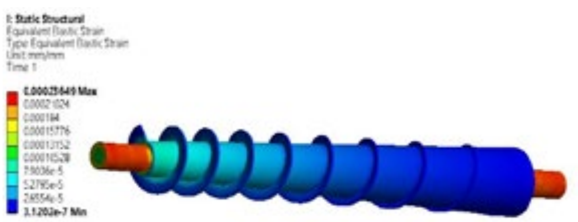

Fig. 32: Equivalent Strain - Variable Pitch Screw (Tapered Shaft)

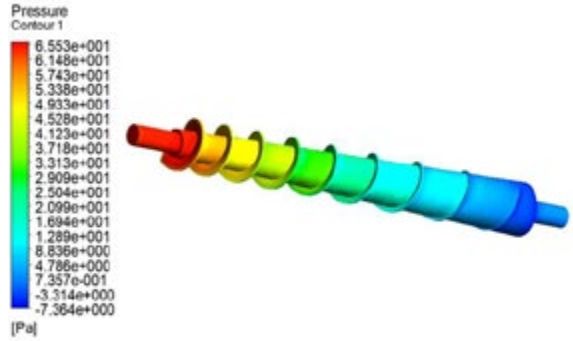

Fig. 33: Pressure Contour - Variable Pitch Screw (Tapered Shaft)

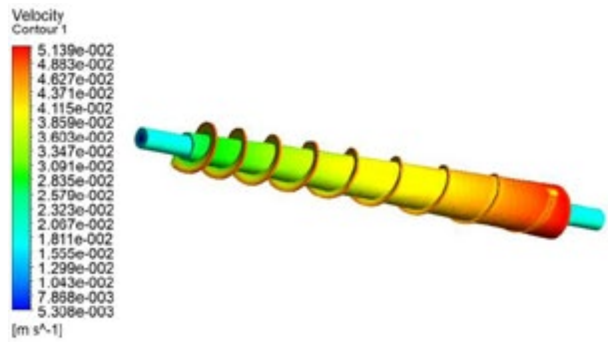

Fig. 34: Velocity Contour - Variable Pitch Screw (Tapered Shaft)

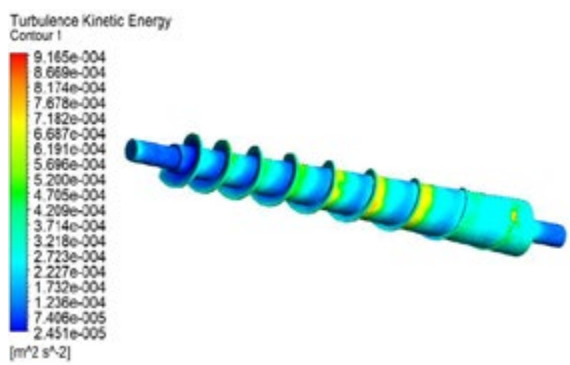

Fig. 35: TKE - Variable Pitch Screw (Tapered Shaft)

Table 1: Deformation, equivalent stress and equivalent strain (Static Results)

Types of Screw and shaft	**Deformation (mm)**	**Equivalent Stress (MPa)**		**Equivalent Strain (mm/mm)**	
	Max	Max	Min	Max	Min
Constant pitch screw (Straight shaft)	0.2129	46.19	0.004649 3	0.0002438 5	3.6288e-8
Variable pitch screw (Straight shaft)	0.21344	45.035	0.008304 4	0.0002260 7	7.1824e-8
Constant pitch screw (Tapered shaft)	**0.17151**	**43.941**	**0.0259**	**0.00022244**	**4.1637e-7**
Variable pitch screw (Tapered shaft)	0.17116	46.285	0.048465	0.00023649	3.1202e-7

Table 2: Pressure Contour (CFD results)

Pressure (Pa)	Max	Min	Difference
Constant pitch screw (Straight shaft)	3.608e+001	-1.471e+000	37.551
Variable pitch screw (Straig	2.338e+001	-1.631e+000	25.011

ht shaft)			
Constant pitch screw (Tapered shaft)	**8.258e+001**	**-7.585e+000**	**90.165**
Variable pitch screw (Tapered shaft)	6.553e+001	-7.364e+000	72.894

Table 3: Velocity and turbulence kinetic energy (CFD results)

Types of Screw and shaft	**Velocity (m/s)**		**Turbulence Kinetic Energy (m^2/s^2)**	
	Max	Min	Max	Min
Constant pitch screw (Straight)	9.280e-002	5.308e-003	2.912e-004	1.576e-005
Variable pitch screw (Straight)	9.235e-002	5.308e-003	2.907e-004	1.599e-005
Constant pitch screw (Tapered)	**5.135e-002**	**5.308e-003**	**1.907e-003**	**2.399e-005**
Variable pitch screw (Tapered)	5.139e-002	5.308e-003	9.165e-004	2.451e-005

3.2 Results from Performance analysis related calculations

Among the options, the constant pitch screw with a tapered shaft exhibits the highest reliability factor (Ke) of 0.00737, indicating superior structural integrity and resistance to stress concentration. This is primarily due to its lower deformation and equivalent stress levels. In terms of endurance limit (Se), the constant pitch screw with a tapered shaft again surpasses the others, with a Se value of 157.529 MPa. This indicates its capacity to withstand cyclic loading and maintain its structural integrity over an extended period. When considering the total rotation of the screw (N rotations) and the total lifespan (hours), the constant pitch screw with a tapered shaft demonstrates impressive values, with 265.49*103 rotations and a lifespan of 2465.273 hours. These results collectively highlight its robustness and suitability for prolonged operation. In conclusion, the constant pitch screw with a tapered shaft emerges as the optimal choice for the dewatering system, as it combines structural stability, high reliability, and extended operational lifespan. Hence, this technology is implemented for further experimentation.

For constant pitch screw (Tapered Shaft)

a. Reliability factor, K_e

Factor of Stress Concentration,

K_t = max to min stress ratio =1696.56

$K_f = 1+q(K_t - 1) = 1+0.8(9934.82 - 1)$ =1357.248

$K_e = 1/ K_f$ =0.000737

b. Endurance limit, S_e (MPa)

S_{ut} = Ultimate strength (450Mpa for mild steel)

$S_e' = 0.504 * S_{ut} = 0.504 * 450$Mpa

=226.800Mpa (or 32894.618 psi)

$S_e = K_a. K_b. K_d. K_e. S_e' = 22847.671$ psi = 157.529Mpa

c. Total rotation of screw, N

S_f = fatigue case =480Mpa

b= (-1/3)*log [(0.8*S_{ut})/S_e] = -0.840; c= log [(0.8*S_{ut})^2/S_e]=7.238 (here, S_{ut} in psi but S_e in Mpa)

$N= 10^{(-c/b)}.S_f^{(1/b)} = (10)^{8.6038}.(490)^{-1.1962} =$ 265489.904 =265.49* (10^3) rotation

d. Total life-span (hour)

Distance of pitch, L=172.307mm

Time to complete one cycle, $t_{total} = t+t_p =$ 33.429sec

Total rotation within 1 hr, $N_p = 3600/ t_{total}=$ 107.692 rotation

$L_t = N / N_p =$ 2465.273 hours.

Table 4: Summary of performance parameters for four types of screw presses

Types/ properties	Constant pitch screw (Straight)	Variable pitch screw (Straight)	Constant pitch screw (Tapered)	Variable pitch screw (Tapered)
Reliability factor, K_e	0.00012581	0.00023043	0.00737	0.001308
Endurance limit, S_e(Mpa)	147.027	154.028	157.529	143.526
Total rotation of screw, N rotations	244.56*(10^3)	258.482*(10^3)	265.49*(10^3)	237.644*(10^3)
Total life-span (hours)	2270.913	2400.204	2465.273	2206.703

(I. Nawi, Z. Ngali, M. Firdaus, S.M. Salleh, E.M. Yusup & W.A. Siswanto , 2017)

3.3 Results of Nutrients Concentrations from sun-drying of slurry

An examination of these results reveals a clear correlation between the duration of sun-drying and its effects on various parameters. As the duration increases from 24 to 72 hours, weight reduction becomes more pronounced, with the most significant reduction occurring after 72 hours. pH values exhibit a gradual decline, suggesting an increasing acidity as drying time extends. Total solids, on the other hand, show an initial rise followed by a substantial decrease, indicative of improved drying. Notably, the percentage reduction in total Kjeldahl nitrogen content is most prominent after 72 hours, indicating effective nitrogen compound removal. Similarly, available phosphorus and potassium levels decrease, with the most substantial changes observed after 72 hours. These findings collectively suggest that a 72-hour sun-drying duration yields the most favorable outcomes in terms of weight reduction, nutrient removal, and drying efficiency. In conclusion, the optimal scenario for achieving superior results in weight reduction and nutrient removal is a sun-drying period of 72 hours.

Table 5: Results from Sun-drying of biogas slurry

Experimental Parameters	**Before Sun-drying**	**After 24 hours of Sun-drying**	**After 48 hours of Sun-drying**	**After 72 hours of Sun-drying**
Weight (kg)	10.38	5.42	2.74	1.36

pH Value	6.9	5.4	5	4.8
Total Solids (%)	14.67	22.11	29.55	44.87
Total Kjeldahl Nitrogen, N (%)	0.3	0.26	0.21	0.09
Available Phosphorus, P (mg/kg)	89.67	86.73	83.79	81.48
Available Potassium, K (mg/kg)	1637.5	1317.5	997.5	860

Table 6: Results in terms of Reduction Percentage for Sun-drying of biogas slurry

Reduction Percentage	**Before Sun-drying**	**After 24 hours of Sun-drying**	**After 48 hours of Sun-drying**	**After 72 hours of Sun-drying**
Weight (kg)	……	47.78	49.45	50.36
pH Value	……	21.74	7.41	4.00
Total Solids (%)	……	-50.72	-33.65	-51.84
Total Kjeldahl Nitrogen, N (%)	……	15.00	17.65	57.14
Available Phosphorus, P (mg/kg)	……	3.28	3.39	2.76
Available Potassium, K (mg/kg)	……	19.54	24.29	13.78

Table 7: Results based on MC, DM, D_E, D_R for sun-drying process

Performance Parameters with the Dewatering Process	**Before Sun-drying**	**After 24 hours of Sun-drying**	**After 48 hours of Sun-drying**	**After 72 hours of Sun-drying**
Weight (Kg)	10.38	5.42	2.74	1.36
Moisture Content, MC (%)	0	48.25	50.38	52.27

3.4 Results of Nutrients Concentrations from combined sun-drying and dewatering of slurry

Solid Form:

An analysis of the observed results regarding nutrient concentrations following the combined process of sun-drying and dewatering of slurry indicates a substantial reduction in various parameters as the duration of treatment increases. The weight experiences the most significant reduction after dewatering, with a notable reduction of 38.27%. pH values gradually decrease, indicating a shift towards a less alkaline state. Total solids exhibit a decrease, especially after dewatering, showcasing an effective removal of moisture content. Total Kjeldahl Nitrogen levels rise slightly throughout the process, with the most significant increase noted after dewatering. Similarly, available phosphorus and potassium concentrations display a notable increase, particularly after dewatering. These findings suggest that the combined process effectively reduces moisture content and concentrates nutrient levels in the solid form. In conclusion, the most favorable outcome for nutrient concentration enhancement is achieved through a combination of 48 hours of sun-drying followed by dewatering, resulting in higher nutrient levels in the solid form.

Table 8: Results on Performance of Dewatering Machine in terms of Nutrient Concentrations (Solid form of Output)

Experimental Parameters	Pre-treatment (Before Sun-drying)	Pretreatment (After 24 hours of Sun-drying)	Pretreatment (After 48 hours of Sun-drying)	After Dewatering (Solid Form)
Weight (kg)	102.44	81.45	72.56	50.28
pH Value	8.4	8	7.9	7.8
Total Solids (%)	15.95	20.14	22.23	24.32
Total Kjeldahl Nitrogen, N (%)	0.36	0.39	0.41	0.42
Available Phosphorus, P (mg/kg)	81.48	76.16	73.05	70.84
Available Potassium, K (mg/kg)	1005	958.22	934.33	911.44

Table 10: Results as Reduction Percentage (Solid form of Output)

Reduction Percentage	Pretreatment (Before Sun-drying)	Pretreatment (After 24 hours of Sun-drying)	Pretreatment (After 48 hours of Sun-drying)	After Dewatering (Solid Form)
Weight (kg)	……	20.49	10.91	38.27
pH Value	……	4.76	1.25	2.50
Total Solids (%)	……	-26.27	-10.38	-20.75
Total Kjeldahl Nitrogen, N (%)	……	-8.33	-3.85	-7.69

Available Phosphorus, P (mg/kg)	……	6.53	4.08	6.99
Available Potassium, K (mg/kg)	……	4.65	2.49	4.88

Table 11: Results in terms of Moisture Content, Dry Matter, Dewatering Efficiency, and Dewatering Rate (Solid form of Output)

Performance Parameters with the Dewatering Process	**Pretreatment (Before Sun-drying)**	**Pretreatment (After 24 hours of Sun-drying)**	**Pretreatment (After 48 hours of Sun-drying)**	**After Dewatering (Solid Form)**
Weight (Kg)	102.44	81.45	72.56	50.28
Moisture Content, MC (%)	0	20.53	10.94	30.79
Dry Matter, DM (%)	0	79.51	89.09	69.29
Dewatering Efficiency, D_E (%)	0	20.49	8.68	21.75
Dewatering Rate, D_R (%)	0	87.46	18.52	46.42

Liquid Form:

A meticulous examination of the results detailing the nutrient concentrations resulting from the combined processes of sun-drying and dewatering of slurry reveals a distinct pattern. As the sun-drying duration extends from 24 to 48 hours and culminates in the liquid form after dewatering, several noteworthy trends become apparent. Weight reduction, indicative of effective moisture removal, is most pronounced after the dewatering process, with a substantial 63.72% decrease. The pH values gradually decrease across the pre-treatment phases, signifying a shift towards acidity. Total solids initially rise and then decline, highlighting improved drying and solid formation. Importantly, total Kjeldahl nitrogen content exhibits a substantial reduction after 48 hours of sun-drying, while available phosphorus and potassium experience noteworthy decreases. Based on these findings, it is evident that the most favorable scenario for effective nutrient concentration is the liquid form after dewatering, as it demonstrates the highest weight reduction, pH stabilization, and nutrient concentration. In conclusion, the liquid form after dewatering represents the optimal outcome for achieving superior results in nutrient concentration and overall efficiency due to its substantial reduction in weight, pH stabilization, and notable nutrient concentration.

Table 12 : Results on Performance of Dewatering Machine in terms of Nutrient Concentrations (Liquid form of Output)

Experimental Parameters	Pre-treatment (Before Sun-drying)	Pretreatment (After 24 hours of Sun-drying)	Pretreatment (After 48 hours of Sun-drying)	After Dewatering (Liquid Form)
Weight (kg)	102.44	81.45	72.56	26.45
pH Value	8.4	8	7.9	7.6
Total Solids (%)	15.95	20.14	22.23	14.57
Total Kjeldahl Nitrogen, N (%)	0.36	0.39	0.41	0.31
Available Phosphorus, P (mg/kg)	81.48	76.16	73.05	79.59
Available Potassium, K (mg/kg)	1005	958.22	934.33	917.10

Table 13: Results in terms of Reduction Percentage (Liquid form of Output)

Reduction Percentage	Pretreatment (Before Sun-drying)	Pretreatment (After 24 hours of Sun-drying)	Pretreatment (After 48 hours of Sun-drying)	After Dewatering (Liquid Form)
Weight (kg)	……	20.49	10.91	63.55
pH Value	……	4.76	1.25	3.80
Total Solids (%)	……	-26.27	-10.38	34.46
Total Kjeldahl Nitrogen, N (%)	……	-8.33	-3.85	23.46
Available Phosphorus, P (mg/kg)	……	6.53	4.08	-8.95
Available Potassium, K (mg/kg)	……	4.65	2.49	1.84

Table 14: Results in terms of Moisture Content, Dry Matter, Dewatering Efficiency, and Dewatering Rate (Liquid form of Output)

Performance Parameters with the Dewatering Process	**Pretreatment (Before Sun-drying)**	**Pretreatment (After 24 hours of Sun-drying)**	**Pretreatment (After 48 hours of Sun-drying)**	**After Dewatering (Liquid Form)**
Weight (Kg)	102.44	81.45	72.56	26.45
Moisture Content, MC (%)	0	20.53	10.94	63.72
Dry Matter, DM (%)	0	79.51	89.09	36.45
Dewatering Efficiency, D_E (%)	0	20.49	8.68	45.01
Dewatering Rate, D_R (%)	0	87.46	18.52	96.06

3.5 Performance results of Dewatering Machine

When the performance results from the washing machine tests are looked at in detail, a few important things become clear. The tests were done at different RPM levels, and the main things that are looked at were the weight of the solid cake that was removed (Wce) and the weight of the liquid that was extracted (Wle). It is clear that as the RPM goes down, the extraction yield (Ey) goes up. This means that lower RPM settings make solid-liquid separation work better. Along with this trend, the extraction efficiency (Ee) goes down as the RPM goes down. It's interesting that the extraction loss (El) stays pretty fixed, which shows that the dewatering machine works the same way at all RPM levels. It is important to note, though, that the test at 8 RPM shows the best results, with the biggest extraction yield (52.51%) and extraction rate (79.11%). Because of this, it can be said that lower RPM options, with 8 RPM being the best, improve the dewatering machine's ability to separate solids from liquids, leading to higher extraction rates and efficiencies.

Table 15: Performance Results

Test No.	Weight of Feed Sample, W_{fs}(Kg)	RPM	Weight of solid cake extracted, W_{ce} (Kg)	Weight of Liquid Extracted, W_{le} (Kg)	Weight of Liquid in cake, W_{lc} (Kg)
1	15	36	7.86	3.26	2.85
2	15	25	7.95	3.07	2.64
3	15	20	8.28	2.96	2.58
4	15	15	8.57	2.85	2.42
5	15	10	8.72	2.76	2.26
6	15	8	8.9	2.55	1.95

Table 16: Results on Yield, Extraction Efficiencyand Loss

Test No.	RPM	Extraction Yield, E_y (%)	Extraction Efficiency, E_e (%)	Extraction Loss E_l (%)
1	36	44.03	69.87	25.87
2	25	45.07	70.67	25.73
3	20	47.10	73.60	25.07
4	15	49.20	76.18	23.87
5	10	50.52	77.51	23.47
6	8	52.51	79.11	22.80

3.6 Comparative Results based on Performance parameters and Nutrient Concentrations

A close study of the differences between the outcomes of the sun-drying method and the method that combines sun-drying and draining shows important insights. First, the weight comparison graph shows that both processes consistently reduce weight, but the sun-drying and dehydration process together is much better at reducing wetness and increasing solid concentration. The graph showing the difference in pH values shows that the combined process keeps the pH level more stable and appropriate. This makes it the best way to process cow dung slurry when it comes to controlling and maintaining pH levels. The analysis of total solids shows that the combined method regularly produces higher amounts of total solids. This makes the solids concentration in the slurry higher, which is useful for many farming uses. The Total Kjeldahl Nitrogen comparison graph also shows that the combined process is better at adding TKN to the slurry, which makes it a useful biological fertilizer for plant growth. Available potassium and phosphorus amounts go down in both processes, but the combination method keeps a lot of the nutrients. In the end, the process that combines sun-drying and dehydration is the best because it works better at reducing wetness, keeping the pH stable, increasing solid concentration, and adding nutrients. The study also shows that the combination method is much better than natural sun-drying in important ways. It demonstrates higher nutrient preservation for nitrogen, while also excelling in terms of time and cost efficiency. This makes combined sun-drying and dewatering an attractive option for industries or processes where optimizing time and cost factors is paramount. Ultimately, the dewatering process emerges as the more efficient and cost-effective choice.

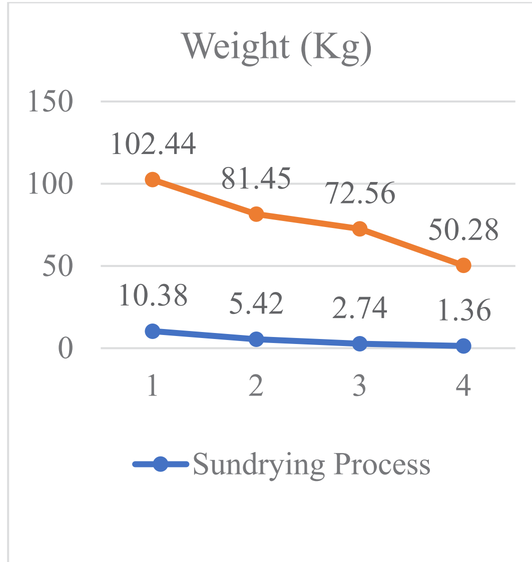

Fig. 36: Weight Comparison

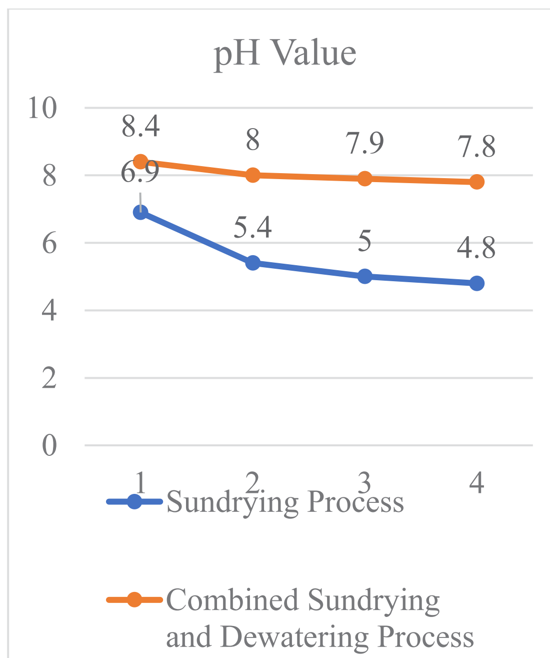

Fig. 37: pH Value Comparison

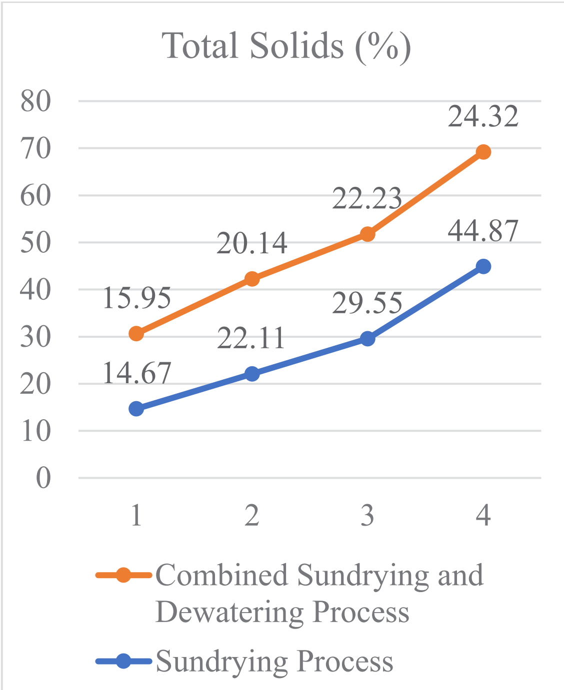

Fig. 38: Total Solids Comparison

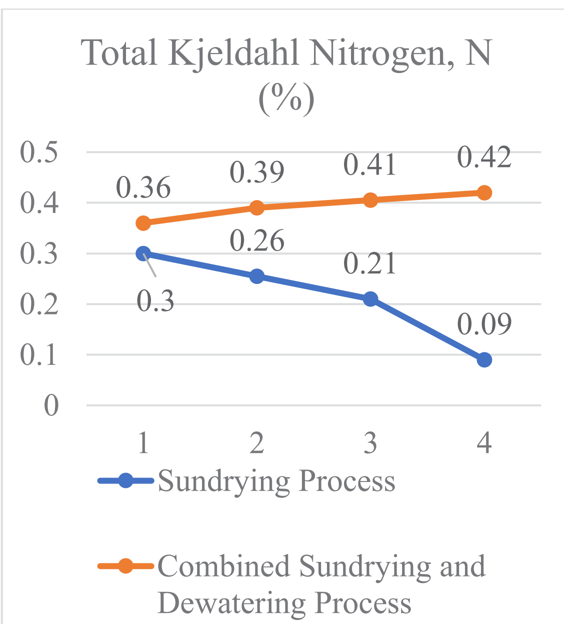

Fig. 39: Total Kjeldahl Nitrogen Comparison

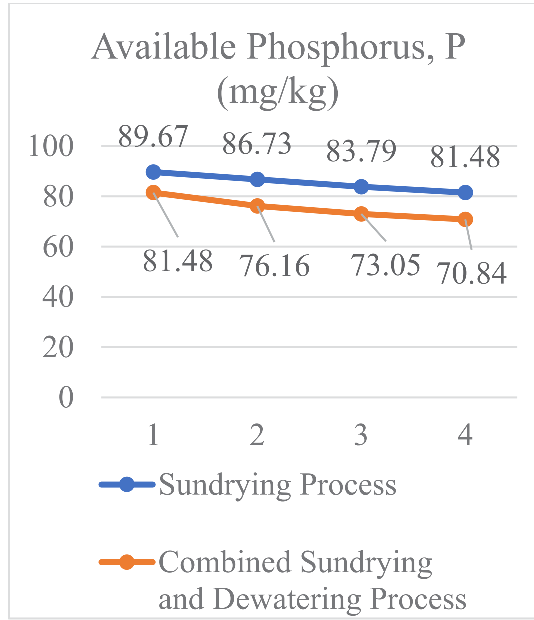

Fig. 40: Available Phosphorus Comparison

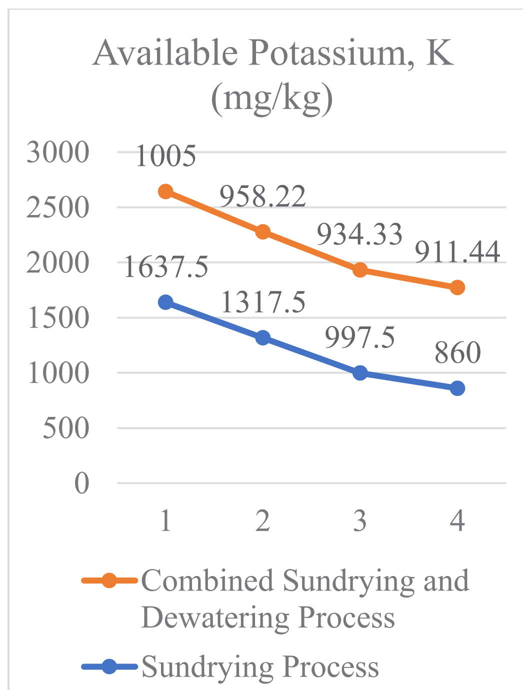

Fig. 41: Available Potassium Comparison

3.7 Efficiency Analysis with respective to time and cost efficiency

3.7.1 Calculations

a. Time Efficiency = (Time saved with dewatering ÷ Total time for sundrying) ×100

= [(72 – (48+4)) ÷72]×100 = 27.78%

b. Cost Efficiency = (Cost saved with dewatering ÷ Cost of sundrying) ×100

Where, Cost saved with dewatering = Cost of sundrying - Cost of dewatering

And, Cost of sundrying = 12,000 (land on rent per month) + 20,500 (labor cost per month) + 165,500 (Loss of Cost due to selling the manure with reduced nutrient content) = NRs. 197,500

Cost of dewatering = 3266 (Maintenance Cost per month) + 13,898 (operating cost per month) + 61,500 (labor cost) + 3266 (Interest paid for loan per month) + 32,666(Investment cost per month) = NRs. 114,596

So, Cost Efficiency = (82,904 ÷ 197,500) ×100 = 42%

c. Cost Efficiency Ratio (Sun-drying) = 197,500 ÷ 86.89 = 2272.989

d. Cost Efficiency Ratio (Dewatering) = 114,596 ÷ 50.91 = 2250.953

3.8 Results from Financial Analysis

The financial analysis of the investment on dewatering machine demonstrates its viability. The payback period for the initial investment is determined to be 1 year, 10 months, and 23 days, signifying a relatively swift return on the capital employed. The internal rate of return (IRR) stands at an impressive 44%, indicating a substantial

return on investment over the considered time frame. Moreover, the net present value (NPV) is calculated at NRs. 353,575.86, underlining the positive financial outlook for the dewatering machine. This financial evaluation underscores the viability of the dewatering machine, making it a financially sound choice for potential investors and stakeholders.

3.8.1 Mathematical Analysis

For the dewatering equipment, the user may incur a cost of NRs. 392,000. As, the operation and packaging of fertilizer after complete dewatering of product will need the involvement of three laborers. Assuming a monthly compensation of NRs. 20,500, inclusive of salary with benefits, the total yearly labour cost amounts to NRs. 738,000.

Assuming that the dewatering machine is run for a total of 300 days per year.

The operational expenses of the dewatering machine include a (5Hp) of motor and a (1Hp) of slurry pump. The machine runs for a duration of 10-hours every day. Subsequently, the monetary value associated with the use of power amounts to NRs. (10*6*0.7457*12.50*300 = 166,770). The yearly maintenance cost of the dewatering machine is estimated to be 10% of the overall cost. So, annual maintenance expense amounts to NRs. 39,200.

Table 17: Annual Cash Flow

S. No.	Particulars of Cash Flow (Annual)	Amount (NRs)
1.	Initial Cost	3,92,000
2.	Operating Cost	1,66,770
3.	Labour Cost	7,38,000
4.	Maintenance Cost	39,200
5.	Interest Paid to Donor @10% annually	39,200
6.	Income	11,90,000

1. Initial Cost = NRs. 384000 + 8000 (Cost of assembly and testing) = NRs. 392000
2. Annual Operating cost = Cost of electricity usage (Motor: 5hp; Slurry pump: 1hp; Machine operated: 10 hrs. a day) = 10*6*0.7457*12.50(NRs.) = NRs. 555.9 per day = NRs. 166770 (Assuming 300 days of operating the machine).
3. Annual Labour Cost: (Assuming the monthly salary of one labour as NRs. 20500 and in total three labors are required in operation) = 3*12*20500 = NRs. 738000
4. Annual Maintenance Cost = 10% of initial cost = NRs. 39200
5. Annual Simple Interest Paid to Donor = 10% of initial cost = NRs. 39200
6. Annual Income:

Considering biogas plant of 1m3, then output of plant: 1000 kg/day.

Performance ratio by weight is 7, so output: 173 kg per day.
With 70% as efficiency; output per day is 100 kg per day.

Market value of per kg of organic fertilizer = NRs 35. (Assuming 365-25=340days of active production) Hence, annual income = NRs. 11,90,000

3.8.2 Payback Period

It denotes number of years needed to get back the initial investment.
Annual Income = 11,90,000

Annual Expenses = Operating cost + Labor cost + Maintenance cost + Annual interest paid

= 166770 + 738000+ 39200 + 39200

= NRs. 983170

Now, Net Annual Profit = Annual Income – Annual Expenses

= 1190000 - 983170

= NRs. 206830

Therefore, Payback period = $\frac{\text{Total Investment (Initial)}}{\text{Annual Profit}}$

$= \frac{392000}{206830}$ = 1.895276314 years = 692.2354608 days

= 1year 10months 23days

The repayment duration in this research is computed as 1 year 10 months and 23 days, which is less than the payback period in Sherpa et al.'s 2017 study. This is because a lower price is selected as NRs. 35 rather than NRs. 50 in previous study, which is closer to the real market price for the fertilizer extracted from the dry cake. The overall machine cost in our analysis is NRs 392,000, which is a little more than the NRs 350,000 in Sherpa et al.'s study. The usage of a 5HP motor with a reduction gear system, as opposed to their 1HP motor, and the modification of worker salaries on a monthly basis rather than daily salary along with operating cost increment are credited for this difference.

3.8.3 Internal Rate of Return

Let us consider a hypothetical scenario in which the equipment operates for a duration of five years, after which it needs a full replacement.

And, when this discount rate is applied, the NPV of a business project's cash flows is zero. The rate of profit retained by the business is known as IRR.

Here,
Using excel command; IRR = IRR (-392000, 376830, 376830, 376830, 376830, 376830)
i.e., IRR = 44 %

It has been determined that the dewatering machine has IRR of 44%. It is taken as a financial measure for evaluating the profitability of project. An IRR of 44% means that the investment is estimated to produce a return of 44% on the initial capital invested over a specified time period.

3.8.4 Net Present Value

The NPV is a financial measure used to determine the PV of a dewatering machine. Given an assumed duration of 5 years.

So, Using excel command; NPV = NPV (- 392000, 376830, 376830, 376830, 376830, 376830) @10% interest per annum i.e., NPV = NRs. 353575.86

The net present value is calculated as Nepalese Rupees Three lakh fifty-three thousand Five hundred seventy-five rupees and Eighty-six paisa.

Chapter 4: Conclusions

In conclusion, this research has successfully designed, simulated, and tested a dewatering machine, aiming to optimize the separation and dewatering of biogas slurry byproducts. The analysis of the structural and computational fluid dynamics simulations has led to the selection of the Constant pitch screw with a tapered shaft as the most suitable design for the pressing screw, ensuring minimal stress and strain, as well as superior fluid flow characteristics. Furthermore, the results reveal that higher rotational speeds (RPM) in the dewatering process result in increased cake weight, higher liquid extraction, and enhanced efficiency, making it a valuable parameter for improving dewatering performance. Additionally, sun-drying of biogas slurry over 48 hours is determined as the optimal duration for moisture reduction while minimizing nutrient loss, particularly Total Solids. The study also reveals that cow dung biogas slurry, after sun-drying and dewatering, closely aligns with standard nutrient values for solid samples but surpasses comfrey liquid in the liquid form. Comparisons with DAP and Urea highlight lower nitrogen and phosphorus content in the treated sample, making it a potential potassium source. Efficiency analysis favors sun-drying for nitrogen preservation but indicates advantages in phosphorus and potassium retention with the combined process.

The financial evaluation indicates a short payback period of 1 year, 10 months, and 23 days, complemented by an impressive internal rate of return (IRR) of 44% and a net present value (NPV) of NRs. 3,53,575.86. This collectively emphasizes the feasibility and profitability of the dewatering machine investment. Ultimately, these findings support the selection of the Constant pitch screw with a tapered shaft design for the pressing screw and highlight the potential for improved dewatering and sun-drying processes in the management and utilization of biogas slurry [10-27].

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Annex A

Fig A.1: Motor drive with screw press

Fig A.2: Complete fabricated system with pressure cone

Fig A.3: VFD with complete assembled dewatering machine

Fig A.4: Assembling work on dewatering machine

Fig A.5: pH mesurement for the sample before and after sundrying

Fig A.6: pH mesurement for the pretreatment of sample before dewatering

Annex B

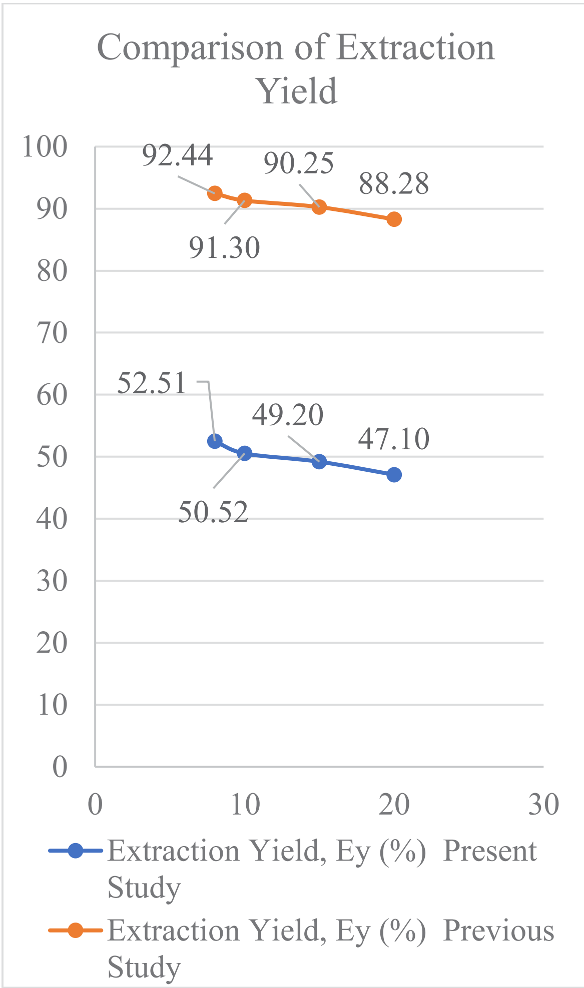

Fig B.1: Comparing Extraction Yield

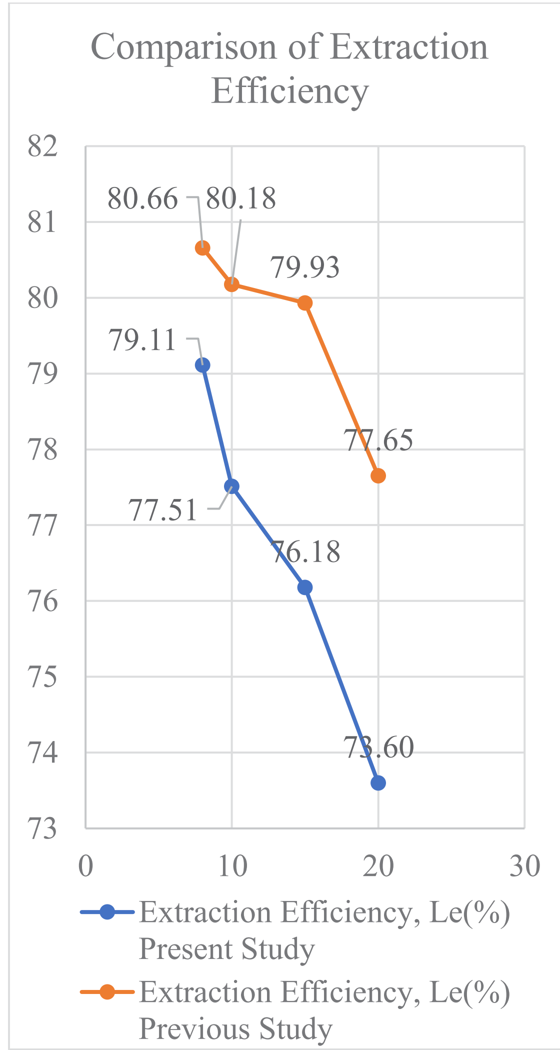

Fig. B.2: Comparing Extraction Efficiency

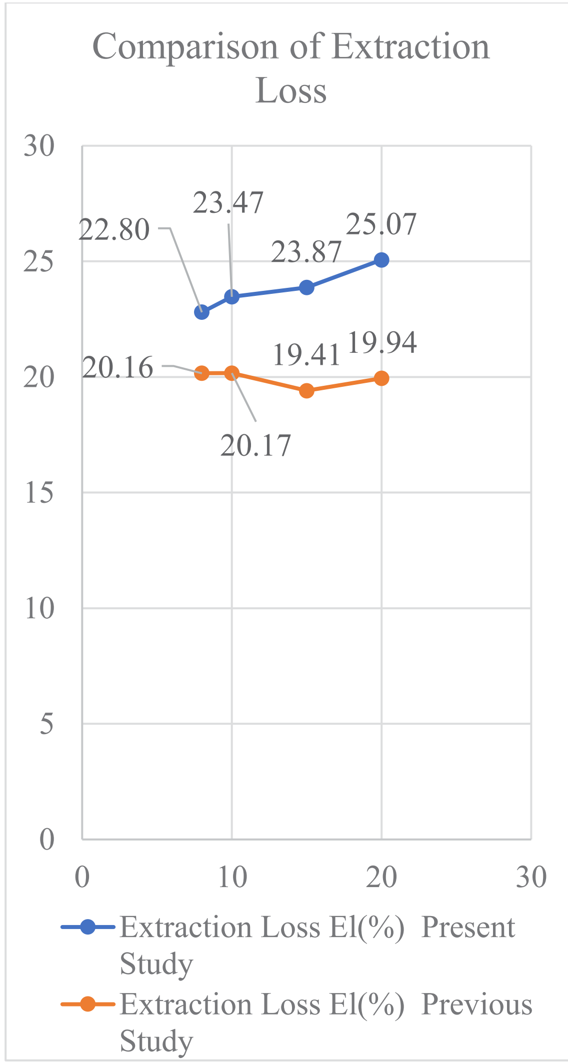

Fig. B.3: Comparing Extraction Loss