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RESEARCH ARTICLE

DESIGN AND FINANCIAL FEASIBILITY OF THE SMALL-SCALE SIZE BIOGAS PLANTS

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Abstract

The least & developing countries rely heavily on firewood as a fuel source. Among several technologies, biogas, as a renewable technology, provides multiple benefits; locally and globally.People lack access to biogas plants due to inadequately qualified specialists and specialized companies in designing and constructing the plants. This paper mentioned the biogas compositionand briefly elaborated its application worldwide. It discussed the design criteria and parameters for sizing the biogas plants.It also discussed thoroughly the most two popular types (with design)of small-scale size biogas plants used in the developing countries, that are, floating drum and the fixed dome plants. The paper clearly explained the modified fixed-dome Chinese biogas plant named GGC-2047 model plant that is widely used in Nepal. It also gave a great overview of the advantages and drawbacks of these plants. In this paper, the design of the fixed-dome Chinese and GGC-2047 model biogas plants were presented for example values, to get an insightful understanding of design for future use. The main input variables were chosen from operating ranges of these values via literature reviews/researchers data, and calculations were made based on selected values for each parameter. Obviously, the different input parameters will yield different outputs. Lastly, it described the concept and terminology used to access the financial analysis of the biogas plants. Moreover, it expounded how the financial indicators are computed, discussed, and analyzed to see if it is worth investing in a particular biogas project or not. This paper might help as a document for sizing the fixed-dome Chinese and GGC-2047 model biogas plants technically and economically.

Introduction:-

Biogas has been one of the most successful models for the production of clean, environmentally friendly, cost-effective source of energy and has multiple benefits [1]. It allows exploiting biodegradable organic matters i.e., animal manure or kitchen waste or agricultural residues, with a lower impact on air quality when compared to combustion-based strategies for these biomasses [2].

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Biogas is produced through anaerobic digestion (AD)process and utilizing the increasing amounts of organic waste produced worldwide [3]. The by-product of AD, i.e., digestate, is used for an agricultural purpose [2]. The performance of AD or biogas production depends on different factors including Carbon-to-Nitrogen (C/N) ratio, pH value, temperature, substrate, organic loading rate, hydraulic retention time (HRT) and stirring [4, 5, 6, 7]. It also depends on the operator experience, skilled staff, and well-trained personnel [8].The small-scale size biogas plants predominantly exist in rural households (with cattle) capacities ranging from 1 to 10 m^3/day biogas [9, 10]. Mostly such plants are used to generate energy for cooking and lighting [9, 10] and are managed by the individual households requiring financial investment but only yielding non-monetary benefits i.e., biogas used as cooking and lighting substituting gathered fuel-wood [10]. Replacing firewood with biogas preserves forest, improve the livelihood of rural people, local environments, ecosystems, problems with erosion, and mitigate Greenhouse gases (GHGs) [11, 12].

Nepal, one of the least developed countries [13], relies heavily on traditional fuel sources, especially firewood [14]. Of Nepal, 80.26% population is in rural areas as of 2018 [15] and 64% population still depend on fire to cook as of 2017 [14]. Among several technologies, biogas has been proved to be viable and emerged as a promising technology [1]. The biogas technologytackles climate change and improves the living and working conditions of people in the developing countries [11, 16] like Nepal.

People are lacking access to biogas plants due to a shortage of qualified specialists and specialized companies in designing, constructing, and exploiting agricultural biogas plants [8].The design of the biogas plant depends on the quantity, quality, and kind of available biomass, the digesting temperature, and hydraulic retention time [17].Obviously, the different input parameters will yield different outputs and, then the design will vary.The financial feasibility of establishing small-scale biogas plants in rural and low-income communities is the major issue [11]. Moreover, these plants arestill costly for poor households, who are also excluded from the benefit of subsidies [8].The aim objectives of the paper are to:

(i) Review the most popular used small-scale size biogas plants in the developing country. (ii) Present thedesign examples of small-scale biogas plants, fixed-dome Chinese model biogas, and GGC-2047 model biogas plants (the most popular in Nepal), based on design criteria, parameters, and other literature/researchers data. (iii) Discussthe financial indicators (Benefit-Cost ratio, Net Present Value (NPV), Pay Back Period (PBP), and Internal Rate of Return (IRR) for the economic analysis of the biogas plant installation and operation. (iii) Get an insight understanding for sizing the biogas plants via economically, technically, and environmentally for future use.
The paper might help as a document for sizing the fixed-dome Chinese and GGC-2047 model biogas plants technically and economically.

Biogas: Composition and Application:
Biogas has emerged as a promising renewable energy technology [2, 10]. It is a mixture of gases, mainly consisting of methane (CH_4) and carbon dioxide (CO_2) [18, 19, 20] resulting from the biological process of anaerobic digestion (AD) of various organic matters [18]. It also consists of trace amounts of water vapor, hydrogen (H_2), nitrogen (N_2), hydrogen sulfide (H_2S), oxygen (O_2),and saturated hydrocarbons (i.e.ethane, propane)[18, 19, 20] is given inTable1.

The performance of the AD process not only depends on the characteristics of organic matters but also on the activity of the microorganisms involved in different degradation steps [3]. The conversion of organic matters into biogas can be divided into three stages: hydrolysis, acid formation, and methane production [3]. In these different stages which are however carried out in parallel, different groups of bacteria collaborate by forming an anaerobic food chain where the products of one group will be the substrates of another group [3]. The process proceeds efficiently if the degradation rates of the different stages are in balance [3].

Table 1:-Typical composition of Biogas [19, 20].

Constituent	**Formula**	**Concentration (v/v)**	**Remarks**
Methane	CH_4	50 – 70 %	Combustible
Carbon dioxide	CO_2	25 – 50 %	Non-combustible
Water Vapor	H_2O	1 -5 %	Non-combustible
Nitrogen	N_2	0 – 5 %	Non-combustible
Hydrogen	H_2	< 1	Combustible
Hydrogen Sulfide	H_2S	0 – 5000 ppm	Combustible

Oxygen	O_2	0 – 0.5 %	Non-combustible
Ammonia		0 – 500 ppm	

Biogas has varied end uses. In developing countries, biogas is mainly produced in small, domestic-scale for cooking or even lighting, in comparison to developed countries, where biogas developments focused on a larger scale such aselectricity generation, heat biogas plants, Combined Heat and Power (CHP) generation, transportation fuel (after being upgraded to biomethane) or upgraded to natural gas quality for other purposes [21, 22]. Globally the most common use of biogas goes for cooking followed by lighting [21].

Factors Affecting Biogas Production/Design Parameters of Biogas Plant:

The parameters for the design of biogas plants have been discussed below. These are also the main factors affecting biogas production.

C/N Ratio:

It is the ratio of Carbon-to-Nitrogen present in the organic matter. The optimum value of the C/N ratio lies between 20 and 30 [4, 23, 24]. If the C/N ratio is very high then, nitrogen will be consumed rapidly and the rate of reaction will decrease. On the other hand, if the C/N ratio is very low then, nitrogen will be liberated and accumulated in the form of ammonia, which is toxic under certain conditions [4].Materials with a high C/N ratio could be mixed with those of a low C/N ratio to bring the average ratio of the composite input to a desirable level [4]. C/N ratio of some of the commonly used feed materials is presented in Table 2.

Table 2:- Various substrates and their C/N ratio [25, 26, 27, 28].

Substrate	**C/N ratio**
Duck droppings	8
Elephant dung	43
Straw (maize)	60
Goat manure	9-12
Human excreta	6-10
Sheep manure	19-34
Straw (rice)	50-68
Mixed food waste	15-32
Pig manure	6-14
Cow dung/buffalo dung	15-25
Poultry manure	4-15
Straw (wheat)	50-150
Sawdust	199-501
Kitchen waste	25-29
Fallen leaves	50-53

P^H:

P^H is a measure of acidity/alkalinity of the input. A P^H value of 7 is neutral; P^H less than 7 is acidic and higher than 7 is alkaline [4]. The optimal value of P^H which maximizes biogas production lies in the range 6.5 to 7.2 [5, 29].

Digestion Temperature:

Anaerobes are the most active in mesophilic (15-45^{o}C) and thermophilic (45-60^{o}C) temperature range and hence, commonly used temperatures during anaerobic digestion of organic matters [5, 30].

Hydraulic Retention Time (HRT):

The HRT is defined as the average time that a given quantity of input remains in the digester [4]. Longer HRT will require large digester volume which increases capital cost. Short HRT will wash away the active bacterial population [6]. Maximum methane production occurs at the optimal value of HRT. If HRT is less than the optimal value then, volatile fatty acids (VFAs) will accumulate which will cause server fouling and result in reduced biogas production, and if HRT is above optimal value then, the biogas component will not be utilized effectively, and hence, biogas production will be reduced [6].

For instance, for cow/buffalo dung input, HRT of 70 days in the colder/temperate climate and 55 days in the warmer/tropical climate and for human excreta, HRT of 90-100 days (effective stabilization as human excreta contains more pathogens) are used [4].

Organic Loading Rate:
The amount of feed supply per day to the digester is called the organic loading rate. The size of the plant also depends on it [7]. The under loading and overloading reduces biogas production. The loading of feed must be carried out every day at the same time to keep the solid concentration ratio constant in the digester [7].

The GGC model plants (the most popular biogas plant in Nepal, will be discussed later) of size (4-20 m^3) to the daily organic loading rates [4, 31] is mentioned in Table 3.

Table 3:- Loading rate with various GGC plant sizes [4, 31].

GGC Model Plant Size (m^3)	Daily Loading Rate (kg) (For Cow/buffalo Dung)	
	Colder/temperate climate (Hills), HRT = 70 days	Warmer/temperate climate (Terai), HRT = 55 days
4	24	30
6	36	45
8	48	60
10	60	75
15	90	110
20	120	150
* Plant size is the sum of digester volume and gas storage ** Manure/dung : water = 1:1		

Stirring or Agitation of the Content of Digester:
Stirring or agitation is done to make sure that the contact between substrate and microorganisms is intimated, and hence, results in the enhanced degradation rate of the substrate. It is not essential but always advantageous [6, 7]. If not stirred then, the slurry will tend to settle out and form a hard scum on the surface, which will prevent the release of biogas [6, 7]. This problem is much greater with vegetable waste than with manure, which will tend to remain in suspension and have better contact with the bacteria as a result. Since bacteria in digester have very limited reach to their food, it is necessary that slurry is properly mixed and bacteria get their food supply [7]. It is found that occasional mixing allows the masses that float at the top in the form of scum allow mixing with the deposits at the bottom. It helps in improving fermentation [7].Biogas production enhanced by about 62% compared to gas production without agitation [6].

Types and DesignofBiogasPlants:
The design of a biogas plant shouldoptimizethe gas production per unit volume of a biogas plant for a given type and quantity of input [4, 32, 34]. The plant should be easy to operate, cost-effective, durable, and should be constructed from local materials as far as possible and should attempt to reduce time and money costs associated with repair and maintenance [4, 16, 32, 33]. The plant should be a continuous flow anaerobic digester for a small-scale domestic application [34, 35]. Another mechanism to effectively sell the concept is – the plant should look aesthetically pleasing [35].

The various types of biogas plants designed are [34]: floating drum; fixed-dome; bag digester; plastic digester; plug flow; anaerobic filter, and Uplift Anaerobic Sludge Blanket (UASB). Of the various types of biogas plants designed, two plants have gained widespread acceptance, particularly in the developing countries [16, 32, 33] in agricultural practice which are discussed below [17].

1. floating-drum plant in which the metal gasholder floats on the digester, and
2. fixed-dome plant in which gas storage is effected according to the displacement principle.

Floating drum biogas plant:
In 1956, a design of a floating drum biogas plant was developed in India which is popularly known as the Gobar Gas plant. In 1962, Patel's design was approved by the Khadi and Village Industries Commission (KVIC) of India and this design soon became popular in India and the world [32, 33, 34, 36].

In this design, the digester chamber is made of brick masonry in cement mortar. A mild steel drum is placed on top of the digester that floats on the slurry to collect the biogas produced from the digester [16, 34, 35]. When biogas is produced, the gas pressure pushes the steel drum upwards, and as the gas is consumed, the drum lowers down. Since the mild steel drum practically floats above the digestion chamber, it is known as the floating drum gas-holder biogas plant [35,36] is depicted in Figure 1 [36].

Floating-drum plants are used chiefly for digesting animal and human excrements on a continuous flow (with daily input). They are used most frequently by: small-to-midsize family farms (digester size: 5 – 15 m^3), and institutions and large agro-industrial estates (digester size: 20 – 100m^3) [17]. Advantages: It is easy to understand and operate, provide gas at constant pressure, and the stored volume is immediately recognizable [17]. Drawbacks: The steel drum is relatively expensive and maintenance-intensive due to the necessity of periodic painting and rust removal [17, 35, 36]. If fibrous substrates are used then, the gasholder shows a tendency to get "stuck" in the resultant floating scum [17].

The life-time of the drum is short (up to 15 years; in tropical coastal regions about 5 years) [35]. The different types of floating-drum plants are [35]:
1. KVIC model with a cylindrical digester, the oldest and most widespread floating drum biogas plant from India
2. Pragati model with a hemisphere digester
3. Ganesh model made of angular steel and plastic foil
4. BORDA model: The BORDA-plant combines the static advantages of the hemispherical digester with the process-stability of the floating-drum and the longer life span of a water jacket plant.

Fixed-dome Chinese biogas plant:
With the introduction of a fixed-dome Chinese model plant, the floating drum plants became obsolete because of comparatively high investment and maintenance costs along with other design weaknesses [9].

A fixed-dome comprises a closed, dome-shaped digester with an immovable, rigid gasholder and a displacement pit, also named 'compensation tank'[16, 17].The gas is stored in the upper part of the digester. Gas production increases the pressure in the digester and pushes slurry into the displacement pit[16, 17]. When gas is extracted, a proportional amount of slurry flows back into the digester. The gas pressure does not remain constant in a fixed-dome plant but increases with the amount of stored gas [16].

A fixed-dome Chinese plant is the archetype of all fixed dome plants [17]. It is built in China as early as 1936 and consists of a cylinder with a round bottom and top with an underground brick masonry compartment (fermentation chamber) with a dome on the top for gas storage [16, 32, 33, 34].

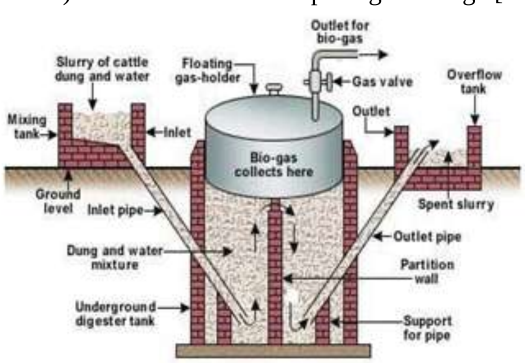

Figure 1:- Schematic diagram of the floating drum biogas plant [36]

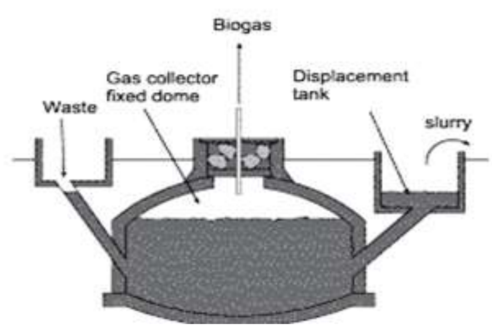

Figure 2:- Schematic diagram of fixed-dome Chinese biogas plant [32]

It should only be built where construction can be supervised by experienced biogas technicians. Otherwise, plants may not be gas-tight (porosity and cracks) [16, 17]. In this design, the fermentation chamber and gas holder are combined as one unit [34]. The plant is depicted in Figure 2 [32] and this design eliminates the use of mild steel gas holders which is susceptible to corrosion [32]. This plant must be covered with earth up to the top of the gas-filled space as a precautionary measure (internal pressure up to 0.1-0.15 bar) [17]. The earth cover makes them suitable for the colder season, and they can be heated as necessary [17]. Based on the principles of the fixed-dome Chinese model, various countries have modified designs to suit their local conditions [32, 33].

In Nepal, the Gobar Gas and Agricultural Equipment Development Company (GGC) modified the fixed-dome Chinese model, which is commonly known as the GGC-2047 model [37, 38]. It is easier to construct having less curved profiles (i.e., digester bottom is fully horizontal instead of concaved) and operates [38, 39, 40] as depicted in Figure 3 [39]. This is used for both private and community biogas plants [38]. It is relatively cheap and durable (20 to 50 years)[38].It is compacted and well insulated, occupies less space and the earth-filled plant maintains inner temperature during the cold season [32].

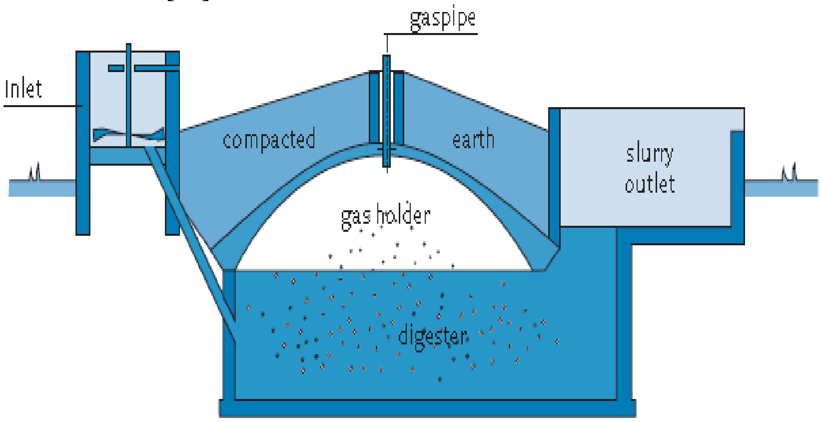

Figure 3:- A typical GGC-2047 model biogas plantin Nepal [39].

Design Criteria, Parameters, and Calculations:

Table 4 mentions some criteria that need to be accountedfor the sizing of the biogas.The mixing ratios between the substrate (input) and water are shown in Table 5.

Table 4:- Design criteria for sizing of the biogas plant [16].

S.N.	Design Criteria	Value
1.	Biogas energy content	6 kWh/m^3
2.	One cow yield	9 – 15 kg dung/day
3.	Gas production per kg of cow dung	0.023 – 0.04 m^3
4.	Gas production per kg of pig feces	0.04 - 0.059 m^3
5.	Gas production per kg of chicken droppings	0.065 – 0.116 m^3
6.	Gas production per kg of human excreta	0.020 – 0.028 m^3
7.	The gas requirement for cooking	0.2 0.3 m^3/person
8.	The gas requirement for lighting one lamp	0.1 – 0.15 m^3/hour

Table 5:- Common substrate mixing ratios [17].

Type of Substrate	Substrate	: Water
Fresh cattle manure	1	: 0.5-1
Semi-dry cattle dung	1	: 1-2
Pig dung	1	: 1-2
Cattle and pig dung from a floating removal system	1	: 0
Chicken manure	1	: 4-6
Stable manure	1	: 2-4

Sizing of a Biogas Plant:
For sizing a simple biogas plant, the certain characteristic parameters are used. These are daily slurry input (Sv), hydraulic retention time (HRT), and Specific gas production per day (Gd), which depends on the retention time and the feed material [17, 41].

The required gasholder size is an important planning parameter [41, 42]. The size of the gasholder or the gasholder volume (V_G) depends on gas production and the volume of gas drawn off. The ratio of gasholder volume (V_G) to daily gas production (G) is called the gasholder capacity (C) [41, 42]. If the gasholder capacity is insufficient then, the part of the gas produced will be lost. The remaining volume of gas will not be enough. If the gasholder is made too large, construction costs will be unnecessarily high but, plant operation will be more convenient. The gasholder must, therefore, be made large enough to be able to accept the entire volume of gas consumed at a time [41, 42].A gasholder capacity of 50-60% is usually used in the design of the biogas plants in rural areas of the developing countries [41].A capacity of 70% or even more must be allowed only where not more than one meal a day is cooked regularly or where eating habits are highly irregular. The safety margin of 25% for fluctuating gas production must be added to the value V_G [41].

To become eligible to receive the investment subsidy provided by Nepal's Government under the Biogas Support Programme (BSP), only the GGC-2047 model plants of 4, 6, 8, 10, 15 and 20 m^3 capacity should be constructed. If the design and size of the plant other than mentioned in Table 3 are chosen, the subsidy is not allowed [31].

The designs of the fixed-dome Chinese and GGC- 2047 model biogas plants are presented for example values. Obviously, the different input parameters will yield different outputs and, then the design will vary. The main input variables are chosen from operating ranges of these values via literature reviews or researcher data and calculations are made based on selected values for each parameter.

Fixed-dome Chinese model plant:
The design parameters and formulae proposed by Sasse, (1988)are considered in the design of the fixed-dome Chinese biogas plant [43]. Some parameters considered in design are presented in Table 6.

Table 6:- Some dimensions considered for V_G: V_D ratios [43].

V_G:V_D	1: 5	1:6	1:8
R	$\sqrt[3]{0.42\ VD}$	$\sqrt[3]{0.42\ VD}$	$\sqrt[3]{0.42\ VD}$
r	0.70R	0.66R	0.60R
H	0.16R	0.15R	0.14R
H	0.33R	0.31R	0.28R
p	0.64R	0.60R	0.53R

V_G= volume of the gas holder, V_D= volume of the digester, R=radius of the fixed-dome Chinese model bioreactor, r = radius of the displacement pit, H = the distance between the bottom of gas holder wall and the bottom of the displacement pit, h = height of the slurry in the displacement pit, p = the distance between the ground and the entrance point of the inlet pipe.

Design Example Calculation:
Sizing the digester:
According to Sasse (1988) and Sasse et al. (1991), the size of the digester, i.e., the digester volume, $V_D$is determined based on HRT and the daily slurry input, Sv and is calculated from the equation 1 [12].The amount slurry consists of the feed material (e.g., cattle dung) and the mixing water [41]**.**The calculations based on design criteria and literature data are also presented in the required section.

V_D (L) = Sv (L/day) x HRT (day) ----------1.
Suppose the number of breeding hens (N_h) on the farm is about 100. The quantity of waste generated per hen per day (W_h) = 0.175 kg hen/day (on average) [43]. Waste (manure) load = N_h x W_h = 100 x 0.175 = 17.5 kg/day, where, N_h is the number of breeding hens in the farm.

For an unheated digester, in the warmer/tropical climate (HRT = 55 days), colder/temperate climate (HRT = 70 days), or a heated digester in mesophilic range (35-42^{o}C, 30 days HRT) or in thermophilic range (>45 ^{o}C, 15 days

HRT) [44].From Table 5, for dilution, chicken/hen manure: water = 1: 5 and taking HRT = 50 days (unheated, warmer climate).

Daily slurry input (Vs) = manure load + water = 17.5 + (5 x 17.5) = 105 L/day = 0.105 m^3/day = 0.0044 m^3/hour.Therefore, substituting the values in equation 1, V_D = 0.105 m^3/day x 55 days = **5.78 m^3**

Calculating the daily gas production:
From Table 4, 1 kg hen manure produces = 0.09 m^3 gas (on average). Daily gas produced (G) = 0.09 m^3/kg x 17.5 kg/day =1.58 m^3/day. The gasholder capacity (C) and safety margin are 55% (on average) and 25 % respectively as already mentioned [41].V_G =C xG x1.25 =0.55 x 1.58x1.25 m^3= **1.08 m^3**. Now, V_G:V_D = 1.08/5.78 **= 1 : 5.3 = 1 : 5**

Establishing the plant design parameters:
From Table 6, for V_G:V_D = 1:5. We have,
R = $\sqrt[3]{0.42\ VD}$ = $\sqrt[3]{0.42 * 5.78}$ = 2.5 m
r = 0.70 x 2.5= 1.8m = 18 cm
H = 0.16 x 2.5 = 0.4 m = 40 cm
h = 0.33 x 2.5 = 0.83 m = 83 cm
p = 0.64 x 2.5 = 1.6 m

GGC 2047 ModelPlant- Biogas Plant Design in Nepal:
The criteria, parameters, and formulae proposed by Shakya, [42] in Sustainable energy technologies (Session 7), Biogas Technology are considered in the design of the GGC-2047 model biogas plant [42].

Design Example Calculation:
Suppose 40 kg cow dung available daily. In calculation, dilution ratio (cow dung: water) and HRT are selected as 1: 1 (from Table 5) and 55 days for the warmer/tropical climate (Terai) as mentioned already [4] respectively.

Sizing the digester:
Daily slurry input (Vs) = 40 +(1 x 40)= 80 kg. Volume of digester (V_{D*}) = Vs (kg/day) x HRT (day) = 80 x 55 = 4,400 kg = 4.4 m^3. Additional, Volume of digester**(V_D)** to over-come scum and gas bubbling 10% [42]= 4.4 +(10 % x 4.4) **=V_D = 4.84 m^3**

Calculation of H and D:
Usually D: H = 2-2.5: 1 [42], where, D and H are the diameter (m) and height (m) of the digester respectively.Taking D = 2.25 (on average), D = 2.25 H. Volume of digester (V_D) = $\frac{\pi}{4}$ D^2H; It implies, H = $\sqrt[3]{0.25\ VD}$ = $\sqrt[3]{0.25 \text{ x } 4.84}$ = 1.06 = 1.1 m (let say) and D = 2.25 x 1.1 = 2.5 m

Sizing dome:
Usually dome volume = 40 - 60% of digester volume [42]. Therefore, Volume of dome **(V_G or V_d)=**0.45 x 4.84=**2.2m^3**

Calculation of h and r:
r = D/2 [42], Therefore, r = 2.5/2 = 1.25 m. The volume of the dome is given by V_G= 2.2 =$\frac{\pi h}{6}(3r^2+h^2)$ [42]. Substituting all the known values in this cubic equation, we get, h= 0.79 m = 79 cm; where, r, and h are radius (m) and height (m) of dome respectively.

Outlet Sizing:
Usually outlet volume= 60 – 70% of dome volume [42]. Therefore, outlet volume = 0. 65 x 4.84 =**3.15 m^3**

Calculation of L, B and h_o:
Height of outlet chamber (h_o) depends upon how much structure can take the pressure for safe side 0.80 -1.35 m water gauge pressure taken for concrete work [42]. Usually, L = 1.2 - 1.5B [42]. Taking L = 1.35B, h_o = 1 m, where, L, B, and h_o are the length (m), breadth (m), and height (m) of the outlet chamber respectively.Therefore, Outlet Volume (Vo)= 3.15 = L x B x h_o. Substituting all know values , we get, B = 1.53 m and L = 1.35 x 1.53 = 2.1 m.

Inlet Sizing:
Daily slurry input (Vs) = 80kg = 0.08 m^3.Additional space10% to prevent spell out [42].Therefore, Inlet volume (Vi)= 0.08 +(10% x 0.08) = 0.088 m^3.

Calculation of D_i and h_i:
For convenient, height of inlet (h_i) = 0.5 - 0.6 m [42]. Therefore, Inlet Volume (Vi) = 0.088 =π/4 x D_i^2 x h_i [42] where, D_i and h_i are the diameter (m) and height (m) of the inlet chamber respectively. Taking h_i = 0.55 m = 55 cm, Substituting the value, we get, D_i = 0.46 m = 46 cm.

To check Table 3:
Suppose a household is in a cold climate and has 34 kg/day cow dung (i.e., >24 but <36 kg/day). Which GGC model biogas plant size has to be designed and constructed in the same climate? Now, according to Table 3, it implies that the GGC model biogas plant size of 6m^3 should be designed and constructed to these mentioned data and information.

Solution: V_{D*}= Sv x HRT = (34 + 34) x 70 = 4.76 m^3/day. To over-come scum and gas bubbling 10%, V_D = 5.24 m^3.From Table 4, 1 cow dung produces 0.0315 m^3 gas. Therefore, V_{G*} = C x G =0.55 x (34 x 0.0315 m^3) = 0.59 m^3. Taking, safety margin 25 %, V_G= 1.25 x 0.59 m3 = 0.74 m^3. Therefore, the plant size = V_D + V_G = 5.24 + 0.74 = 5.98= 6.0 m^3 (let say). Hence, it is fine. The Table 3 is checked to make sure about my calculation/design work.

Financial Analysis:
This helps to decide whether a user benefits by installing a biogas plant and, if so, by how much. Since this analysis is undertaken before deciding to install the plant, it is important to ensure that all costs and benefits are estimated as they are most likely to be realized by the user after the plant installation [9]. To make the analysis more comprehensive, costs and benefits should be reflected for each year of the project life. It should include all those costs and benefits that will be changed or influenced by the use of a biogas plant [9].The following financial indicators need to be considered for the biogas plant to see if it is worth investing in the project or not and are discussed below.

Project Life:
For instance, the fixed dome Chinese plant lasts longer, from 20 to 50 years [34] depending on the quality of construction and materials used [9]. However, the economic life of a plant is taken as 20 years mainly because any cost or benefit accrued after 20 years will have insignificant value when discounted to the present worth [9, 32].

Cost of capital (RRR)[25, 45]:
For an investment to be worthwhile, the expected return on capital (IRR) must be greater than the cost of capital (RRR). Given several competing investment opportunities, investors are expected to put their capital to work to maximize the return. In other words, the cost of capital is the rate of return that capital could be expected to earn in an alternative investment of equivalent risk. If a project is of similar risk to a company's average business activities it is reasonable to use the company's average cost of capital as a basis for the evaluation. A company's securities typically include both debt and equity, one must, therefore, calculate both the cost of debt and the cost of equity to determine a company's cost of capital. However, a rate of return larger than the cost of capital is usually required [25, 45].

Benefit-Cost Ratio:
The benefit-cost ratio (BCR) is a tool for assessing the profitability of a project. If the ratio is greater than unity (i.e. B/C > 1.0), the rule of thumb is to accept the project [9].

Net present Value (NPV):
The NPV technique measures the worthiness of a project by converting the annual cash flow to a single present value [9].

As the costs and benefits of a project are spread over the useful years of project life, they need to be expressed in terms of one common denominator to make the comparison possible [9]. Once the annual cash flow of a project is derived, it needs to be discounted so that all values could be compared to the value of a single year [9]. This discounted net cash flow will provide a widely used criterion for measuring the profitability of a project. For this purpose, all future values are discounted to make them equivalent to the present value and are expressed as Net Present Worth (NPW) or Net Present Value (NPV) [9]. In short, it is defined as the sum of the present values of incoming and outgoing cash flows over a period of time; incoming and outgoing cash flows can also be described as benefit and cost cash flows [46].

A negative NPV should be rejected while a zero NPV makes the investor indifferent, in which case other factors and benefits relating to the investments should be considered [11, 25]. A positive NPV indicates that the benefits are higher than the costs that accrue over the project life [9, 25].

The NPV of a sequence of cash flows takes as input the cash flows and a discount rate or discount curve and outputs a price. Each cash inflow/outflow is discounted back to its present value (PV). Then they are summed. Therefore NPV is the sum of all terms [25],

$$\frac{\mathbf{Rt}}{(\mathbf{1}+\mathbf{i})\hat{}\mathbf{t}}$$

where,
t – the time of the cash flow;
i - the discount rate (the rate of return that could be earned on an investment in the financial markets with similar risk.); the opportunity cost of capital
Rt - the net cash flow i.e. cash inflow – cash outflow, at time t. For educational purposes, R_o is commonly placed to the left of the sum to emphasize its role as (minus) the investment.

The result of this formula is multiplied with the Annual Net cash in-flows and reduced by Initial Cash outlay the present value but in cases where the cash flows are not equal in amount, then the previous formula will be used to determine the present value of each cash flow separately [25]. Any cash flow within 12 months will not be discounted for NPV purposes. Nevertheless, the usual initial investments during the first year $R_{\mathbf{0}}$ are summed up a negative cash flow [25].

Given the (period, cash flow) pairs (t, Rt) where N is the total number of periods, the net present value NPV is given by [25]:

$$\mathbf{NPV}\,(\mathbf{i},\mathbf{N}) = \sum_{\mathbf{t}=\mathbf{0}}^{\mathbf{N}} \frac{\mathbf{Rt}}{(\mathbf{1}+\mathbf{i})^{\mathbf{t}}}$$

Discount rate:
The commonly used discount rate is the rate of interest that a bank/micro-finance institution charges on loans and the opportunity cost of capital in situations where private capital is being committed [9, 47]. For instance, the on-going discount rate in Nepal is 16 % [9, 47]. Therefore, the NPV and Benefit-Cost Ratio (BCR) are calculated at the discount rate of 16 % [9].

Internal rate of return (IRR):
IRR is used to measure the efficiency of capital investment [25]; also measures the project profitability [9,11, 25, 46], and is defined as the discount rate which makes the NPV of a project zero [9, 11, 25]. In other words, the IRR of an investment is the discount rate at which the net present value of costs (negative cash flows) of the investment equals the net present value of the benefits (positive cash flows) of the investment [25].

The calculation of IRR requires trial and error methods. The NPV needs to be calculated assuming several discount rates until the value is zero. The following equation (based on interpolation) can be used to derive an approximate value of IRR [9]. IRR higher than the discount rate means the investment is profitable [11].

$$\mathrm{IRR} = \frac{\mathrm{r1\,.\,NPV2 + r2.\,NPV1}}{(\mathrm{NPV1 + NPV2})}$$

where,
r1 = discount rate of the positive value of NPV
r2 = discount rate of the negative value of NPV
NPV1 = value of positive NPV
NPV2 = value of negative NPV

Payback period (PBP):
It is often used because it is easy to apply and easy to understand for most individuals, regardless of academic training or field of endeavor [25]. It is defined asthe period of time required to recoup the funds expended in an investment [11, 46].

For instance, an Rs.10,000 investment that returned Rs.5,000 per year would have a two-year payback period. The time value of money is not taken into account. Payback period intuitively measures how long something takes to "pay for itself." PBP is given as [11]:

$$\text{PBP} = \frac{\text{Initial investment (Rs.)}}{\text{Annual return (Rs)}}$$

All else being equal, shorter payback periods are preferable to longer payback periods [46].

Conclusion:-
Biogas is a renewable energy source that mainly consisting of CH_4 (50-70 %) and CO_2 (25-50 %). Biogas has varied end uses. Mostly small-scale plants are managed by individual households to generate energy for cooking and lighting in the developing countries. In developed countries, biogases are used to generate electricity, heat plants, fuel transportation, etc.

The biogas plant has been seen as one of the most popular and environmentally friendly strategies for tackling climate change and improving the living and working conditions of people in developing countries like Nepal.

The review revealed that the family-type (small-scale) size biogas systems predominantly exist in the rural households (with cattle) capacities ranging from 1 to 10 m^3/day biogas. The review also noted that such scale plants are reasonably simple and cheap, and can be manufactured locally.It pointed out that with the introduction of a fixed-dome Chinese model plant, the floating drum plants became obsolete because of comparatively high investment and maintenance costs along with other design weaknesses. Moreover, the modified fixed-dome Chinese biogas plant named GGC-2047 model plant is widely used in Nepal. The C/N-ratio, pH value, temperature, HRT, organic loading rate, mixing, and other criteria & parameters required in the design of biogas plants are presented.

The design criteria, parameters and formulae proposed by Sasse, (1988) [43] and Shakya, [42] are considered in the design example of a fixed-dome Chinese model and GGC-2047 model biogas plants respectively. These design examples provide an insight understanding to design plants of research/survey/experimental data shortly. It is found that the volume of the digester (V_D) and that of the gas holder (V_G) are crucial in the design of the biogas plant. It summarized how the financial indicators are computed, discussed and analyzed to see if it is worth investing in a particular biogas project or not. The main financial indicators discussed are Cost of Capital (RRR), Benefit-Cost ratio (B/C-ratio), Net Present Value (NPV), discount rate, Internal Rate of Return (IRR), and Pay Back Period (PBP).

Finally, it also noted that the financial feasibility of establishing biogas plants in rural and low-income communities is the major issue. So, along with designing plants technically and economically, the users should be provided with various appropriate policy, schemes, subsidy, or/and loan, for installation and operation & maintenance of the plants. It also pointed out that the cattle dung has been used primarily as an input, and the biogas plants are limited to households only. The improvement and encouragement of biogas plants should be done which will contribute several socio-economic, agricultural, technical, and environmental benefits.

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