SRI SHANMUGHA COLLEGE OF ENGINEERING AND TECHNOLOGY

(Approved By AICTE, Accredited by NAAC, Affiliated to Anna University)

Tiruchengode – Sankari Mani Rd, Pullipalayam, Morur (PO), Sankari (Tk), Salem 637304.

AI8712 – RENEWABLE ENERGY LABORATORY

DEPARTMENT OF AGRICULTURE ENGINEERING

Anna University - Regulation: 2017

B.E AGRICULTURE ENGINEERING – VII SEMESTER

AI8712 –RENEWABLE ENERGY LABORATORY

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RECORD NOTE BOOK

REGNO. _____

Certified that this is a bonafide observation of Practical work done by Mr/Ms/Mrs……………………………………of the……………………………………… Semester……………………………………………. Branch during the Academic year……………in the………………………………laboratory.

Staff–in–Charge   **Head of the Department**

Internal Examiner   **External Examiner**

GENERAL INSTRUCTIONS

❖ All the students are instructed to wear protective uniform and shoes before entering into the laboratory.

❖ Before starting the exercise, students should have a clear idea about the principles of that exercise

❖ All the students are advised to come with completed recorded and corrected observation book of previous experiments, defaulters will not allowed to do their experiment.

❖ Don't operate any instrument without getting concerned staff member's prior permission.

❖ All the instruments are costly. Hence handle them carefully, to avoid fine for any breakage.

❖ Almost care must be taken to avert any possible injury while on laboratory work. In case, anything occurs immediately report to the staff members.

❖ One student from each batch should put his/her signature during receiving the instrument in instrument issue register**.**

LIST OF EXPERIMENTS

S.No	Date	Name of the Experiments	Page No	Mark Obtained	Faculty Signature
S.No	Date	Name of the Experiments	Page No	Mark Obtained	Faculty Signature

AI8712 RENEWABLE ENERGY LABORATORY

OBJECTIVE:

To gain the practical knowledge on various renewable energy gadgets.

EXPERIMENTS:

1. Characterization of biomass – proximate analysis

2. Determination of caloric value of fuels – solids and gases

3. Design of KVIC / Deenbandhu model biogas plant

4. Study of UASB biomethanation plant

5. Performance evaluation of agro based gasifier

6. Purification of biogas – CO_2 and H_2S removal

7. Study on pyrolysis unit – Biochar, Charcoal and Tar making process

8. Testing of biogas/producer gas engines

9. Study on briquetting and Stoichiometric calculations

10. Determination of BOD and COD

11. Testing of solar water heater

12. Testing of natural convection solar dryer

13. Study on Solar power and I-V Characteristics

14. Testing of solar photovoltaic water pumping system

EXPERIMENT: 1 CHARACTERIZATION OF BIOMASS – PROXIMATE ANALYSIS

Aim:

To determine the proximate composition of given feedstock such as moisture content, volatile matter, fixed carbon and ash.

Apparatus required:

Hot air oven, Muffle furnace

Materials required:

Biomass, Petri dish and Silica crucible with lid

Procedure:

i. Moisture content

- Take a petri dish and weigh it (W_1).
- Weigh 5 g of sample in petri dish (W_2) and keep it in the hot air oven at $105 \pm 3°C$.
- At an hour interval, weigh the sample kept in oven and note down the readings. Repeat this until obtaining the constant weight (W_3).

$$\text{Moisture content } (\%_{db}) = W_3 - W_2 / W_3$$

$$\text{Moisture content } (\%_{wb}) = W_3 - W_2 / W_2$$

$$\text{Total solids } (\%) = 100 - MC (\%)$$

ii. Volatile matter

- Switch on the muffle furnace and allow the temperature to reach $650°C$
- Weigh the dried sample (W_1) in a silica crucible and cover with lid (W_2).
- Keep the sample (W_2) in muffle furnace at $650°C$ for six minutes and again at $750°C$ for another six months.
- Remove the silica crucible from the muffle furnace and note down the weight (W_3).
- Loss in weight of the sample was found out and volatile matter was calculated as,

$$\text{Volatile matter } (\%) = \frac{Loss\ in\ weight\ of\ the\ sample\ (g)}{Weight\ of\ the\ dried\ sample\ (g)} \text{x } 100$$

iii. Ash content

- Weigh the moisture free sample in anopen silica crucible
- Switch on the muffle furnace and keep the weighed sample at $600°C$ for an hour.
- Allow the sample to cool and check for the presence of carbon. If any carbon particle is found in the sample, heat it for another 30 min in the muffle furnace at the same temperature until the observance of greyish white colour ash.
- Note down the final weight.

- The residue left in the silica crucible is the amount of ash present in the sample. It can be calculated as,

$$\text{Ash content (\%)} = \frac{Residue\ left\ in\ the\ silica\ crucible\ (g)}{Inital\ weight\ of\ the\ sample\ (g)}$$

iv. Fixed carbon

Difference between the 100% and sum of the volatile matter and ash percentage of the bone dried sample is termed as fixed carbon content.

$$\text{Fixed carbon (\%)} = 100 - (\text{VM} + \text{Ash})\ (\%)$$

Result:

i. Moisture content of the sample = _____ %

ii. Volatile matter of the sample = _____ %

iii. Ash content of the sample = _____ %

iv. Fixed carbon content of the sample = _____ %

EXPERIMENT: 2 DETERMINATION OF CALORIC VALUE OF FUELS – SOLIDS AND GASES

Aim:

To determine the gross and net calorific value of biogas using Junker's and Boy's gas calorimeter

Apparatus required:

Junker's gas calorimeter

Materials required:

Biogas, Match box and water

Calorific value

It is the total quantity of heat liberated, when a unit mass (or volume) of the fuel is burnt completely.

Higher or Gross calorific value

It is the total amount of heat produced, when one unit of the fuel has been burnt completely and the products of combustion have been cooled to room temperature.

Net / Lower heating value of Biogas

It is the net heat produced, when mass / volume of the fuel is burnt completely and the products are permitted to escape.

Difference between the gross (higher) and net (lower) heating value is the latent heat of vaporization of water vapour formed by combustion.

Junker's gas calorimeter

Procedure:

- Connect the water inlet and outlet hose to calorimeter. Place the thermocouples through rubber cock at water inlet and outlet, one each at exhaust gas and gauge glass.
- Turn on the water mains by opening the control knob of the gas calorimeter setting "ON". Adjust water supply in such a way that there will be only a small amount of overflow of excess water to sink. By this the air bubbles inside the water circulating will be let out.
- Remove burner from the calorimeter.
- Open the outlet gas flow control valve slowly. Allow the gas to pass through the governor and gas flow meter and allow needle for three-four revolutions as indicated by the flowmeter.
- Light the burner.Adjust air regulator sleeves and the gas tap to get a non-luminous flame.
- Clamp the burner keeping it to the top most position.

- Adjust the flow of water to get a temperature difference of 12 to 15°C between the water inlet and outlet temperatures.
- Allow the indicator provided for the water outlet temperature to indicate a steady temperature.
- Keep the measuring jar beneath the swinging water outlet tube and swing the water outlet arm to measure the water flow with known time and rotate back to drain.
- Simultaneously, count the number of revolutions made by gas flow meter pointer with respect to time for 1 or 2 revolution *i.e.,* to find the volume of gas consumed during the test period.
- Immediately note the temperatures of water inlet and outlet as well as gas flow meter keeping the water flow and gas flow.
- Repeat the experiment thrice or four times and take average of the readings and calculate the calorific value of gas using the following formula:

$$\text{Gross Calorific value of biogas } (C_v) = \frac{V_w \times C_p \times (T_2 - T_1)}{V_g}$$

Where,

V_w – Volume of water (l)

V_g – Volume of gas (l)

C_p – Specific heat of water (KJ kg K^{-1})

T_1 – inlet water temperature (°C)

T_2 - outlet water temperature (°C)

Net / Lower heating value of Biogas

Mass of water condensed in kg from 1 m^3 of gas $= m/V$

Latent heat of steam per m^3 of gas $= \frac{m}{V} \times 587$

$$LHV \ (kCal/m^3) = GCV - \frac{m \times 587}{V}$$

1 INLET

2 ...

3 PRESSURE REGULATOR

4 AIR HUMIDIFIER

5 FUEL BURNER

6 AIR INLET

7 COOLING WATER

8 COOLING WATER DISCHARGE

9 THERMOMETER (INLET WATER TEMPERATURE)

10 THERMOMETER (OUTLET WATER TEMPERATURE)

11 FLUE GAS OUTLET

12 CONDENSATE OUTLET

Junkers gas calorimeter

Observation table

Replication No.	Sample	V (m³)	W (kg)	t_1 (s)	t_2 (s)	M (kg)	GHV (cal/m³)	LHV, (cal/m³)
.								

Result:

EXPERIMENT: 3 DESIGN OF KVIC / DEENBANDHU MODEL BIOGAS PLANT

Aim:

To design KVIC and Dheenbhandu biogas plant for household and community level applications.

1. Design of KVIC biogas plant

Gas production	:	$0.04\ m^3$/kg of cow dung
Retention Time	:	30 – 60 days (Assume: 40 days)
Diameter to Height	:	0.5 – 0.75
Slurry requirement	:	50 kg per m^3

$$\text{Volume of the digester} = \frac{\text{Weight of slurry}}{\text{Density}} \text{ x Retention time}$$

(Weight of slurry = equal quantity of dung and water)

Actual volume

Actual Volume of the digester should have 10% additional volume which indicates the headspace.

Actual volume=   Digester volume+ 10% of the Digester volume

= $\pi\ r^2\ H$

With the assumption of D/H, calculate r and H $(\frac{D}{H}=0.5)$

$\pi r^2 H = \pi \left(\frac{D}{2}\right)\left(\frac{D}{2}\right) H$ = Actual digester volume

$\pi \ x \ \left(\frac{0.5\ H}{2}\right)\left(\frac{0.5H}{2}\right) H$ = Actual digester volume

Find out the diameter and height from the above equation.

Gas storage

Assume 20 cm gap between drum and wall,

∴ Diameter of the gas holder (d) = Diameter of digester (D) – 0.2 m

Find the diameter of the gas holder (d).

Actual gas produced = Weight of dung x 0.04 = m^3 / day

Volume of gas holder = 50% of the gas production = m^3

Volume of gas holder = $\frac{\pi}{4}d^2 h$

Substitute (d) and find out h.

Design the drum dimensions and Draw the KVIC biogas plant.

Example:

   A village consists of 98 families with five members in each family. Village survey report gives the following information about cattle. Design a community biogas plant to meet out the cooking and lighting requirements.

Cows	=	102 No.
Oxen	=	124 No.
Buffalo	=	52 No.
Pig	=	2 No.
Total	=	280 No.

Gas required for cooking/ person / day $\quad\quad = 0.227\ m^3$

Gas required for lighting 100 cp. Lamp/h $\quad\quad = 0.126\ m^3$

Each family is allotted with a lamp, which would burn 2 h daily.

Solution

i. Calculate the total quantity of dung available

Cow dung	= 10 kg / day / cow
Total cow dung	= 10 x 102 = 1020 kg / day
Ox	= 12 kg / day / ox
Total dung from oxen	= 12 x 124 = 1488 kg / day
Buffalo	= 15 / day / buffalo
Total dung from buffalo	= 15 x 52 = 780 kg / day
Pig	= 2 kg / day / pig
Total dung from pig	= 2 x 2 = 4 kg / day
Total quantity of dung available	= 1020 + 1488 + 780 + 4
	= 3296 kg/day = 3300 kg

ii. Gas generation

Gas produced from 1 kg of cow dung = 42 L = 0.04 m^3

Calorific value of the biogas / m^3	=	4700 kcal(with burning efficiency of 60 %)
Density of slurry	=	1090 kg / m^3
Total gas produced / day	=	42 x 3300
	=	138600 L / day = 138.6 m^3 / day

It is advisable to design for the minimum gas generating capacity i.e., 138.6 m^3 / day

iii. Gas requirement

   a. Total gas required for cooking

(There are 490 people) $\qquad$ = $\qquad$ 0.227 x 490 = 111. 23 m^3

Gas required for lighting / day [40 W lamp two hours daily burning per connection] for 98 families $\qquad$ = $\qquad$ 2 x 0.126 x 98= 24.69 m^3

Total gas required for cooking and lighting = 111.23 + 24.69 = 136.92 m^3

The gas produced is 138.6 m^3/day (Assume all the cattle dung is available)

Surplus gas = 138.6 – 136.92 = 1.68 m^3

It can be used for 5 street lamps

Gas required = 5 x 0.252 = 1.16 m^3

Rest (1.68 – 1.16) = 0.52 m^3, can be accounted for leakage etc.

iv. Estimating the dimensions of digester

For the sake of convenience in distribution we can have 4 digesters.

Quantity of dung for each digester $\qquad$ = $\qquad$ $\dfrac{3300}{4}$ = 825 kg

Volume of the daily charge $\qquad$ = $\qquad$ $\dfrac{\text{Weight of (dung} + H_2O)}{\text{Density of slurry}}$

$\qquad$ = $\dfrac{825 + 825}{1090}$ = 1.51 m^3

$\qquad$ Digester volume $\qquad$ = Volume of the daily charge x Retention time

$\qquad$ = $\qquad$ 1.51 x 30 $\qquad$ = $\qquad$ 45.3 m^3

$\qquad$ Actual digester volume $\qquad$ = $\qquad$ 1.1 x 45.3 $\qquad$ = $\qquad$ 49.83 m^3

$\qquad$ Volume of gas holder $\qquad$ = $\qquad$ $\dfrac{\pi}{4}D^2H$

Considering $\quad$ D =H

$$\pi \text{ x } \left(\frac{H}{2}\right)\left(\frac{H}{2}\right) H = 49.83 \text{ m}^3$$

$$H = 3.93 \text{ m}$$

Height of the digester = 3.93 m = 4m

Diameter of the digester = 3.93 m = 4 m

v. Estimating the dimensions of gas holder

Volume of the gas to be retained by the gas holder = (825 x 0.04) /2 = 16.50 m^3

∴ Diameter of the gas holder (d) = Diameter of digester (D) – 0.2 m

$$= 4 - 0.2 \text{ m} = 3.8 \text{ m}$$

$$16.50 = 0.785 \, d^2 h = 0.785 \, (3.8)^2 \, h$$

$$h = 1.455 \text{ m} = 1.5 \text{ m}$$

Total volume of the slurry = volume fed in total dung + vol. of water

$$= 3300 + 3300 = 6600 \text{ kg}$$

2. Design of Dheenbandhu model biogas plant

Dheenabandhu model offers reduction in the overall construction cost, elimination of the loss of biogas through inlet chamber and maximum utilization of digester volume to make the operational HRT close to the design HRT.

Important design aspect of this model is that due to its spherical shape, surface area become minimum, requiring less construction materials and lesser the cost. This design essentially consists of segments of two spheres of different diameters joined at their bases. A safe distance is provided between the inlet and outlet to prevent the possible short circuiting of fresh slurry. The entire structure could be considered as an integrated unit of digester (bottom portion) and gas storage chamber. While the base diameter to rise of arch ratio is kept at 5:1 for the bottom of the unit and the top dome is a hemisphere.

Capacity of biogas plant   – 2 m^3

Retention time   – 40 days

Density of slurry   – 1000 kg/m^3

Gas production/kg of dung – 0.04 m^3

Cow dung required to produce 2 m^3 of biogas – 50 kg

Daily slurry fed into the plant = 100 kg   (50 kg cowdung + 50 kg of water)

$$\text{Volume of digester} = \frac{\text{weight of slurry}}{\text{Density of slurry}} \times \text{Retention time}$$

$$= \frac{100}{1000} \times 40$$

$V = 4 \text{ m}^3$

$V = V_1 + V_h - V_3$

$V_1 + V_h - V_3 = 4$

Assume, $V_1 = V_3$

$$\therefore V_h = 4$$

$$\frac{2}{3} \pi R^3 = 4$$

$$R = 1.24 \text{ m}; R = 1.2 \text{ m}$$

Assume,

$$h_1 = D/5 = \frac{2.4}{5} = 0.48 \text{ m}$$

Volume of dome,

$$V_1 = \pi h_1 \left[\frac{D^2}{8} + \frac{H_1^2}{6} \right]$$

$$V_1 = \pi \times 0.48 \left[\frac{(2.4)^2}{8} + \frac{(0.48)^2}{6} \right]$$

$$V_1 = 1.14 \text{ m}^3$$

Actual,

$$V_h = \frac{2}{3} \pi R^3 = \frac{2}{3} \pi (1.2)^3$$

$$V_h = 3.61 \text{ m}^3$$

Substitute the values of V_h & V_1 in

$$V = V_1 + V_h - V_3$$

$$4 = 1.14 + 3.61 - V_3$$

$$V_3 = 0.759 \text{ m}^3$$

Let $h_2 = \frac{D}{4.2} = \frac{2.4}{4.2}$

$$h_2 = 0.57\text{m}$$

$$A = R = 1.2 \text{ m}$$

$$A = h_2 + h_3 = 0.57 + h_3$$

$$h_3 = A - 0.57 = 1.2 - 0.57 = 0.63 \text{ m}$$

Let us consider that gas storage volume as 1/3 gas produced per day.

$$V_3 - V_4 = \frac{1}{3} \times 2 = 0.67$$

$$V_4 = 0.754 - 0.67$$

$$V_4 = 0.08 \text{ m}^3$$

$$\text{Let } h_4 = \frac{D}{8} = \frac{2.4}{8} = 0.3 \text{ m}$$

$$V_4 = \pi h_4 \left[\frac{d^2}{8} + \frac{h_4^2}{6} \right]$$

$$0.08 = \pi \times 0.3 \left[\frac{d^2}{8} + \frac{(0.3)^2}{6} \right]$$

$$0.085 = \frac{d^2}{8} + \frac{(0.3)^2}{6}$$

$$d = 0.74 \text{ m}$$

Storage Volume = 0.67 m^3

       l x bx h = 0.67

Assume l = 1.5b

          1.5 b x b x h = 0.67; $1.5 \, b^2 h = 0.67$

h = $h_3 - h_4$ = 0.63 − 0.3 = 0.33m

            $1.5 \times 0.33 \times b^2 = 0.67$

                b = 1.16 m

                     l = 1.74m; b = 1.16 m; h = 0.33 m

Result:

Aim:

To design anup flow anaerobic sludge blanket reactor for waste water treatment.

Design:

The physico-chemical characteristic of the sludge bed is an important factor in deciding the biomethanation capacity of the reactor. The amount of daily deposition of sludge depends on the characteristics of raw wastewater. Design of the reactor is as follows:

1. Total sludge production

    i. New VSS produced by BOD removal

$$\text{(Assume the yield coefficient as 0.1 g VSS / g BOD removed)}$$

New VSS produced in BOD removal (mg l^{-1})	=	influent BOD (mg l^{-1}) x BOD removal (%) x Yield coefficient (g VSS / g BOD removed)

    ii. Non-biodegradable residue of the VSS coming in the inflow is,

Non-degradable residue (mg l^{-1})	=	VSS (mg l^{-1}) x(1 – degradable fraction)

    iii. Ash received in the inflow can be calculated as

New ash received in the inflow (mg l^{-1})	=	TSS (mg l^{-1}) – VSS (mg l^{-1})

Sum of the above three components gives the total sludge produced per day

Total sludge produced (kg day^{-1})	=	New VSS produced in BOD removal (mg l^{-1}) + Non – degradable residue (mg l^{-1}) + Ash received in the inflow (mg l^{-1})

2. Solid retention time

Solid retention time of a system depends on the characteristics of the wastewater.

$$\text{Solid retention time (days)} = \frac{Total\ quantity\ of\ sludge\ present\ in\ the\ reactor\ (kg)}{Quantity\ of\ sludge\ removed\ per\ day\ (kg/day)}$$

Average concentration of sludge in the blanket (kg m^{-3}) x

$$\text{Solid retention time (days)} = \frac{\text{Effective depth of sludge blanket (m) xEffectiveness coefficient (\%)xHydraulic retention time (h)}}{\text{Total quantity of sludge produced (mg l}^{-1}\text{)}}$$

3. Hydraulic retention time

$$\text{Hydraulic retention time} = \frac{\text{SRT x total quantity of sludge produced x 24}}{\text{Average concentration of sludge in the blanket xEffective depth of the sludge blanket x Effectiveness coefficient}}$$

4. Up flow velocity

The liquid upflow velocity in the reactor is directly related to reactor height. In a conventional UASB system, the average daily value of liquid upflow velocity for domestic wastewater should not exceed 0.7 m h^{-1} (Lettinga and Hulshoff Pol, 1991).

$$\text{Up flow velocity (m h}^{-1}) = \frac{\text{Reactor height (m)}}{\text{Hydraulic retention time (h)}}$$

5. Area of reactor

Consider the reactor of cylindrical in shape,

$$\text{Cross sectional area of reactor (m}^2) = \frac{\text{Flow rate (m}^3\text{/h)}}{\text{Up flow velocity (m/h)}}$$

6. Diameter of the reactor

$$\text{Reactor area (m}^2) = \frac{\pi}{4}\text{xD}^2$$

Result:

EXPERIMENT: 5 PERFORMANCE EVALUATION OF AGRO BASED GASIFIER

Aim:

To study the working principle of rice husk gasifier and to test its performance
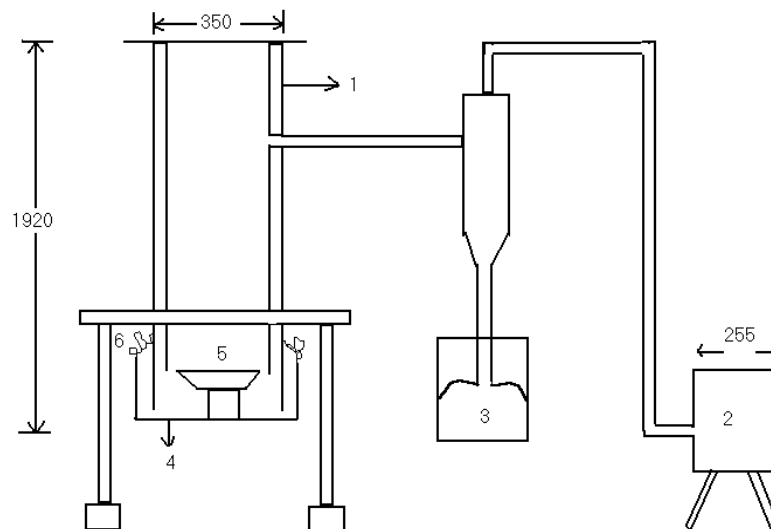
Apparatus of the unit:

Balance, measuring jar, thermometer, watch etc.,

Description of gasifier

1. Function   :   For thermal applications in small scale industries

2. Specification

Rice husk consumption rate	:	6 – 8 kg/h
Thermal efficiency	:	55 – 60 %
Gas yield	:	10 – 12 m^3/h
Power required for blower	:	0.2 kW
Thermal capacity	:	10,000–15,000 kcal/h

All Dimensions are in mm   Open Core Agro Residue Gasifier

Components of Open core Gasifier

1→ Reactor

2 → Burner

3 → Tar collecting bottle

4 → Bottom lid

5 → Grate

6 → Tie rods

3. General information :

  The 4.5 kW downdraft open core rice husk gasifier consists of two cylindrical drums of 300 mm and 370 mm diameter, joined with flange at the top and fitted with a grate and a lid at the bottom. A 0.2 KW electrical motor run blower sucks gas, produced from the plant and supplies to the burner. A gas cooling and cleanup system was provided in between the reactor and the burner.

4. Cost of unit   : Rs. 25,000

5. Cost of operation   : Rs.30/h

6. Salient features   :

   ☞ Thermal applications of rice mills can be suitably met out with thermal efficiency of 55 to 60%

   ☞ Compared to diesel system about Rs.300/day can be saved

Observations

  The gasifier can be ignited from bottom. A bed of ignited charcoal (0.5 kg.) to a depth of 50 mm is placed over the grate. Then the biomass is dumped over the red-hot charcoal. A white gas emanates and it is ignited.

1) Mass of water taken (m) kg
2) Initial temperature (t_1)
3) Final temperature (t_2)
4) Loss in weight of water (Δm) kg
5) Mass of fuel used in kg
6) Initial time T_1
7) Final time T_2

CALCULATIONS

Known values

  Specific heat of water (S) = 1 k. cal./kg

  Latent heat of water (L) = 540 k. cal./kg

  Calorific value of firewood = 4271 k. cal./kg

Heat output H_O = msΔt + L Δm

Heat input H_i = (mass of fuel used x calorific value of fuel) + (mass of charcoal x calorific value of charcoal)

Thermal efficiency η = H_O/ H_I

Power output rating PR = f $C_v\eta$/860

Where,   f = quantity of fuel burnt kg/h.

C_v = calorific value of fuel k. cal/kg

η = Thermal efficiency of the stove.

RESULTS:

Thermal efficiency of gasifier burner system

Power Rating of gasifier burner system

Ex.No.6.   PURIFICATION OF BIOGAS

Biogas is a promising source of renewable energy and has now become an important area of research. Biogas contains CH_4, CO_2, H_2S, CO and N_2O. methane gives heating value to biogas. Scrubbing is the isolation of CO_2, H_2S and nitrogen oxides from biogas. The compression ignition engine run on biogas free of CO_2 and trouble free, develop higher horse power, has least repair and maintenance problems and provide better service life. Its cooking efficiency improves as cooking gas. Unit volume of scrubbed biogas has less CO_2 and high CH_4 which promotes heating value of calorific value.

Different methods of purification

1. Water spray method

The purifying unit is made up of emptied kerosene drum. A water spray boom arrangement is provided from the top of the drum. Water is applied through the spray boom from the top water connection from an overhead tank and the biogas is allowed to move through this passage. Due to the pressurized action of water molecules on biogas, the CO_2 content of biogas was reduced from 40% to 8%.

2. Sweep diffusion process

Sweep diffusion is a technology in which one of the gases from binary fluid can be separated by the process of diffusion arising from differential physical properties of the component. Two concentric tubes are placed such that the inner one is perforated with a center to pass steam. Biogas comprising of CO_2 and CH_4 is passed through the annular space between the concentric cylinders in a counter flow direction. The steam having affinity for CO_2 which is heavier in density is in the vicinity of biogas which is separated by sharp clustered orifices of capillary nature. This creates a situation where the different viscosity causes a

variable velocity flow under laminar condition resulting in the CO_2 being swept along the steam flow and thereby of biogas results in.

The quantum of separation is influenced by both velocity of flow of both the fluids as well as the velocity difference between each. The fluid pressure difference is influenced by the relative area of cross section of the two cylinders besides the characteristics of the fluid flow. The concentration gradient between the inner and outer fluids in conjunction with the coefficient of concentration that is confronted during the fluid mixing is also vital in regulating the diffusion.
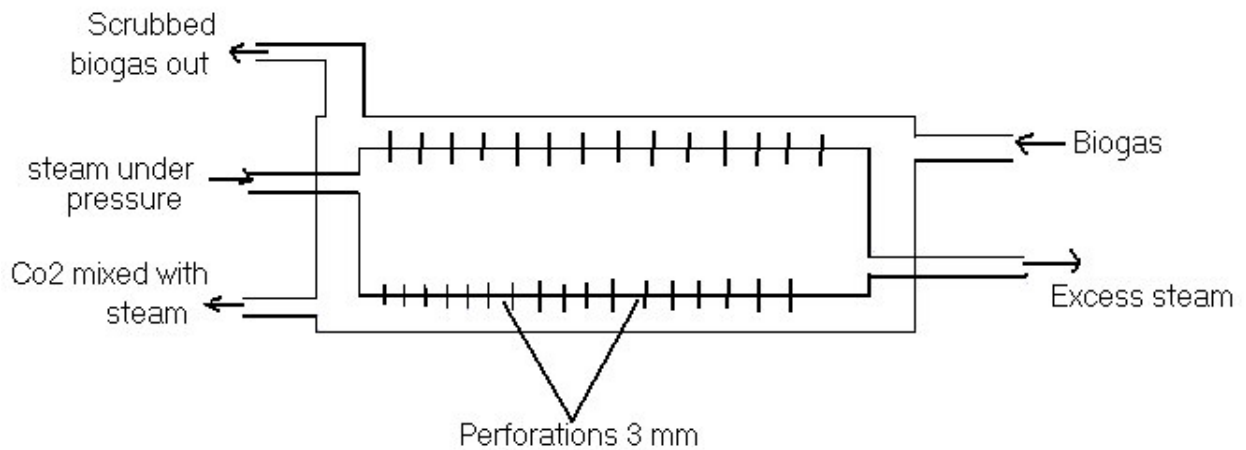
Fig. Water Spray Boom Arrangement

Fig.Sweep diffusion process

3. Scrubbing tower

Galvanized iron sheet of 22 gauge of 1 m length and 0.2 m width was taken. It was rolled to form a cylinder of 1 m length and internal diameter of 0.2 m. But joints were made at the joining surface. Brazing was done along the joining surface to make the joints leak proof. Similarly, 6 cylinder of same dimensions were made and jointed mouth to mouth by flanges and bolts. The top and bottom end were conical. The maximum and minimum diameters of conical cylinder were 0.2 and 0.1 m respectively. The top end had 2 openings, one for the entry of water and other for the exit of scrubbed biogas. Exit point was concerned with sampling system by rubber tube. The bottom end of the tower rested on a stand. This end also had 2 openings, one for the entry of raw biogas and the other for exit of wash water. A compressor with pressure gauge was used in between the source of raw biogas and scrubbing tower. The through the energy meter. A rotometer was used near the entry point of raw biogas into scrubbing tower. A pump was used to fill the scrubbing tower with water. The power requirement of the pump was 0.186 kW.

The rotameter maintains the constant flow of biogas at 5 m. the water level in the scrubbing tower was kept constant. The tower had provision for continuous entry and exit of water. CO_2 was absorbed by water and gas coming out of tower was scrubbed gas. Scrubbed biogas then passed to a vacuum pump having an outlet with a cock for opening and closing, cycle tubes were used for taking the samples.
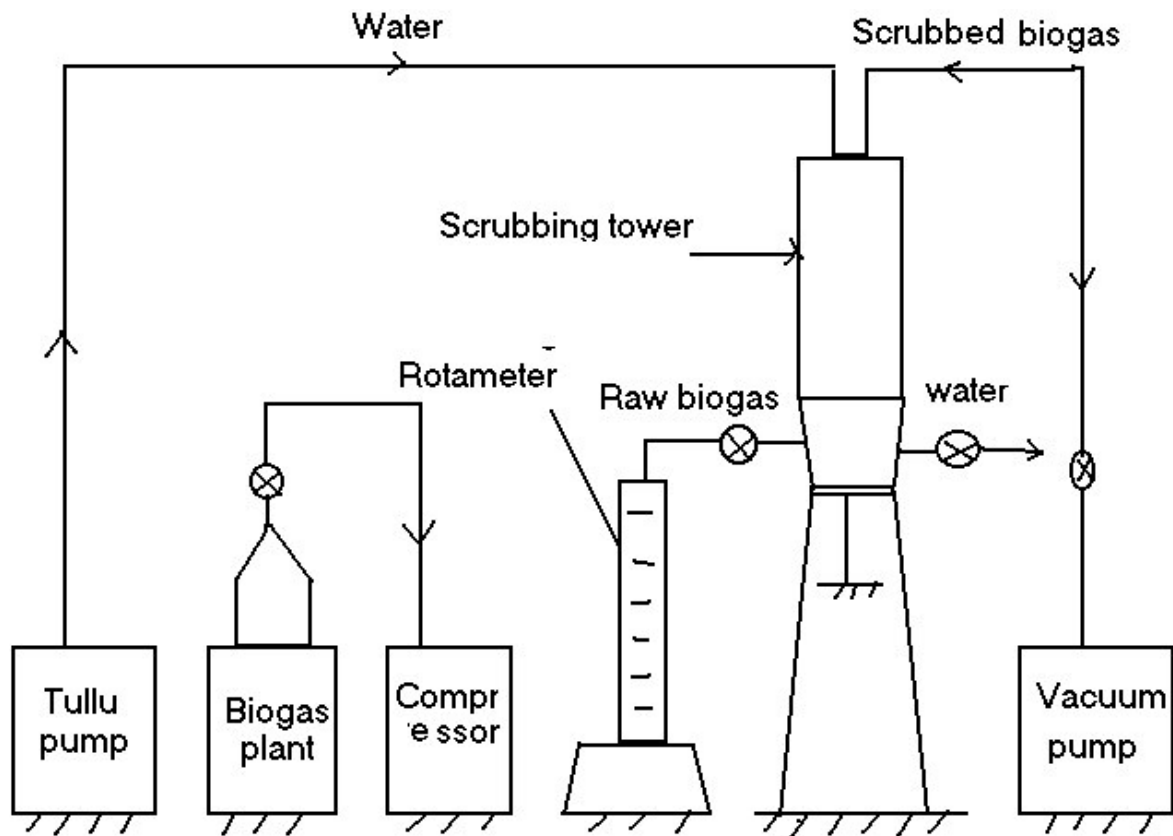

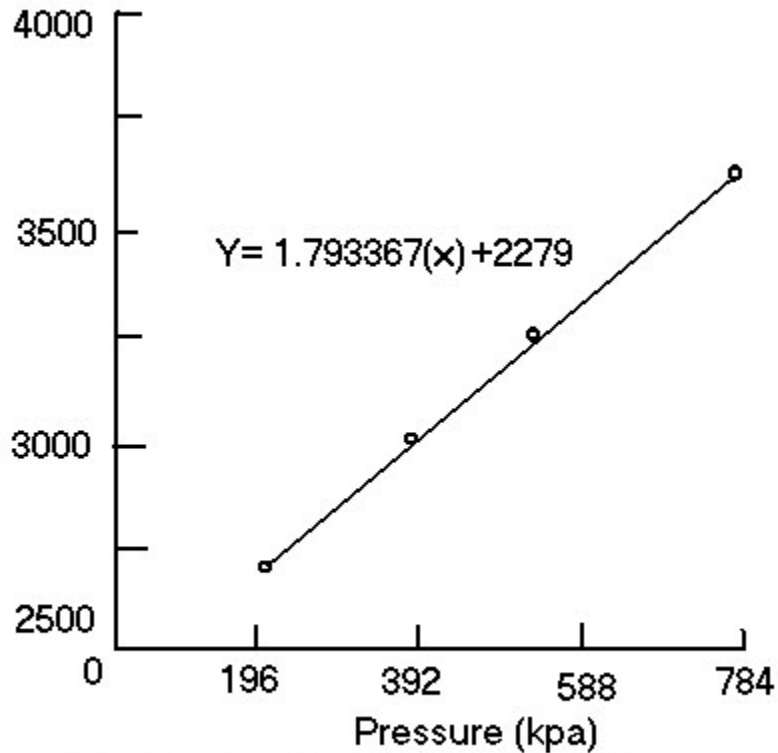Fig. Schematic View of Scrubbing Tower

Fig. Effect of Pressure on Gain of Energy

Conclusion

Gain in energy was proportional to pressure. With the increase in pressure – gain in energy also increase. Since the pressure increased, the scrubbing of biogas, this envisaged higher calorific value of scrubbed biogas and resulted in higher gain of energy. The curve followed the following equation.

$$Y = 1.793367\ x + 2279$$

Where   Y   =   gain in energy in kJ/m^3 and

          X   =   pressure, kPa

EXPERIMENT: 7 STUDY ON PYROLYSIS UNIT – BIOCHAR, CHARCOAL AND TAR MAKING PROCESS

EXPERIMENT: 8 TESTING OF BIOGAS/PRODUCER GAS ENGINES

Utilization of biogas

Biogas being a very clean and good quality fuel, so it can be utilized for following purposes as:

Biogas for cooking purposes

Biogas provides a clean and efficient fuel for the kitchen, a special biogas burner (stove) other than L.P. burner is used for cooking purposes. It consists of nozzle, an air inlet, mixing chamber and fire sieve element. The nozzle is a hollow tube made of glass, metal, plastic or bamboo. As biogas passes through the nozzle, air is allowed to be drawn into the mixing chamber. For obtaining desired flame temperature, nozzle adjustment is done by trial and error. Biogas stoves normally operates at gas pressure of 7.5 to 9.0 cm of water column. Brightness and combustibility of gas can be maintained as 10:1. Combustibility of gas is maximum when flame is blue. Biogas cannot be burnt on LPG/Natural gas stoves as its nozzle is very small and would permit very little flow of gas.

Biogas can burn if the end of the discharge line is lighted, but this is inefficient and the heat release rate is low due to improper mixing of the air and fuel. The aim of designing a burner is to provide good mixing of air and fuel, to increase-the volumetric heat release rate, the combustion efficiency and heat transfer efficiency. The burner should ensure that the three T's of combustion are satisfied-temperature, turbulence and time. A good burner will help to produce intense temperature, regulate air supply, regulate the fuel supply and provide mixing of fuel and air. The air to fuel ratio in a burner can be adjusted by cutting the air supply and observing the flame. If incomplete combustion is observed, the air supply should be increased. Excess air should also be avoided as this lowers the combustion temperature and consequently some unburnt gas will flow out defeating the very purpose of excess air.

Biogas stoves should have the following characteristics:

1   Inlet channels should be smooth to reduce the resistance to flow of gas and air;
2   Spacing and size of air holder should be sufficient.
3   Volume in the channel where the gas and air mix should be large enough to allow complete mixing;
4   Gas jet holes should not be too large but should allow easy passage of the mixed gas and air;
5   The appliance should be simple, economical and easy to make.
6   While designing a biogas stove the following characteristics of the biogas are to be considered.

7   Composition of biogas (generally 60% methane and 40% carbon dioxide).

8   Pressure of the gas (8.75 - 10 cm water column).

9   Flame velocity.

The following rules should be observed while designing the biogas stove:

1   Air must be thoroughly mixed with gas before it reaches the flame ports and should flow near the gas jet, ideally with a venturi (In the absence of sufficient air there is a smell from burning gas).

2   Total area of the flame ports should be between 8-200 times the area of the gas jet. It may be noted that biogas stoves have large flame port diameters than stoves using LPG.

3   Distance from the flame ports to the surface of the cooking pot should be between 2.5 cm and 3.0 cm.

4   Supports for cooking pots should not prevent air from getting to the flame.

5   To allow cross-lighting from one flame port to the next, the distance between flame ports should not be more than 2.0 cm.

6   For corrosion-resistance properties, cast iron is better than mild steel.

Given below are the specifications for a 0.45 m^3 per hour common biogas stove for domestic use

Jet size	2.25 mm dia
Area of jet.	3.98 mm^2
Flame port size	6.0 mm dia
Number of ports	20
Total area of ports	565 mm^2
Ratio of jet area to flame port area	1:142
Length of gas mixing pipe	20 mm
Diameter of gas mixing pipe	20 mm

Sustainability of flame is another important test to adjust the air to fuel ratio. If the flame does not sustain but is put off when the match stick is removed, it can be concluded that either the air supply or the fuel supply is in excess.

Design of biogas burners

A scheme diagram of the biogas burner is shown in Fig. 11.1. It consists of (i) an orifice for injecting the biogas (ii) an adjustable air port for air entry (iii) a chamber of thorough mixing of gas and air and (iv) ports for exit and burning of gas-air mixture.
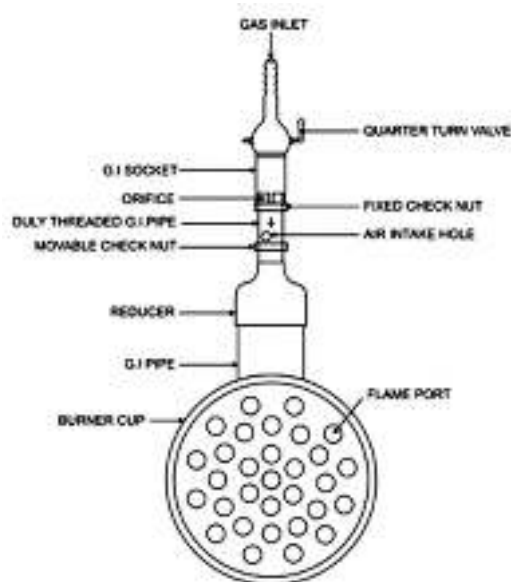
Fig. 7.1 Schematic diagram of biogas burner

The diameter of the orifice can be obtained by the equation.

$$Q = 3.6\ C_dA_0\ [2g\ (pw/pg)hg]^{1/2}$$

Where Q = gas flow rate (lit/hr)

        C_d = coefficient of discharge (about 0.6)

    A_0 = area of the orifice (cm^2)

    g = acceleration due to gravity (981 cm/sec^2)

    pw = density of water (1000 kg/m^3)

    pg = density of gas (1.128 kg/m^3)

    hg = pressure of the gas (cm.w.g.)

For gas pressures of 5-10 cm. w.g., the orifice area per unit flow rate (A_0/Q) can be calculated to be about 0.01 mm^2 hr/lit. For higher pressures the above formula can be used.

Two 8 mm dia holes with an adjustable check-nut over them should be provided immediately after the orifice for air entry.

The mixing chamber should be about 15-20 cm. long. For high pressures, the length should be increased. The total area of the flame ports should be about 300 times the orifice area for proper flame propagation. Thus the diameter of each hole can be decided once the total number of holes is fixed. A total of 12 holes should be reasonable. The distance of the flame ports to the base of the utensil should be about 2.5 cm.

For cooking purposes, the following types of biogas burners can be used :

KVIC design burners

KVIC designed burners (utility type and deluxe biogas burners) are made of cast iron with injectors made of gun metal (Fig. 7.2). These two types of burners consume 0.45 m³ of gas per hour which are adequate for 1-2 member and 5-6 member family, respectively. Initial pressure of gas in gas holder and burners vary from plant to plant. While designing these burners, initial pressure of gas in gas holder is assumed as 8.8 cm water column and in burner, between 7.6 cm and 8.3 cm water column. KVIC has also designed biogas burners for commercial use (for Dhabas, Hostel Messes etc), which are shown in Fig. 7.3.

Tin burners

These burners though not very efficient are made of tin to which gas is supplied from base pipelines (Fig. 11.4). Perforations are provided at upper portion of the tin to enable the gas to spurt out for burning. A number of small sized stones are kept outside to facilitate improved air and gas mixing. Tin burner can be embedded inside the earthern 'chulah' to suit flat bottomed and round bottomed cooking vessels.

Utility type burner   Delux biogas burner

Fig. 7.2 KVIC design burner of small capacity

(A) Biogas flate burner (450 litre/h capacity)   (B) Biogas angle burner (1150 litre/h capacity)

(C) Biogas double flate burner (450 litre/h capacity for each burner)
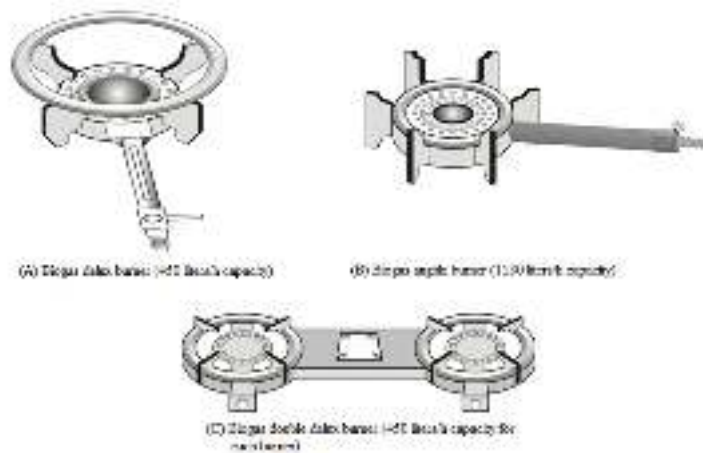
Fig. 7.3 KVIC design burner for commercial use

Fig. 7.5 Biogas burner made from tin

Biogas as a lighting fuel

Biogas can be fed into any gas lamp using a mantle for lighting. Biogas lamp consists of nozzle, an air inlet, mixing chamber, mantle and glass globe. In biogas lamp, when gas is burnt, mantle of the lamp glows which causes lighting. Mantle in biogas lamp is similar to one used in a 'Coleman' or propane lamp. Mantle is normally made of Ramie fibre (which is also used in making glass cloth and liner) and is coated with thorium nitrate solution. While burning, the Ramie fibre reduces to ash forming a layer of thorium dioxide which emits dazzling white light at high temperatures. Nozzle of this burner is of the size of a needle point having 0.5 to 0.7 mm diameter. The other end of the nozzle is connected to gas supply hose which is linked to a biogas plant. Biogas emerges out from the nozzle at very high temperature forming low pressure area around it. As biogas passes through the nozzle, air is allowed to be drawn into the mixing chamber to freely mix with it. Brightness of biogas lamp mainly depends on factors like gas pressure, and relative proportion of gas and air which is about 1:10 and thoroughness in mixing. For achieving bright intensity, nozzle needle to be adjusted by trial and error. Low gas pressure causes poor light intensity, but higher pressure though it improves brightness but tends to lower mantle-life. Biogas lamps can be either suspended (hanging type) or put on table (standing type). As weight of biogas is almost half as that of air and as hot air flows upwards, brightness of a standing biogas lamp is somewhat greater than that of a hanging type. Biogas lamps are generally designed to produce 100 candle power (C.P.) and consume 0.11 to 0.15 m^3 biogas per

hour.

In India, the biogas lamps are designed with single or double mantles. Both single and double mantel types can be further classified as internal or external types. An internal mantle lamp has a simple cover and is designed to produce 100 candle power (C.P.) which is equivalent to light intensity of 60 watts electric bulb. An external single mantle lamp has an outside protective cover to safeguard it from rain and wind and is also capable to produce same light intensity of 100 candle power. Designs of these two lamps are shown in Fig. 11.5 which works at gas pressure of 7.0 to 8.5 cm water column. A double mantle lamp can also be of both internal and external type. The internal type is fitted with a simple cover and can produce upto 100 candle power. The two mantle external type is equipped with a special cover to protect it from rain and wind and is also capable to produce 100 candle power (C.P.).

As for the starting sequence of the lamp, after opening gas cock and regulator, mantle is lit to light the lamp. Lamp can be turned-off by operating the gas cock. Regulator is adjusted for achieving requisite brightness. For preventing the possibility of any hazard, the lamp should be lit by bringing the match-stick close to the mantle either via the hole in the base of glass globe or via the reflector after opening it.
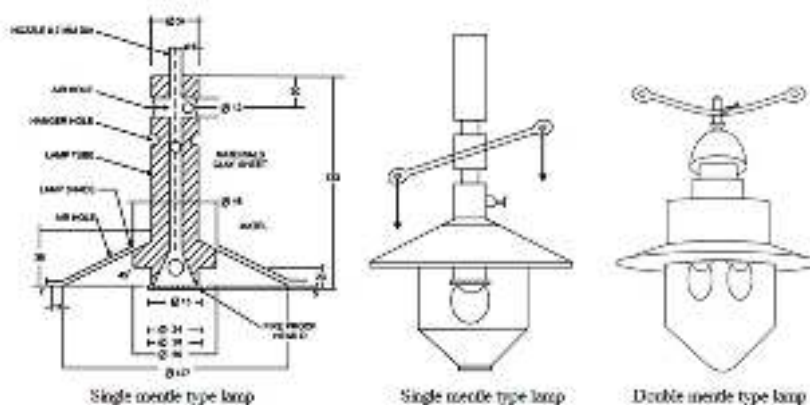

Fig. 8.1 Biogas fuelled lamps

Biogas for running dual fuel engines

Biogas as an engine fuel offers several advantages, biogas being a clean fuel causes smokeless combustion and reduced contamination of engine oil. It also reduces deposits on piston and combustion chamber. As gas needs is considerable, large capacity biogas plants are needed to supply gas for running IC (Internal Combustion) engines. It is to be noted that, even a 5 H.P. engine for 8 hourly operation requires gas supply from a biogas plant of 15 m^3/day capacity. Community biogas plants with a gas output of 50 m^3 per day are generally used to drive biogas fuelled electricity generating sets.

Normal consumption rate of biogas for running IC engines is 0.45 to 0.54 m^3/hour/H.P. or 0.60 to 0.70 m^3/hour kW if used for power generation. Biogas pressure is found to vary from 2.5 to 10.0 cm water column. If an engine consumes 0.50 m^3 of biogas/hour/H.P., then quantity of engine consumes 0.50 m^3 of biogas/hour/H.P., then quantity of gas needed for running a 10 H.P. engine for 10 hour operation per day becomes.

$$= (0.50 \text{ } m^3/\text{hour/H.P.}) \times 10 \times 10 = 50 \text{ } m^3.$$

Norms of biogas consumption for operating different capacity engines on dual-fuel are given in Table 8.1. These ratios are based on 8 hourly operation with 75 per cent plant efficiency with biogas consumption rate being 0.257 m^3/H.P./ hour having 50 per cent diesel replacement with biogas, although replacement of diesel can be as high as 80 per cent.

Table 8.1 Rates of biogas consumption for operating different capacity engines on dual-fuel

S. No.	Engine rating H.P.	Biogas consumption (m^3/day)	Capacity of plant to supply biogas (m^3/day)
1.	5	360	480
2.	10	720	960
3.	15	1080	1440
4.	20	1440	1920

During the operation of an diesel engine, it is noted, when the piston moves downward during first stroke, then the inlet value opens and the fresh air is filled in the cylinder which enters through the air cleaner. In the second stroke, the piston moves upwards, then both the valves are closed and the air which is already entered in the cylinder is being compressed upto the ratio 17:1. Due to this compression, temperature of air is very much raised. After that the diesel is being injected into this hot air which catches fire and the piston again moves downward due to the high pressure of air. In the fourth stroke, the exhaust valve opens and the fuel gases are exhausted outside due to upward movement of the piston. Thus it is very clear from the operation of diesel engine that small quantity of diesel should be must for ignition. Due to this reason, a dual-fuel engine is first started with diesel fuel only. After it has attained normal running for some time, biogas choke is opened to admit gas into the combustion chamber. Biogas combustion can be controlled by adjusting the choke. In a steady engine operation, dual-fuel achieves nearly 75 per cent saving in diesel consumption. For stopping dual-fuel engine, biogas choke should be stopped first followed by throttle.

To run diesel engine on biogas, the biogas pipe is joined with the air cleaner of the engine to prepare the mixture of biogas and air. In the first stroke of the piston, the engine sucks biogas

and air and it catches fire after injecting the diesel by the nozzle. A special and simple instrument shown in Fig. 8.2 can also be used to prepare the mixture of biogas and air and is joined with the diesel engine at modified inlet. The control of biogas is being done with the help of gate valve attached to this instrument.
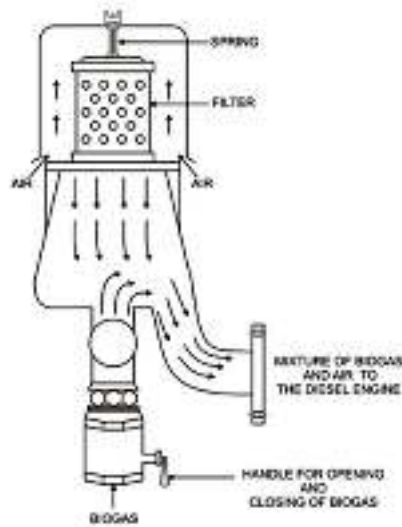

Fig. 8.2 Carburetor for diesel engine running on biogas

Methane, the lightest organic gas, has two fundamental drawbacks to its use in heat engines: it has a relatively low fuel value and it takes nearly $34450kP_a$ pressure to liquefy it for easy storage, (2.48 m^3 of methane gas can be converted to 4.55 litre of liquid methane). So a great deal of storage of methane is required for a given amount of work. For comparison, propane liquefies around $1722.5kP_a$.

Modified petrol engines

A petrol engine can be modified to run on biogas by drilling a hole in the carburetor near the choke. A tube is then inserted which is connected to the gas through a control valve. The engine is to be started on petrol and then switched on to run on biogas only.

In some cases, gas is admitted into the inducted air through a cam operated valve. A governor controlled disc regulates the quantity of gas admitted in accordance with the engine output. The governor also throttles the air supply so that the gas air mixture is within the ignition limits.

Typically a 4-stroke single cylinder 1 BHP engine running at 1800 rpm needs a biogas supply line of 9 mm diameter and gas pressure of 50 to 100 mm of water. The power developed is 85% of the older rating. The gas consumption is 0.51 m^3/h at full load and air to fuel ratio is 5.83 :1 at full load and 5.75:1 at normal load. The engine dissipates more heat than a conventional engine and the cooling system must be preferably water cooled.

Modifications

The conversion of SI engine for operation on biogas includes provisions for the entry of biogas , throttling of intake air and advancing the ignition timing. Biogas can be admitted to a stationary SI engine through the intake manifold and an air flow control valve can be provided on the air cleaner pipe connecting the air cleaner and carburetor for throttling of intake air. In this case the intake air is required to be manually throttled in the initial stage.

Modified diesel engines (The dual fuel engine)

A diesel engine can be easily converted to run on 80 to 90% biogas and 20% to 10% diesel by feeding the gas in between the air intake and the engine. After the engine is started on diesel oil, the gas valve is opened gradually and the engine's governor automatically reduces the intake of diesel oil. Since the compression of the gas-air mixture is not sufficient to produce the temperature required for ignition, there is no danger of pre-ignition.

CI engine can operate on dual fuel and the necessary engine modifications include provision for the entry of biogas with intake air, advancing the injection timing and provision of a system to reduce diesel supply.

The entry of biogas and mixing of gas with intake air can be achieved by providing a mixing chamber below the air cleaner which facilitates thorough mixing of biogas with air before entering into the cylinder. The arrangements largely used in stationary engines commercially available in India. The capacity of mixing chamber may be kept equal to the engine displacement volume. The pilot injection of diesel in the cycle is required to be advanced for smooth and efficient running of engine on dual fuel.

Biogas for electricity generation

Biogas can be used to produce electricity by coupling a dual-fuel engine to an asynchronous generator. Based on results of several studies carried out. 1 kWh of electricity can be generated from 0.75 m^3 of gas which can light 25 electric bulbs of 40 w rating whereas 0.75 m^3 of gas if directly burnt can light only 7 biogas lamps for one hour. Hence it is advantageous to first generate electricity and then light larger number of electric bulbs. In China asynchronous generators of 3, 3.5 and 7.5 kW rating coupled to biogas-based IC engines are commonly used. However, electricity generation from biogas is economical only when gas is supplied by large community plants but it requires high initial capital investment. Decentralized power systems can be cost-effective especially when they minimize transmission and distribution costs. For cost-effective system, unit cost of biogas-based electricity should be less than supplied by the electricity boards.

Biogas in boilers and water heaters

Biogas successfully fueled the boiler that heated the digester chamber. Preliminary tests were made of its usefulness as fuel for a household-type water heater and for operating spark-ignition and compression-ignition internal-combustion engines.

The gas-fired cast-iron boiler was of commercial manufacture, of a type that would normally be fueled with LP gas. Several changes were required to prepare the unit for fueling with biogas:

1   The diameter of the nozzle orifice was increased. The heating value of biogas is only 30 per cent that of LP gas and only 60 per cent that of natural gas, and line pressures were less with biogas than with LP gas. Consequently, the diameter of the burner nozzle orifices was enlarged approximately 70 per cent of biogas utilization.

2   Air supply to the burner was decreased. The air-inlet ports had to be almost completely closed, which required special covers for the air inlets.

3   Moisture was removed. A system of cooling and heating the gas in combination with condensate traps facilitated delivery of the gas to valves and orifices without risk of condensation in these narrow channels. pressure-regulator valves were kept warm to prevent condensation.

4   An independent fuel source (LP gas) was used for the pilot light. This was because the quality and supply of biogas may not be totally reliable. The pilot light required approximately 0.45 kg LP gas per day.

5   A 40-gal (150-liter) water heater was operated experimentally, using biogas as fuel. This test indicated that a gas consumption of 40 liter/min of water from 10 to 65°C. This corresponds to a thermal efficiency of 65 per cent, compared to a rated efficiency of 70 per cent. Further adjustment of the burner would probably improve its performance when fueled with biogas.

Since well-adjusted and fully loaded boilers and other water-heating devices may be assumed to have 70 per cent efficiency on biogas, as well as on other gaseous fuels, the fuel consumption for a water heater can be calculated from the relationship that 3.2 m^3 of biogas 62 MJ will heat 190 liter of water from 50 to 10 to 65°C. In a home-heating system, 5.2 m^3/h of biogas would give a rated (input) heating capacity of 29 kW.

Biogas use in stationary power plants

Biogas can be used in both spark ignition engines and compression ignition engines. The choice of the engine depends on the following factors:

(a) If the gas supply is assured, a S.I. engine can be used.

(b) If the gas supply is not assured, a C.I. engine with dual fuel operation can be used. This engine can run completely on diesel when gas is not available.

Biogas can be used in stationary power plants in the following modes :

(i) In a spark ignition engine by using a higher compression ratio with magneto ignition and modifying the carburetor system.

(ii) In a compression ignition engine with gas injection and pilot diesel injection. This requires biogas at high pressure. This is not generally used.

(iii) As a dual engine with diesel and biogas. Also dual fuel engine with petrol and biogas can be used, but this require relatively greater modifications.

(iv) In dual fuel gas turbines.

The following points be noted:

(a) Purification of gas by separation of H_2S prevents corrosion. Removal of H_2S prolongs engine life. Exhaust would be free of sulphur compounds.

(b) Removal of CO_2 by scrubbing the gas through lime water improves the calorific value by 30% on volume basis. Volumetric efficiency would improve and also higher specific output can be obtained.

(c) Gas burn carburetor for controlling intake of gas and air would be preferable.

(d) Regulation of engine cooling water flow rate would be desirable as the engines dissipate more heat than conventional engines.

(e) Use of biogas receiver bag for maintaining a constant pressure and flow rate may be considered. This consists of a cylindrical tube of 300 mm length and 75 mm diameter with a half return valve on the outlet side and a wire netting ball at the constriction point of cylinder outlet tube.

(f) Slow speed engines should be preferred.

(g) Ignition/injection timing advance to be set optimally.

Biogas in gas turbines

The main advantage of the use of gas turbines is that the capital cost is considerably lower compared to reciprocating engines-particularly when used aircraft engines whose normal flying duty is over are utilized. There are additional advantages of easy installation, modular maintenance, quick starting and reliable operation. National Aerospace Laboratory has studied the applications of Rolls Royee 'Dart' Engines used by IAF and Indian Airlines to provide mechanical energy for 1.0 to 2.5 MW electrical generators. These can be operated on dual fuels [biogas + diesel or kerosene]. This approach seems to be promising.

The production of electrical energy only by biogas fuel is not economical. However, cogeneration with I.C. engine connected with a generator and with waste heat recovery would be economical. The waste heat recovered can be cycled for digester heating.

Biogas in refrigerators

Biogas can be used in absorption refrigeration system without any problems as long as assured gas supply for burner is available. For a Refrigerator of 230 litres capacity, the biogas consumption will be approximately 0.044 m^3/l.

Particular problems also arise with biogas operated refrigerators. The composition of biogas varies substantially from day to day. The gas pressure fluctuates excessively with the amount of gas stored even in a floating drum plant. Special, stable-burning jets are therefore needed-especially if the refrigerator is thermostatically controlled and the flame burns only when required. On every ignition there is a risk of the flame going cut. Gas will then discharge without burning. The gas supply must therefore automatically be cut off if the flame goes out.

Small scale dairies handling 500 litres of milk per day seems to be feasible units for the rural setup. It is assumed that water is available in abundance and cooling of the milk from pasteurizing temperature of about 70°C to, say, 35°C can be done with the available cold water. Heat to be removed by water (taking the specific gravity and specific heat of milk as 1.03 and 0.95) is 500 x 1.03 x 0.95 x 35 = 17124 kcal.

For a raise in temperature of water of 5°C, the amount of water necessary = 17124/5 = 3425 kg.

Taking 4hrs.period for cooling, the required water flow rate = 3425/4 = 856 kg/hr.

For a 10m delivery head of water and a pump efficiency of 50%, the shaft HP required for the circulation pump = 856 x 10/(60x4500x0.5) = 0.06.

To cool the milk from 35°C to 3°C heat to be removed

= 500 x 1.03 x 0.95 x (35 - 3) = 15656 kcal.

Assuming 30% heat loss actual heat to be removed at the evaporator = 20 353 kcal.

Considering 8 hrs. operating time the refrigerating capacity needed

= 20353/(8x60x50) = 0.848 tons.

For a 3 m x 3m x 3m walk in cold storage the approximate cooling required would be 0.6 tons of refrigeration.

Total cooling capacity needed for the dairy = 1.448 tons. Hence the engine power needed for the dairy plant is approximately 2 hrs. Biogas out put needed for a dual fuel diesel engine for the above purpose = 4 m^3/day. For a spark ignition engine running totally on biogas the gas out put needed is 6.4 m^3/day. This would necessitate output from over 15 cattle heads.

EXPERIMENT: 9 STUDY ON BRIQUETTING AND STOICHIOMETRIC CALCULATIONS

Densification

Biomass densification represents a set of technologies for the conversion of biomass into a fuel.The technology is also known as briquetting and it improves the handling characteristics of thematerials for transport, storing etc. This technology can help in expanding the use of biomassin energy production, since densification improves the volumetric calorific value of a fuel, reducesthe cost of transport and can help in improving the fuel situation in rural areas. Briquetting isone of several agglomeration techniques which are broadly characterized as densificationtechnologies. Agglomeration of residues is done with the purpose of making them denserfor their use in energy production.

Advantages

- The process increase the net calorific value of material per unit volume
- End product is easy to transport and store
- The fuel produce is uniform in size and quality
- Helps solve the problem of residue disposal
- Helps to reduce deforestation by providing a substitute for fuel wood.
- The process reduce/eliminates the possibility of spontaneous combustion waste
- The process reduces biodegradation of residues

Disadvantages

- High investment cost and energy input to the process
- Undesirable combustion characteristics often observed e.g. poor ignitability, smoking, etc.
- Tendency of briquettes to loosen when exposed to water or even high humidity weather

Densification Process

There are four basic steps involved in the densification process namely, collection of raw materials, preparation of raw materials, compaction and Cooling and Storage.

Collection of raw materials

In general, any material that will burn, but is not in a convenient shape, size or form to be readily usable as fuel is a good candidate for briquetting.

Preparation of raw materials

The preparation of raw materials includes drying,size reduction, mixing of raw materials in correct proportion, mixing of raw materials with binder etc.

Drying

The raw materials are available in higher moisture contents than what required for briquetting. Drying can be done in open air (sun), in solar driers, with a heater or withhot air.

Size reduction

The raw material is first reduced in size by shredding, chopping, crushing, breaking, rolling, hammering, milling, grinding, cutting etc. until it reaches a suitably small and uniform size (1 to 10 mm). For some materials which are available in the size range of 1 to 10mm need not be size reduced. Since the size reduction process consumes a good deal of energy, this should be as short as possible.

Raw material mixing

It is desirable to make briquettes of more than one raw material. Mixing will be done in proper proportion in such a way that the product should have good compaction and high calorific value.

Compaction

Compaction process takes place inside the briquetting machine. The process depends on the briquetting technology adopted.

Binding Mechanisms of Densification

In order to understand the suitability of biomass for briquetting, it is essential to know thephysical and chemical properties of biomass which also influence its behavior as a fuel.Physical properties of interest include moisture content, bulk density, void volume and thermalproperties. Chemical characteristics of importance include the proximate and ultimate analysis,and higher heating value. The physical properties are most important in any description of thebinding mechanisms of biomass densification. Densification of biomass under high pressurebrings about mechanical interlocking and increased adhesion between the particles, formingintermolecular bonds in the contact area. In the case of biomass the binding mechanisms underhigh pressure can be divided into adhesion and cohesion forces, attractive forces between solidparticles, and interlocking bonds. High viscous bonding media, such as tar and other molecular weight organic liquids can formbonds very similar to solid bridges. Adhesion forces at the solid-fluid interface and cohesionforces within the solid are used fully for binding. Lignin of biomass/wood can also be assumedto help in binding in this way. Finely divided solids easily attract free atoms or molecules fromthe surrounding atmosphere. The thin adsorption layers thus formed are not freely movable.However, they can contact or penetrate each other. The softening lignin at high temperature andpressure conditions form the adsorption layer with the solid

portion. The application of externalforce such as pressure may increase the contact area causing the molecular forces to transmithigh enough which increases the strength of the bond between the adhering partners. Anotherimportant binding mechanism is van der Waals' forces. They are prominent at extremely shortdistances between the adhesion partners. This type of adhesion possibility is much higher forpowders. Fibres or bulky particles can interlock or fold about each other as a result forminginterlocking or form-closed bonds. To obtain this type of bond, compression and shear forcesmust always act on the system. The strength of the resulting agglomerate depends only on thetype of interaction and the material characteristics.

Binding Agent

A binding agent is necessary to prevent the compressed material from springing back and eventually returning to its original form. This agent can either be added to the process or, when compressing ligneous material, be part of the material itself in the form of lignin. Lignin, or sulphuric lignin, is a constituent in most agricultural residues. It can be defined as a thermo plastic polymer, which begins to soften at temperatures above 100°C and is flowing at higher temperatures. The softening of lignin and its subsequent cooling while the material is still under pressure, is the key factor in high pressure briquetting. It is a physico-chemical process related largely to the temperature reached in the briquetting process and the amount of lignin in the original material. The temperature in many machines is closely related to the pressure though in some, external heat is applied.

Usually high pressure processes will release sufficient lignin to agglomerate the briquette though this may not be true for all for all materials. Intermediate pressure machines may or may not require binders, depending upon the material whilst low-pressure machines invariably require binders.
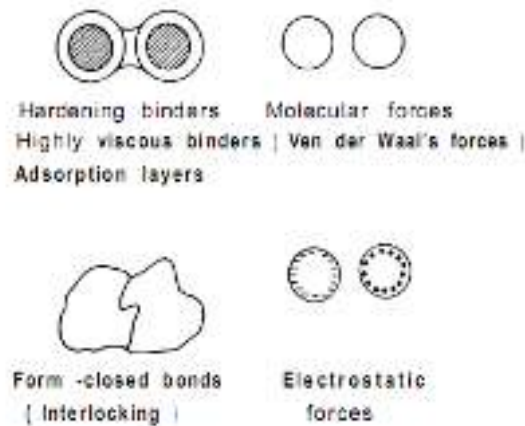
Densification techniques

Densification essentially involves two processes, the compaction under pressure of loose material to reduce its volume and to agglomerate the material so that the product remains in the compressed state. Raw materials for densification include waste from woodindustries, loose biomass and other combustible waste products. On the basis of compaction,the densification technologies can be divided into

- High pressure compaction
- Medium pressure compaction with a heating device
- Low pressure compaction with a binder.

In all these compaction techniques, solid particles are the starting materials. The individualparticles are still identifiable to some extent in the final product. Briquetting and extrusion bothrepresent compaction i.e., the pressing together of particles in a confined volume. If finematerials which deform under high pressure, are pressed, no binders are required. The strengthof such compacts is caused by van der Waals' forces, valence forces, or interlocking. Naturalcomponents of the material may be activated by the prevailing high pressure forces to becomebinders. Some of the materials need binders even under high pressure conditions.

Hardening binders   Molecular forces
Highly viscous binders | Van der Waal's forces |
Adsorption layers

Form -closed bonds   Electrostatic
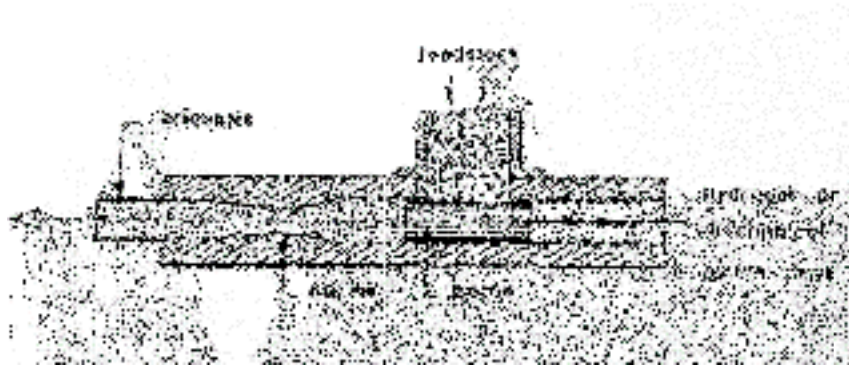[Interlocking]   forces

Fig. Binding mechanisms

At present two main high pressure technologies: ram or piston press and screw extrusion machines, are used for briquetting. While the briquettes produced by a piston press are completely solid, screw press briquettes on the other hand have a concentric hole which gives better combustion characteristics due to a larger specific area. The screw press briquettes are also homogeneous and do not disintegrate easily. Having a high combustion rate, these can substitute for coal in most applications and in boilers.

Piston press densification

A reciprocating piston pushes the material into a tapered die where it is compacted and adheres against the material remaining in the die from the previous stroke. A controlled expansion and cooling of the continuous briquette is allowed in a section following the actual die. The briquette leaving this section is still relatively warm and fragile and needs a further length of cooling track before it can be broken into pieces of the desired length.

In mechanical systems, the piston gets its reciprocating action by being mounted eccentrically on a crank-shaft with a flywheel. The shaft, piston rod and the guide for the rod are held in an oil-bath. The moving parts are mounted within a very sturdy frame capable of absorbing the very high forces acting during the compression stroke.The most common drive of the flywheel is an electric motor geared down through a belt coupling.The piston top is normally

shaped with a protruding half-spherical section in order to get better adherence of the newly compressed material to that formed in the previous stroke. The most common type of briquette press features a cylindrical piston and die with a diameter ranging from 20-125 mm. The die tapers somewhat towards the middle and then increases again before the end. The exact form of the taper varies between machines and biomass feedstock and is a key factor in determining the functioning of the process and the resulting briquette quality.

Fig. 1. Piston press densification

The merits and demerits of this technology are

- There is less relative motion between the ram and the biomass hence, the wear of the ram is considerably reduced.
- It is the most cost-effective technology currently offered by the Indian market.
- Some operational experience has now been gained using different types of biomass.
- The moisture content of the raw material should be less than 12% for the best results.
- The quality of the briquettes goes down with an increase in production for the same power.
- Carbonization of the outer layer is not possible. Briquettes are somewhat brittle.
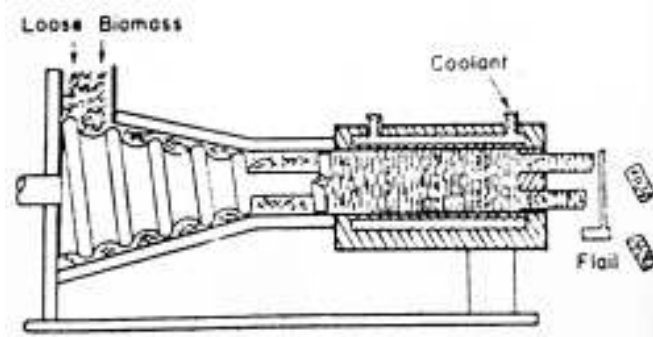
Screw Press densification

In the screw press technology, the biomass is extruded continuously by a screw through a taper die which is heated externally to reduce the friction.Material is fed continuously into a screw which forces the material into a cylindrical die, which is often heated to 250-300°C to raise the temperature to the point where lignin starts flowing and pressure builds up smoothly. Briquettes produced from screw press are often of high quality   than   piston-press unit but the power requirement per tonne of briquette produced is also high.

The merits and demerits of this technology are

- The output is continuous and the briquette is uniform in size.

- The outer surface of the briquette is partiallycarbonized facilitating easy ignition and combustion. This also protects the briquettes from ambient moisture.
- A concentric hole in the briquette helps in combustion because of sufficient circulation of air.
- The machine runs very smoothly without any shock load.
- The machine is light compared to the piston press because of the absence of reciprocating parts and flywheel.
- The machine parts and the oil used in the machine are free from dust or raw material contamination.
- The power requirement of the machine is high compared to that of piston press.

Fig 2. Conical screw press densification

Table. Comparison of piston press and screw press densification

	Piston press	Screw Press
Optimum moisture content of raw material	10-15%	8-9%
Wear of contact parts	low in case of ram and die	high in case of screw
Output from the machine	In strokes	Continuous
Power consumption	50 kWh/ton	60 kWh/ton
Density of briquette	1-1.2 gm/cm³	1-1.4 gm/cm³
Maintenance	high	Low
Combustion performance of briquettes	not so good	very good
Carbonisation to charcoal	not possible	makes good charcoal
Suitability in gasifiers	not suitable	Suitable
Homogeneity of briquettes	non-homogeneous	homogeneous

Result:

Aim:

To determine the biological oxygen demand and chemical oxygen demand of waste water.

1. Determination of Bio-Chemical Oxygen Demand of Waste Water

Biochemical oxygen demand

Biological Oxygen Demand is used to designate the oxygen consuming capacity of a liquid which is a measure of the level of degradable organic matter present. It can be measured by incubating a sample of the liquid in a sealed container and the amount of oxygen consumed in a definite interval of time (20°C/5 days) is measured. A high BOD represents a large amount of degradable organic matter in the sample.

Apparatus required:

300 ml BOD bottles, 250 ml conical flasks, BOD incubator, burette, pipette and measuring cylinders *etc.*

Reagents required:

0.025 N sodium thio-sulphate solution, Concentrated sulphuric acid, Manganese sulphate solution, Alkaline iodide azide reagent, Starch Indicator, Phosphate Buffer, Ferric chloride, Calcium Chloride solution

i. Standard 0.025 N Sodium Thiosulphate solution

Prepare standard 0.1N stock solution of sodium thiosulphate by dissolving 24.82 g in 1 l of distilled water. For preservation, add 3 drops of chloroform. Prepare 0.025 N sodium thiosulphatesolution by taking 250 ml of above stock solution and diluting it to 1000 ml.

ii. Concentrated sulphuric acid

iii. Manganese Sulphate

Dissolve 400 g of $MnSO_4$ to 1litre of distilled water.

iv. Alkaline iodide-azide reagent

Dissolve 500 g of NaOH and 150 g of potassium in distilled water. Add 10 g of $NaNO_3$ in 40 ml water. Dilute to 1 litre.

v. Starch Indicator

Take 0.5 g of starch. Prepare paste with distilled water. Make 100 ml with water and boil by stirring. Cool it.

Procedure

- Take pure water in a glass container (about 5 l) and bubble compressed air for 2 days to attain saturation.

- Add 1 ml each of manganese sulphate, phosphate buffer, ferric chloride and calcium chloride solution for each litre of water.

- If the wastewater is not expected to contain sufficient bacteria population, add 2 ml of settled sewage for 1000 ml of water.

- Neutralize the sample.

- Take the sample and blank in twoBOD bottles. Keep these bottles in incubator at 20°C for 5 days.

- Take the sample and blank separately in two BOD bottles for determination of initial DO as given below.

- Add 2ml $MnSO_4$ and 2 ml alkaline iodide-azide reagent. Dip the pipette below the liquid surface. Allow to stand for 5 minutes.

- Add 2 ml of concentrated H_2SO_4 in the same way. Mix it properly and allow to stand for 5 minutes.

- Take 200 ml of clear solution in conical flask. Add 2 ml of starch indicator. The colour becomes deep blue.

- Titrate with standard N/20 sodium thiosulphate solution till the colour changes to colourless.

DO can be estimated using the following formula

$$\text{Dissolved oxygen in mg/L} = \frac{\text{Burette reading x Normality of sodium thiosulphate x 8000}}{\text{Volume of sample}}$$

If, D_o DO of sample on 0th day

   D_1 DO of sample on 5th day

   C_o DO of Blank on 0th day

   C_1 DOof Blank on 5th day

   BOD (mg/lit) $= (D_o - D_1) - (C_o - C_1)$ x Dilution   factor

Observation:

S. No.	Content	Dilution factor	Run down sodium thiosulphate in Burette			
			D_o	D_1	C_o	C_1
			0th day	5th day	0th day	5th day
1	Blank	Nil				
2	Sample					
3	Sample					
4	Blank	Nil				

Calculation:

2. Determination of Chemical Oxygen Demand

Chemical Oxygen demand

Chemical Oxygen Demand is a measure of oxygen equivalent of organic matter in the sample that is susceptible to oxidation by strong chemical oxidant.

Principle:

Most of the organic matter is destroyed in boiling mixture of chromic and sulphuric acid. The purpose of running blank is to compensate for any error that may result because of presence of extraneous organic matter in the reagents.

Apparatus required:

COD reflux apparatus - 500 ml flat bottom flask with ground glass joints and condensers, pipette, burette and measuring cylinders *etc*.

Reagents Required:

i. Standard 0.25 N potassium dichromate($K_2Cr_2O_7$)solution

Dissolve 12.259 g of pure $K_2Cr_2O_7$ in distilled water and dilute to 1 l. Add 120 mg of sulphuric acid.

ii. Sulphuric acid-Silver sulphate reagent

Add 5.5 g of $AgSO_4$ to 1 Kg of Concentrated H_2SO_4 and keep the same overnight.

iii. Standard 0.1 N Ferrous Ammonium Sulphate Solution

Dissolve 30 g of pure ferrous ammonium salt in distilled water. Add 20 ml of concentrated H_2SO_4 and dilute to one litre.

iv. Ferroin indicator

Dissolve 1.485 g of 1-10 Phenanthralinemonohydrate with 0.695 pure $FeSO_4.7H_2O$ in distilled water. Dilute to 100 ml. This indicator is commercially available.

v. Concentrated H_2SO_4

Procedure

- Take three COD reflux flask; one of the reflux flasks is for blank and others for sample.
- Add 20 ml of sample in a reflux flask (if required dilute to suitable degree) and add 0.4 g of H_2SO_4. Mix thoroughly.
- Add 10 ml of 0.25 N $K_2Cr_2O_7$. Drop some pumice stone and slowly add 30 ml of concentrated silver sulphate- sulphuric acid solution.
- Mix the contents thoroughly and connect the flask to condenser. Reflux for 2 hours at 150°C.

- Cool and wash down the condensers. Dilute the mixture to 150 ml by adding distilled water.
- Add 3 drops of Ferroin indicator and titrate with N/10 Ferrous Ammonium sulphate solution till the colour changes from green to wine red. Note the end point.
- Perform the same procedure with 'Blank' using distilled water instead of sample.

The chemical oxygen demand of the given sample can be estimated using the following formula

$$COD \ (mg/l) = \frac{(V_1 - V_2) \ X \ Normality \ of \ Ferrous \ Ammonium \ Sulphate \ X \ 8000}{Volume \ of \ Sample}$$

If the sample is diluted, COD in mg/l = COD as above x Dilution factor

(For example if dilution is 10% i.e. 10 ml of sample in 90 ml of distilled water. Then COD in mg/l = 520x10 = 5200 mg/l).

Observation:

S. No	Sample volume (ml)	ml of Ferrous Ammonium sulphate rundown	
		Sample (V_1)	Blank (V_2)
	20 ml		
	20 ml		

Calculation:

Result

Biological oxygen demand and Chemical oxygen demand of the wastewater is _____ mg/l and _____ mg/l, respectively.

Ex. No: 11   **Experiment on performance of Flat Plate Collector –**
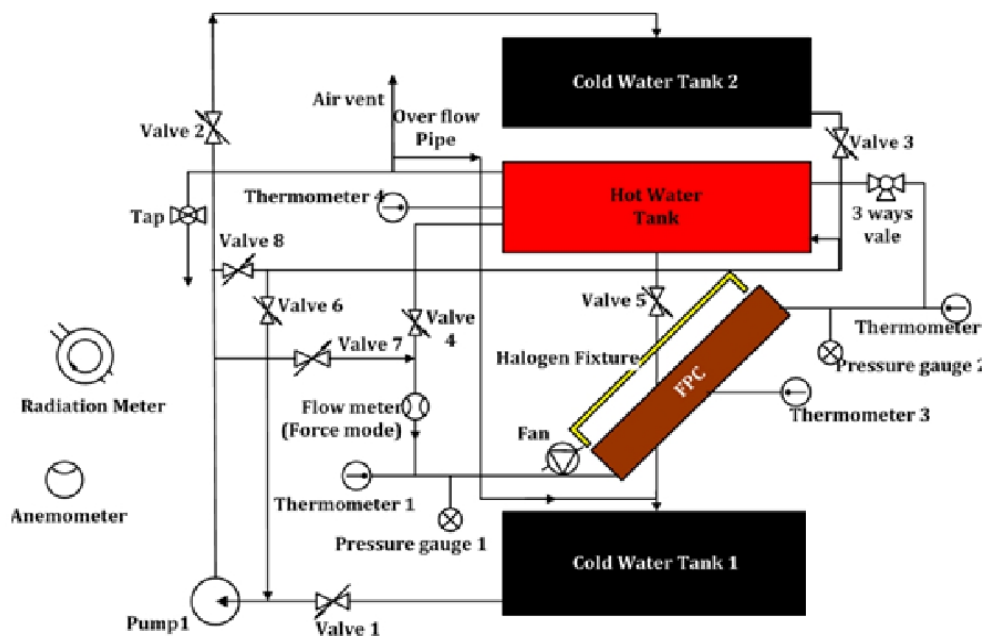**Date:**   **Thermosyphonic mode solar water heater (FPC & ETC)**

Aim :

        Evaluation of U_LF_R and η in Thermosyphonic mode of flow with fixed and variable Input parameters.

Equipments required :
- Solar water heater with thromoshipon mode (solar thermal training system)
- Pyranometer
- Anemometer
- Magnetic D
- Halogen lamps with movable frame for artificial source of heat

Experimental set-up :

Fig. 3.1.Schematic of experimental setup of solar water heater

Theory:

        A typical flat-plate collector consists of an absorber plate in an insulated box together with transparent cover sheet(s). Work and properties of different components of a flat plate collector
- **Absorber plate:** It is a flat conducting plate to which the tubes, fins, or passages are attached It may be a continuous or discrete plate. The plate is usually coated with a high absorptance and low emittance layer.
- **Cover plate:** One or more sheet of glass or other radiation - transmitting material forms the cover plate. The cover plate serves two purposes, minimization of convective heat loss and blocking of IR radiation.
- **Heat removal passages:** These are tubes, fins, or passages which conduct or direct the stream of water from the inlet to the outlet of the collector.

- **Headers or manifolds:** These are the pipes to admit and discharge water that is meant to be heated.
- **Insulation:** Insulations such as Rockwool or Glass wool are fitted in the back and sides of the collector to prevent heat loss from the collector.
- **Casing:** The casing surrounds the aforementioned components and protects them from dust, moisture and any other material.

In the following figure schematic diagram of a typical flat-plate collector is shown with different parts at their proper locations.

Table 3.1: Overall Specifications of the system

Components	Specification	Remarks
Water heating system (Collector and water tank)	Collector area: 0.716 m^2 Tank capacity: 50 L	Collector: Flat plate collector. To collect and transfer heat Tank: non pressurized aluminum tank. To store water
Halogen system	Halogen fixture's area: 0.72 m^2 Number of halogen lamp: 21 Power 150 W each Regulator: 5000 W	Halogen: To supply the required intensity on the collector. Regulator: To adjust the intensity at the desire level
Radiation meter	Range: 0 to 1999 W/m^2 Power Supply: DC	To measure the radiation level on the collector
Water pump	Power supply: AC Power 0.5 hp	To lift water upto the desired level. To facilitate the forced mode operation.
Water flow meter (for forced mode)	Flow range: 0.5 to 25 LPM Working voltage: 4.5 to 24 VDC Max. Pressure: 1/.5 bar Working pressure. 0 to 10 bar Max rated current: 8 mA Withstand current: 15 mA Working temp: up to 80°C Storage temp: 25 to 65°C Supply voltage – 230 VAC.	Mini turbine wheel based technology. To measure the water flow rate during the forced mode operation
Stop watch	With electronic On-Off switch and a Reset button	To detect the time during natural flow rate
Anemometer	Air velocity: Range: 0.4 to 45.0 m/sec Resolution: 0.1 m/sec Accuracy(±2% + 0.1 m/sec) Range: -14 to 60°C Resolution: 0.1°C Accuracy: 0.5°C Power supply: DC 4*1.5 AAA size	The anemometer can measure the air velocity and the ambient air temperature. The air flow sensor is a conventional angled vane arms with low friction ball bearing. The temperature sensor is a precision thermistor.
Pressure Gauges	Sensor: Range: 0 to 6 bar Accuracy: ±3 kpa Output: 4 to 20 mA (±3) Input. 4-20 mA DC Power: 220 VAC	Semiconductor thin film based technology. Works on the principle of generation of electrical signal due to exertion of pressure. To measure the inlet and outlet pressure
Thermometers	Sensor: Class A sensor Range -200 to 650°C Accuracy: ±0.15 + 0.002*(t) Where t is absolute value of temperature in°C Supply Voltage: 230AC	Sensor is RTD based platinum probe. Works on the principle of variation of resistance with temperature. To measure the inlet curler. Output plate, and tank water temperature.
Fan	Range: 0 to 5 m/sec Power supply: AC with regulators	To supply the wind at the desire speed

Table 3.2: Detailed Specification of the Solar water heater system

Overall collector dimension	915 x 810 x 95 mm		
Weight of the collector	13 Kg		
Aperture Area	0.63 m^2		
Glazing		*Insulation*	
Glazing type and number	Toughened Glass (1 No)	Insulation material	Rockwool
Glazing thickness	3 mm	Insulation density	48 Kg/m^3
Glazing transmissivity	85 %	Insulation thickness base	50 mm
Glazing Emissivity	88 %	Insulation thickness-side	25 mm
Absorption plate		Conductivity	0.04 W/mK
Absorber material	Copper	*Casing*	
Absorber plate thickness	0.12 mm	Frame type	Aluminium
Absorber plate dimension	115 mm	Frame colour	Black
Emissivity of surface	12 %	Casing thickness	1.4 mm
Absorptivity	96 %	*Storage tank*	
Risers & headers		Tank type	Horizontal
Number of risers	6	Tank Materials	SS-304
Riser dimension	800 mm	Tank insulation	PUF
Headers dimension	882 mm	Tested pressure	3 kpa
fest pressure	4 kpa	Tank size	815 X400
Maximum working pressure	25 kpa		

Parameters of a flat plate collector based solar water heating system:

The performance of a solar water heating system depends upon different design and atmospheric parameters. The importance of some of the most dominating parameters are described below.

Overall Heat loss coefficient (U_L):

All the heat that is generated by the collector does not resulted into useful energy. Some of the heat gets losses to the surroundings. The amount of heat losses depends upon the convective, conductive and radiation heat loss coefficients.

Estimation of heat loss coefficient or the flat plate collector is Important for its performance evaluation. A higher value of heat loss coefficient indicates the lower heat resistance and hence tl1e lower efficiency.

Among all heal loss parameters the top loss contributes the most. The top heat loss coefficient is a function of various parameters which includes the temperature of the absorbing plate, ambient temperature, wind speed, emissivity of the absorbing and the cover glass plate, tilt angle etc.

Heat Removal Factor (F_R):

Heat removal factor represents the ratio of the actual useful energy gain to the useful energy gain if the entire collector were at the fluid inlet temperature. It depends upon the factors like inlet and outlet water temperature, the ambient temperature, area of the collector etc, The importance of heat removal factors remains with the efficiency of the system. For a highly efficient system a higher value of heat removal factor is must.

Efficiency (η):

Efficiency is the most important factor for a system. This factor determines the system's

output. For a flat plate collector based solar water heater system the efficiency is defined as the ratio of the useful energy delivered to the energy incident on the collector aperture. The value of efficiency is dominated by parameters like product of glazing's transmittance and absorbing plate's absorptance, intensity of global radiation falling on the collector, water inlet temperature and ambient air temperature.

Collector Time Constant:

Collector time constant is required to evaluate the transient behaviour of a collector. It is define the time required rising the outlet temperature by 0.632 of the total temperature increase from T_{fo} -T_a at lime zero to T_{fo} -T_a at time infinity i.e. time at which the outlet temperature attains a stagnant value. It can be calculated from the curve between R and time as shown below. The time interval for which R value is 0.632, is the time constant of the give collector.

In terms of temperatures R is define as,

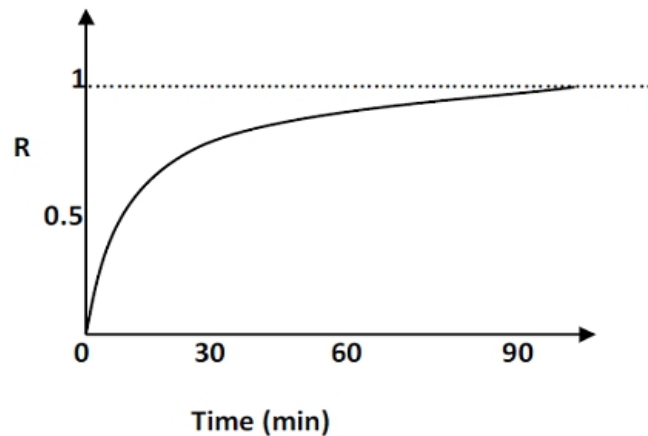$$R = \frac{T_{fo}(t) - T_{fo}(o)}{T_{fo}(\alpha) - T_{fo}(o)}$$

Where,

T_{fo} (t): Outlet water temperature at any time t

T_{fo} (o): Outlet water temperature at time zero

T_{fo} (α): Outlet water temperature at infinite time (maximum temperature)

Shape of the graph between R and time is as shown below.

Basic Equations to calculate different parameters:

U_L is the overall heat transfer coefficient from the absorber plate to the ambient air. It is a complicated function of the collector construction and its operating conditions.

In simple term it can be expressed as,

$$U_L = U_t + U_b + U_E \qquad\qquad (1)$$

According to Klein (1975), the top loss coefficient can be calculated by using the flowing formula.

$$U_t = \left\{ \frac{\frac{1}{N}}{\frac{C}{T_p}\left[\frac{T_p - T_a}{N+f}\right]^{0.33} + \frac{1}{h_a}} \right\} + \left\{ \frac{\sigma\left(T_p + T_a\right)\left(T_p^{\,2} + T_a^{\,2}\right)}{\left(\varepsilon_p + 0.05N\left(1 - \varepsilon_p\right)\right) - 1 + \frac{2N + f - 1}{\varepsilon_g} - N} \right\} \dots\dots(2)$$

Where,

C $\quad$ = 365.9 x (1 - 0.00883 β + 0.0001298 x β²)

f $\quad$ = (1+0.04h_a – 0.0005h_a^2) x (1+0.091N)

h_a $\quad$ = 5.7+3.8v

The heat loss from the bottom of the collector is first conducted through the insulation and then by a combined convection and infrared radiation transfer to the surrounding ambient air. However the radiation term can be neglected as the temperature of the bottom part of the casing is very low. Moreover the conduction resistance of the insulation behind the collector plate governs the heat loss from the collector plate through the back of the collector casing. The heat loss from the back of the plate rarely exceeds 10% of the upward loss. So if we neglect the convective term there will not be much effect in the final result. Thus to calculate the bottom loss coefficients we can use the following formula

$$U_b = \frac{k_b}{x_b} \quad\dots\dots\dots\dots(3)$$

Typical value of the back surface heat loss coefficient ranges between 03 to 0.6 W/m²K.

In a similar way, the heat transfer coefficient for the heat loss from the collector edges can be obtained by using the following formula

$$U_e = U_b \left(\frac{A_e}{A_c c} \right) \quad\dots\dots\dots\dots(4)$$

Factors of a flat plate collector (F, F', FR, F")

1. Fin efficiency (F)

For a straight fin with rectangular profile the fin efficiency is given as

$$F = \frac{\tanh\left[\dfrac{m(W-D)}{2}\right]}{\left[\dfrac{m(W-D)}{2}\right]} \quad\dots\dots\dots\dots(5)$$

$$m = \sqrt{\frac{Ul}{k\delta}}$$

2. Collector efficiency factor (F')

$$F' = \frac{Actual\ useful heat collection rate}{Useful heat collection rate when the collector}$$
$$absoring plate is at the local fluid temperature$$

Mathematically.

$$F' = \frac{\dfrac{1}{U_L}}{W\left[\dfrac{1}{U_L[D+(W-D)F]+\dfrac{1}{C_b}+\dfrac{1}{\pi D_i h_{fi}}}\right]} \quad\dots\dots\dots(6)$$

F_r = (Actual Useful energy gain) / (useful energy gain if the entire collector were at the fluid inlet temperature)

3. Heat Removal Factor (F_R)

$$F_R = \frac{Actual\ useful\ heat\ energy\ gain}{Useful\ energy\ gain\ if\ the\ entire\ collector}$$
$$were\ at\ the\ fluid\ inlet\ temperature$$

Mathematically

$$F_R = \frac{mC_P}{A_c U_L}\left[1 - \exp\left(-\frac{U_L F' A_c}{mC_p}\right)\right] \dots\dots(7)$$

Another formula for F_R,

$$FR = \frac{mC_p[T_{fo} - T_{fi}]}{A_c c[I_t \tau_0 \alpha_0 - U_L(T_{fi} - T_a)]} \dots\dots\dots(8)$$

4. Flow Factor (F'')

It is the ratio of the heal removal factor (F) and the collector efficiency factor (F)

Mathematically,

$$F'' = \frac{mC_p}{A_c U_L F'}\left[1 - \exp\left(-\frac{U_L F' A_c}{mC_p}\right)\right] \dots\dots(9)$$

The parameter is called the collector capacitance rate. It is a dimensionless parameter and the sole parameter upon which the collector flow factor depends.

C. Collector Plate Temperature (T_p)

At any point of time the collector plat temperature is given a

$$T_p = T_i + \frac{Q_u}{A_c F_R U_L}(1 - F_R) \dots\dots\dots(10)$$

Where, the useful heat gain Q_u is given as

$$Q_u = A_c F_R[H_T(\tau.\alpha) - U_L(T_i - T_a)] \dots\dots\dots(11)$$

D. Thermal Efficiency of the collector (η)

It is the ratio of the useful heat gain to the Total Input energy

Mathematically,

$$\eta = F_R(\tau.\alpha) - F_R U_L \frac{(T_i - T_a)}{H_T} \dots\dots\dots\dots(12)$$

E. Thermal Efficiency of the collector when angle of incident is not 90° (η_θ)

The equation number (12) for the thermal efficiency is applicable for a normal modem angle situation. In a situation where angle of incident is not 90° we will have to add a new parameter in the equation number (12). The new parameter is known as incident angle modifier (k_θ). The necessity of (k_θ) is arises due to change in (Ta) product.

For a flat plate collector (k_θ) is given as :

$$k_\theta = 1 - b_0\left(\frac{1}{\cos\theta} - 1\right) - b_1\left(\frac{1}{\cos\theta} - 1\right)^2 \dots\dots(13)$$

For a single glaze collector we can use a single order equation with, $b_0 = -0.1$

$$k_\theta = 1 - b_0\left(\frac{1}{\cos\theta} - 1\right)$$

Thus for a collector where angle of incident is not 90^0, the efficiency can be calculated by using the following equation,

$$\eta_\theta = k_\theta F_R [(\tau_0 \alpha_0) - \frac{U_L(T_i - T_a)}{I_t}] \quad \dots\dots\dots\dots(14)$$

Nomenclature

A_c: Area of the collector (m²)

A_e: Area of the edge (m²)

B_c: Bond conductance

C_p: Heat capacity of water (kj/(kg°C))

D: Outer diameter of the risers (mm)

H_{fi}: Heat transfer coefficient between the water and the riser wall

I_t: Radition falling ton the collectors per unit area (W/m²)

K_b, K_e: Conductivity of the back and edge insulation (W/mk)

K: Conductivity of the fin (W/mk)

L: Collector's length (mm)

M: Water mass flow rate (kg/sec)

N: Number of glass cover

T_a: Ambient temperature(°C)

T_p: Plate temperature(°C)

U_t, U_b, U_e: Top, bottom and edge heat loss coefficient respectively.

V: Wind velocity (m/sec)

w: Distance between two rises (mm)

X_b, X_e: Back and edge insulation thickness (mm)

τ_0: Transmissivity of the glass cover

α_0: Absorptivity of the absorbing plate

ε_p: Emissivity of the absorbing plate

ε_g: Emissivity of the glass cover

σ: Stephen Boltzmann constant (W/m²K4)

∂: Thickness of the fin (mm)

θ: angle of incident (Deg)

Constant values:

A_c = 0.74115 m²

A_e = 0.32775 m²

K_b = 0.04 m²

N = 1

C_p = 4180 J/ kg°C

X_b = 0.05 m

X_e = 0.025 m

τ_0 = 0.85

α_0 = 0.96

ε_p = 0.12

ε_g = 0.88

σ = 5.67 x 10⁻⁸ W/m² k⁴

Experimental set-up:

Fig 3.1 shows the experimental setup.

Assumptions:

To perform different experiments with this set-up a number of assumptions need to be made. These assumptions are not against the basic physical principles but simplify the problems up to a great extent.

- The collector is in a steady state condition.
- The headers cover only a small area of the collector and can be neglected.
- Heaters provide uniform flow to the riser tubes.
- Flow through the back insulation is one dimensional.
- Temperature gradients around tubes are neglected.
- Properties of materials are independent of temperature.
- No energy is absorbed by the cover.
- Heat flow through the cover is one dimensional.
- Temperature drop through the cover is negligible.
- Covers are opaque to infrared radiation.
- Same ambient temperature exists at the front and back of the collector.
- Dust effects on the cover are negligible (if otherwise mention).
- There is no shading of the absorber plate (if otherwise mention).

Experimental procedure:

1. Keep all valves closed.
2. Fill cold water tank number1.
3. Open the valves I and 2 and fill cold water tank 2 by using the pump.
4. Once the cold-water tank 2 is full, open valve 3 and 4 and allows the water to flow into the hot water tank and the collector by gravity.
5. Once the hot water tank overflows and water comeback to the cold water tank 1 close the valves 1, 2 and 3.
6. Switch on the Wind generating fan.
7. Measure the wind speed at different locations of the collector by using the Anemometer. Use an average value for calculation.
8. Similar to the wind speed measure the ambient air temperature by using the same Anemometer at different locations around the experimental setup. Use an average value for calculation.
9. Connect all the meters and note all the readings
10. Switch on the Halogen system and set the regulator for maximum radiation level.
11. Measure the radiation level at different locations on me collector glazing by using the radiation meter. To get the radiation levels at the desire value apply the regulator Use an average value for calculation.
12. Note the values shown by different metes after every 15 minutes.
13. To know the mass flow rate, open the three ways valve and note the time required to fill a desire amount of water in the beaker

14. Repeat tile above step (13) at least five times during the whole experiments. Use an average value for calculation.

15. Keep the halogen system ON until the outlet water achieved a stable temperature.

16. Once the experiment is over drain the hot to the cold water tank I by opening valve 5.

Note : Before draining the hot water to the cold water tank 1, make sure that you nave fill up the cold water tank 2 for the next experiment.

S. N	Time (t, min)	Ambient Temperature ($T_a°C$)	Inlet water temperature ($T_{fi}°C$)	Plate temperature ($T_p°C$)	Outlet water temperature ($T_{fi}°C$)	Water temperature in the storage tank($T_g°C$)	Water mass flow rate (m,Kg/sec)	Inlet water pressure (P_i, kpa)	Outlet water pressure (P_{out}, kpa)
1									
2									
3									
4									
5									
6									
7									
8									

Observations:

- Tilt angle of collector (β) :-----------deg
- Wind speed (v) :----------m/sec
- Radiation level (I) :--------W/m^2
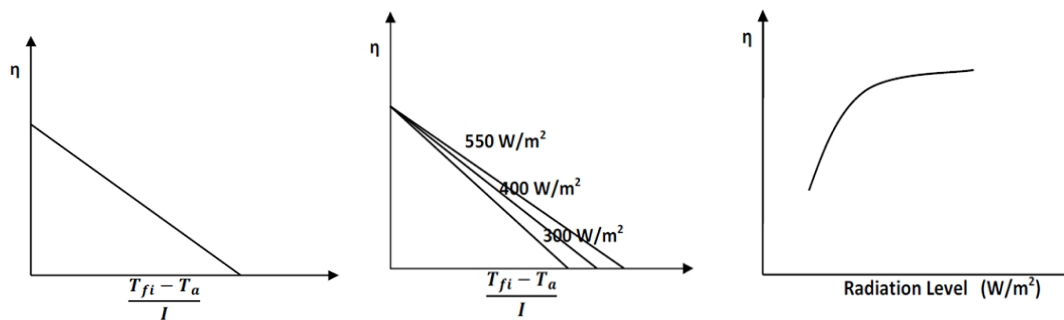
Calculations:

1. Calculate U_t and hence U_L by using equations 1 through 4

2. Calculate Heat Removal factor (F_r) by using equation 7

3. Calculate thermal Efficiency (η) of the collector by using equation 12

4. Evaluate time constant of collector by drawing the graph between R and time.

By using tile values of different entries from the Table-1 user can examine some other characteristic parameters of the collector. The parameters are,

1. Collector efficiency factor (F') by using equation 8.

2. Collector Flow factor (F") by using equation 9.

3. Comparison of the experimented and calculated value of plate temperature by using equation

Results:

1. Draw the following efficiency graph.

2. Find the value of optical efficiency of the collector from the graph.
3. Find the slop of the curve which gives the sense of the overall heat loss coefficient of the collector.
4. Find the gain and loss equalization point.

_____

2. Find out the area rqured and estimate the simple payback period.
   Assumption:
   a. Hot water requirement = 250 litre
   b. Water required at temperature = 80°C (may be 120 °C for other than solar water heating requirement
   c. Ambient temperature = 30°C
   d. Daily solar radiations = 5.5 kWh/ m^2 – day
   e. Efficiency of solar water heater = 40%
   f. Heat capacity of fluid (water in this case) = 4.18 kJ/kg- K

3. Generate a hot water utility for a small washing industry that needs 15000 litre of hot water. Solar radiation available on the location is 7 kWh/ m^2- day. Temperature of feed water is   27 °C and it is to be heated upto 150°C. Which types of collectors can cater to the demand? Why?

4. Estimate the temperature rise of the water in a 100-litre capacity thermosyphon solar water-heating system during a typical day of operation. Estimate also the electricity saved because of the use of a solar water heater and the corresponding reduction in the monthly electricity bill.

Ex. No: 12   **Experiment on performance evaluation of solar dryers**

Date :

Aim:
- To evaluate the performance of natural convection (direct and indirect mode) solar dryers.
- To expose working of active solar air heating system and hybrid solar-biomass air heating systems for drying applications.

Equipments required:

Domestic Solar drier - direct mode and indirect mode (PAU model and TNAU Dome model), Pyranometer, Thermocouples, Timer and Humidity/temperature meter

Description

Performance evaluation of domestic solar dryer

The PAU domestic solar will be loaded with selected product of 1kg capacity. The tests will be carried out under full load condition.
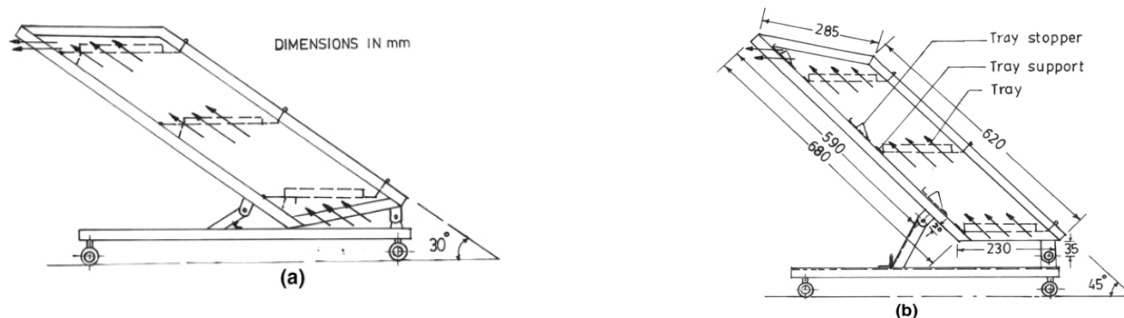
Specifications

Aperture area	:	$0.36 \, m^2$
No. of trays	:	3
External dimensions of dryer	:	620 x 620 x 350 mm.
Weight of the dryer	:	17 kg
Inclination of the dryer	:	fixed / variable

The temperature, relative humidity, and solar insolations were measured using mercury bulb thermometer, digital RH meter and digital pyranometer in terns of W/m^2 respectively.

Fig. 5.1. Photograph of PAU domestic solar dryer with door open

Fig. 5.2. Side view of the dryer showing the position of tray supports at different inclinations: (a) 30° and (b) 45°

The following other important parameters to be measured during the experiment.

- Loading density
- Loading/unloading time
- Mositure content of initial and final products
- Maximum drying temperature at load condition
- Drying time/ drying rate

Exercise 1: Draw a sketch of natural convection PAU Solar Domestic dryer (direct and indirect mode), TNAU dome model with all dimensions

Observations

Place the drier in an open space, facing south to north direction. Close the openings provided to keep the trays. Find the initial temperature of the trays. Measure the raise in temperature inside the drier at every 10 minute's interval. Simultaneously observe the solar intensity at each interval and tabulate the readings.

Tabulate the observations as shown below:

Time, Hr : min.	Ambient temperature, °C	Solar intensity, W/m²	Ambient RH, %	Tray Temperature, °C			Dryer efficiency, %
				Step 1	Step 2	Step 3	

Draw the following graphs

a. Time Vs. Solar intensity
b. Time Vs. temperature in each step
c. Find out the efficiency of the domestic dryer

Exercise Problem

1. Rice is harvested at a moisture content m = 0.28. Ambient conditions are 30°C and 80% relative humidity, at which m_e (equilibrium moisture content) = 0.16 for rice. If at 30°C and 80% relative humidity has mass of H_2O in 1 m^3 of saturated air=30.3 g/m^3. Calculate how much air at 45°C is required for drying 1000 kg of rice.
L_v = 2.40 MI/kg at 30°C
ρ = 1.15 kJ/m^3 and
C_P = 1.0 kJ/kg°K

2. The efficiency curves shown in Fig. are obtained for a solar air heater (L_1=1.2m, L_2=0.9 m) which is tested over a range of flow rates varying from 25 to 200 kg/h. Find the efficiency which would be obtained and the corresponding mass flow rate if the air heater is used under the following conditions

Air inlet temperature	:	55°C
Air outlet temperature	:	75°C
Ambient temperature	:	27°C
Solar flux incident on collector face	:	950 W/m^2

3. The following data is given for a conventional solar air heater with one glass cover:

Length of collector	: 2.0
Width of collector	: 0.9 m
Length of absorber plate	: 1.90 m
Width of absorber plate	: 0.80 m
Spacing between absorber plate and bottom plate	: 2 cm
Absorber plate/bottom plate emissivity for long	
Wavelength radiation (for the surfaces facing each other)	: 0.93
Absorber plate absorptivity for solar radiation	: 0.93
Glass cover thickness	: 3 mm
Refractive index of glass	: 1.526
Extinction coefficient	: 10.5 m^{-1}
Air flow rate	: 440 kg/h
Air inlet temperature	: 48°C
Location of collector	:Chennai (13.00°N)
Date	: March 3
Time	: 1230 h (LAT)
Collector tilt	: latitude angle
Surface azimuth angle	: 0°
I_g	: 0.968 kW/m^2
I_d	: 0.195 kW/m^2
Ambient temperature	: 31.5°C
Top loss coefficient	: 4.5 W/m^2-K
Bottom loss coefficient	: 0.55 W/m^2-K

i. Calculate the instantaneous efficiency, the exit air temperature and the pressure drop. (Assume that the heat transfer surfaces are smooth).

ii. Is it advantageous to have a low or a high value of emissivity (for large wave length radiation) for the surfaces of the absorber plate?

4. The efficiency curves shown in Fig. are obtained for a solar air heater (L_1=1.2m, L_2=0.9 m) which is tested over a range of flow rates varying from 25 to 200 kg/h. Find the efficiency which would be obtained and the corresponding mass flow rate if the air heater is used under the following conditions

Air inlet temperature	:	55°C
Air outlet temperature	:	75°C
Ambient temperature	:	27°C
Solar flux incident on collector face	:	950 W/m²

5. The following data is given for a conventional solar air heater with one glass cover:

Length of collector	: 2.0
Width of collector	: 0.9 m
Length of absorber plate	: 1.90 m
Width of absorber plate	: 0.80 m
Spacing between absorber plate and bottom plate	: 2 cm
Absorber plate/bottom plate emissivity for long	
Wavelength radiation (for the surfaces facing each other)	: 0.93
Absorber plate absorptivity for solar radiation	: 0.93
Glass cover thickness	: 3 mm
Refractive index of glass	: 1.526
Extinction coefficient	: 10.5 m⁻¹
Air flow rate	: 440 kg/h
Air inlet temperature	: 48°C
Location of collector	:Chennai (13.00°N)
Date	: March 3
Time	: 1230 h (LAT)
Collector tilt	: latitude angle
Surface azimuth angle	: 0°
I_g	: 0.968 kW/m²
I_d	: 0.195 kW/m²
Ambient temperature	: 31.5°C
Top loss coefficient	: 4.5 W/m²-K
Bottom loss coefficient	: 0.55 W/m²-K

iii. Calculate the instantaneous efficiency, the exit air temperature and the pressure drop. (Assume that the heat transfer surfaces are smooth).

iv. Is it advantageous to have a low or a high value of emissivity (for large wave length radiation) for the surfaces of the absorber plate?

EXPERIMENT: 13 STUDY ON SOLAR POWER AND I-V CHARACTERISTICS

Ex. No: 14   **Experiment on Performance testing of Solar PV water pumping**
Date: **system and design problems**

Aim:

To design and evaluate the performance of solar PV water pumping system.

Apparatus Required:

PV module, Tracking system, Motor, Water tank and Storage

Description

A solar water pumping system consists of PV modules, motor, pump and storage tank. A DC motor can directly be coupled with a solar PV panel, avoiding the use of any inverter. An AC motor can also be used with an inverter, which converts DC power of a PV module into AC power. Additionally a PV water pumping system can also have a Maximum Power Point Tracking device to match the PV module output impedance with that of motor to extract maximum power throughout the day.
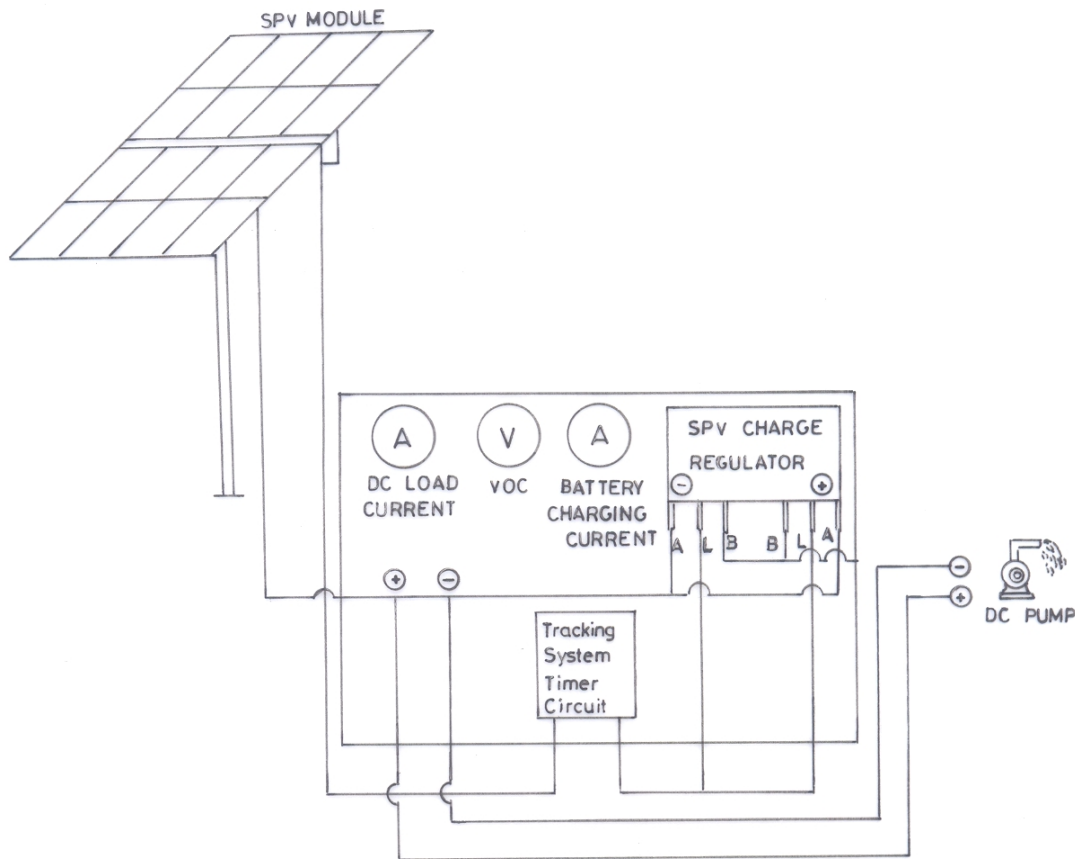

Fig 13.1. Experimental set up of solar pumping system

Specifications:
     Capacity: 1 hp
     Dc pump: 746 W

Observation:

S.No.	Solar Intensity, W/m^2	Open Circuit Voltage, V	Short Circuit Current, A	Water Discharged, m^3/min

Exercise: Draw the solar water pumping system setup with module connections

Design of Solar PV Pumping System

     Design of solar PV pumping system requires details about the

(i). Quantity of water needs to be pumped

(ii). Depth of suction level at which water has to be pumped

(iii). Number of panels to meet the requirement

The overall design of the system can be divided in the following steps:

Step 1: Determine the amount of water required per day

Step 2: Determine the Total Dynamic Head for water pumping

Step 3: Determine the hydraulic energy required per day (watt-hour/day)

Step 4: Determine the solar radiation available at given location in terms of equivalent of peak sunshine radiation (1000 W/m^2) hours for which solar PV module is characterized. Typically this number is 5 to 8 varying from season and location to location.

Step 5: Determine the size of solar PV array and motor, consider motor efficiency and other losses.

Total water requirement (litre/day or m^3/day)

     The size and cost of the system depends on the amount of water required per day. Solar pumping systems are designed to provide a certain quantity of water per day, where the daily water quantity required is sum of all requirements during 24 hours. For more reliable design, worst case of water requirement should be considered.

Total Dynamic Head (m)

It is an important factor, which signifies the effective pressure at which pump must operate. It primarily consists of two parameters, **total vertical lift** and **total frictional losses**.

Total vertical Lift (m)

The total vertical lift is sum of **elevation, standing water level and drawdown**. The elevation is the height difference between the ground and the height at which water is discharged. Standing water level is the height difference between the ground surface and the water level in the well, when the well is in fully charged condition. Drawdown is the height by which standing water level drops due to pumping.

Frictional losses (m)

Frictional loss is the pressure required to overcome friction in the pipes from the water pump to the point of water discharge. It depends on many factors like size of pipe, flow rate, type of fittings, number of bends, etc. If the tank is within 10 m of the well, then frictional loss is taken as 5% of the total vertical lift.

Problems

1. Design a PV system for pumping 25000 litres of water every day from a depth of about 10 m is considered.
a. Amount of water to be pumped per day = 25000 l = 25 m^3
b. Total vertical lift = 12 m (5m- elevation, 5m- standing water level, 2m–drawdown)
c. Water density = 1000 kg/m^3
d. Acceleration due to gravity = 9.8 m/s^2
e. Solar PV module used = 75 W_P
f. Operating factor = 0.75
g. Pump efficiency = 30%
h. Mismatch factor = 0.85
2. Design a solar PV to pump 10000 litre of water from a depth of 4 m (the drawdown will be about 2 m). The water needs to be discharged at about 5m from the well. What would be the cost of the system?
3. A photovoltaic system for supplying drinking water is installed in a village in Rajasthan as part of the National Drinking Water Mission. The water is pumped from a bore well, from a depth of 48 m. The solar cells are made from single crystal silicon and the array consists of 24 modules. It is given that the inverter efficiency is 85 per cent and the pump-motor set efficiency is 45 per cent. Calculate the water discharge rate at noon when the global radiation incident normally on the cells is 945 W/m^2.
Assume the conversion efficiency is 13 per cent, which is based on the cell area and is valid for global radiation.