Retrofitting a CST Biogas Plant for the Production of Biogas from Rice Cooking Waste Water

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Abstract

The production of biogas from rice cooking effluent is a sustainable and ecologically friendly method of waste management and renewable energy production. This study explores the feasibility of employing rice cooking wastewater, a significant by-product of food preparation, as a substrate for the production of biogas through anaerobic digestion. The study highlights how this waste stream might reduce its unfavorable effects on water systems and alongside produce methane-rich biogas. The primary goals of the study are to determine the present problems with the College of Science and Technology's (CST) biogas facilities that rendered the plant unusable and to create a retrofitting design for the current plant that will make it both technically and financially feasible. The study also provides a quantitative analysis of the methane content of rice-cooking wastewater, and the findings show the possibility of using rice-cooking wastewater to produce biogas as a dual-benefit solution to energy needs and waste management issues.

Keywords— Methane content, P&ID diagram of biogas plant, Rice cooking wastewater, starch water

1 Introduction

The world's population growth and expanding energy needs make it uncertain if fossil fuels like coal, petroleum, and natural gas will still be available in the years to come. The price of these petroleum items would be exorbitant even if they did not exhaust. As a result, people have already changed their behavior to tap renewable energy. Energy sources like solar, wind, geothermal, biomass, and hydro that exist naturally in the environment and can be replenished on a scale suitable for human life are referred to as renewable energy. Biogas is one of the promising alternative energy sources that is currently gaining ground. 2016 saw the installation of one such biogas plant at the College of Science and Technology (CST) with the capacity to hold $4m^3$ of biogas at a time.

The College of Science and Technology (CST) previously experimented with a method to recover biogas from leftover food. Later, it was discovered that this strategy was ineffective for a number of reasons, including an undefined waste-to-water ratio, temperature variations, gas leaks, and the plant operator's lack of sincerity [1]. Therefore, this article aims to implement a retrofitting project on the current plant to increase its effectiveness with economic viability. This article adapts cooked rice starch water (Zarjay) as a biodegradable substrate for the generation of biogas. The College of Science and Technology (CST) produces 784 liters of starch water on average per day. Currently, this wastewater is discharged straight into the drain. If left unchecked, this effluent can contribute to methane CH_4 emission into the atmosphere, which is a significant contributor to global warming [1]. However, a study on the generation of biogas from starch water revealed that this substance has great potential for producing biogas [2]. Thus, considering the paper as the basis for this study, the gross potential of biogas production from starch water at the CST kitchen was estimated to be $148.96m^3$. Furthermore, biogas produced from starch water contains 78% methane gas, according to [2]. Following this information, $116.19m^3$ of biogas (CH_4) from starch water will be determined at CST kitchen.

1.1 Problem Statement

In 2016, a biogas facility was set up near to the student dining hall at CST. This facility was designed to convert kitchen food waste into biogas through an anaerobic digestion process. The resulting biogas had a composition of approximately 50 – 70% methane, 50 - 30% carbon dioxide, and 10% other gases [3]. However, the plant encounters challenges such as an undefined waste-to-water ratio, fluctuations in temperature in the methanation tank, and gas leakages. These issues led to a reduction in the quantity of generated biogas. Additionally, the plant releases its waste directly to a landfill, causing an unpleasant odor on the campus.

1.2 Aim and Objectives

The goal of this paper is to retrofit the existing biogas facility using starch (rice cooking wastewater) sludge. The following are the objectives to fulfill the aim:

- Examine and comprehend the operation of the current biogas facility in detail.
- Compute the theoretical potential for methane generation from the amount of starch water that the CST kitchen produces each day.
- Develop a P&ID diagram of the new design biogas plant at CST mess.
- Perform a financial analysis for the retrofit.

2 Methodology

2.1 Details On Existing Biogas In CST Mess

2.1.1 Problem associated with an existing biogas plant in CST

The main objective of the biogas plant installed at CST is to replace the usage of liquefied petroleum gas by using kitchen waste. The pilot project was commissioned on 16th March 2016 and data were collected. It was found that the average monthly bill for LPG used by student mess was reduced to Nu. 5726 from Nu. 8902. In 2018, CST undergrad students did their final year project on the optimization of the existing biogas plant [1]. After it was discovered that the biogas production was insufficient to feed the mess, the plant was shut down. There were many problems associated with it. The problems are as follows:

- No proper technical person to supervise the working of biogas plant.
- There was gas leakage from the gas holder.
- The digester was too large for the daily feed produced.
- Lacking of BMP test, BOD test, and COD test for the kitchen waste.
- Too much manual work and it is complex.
- Unspecified pump speed.
- The gas holder was too big for the bio-gas to lift it.
- The gas stove or burner used was not designed for biogas.

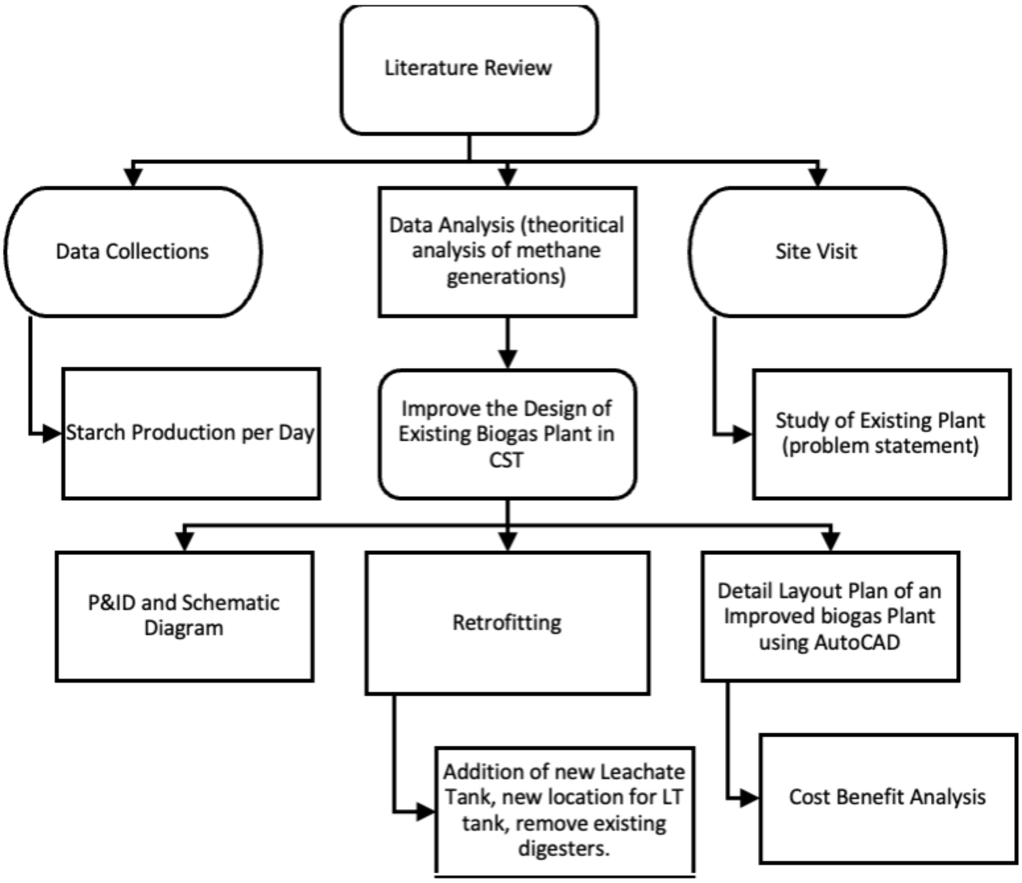

Figure 1: The methodology Adopted

2.1.2 General Working of Existing Bio-gas Plant in CST

Figure 2, shows the schematic diagram of the existing biogas plant installed in the CST mess. It contains components such as an acidification reactor (AR), leachate collection tank, methenation tank, effluent collection tank, and bio-gas holder. Firstly mixed kitchen food is directly fed in the acidification reactor and kept for six days to digest. There are six reactors and it is kept to digest alternatively. The retention time is maintained. After that leachate is transferred to the leachate collection tank from AR alternatively and the pH is maintained to 7 by adding NaOH before feeding to the up-flow anaerobic sludge blanket tank. By using a dosing pump, the leachate is fed to the methanation tank. For the sake of the organism's stability, the methanation tank's temperature is kept constant, and the purified gas it produces is fed through a gas holder. Digestate, or effluent, is the term for the digested material that is kept in the effluent tank following the process of digestion. This substance has a lot of nutrients and can be applied as fertilizer. Finally, the pure biogas is fed to the CST mess.

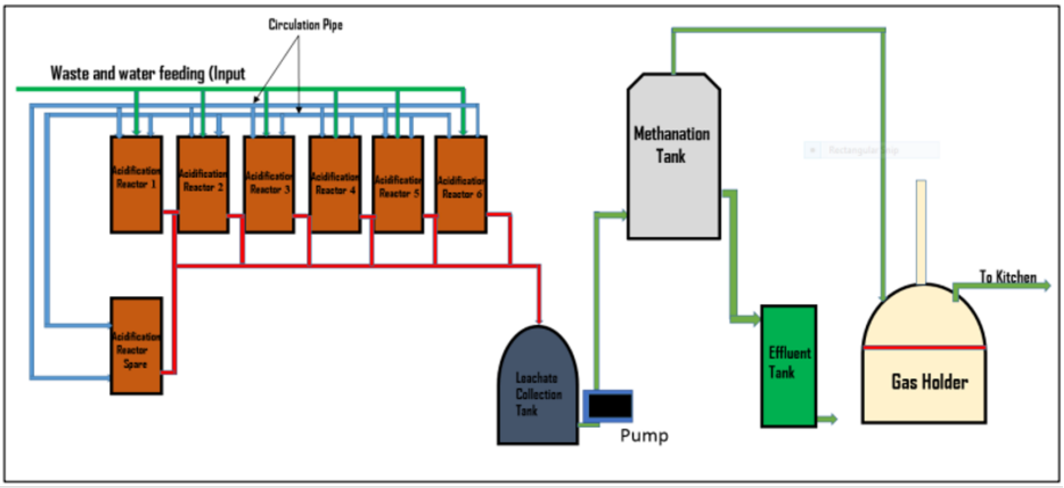

Figure 2: Schematic Diagram of Existing Biogas Plant in CST

3 Retrofitting

3.1 Methane content from starch water at CST kitchen

This section computes the methane gas production potential from starch water released from the common student kitchen at the CST. The theoretical calculation showing the potential for methane gas using the empirical formula as well as an estimation based on the paper, "Defining the Biogas Generation Potential and the Kinetics of Biogas Generation for House- Hold Generated Rice Cooking Wastewater" is presented. [4] From the paper, the following findings were reported by the investigation into the biogas potential of cooking wastewater.

$$1 \text{ g of maar} = 190 \pm 46\,\text{mL of Biogas} \tag{1}$$

The features of the starch utilized in the Biological Methane Potential (BMP) investigation are listed in Table 1.

Table 1: Population data

PH	BODs (mg/L)	PDensity (g/mg)	TS (mg/L)	VS fractions (%)
8.3 ± 0.1	23450 ± 796	0.95 ± 0.01	0.47 ± 0.01	98.7

This study showed that 78% of the total biogas generated during the experiment test included methane [4]. The finding is used to determine the potential of methane content in the starch water from the CST kitchen in a day.

3.2 Quantity of starch water produced per day

Three electric rice cookers are used for cooking in the CST kitchen. On average one rice cooker produces 98 liters of starch water per meal. For breakfast, only two rice cookers are used, whereas for lunch and dinner three rice cookers are used. Hence, $Breakfast = 98 * 2 = 196L$ Lunch & $Dinner = 2 * (98 * 3) = 588L$ The total starch produced per cooking day is 784 L. Theoretical methane content in 784 L of starch water can be calculated by using an organic formula for starch, this is given by: $C_6H_{10}O_5$ and the molecular weight is 162 g. [5] Using the following equation, one can forecast methane production.

$$C_nH_aO_b + \left(n - \frac{a}{4} - \frac{b}{2}\right) H_2O \rightarrow \left(\frac{n}{2} - \frac{a}{8} + \frac{b}{4}\right) CO_2 + \left(\frac{n}{2} + \frac{a}{8} - \frac{b}{4}\right) CH_4$$

Hence,

$$C_6H_{10}O_5 + \left(6 - \frac{10}{4} - \frac{5}{2}\right) H_2O \rightarrow \left(\frac{6}{2} - \frac{10}{8} + \frac{5}{4}\right) CO_2 + \left(\frac{6}{2} + \frac{10}{8} - \frac{5}{4}\right) CH_4$$

$$C_6H_10O_5 + H_2O \rightarrow 3CO_2 + 3CH_4$$

The chemical equation above demonstrates that 1 mole of starch contains 3 moles of methane. 784 kg of starch in mole:

$$\frac{784\,\text{kg} \times 1000\,\text{g} \times 1\,\text{mole}}{1\,\text{kg} \times 162\,\text{g}} = 4839.51\,\text{moles of starch}$$

Methane content in 784kg of starch: At STP 1 mole of gas = 22.4 L
Therefore,

$$\frac{3 \times 4839.51\,\text{mole} \times 22.4\,\text{L} \times 1\,\text{m}^3}{1\,\text{mole} \times 1000\,\text{L}} = 325.22\,\text{m}^3\,\text{of}\,\text{CH}_4$$

Hence, theoretically, 784 L of starch produces $325.22m^3$ of Methane gas per day. Methane content in 784 L of starch water as per equation (1).

We have from [4]
1 g of maar=190±46 mL of Biogas
OR
0.001 kg of starch = 190 mL

$$\therefore\ 784\,\text{kg of starch} = \frac{190\,\text{mL} \times 784\,\text{kg}}{0.001\,\text{kg}} = 148,960,000\,\text{mL of biogas}$$

Or
784 kg of starch = 148.96 m^3 of Biogas.

As per [4], the biogas produced from maar contained 78% Methane gas. Hence, $148.96m^3$ of Biogas contains $116.19m^3$ of Methane gas.

3.3 P & ID diagram of biogas plant at CST mess

The pump is placed in the pump house in front of the kitchen so that the pipe from the pump outlet to the leachate collection tank has an easy route, the pictorial view is illustrated in Figure 3. HDPE pipe of 25 sq. mm was employed for the same. A Galvanized Iron (G.I) pipe of 25 sq. mm is fixed between the storage point and the pump inlet. G.I. pipe is used for its anti-corrosive, rust resistance, and durability features. In order to prevent external damage, the cable connecting the pump has been drawn through an HDPE pipe. The cooks may easily operate the pump by pushing a switch that is located close to the kitchen entrance.

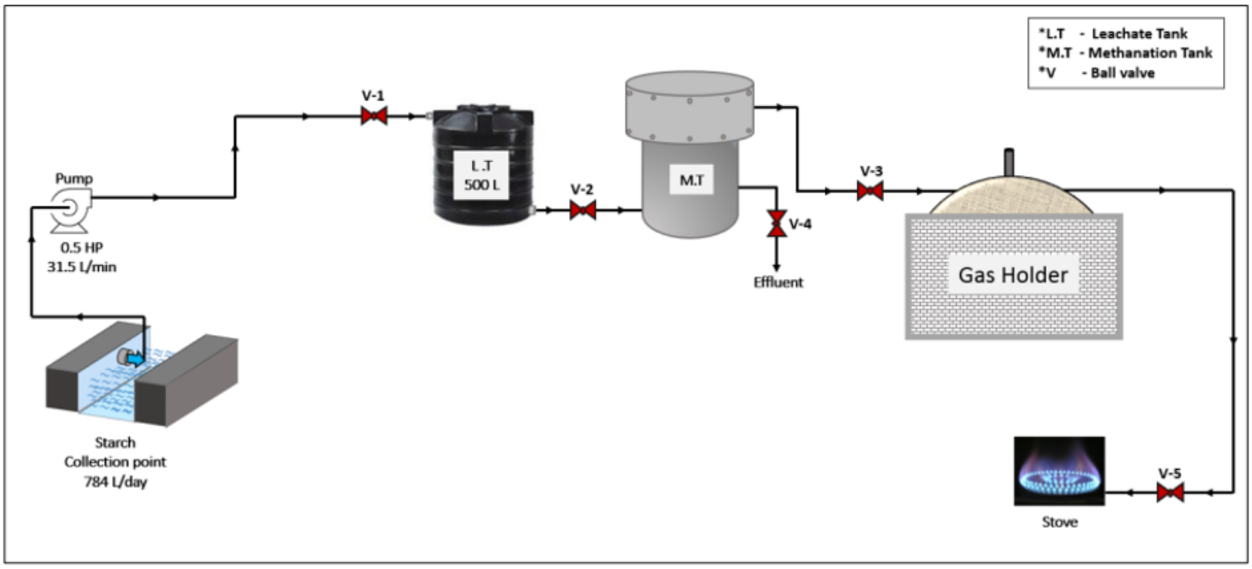

Figure 3: P&ID diagram of the biogas plant (option 1)

The leachate tank (L.T) is placed at a height of 4.2m on the roof of the Methanation tank (M.T) chamber the schematic diagram showing a detailed layout is given in Figure 5. This is because the difference in height is used to pump the starch water from the leachate tank to the Methanation tank. The leachate outlet to the M.T. is taken from the bottom of the L.T. so as to avoid the use of a mixer. The M.T. has a biogas capacity of $0.325m^3$ with a height and width of 1.6 meters and 1.4 meters respectively [1].

The effluent from the M.T is directly released to the drain as it is much cleaner than the effluent from solid waste. The biogas produced is collected in the $4m^3$ capacity of gas holder. Currently the biogas collection is limited by the gas collector capacity. With huge potential of biogas from starch water, a higher capacity of air bag is recommended for gas collection.

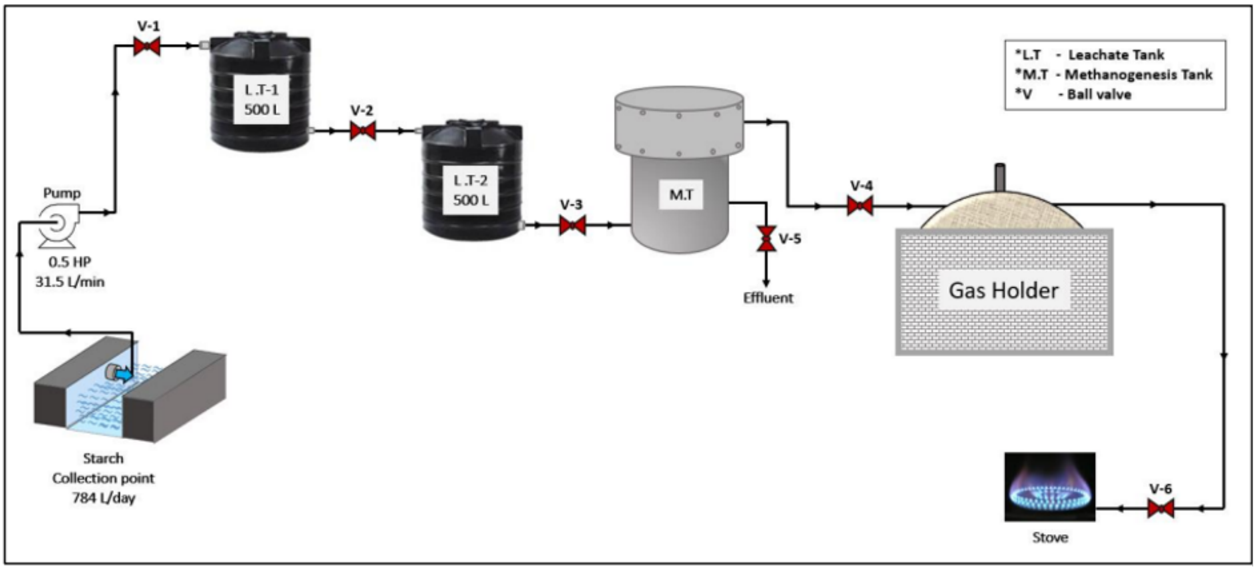

Figure 4: P&ID diagram of the biogas plant (option 2)

The cooking is done in the kitchen using the biogas generated from the rice cooking wastewater. However, for the efficient usage of biogas, the biogas burner is proposed instead of the normal stove which is being used currently.

Consequently, a second design is proposed as illustrated in Figure 4. In this plant design, two numbers of L.T. are proposed so as to contain a larger volume of starch water which can further help in the continuous generation of biogas. To reduce the cost, the liquid transfer from L.T. to M.T. is proposed by using gravitational force in the first design, however, maintaining height becomes a limitation in the second design, and might have to use the second pump.

3.4 Operation of the plant

For the first proposed design as shown in Figure 3, starch will be pumped to L.T as and when it is produced from the kitchen and simultaneously is released to M.T. This is with the aim that biogas produced overnight is used in the following day and a new volume of starch water is pumped to the L.T and the process repeats. In this design, the aim is also to use the existing $4m^3$ biogas capacity of the gas holder, hence it was the design limitation factor. However, in the second proposed design as shown in Figure 4, with the use of two L.T., the starch water can be pumped and stored but can be released to M.T. every 48 hours. This is also limited by gas holder capacity. Nevertheless, with the use of a higher-capacity gas holder such as airbags, the plant can be operated in a continuous manner with a higher volume of biogas production. The existing facility's gas holding capacity and structure are utilized in the proposed design of the biogas plant. The proposed design reuses even the M.T. tank from the existing biogas plant. This will assist in lowering the overall cost of the renovated biogas plant. The converted biogas plant's precise installation details are shown in Figure 5.

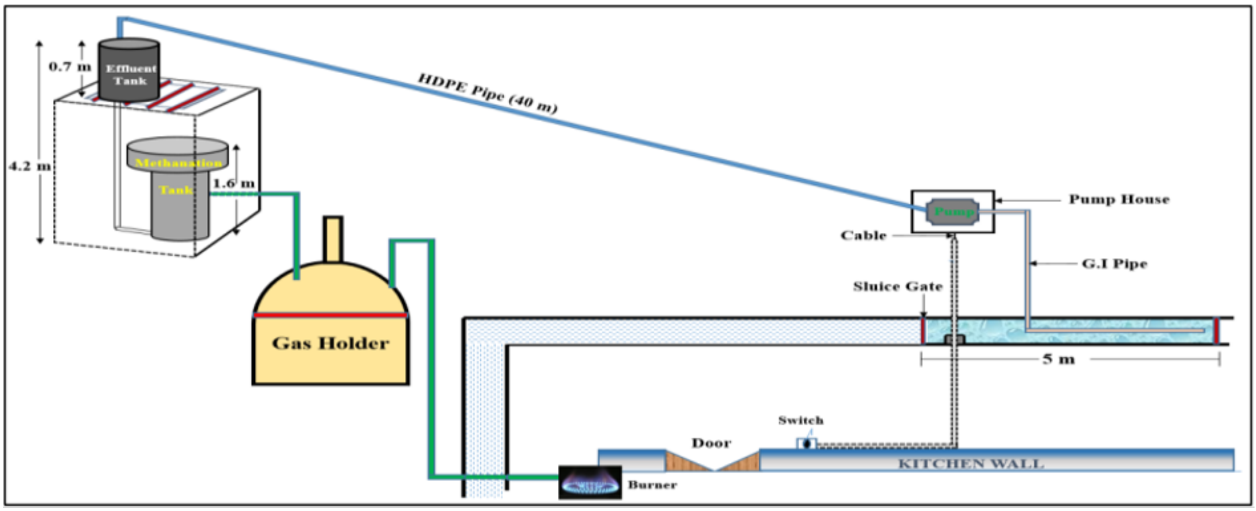

Figure 5: Detail layout of the proposed biogas plant design

Starch water effluent is directly pumped into the L.T. from the drain. Effluent is moved from L.T. to M.T. using gravity pressure. From the M.T. tank, the generated methane gas along with other gases reaches to gas holder chamber. It could be a good idea to filter the gases using various methods and conduct only the net methane gas to the burner.

4 Cost Estimation for Retrofitting

Following the completion of the revised design and retrofitting work for the biogas production from starch in the CST mess, it was determined that the approximate total cost for the system equipment to be purchased, exclusive of installation fees, would be around Nu. 14425. The equipment and materials which are available in the Amazon web site for online shopping based in India, were the only sources of this estimate. In the table below, the specifics of the approximated cost are listed.

Sl. No.	Items	Specifications	Quantity	Rate (Nu.)	Total Amount (Nu.)
1	GI pipe	25 sq.mm	5.5 m	50	275
2	GI elbow	25 sq.mm	2	75	150
3	Cable	CRI 2.5 sq.mm, 3-core, copper	30 m	117	3510
4	Centrifugal pump	Havells, 0.5 Hp	1	4945	4945
5	HDPE pipes	25 sq.mm	40 m	50	2000
6	HDPE pipes	30 sq.mm	5 m	70	350
7	Switch	6 A, 230 V, anchor	1	45	45
8	PVC C-clamp		5	10	50
9	MS C-clamp		15	25	375
10	Gas Stove		1	1200	1200
11	MS C-channel	10 mm	4 m	350	1400
12	Flexi PVC Pipe	25 sq.mm	9 m	25	225
				Total	**14,425**

Table 2: Cost of Materials

5 Result

Theoretical calculations indicate that the daily wastewater generated by the CST kitchen during rice cooking has the capacity to produce 116.19 m^3 of methane gas. Considering the total volume of rice cooking waste water produced per day, the retrofitting of the plant is carried out as demonstrated in Figure 5. In here, over all plant design become simplified compared to the existing plant reducing the everyday human involvement to operate, because the acidification reactor components are removed permanently. In the new design effluent will be directly pumped to leachate tank and from LT the sludge flows to methanation tank by gravitational action. The slurry generated after the methanation tank can be directly drained to the drain. This is the additional advantages of the retrofitted plant. The overall cost estimation has been done according to the price of materials available in the Amazon online shopping website. Taking the cost reference form Amazon online shopping website, the total cost of the retrofitting of biogas plant is shown in Table **??**. Here, we can see huge cost cutting compare to the preexisting biogas plants. However, it is vital to take into consideration not just the biogas plant project costs, but the lifetime running costs of the plant as well [6].

6 Challenges and Conclusion

6.1 Challenges

The limitation of running a biogas plant at college is, the plant remains idle during vacation that is two times in a year for an average of one months. In the other sense the feed for the plant will be completely stopped. These sudden change in feed input and sudden drop in pH value will cause treatment unbalance [7]. This will result in bringing the plant to startup phase every vacation. Therefore, a scheme to continuously use the plant is required.

6.2 Conclusion

The need for biogas energy rises along with the need for other forms of energy [8]. In order to decrease the use of LPG gas, many urban and rural areas now have biogas facilities erected. Fossil fuels will soon be phased out, then the alternative could be biogas as a fuel source. As a result, the greenhouse effect and global warming will gradually decline. Education and awareness campaigns will undoubtedly remain the most effective approaches to promote the use of biogas as we enter a new era. The goal of this proposed project is to modify the already-installed biogas plant in CST mess, which will help to lower the amount of LPG gas that is consumed there. This project will eventually enable individuals to contribute to the biogas plant and appreciate it as a better source. As a result, if many people use biogas plants, there will be less global warming and individuals can save money and invest in various other things. The study showed that the biogas generation potential from starch water is as high as $116.19m^3$ of methane daily from 784 kg of starch. However, the current plant design impacts the benefit mainly due to the manual tasks involved. This issue is addressed by employing a pump as the biodegradable substrate is starch water which can be easily pumped. Moreover, the college can easily retrofit the existing biogas plant to the proposed design with the minimum cost of Nu. 29610 only.

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