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Investigation of biogas emitted from a dairy plant lagoon and proposing an innovative Honeycomb Gas Collector(HGC)

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Abstract

Peghah Dairy Plant in Tabriz, Iran, near Shahid Madani International Airport uses a combination of two wastewater treatment systems, namely, lagoon and activated sludge system. Presence of a lagoons near airports can affect passengers getting off the planes due to unpleasant odor and has always been a controversial issue from the urban planners' point of view. Most of the biological activities in the lagoons are anaerobic producing odorous gases as a result. On the other hand, biogas produced by biological activities enters into the atmosphere, contributing to global warming. To avoid an environmentally adverse effects of the emitted gases from the lagoon in Peghah Diary Plant in Tabriz, the possibility of using the collected gases from the lagoon in heating processes within the plant was studied. In this study, a single experimental unit of an innovative gas collector, named Honeycomb Gas Collector (HGC), was designed and constructed to cover the surface of the lagoon and lagoon inputs were recorded and samples of biogas from the lagoon were collected and analyzed during April 2016 until March 2019. The highest daily amount of 44.82 m^3 biogas from the entire lagoon was recoded in August 2016. Temperature and pH had the most and least significant effect on biogas production respectively. There was a strong relationship with a coefficient of 0.94 between the temperature and the volume of biogas produced. This system proved to be less costly and maintenance free method for covering the lagoon surface.

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Introduction

Peghah Dairy Plant is located in north of Tabriz, Iran, about 1.7km far from Shahid Madani International Airport. Passengers getting off the planes as well as nearby residents are affected by unpleasant odor emitted from lagoon. About 330 to 400 tons of raw milk is delivered to the diary plant for processing on daily basis. Around 1000m^3/day of effluent is discharged from the plant. The capacity of anaerobic sewage and the activated sludge systems are 7500m^3 and 800m^3, respectively.

The high volume of wastewater produced by diary industries, along with their significant contamination, have led to enforcing strict regulations for these industries in different countries. Organic matter in dairy effluents comprises mainly of carbohydrates, proteins, and fats (Vlyssides *et al.*, 2012). The dairy industries are one of the most polluting industries not only because of their high volume of wastewater, but also due to its characteristics (Kushwaha *et al.*, 2011). Wastewater from such industries often cannot be treated by aerobic methods alone because of its high toxicity and chemicals as well as high Biological Oxygen Demand (BOD). The amounts of suspended solids are 2000gr/m^3, COD (Chemical Oxygen Demand) 3700gr/m^3, and BOD 2500gr/m^3 (Sabliy *et al.*, 2009). The combined method is the best for the treatment of dairy wastewater. Researchers have proposed an anaerobic-anaerobic treatment method for dairy wastewater treatment (Kushwaha *et al.*, 2011).

The average consumption of milk per capita per year in Iran is about 91kg, while the average consumption in the world is 156kg and in European countries it is 300kg. In order to increase per capita consumption of milk in the country, the volume of milk and dairy products will have to be increased and this will result in producing more wastewater. The wastewater of the dairy industries is warm and has high COD, this makes it suitable for anaerobic treatment in the first stage. Anaerobic processes produce significant amounts of methane. Also the unpleasant odor production occurs in this stage. Whey is one of the most polluting wastewater. Its biochemical constituents are rich in organic matter (Shete, and Shinkar, 2013; Rajshoori *et al.*, 2000). Worldwide cheese production generates more than 145 million tons of whey each year. Wastewater from the cheese industry has a very high level of COD about 50,000 to 80,000mg/L. (Najafpour *et al.*, 2008).

Common anaerobic methods in dairy wastewater treatment mainly include Up flow Anaerobic Baffled Reactor (UABR), Up flow Anaerobic Sludge Blanket reactor (UASB), up flow Anaerobic Fixed Biofilm Reactor (UAFBR), Anaerobic Lagoon and common aerobic methods include conventional Activated Sludge, Moving Bed Biofilm Reactor (MBBR), Sequencing Bach Reactor (SBR) based on activated sludge method. Sometimes the post-treatment phase for the dairy industry wastewater is carried out by physio-chemical methods which include coagulation and flocculation methods. These methods can be referred to as membrane processes such as Nano filtration and reverse osmosis (Kushwaha *et al.*, 2011).

Lagoon systems are suitable for wastewater treatment in food processing industries. Anaerobic lagoons in the US and Australia have high acceptability due to their ability to treat high BOD wastewater, availability of large areas for lagoon construction, and low operating costs (Johns, 1995). It should be noted that due to space constraints in Europe, demand for lagoons is low and they are more inclined to use reactor systems. In Asia, lagoons are mostly used for palm oil purification (BOD>25000mg/L) (Laginestra, 2012).

The main advantage of using lagoon systems is the ease of construction, operation, and maintenance. However, a larger land is needed to build it. It is possible to use the lagoon if the whole complex of treatment system is located out-of-town space of city. Warm weather improves bacterial growth conditions. The pH of the lagoon should be 7 to 8. At pH below 6.5, the condition becomes acidic, odor production and sludge production increases. Under normal anaerobic conditions, organic matter is converted to biogas during the process of Hydrolysis, Acidogenesis, Acetogenesis and Methanogenesis.

If there is no equilibrium between Acidogenesis and Methanogenesis phases, the odor is more likely to be produced (Zhang *et al.*, 2013).

In UASB, Fat, Oil and Grease (FOG) may accumulate. The growth of dispersed grains and the accumulation of sludge and FOG leaching from the reactor cause severe operational problems. To overcome these problems, pre-treatment methods such as fat removal by Dissolved Air Flotation (DAF) or the use of some contact reactors will be required (Rilo *et al.*, 2014). This operation needs a long launch time. The reactor requires a skilled operator and continuous monitoring operations. (Rajeshwari *et al.*, 2000).

In the UABR, the wastewater is treated by passing through a number of upward and downward chambers. In this type of reactor, the solids retention time in the reactor is longer than the hydraulic retention time. The severe effect of shocks gradually diminishes on Sequential baffles. Due to the accumulation of gas in the UABR reactor, there is no access to the reactors in case of any problems or to check overflows.

To increase the efficiency in UABR, the media is mounted in the upstream section of the reactor (UAFBR), which is used to prevent sludge escape as well as increase biological contact and subsequently increase the treatment efficiency.

Each of the anaerobic methods already mentioned above require their own equipment and has its own complications. The biogas produced by the anaerobic process includes CH_4 (70-60%), CO_2 (40- 30%), H_2S (10-2000 ppm), N_2 (less than 2%), NH_3, H_2, CO, and O_2 (Siefers, 2010). The biogas odor arises mainly from H_2S, *Volatile Organic Compounds* (*VOCs*), and NH_3. H_2S is extremely odorous and corrosive and even in very small quantities causes severe corrosion in pipes and other equipment (Krich, 2005).

The overall goal is to prevent the releasing of biogas and some odorous gases produced during the anaerobic process into the atmosphere. In the present work, a single experimental unit of an innovative gas collector, named Honeycomb Gas Collector (HGC), was designed and constructed to cover the surface of the lagoon for reducing odor, especially in windy days and preventing methane release into the atmosphere. Then, the amount of methane and hydrogen sulfide in biogas and the factors affecting biogas production were studied over three years.

Materials & Methods

A single experimental unit of HGC, was designed and constructed to cover the surface of the lagoon and lagoon inputs were recorded and samples of biogas from the lagoon were collected and analyzed during April 2016 until March 2019.

Design and construction of HGC

The following considerations were taken into account in design of HGC:

- The experimental HGC should be able to cover a sample area of the lagoon
- The HGC should be easily floated on the surface of the lagoon.
- One should be able to move HGC from one to another point of lagoon surface.
- The collected gases should be transferred into Tedlar gas sampling bag kept off the lagoon.
- The volume of collected biogas should be measured for a known period of time.

Fig. 1 shows the single experimental unit HGC. Gas collecting tank 1800mm × 850mm (diameter × height) was made from polyethylene and floated easily on the surface of the lagoon. Gas volume measuring device is shown in Fig. 2 which is connected to HCG through a piece of flexible gas hose.

Factors affecting the amount of biogas, namely, ambient temperature, amount of milk consumed, COD remove and lagoon pH were all recorded starting from spring 2016 for three consecutive years. During these years, the volume of daily collected biogas was measured and then the total amount of the gas emitted from the lagoon was estimated.

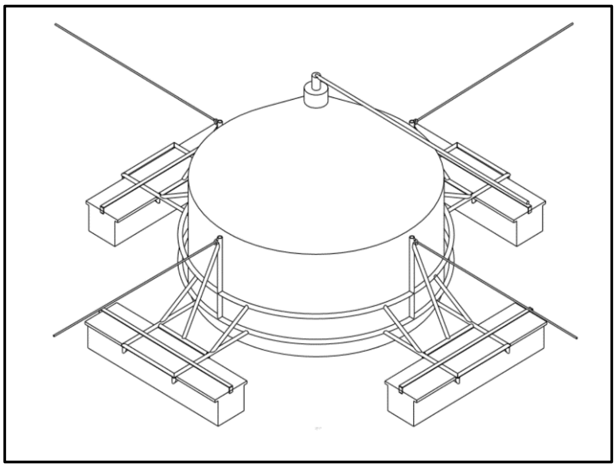

Fig. 1. The experimental HGC (left), HGC floated on the surface of the lagoon (right).

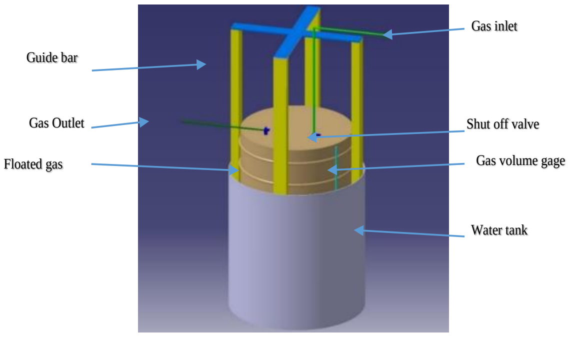

Fig. 2. Gas volume measuring device.

The lagoon was divided into 12 zones as the bacterial interactions and even the color of the lagoon is different in different parts, then data were collected from each zone separately. Methane content and carbon dioxide content in the gas sample were determined by EX-TEC HS 680 gas sampling device. The ambient temperature was recorded by AZ77535 thermometer. Methane and hydrogen sulfide in the environment were measured by MSA device. pH measurement was made using HACH sension1, and HACH COD REACTOR was used to measure the COD. Then the relationship between the amount of the emitted biogas volume from the lagoon as a dependent variable and ambient temperature, milk consumed in the production line, COD remove, and lagoon pH as the independent variables was mathematically modeled.

Results

Biogas volume and ambient temperature

As shown in table 1, there is a significant difference at the 1% level in terms of biogas production between different months and years. The results of the analysis of variance of the effect of ambient temperature on the amount of gas emitted during the years of 2016-2018 and in different months can be seen in table1 (right). There was no significant difference between years but there is a significant difference between the months. The volume of extracted biogas has declined since 2016 (Fig. 3). The average amounts of biogas collected by HCG were 60.38, 49.21, and 39.13 liters, in 2016, 2017, and 2018 respectively. According to Duncan's method at probability level of 5% as shown in Fig. 3, the highest volume of biogas collected by HCG was in August and September and the lowest amount of biogas was obtained in December, January and February. The ambient temperature is highest in August. During June until the end of October the volume of extracted biogas is maximum. The lowest ambient temperature occurs in December, January and February.

Milk consumption

To find the relationship between milk consumption and biogas production, analysis of variance was performed for each month during three years (Table 2).

Comparison of annual milk consumption with Duncan test at 5% was not significant between 2017 and 2018 but there was a significant difference between them with 2016. Milk consumption increased in 2017 and 2018 compared to 2016. Milk monthly consumed in production line was highest in June and lowest in October (Fig. 4).

Table 1. Analysis of variance of biogas (left) and ambient temperature (right).

Analysis of variance of biogas	source	Squares	df	Mean squares	F	Analysis of variance ambient temperature	source	squares	df	Mean squares	F	squares
	year	2711.701	2	1355.850**	49.578		year	8.273	2	4.137ns	1.434	8.273
	month	1592.385	11	144.762**	5.293		month	2359.249	11	214.477**	74.353	2359.249
	error	601.655	22	27.348			error	63.461	22	2.885		63.461
	total	93395.133	36				total	19693.439	36			19693.439

**, * and ns are significant at 1%, significant at 5% and non-significant respectively.

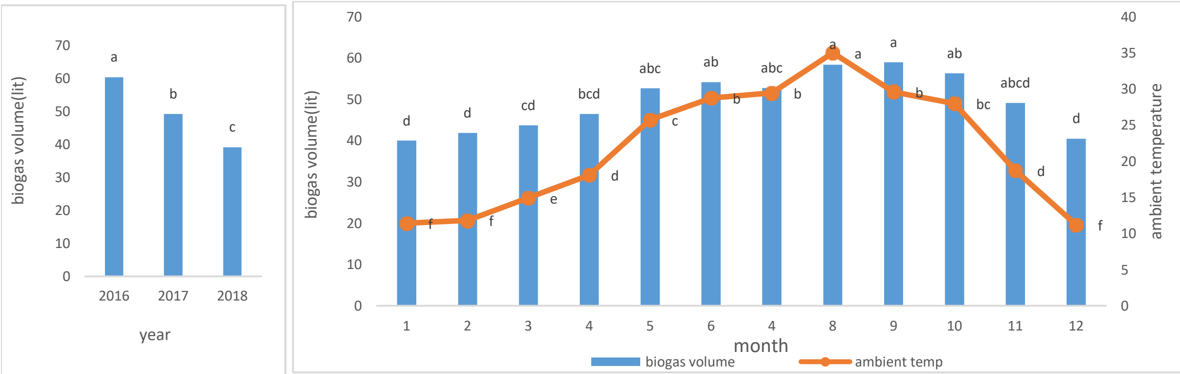

Fig. 3. Comparison of annual biogas (left side) and monthly (right side) mean biogas and ambient temperature with Duncan's method.

Table 2. Analysis of variance of milk consumption in months and years.

	Squares	df	Mean squares	F
Year	93856245471465.140	2	46928122735732.570**	105.123
Month	20656580672768.670	11	1877870970251.698**	4.207
Error	9821028232446.168	22	446410374202.099	
Total	4944914298536680.000	36		

**, * and ns are significant at 1%, significant at 5% and non-significant respectively

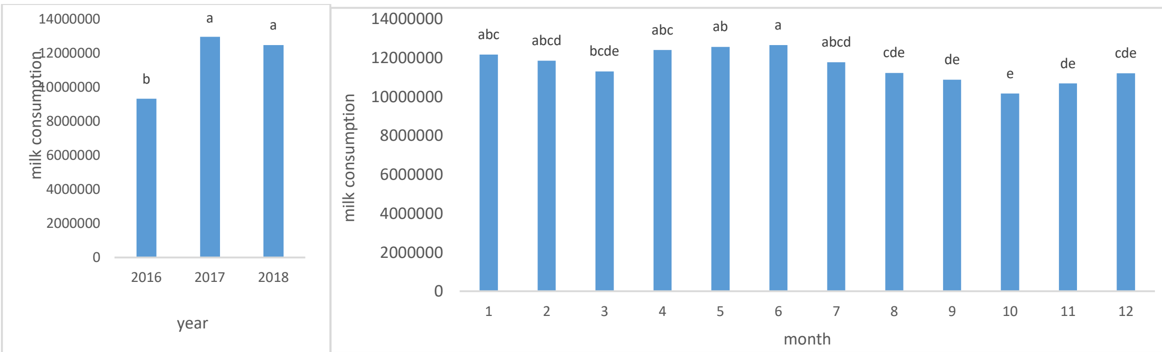

Fig. 4. Comparison of the mean milk consumption annually (left side) and monthly (right side).

COD remove and pH lagoon

Analysis of variance showed that there was no significant difference between COD remove of different years and months (Table 3). Therefore, the COD reductions is almost constant regardless of different months and years. According to results from analysis of variance in table 3, there was a significant difference between pH of the lagoon at different years and months.

The pH of the lagoon with Duncan test at 5% is at the same level in year 2017 and 2018 and is different from year 2016. The pH of the lagoon varies from 7.3 to 7.6. and there is little difference between the different months. In May it has the highest and in February it has the lowest value (Fig. 5).

Table 3. Analysis of variance for COD remove (left) and lagoon pH (right).

	source	squares	df	Mean squares	F		source	squares	df	Mean squares	F
Analysis of variance for COD remove	year	449769.500	2	224884,750^{ns}	2,344	Analysis of variance related to lagoon pH	year	0.096	2	0.048**	9.389
	month	2172392.083	11	197490,189^{ns}	2,059		month	0.226	11	0.021**	4.026
	error	2110531.167	22	95933,235			error	0.112	22	/0.005	
	total	877314753,000	36				total	1983.207	36		

**, * and ns are significant at 1%, significant at 5% and non-significant respectively

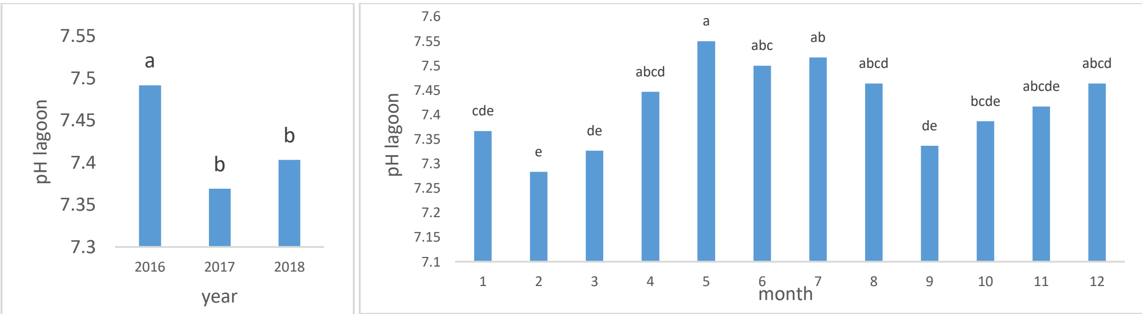

Fig. 5. Comparison of mean pH in different years (left side) and months (right side).

Results of environmental parameters

The average amount of hydrogen sulfide in the environment around the lagoon in 2016 was 2 ppm in spring, 2 ppm in summer, 1 ppm in autumn and 1 ppm in winter**.** The average amount of methane in around lagoon area was 6% in spring, 7% in summer, 6% in autumn and 5% in winter in this year.

The average amount of hydrogen sulfide in the environment around the lagoon in 2017 was 2 ppm in spring, 2.5 ppm in summer, 2 ppm in autumn and 2 ppm in winter. The average amount of methane in around lagoon area was 4% in spring, 4% in summer, 5% in autumn, and 5% in winter in this year.

The average amount of hydrogen sulfide in the environment around the lagoon in 2018 was 1ppm in spring, 0 ppm in summer, 0 ppm in autumn and 0 ppm in winter. The average amount of methane in around lagoon area was 5% in spring, 4% in summer, 4% in autumn, and 3% in winter in this year.

Discussion

mathematical model for biogas production

In order to make better decisions in controlling the lagoon in terms of more gas extraction, it is better to identify the variables involved and determine their order of importance. For this purpose, standard and non-standard coefficients of influential factors in biogas production (ambient temperature, COD remove, lagoon pH and amount of milk consumed) can be used as shown in Table 4. The coefficient R was 0.794 and R^2 was 0.63.

Table 4. Factors affecting biogas production.

	Unstandardized Coefficients		Standardized Coefficients
	B	Std. Error	Beta
(Constant)	-67.382	100.762	
Temperature	0.498	0.187	0.351
COD remove	0.009	0.004	0.289
Milk Consumption	$-3.603e^{-6}$	0.000	-0.574
pH Lagoon	13.737	12.841	0.129

According to standard coefficients, the effect of temperature is the most and the pH of lagoon has the least effect. Multivariate regression relation is as follows.

Y = Temperature * 0.498 + COD remove * 0.009- Milk* $-3.603e^{-6}$ + pH Lagoon* 13.737 * - 67.38 (1).

The milk Consumption coefficient is negative and its value is very low. Ever since phase 2 of the plant has been launched in 2017, the volume of milk entering the plant has increased significantly, but the volume of effluent entering the sewage has not changed.

Linear regression between temperature and volume of biogas

As noted above temperature has the highest effect on the volume of biogas produced from the surface of the lagoon; representing a linear relationship between temperature and biogas volume ($R^2 = 0.94$):

$y = 0.7964x + 32.14$ (2)

Biogas results of the whole lagoon

The amount of extracted biogas from the surface of the lagoon varied between 0.009 m^3_{CH4}/m^2 lagoon surface. day to 0.017 m^3_{CH4}/m^2 lagoon surface. day. In a study on anaerobic lagoon by Seifley and Westerman (1988), the amount of methane obtained was 0.02 to 0.5 $m^3_{CH4}/m^2{}_{lagoon\ surface}$. day. It was reported by Sharp and Harper's (1999), the amount of gas extracted from surface of the lagoon with cover in summer was 60.3kg $_{CH4}$/ha.day equivalent to 0/005 $m^3_{CH4}/m^2_{lagoon\ surface}$.day and in winter 44.7kg$_{CH4}$/ha. day equivalent to 0.009 $m^3_{CH4}/m^2_{lagoon\ surface}$.day. Considering that the lagoon in this study was not covered, therefore, it is obvious that there is no complete anaerobic condition in this case. In covered lagoon, the anaerobic condition becomes prevalent and biogas is produced more.

The average percentage of methane in the gas samples collected was 0.698 in 2016, 0.691 in 2017 and 0.659 in 2018. In the samples taken, average daily methane from the entire lagoon in 2016 was 41.8 m^3, in 2017 this value was 32.78 m^3 and in 2018 this value was 26.25 m^3. The volume of gas from the entire lagoon was declined by the end of the year 2018; the reason being that in the middle of the year 2017, the "dry powdered cheese from whey" plan was launched (Phase 2), and large quantities of whey was prevented from entering the lagoon.

Honeycomb Gas Collector Structure Design (HGC), Floated on the surface of the lagoon

Over three years, a single cell pilot design of HGC was used for collecting emitted biogas from the lagoon surface and transferring it to the gas volume measuring tank successfully. Therefore, a Honeycomb Gas Collector Structure (HGCS), floated on the surface of the lagoon can be suggested as an appropriate design for covering the surface of the lagoon (Fig. 6). This design can be maintenance free and if one unit fails for any reason, it can be easily shutdown for appropriate action. Service and maintenance costs can be very low compared to anaerobic reactors**.** The outlets of the HGC cells can be routed to a main gas transferring line. In this design, 144 cells (12 by 12) are needed to cover the entire surface of the lagoon. The biogas collected from the surface of the lagoon can be used either for direct combustion or for use in heating the incoming sewage or other purposes. The following table (5) compares the proposed HGC with the UASB, UABR and UAFBR reactors.

Table 5. Comparison of HGC with Other Anaerobic Reactors.

Anaerobic system	material	The cost of foundation	Fat removal	Startup time	Cost of construction	careful monitoring	Cost of service and maintenance	Total cost
UASB	Stainless steel	medium	Needed	Several months	Very high	Highly Needed	high	Very high
UABR	Polyethylene	high	Needed	2-1 months	medium	Needed	high	medium
UAFBR	Stainless steel	high	Needed	1-2 months	high	Needed	high	high
HGC	Polyethylene	Non	Non	-	low	Little need	low	low

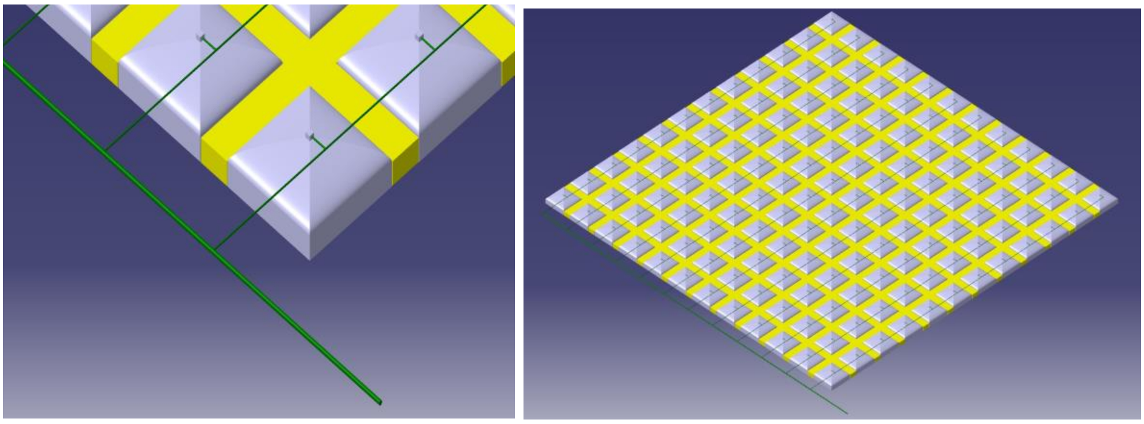

Fig. 6. Honeycomb Gas Collector Structure Design (HGC).

Methane's potential in global warming is 21 times higher than carbon dioxide and can contribute to climate change (Stenglin2011). It is better to burn it before it enters the atmosphere even if it is not intended to be recycled.

Conclusion

Considering the fact that Peghah Dairy Plant in Tabriz, Iran, near Shahid Madani International Airport is located within the city, a system was proposed to cover the lagoon and eliminate the odor and preventing methane entering the atmosphere. The following criteria was considered in proposed design:

- This system should not interfere with the daily activities of the factory.
- Its technology should be appropriate in the region.
- Its released gases can be mainly controlled.
- should have high security.
- The cost of building and operating it could be low as possible.
- The set up stage should not take so long.
- Low cost management and maintenance.
- The system should be simple and efficient.
- Do not require high expertise for maintaining

According to the three-year monitoring in the lagoon during 2016-2018, the amount of methane emitted from the entire lagoon varied from 22m^3/day to 45m^3/day. Pegah Diary plant consumes 138860.8 tons of milk annually and in the anaerobic part of the wastewater, 12184.624 cubic meters of methane is produced per year. If this amount of methane is trapped, it will be very useful in helping to control greenhouse gas emissions.

Among the factors affecting the production of biogas from the lagoon surface, the effect of temperature was the most. There is a strong relationship with a coefficient of explanation of 0.94 between the monthly temperature and the volume of biogas produced.

Milk consumption increased in 2017 and 2018 due to the Launching the production line of dry milk powder and cheese powder. In this regard The hydrogen sulfide content in the surrounding environment was decreased. Because whey was no longer dumped into the sewage. The COD remove in the lagoon has been uniform over three years and in different months. This is probably due to the high volume of the lagoon and its stability in this case. The total cost of the proposed design is considerably lower than the other methods. It does not require high expertise to monitor and service and maintenance costs are much lower.

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