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CONTROL OF TEMPERATURE IN BIO-DIGESTER USING PHASE CHANGE MATERIAL (PCM)

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ABSTRACT

A comprehensive review of control and maintenance of temperature in bio digestion process is presented in this paper. Maintaining a temp level of about 40 to 60 ^{0}C, the optimum temperature for thermophilic bacteria's growth and activity, is crucial for obtaining the best results with respect to biogas production in bio-digesters. This study investigates the utilization of phase change material (PCM) to control and maintain the optimum temperature of 45 ^{0}C around it. For purposes of this study, a dome type digester is chosen as experimental set up, which is then to be incorporated with PCM around the walls. In this review, the rate of gas production is found to be increased and the retention time is decreased with the elimination of insulations. The main objective of controlling the process temperature to obtain a high yield of biogas is highlighted in this paper.

Key words: *phase change material, anaerobic digestion, temperature, insulation, microbial growth*

INTRODUCTION

Digestion is a biological process that occurs in the absence of oxygen and in the presence of anaerobic organisms at ambient pressures and temperatures of 35-70^{0}C. The container in which this digestion takes place is known as the digester. Anaerobic digestion involves the microbial digestion of biomass. The process takes place at low temperature up to 65^{0}C, and requires a moisture content of at least 80 per cent. It generates gas consisting mostly of CO_2 and methane (CH4) with minimum impurities such as hydrogen sulphide. The digestion process, however, takes much longer time. The process can be speeded up by using a thermally insulated, air-tight tank with a stirrer unit and heating system. At optimum temperature (35^{0}C) complete decomposition of animal or human faces takes around 10 days. Methane bacteria work best at a temperature of between 35 -38^{0}C. The fall in gas production starts at 20^{0}C and stops at a temperature of 10^{0}C. At one experiment 2.25cu-m of gas was produced from 4.25m^3 of cattle dung every day when the digester temperature was 25^{0}C. When the temperature raised to 28.3^{0}C, the gas production is increased by 50% to 3.75cu-m/day. There are two significant temperature zones in anaerobic digestion. These have been studied in some detail for digestion of sewage sludges for 90% digestion. The time required for 90% digestion at various temperatures, and the two temperature zones. It has been established that two types of microorganisms, mesophilic and thermophilic are responsible for digestion at the two temperature ranges. The optimum mesophilic temperature lies at about 35^0C, while the optimum thermophilic temperature is around 55^0C. The thermophilic range has not been put to use because of the problems associated with heating the tanks to such high temperatures. Heating of tanks designed mainly for collection of biogas may not be practicable, but it must be understood that temperature is a very important factor since it affects the bacterial activity directly. Any gross deviation from a normal operating temperature may result in the unsatisfactory performance of the digester.

The production of biogas is a temperature dependent process. Controlled biogas processes are required for optimal production and for understanding the mechanisms involved in such process. Heating the bioreactor to a temperature of about 40 to 60^0C is important for thermophilic bacteria's growth and activity [1], in order to obtain optimum biogas production. Energy is required for this process, and researchers must find ways to supply the necessary energy requirements at minimum cost. The other problem encountered for such a bio reaction is the ability to control the temperature and to minimize its range of variation so that the activity of the bacteria will not significantly be affected and its action will not be inhibited by large temperature variation. This study involves utilization of phase change material (PCM) in order to achieve this task by incorporating it around the walls of a bioreactor. Though there are various possible methods for heating and maintaining an optimum temperature in digesters like solar heaters [2], electrical heaters and insulating materials, PCM will be the cheap and best in this type of thermal energy storage systems. Various types of PCMs and their properties are discussed in this paper. Moreover, the system is studied for economic viability of the materials and for its technically feasible application.

NEED FOR CONTROL OF TEMPERATURE IN DIGESTION

Temperature profile plays a major role in bacterial growth rate which in turns biogas production. Controlled biogas processes are required for optimal production and for understanding the mechanisms involved in such processes. Maintaining a temperature level of about 40 to 60^0c, the optimum temperature for thermophilic bacteria's growth and activity, is crucial for obtaining the best results with respect to biogas production in bio-digesters. In addition to this, heating requirements of bioreactor are directly linked to increased production as well as decreased retention time. Anaerobic digestion under thermophilic condition results in higher metabolic rates and greater destruction of pathogens and weed seeds.

The temperature has a significant influence on the efficiency of biogas production, energy input to output ratio, retention time and total cost of the construction investment [3]. Raising the fermentation temperature can improve the efficiency of biogas production and reduce the volume of digester and consequently reduce the investment cost for digester construction.

Chengliu and Haiyin found that the highest Gas Production Rate (GPR) at a temperature of 55^0C was 1.6 and 1.3 times higher than that at 35 and 45^0C [4]. Temperature had a more remarkable effect on the richness and diversity of microbial population than the Organic Loading Rate (OLR). Thermophilic bacteria were more sensitive to the variation of environment than those at 35 and 45^0C, which, as a result, caused a more rapid decline in CH4 yield and the Volatile Solid (VS) removal efficiency. The authors also presented that best process stability found in mesophilic system with the most richness of bacteria. Highest productivity and best load bearing capacity were observed in thermophilic system.

Garba [5] investigated the effect of temperature and retention period on biogas production from lignocellulosic material. He has been observed that optimum yield of biogas obtained at thermophilic range of 50 to 60^0C. In this range, an increase in the metabolic rate is observed, resulting in a higher rate of gas production. This implies that shorter retention times are possible. Methane producing bacteria are very sensitive to sudden thermal changes. Therefore, any drastic change in temperature should be carefully avoided. The digestion process must be designed to operate at constant temperature conditions.

James and Stephen [6] studied the effects of storage time and temperature on biogas production from dairy cow slurry. According to his study, storage of slurry for 26 weeks at 9^0C had no significant impact on the subsequent production of biogas. Storage of slurry at20^0C for 8 weeks had little effect on subsequent biogas production. However, after 8 weeks of storage at 20^0C, there was a steep linear decrease in subsequent biogas production. After 26 weeks of storage at 20^0C, the subsequent biogas production was approximately 32% of that from slurry stored at 9^0C. Storage time and temperature had no effect on the total nitrogen concentrations but resulted in small increase in ammonia nitrogen concentrations.

Upama and Sanjay [7] designed and constructed a new type of temperature controlled digester by using a composite insulation and solar energy. In their study, the temperature is controlled by providing an insulation made up of glass wool, saw dust and plaster of Paris. A solar energy device was used in the biogas digester for control of the temperature in the range of 25 to 37^0C. The initial temperature was constant up to nearly 36 hours with maximum production of gas. Thereafter, the variation in temperature took place. A 30^0C reading was observed up to 9 hours without affecting the gas production. Production of biogas slows down considerably below 18^0C and ceases completely at 9^0C. The initial temperature was controlled either by use of hot water or by use of calcium oxide, but excess calcium oxide should be avoided, as it increases the pH of the solvent as well as producing Calcium ions which are toxic against microbial growth.

Utilization of solar energy as renewable source in this purpose, however, it complicates the design on digester and increases the cost of construction and maintenance. Electrical and diesel heating can also be avoided to minimize the cost of bioenergy production. Thus PCM will be the considered as a best solution for the problem stated above.

PCM A THERMAL ENERGY STORAGE MEDIUM

It is well known that thermal energy can be stored in PCMs as a heat of vaporisation (liquid-vapour transition) or heat of fusion (solid-liquid transition). Lower ambient temperatures and higher airflow rates are advantageous to complete the solidification [8].

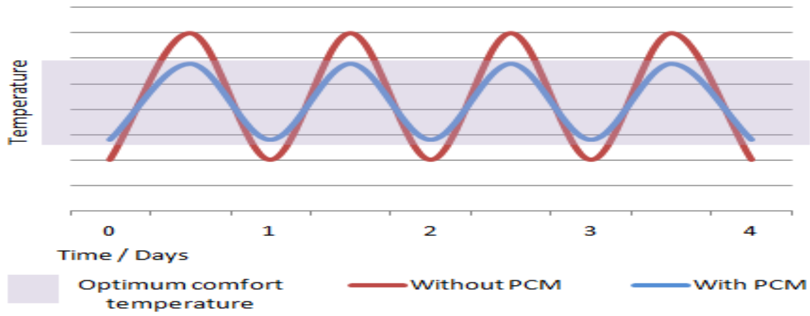

Figure 1 Performance of PCM

CLASSIFICATION OF PCM

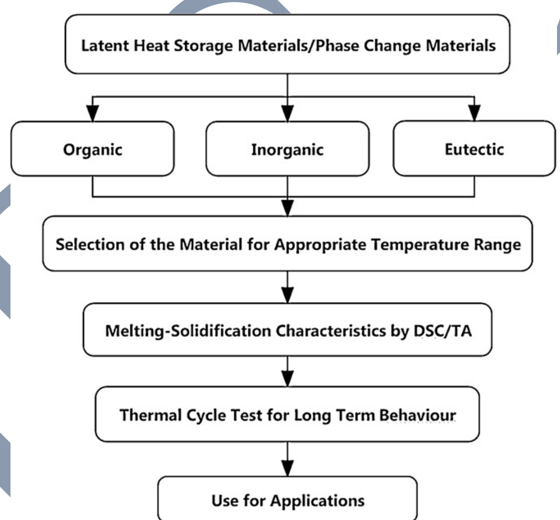

Figure 2 Flow chart for classification of PCM

When used in construction materials, phase-variable thermal properties of the materials must be accurately known. To determine the properties of the PCM as a function of temperature, the equipment such as heat meter, electronic sensors and thermocouples can be used [9]. Among all possible thermal analysis methods to determine PCM thermo physical properties such as fusion enthalpy, specific heat and thermal conductivity, the t-history method is known to be more suitable[10]. Investigation of Rezaei and Anisur [11] is also helpful in choosing the best PCM regarding the lowest total life cycle cost. They have calculated life cycle cost for different melting temperatures of PCMs and energy efficiency of the system is also computed.

IMPORTANT PROPERTIES FOR THE SELECTION OF PCM

Thermo physical properties

i. Melting temperature in the desired operating temperature range.
ii. High latent heat of fusion per unit volume so that the required volume of the container to store a given amount of energy is less.
iii. High specific heat to provide additional significant sensible heat storage.
iv. High thermal conductivity of both solid and liquid phases to assist the charging and discharging energy of the storage system.
v. Small volume change on phase transformation and small vapour pressure at operating temperature to reduce the containment problem.
vi. Congruent melting of the phase change material for a constant storage capacity of the material with each freezing/melting cycle.

Kinetic properties

i. High nucleation rate to avoid super cooling of the liquid phase.
ii. High rate of crystal growth, so that the system can meet demand of heat recovery from the storage system.

Chemical properties

i. Complete reversible freeze/melt cycle.
ii. No degradation after a large number of freeze/melt cycle.
iii. No corrosiveness to the construction materials.
iv. Non-toxic, non-flammable and non-explosive material for safety.

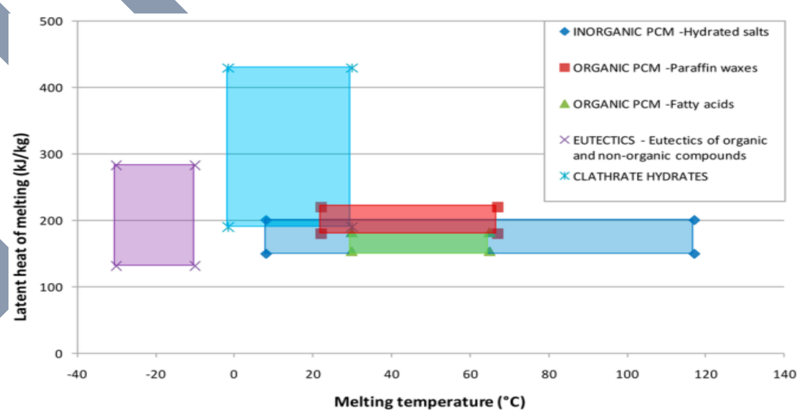

Figure 3 Classification based on Melting point and Latent heat of melting

More than 300 PCM with phase change temperatures between -50 to 150^{0}C considering commercial and non-commercial PCM were studied by their properties. CES selector software database developed by Granta [12] is used to select the most appropriate material for the determined application, taking into account the constraints. Through the PCM database generated by Camila and Elena [13], the most suitable PCM depending on the TES application is decided. Finally, by considering all these parameters the most efficient and economical PCM in chosen.

- Paraffin C23
    i. Density = 900kg/m³
    ii. Thermal conductivity = 0.24W/mK
    iii. Melting point = 47^{0}C
    iv. Latent heat of fusion =230KJ/kg
    v. Specific heat = 2890J/kgK
    vi. Energy density = 170MJ/m³

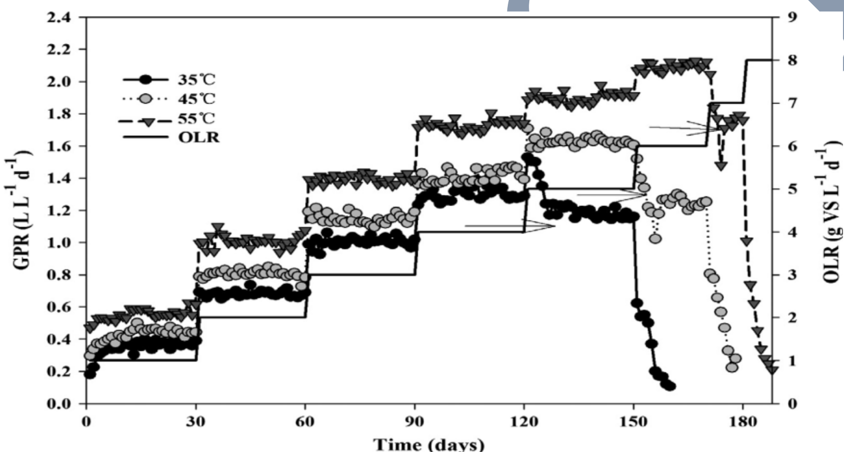

Figure 4 Variation of GPR according to different temperatures and OLRs.

CONCLUSION AND FUTURE WORK

As reported in literatures, it is observed that the temperature control in biogas production is an essential as well as a challenging process. This review paper suggests that Phase Change Materials (PCMs) can be used to control the temperature of a digester in an efficient and economical way. When compared to other thermal energy storage mediums, PCM is considered as the cheap and best solution for this case. Further work of design and fabrication should be done and also the experimental analysis and improved output of performance should be evaluated in a good manner.

REFERENCES

[1] T.M.Alkhamis, R.El-Khazali, M.M.Kablan and M.A.Alhusein, "Heating of a biogas reactor using a solar energy system with temperature control unit," Faculty of Engineering, Jordan, PII: S0038-092X (00)00068-2, January 2000.

[2] K.Vinoth Kumar and R.Kasturi Bai, "Solar greenhouse assisted biogas plant in hilly region – A field study," Department of Bio-Energy, Madurai Kamaraj University, India, April 2008.

[3] Liangwei Deng, Hongnan Yang, Gangjin Liu, Dan Zheng, Ziai Chen, Yi Liu, Xiaodong Pu, Li Song, Zhiyong Wang and Yunhui Lei, "Kinetics of temperature effects and its significance to the heating strategy for anaerobic digestion of swine wastewater," Biogas Institute of Ministry of Agriculture, Chengdu, PR China, 2014.

[4] Chengliu Gou, Zhaohui Yang, Jing Huang, Huiling Wang, Haiyin Xu and Like Wang, "Effects of temperature and organic loading rate on the performance and microbial community of anaerobic co-digestion of waste activated sludge and food waste," Hunan University, Changsha 410082, PR China, 2014.

[5] B.Garba, "Effect of temperature and retention period on biogas production from lignocellulosic material," Sokoto Energy Research Centre, P.M.B. 2346, Sokoto Nigeria, 1996.

[6] James D. Browne, Stephen R. Gilkinson and John P. Frost, "The effects of storage time and temperature on biogas production from dairy cow slurry," Agri-Food & Biosciences Institute, Northern Ireland, UK, 2015.

[7] Upama Misra, Sanjay Singh, Amarika Singh and G.N.Pandey, "A new temperature controlled digester for anaerobic digestion for biogas production," Energy convers. Mgmt. Vol.33, No.11, pp.983-986, 1992.

[8] E.Osterman, V.V.Tyagi, V.Butala, N.A.Rahim and U.Stritih, "Review of PCM based cooling technologies for buildings," University of Malaya, 50603 Kuala Lumpur, Malaysia, 2012.

[9] Anna Zastawna-Rumin and Katarzyna Nowak, "Experimental thermal performance analysis of building components containing phase change material (PCM)," Cracow University of Technology, Krakow, Poland, 2015.

[10] Aran Sole, Laia Miro, Camila Barreneche, Ingrid Martorell and Luisa F. Cabeza, "Review of the T-history method to determine thermophysical properties of phase change materials (PCM)," University of Barcelona, Barcelona, Spain, 2013.

[11] M.Rezaei, M.R.Anisur, M.H.Mahfuz, M.A.Kibria, R.Saidur and I.H.S.C.Metselaar, "Performance and cost analysis of phase change materials with different melting temperatures in heating systems," University of Malaya, 50603, 59990 Kuala Lumpur, Malaysia, 2013.

[12] Granta, C. University, CES Selector 2012 Software, (2012).

[13] Camila Barreneche, M.Elena Navarro, Luisa F. Cabeza and A.Ines Fernandez, "New database to select phase change materials: Chemical nature, properties and applications," University of Lleida, Spain, 2015.

[14] Upama Misra, Sanjay Singh, Amarika Singh and G.N.Pandey, "A new temperature controlled digester for anaerobic digestion for biogas production," Energy convers. Mgmt. Vol.33, No.11, pp.983-986, 1992.

[15] Anna Zastawna-Rumin and Katarzyna Nowak, "Experimental thermal performance analysis of building components containing phase change material (PCM)," Cracow University of Technology, Krakow, Poland, 2015. doi: 10.1016/j,proeng.2015.06.167