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Energy Recovery from Sugarcane Press Mud

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ABSTRACT

This study deals with mechanism to harness energy from solid waste generated from chemical process industries. As an illustration, the press mud from sugar industry was utilized to recover energy through native microbial degradation process. Aerated and forced aerated press mud was investigated and the heat evolved was studied systematically and conclusions arrived thereof. Further, the process also resulted in the production of manure, rich in humus content.

Key words: Sugarcane press mud, compost heat recovery, compost heat extractor

INTRODUCTION

Solid waste is one of the deleterious by-products of the Industrial and Agricultural revolutions. According to Batstone *et al.* (1989), a waste is a movable object which has no direct use and is discarded permanently. Solid waste irrespective of its origin becomes a resource when a new application is identified.

Most of the organic wastes are acted upon by micro-organisms and liberate heat turning into simpler compost-products. 20-30% of volatile solids are converted to CO_2 and water. A study by Peavy *et al.* (1985) indicated that organic materials other than plastics, rubber and leather could be subjected to bacterial decomposition to produce compost or humus.

Typically, the sugarcane is crushed in the mill to obtain the juice. The juice is further heated and neutralized by adding lime. The residue formed is separated by filtration and is known as Press mud. In this study, the press mud was allowed to undergo composting with the local microbes present.

Any biodegradable material is decomposed naturally by mesophilic microorganisms which initially utilize the most readily degradable carbohydrates and proteins. When such a material is gathered up into heaps, the insulating effect leads to a conservation of heat and a rise in temperature. The process may be divided into four stages: mesophilic, thermophilic, cooling and maturation or curing. At the start of the process the mass is at ambient temperature and is usually slightly acidic. As the indigenous mesophilic organisms multiply, the temperature rises rapidly. Among the products of this initial stage of degradation are simple organic acids produced by acidogenic bacteria and these cause a drop in pH. At temperatures above 40°C the activity of the mesophiles is reduced and degradation is taken over by the thermophilic fungi. The pH turns alkaline and ammonia may be liberated if excess readily available nitrogen is present. At 60°C the thermophilic fungi die off and the reaction is sustained by the spore forming bacteria and the actinomycetes. At temperatures of over 60°C waxes, proteins and hemicelluloses are readily degraded, although cellulose and lignin fractions are scarcely attacked. As the rapidly degradable material is depleted, the reaction rate slows down, until eventually the rate of heat generation becomes less than the rate of heat loss from the surface of the heap and the mass starts to cool down. The final stage, maturation or curing, normally requires a period of 1-2 months. This takes place at ambient temperature with mesophilic organisms predominating and macro fauna appearing. Heat evolution and weight loss are small. During this period, complex secondary reactions of condensation and polymerization are taking place which give rise to the final end-product, humus and more particularly, the stable and complex humic acids.

MATERIALS AND METHODS

Naturally aerated press mud bed construction: A cylindrical mild steel tank of 0.3 m diameter, 0.9 m height was fabricated with perforations in the vertical direction at a space of 0.1 m (Fig. 1). The perforations acted as thermometer ports. Four perforations were equally spaced along the periphery at every level. The bottom plate of the tank was perforated in the form of a cross; the top surface of the tank was not covered and was open to the atmosphere. The sides of the tank were insulated with 6 mm thick thermocole. The perforations of the tank helped in aeration and also served as thermometer ports for the bed.

Factory fresh press mud was packed into a bed inside the metal tank. The axial temperature distribution was determined with the thermometers in their ports. The tank loaded with the press mud was placed on a pedestal inside the laboratory such that the bottom perforations and the top bed surface were open to natural air draughts.

The composting was carried out with the native microbes in the press mud and no microbes were added. The moisture content in the bed fell in the 3 days and about 500 mL water was slowly sprinkled on the bed daily to maintain the moisture content. Greater than 65% moisture impedes

Fig. 1: Naturally aerated press mud bed

Table 1: Range of variables for naturally aerated press mud bed

Variable	Range
Press mud	36.9 kg
Particle size	2-10 mm
Initial moisture	70%
No. of thermometer ports	8
Bed moisture	60%
Temperature reading timings	8:00, 12:00, 16:00 h
No. of composting days	49 days
Bed height	0.8 m

Table 2: Range of variables for forced aerated press mud bed

Variable	Range
Press mud	36.9 kg
Particle size	2-10 mm
Initial moisture	70%
No. of thermometer ports	8
Bed moisture	60%
Temperature reading timings	8:00, 12:00, 16:00 h
No. of composting days	60 days
Bed height	0.8 m

the composting. The temperatures at all the axial locations of the bed were determined thrice everyday. The maximum and minimum temperature of the day, % humidity and the rainfall for the day were also recorded. Separate experiments were conducted with two packed beds and the temperature distribution data were obtained for both the beds regularly at various bed heights for 49 days (Table 1).

Forced aerated press mud bed: To a similar press mud bed a vertical air- sparger tube of 1 dia and 0.3 m height made of PVC was provided at the centre of each tank-bottom. A facility to force through compressed air at 2 kgf cm^{-2} through the bed is also made. A schematic arrangement of Forced aerated Press mud bed is shown (Fig. 2). The 110 mL of water was sprayed every day on the top surface of the bed and compressed air at 2 kgf cm^{-2} was forced through the bed for 10 min. The bed temperatures at the various bed-heights, ports are measured at 08:00, 12:00 and 16:00 h every day (Table 2).

Compost heat extractor: A Copper plate of 1'×1'square was suitably welded to a 0.01 m dia. heat-pipe made of copper. Water was used as working fluid inside the heat pipe. The welded portion of the heat pipe forms the evaporation region and the other end-region of the heat pipe forms the heat sink region. An outer jacket was provided in the heat sink region of the heat pipe to transfer heat to the coolant. Water at room conditions was used as coolant. The schematic diagram of the press mud heat extractor is shown in Fig. 3 and the experimental facility is shown in Fig. 4.

Factory fresh press-mud was packed on either side of the copper plate. The press mud bed had the shape of a cuboid extending to a thickness of 0.1 m on either side of the

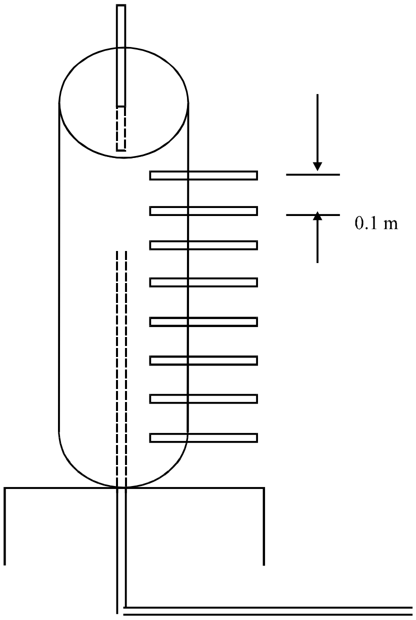

Fig. 2: Schematic of compost heat extractor arrangement

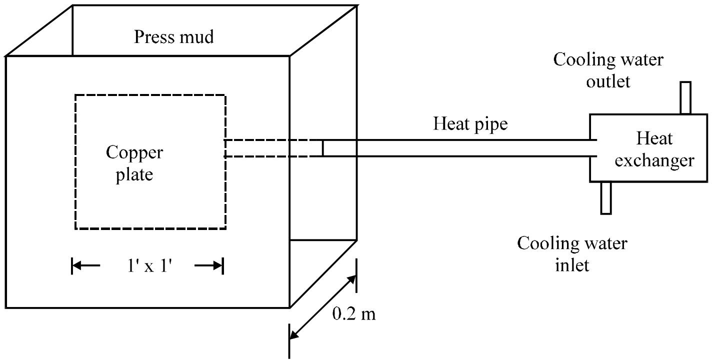

Fig. 3: Schematic of compost heat extractor arrangement

copper plate attached to the heat pipe. Steel wire mesh was used to hold the press mud-bed in position.

The natively available bacteria in the press mud were sufficient for its composting. The bed moisture was maintained by spraying 100-300 mL of water/day on the top surface of the vertical (plate-press mud) arrangement from the fourth day of composting, onwards. The press mud was in seamless contact with the copper plate surfaces. Within 24 h the temperature of the copper plate increased to become higher than that of the room maximum temperature. The heat was extracted by sending water as coolant into the heat exchanger jacket. The room temperature, heat-pipe copper plate temperature, coolant mass flow rate, coolant inlet and outlet temperatures were noted periodically and the thermal power gained by the coolant was calculated. The operating parameters are given in Table 3.

Fig. 4: Compost heat extractor arrangement

Table 3: Range of variables for the compost heat extractor

Variable	Range
Press mud	36.9 kg
Particle size	0.002-0.01 m
Initial moisture	70%
Bed moisture	60%
Temperature reading timings	Hourly between 09:00 and 17:00 h
No. of composting days	42 days
Bed thickness	0.1 m on either side of the copper plate

RESULTS AND DISCUSSION

Naturally aerated press mud bed: The temperature profiles of the press mud-bed at the morning, noon and evening at a bed height of 0.1 m during the composting days are shown in Fig. 5. The day maximum and minimum room temperatures during the composting period are also plotted in Fig. 5.

The press mud bed temperature profiles generally are higher than the day maximum temperature profile. The after noon and the evening temperature profiles are higher than the morning bed-temperature profile. The temperature profiles in the early days are higher than those of the later days. There is a steep fall in the temperatures on the day-19 due to high humidity caused by rain in the campus. Since, the microbial heat generation depends only on the nutrients, microbes, water and oxygen present inside the bed, it is fairly constant in a day.

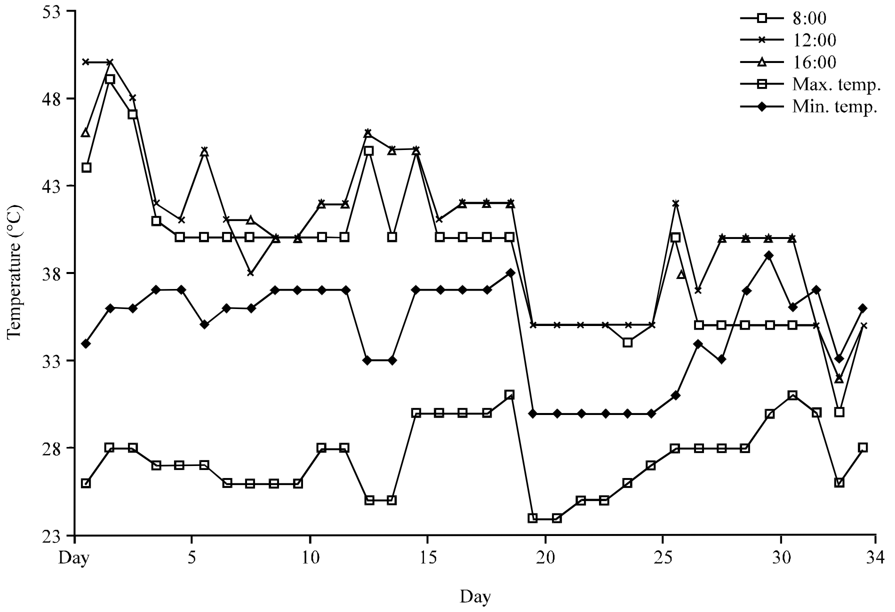

Fig. 5: Temperature distribution at the bed height of 0.1 m

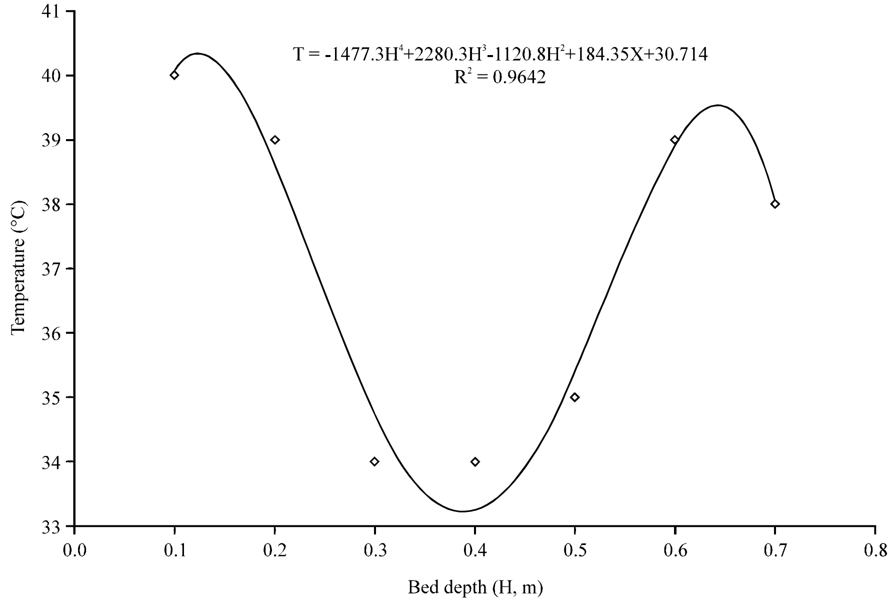

Fig. 6: Axial average temperature distribution in the bed

Similar temperature profiles were obtained at various bed heights. The temperature profiles at 0.1 m height were the highest in magnitude. Thus, the optimum bed height is 0.1 m for a naturally aerated press mud bed. Figure 6 shows the vertical axial distribution of the temperature in the press mud bed. The bed temperature increased with the degree of aeration.

Forced aerated press mud bed: Figure 7 represents the typical bed temperature profile at 0.3 m bed height. The bed temperature increases in the day with the ambient temperature. The morning

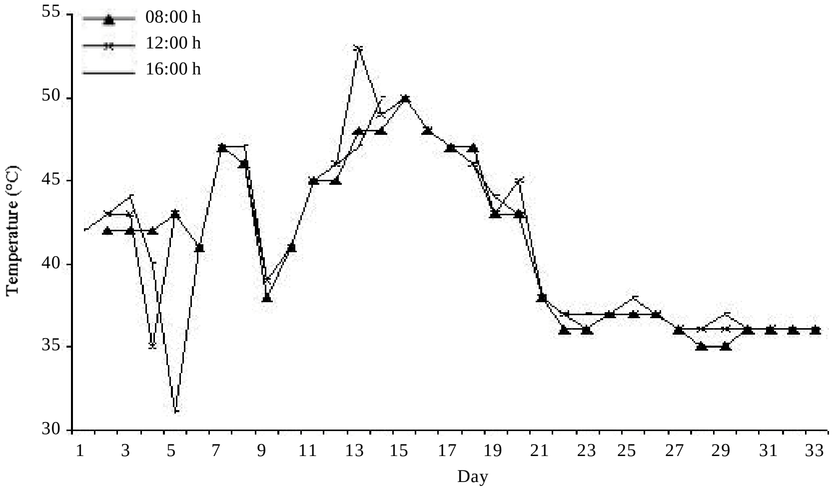

Fig. 7: Daily temperature profile

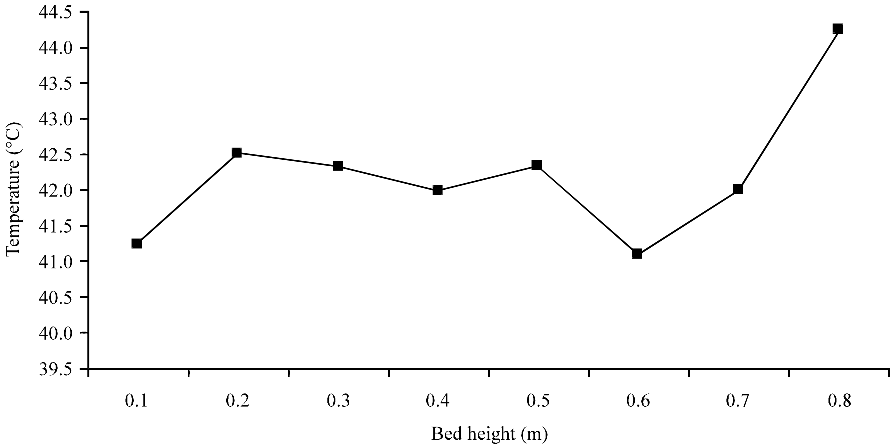

Fig. 8: Axial temperature distribution

temperatures are the minimum. The magnitudes of the temperature profiles are generally higher because, the daily air sparging increases the amount of oxygen available in the bed. Heat loss from the bed is high in the morning.

For a natural diffusion aerated bed, the temperature at the middle of the bed will be very low because of lesser diffusion of oxygen. But, here the temperatures are fairly high and are constant between 41 and 43° (Fig. 8). Air sparging helps to maintain high bed temperature throughout the bed as it contributes to microbial heating by supplying oxygen.

Air sparge cooling: Figure 9 represents the air sparge cooling-curves at 0.1, 0.2 and 0.3 m bed heights on day 12. The data were obtained during the 10 min-air sparging through the press mud bed.

The temperature-time curve for the bed at 0.3 m height starts at the highest temperature and has the steepest fall. The temperature-time curve for the bed at 0.1 m height curve starts at the lowest temperature and has a gradual decline. All the curves terminate almost at the same low temperature.

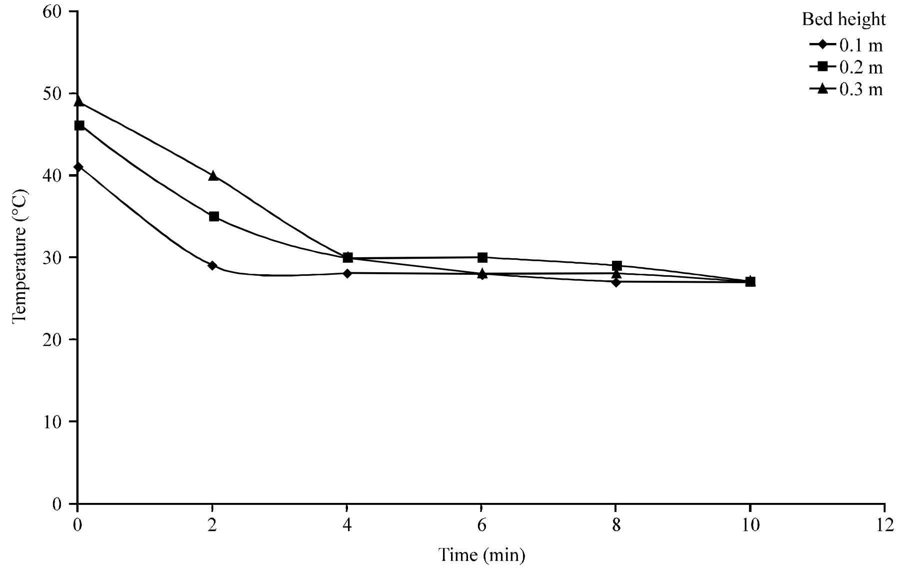

Fig. 9: Air sparge cooling curves at 0.1, 0.2 and 0.3 m bed heights-Day 12

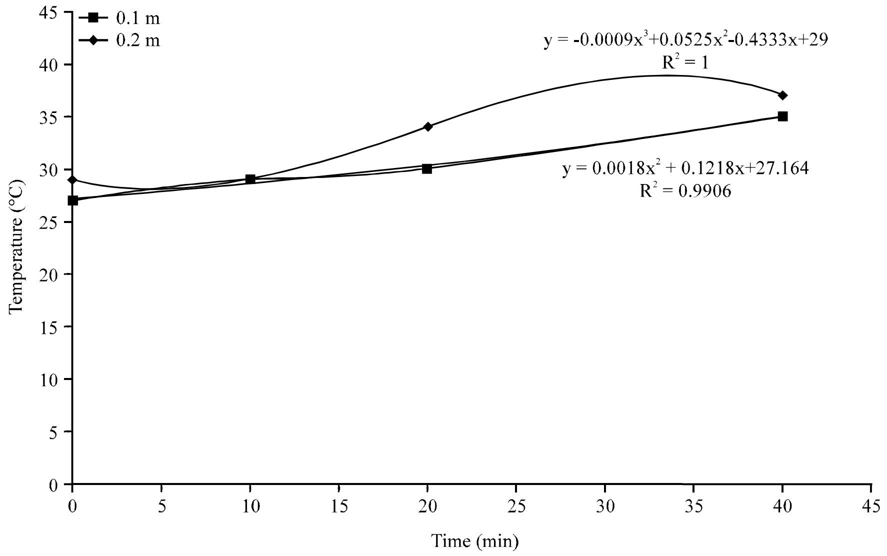

Fig. 10: Microbial heating of the bed at 0.1 and 0.2 m

When the composting has progressed for 33 days and the cooling off sets in, the temperature profiles fall in magnitude.

Microbial heating of the bed: Figure 10 represents the typical microbial heating of the press mud compost- bed at 0.1 and 0.2 m bed heights. Tchobanoglous *et al.* (2003) has indicated that Auto thermal thermophilic aerobic digestion can provide about 20,000 kJ of energy per kg of volatile solid destroyed.

For every 100 kg of cane crushed, 10 kg of sugar, 6 kg of molasses and 4 kg each of bagase and press mud are obtained (www.thehindubusinessline.com). Accordingly, the thermal potential

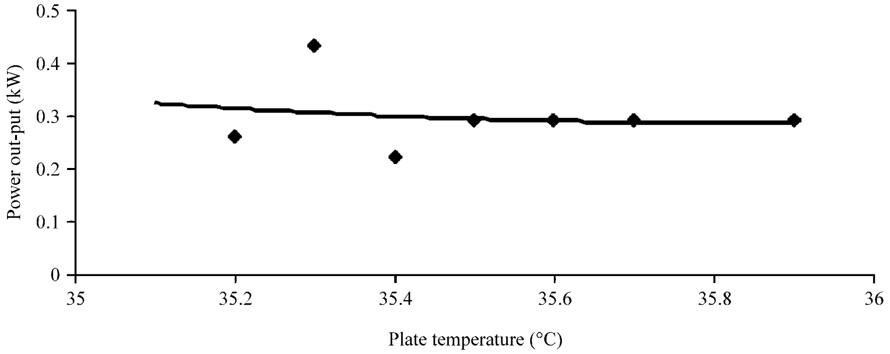

Fig. 11: Power-plate temperature variations (day 17)

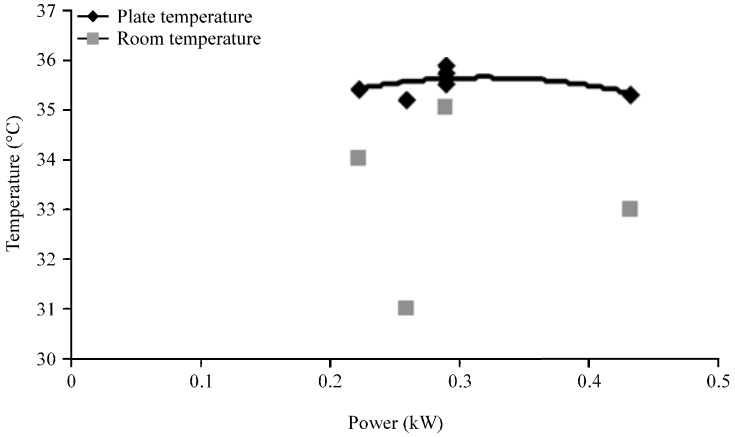

Fig. 12: Power-temperature variations (day 17)

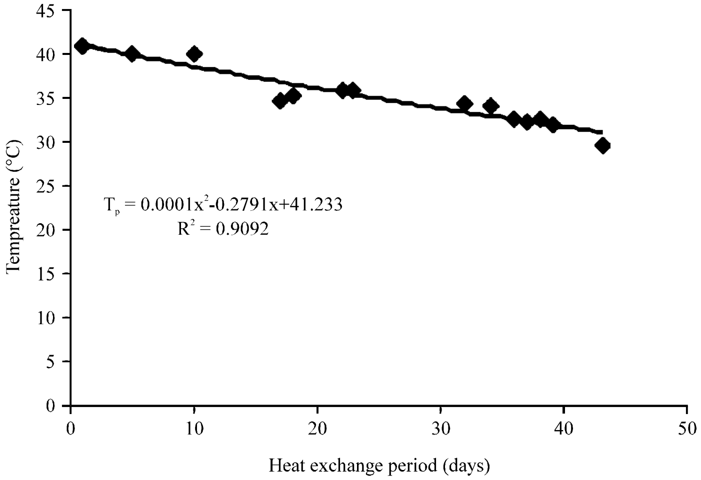

Fig. 13: Average plate temperature variations with composting days

of composting the press mud refuse from the Indian Sugar Mills (according to 2003 yield) amounts to 369.5 MW of heat generated round the clock throughout the year.

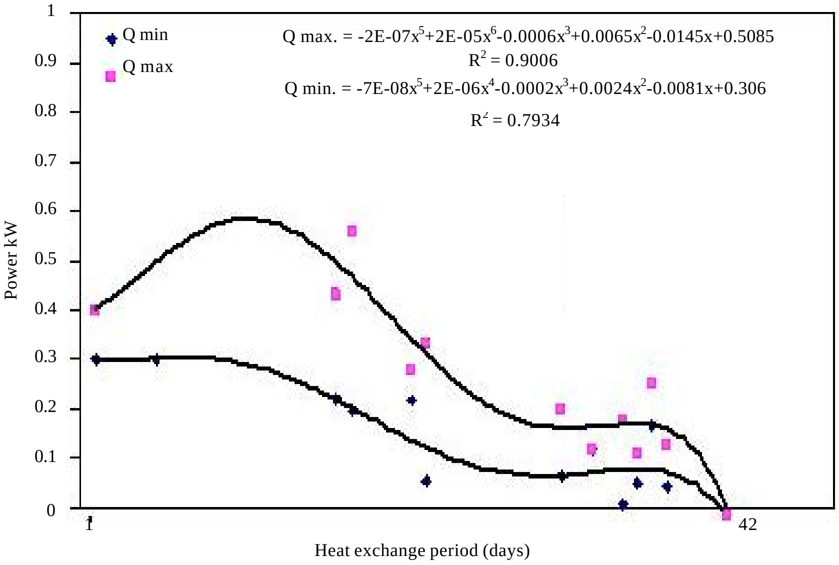

Fig. 14: Compost heat transfer rate variations with days

Compost Heat Extractor (CHE): The compost heat extractor (Gnanaraj *et al.*, 2009) plate maintained almost constant temperature in spite of continuous heat withdrawal through the heat pipe. The plate temperature of the heat extractor is higher than the room temperature. An average heat power of 0.3 kW is obtained from the compost heat extractor. The average plate temperature gradually falls with the composting days. The compost heat transfer rate varies with the plate temperature and gradually falls with the no. of composting days (Fig. 11-14).

CONCLUSION

From these experiments the energy potential of the press mud composting was manifested. No external addition of microbes was necessary to compost the bed as the press mud would contain the microbes needed.

A naturally aerated press mud bed easily and steadily maintained a temperature 5-20° higher than the room temperature under Indian conditions. The composting reactions proceeded from the outer regions of the bed, in the inward direction. The thermal conductivity of press mud was due to its moisture content. The press mud thermal conductivity was close to that of water. The air diffusion into the bed was a significant factor. The middle regions deficient of air or oxygen have a low temperature. Major portion of the heat generating reactions were over by 29 days of composting. The maximum temperature was obtained at 0.1 m bed depth for any press mud bed that is naturally aerated.

The heat transfer/production rate of the bed has been equaled by the heat transfer rate of the Compost Heat Extractor (CHE). The CHE was reusable and can be used any similar system. The CHE also provides good quality humus as the product of composting.

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