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Proper Insulated Materials for Temperature Accumulation in Box Technology to Catalyze the Organic Digestion Processing on Community Garbage Disposal

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Abstract

The research is aimed to determine the appropriate insulated materials and the thickness of insulated boxes for keeping in-box temperature around 70 °C. The experiments were conducted by taking amount of 500 g river gravels (number 3) to heat in Hot air oven at 100 °C for 24 hours before putting in the 0.027 m^3 (30x30x30 cm) insulated boxes. The in-box (T1) and out-box (T2) ambient air temperature were recorded by automatic data locker from beginning to the end of experiments. The relationship between time (t) and in-box temperature by graphical techniques in order to select the appropriate insulated material under the criterions of The King's Royally initiative nature-by-nature process, simplicity technology, and low expense (or local materials using for constructing technology), Also, the relations between Q (heat conduction) of temperature differences (in-box and outside box) in varying time (t) as same as the insulated material thickness was evaluated from graphical products of fixing T1 (equivalent to 70 °C) and Q of varying ambient air temperature. The results found that rice straw as the appropriate insulated material tether with the minimum rice-straw insulated thickness of 6 cm in which the in-box temperature could be kept long enough for psychrophiles, mesophiles, thermophiles, and hyper-thermopile to complete the digestion of carbohydrates, proteins, celluloses, hemicelluloses, and fibers. Moreover, the research result was also pointed out the values of ambient air temperature (from -10 °C to 70 °C) is inversely related to thickness of the rice-straw insulated boxes, by taking the minimum thickness of 6 cm for T2 equivalent to 30 °C.

Keywords: insulated materials, heat conduction, box technology

1. Introduction

Thailand has been confronted on community and industrial solid waste disposal as well as infectious garbage in all parts of the country, especially populated cities, populated communities, and industrial estates due to the population growth and tourism promotion. In consequence, such solid wastes were over the carrying capacity because of sanitary landfills which located in good land for agriculture, particularly paddy areas and non-steep slope areas. It is realized that the failure of unqualified local management agencies, and people participation could be the reason why handling solid wastes did not success as appeared at the present time. Expectedly, the garbage disposal techniques are mostly used the machineries for sanitary landfill works in order to obtain the disposed products in terms of organic fertilizer, fermented objects, exchanging toxicants to non-toxic materials, sterilization, eliminating bad smells, disease spreading control, and treating leachate. Unfortunately, there has been very less sanitary landfill that could be achieved the target according to the failure of local administration and working experiences. It is no doubted that the landfill problems have been found scatteringly in all parts of the country, not only waste contaminants but also forming the visual pollution to the residents and tourists. In facts, every administer of the local administration offices really need to solve those problems but the success seems far distance to get the achievement due to politically discontinued measures as well as the discipline of residents and visitors concerning with garbage disposal management plan. However, the most important issue would be placed on changing behaviors of stakeholders for their lifestyle in relation to garbage disposal management rather than issuing the obligations which is King Bhumibol's motto for community garbage disposal in Thailand. The King also stressed that it has to be taken in longer time, but it would be worthwhile in the future time (LERD 1999, 2000, 2011).

Accordance with community garbage composition is normally comprised of organic, recycling, and hazardous materials which are existed their own particularity. In principles, the recycled wastes can be reused by direct modifying for appliances, and also through industrializing processes for new products (Ahmed, 2004; Okot-Okumu & Nyenje, 2011; Phetchaburi Municipal, 2011; and Thapa, 1998). In addition, both the recycled and hazardous wastes have been paid more attention on how to get rid of them in terms of promoting the extension programs and declared obligations. In part of organic matter point of view, the landfill technique is applicably used for all over the word instead of using for energy (Geng et al., 2010; Chang & Chang, 1998; Fernandez-Rodriguez et al., 2014). As stated before, developing countries are still in using landfill technique for community garbage disposal, but land constraint is still existed in populated cities and communities (JICA, 1981, 1982, 1991; Bhuiyan, 2010). Followings found toxic contamination not only landfills but also the surrounding areas (Finnveden et al, 1995; Hao et al, 2008; Koroneos & Nanaki, 2012; Keenen et al., 1984). This is the reason why King of Thailand has to pay attention on using the concrete box technology for community garbage disposal that can be applicable in house gardens, towns, big or small cities, flatlands, uplands, highlands, arid areas, and islands (LERD, 1999, 2000, 2011, 2012).

LERD (1999, 2000, 2011, 2012) emphasized that the King's Royally Initiated Laem Phak Bia Environmental Research and Development Project, Laem Phak Bia sub-district, Ban Laem District, Phetchaburi province, Thailand has been announced to become the learning center of research and development on community garbage disposal and wastewater treatment. The said research and development projects, especially community garbage disposal, have to follow the King's words on applicable nature-by-nature process, simplicity technology, and useable local materials for constructing technology or very low expense. For serving the King's intention, the research and development on community garbage disposal project has been conducted since 1990 together with the environmental education promotion and academic servicing at the Royal LERD's Learning Center itself and also in all parts of the country. (LERD, 1991, 2000, 2011) However, the simple technology was used for making organic wastes to become inorganic materials (garbage compost) through aerobically bacterial organic digestion process by using Royal Concrete Box technology (RCB technology). The strength of RCB technology is that it can be constructed in limited area in small size and even concrete floor of populated city, So, the RCB technology is applicable everywhere, even in the populated areas and concrete ground floors. Unexpectedly, when it was constructed in highland areas (elevation above 700 mMSL) in Chiangrai province which is normally cool climate. It was functioned to digest only carbohydrate (at temperature 30-40 ^{o}C) and proteins (at temperature 40-50 ^{o}C) of the organic home garbage but no digesting cellulose and hemicellulose at temperature (> 50 ^{o}C) and fiber as well. Actually, RCB technology could release temperature above 70 ^{o}C as found during the bacterial organic digestion processing in which the carbohydrates, proteins, celluloses, hemicellulose and fiber were become to inorganic materials (LERD, 1999, 2000, 2011, 2012; Metcalf & Eddy, 1972; Nopparatanaporn, 1992; Steger et al., 2007; Ugwuanyi et al., 2005; Wilson, 1977).

Naturally, either aerobic process or anaerobic process, the heat has exactly to liberated during the bacterial organic digestion processes in landfills, garbage piles, and litter bins as stated by Keenen et al. (1984), Botkin & Keller (2010), Atchley & Clark (1979), Ugwuanyi et al. (2005), Tchobanoglous et al. (1993), Wilson (1977), Steger et al. (2007), Metcalf & Eddy (1972), Nopparatanaporn (1992), Fernandez-Rodriguez et al. (2014), Geng et al. (2010), and Appels et al. (2010). The liberated heat quantity and producing time are relied on the content and proportion of carbohydrates, proteins, celluloses, hemicelluloses, and fibers in their composition of community solid wastes (Ariunbaatar et al., 2014; Finnveden et al., 1995; Chang & Chang, 1998; Koroneos & Nanaki, 2012; Swati & Joseph, 2008; Chunkao, 1998). In parallel conditions, the liberated heat plays a significant role in activating on both the aerobes and anaerobes for specific functions to their processes in organic digestion for converting the fresh dead plants and animals to become the inorganic materials as nutrient sort for plat growth (Prabuddham, 1985; Botkin & Keller, 2010; Atchley & Clark, 1979). However, elongation of liberated heat is very necessary to complete the maturing organic compost through the natural processes of bacterial organic digestion (Ariunbaatar et al., 2014; Appels et al., 2010; Swati & Joseph, 2008; Atchley & Clark, 1979; Ugwuanyi et al., 2005; Steger et al., 2007; Fernandez-Rodriguez et al., 2014), in other words, the prolongation of heat liberation during bacterial organic digestion processes from the beginning to the end is expected to keep in-box temperature equivalent to ambient air up to more 70 ^{o}C which provides the conditions for completely fermentation of all kinds of organic wastes.

The aforesaid description brought to take part for elongating liberated heat from bacterial organic digestion processing in order to achieve the completion of community solid wastes, especially in parts of carbohydrates, celluloses, hemicelluloses, and fibers. Hence, using insulated boxes are needed to prolong liberated heat from organic waste digestion to enhance the digesting activities of psychrothermopiles, mesothermopiles, thermopiles, and hyper thermopiles one way or another. So far as stated before, an attention has to focus on liberated-heat concrete boxes due to rapid re-radiation to transfer through the 3 cm thick concrete walls to the cooler air outside boxes that making difficult to apply the concrete box technology in highlands or the areas with low temperature all-year periods. For research experiences of LERD (1999, 2000, 2011, 2012) from northern highland of Thailand (Doi Tung in Chiangrai province, elevation above 1200 mMSL), the temperature inside concrete boxes has been measured below 50 ^{o}C and found the existence of high-pertained cellulose and fiber of dead plants still fresh after fermenting 30 days due to the concrete boxes not being all-the-time keeping the liberated heat during bacterial organic digestion processing as stated by Botkin & Keller (2010), Metcalf & Eddy (1972), Tchobanoglous et al. (1993), Atchley & Clark (1979), and Appels et al. (2010). If the RCB technology was covered with insulated materials, the heat liberation was expected to elongate for making the shorter solid retention time (SRT). In consequence, the bacterial organic digestion process could be fully functioned on carbohydrates by psychrophilic bacteria, proteins by mesophilic bacteria, celluloses /hemicellulose by thermophilic bacteria and fiber by thermophilic bacteria/ hyperthermophilbacteria (Swati & Joseph, 2008; Zupancic & Ros, 2003; Chunkao, 1998; Shahriari et al., 2013; Juteau, 2006).

As mentioned before, this study is aimed to find the insulated materials to reduce heat transfer between objects of differing temperature in thermal contact in which it can be achieved with specially engineering method concerning with suitable shape and insulation capacity (thermal conductivity) of materials. However, the thermal conductivity plays role in heat conductive transfer in which the Fourier's law of heat transfer have been applied Fourier's law of heat conduction by Holman (2009), Sellers (1965), Chunkao (1979), Gates (1965, 1980), and Hartman (1994) in the content of "the law of heat conduction states that the time rate of heat transfer through a material is proportional to the negative gradient in temperature and to the area at right angle to that gradient, through which the heat flows". It can be illustrated in equation (1) and showed the hypothetical views in Figure1:

$$Q/t = - kA\,(T1 - T2) / X \qquad (1)$$

where:

Q = heat transfer, cal/cm

k = thermal conductivity, cal/cm^2/sec/^{o}C

A = surface area, cm^2

T1 = hot temperature, ^{o}C

T2 = cold temperature, ^{o}C

X = thickness of insulated material, cm

t = time taken, sec

q = Q/t, cal/cm/sec

According to vary X (thickness) of materialized surface area, and q = Q/t, then equation (1) can be rewritten as:

$$q = - kA\,(T1 - T2) / X \qquad (2)$$

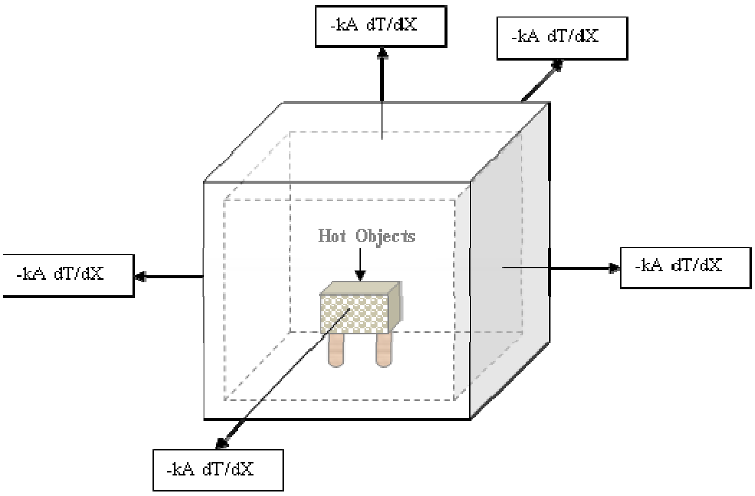


Figure 1. Hypothetical illustration Fourier's law of transferring heat conduction from higher-temperature to cooler-temperature objects at right angle to the temperature gradient

T1 is hot temperature due to heat liberation during the bacterial digestion processes for cellulose, hemicellulose and fiber in which the thermophilic bacteria required temperature inside the boxes above 70 ^{o}C as followed the research results from LERD (1999, 2000, 2011, 2012), Ariunbaatar et al. (2014), Appels et al. (2010), Steger et al. (2007), and Shahriari et al. (2013). Thus, T1 could be fixed at temperature of 70 ^{o}C. Then, T1 in equation (2) can be replaced by 70 ^{o}C which will be presented as:

$$X = - kA (70 - T2) / q \quad (3)$$

Actually X (thickness of insulated material) is used for this experiment on 2.5 cm for reduction of heat transfer (q) from T1 point to the T2 point through thermal conductivity with cross sectional area A. So, the equation (3) can be expressed below:

$$Q/t = - (kA)(T1 - T2) / X \quad (4)$$

In case of expressing the heat transfer per unit area, then the equation (4) becoming to equation (5) as following:

$$Q = - (kA (T1 - T2)/X)(t) \quad (5)$$

If t is fixed, then T2 is varied from place to place, the same as fixed T2 value and taking time (t) is varied. Then after, the relationships between Q and T2 can do the same as Q and t relation. Because of aforesaid statement, those relations can be graphically constructed in which the proper t (time taken) and proper T2 (temperature of applicable location) can be calculated in order to determine the thickness of specific insulated materials.

The proper thickness of insulated materials for reduction heat transfer from organic digested boxes plays vital role in keeping all-time high temperature inside boxes for accelerating the psychrophilic, mesophilic, and thermophilic bacteria activities to digest carbohydrates, proteins, cellulose, phemicellulose and fibers in which they are in part of home garbage. Besides, the levels of released heat in boxes are belonged to the important environment in catalyzing the bacteria activation on the organic-sort digestion under aerobic and anaerobic processes, such as psychrophiles (cold-loving bacteria) for below 20 ^{o}C, mesophiles for 20 to 45 ^{o}C, and thermophiles (hot-loving bacteria) for 45 to 70 ^{o}C, hyperthermophiles for more 70 to 122 ^{o}C. However, the environmental scientists are agreed on the bacterial organic digestion process as the basic heat releasing that are depended on the sorts of organic matter, for example, up to 40 to 50 ^{o}C from carbohydrate group, 50 to 60 ^{o}C from proteins, and above 60 ^{o}C from cellulose, hemicellulose, and fibers. In facts, the composition of Thai municipality and household solid wastes is generally varied on proportion of organic matters, recycles, and hazardous wastes. It is remarkable that the organic matters are comprised of various proportions of carbohydrates, proteins, celluloses, hemicelluloses, and fibers. In other words, the ratio of carbohydrate: protein: cellulose/hemicellulose/fiber plays a significant role in heat releasing from organic wastes during digestion processing by providing gradually higher temperature until no organic matters left in technological boxes. Keeping higher temperature in boxes is depended on how thick of insulated materials as thermal conductivity to reduce heat transferring to the next one.

Not only thickness of insulated materials is influenced on heat transfer from hot temperature from inside to outside boxes but also the density and its specific gravity are involved with the pathway of transferring heat as liberated during the bacterial organic digestion process. In conclusion, the Q values are directly varied to insulated material density and specific gravity but inversely to the thickness of insulated materials and ambient air temperature (outside technological boxes). In facts, the outside box temperature is supposed to be the temperature at any concerned areas in which the box technology for organic waste disposal. Only thickness of insulated materials plays vital role in control the inside box temperature to enhance the thermophilic bacterial activities for digesting cellulose, hemicellulose, and/or fibers which are in part of vegetables. In other words, the application of insulated-material box technology is really needed the proper temperature to enhance psychrophiles, mesophiles, thermophiles and hyperthermophiles for digesting carbohydrates, proteins, celluloses, hemicellulose, and fibers to become mature-garbage compost as the final products of fermenting organic solid wastes.

This study is aimed to determine the thickness of insulated materials for reduction of heat transfer from bacterial organic digestion process in order to keep the enough hot temperature up to higher than 70 ^{o}C which is proper heat to activate the thermophilic bacteria to release enzyme for digesting cellulose, hemicellulose, and fiber as in part of municipality and household garbage. Also, the solid retention time (SRT) is to show how short of time for doing digestion of organic solid wastes that turning to become garbage compost (organic compost).

2. Method

2.1 Experimental Area

The experimental area was taken the zinc-roof cottage inside the Royal LERD project site at Laem Phak Bia subdistrict, Ban Laem district, Phetchaburi province, in southern part of Thailand about 120 km distance from Bangkok. The zinc-roof cottage was covered with open space about 100 m^2 together without walls of all-four sides in order to provide all-direction wind blowing as shown in Figure 2.

2.2 Choosing Insulated Materials

This research project is belonged to The King's Royally Initiative Laem Phak Bia Environmental Research and Development Project (Royal LERD Project) which is qualified nature-by-nature process, simplicity technology, and either intentionally using domestic materials for creating technology or low expense. For serving the Royal LERD project criteria, the six-type appropriate insulated materials were chosen, that is, earth soil, rice husk, rice straw, wood, cement, plastic PVC, and foam (see Figure 2).

2.3 Insulated Sheet Making

The research methodology is required the cube-shaped experimental units with 30 cm in equal sizes of width, length, and height and 2.5 cm thickness (0.027 cubic meters) for molding the insulated sheets which are used for box walls , beds, and covers. According to the six-malleable insulated walls were needed to assemble for one cube-shaped experimental unit and 21 boxes required (7 treatments and 3 replications) for each insulated materials (earth soil, rice husk, rice straw, wood, cement, plastic PVC, and foam) by mixing with some cementing agents to insulated sheets for assembling the cube-shaped experimental unit before laying down on the smooth floor under the zinc-roof cottage in order to air drying (see Figure 2).

2.4 Determination of Insulated Material Density and Specific Gravity

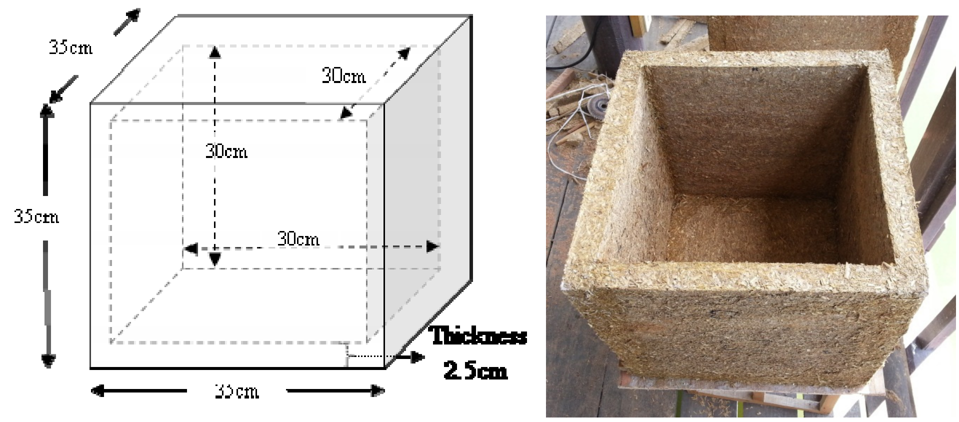
Each of insulated-material molding sheets had to determine the density, specific gravity, and thermal conductivity in which they played vital role in amount and transferring rate of heat conduction from hot objects or heat liberation during the bacterial organic digestion processing.

2.5 Heating Insulated Boxes

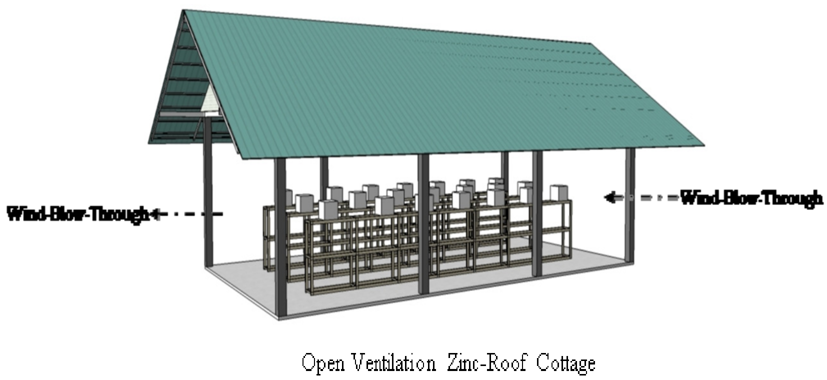
Since this research purpose is aimed to select the type of insulated materials and its appropriate thickness of insulated-material molding sheet, the 0.5 kg river gravels (number 3) at 100 ^{o}C by oven heating were used as hot objects to put in every experimental unit before closing the thermometer-inserted cover for measuring in-box temperature. Also, the outside experimental-insulated box temperature was measured by hanging the thermometer above the cottage floor about 1.50 m height.

2.6 In-Box and Outside-Box Temperature Measurement

Two automatic thermometers (Data Logger Testo 0572.1764 Waterproof Immersion Probe T/C Type K) was inserted through the insulated box cover for measuring inside insulated box temperature, and another one that hanging above cottage floor about 1.50 m height for measuring ambient air temperature.



(a) Insulated box of cube shape with the size of 0.027 cubic meter



(b) The experimental sites for laying down 21 boxes experimental unit

Figure 2. Insulated box of cube shape with the size of 0.027 cubic meter (30 x 30 x 30 cm) and 2.5cm thickness as constructed by seven- insulated materials of plastic PVC, cement, wood, foam, rice husk that mixing with another cementing agents in different proportions and laying down on the smooth floor under the zinc-roof cottage in order to air drying

2.7 Calculation of Heat Conduction

By taking in-box and outside box temperature as measured continuous period from beginning to the end of experiments, the relation graphs between in-box temperature (T1) and time (t), heat conduction (Q) and time (t) by fixing hot T1 equivalent to 70 ^oC, Q and t of the seven-type insulated materials by fixing T1 equivalent to 70 ^oC, and finally between Q and t of selecting insulated material by fixing T1 equivalent to 70 ^oC and varying selected insulated thickness from 1.0, 1.5, 2.0 to 9.0 cm with 0.5 cm interval.

2.8 Graphical Techniques for Evaluating Insulated Materials and Thickness

The relations as described in number 2.7 above were plotted graphs into 4 cases: firstly, the relation between T1 and t of seven-type insulated materials by fixing box thickness equivalent to 2.5 cm, and T1 equivalent to 70 ^oC, secondly, Q and t relation by fixing box thickness equivalent to 2.5 cm and T1 equivalent to 70 ^oC, thirdly, for selected-insulated-material heat conduction Q and t by fixing box thickness equivalent to 2.5 cm and T1 equivalent to 70 ^oC, and finally, Q and t by fixing T1 equivalent to 70 ^oC and varying selected insulated thickness from 1.0 to 9.0 cm with 0.5cm interval.

Intentionally, the appropriate thickness of selected insulated materials for making the insulated sheets that becoming the experimented box walls can be presumably find out which plays the significant role in keeping the liberated heat from bacterial organic digestion process inside the boxes, and also it can elongate enough working time of psychrophiles, mesophiles, thermophiles, and hyper-thermophiles to digest the organic wastes in parts of carbohydrates, proteins, fats and oils, cellulose, hemicellulose, and fiber to become the inorganic materials in form of the organic compost.

3. Results and Discussion

Since, this research is focused on determine the kind of insulated material and its composition to mold in sheet form in order to construct the squared-insulated box technology (INBOT) to keep the hot-temperature for thermophilic bacteria activities in digesting cellulose-fiber organic wastes. Nevertheless, the insulated-sheet thickness is another purpose of this study on shortening the solid retention time (SRT) through the King's Royally initiative nature-by-nature process at the hand of bacterial organic digestion process. To achieve the aforesaid statement, the followings will be presented in details on both the appropriate insulators and its thickness that can be applicable in every climatic condition in Thailand. The research results will be presented in the followings.

3.1 Molding Insulated-Material Sheets

As stated before, there were 7 insulated materials that laminating to the insulated sheets for assembling the insulated boxes in order to keep the liberated heat from bacterial organic digestion process. Actually, some insulated materials were required another materials together with cementing agents in order to mold the insulated-laminated sheets. The component of mixed insulated-laminated sheets was shown in Table 1 in which they applied to calculate the averaged thermal conductivity (k) by weighing system as illustrated in Table 2. At the same time, the density and specific gravity were determined by laboratory techniques as Table 3.

Table 1. Insulated materials and mixing components for molding insulated- laminated sheets (30 cm width, 30 cm length, and 2.5 cm thickness) to assemble the cube-box (30 x 30 x 30 cubic centimeters) as the experimental units

Insulated Materials	Ratio of Mixing Materials	Component
Rice Straw	Rice straw : cassava starch solution = 1:1	Rice straw + cassava starch solution
Rice Husk	Rice husk : cassava starch solution = 1:1	Rice husk + cassava starch solution
Earth Soil	Clay : rice husk : sand = 3:1:1	Clay + rice husk + sand
Cement	cement Portland : Sand = 1:3	cement Portland + Sand
Plastic, PVC	-	PVC + epoxy
Wood	-	Wood + Latex glue
Foam	-	Foam + Latex glue

Note. Concentration of cassava starch solution is 25% of cassava starch.

Table 2. Calculation by weighing system of averaged thermal conductivity values of earth soil, rice husk, rice straw, cement, foam, plastic PVC, wood, as used for molding insulated sheets to assemble the cube boxes (30 x30 x 30 cm^3) with 2.5 cm thickness

Insulated material	Averaging by Weighing System									Average k
	k1	w1 (Kg)	k1w1	k2	w2 (Kg)	k2w2	k3	w3 (Kg)	k3w3	
Rice Husk	Rice Husk 0.00009	0.745	0.0001	CS Solution 0.00071599	0.745	0.000533	-	-	-	0.00040
Rice Straw	Rice Straw 0.0002	0.85	0.00018	CS Solution 0.00071599	0.85	0.000609	-	-	-	0.00047
Earth Soil	Earth Soil 0.0026	3.24	0.0085	Rice Husk 0.00009	1.08	0.0001	Sand 0.001	1.08	0.000696	0.00172
Cement	Cement 0.0007	1.4	0.000969	Sand 0.000644391	4.2	0.002706	-	-	-	0.00066
Plastic, PVC	-	-	-	-	-	-	-	-	-	0.00021
Wood	-	-	-	-	-	-	-	-	-	0.00029
Foam	-	-	-	-	-	-	-	-	-	0.00007
Concrete	-	-	-	-	-	-	-	-	-	0.00239

Table 3. Averaged thermal conductivity, density, and specific gravity of insulated materials and some components for applying to calculate the heat conduction transferring

No.	Materials	Density (g/cc)	Specific Gravity	Thermal conductivity, k,(cal/sec)/(cm^2°C/cm)
1	Rice Husk	0.64	0.641	0.00040
2	Rice Straw	0.50	0.501	0.00047
3	Earth Soil	1.63	1.643	0.00172
4	Cement	1.84	1.855	0.00066
5	Plastic,PVC	1.51	1.522	0.00021
6	Wood	0.48	0.483	0.00029
7	Foam	0.01	0.01	0.00007
8	Cassava Starch Solution	-	-	0.00072
9	Sand	-	-	0.00064
10	Concrete	-	-	0.00239

3.2 Selection of Insulated Materials

The measured inside insulated-box temperature (T1) and ambient air temperature (T2) of each insulated-material box were conducted in ration to measuring time (t) and heat conduction (Q) in order to use for making decision of selecting the appropriate insulated materials as shown in Figures 3 and 4.

The results found that the outside box temperature was not influenced to uprise the inside box temperature but they were up to the powering radiated heat from 100 °C river gravel in which they were gradually released until all-box temperature equivalent to outside box temperature after radiating for 265 minutes. Among those temperature tendency, foam insulated boxes could be most sensitive changing in relation to outside box temperature by rapid increasing at the beginning and fast decreasing after radiating about 90 minutes, and sinking to the lowest level of temperature decreasing at night time. This phenomena is brought to point out that the foam insulated box technology would be used for keeping heat in box if the outside temperature was cool at night time. In spite of rice husk and rice straw can be used for insulated box technology, but the plastic PVC, cement, earth soil, and wood insulated boxes would be appropriate technology for keeping high temperature for longer period in boxes as well. If the convenience is concerned with the local materials available, the rice straw should be compensated by local grasses because of its grow everywhere in the whole country. Neither more effective insulated-box technology nor less appropriate ones, their box temperature lines as belonged to insulated materials (foam, rice husk, rice straw, plastic PVC, cement, earth soil, and wood) technology have met together at about 265 minutes after putting the hot river gravels in insulated boxes as shown in Figures1 and 3.

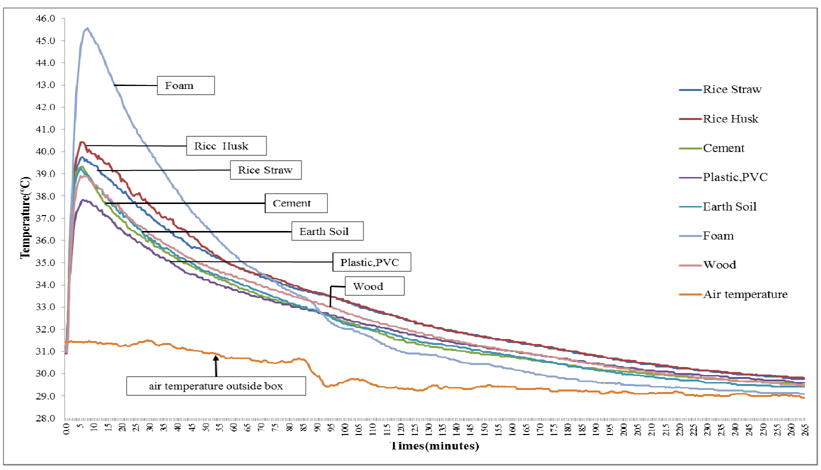


Figure 3. Tendency of air temperature outside boxes (inside of the insulated zinc-roof hut) and inside box temperature from beginning and climbing up to the maximum of insulators as made by foam, rice husk, rice straw, cement, earth soil, plastic PVC, and wood as obtained from the experiment

For making sure of selecting the insulated materials for assembling the box technology to dispose the community solid wastes, the heat transfer from hot river gravels was applied to make decision. In experimental point of view, the insulated materials which use for box making were determined their density and specific heat capacity as well as thermal conductivity in order to induce heat flow from 100 ^{o}C hot river gravels to transfer to outside boxes. The weighting system was determined the averaged values of insulated-material, specific gravity, density, specific gravity, and thermal conductivity as illustrated in Table 3. The results found the thermal conductivity of foam, plastic PVC, wood, rice husk, rice straw, cement, and earth soil as 7x10^{-5}, 22.1x10^{-4}, 29x10^{-5}, 4x10^{-4}, 4.7x10^{-4}, and 6.6x10^{-4} cal/cm^{2}/sec, respectively as shown in Table 3. Based on Fourier's law of heat transfer in equation (5), the thermal conductivity is related directly to quantity of heat transfer, which means that the more the thermal conductivity are the heat transfer. In the same manner, the density and specific gravity of insulated materials showed the same trends of thermal conductivity as illustrated in Table 4 and Figure 4. It is observed that the maximum in-box temperature found 45.5 ^{o}C for foam, 40.3 ^{o}C for rice husk, 39.8 ^{o}C for rice straw, 39.3^{o} C for cement, 38.9 ^{o}C for earth soil, 38.8 ^{o}C for wood, and 37.9 ^{o}C for plastic PVC (see Figure 3). This would be reasoned that the radiation transfer from a handful of hot river gravels (100 ^{o}C) was not forceful enough to homogeneously spread out to nearly empty boxes as shown in Figure 1.

The results pointed out that the outside box temperature was not influenced to uprise the inside box temperature but they were up to forcefulness of heat radiating from 0.5 kg river gravels at 100 ^{o}C in which they were gradually liberated until equilibrium temperature between inside and outside box temperature after radiating for 265 minutes (Figure 3). Among those temperature tendency, foam insulated boxes could be most sensitive changing in relation to outside box temperature by rapid increasing at the beginning and fast decreasing after radiating about 70 minutes, and sinking to the lowest level of temperature decreasing at night time. This phenomena is brought to express that the foam insulated box technology would be good enough to use for keeping heat in box at daytime, only the outside box temperature was cool at night time. Besides, the rice husk and rice straw can be better useable for insulated box technology, the plastic PVC, cement, earth soil, and wood insulated boxes might be appropriate to assemble the insulated-material technology for keeping high temperature for longer period in boxes as well. Neither more effective insulated-box technology nor less appropriate ones, their box temperature lines as belonged to insulated materials (foam, rice husk, rice straw, plastic PVC, cement, earth soil, and wood) technology have met together at about 265 minutes after pouring the hot river gravels as shown in Figure 3. In other words, every studied insulated material could be appropriate to use for insulated-material technology.

When the relationships between Q and time t in equation (5) was calculated under real time measurement of in-box temperature (T1) and ambient air temperature (T2) by fixing the values of X (thickness) equivalent to 2.5 cm, the relationships between Q and t by graphical techniques of foam, rice straw, rice husk, cement, plastic PVC, earth soil, foam, and wood were constructed as illustrated in Figure 4 and heat transfer values as shown in Table 4.

Table 4. Heat transfer of insulated boxes as used for evaluating the appropriate insulated materials

Times	Q, heat transfer (cal/cm)						
(minutes)	Rice Straw	Rice Husk	Cement	Plastic,PVC	Earth Soil	Foam	Wood
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	803.0	731.5	1000.6	279.7	2653.6	197.3	447.2
20	1417.9	1284.5	1614.2	480.3	4513.6	322.6	773.8
30	1723.7	1598.4	1925.8	574.6	5133.6	373.0	904.8
40	2029.4	1889.3	2303.4	674.9	6249.6	410.9	1106.6
50	2318.4	2059.2	2572.4	752.4	6882.0	412.8	1227.2
60	2540.2	2177.3	2832.0	839.0	7812.0	406.1	1385.3
70	2704.8	2378.9	2973.6	925.7	8246.0	403.2	1514.2
80	2768.6	2442.2	2945.3	936.3	7936.0	372.5	1514.2
90	3326.4	2903.0	3653.3	1190.2	9709.2	393.1	1853.3
100	3662.4	3139.2	3870.4	1292.0	9796.0	345.6	1976.0
110	3696.0	3199.7	3790.2	1320.9	9957.2	332.6	1944.8
120	3830.4	3317.8	3681.6	1386.2	10564.8	293.8	2046.7
130	3669.1	3145.0	3497.5	1323.9	9833.2	280.8	1919.8
140	3622.1	3024.0	3370.1	1276.8	9721.6	248.6	1834.6

150	3326.4	2894.4	3044.4	1208.4	8556.0	216.0	1684.8
160	3279.4	2857.0	3020.8	1167.4	8332.8	192.0	1630.7
170	3255.8	2888.6	2968.9	1162.8	8010.4	155.0	1591.2
180	3265.9	2799.4	2888.6	1176.5	7812.0	138.2	1572.5
190	3064.3	2681.3	2780.1	1097.4	6832.4	118.6	1462.2
200	2822.4	2419.2	2548.8	1003.2	5704.0	96.0	1289.6
210	2751.8	2419.2	2577.1	989.5	5728.8	90.7	1223.0
220	2365.4	2090.9	2180.6	836.0	4637.6	73.9	1006.7
230	2550.2	2252.2	2388.3	909.0	4848.4	88.3	1100.3
240	2257.9	2004.5	2039.0	802.6	4166.4	57.6	948.5
250	2268.0	2016.0	2124.0	836.0	4340.0	48.0	988.0
260	2009.3	1797.1	1963.5	711.4	3868.8	37.4	811.2

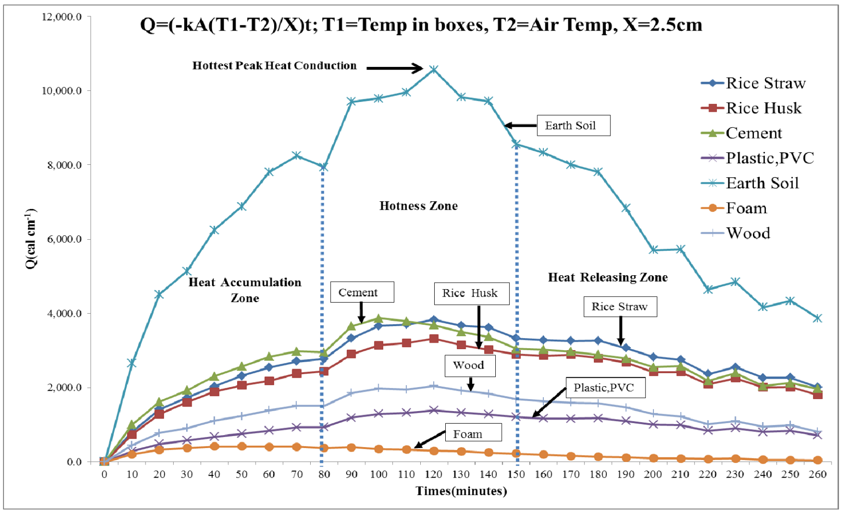


Figure 4. Amount of heat transfer through Fourier's law of heat transfer under the fixed values of insulated box thickness (2.5 cm), inside box temperature, and averaged k-values of each insulated materials, surface area (A = 900 squared cm), and varying with time (minutes)

The relationship between amount of heat transfer (Q) and measuring time (t) which was constructed (as shown in Figure 4) can be gathered into 3 groups of insulated groups; they are low (wood, plastic PVC, and foam), medium (cement, rice husk, and rice straw), and high (earth soil) heat transferring by conduction process. Accordance with more minerals in composition, the highest heat conduction was placed on earth soil that should be ignored in using for assembling the insulated boxes. While the lowest heat conduction is identified in wood, plastic PVC, and foam but it might be risky to create the environmental problems even they are so convenient to get in everywhere. Finally, the medium heat conduction group is the most appropriate insulated materials (cement, rice husk, rice straw) to be selected for molding insulated-material sheets for assembling the insulated boxes. If the convenience is concerned with the local materials available, the rice straw should be the best one because it can be compensated by local grasses as grow everywhere in the whole country.

It is obvious that the graphical techniques in Figure 4 can be divided into 3 zones; first zone is called as "heat accumulation zone" beginning with rising limb in order to accumulate the heat storage for about 80 minutes; second zone called as "hotness zone" it starts transferring heat from "heat accumulation zone" with the energetic conduction before entering "hotness zone" between 80 - 150 minutes (70 minutes) for maintaining the maximum hottest period to digest some more cause textural organic wastes. Evidently, the heat was transferred from the hotness zone throughout the 'heat releasing zone" until the ending of bacterial organic digestion process around 265 minutes (4 hours and 25 minutes) and plus (see Figure 3). However, the period from the beginning of organic digestion process to hottest-peak heat conduction at the 120 minutes (2 hours) before gradually heat liberating more than twice. In reality, the hottest peak heat conduction was placed on around the fifth days (in-box temperature at 77 ^{o}C) and heat liberating period up to 25 days for converting the organic wastes to become the mature organic compost (Figures 4 and 5) through the bacterial organic digestion process (LERD 1999, 2000, 2011, 2012; Shahriari et al., 2013; Appels et al., 2010; Steger et al., 2007; Fernandez-Rodriguez et al., 2014; Zupancic & Ros, 2003; Metcalf & Eddy, 1972: Ariunbaatar et al., 2014; JICA, 1982; Atchley & Clark, 1979; Ugwuanyi et al., 2005; Juteau, 2006).

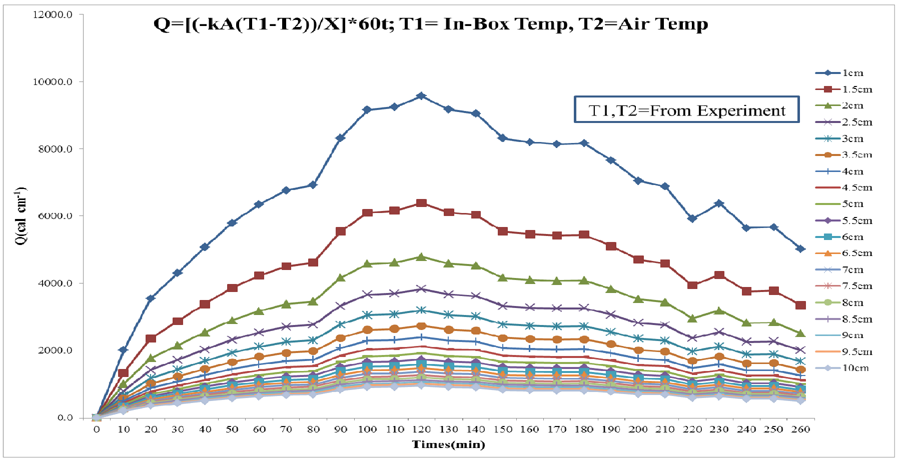


Figure 5. Systematic appearances of transferring heat in various times of "heat accumulation zone", "hotness zone" and "heat releasing zone" in relation to various rice-straw insulated thicknesses

3.3 Box Insulated Thickness Determination

As finalized before and sown in Figure3, the rice straw was selected to as appropriate insulated materials for assembling the insulated box technology under the fixed thickness of 2.5 cm because of its minimum thickness to make sheet insulators, the amount of heat transfer (Q) in relation to another thickness sizes were calculated as illustrated in Figure 5. It was obviously seen that no matter the insulated thickness of any sizes, the systematic appearances of "heat accumulation zone", "hotness zone", and "heat releasing zone" were somewhat the same as illustrated in Figure 4. In other words, the thickness sizes of rice straw insulators cannot change in their systematic appearances even its thickness changed in which the Figure 5 can be useable for selecting the appropriate thickness. In contrary, it was so difficulty to make decision what thickness of rice-straw insulated box should be the best one. Roughly, the minimum rice-straw insulated box should be placed at 6 cm due to the Q-t line looked steadier rather than Q-t lines 1 cm to 5.5 cm, but this result could not make sure to the decision makers. Therefore, the Figure6 was constructed in order to emphasize the aforesaid decision making in which the Q-thickness lines of each ambient-air-temperature line by fixing 70 ^{o}C as the in-box temperature seemed agreeable at the 6-cm thickness but it was still confused to the decision makers due to the existence of less sloping characters.

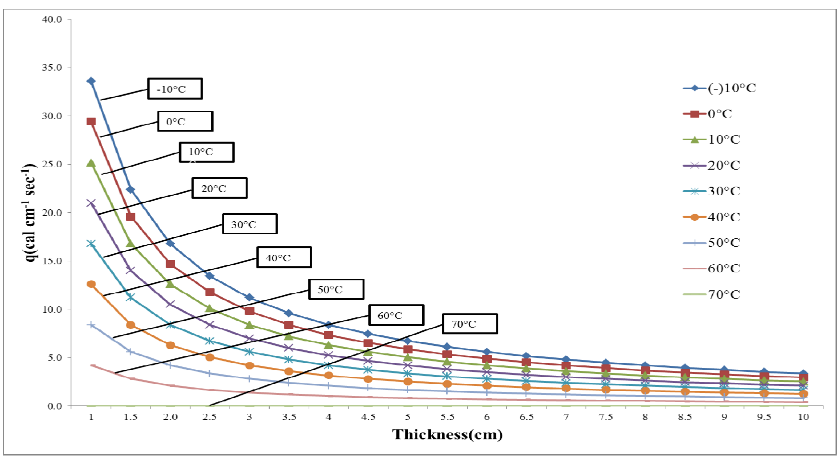


Figure 6. Determining appropriate thickness of rice straw as insulated material to assemble the insulated box technology for elongating solid retention time (SRT) to enhance the well-fermented community garbage to become the fruitful compost

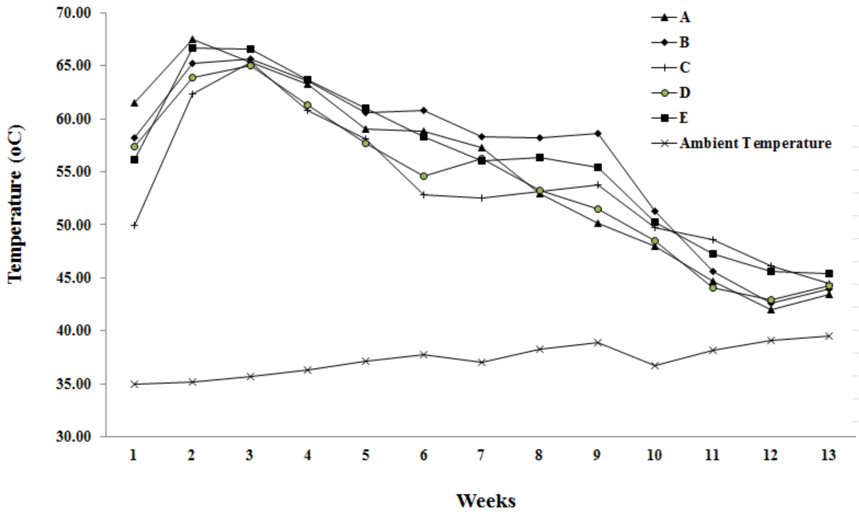
Finally, the relationship between heat conduction (Q) and rice-straw insulated thickness through ONE-WAY ANOVA statistical method which uses for its stratification as shown in Table 5. The similarity of numbers in small frames was indicated the coordination between the rice-straw insulated thickness (Thickness) and ambient air temperature (T2), for example, if T equivalent to -10 ^{o}C, Thickness equivalent to 9.5 cm to 10 cm; 30 ^{o}C of T going hand in hand with Thickness of minimum 6 cm to maximum 10 cm. therefore, the Table5 is applicable to give the ambient air temperature and reading downwards to the T2-Thickness frames before reading the thickness column in order to get the appropriate rice-straw insulated box for bacterial organic digestion process by controlling in-box temperature at 70 ^{o}C. By this method, the means how to find out the rice-straw appropriate insulated box can exactly be applicable not only one ambient-air-temperature condition but also to extend to anywhere with different local temperature to coordinate with the appropriate thickness. However, the minimum thickness in Thailand should be placed on 6 cm. expectedly, this minimum rice-straw insulated box can be applicable in all parts of the country, either lowland, flatlands, mountainous lands, and islands.

Table 5. Calculated frame values between heat conduction (Q) and rice-straw insulated thickness by fixing in-box temperature at 70 ^{o}C through ONE-WAY ANOVA statistical method (level of significant 95%) for finding the appropriate thickness of insulated boxes

Thickness	Air Temperature,T2 (°C)								
(cm)	-10ºC	0ºC	10ºC	20ºC	30ºC	40ºC	50ºC	60ºC	70ºC
1.0	33.6^{r}	29.4^{s}	25.2^{r}	21.0^{q}	16.8^{p}	12.6^{q}	8.4^{p}	4.2^{l}	0^{a}
1.5	22.4^{q}	19.6^{r}	16.8^{q}	14.0^{p}	11.2^{o}	8.4^{p}	5.6^{o}	2.8^{k}	0^{a}
2.0	16.8^{p}	14.7^{q}	12.6^{p}	10.5^{o}	8.4^{n}	6.3^{o}	4.2^{n}	2.1^{j}	0^{a}
2.5	13.4^{o}	11.8^{p}	10.1^{o}	8.4^{n}	6.7^{m}	5.0^{n}	3.4^{m}	1.7^{i}	0^{a}
3.0	11.2^{n}	9.8^{o}	8.4^{n}	7.0m	5.6^{l}	4.2^{m}	2.8^{l}	1.4^{h}	0^{a}
3.5	9.6^{m}	8.4^{n}	7.2^{m}	6.0^{l}	4.8^{k}	3.6^{l}	2.4^{k}	1.2^{g}	0^{a}
4.0	8.4^{l}	7.4^{m}	6.3^{l}	5.3^{k}	4.2^{j}	3.2^{k}	2.1^{j}	1.1^{f}	0^{a}
4.5	7.5^{k}	6.5^{l}	5.6^{k}	4.7^{j}	3.7^{i}	2.8^{j}	1.9^{i}	**0.9^{e}**	0^{a}
5.0	6.7^{j}	5.9^{k}	5.0^{j}	4.2i	3.4^{h}	2.5^{i}	1.7^{h}	**0.8^{de}**	0^{a}
5.5	6.1^{i}	5.3^{j}	4.6^{i}	3.8^{h}	3.1^{g}	2.3^{h}	1.5^{g}	**0.8^{de}**	0^{a}
6.0	5.6^{h}	4.9^{i}	4.2^{h}	3.5^{g}	**2.8^{f}**	2.1^{g}	1.4f^{g}	**0.7^{cd}**	0^{a}
6.5	5.2^{g}	4.5^{h}	3.9^{g}	3.2^{f}	**2.6^{ef}**	1.9^{f}	1.3^{ef}	**0.6^{bc}**	0^{a}
7.0	4.8^{f}	4.2^{g}	3.6^{f}	3.0^{e}	**2.4^{de}**	1.8^{ef}	1.2^{de}	**0.6^{bc}**	0^{a}
7.5	4.5^{e}	3.9^{f}	3.4^{e}	2.8^{d}	**2.2^{cd}**	1.7^{de}	1.1^{cd}	**0.6^{bc}**	0^{a}
8.0	4.2^{d}	3.7^{e}	3.2^{d}	2.6^{c}	**2.1^{bcd}**	1.6^{cd}	1.1^{cd}	**0.5^{ab}**	0^{a}
8.5	4.0^{c}	3.5^{d}	3.0^{c}	2.5^{c}	**2^{abc}**	1.5^{bc}	1.0^{bc}	**0.5^{ab}**	0^{a}
9.0	3.7^{b}	3.3^{c}	**2.8^{a}**	**2.3^{b}**	**1.9^{ab}**	1.4^{ab}	0.9^{ab}	**0.5^{ab}**	0^{a}
9.5	**3.5^{a}**	3.1^{b}	**2.7^{a}**	**2.2^{ab}**	**1.8^{a}**	1.3^{a}	0.9^{ab}	**0.4^{a}**	0^{a}
10.0	**3.4^{a}**	2.9^{a}	2.5^{b}	**2.1^{a}**	**1.7^{a}**	1.3^{a}	0.8^{a}	**0.4^{a}**	0^{a}

3.4 Applicability of Rice-Straw Insulated Box Technology

Referring to the previous study of The King's Royally Initiated Laem Phak Bia Environmental Research and Development (Royal LERD) Project in Phetchaburi Province, Thailand through nature-by-nature process, the concrete box technology has been mainly used for community garbage disposal and also for innovating the new applicable technique in some constraint areas as shown in Figure7. The matured compost was obtained after fermenting 30 days (SRT equivalent to 30 days) for separating organic wastes and 90 days (SRT equivalent to 90 days) for unseparated community (municipal) garbage. It was pointed out that the separation of organic wastes from the whole proportion of community solid wastes could make the shorter SRT from 90 days to become 30 days. Consequently, the compost texture was composed of cause texture of some solid component which could be identified mostly as fibers but they were excellently useable for fertilizing to plant growth after cutting in tiny pieces.



Weeks	A	B	C	D	E	TA
1	61.50	58.20	49.90	57.40	56.10	35.0
2	67.47	65.20	62.30	63.90	66.70	35.2
3	65.37	65.63	65.33	64.97	66.57	35.7
4	63.23	63.58	60.80	61.28	63.65	36.3
5	59.07	60.60	58.07	57.70	60.97	37.2
6	58.83	60.75	52.80	54.55	58.28	37.8
7	57.30	58.30	52.50	56.25	56.00	37.0
8	52.90	58.15	53.18	53.25	56.30	38.3
9	50.17	58.57	53.77	51.50	55.37	38.8
10	47.93	51.25	49.73	48.45	50.20	36.8
11	44.67	45.63	48.60	44.00	47.27	38.2
12	42.03	42.58	46.10	42.88	45.58	39.1
13	43.38	43.98	44.50	44.23	45.38	39.5

Figure 7. Consecutive temperature as measured during fermenting community garbage inside box with the size of 1.5 m height, 2.0 m width, and 3.0 m length for 2 tons garbage accommodation accordance with fermenting time 30 days for only separated organic wastes and 90days for unseparated community garbage

Note. Treatment A: The unseparated community garbage pile left to be decomposed naturally.

Treatment B: The pile with glass, metal and plastic scraps sorted out, then spread over with compost starter, phosphate supplement, urea and loose soil.

Treatment C: The pile with glass, metal and plastic scraps sorted out, then mixed with compost starter, phosphate supplement, urea and loose soil.

Treatment D: The unseparated community garbage pile spread over with compost starter, phosphate supplement, urea and loose soil.

Treatment E: The unseparated community garbage pile mixed with compost starter, phosphate supplement, urea and loose soil.

In practical point of view, there was 30% hollow in each concrete box (3-cm thickness) and without insulating materials for reduction of transferring heat (as liberated from bacterial organic digestion process) which used for assembling the concrete box technology. Nevertheless, the temperature was still risen in rapid rate in the heat accumulation zone, and also it still met the peak temperature inside hotness zone close to the averaged values of 70 ^{o}C in the hotness zone. In reality, there were some experimental concrete boxes found the peak temperature up to 69 ^{o}C during fermenting the Phetchaburi municipal solid wastes. Besides, the heat transfer was taken in account with quite low rate in the heat releasing zone (see Figures 7 and 8) due to the outside concrete box above 35 ^{o}C that caused low net re-radiation rate from naturally heat liberation from bacterial organic digestion process inside experimental boxes. Although the peak temperature was more or less 70 ^{o}C, the hotness zone in Figure 7 found quite narrow which would be shorter period of heat storage inside concrete boxes. If the 4-side concrete box were strict by 2.5-cm thickness of rice-straw insulated sheets (k equivalent to $4.7x10^{-4}$ cal/cm^2/^{o}C/sec) the in-box temperature should be less than one fifth of heat conduction from bacterial organic digestion process in the concrete boxes (k equivalent to $2.3x10^{-3}$ cal/cm^2/^{o}C/sec). It could be concluded that the rice straw plays vital role in keeping heat as liberated from the digestion process of organic wastes rather than without rice straw insulated sticking in concrete box walls.

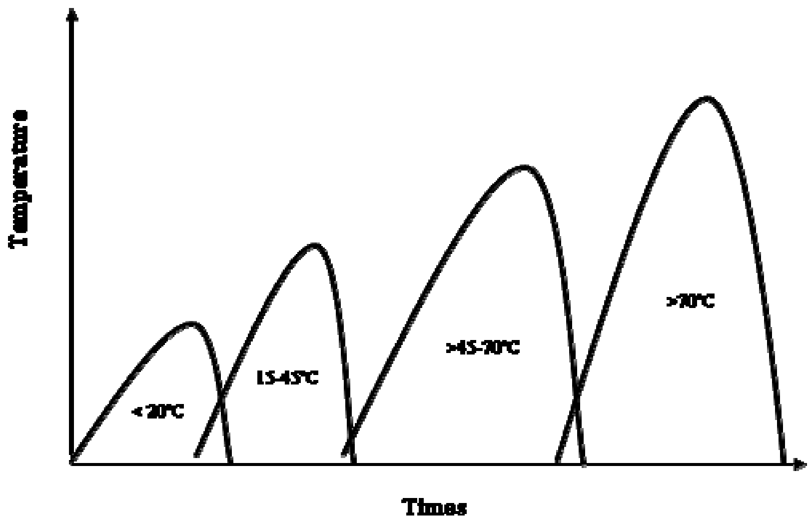


Figure 8. Hypothetically consecutive temperature rising during bacterial organic digestion processes on carbohydrate protein celluloses hemicellulose and fibers

Theoretically speaking, the organic wastes of Phetchaburi municipal garbage have evidently converted to become inorganic-material garbage compost through aerobically bacterial organic digestion process for 30 day SRT (LERD, 1999, 2000, 2011, 2012). Then after, the garbage compost was produced by constructing the 9 m^3 concrete box (1.5 m deep, 2 m wide, 3 m long) for 5 treatments 3 replications on slope of 1:1,000; compacting before paving gravel at the level above 2 cm diameter PVC pipe for leachate draining, then overtopping on 2 cm height of sand; putting 3 alternated layers of two level of 670 kg organic wastes along with overtopping 5 cm height of clayed soils (called electron acceptors), and the top layer of 670 kg organic wastes with overtopping 15 cm of clayed soils. Amount of water which is plenty of dissolved oxygen (DO) about 60 liters will be showered every seven days in order to bring down the electron acceptors (such as O_2, Fe^{3+}, Mn^{2+}, etc.) to catch with the electrons as broke from bacterial organic digestion process to form the inorganic materials in terms of chemical compounds (Prabuddham, 1985) as illustrated in Figure 7.

This would be stressed that the releasing heat from bacterial organic digestion process was kept longer period because of the smaller temperature gradient between inside-outside concrete box which caused low heat transferring by re-radiation. In contrary, concrete box may become heat acceptor whenever the surrounding temperature is higher than inside concrete box. Naturally, it is inevitable to stop transferring the releasing heat from bacterial organic digestion process in box of CB technology due to contact between inner and outer surfaces. Unavoidably, the hot temperature inner concrete box has been gradually decreased due heat conduction transfer to outer surface until temperature of both sides was in balancing condition. Exactly, the insulated-covered materials on concrete box surfaces are not preferable to use for reduction of heat transfer to outer ambient air due to high thermal conductivity of concrete boxes. There are a lot of suggestions to use insulated materials for constructing the insulated box technology instead of single concrete box technology.

Undoubtedly, if the inner concrete box was assembly insulated by the effective materials, no matters rice straw and others (rice husk, wood, plastic PVC, earth soil, and cement together with another cementing agent) might be enhanced to elongate the hotness zone including peak temperature increasing more than 70 ^{o}C, and also high rate of bacterial organic digestion process. The expectation of better quality of community garbage compost would be obtained one way or another.

4. Conclusion

The research is aimed to select the insulated materials in which they were taken in pre-selection of foam, earth soil, rice husk, rice straw, plastic PVC, and cement. Those insulated materials were laminated in frame with the size of 30 cm width, 30 cm length and 2.5 cm thickness (22.5 cm^3/sheet) in order to use for assembling the insulated-cube box (30x30x30 cm^3 or 0.027 m^3). Then after, the density, specific gravity, and averaged thermal conductivity were determined under the laboratory basis. For serving research needs, the amount of 500 g river gravels (number 3) was heated in Hot air oven at 100 ^{o}C for 24 hours before putting in the insulated boxes. The in-box (T1) and out-box (T2) ambient air temperature were recorded by automatic data logger from beginning to the end of experiments. The relationship between time (t) and in-box temperature by graphical techniques in order to select the appropriate insulated material under the criterions of The King's Royally initiative nature-by-nature process, simplicity technology, and low expense (or local materials using for constructing technology), Also, the relations between Q (heat conduction) of temperature differences (in-box and outside box) in varying t (time) as the same as the insulated material thickness was evaluated from graphical products of fixing T (equivalent to 70 ^{o}C) and Q of varying ambient air temperature.

The results found that the rice straw looked better appropriate insulated material rather than rice husk, earth soil, cement, foam, and plastic PVC. Nevertheless, the minimum thickness could be placed on 6 cm in which the in-box temperature could be elongated period for psychrophiles, mesophiles, thermophiles, and hyper-thermopile to complete the digestion of carbohydrates, proteins, celluloses, hemicelluloses, and fibers. So far, the relation between the ambient air temperature and rice-straw insulated thickness that brought to direct how to obtain the insulated thickness in case of ambient air temperature to be identified its level.

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