

Thermal Sorption and Characteristics of Compost Moisture Equilibrium with Relative Humidity under Constant Temperatures.

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ABSTRACT

Laboratory experiments were conducted to study the effect of thermal sorption (ΔH_s) and relative humidity (rh), on the characteristics of the equilibrium moisture content (Θ_r) at constant temperatures (T) K^o for two different types of compost, (compost A: less than 10 mm and referred here as coarse compost, and compost B: less than 4 mm and enriched with mineral fertilizers and re-fermented (referred here as fine compost). Chemical and physical properties for coarse and fine compost were laboratory determined. A modified apparatus was used to measure the temperature and consequently, relative humidity and equilibrium moisture content, for coarse and fine compost, at constant temperatures. Obtained data indicated that, there are considerable differences of chemical constituents and physical properties between the two compost types, in bound and unbound water. The calculated thermal sorption (ΔH_s) values using Clausius – Clapyron equation were, 13.49 kJ/mole at temperature ranged between 293 K^o and 323 K^o for coarse compost, and 14.719 kJ/mole at temperature ranged between 292 K^o and 322 K^o for fine compost respectively. Laboratory data of changing the equilibrium moisture content (Θ_r), and relative humidity (rh), under different constant temperature (T) K^o, were analyzed according to Henderson and Chung – Pfof models for both coarse and fine compost, to identify their equilibrium moisture data (EMD), in terms of constants (β) and (η). Estimated values of (β) and (η) for coarse compost using Henderson formula, were 7×10^{-5} and 1.226 respectively at temperature ranged between 293 K^o and 323 K^o, while for fine compost, (β) and (η) values were 7.86×10^{-5} and 1.258 respectively, at temperature ranged between 292K^o and 322 K^o. For Chung – Pfof model, (β) and (η) values for coarse compost were 96.903 and -0.064 respectively, while for fine compost, (β) and (η) values were 83.778 and -0.085 respectively, at the same conditions. Obtained results indicated that values of equilibrium moisture content (Θ_r), for fine compost were less than that of coarse compost. Equilibrium moisture content (Θ_r) increased with increasing relative humidity (rh), for both coarse and fine compost. This could be attributed to the difference of porosity, pore size, and aggregation for both kinds of compost. With increasing temperature, (Θ_r) decreased and relative humidity (rh) decreased as expected. Henderson and Chung –Pfof models can be used to estimate the (Θ_r) by using EMD (β) and (η) of compost and knowing rh and air temperature. Also, obtained data are essential to determine the optimum conditions for compost storing, the relative humidity must less than 70 % and moisture content less than 22 % and temperature ranged between 20 – 40 C^o

INTRODUCTION

Compost and organic materials manufactures by fermentation method, both from plant residues or municipalities, were increased in the few later years. Particularly troublesome storage compost production of increasing humidity and temperature inside closed warehouse. The long period storage of the product in polyethylene or polypropylene bags often decay and burnet the bags, that have been accentuated the problem. Previous research work in improvement of storekeeping Knowledge, and storage conditions for safe keeping long period, has been extremely limited.

Robert et al., (1984) reported that, in the special case of safe keeping of hygroscopic materials such as organic food product, compost and organic matter, temperature and humidity control is very important in obtaining the desired degree of moisture removal and the proper conditions must be determined from data on the water of dehydration or crystallization as a function of air temperature and humidity.

Composting can be defined as the biological conversion of waste materials into humus-rich, relatively bio-stable product that conditions soil. It is a simple and economically attractive alternative for treating and stabilizing home and agricultural wastes. Accumulation of home and agricultural residues results not only in deterioration of the environment but also in a loss of potentially valuable material. Composting these residues is a promising route especially with the increase in fertilizers price. Ward (2003) reported that, compost and agricultural management practices are important factors that strongly affect soil properties and water entry, and subsequent nutrients cycling processes in the soil profiles. Shehata et al., (1993) and Percival (1984) stated that, an active composting process requires oxygen, moisture, nitrogen, phosphorus, potassium, carbon and a host of trace elements. The critical factor is the relationship between carbon and nitrogen (C/N ratio). In addition to C/N ratio, moisture and air temperature. The minimum moisture content at which microorganisms can live 12-15 percent. Working compost heaps often heat to 160°F.

Sadaka and Sabbah (1999) reported that, concealment compost and crop residues into the soil is consider the most effective method for improving subsurface drainage soil, reducing runoff and soil erosion and increasing the yield. In the other hand, compost considered as one of the most suitable media for breeding and production of mushrooms (fungus) and nursery plants in green houses, which need a desired temperature and relative humidity during their growing stages. Mastalertz (1977) reported that, breeding and production of mushroom (Fungi) required a dark place

with suitable temperature ranging between 15-22% C° and high relative humidity ranging between (85-95%). Therefore, basic data such as physical, chemical and thermal properties of compost or for the selected media are essential in the design of media heating system in greenhouses and in determining the perfect condition to back, store and keep the media in a stable form.

Thermal sorption (ΔH_s) is a measure to water cohesion energy between water and the substance-bounded water. Therefore, its value is very essential by designing desiccation (drying) systems and to desire the optimum crop preparation conditions. Vandan Berg (1984) reported that, the thermal sorption (ΔH_s) and equilibrium moisture content (Θ_r) with relative humidity (rh) are a matter of great interest in many branches of soil science; agricultural products and food processing. Robert et al., (1984) mentioned that, the thermal sorption (ΔH_s) is a measure to water cohesion energy between water and the substance bounded water and its important to determine the perfect condition to store or keep the materials contains moisture in a stable form. In an evaporating process, if an adequate supply of heat is assumed, the temperature and rate at which liquid vaporization occurs well depend on the vapor concentration in the surrounding atmosphere. The relation between thermal sorption (ΔH_s) for substance and relative humidity (rh) was reported by Bakri (2000). He stated that, thermal sorption (ΔH_s) as a function of relative humidity (rh) was computed using the equation proposed by Clausius- Clapyron as follows:

$$\frac{\partial \ln rh}{\partial \left(\frac{1}{T}\right)} = - \frac{\Delta H_s}{R} \quad (1)$$

Where: T is the absolute temperature, (Kelvin), (ΔH_s) thermal sorption at constant moisture equilibrium and its unit (kJ/mole) and R is the gas constant, its value equals to 8.314 (KJ/k mole. K°).

Iglesias and Chirife (1976 and 1984) mentioned that, the soil moisture content (SMC) is considered as an important factor affecting microbial activity, germination, and crop production. (Rizvi, 1995; Alhamdan and Hassan, 1999). Jayas and Mazza (1993) and Yu et al. (1999) reported that, values of equilibrium moisture content (Θ_r) in relation to relative humidity (rh) are essential to desire the optimum conditions for agricultural and food processing and for storing and handling the dried food. Hayes

(1987) reported that microbial activity decreased when the relative humidity (rh) was less than 0.1.

The removal of moisture from a solid is known as drying or dehydration to moisture content in equilibrium with normal atmospheric air (Henderson and Perry, 1955; Ibrahim et al., 1976; Coulson et al., 1978; and Robert et al., 1984). Moisture sorption or dehydration by a solid in equilibrium with humid air is depending upon kind, size and the structure of the solid, and combined by the temperature of the air. It's important to distinguish between hygroscopic, i.e., organic materials and nonhygroscopic materials, i.e., inorganic salts such as copper sulfate. At reduced pressure equilibrium moisture (EM) may be adsorbed as a surface film, or condensed in the fine capillaries of the solid, and its concentration will vary with the temperature and humidity of the surrounding air. However, at low temperatures, e.g., 15 to 50 °C, a plot (EM) verses percent of (rh) is essentially independent of temperature. For nonporous the (EM) is essentially zero at all temperatures and humidities (Robert et al., 1984).

Robert et al., (1984) and Alan et al., (1980), reported that, for safe keeping of hygroscopic materials, temperature and humidity and thermal enthalpy are very important in obtaining the desired degree of the proper conditions must be determined from data on the humidity chart for the air-water system at atmospheric pressure. The enthalpy of moist air may be related to appropriate latent heat and specific heat by the relation:

$$H = c_b (T - T_0) + Y [c_a (T - T_0) + \lambda_0] \quad (2)$$

$$\Delta H_s = H_{dry} + (H_{sat} - H_{dry})(rh) \quad (3)$$

The relations are given in SI units. Enthalpy may be calculated from the equation (3) as a function of air temperature and humidity. Where C_b specific heat of air (29.08 joule/mole °C), C_d specific heat of water vapor (33.89 joule/mole °C), Y is the molal humidity (mols water vapor/ mol dry air), T air temperature °C, T_0 is the base temperature, (0 °C) and λ_0 is the latent heat of evaporation of water at base temperature(T_0), joule/mole (45070 joule/mole), ΔH_s is the enthalpy k joules/mole dry air, H_{sat} enthalpy of saturated air joules/mole dry air H_{dry} enthalpy of dry air (joules/mole dry air).

The removal of water vapor from the evaporating surfaces (leaves and soil) to the free air, is governed by the vapor pressure gradient between surfaces and air by the aerodynamic resistance. The transport happens by the molecular diffusion in the very thin laminar boundary layer, and by turbulence in the free air (Alan et al., 1980; and Gates, 1976). Evaporation processes approaches zero at equilibrium moisture content, which is the lowest moisture content obtainable with solid under the evaporation conditions used. If the material is wet and contacts with air of lower humidity than that corresponding to the moisture content of the solid, the solid tends to lose moisture and dry to equilibrium with the air moisture. When the air is more humid than the solid in equilibrium with it, the solid absorbs moisture from the air until (Θ_r) is attained. Also the mechanism of liquid movement and consequently, the rate of this movement vary markedly with the structure of the solid itself. With solids having relatively large, open void spaces, the movement is likely to be controlled by surface tension and gravity forces within the solid. With solids of fibrous or amorphous structures, liquid movement is by diffusion through the solid. Since the diffusion rates are much slower than the flow by gravity and capillary (Warren and Julian, 1976; Alan, et al., 1980 and Robert et al., 1984).

The relation between the equilibrium moisture content (Θ_r) and the relative humidity (rh) at a constant temperature is governed by many mathematical models. Bakri (2000) stated that, the American Society for Agriculture Engineers ASAE (1991) chosen and considered Henderson and Chung – Pfoest models as the best to determine the moisture equilibrium curve (MEC) which used to describe the relation between (rh) and (Θ_r) for materials adsorb and desorb moisture. The Henderson 1952, Henderson, and Perry 1955 model is defined as:

$$1 - rh = e^{-\beta T \Theta_r^{\eta}} \quad (4)$$

The second model proposed by (Chung - Pfost, 1967 and Pfost et al., 1976) and takes the following form:

$$rh = e^{-(\beta/T) \cdot e^{-(\eta \Theta_r / 100)}} \quad (5)$$

Where: (rh) is the relative humidity in decimal, (Θ_r) is the percentage of the equilibrium moisture content (oven dry weight), (T) is the temperature (K°), (β) and (η) are constants depending on the material and defined as equilibrium moisture data (EMD) for both models. Henderson and Perry (1955) stated that equilibrium moisture data could be reported in terms of the constants (β) and (η). These constants are depending on the material used. They also stated that the equilibrium moisture prosperities of a material are important in storage and drying. If the (rh) of the air in contact with a material is higher than the equilibrium (rh) of the material at its current moisture content, the material will increase in moisture content, the moisture content at the air relative humidity being the value approached. An air relative humidity lower than the equilibrium will cause the moisture

content to decrease.

There are no much scientific works in literature considered the thermal properties of compost. Therefore, the objectives of this study were: (1) to calculate thermal sorption as a function of moisture content, (2) to calculate (β and η) and quantify (Θ_r) for compost, (3) to identify the (Θ_r) from rh and temperature and application of Henderson and Chung – Pfost models by prediction of the thermal properties of compost, and (4) to determine the optimum conditions for backing, storing and handling of the compost in a stable form.

MATERIALS AND METHODS

Preparing the organic matter (compost):

Two types of fermented compost were used. The first compost (A) was primary fermented from solid waste of Alexandria city residual, which sieved using (10 mm) sieve. The second type was taken from compost (A), which sieved using (4mm) sieve, leached with tape water with a ratio of 1:5, and air-dried. Then enriched with mineral fertilizers and refermented and will be referred hereafter as compost (B). The mineral fertilizers (kg / ton) were added according to Shehata et al. (1993) as follows: 50 kg di-ammonium phosphate (18/46/0), 30 kg ammonium nitrate (N 33.5 %), 40

kg potassium sulfate (50% K₂O), 15 kg ferrous sulfate (19% Fe), 10 kg zinc sulfate (22% Zn), 5 kg manganese sulfate (31% Mn), 1 kg copper sulfate (24% Cu), 20 kg Magnesium sulfate (17% Mg), 40 Calcium sulfate, CaSO₄.2H₂O, (gypsum). The fermentation was carried out by putting the mixing in a pile (windrow) with dimensions 1.25m height, 2.25m bottom width, 0.75m top width and 6 m length. Windrow watered and turned in three cycles .The cycle period was 5 days for each. Temperatures were recorded daily using thermocouple.

Chemical and physical analysis:

The chemical and physical properties for compost (A) and (B) were laboratory determined. The chemical properties were (pH; EC (dS m⁻¹), organic carbon, organic matter, total nitrogen, total phosphorous, total potassium, total calcium, total magnesium, ash, Fe, Zn, Mn, and Cu according to Chapman and Pratt (1961), Douglas and Donald (1982) and FAO (1980). The physical properties were carried out according to American Society for Testing and Materials, ASTM (1992).The bulk density (g cm⁻³) was determined according to (ASTM, D 2937-83); and the organic density according to (ASTM D854-41). Organic porosity (void ratio %) was calculated from the relation (Porosity % or void ratio (ε%) = (V_p / V_b) x 100 = (1-(ρ_b/ρ_s)) x100). Saturation percentage as well as, bound and un-bound water were estimated according to ASTM Standards (1992); (ASTM, D 2325- 68), and (ASTM, D 3152 - 72). The percent of reject (more than 4mm) were determined manually by taken fixed weight of compost (A), which sieved using (4mm) sieve .The rest of compost more than 4 mm separates the non-organic substances such as plastic, glass, textile, gravel, minerals and rubber. The reject percentage calculated using the following relation (reject %) = ((weight of non-organic substance / total weight of compost (A)) x 100).

Mathematical and theoretical consideration:

a-Determination of thermal sorption (ΔH_s):

To calculate thermal sorption (ΔH_s) as a function of moisture content from Clausius- Clapyron equation as stated by (Bakri , 2000). The solution of the equation for coarse compost (less than 10 mm) at temperature ranged between 293 K^o and 323 K^o will be in the form

$$\ln\left(\frac{rh_{50c}}{rh_{20c}}\right) = \frac{\Delta H_s}{R} \left[\frac{1}{273.15+20} - \frac{1}{273.15+50} \right] \quad (6)$$

while for the fine compost (less than 4 mm) at temperature ranged between 292 and 322 K° has the form:

$$\ln\left(\frac{rh_{49c}}{rh_{19c}}\right) = \frac{\Delta H_s}{R} \left[\frac{1}{273.15+19} - \frac{1}{273.15+49} \right] \quad (7)$$

b-Determination of equilibrium moisture data (β) and (η):

The ratio of the moisture vapor pressure, to the saturated vapor pressure of pure water at the temperature of the material is called the equilibrium relative humidity (ERH). A plot of (ERH) abscissa and moisture content (ordinate) is known as equilibrium moisture curve (EMC). Many models as mentioned before can define the (EMC). To calculate (β) and (η) values using Henderson Model, it could be written as follows:

$$\ln(1 - rh) = -\beta T \Theta_r^\eta \quad T_1 < T > T_2 \quad (8)$$

$$\ln(-\ln(1 - rh)) = \ln \beta T + \eta \ln \Theta_r \quad T_1 < T > T_2 \quad (9)$$

Equation (9) is a linear equation. When is plotted on log-log scale a straight line is obtained. So, by plotting $\ln(\Theta_r)$ on x-axis and " $\ln(-\ln(1 - rh))$ " on y-axis, we can get straight-line relation. Once we can calculate (β) and (η) values. Where " $\ln(\beta T)$ " in equation (9) is the intercept on y axis and (η) value is the slope of the line.

To calculate (β) and (η) values using Chung- Pfof model .It could be written in the following form:

$$\ln rh = -(\beta / T) e^{(-\eta \Theta_r / 100)} \quad (10)$$

$$\ln(\ln(rh)) = -\ln(\beta / T) + (-\eta \Theta_r / 100) \quad (11)$$

Equation (11) is a linear equation. When is plotted on semi log scale a straight line is obtained. So, values of (β) and (η) can carry out.

Apparatus and measurements:

The apparatus used in this study was described by Mokabel (1988), Bakri (2000) and modified by Mokabel et al. (2004) and illustrated in Fig. (1).

Apparatus:

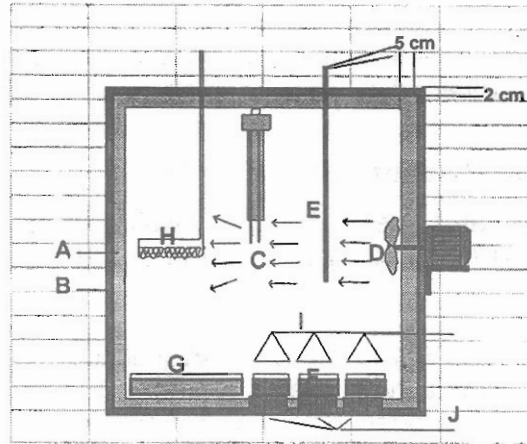
The chamber (A) is made of an isolated material (foam) of 5 cm thickness with inside dimensions of 80 x 80 x 80 cm. The isolated chamber is covered with a wooden box of 2 cm thickness, (B). The chamber is provided with ventilated wet and dry bulb thermometer "Psychrometer", (C) to measure rh inside the chamber. (D) Is an electric fan used for mixing air inside the apparatus, while (E) is a thermometer probe used to measure the temperature of the air. Three replicates of compost sample in three-aluminum cans (F), with a diameter of 12 cm and depth of 4cm, were placed on the bottom of the chamber. (G) Is an aluminum vessel filled with water and is considered as a free water surface. Its dimensions are 25 x 25cm with a depth of 5 cm. The chamber is provided with a heater (H) adjusted to give the desired temperature and clamp (I) is used to hang the sample cans for weighting, to avoid any disturbances for air inside the chamber. At the bottom of the chamber, three perforated holes under the cans were made and plugged to drop cans easily on the balance plate for weighting, and also to avoid any disturbance for air inside the chamber.

Measurements:

Values of (rh) were measured at desired temperature by adjusting the heater inside the apparatus to the desired (T). The compost samples were weighted to determine the moisture equilibrium (Θ_r). Once measuring the air temperature inside the apparatus, (rh) measured from wet and dry bulb thermometer by using "Psychrometer chart", as shown in Figure (2), and determining the (Θ_r) of the compost samples on dry weight basis. The experiment repeated for different selected set of chamber temperature by readjusting the heater for several times to give the desired (T).

Statistical analysis:

To approve the mathematical approach, data of relative humidity, moisture content and temperature were subjected to non-linear regression analysis using SPSS statistical package (SPSS, 10,2002) to estimate (β) and (η) values.



- A) Isolated Chamber B) Wooden Box C) Wet & Dry Bulb Thermometer
 D) Electric Fan E) Thermometer rod F) compost Samples
 G) Free Water Surface
 H) Heater I) Clamp J) Three plugged holes]

Fig. (1): Moisture Equilibrium Apparatus

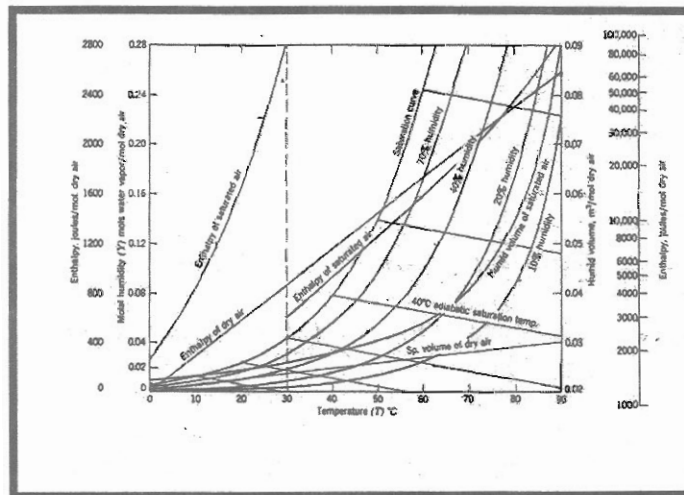


Fig. (2): Psychrometric chart of air-water at atmospheric pressure.

RESULTS AND DISCUSSIONS

1-chemical and Physical analysis of compost (A) and compost (B):

Results of chemical and physical properties of coarse compost (A) and fine compost (B) are presented in table (1). Obtained data indicated that, there are considerable differences of chemical constituents between the two compost types. Generally, coarse compost (A) inhabited lower values of organic carbon; organic matter; total nitrogen; total phosphorous; total potassium; total calcium and total magnesium compared to fine compost (B) as presented in table (1). This is due to that compost (B) enriched with using mineral fertilizers as discussed before. In addition, table (1) shows the physical properties of compost (A) and (B). The bulk density (ρ_b), organic density (ρ_s) and porosity values for coarse compost (A) were 0.575 (g/cm³), 0.955 (g/cm³) and 39.81 %, respectively. The corresponding values for the fine compost (B) were 0.495 (g/cm³), 0.865 (g/cm³) and 42.78 %, respectively. The low value of porosity for coarse compost (A) of 39.81 % is due to the high value of its bulk density (ρ_b). These results were in agreement with Warren and Julian (1976). Values of moisture content (%) on dry and wet weight basis for coarse compost (A) were 22% and 18.5% respectively, while were 24% and 20% respectively for fine compost (B) as presented in table (1). Compost (A) had lower water holding capacity value of 201.5% compared to 224% for fine compost, table (1).

Data of water holding capacity, bound and un-bound water as well the bound water at equilibrium are presented in table (1). The water holding capacity for compost (A) was (201.5%) while was (224%) for compost (B). This means that the saturation percentage was more for compost (B) than compost (A), while moisture equilibrium (Θ_e) value for compost (A) was more than compost (B) at the same range of the relative humidity and temperature by about 3.86%. This may be attributed to the bound water exist in the big size of void volume and the blocked particles of compost (A) than the small void volume between particles for compost (B).

Table (1): Chemical and physical properties of compost (A) and (B).

Organic matter type	Compost (A)	compost (B)
Constituents		
PH (ratio 1:5)	7.64	7.42
Salinity EC, dSm ⁻¹ (1:5)	0.81	3.63
Organic carbon %	23.36	38.58
Organic matter %	40.69	67.20
Total nitrogen %	1.42	2.69
Total phosphorous %	0.46	2.63
Total potassium %	1.33	2.39
Total Calcium %	0.06	1.233
Total magnesium %	0.036	0.36
Ash %	42.42	26.46
C / N	1:16.5	1:14.4
Fe in ppm	2218	3028.7
Zn in ppm	408	2366.3
Mn in ppm	230.3	1315.7
Cu in ppm	220.7	245.5
Moisture content % (dry weight basis)	22-28%	20-24
Moisture content %(wet weight basis)	20 %	18.5%
Bulk density g cm ⁻³	0.575	0.495
Organic density, g cm ⁻³	0.955	0.865
Porosity % (void ratio)	39.81 %	42.78 %
Percent of reject more than 4mm	15%	0.0 %
Sand percent %	5.5 % – 6 %	4.2 % - 5.1 %
Saturation percentage (water holding capacity) %	201.5%	224%
Bound water (%)	121.28	128.18
Un-bound water (%)	80.22	95.82
Bound water at equilibrium (%)	60.19	59.22

It was noticed at fermentation processes to produce matured compost, that the fine particles matured at time less than coarse one because the air moisture diffusion combined with temperature for fine particles progressed more than coarse particles. Also the isotherm distribution for fine one is homogeneous than coarse one. Warren and Julian, 1976, stated that bound water may exist in several conditions. Liquid water in fine capillaries exerts abnormally low vapor pressure because of the highly concave curvature of the surfaces, moisture in cell of fiber and water in natural organic substances.

Unbound water on the other hand exerts its full vapor pressure, and is largely held in the void of the solid. This agree with the obtained data that the total void for (A) compost is less than compost (B) by about 7.46%, and the void volume for compost (A) is larger than compost (B) as presented in table (1). The water holding capacity of compost (B) was more than compost (A) by a percent of 11.16 %. Also the bound water for (B) compost was more than compost (A). At saturation the percent of unbound water equals 95.82% and bound water equals to the rest 128.18% for compost (B). While for compost (A) the percent of unbound water equals 80.22% and bound water equals to the rest 121.28%. At equilibrium all water in pores dried first and remained bound water. So the quantity of bound water at equilibrium for (A) compost equals to 60.19%, while for compost (B) equals to 59.22% approximately as presented in table (1).

2- Thermal sorption (ΔH_s):

Equations (6) and (7) were employed to calculate the thermal sorption (ΔH_s), for coarse compost (A) at temperature ranged between 293 K° and 323 K°, and at temperature ranged between 292 K° and 322 K° for fine compost (B). The calculated values of the thermal sorption were 13.49 kJ/mole and 14.719 kJ/mole for coarse and fine compost respectively, as presented in table (2). This may attribute to the bound and unbound water. The bound water exerts low vapor pressure and unbound water exerts its vapor pressure more than vapor pressure of bound water as stated before. Substances containing bound water are often called hygroscopic substances (Warren and Julian, 1976). The distinction between bound water and unbound water dependent on the material itself, while the distinction between free and equilibrium moisture depends on the evaporation conditions. So, the quantity of heat required to evaporate hygroscopic water for fine or small compost particles is more than coarse particles.

3-Equilibrium moisture data (EMD) under different constant temperature for coarse and fine compost:

The equilibrium moisture curves (EMC), under different constant temperatures for coarse compost (A), and fine compost (B), are presented in Figure (3). The equilibrium moisture content (Θ_r) increased with increasing relative humidity (rh) for both (A) and (B). However, the increasing for compost (A) was more pronounced than compost (B). From Figure (3), (rh) value of compost (A) was 92% and corresponding (Θ_r) value was 48.4%, while for compost (B) was 95 %, and its (Θ_r) was 46.6%. Values of equilibrium moisture content (Θ_r) for compost (A) was more than that of compost (B). This may be attributed to the difference of porosity, pore size and size fraction for both compost types (Warren and Julian, 1976).

Obtained data to identify the characteristics of Equilibrium moisture content; temperature and relative humidity are presented in figures (4) and (5) and tables 3, 4, 5 and 6. Obtained results indicated that, with increasing temperature the equilibrium moisture content (Θ_r) and relative humidity (rh)

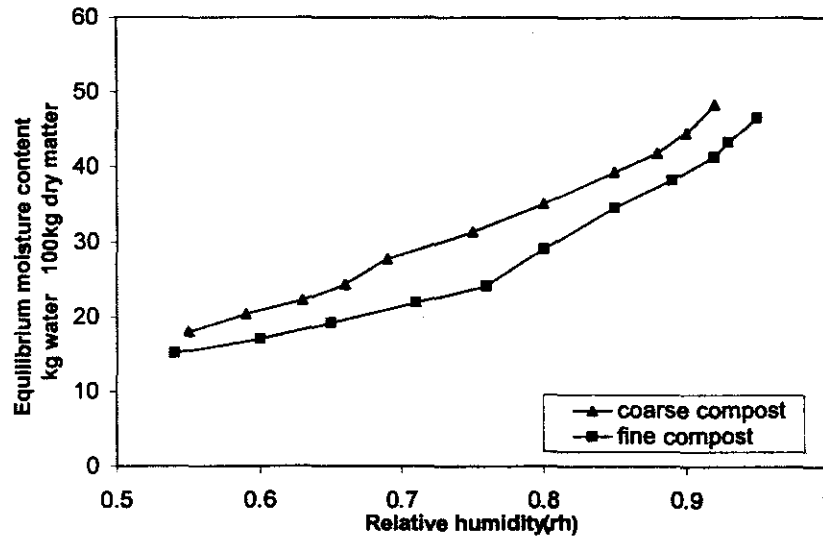
decreased. This is mainly due to that the solids adsorb moisture exerts a moisture vapor pressure, which varies with the moisture content of the material and from material to material (Warren and Julian (1976), Henderson (1952) and Henderson and Perry (1955). This is also in good agreement with Alan et al., (1980) and Warren and Julian, (1976). They stated that, (Θ_r) and (rh) decreased as the temperature increased.

The calculated values of (β) and (η) using Henderson model were 7×10^{-5} and 1.226 at temperature ranged between 293 and 323 K° for compost (A), and were 7.86×10^{-5} and 1.258 at temperature ranged between 292 and 322 K° for compost (B), respectively. While by using Chung –Pfof model values of (β) and (η) were 96.903 and -0.064 for compost (A) and 83.778 and -0.085 for compost (B), respectively. as presented in table (2).

Table (2): Characteristics of moisture sorption for coarse and fine compost.

Type of compost	Thermal sorption (ΔH_s)	Henderson model		Chung –Pfof model	
		(β)	(η)	(β)	(η)
Coarse compost (A)	13.49	7×10^{-5}	1.226	96.903	0.064
Fine compost (B)	14.719	7.86×10^{-5}	1.258	83.778	0.085

As mentioned before, to predict the desired degree of the proper storage conditions, it could be determined from data obtained (enthalpy) and from Figure 2 on the Psychrometric chart for air water system, atmospheric pressure, as well as from equation (2) or equation (3). Directly from the chart, thermal sorption (enthalpy) ΔH_s for fine compost is 13.49 k joules/mole dry air while for coarse compost is 14.719 k joules/mole dry air. The temperature must be less than 50 C° and relative humidity must be less than 70%. The second method by applying eq. 2 – from the chart Y equals to (0.14 mols water vapor/ mol dry air), C_b (29.08 joule/mole C°), C_d (33.89 joule/mole C°), T_o is the base temperature, (0 C°) and λ_o (45070 joule/mole) and the unknown value T air temperature C°. was calculated and equals 55 C° so, the relative humidity will be 70% so the temperature must be less than 50 and relative humidity less than 70%.



Figure(3) : Equilibrium moisture curve(EMC) for coarse and fine compost at 292 K.

The third method by applying eq.3 - and from the chart the adiabatic saturation temperature plotted with 13 or 14 k joule/mole dry air equals to 52 C°, enthalpy of saturated air 18000 joule/mole, the enthalpy of dry air 1700 joule/mole. So the percent of saturation 70% and the temperature 53 C° – so the relative humidity must be less than 70 % and temperature must be less than 50 C°.

Table (3): Characteristics of moisture sorption for Fine compost using Henderson model

Temperature (K°)	Or	rh	η	β
292	46.6	0.95	1.2584	8.16E-05
297	43.4	0.93	1.2584	7.79E-05
299	41.4	0.92	1.2584	7.8E-05
301	38.3	0.89	1.2584	7.46E-05
304	34.7	0.85	1.2584	7.19E-05
306	29.1	0.8	1.2584	7.57E-05
309	24.2	0.76	1.2584	8.38E-05
312	21.9	0.71	1.2584	8.16E-05
316	19.2	0.65	1.2584	8.06E-05
320	17.1	0.6	1.2584	8.04E-05
322	15.2	0.54	1.2584	7.85E-05
307	30.1	0.78	1.2584	7.86E-05

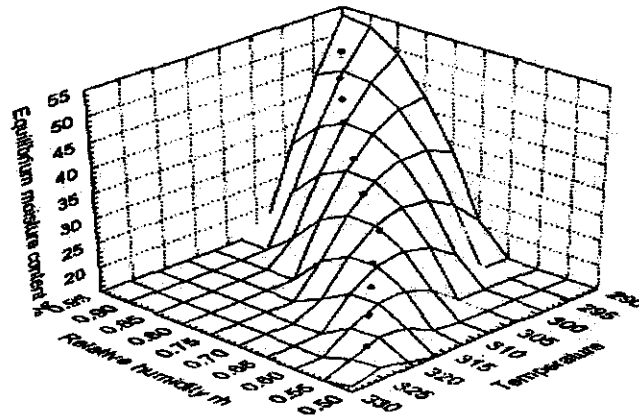


Figure (4): Equilibrium moisture content (%) as affected by relative humidity and temperature (K°) for coarse compost.

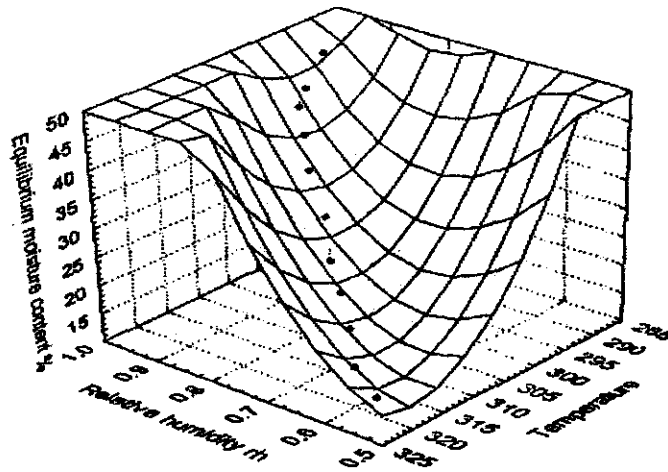


Figure (5): Equilibrium moisture content (%) as affected by relative humidity and temperature (K°) for fine compost

Table (4): Characteristics of moisture sorption for coarse compost using Henderson model.

Temperature (K°)	Θ_r	rh	η	β
293	48.4	0.92	1.226	7.41E-05
295	44.6	0.9	1.226	7.42E-05
296.	41.9	0.88	1.226	7.34E-05
299	39.4	0.85	1.226	7.02E-05
302	35.2	0.8	1.226	6.77E-05
305	31.4	0.75	1.226	6.64E-05
308	27.8	0.69	1.226	6.45E-05
312	24.4	0.66	1.226	6.88E-05
315	22.3	0.63	1.226	7.02E-05
319	20.4	0.59	1.226	6.93E-05
323	18.1	0.55	1.226	7.1E-05
306	32.2	0.75	1.226	7E-05

Table (5): Characteristics of moisture sorption for coarse compost using Chung – Pfof model.

Temperature (K°)	Θ_r	Rh	η	β
293	48.4	0.92	-0.064	25.2
295	44.6	0.9	-0.064	31.982
296.	41.9	0.88	-0.064	38.9335
299	39.4	0.85	-0.064	49.835
302	35.2	0.8	-0.064	68.9259
305	31.4	0.75	-0.064	89.5255
308	27.8	0.69	-0.064	116.341
312	24.4	0.66	-0.064	131.683
315	22.3	0.63	-0.064	147.635
319	20.4	0.59	-0.064	170.528
323	18.1	0.55	-0.064	195.353
306	32.173	0.7473	-0.064	96.9038

Table (6): Characteristics of moisture sorption for fine compost using Chung – Pfof model

Temperature (K°)	Θ_r	Rh	η	β
292	46.6	0.95	-0.085	15.5841
297	43.4	0.93	-0.085	22.3651
299	41.4	0.92	-0.085	25.8259
301	38.3	0.89	-0.085	36.2398
304	34.7	0.85	-0.085	50.8877
306	29.1	0.8	-0.085	69.9954
309	24.2	0.76	-0.085	86.567
312	21.9	0.71	-0.085	108.869
316	19.2	0.65	-0.085	138.372
320	17.1	0.6	-0.085	165.862
322	15.2	0.54	-0.085	200.997
307	30.1	0.7818	-0.085	83.7787

CONCLUSIONS

Agricultural and house residues could be converted to artificial fertilizer through composting process. This is a promising route to face the increase in environmental pollutions sources and in fertilizer prices. For agricultural production under green houses conditions, physical, chemical and thermal properties of compost are essential by designing heating and aeration systems. Compost should be backed in perfectly tightened polyethylene bags at moisture content less than 22 % on dry weight basis. Proper aeration condition is needed to control the environment required for storage process. Compost should be stored in open ventilated and shaded area with relative humidity less than 70 % and temperatures ranged between 20-40 C° and fare away from free water surface.

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الملخص العربي

الامتصاص الحراري و خصائص المحتوى الرطوبي المتوازن مع الرطوبة النسبية
للمادة العضوية المخمرة (الكومبوست) عند ثبات درجة الحرارة

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أجري هذا البحث لدراسة تأثير تغير المحتوى الرطوبي المتوازن (Θ_r) مع الرطوبة النسبية (rh) للكومبوست عند ثبات درجة الحرارة (T) درجة كالفن بهدف 1- دراسة أهم الخصائص الفيزيائية والكيميائية و كذلك الحرارة للكومبوست 2- إيجاد الامتصاص الحراري كداله في المحتوى الرطوبي 3- دراسة مدى ملائمة نموذجين من النماذج الرياضية لاستنتاج ثوابت التوازن للكومبوست 4- إيجاد أنسب الظروف لتعبئة و تخزين و تداول الكومبوست. و لتحقيق هذه الأهداف تم تحضير عينات الكومبوست (خشن أقل من 10م) و (ناعم أقل من 4 مم و تم إعادة كمره بعد معالجته كيميائيا) من المخلفات الصلبة من محافظة الإسكندرية حيث قدرت الخواص الكيميائية والطبيعية و الحرارية لهما ، عند درجات حرارة ثابتة داخل جهاز معزول حراريا و مجهز لهذا الهدف. أوضحت نتائج التحليل الكيميائي زيادة المحتوى من المادة العضوية في الكومبوست الناعم (67.2%) عن الكومبوست الخشن (40.69%) كذلك زيادة نسبة العناصر المعدنية في الكومبوست الناعم عن الخشن. نتائج التحليل الفيزيائي أوضحت زيادة المحتوى الرطوبي و حجم الفراغات و الماء غير المرتبط للكومبوست الناعم (24%) و (42.78%) و (95.82%) علي التوالي عن الكومبوست الخشن (22%) و (39.81%) و (80.22%). أما نسبة التشبع فكانت (224%) للكومبوست الناعم بينما كانت (201,5%) للكومبوست الخشن.

استخدمت النتائج العملية في تقدير حرارة الامتصاص (ΔH_s) كدالة للمحتوي الرطوبي المتوازن باستخدام معادلة كلوزيوس و كلايرون لكلا من الكومبوست الخشن و الكومبوست الناعم ووجدت القيم كالتالي 13.49 (كيلوجول / مول هواء جاف) و 14.719 (كيلوجول / مول هواء جاف) علي التوالي.

هذا و قد تم تقدير قيم الثوابت الحرارية (β) و (η) و التي تتوقف علي نوع الكومبوست باستخدام نموذجين رياضيين هما نموذجا هند رسون ونموذج فوست و كانت قيم كلا من (β) و (η) و علي التوالي باستخدام نموذج هندرسون كالتالي $10 \times 7 \times 10^{-5}$ و 1.226 عند مدي حراري تراوح من 293 إلى 323 درجة كالفن للكومبوست الخشن و $10 \times 7.86 \times 10^{-5}$ و 1.285 عند مدي حراري تراوح من 292 إلى 322 درجة كالفن للكومبوست الناعم ، بينما القيم المقابلة باستخدام نموذج فوست لقيم (β) و (η) هي علي التوالي 96.903 و -0.064 للكومبوست الخشن و 83.778 و -0.085 للكومبوست الناعم. وكما هو متوقع فإن المحتوى الرطوبي المتوازن للكومبوست (Θ_r) أزداد بزيادة الرطوبة النسبية (rh) لكلا النوعان من الكومبوست الخشن و الكومبوست الناعم. أوضحت النتائج أن قيم (η) اعلي للكومبوست لناعم من الكومبوست الخشن عند نفس المدى من درجة الحرارة. المحتوى الرطوبي المتوازن للكومبوست الخشن اعلي من الكومبوست الناعم وهذا راجع إلي الماء المرتبط والماء الغير مرتبط والمسامية وحجم الفراغات لكلا النوعان من الكومبوست ، أيضا مع ازدياد درجة الحرارة انخفاض للمحتوي الرطوبي المتوازن والرطوبة النسبية. يمكن استخدام معادلتني هند رسون و فوست بالتنبؤ بقيم المحتوى الرطوبي للكومبوست عند ثبات الحرارة من معرفة الرطوبة النسبية للهواء. النتائج المتحصل عليها تلعب دورا هاما في تحديد أنسب الظروف لتعبئة و تخزين و تداول الكومبوست حيث وجد ان نسب درجة حرارة تتراوح من 20-40 درجة مئوية والرطوبة النسبية يجب ان تكون اقل من 70% والمحتوي للرطوبي يجب ان يكون اقل من 22%.