International Journal of Mechanical Engineering and Technology (IJMET)
Volume 9, Issue 8, Aug 2018, pp. 1081-1092, Article ID: IJMET_09_08_117
Available online at http://www.iaeme.com/ijmet/issues.asp?JType=IJMET&VType=9&IType=8
ISSN Print: 0976-6340 and ISSN Online: 0976-6359

EFFECT OF PARTICLE THICKNESS AND TEMPERATURE ON THE ENERGY UTILIZATION AND ENERGY UTILIZATION RATIO OF DRYING PROCESS OF ALLIUM CEPA IN A CABINET DRYER

Folayan. J. Adewale, Anawe.A.L Paul
Department of Petroleum Engineering,
College of Engineering, Covenant University, Ota, Nigeria

OSUOLAE F. N
Department of Chemical Engineering,
Ladoke Akintola University of Technology, Ogbomoso, Nigeria

ABSTRACT

The importance of thermodynamic analysis of various energy consuming and energy producing processes as essential tool for system design and optimization of thermal systems in order to achieve design technology and optimum tool performance cannot be underestimated. Hence, this research work examines the energy utilization and energy utilization ratio of drying process of onion fruit (Allium cepa) at different drying temperatures of 65^{O}C, 75 ^{O}C, 85 ^{O}C and 95 ^{O}C and thickness of 0.50cm,1.00cm and 1.50cm in a cabinet dryer with automatic temperature control system.

Preliminary results show that energy utilization and energy utilization ratio increased with an increase in drying air temperature but decreases with an increase in particle thickness. The maximum value of energy utilization was 61.3787 $\left[{}^{KJ}/_{s}\right]$ *and it was obtained at mass flow rate of 6.068 x 10-2kg/s, drying air temperature of 95OC and thickness of 0.50 cm. While the minimum value of energy utilization was 1.0439* $\left[{}^{KJ}/_{s}\right]$ *and it was obtained at mass flow rate of 2.69x10-1 kg/s, drying air temperature of 65OC and thickness of 1.50cm. The highest value of Energy utilization ratio was 0.6914 which occurred at a temperature of 95oC, thickness of 0.50 cm and mass flow rate of 6.068 x 10-2 kg/s while the lowest value of 0.01818 was obtained at drying temperature of 65oC, thickness of 1.50 cm and mass flow rate of 2.690 x 10-1 kg/s.*

Keywords: Cabinet Dryer, Energy Utilization, Energy Utilization Ratio, Allium Cepa, Thermodynamics.

Cite this Article: Folayan. J. Adewale, OSUOLAE F. N and Anawe.A.L Paul, Effect of Particle Thickness and Temperature on The Energy Utilization and Energy Utilization Ratio of Drying Process of Allium CEPA In A Cabinet Dryer, International Journal of Mechanical Engineering and Technology, 9(8), 2018, pp. 1081-1092.
http://www.iaeme.com/ijmet/issues.asp?JType=IJMET&VType=9&IType=8

1. INTRODUCTION

The skyrocketing nature of energy prices in the world is a critical indicator to the fact that only energy efficient and cost effective processes and equipment would remain as time goes by while those that are termed energy-inefficient will naturally go into extinction. An exhaustive method of food preservation exists for lowering the moisture content of various food items obtained from plant sources with a view to inhibiting the rates of biological and chemical reaction that promotes microbial growth and thereby putting them in the required form and shape for possible future consumption. These methods include: direct sun drying, solar drying, lyophilisation or freeze drying, oven drying and most recently osmotic dehydration which involves moisture removal by immersion of water containing cellular solid in a concentrated aqueous solution **[1]**.

Drying in simplest term is defined as the removal of moisture from a wet solid by passing hot air through the solid. The process can be continuous, semi-continuous or a batch process. It is a batch process when the solid material to be dried is exposed to a continuous flow of air stream which dehydrate the water present in the solid and it is a continuous process when both the substance to be dried and the gas stream are passed continuously through the dying equipment **[2]**. The former is operated under unsteady-state condition and the solid material is fed into the dryer until it is dried and the dried product is removed and dryer is filled with a fresh batch while the latter is operated under steady state environment. Two distinct mechanisms have been proposed to define the movement of moisture in a dryer. These are the diffusion theory in which the rate equations similar to those of heat transfer govern the movement of moisture in the air interface and the capillary model which proposes that moisture movement during drying process is controlled by capillary forces arising from small pore spaces between the individual particles **[3]**. A lot of factors control drying rates but the most critical are temperature, feeding rates, humidity, air velocity, air mass flow rate and size of particles. The advantages of drying as stated by **[4-5]** includes tangible reduction in weight and volume of products and thereby reducing packaging, storage and transportation cost and thus enabling the storability of the food product under room temperature without the impending fair of food spoilage by microbes. Cabinet dryers enable us to have an efficient and effective control of various drying parameters such as gas temperature, gas velocity, thickness of solid materials and gas humidity **[6].**

Onion (Allium cepa) (Figure 1) is a vegetable plant that is produced by the bulbs and serves as a very important food item across the globe. In the world, China is the largest producer of onion and next is indian **[7]**. The cost of providing energy is usually a multiple of the cost required to save it, hence energy efficient production process should be embraced as a quick and cheaper source of energy supply **[8]**. Finally, a more economical and feasible method of reducing production cost is improvement on energy efficiency **[9]**.

Figure 1 Allium cepa

2. MATERIALS AND METHOD

2.1. Experimental Procedure

Fresh samples of onion fruit (Allium cepa) were bought from local market in otta, Ogun state, Nigeria. The onion fruits (Allium cepa) were washed with distilled water to remove particles and contaminants that can adversely affect the experimental results.

Hence, 36.50g of Sample of **Allium cepa** at different thicknesses of 0.50cm, 1.00cm and 1.50cm were taken into the cabinet dryer for drying at different temperatures of 65^{O}C, 75 ^{O}C,85 ^{O}C and 95^{O}C and the weight loss at each temperature and thickness was determined with the aid of a digital weighing balance.

Figure 2 Cabinet Dryer

Figure 3 Cabinet Dryer Trays

2.2. Energy Analysis

The energy utilization can be obtained by using equation 1.

$$EU = m_{ai}h_{ai} + m_{pf}\,h_{pf} - m_{ao}h_{ao} - m_{pD}h_{pD} - Q_H \quad (1)$$

Where Q_H= Heat loss through the cabinet dryer due to evaporation.

Neglecting this heat loss, Energy utilization in $\left[{KJ}/{s}\right]$ becomes:

$$EU = m_{ai}h_{ai} + m_{pf}\,h_{pf} - m_{ao}h_{ao} - m_{pD}h_{pD} \quad (2)$$

Assuming that the initial mass flow rate of air is equal to final mass flow rate.

$$m_{ai} = m_{ao} \quad (3)$$

The mass flow rate of fresh and dried products in **kg/s** was calculated using the equation;

$$m_p = \frac{w_{pD}}{t} \quad (4)$$

Where $w_{pD} = weight\ of\ dried\ product\ (kg)\ and\ t = time\ (s)$.

The mass flow rate of products can also be expressed by equation 5.

$$m_p = \frac{U_p w_p}{y} \quad (5)$$

Where w_p = weight of product (kg), U_p = Tray velocity (m/s), y = width of tray (m)

The enthalpy of air was determined by using equation 6 which was proposed by **[10]**

$$h_a = C_a\left(T_a - T_p\right) + h_{fg}w \quad (6)$$

h_a = Enthalpy of air $\left[{KJ}/{Kg}\right]$ T_a = Temperature of air (K), T_p = Temperature of product (K), $h_{fg}w$ = Latent heat of Vapourization of water $\left[{KJ}/{Kg}\right]$ c_a = specific heat of inlet and outlet air $\left[{KJ}/{Kg\,K}\right]$

The enthalpies of the fresh product (h_{pf}) and dried product (h_{pd}) in ${KJ}/{Kg}$ were calculated by using equation 7 and 8 respectively,

$$h_{pf} = c_{pf}\left(T_{pf} - T_\infty\right) \quad (7)$$

$$h_{pd} = c_{pd}\left(T_{pd} - T_\infty\right) \quad (8)$$

Where T∞ is room or reference temperature and is equal to 25^OC or 298k

The specific heat of the fresh and dried product C_p $[^{KJ}/_{Kg}K]$ was also calculated by using the equation 9 proposed by **[11]** as :

$$c_p = 4.187\, X_m + 1.424\, X_c + 1.549\, X_p + 1.675 X_f + 0.837\, X_a \qquad (9)$$

Where X_m = moisture component (%) , X_c = carbohydrate component (%)

X_p = protein component (%), X_f = fat component (%)

X_a = ash component (%)

Hence, the energy utilization ratio was calculated by using equation 10,

$$\text{EUR} = \frac{m_{ai}h_{ai} + m_{pf}hp_f - m_{ao}h_{ao} - mp_d\, mp_d - Q_H}{ma_i(ha_i - h_\infty)} \qquad (10)$$

3. RESULTS AND DISCUSSION

3.1. Specific Heat Analysis of Allium cepa.

The specific heat $c_p\ in \left[^{KJ}/_{Kg}\,K\right]$ was obtained by using Equation 9. Hence, from Table 2, the specific heat was found to decrease with increasing temperature and increased with increasing thickness.

From Mass spectrophotometry analysis, the nutritional composition of Allium cepa is given by Table 1.

Table 1 Nutritional Composition of Allium cepa.

Component	100g	36.50g sample
Moisture/Water	89	32.485
Carbohydrates	9.40	3.431
Protein	1.10	0.4015
Fat	0.10	0.0365
Ash	0.40	0.146
Total	100g	36.50g

Table 2 Specific Heat $\left[^{KJ}/_{Kg}\,K\right]$ of Allium cepa at Different Temperatures and Thicknesses

Temperature(^{O}C)	0.50cm Thickness	1.00cm Thickness	1.50cm Thickness
65^{0}C	3.6924	3.7459	3.801
75^{0}C	3.4450	3.580	3.695
85^{0}C	3.1163	3.4244	3.5965
95^{0}C	2.8294	3.1266	3.3434

3.2. Specific Enthalpy Analysis of Allium cepa.

The specific enthalpy of fresh and dried product in $\left[^{KJ}/_{Kg}\right]$ is given by equation 7 and 8 respectively and the result obtained is shown by Table 7 and 8. From table 3 and 4, it can be observed that the specific enthalpy $\left[^{KJ}/_{Kg}\right]$ increases with increasing thickness and temperature.

Table 3 Specific Enthalpy $\left[{}^{KJ}/_{Kg}\right]$ of Fresh Allium cepa at Different Drying Temperatures and Thicknesses.

Temperature(^{O}C)	0.50cm Thickness	1.00cm Thickness	1.50cm Thickness
65^{0}C	155.28	155.28	155.28
75^{0}C	194.10	194.10	194.10
85^{0}C	232.92	232.92	232.92
90^{0}C	271.74	271.74	271.74

Table 4 Specific Enthalpy $\left[{}^{KJ}/_{Kg}\right]$ of Dried Allium cepa at Different Drying Temperatures and Thicknesses.

Temperature (^{O}C)	0.50cm Thickness	1.00cm Thickness	1.50cm Thickness
65^{0}C	147.70	149.84	152.04
75^{0}C	172.25	179.00	184.75
85^{0}C	186.98	205.46	215.80
95^{0}C	198.06	218.86	234.04

3.3. Energy analysis

3.3.1. Energy Utilization

The Energy Utilization of the cabinet dryer was calculated from Equation 1.

The energy utilization was found to increase with temperature and drying time but showed a reverse scenario with Allium cepa thickness and mass flow rate of dried product because uniform heat distribution exists with smaller particle size than at higher thicknesses (Figure 4,5,6 and 7).

In order words, more energy was utilized at higher temperature and time than at lower ones.

Meanwhile, drying air temperature of 95^{O}C showed the highest value of energy utilization of 61.3787 $\left[{}^{KJ}/_{s}\right]$ at mass flow rate of 6.068 x 10^{-2}kg/s and 0.50cm thickness. Whereas, the lowest value of energy utilization of 1.049 $\left[{}^{KJ}/_{s}\right]$ was obtained at drying air temperature of 65^{O}C, thickness of 1.50cm and mass flow rate of 2.690x10^{-1} kg/s and thickness of 0.50cm **[12-13]** reported a similar result during thermodynamic investigation on the drying process of carrot in a continuous dryer and thin layer drying of berberis respectively

The energy utilization has a direct relationship with the mechanisms of moisture movement in a cabinet dryer.

Table 5 Energy utilization of Allium cepa at 65^{0}C in $\left[{KJ}/{s}\right]$.

Time (S)	0.50cm Thickness	1.00cm Thickness	1.50cm Thickness
900	2.5938	1.8585	1.0439
1200	3.3589	2.5237	1.5502
1500	4.3426	3.3553	2.1689
1800	5.5449	4.3532	2.9003
2100	6.9657	5.5175	3.7441
2400	8.6052	6.8480	4.7004
2700	10.4633	8.3449	5.7693
3000	12.5399	10.0635	6.9506
3300	14.8352	11.7821	8.1882
3600	17.3491	13.6671	9.4821

Table 6 Energy utilization of Allium cepa at 75^{0}C in $\left[{KJ}/{s}\right]$.

Time(s)	0.50cm Thickness	1.00cm Thickness	1.50cm Thickness
900	6.9214	4.8733	2.9356
1200	8.3235	6.1316	3.9609
1500	10.1080	7.7212	5.2597
1800	12.2749	9.64182	6.4218
2100	14.8242	11.8936	8.2675
2400	17.7559	14.4766	10.3865
2700	21.0700	17.3907	12.7107
3000	24.7665	20.6360	15.4449
3300	28.8454	24.2124	18.3844
3600	33.3066	28.1199	21.5972

Table 7 Energy utilization of Allium cepa at 85^{o}C in $\left[{KJ}/{s}\right]$.

Time(s)	0.50cm Thickness	1.00cm Thickness	1.50cm Thickness
900	14.2072	8.9374	5.5823
1200	16.5594	11.2180	7.5784
1500	19.4650	14.0307	10.0537
1800	22.9242	16.9195	12.5289
2100	26.9367	20.7965	15.9623
2400	31.5028	25.2057	19.8747
2700	36.6223	30.0709	24.1864
3000	42.2953	35.6205	29.1368
3300	45.4085	38.2051	30.8935
3600	48.52172	40.7138	32.4904

Table 8 Energy utilization of Allium cepa at 95°C in $\left[{}^{KJ}/{}_{s}\right]$.

Time(s)	0.50cm Thickness	1.00cm Thickness	1.50cm Thickness
900	22.6857	16.7123	11.9147
1200	26.3498	20.3563	15.2919
1500	30.8933	24.8911	19.5350
1800	36.3162	30.3166	24.6441
2100	42.6185	36.6329	30.6192
2400	49.8001	43.8399	37.4602
2700	53.4642	48.6825	45.1671
3000	56.6886	51.1280	47.3319
3300	59.0337	54.6101	49.3237
3600	61.3787	56.3916	50.5360

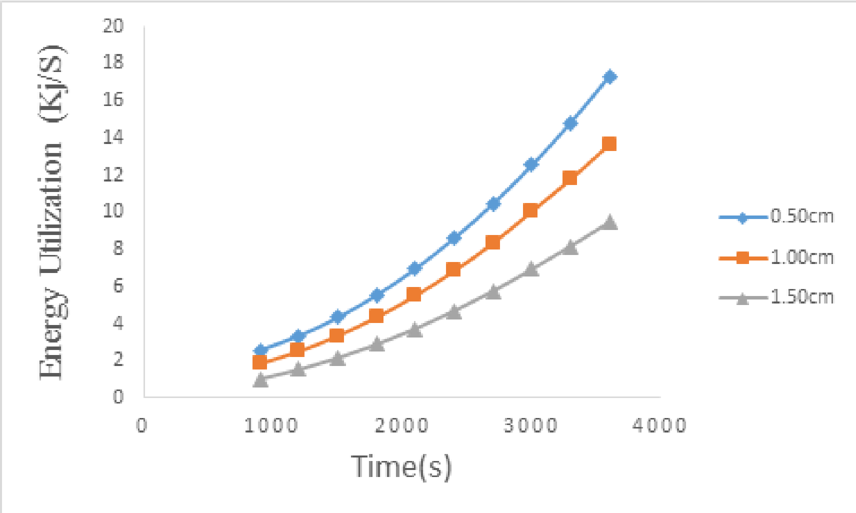

Figure 4 Energy Utilization at 65^{O}C

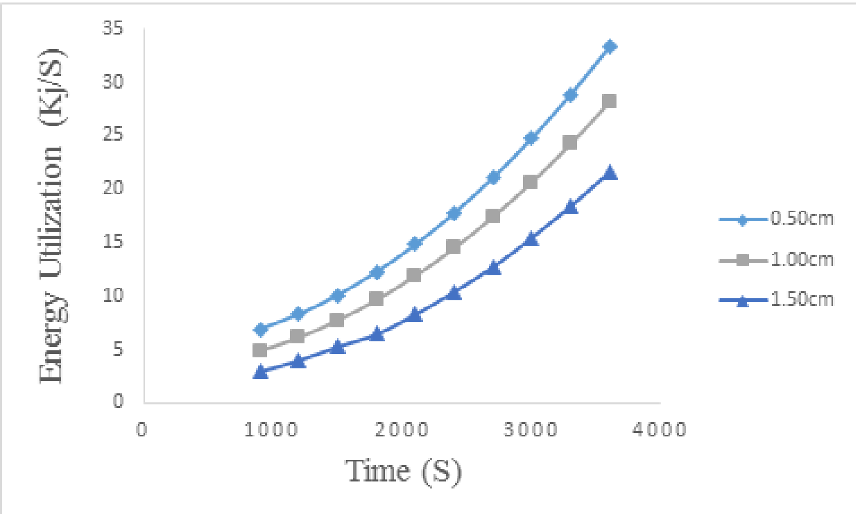

Figure 5 Energy Utilization at 75^{O}C

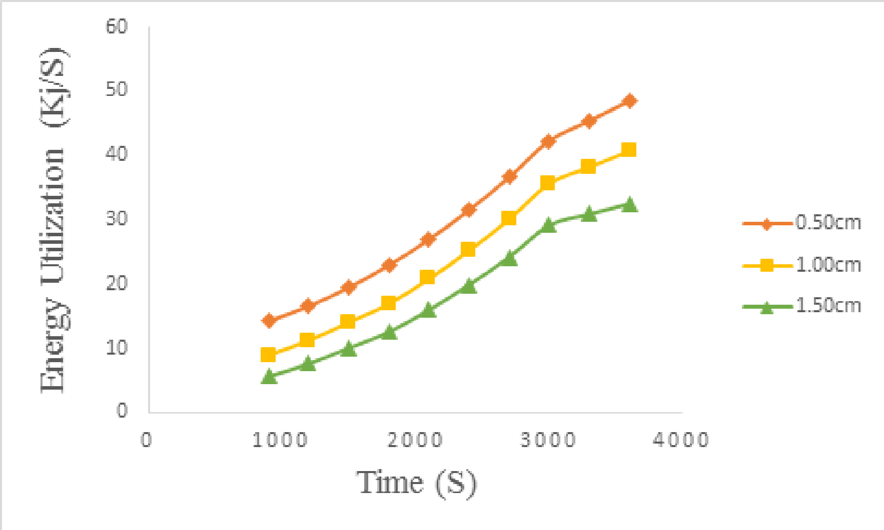

Figure 6 Energy Utilization at 85^{O}C

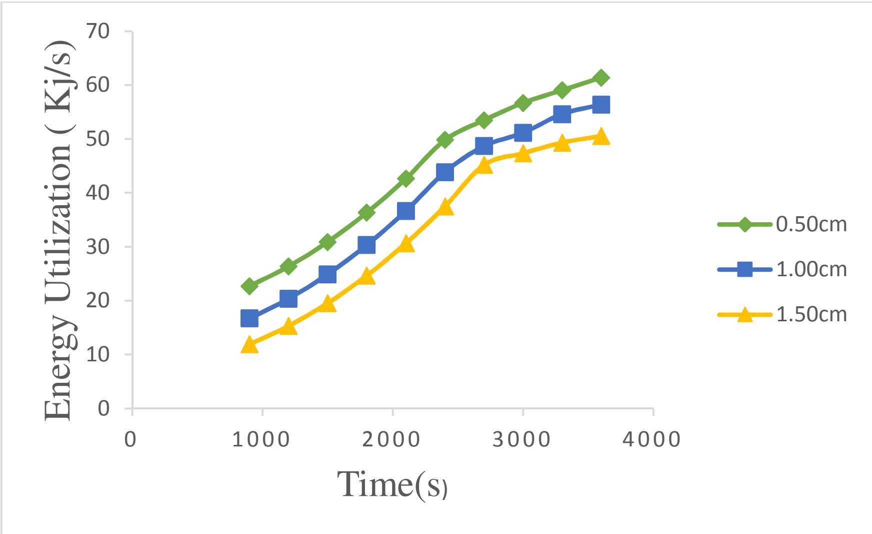

Figure 7 Energy Utilization at 95^{O}C

3.4.2. Energy utilization ratio

The energy utilization ratio (EUR) of the cabinet dryer was calculated by using Equation 10.

Observation of Figure 8,9,10 and 11 shows that the energy utilization ratio (EUR) increased with increase in drying air temperature and time but reduced as Allium cepa particle thickness increases. The critical moisture content will increase with increased drying rate and thickness of solid particles and thus resulting in low energy utilization ratio.

The low value of energy utilization ratio (EUR) of 0.01818 obtained at thickness of 1.50cm and drying air temperature of 65^{O}C is a principal pointer to the fact that energy is still available in the outlet air **[14]**. However, the maximum value of energy utilization ratio of 0.6914 was obtained at drying air temperature of 95^{O}C and thickness of 0.50cm. Identical scenario has been experienced by **[15-16]**.

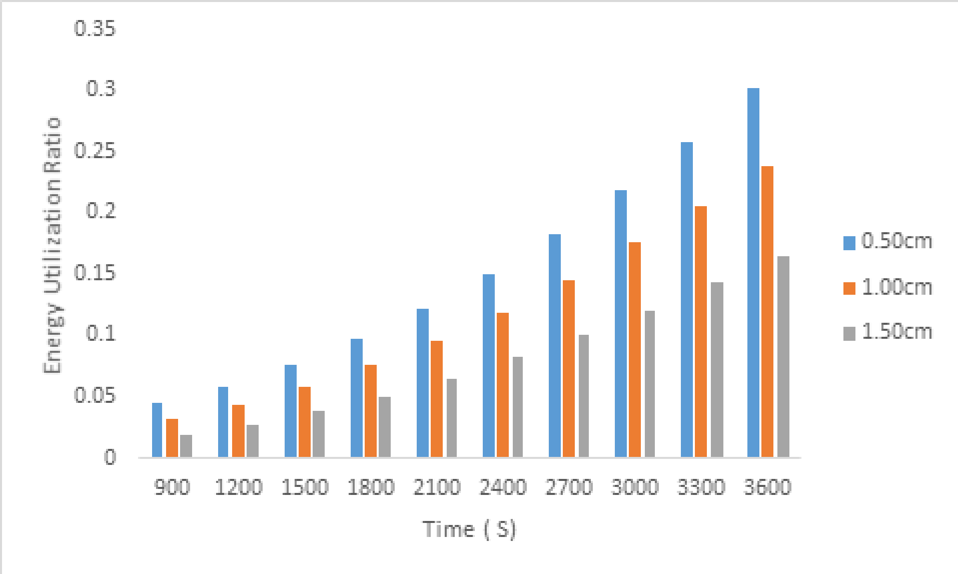

Figure 7 Energy Utilization Ratio at 65^{O}C

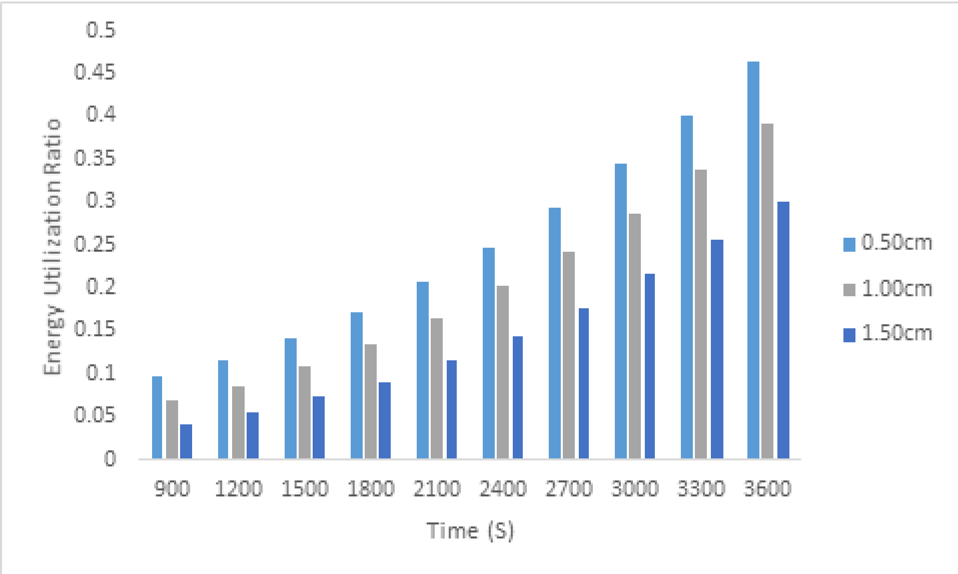

Figure 8 Energy Utilization Ratio at 75^{O}C

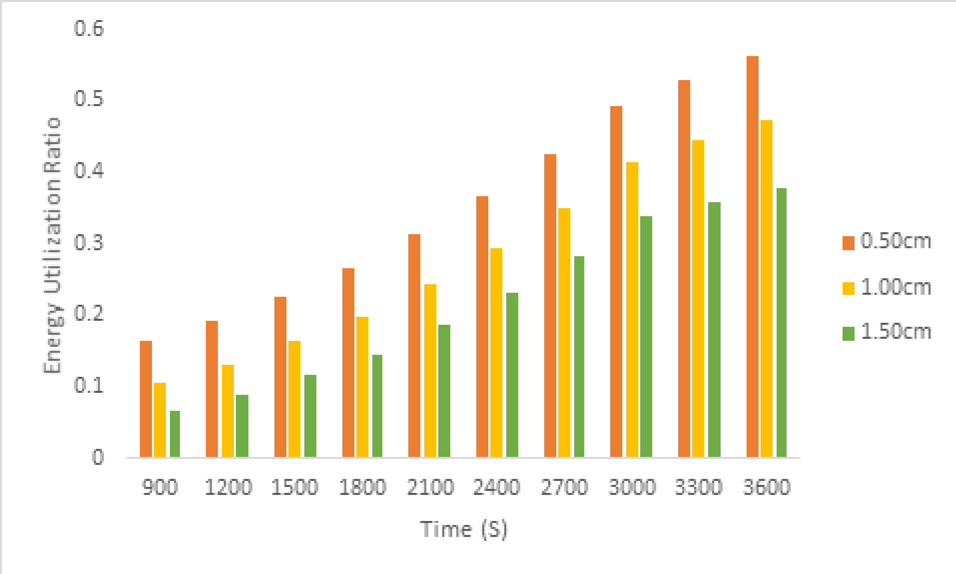

Figure 9 Energy Utilization Ratio at 85^{O}C

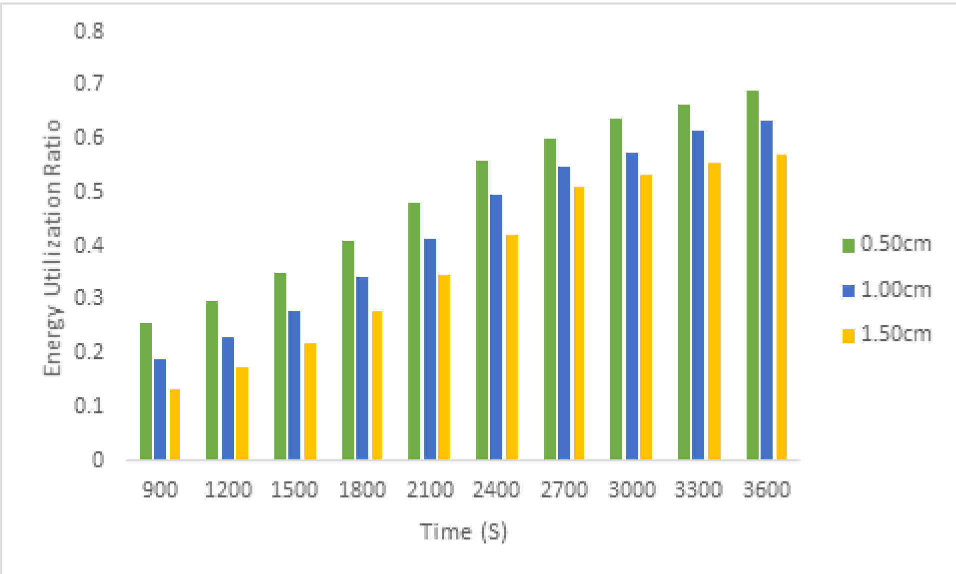

Figure 10 Energy Utilization Ratio at 95^{O}C

4. CONCLUSION

The following inferences can be drawn from the investigation of the energy analysis of Allium cepa in a cabinet dryer.

- The specific enthalpy of both the fresh and dried products increases with temperature and thickness.
- The energy utilization (EU) and energy utilization ratio (EUR) increased with an increase in drying air temperature and time but reduced as particle thickness increases.
- The energy utilization (EU) and energy utilization ratio (EUR) increases as mass flow rate of Allium cepa increases.

ACKNOWLEDGEMENTS

The authors are very grateful to the Chancellor of Covenant University and the university management team for their unalloyed and continuous support for research and development without which this research work would not have seen the light of the day.

REFERENCES

[1] Pointing J. D. (1973). Osmotic Dehydration of fruits. Recent Modification and Application. Proc.Biochem, Vol 8, pp 18-20.

[2] Treybal, R. E (1981). Mass Transfer Operations. Third Edition, MC Graw Hill Books Company, Singapore. pp 655-686.

[3] Richardson, J.F, Harker J.H and Backhurst J.R (2002). Coulson and Richardson's Chemical Engineering: Particle Technology and Separation Processes. Volume 2, Fifth Edition, Butter Worth-Heinemann Publishers, Oxford. pp 901-967.

[4] Brooks M.S, Abouel-Hana N.H and Ghaly A.E (2008). Effects of Tomato Geometries and Air Temperature on the Drying Behaviour of Plum Tomato. American Journal of Applied Sciences Vol 5: pp 1369-1375.

[5] Demir, K & Saçılık, K (2010). Solar Drying of Ayaş Tomato Using a Natural Convection Solar Tunnel Dryer. Journal of Food, Agriculture and Environment. Vol 8 (1): pp 7-12

[6] Dryer.com (2017). Cabinet Dryers. http://dryer.com/dehydrators/cabinet_dryers.html. (accessed December 10, 2017)

[7] Food and Agricultural Organization (2017). Onion(dry) production in 2016. Food and Agriculture Organization, Statistics Division (FAOSTAT). "Onion (dry) production in 2016: Crops/World Regions/Production Quantity from pick lists"

[8] [8] Oyedepo S.O. (2012). Efficient Energy Utilization as a Tool for Sustainable Development in Nigeria. International Journal of Energy and Environmental Engineering. Vol 3, Issue 11, pp 1-12.

[9] Ayoola A.A, Oresegun O.R, Oladimeji T.E and Eneghalu C (2016). Energy Analysis of Biodiesel Production from Waste Ground Nut Oil. International Journal of Research in Engineering and Applied Sciences. Vol 6, Issue 1, pp 202-208.

[10] Akpinar, E.K., Midilli, A.O and Bicer, Y.A, (2006). The First and Second Law Analyses of Thermodynamic of Pumpkin Drying Process. Journal of Food Engineering. Vol 72 (4), 320–331.

[11] Choi, H.K and Okos M.R. (1986). Effects of Temperature and Composition on the Thermal Properties of Foods. Food Engineering and Process Applications. Vol 1 pp 93-101. London: Elsevier Applied Science Publishers.

[12] Aghabashlo, M., Kianmehr, M.H.and Arabhosseini, A (2009). Performance Analysis of Drying of Carrot Slices on a Semi-Industrial Continuous Band Dryer. Journal of Food Engineering. Vol 91, pp 99–108.

[13] Aghbashlo, M., kianmehr, M.H. and Samimi-Akhijahani, H., (2008). Influence of Drying Conditions on the Effective Moisture Diffusivity, Energy of Activation and Energy Consumption During the Thin-Layer Drying of Berberis Fruit (Berberidaceae). Energy Conversion and Management. Vol 49 (10), pp 2865–2871.

[14] Corzo, O., Bracho, N., Vasquez, A., and Pereira, A., (2008). Energy and Exergy Analyses of Thin Layer Drying of Coroba Slices. Journal of Food Engineering Vol 86, pp151–161. Demuth, H., B.

[15] Akpinar, E.K., (2004). Energy and Exergy Analyses of Drying of Red Pepper Slices in Convective Type Dryer. International Journal of Heat and Mass Transfer. Vol 31 (8), pp 1165–1176.

[16] Akpinar, E.K., Midilli, A.O and Bicer, Y.A, (2005).Energy and Exergy of Potato Drying Process via Cyclone Type Dryer. Energy Conversion and Management. Vol 46 (15), pp 2530-2552