The study of the factors affecting density of locally made bio-resin from raw banana peels

Mwesigwa R, Mwasiagi J. I., Nzila C., Oyondi E., Githaiga J. T.

Abstract— Density measurements are very useful for identification and characterization of different substances. It is a very important physical parameter in polymer engineering affecting production cost and profitability of the manufacturing process. A reduction in density reduces the raw material cost hence decreases the manufacturing costs. Therefore, the aim of this research was to study the factors affecting density of locally made bio-resin from raw banana peels. The raw banana peels were washed, boiled, pureed and treated with various ratios of glycerin to obtain a thermoplastic bio-resin. The effect of temperature, time, resin quantity, glycerin and water on bio-resin density were studied through use of the central composite rotatable experimental design and regression analysis. Second order polynomial regression equation for density was fitted and exhibited an R^2 value of 83.4%. From the predictive model, it was evident that to obtain the objective of density minimization, temperature , time, resin and water ratios needed to be increased up to optimal values. However, glycerin ratio required to be eliminated from the model since increase led to increase in density. However, the top five density alternative solutions presented in this research paper permitted room for particular glycerin ratios to be maintained. The developed banana peels resin had a density of 0.83g/cm^3. This density value is above that of tapioca as a bio-resin and close to that of polypropylene as a synthetic resin, both commercially used in bio-composites development.

Keywords —Banana peels, bio-resin, density, regression analysis.

I. INTRODUCTION

Density is a physical property of matter that expresses a ratio of mass to volume. The density depends on the atomic mass of an element or compound. Other factors affecting density include water, glycerin, bio-resin ratios; temperature and time. Density measurements are very useful for identification and characterization of different substances. [1] It is a very important physical parameter in polymer engineering affecting production cost and profitability of the manufacturing process. [2] A reduction in density reduces the raw material cost and therefore decreases the manufacturing costs. [3] Therefore, it is very important to measure the density of polymers with good accuracy using a pycnometer, densymeter, areometer and ultrasonic pulse echo method. These instruments are usually used for measurement of liquid materials density under laboratory conditions. [4]

The densymeter and aerometer are instruments for measuring the density or specific gravity of a solid or liquid substance. The most commonly used densymeters are based on the principle of vibrating tubes. [5] These meters have major drawbacks. They are limited to pipe diameters below 60 mm and high pressure losses occur during the measurements. Also, aerometers and ultrasonic pulse echo methods are expensive. So, it can be suggested that the most appropriate method to measure the density of the locally made bio-resin is the pycnometer or specific gravity bottle method. The pycnometer is an instrument used for measuring fluid density based on Archimedes' principle. [1]

Thermoplastic materials lately dominate as resins for bio-composites production. Among these resin materials, polyetherethrketone (PEEK) is most widely used in bio-composites development. Epoxy, which has higher adhesion and less shrinkage than PEEK, stands second for its high cost. [6], [7] However, biodegradable resins are explored as the best forms of polymers for composites apart from their synthetic alternatives, which are non-renewable. The best known renewable resources capable of making bio-degradable thermoplastics are starch. It is one of the least expensive material available on the global market. Bio-resins from different starch sources including potatoes, maize corn and wheat have been studied and used in bio-composites development. [8] Unfortunately, these starch sources are global food items. However, raw banana fruits possess about 20% starch whereas ripe bananas have starch content between 11-13%. Raw banana peels possess 3% starch, which reduces to between 1% - 2% in ripe banana peels. [9], [10] Although ripe banana peels have been used for production of bio-plastics with a potential for use in insulation and cosmetic prosthetics, [11] raw banana peels have more starch than ripe peels. Several other studies on bio-degradable resins and their properties have been done. [12] – [14] But no literature exists on the density of bio-resins from locally made bio-resin from raw banana peels.

II. MATERIALS AND METHODS

A) *Banana peels bio-resin development*

Raw banana peels were obtained from Kyambogo University, Kampala (Uganda). The peels were weighed as 3kgs that were later washed and boiled in a saucepan using a charcoal stove. At boil, the water was drained from the saucepan leaving only the softened raw banana peels that were allowed to cool for 10 minutes. The peels were then chopped into smaller pieces, and placed in a blender for pureeing to obtain the banana peels fluid paste. 250milli-litres of water were added in 500grams of raw banana peels in the blender for easy pureeing. The blender capacity being 1 litre required appropriate measurements that could fit the amount of chopped banana peels and water at a time. This explains the use of selected chopped banana peels and water measurements above. Five litters of the fluid paste obtained were stored in a freezer and tested over a period of two days. The fluid paste was treated with various ratios of

Mwesigwa Ronald; Department of Manufacturing, Industrial and Textile Engineering, Moi University; Department of Chemistry, Kyambogo University; (+254728280217 / +256776854788, mwero2k@gmail.com)

Mwasiagi Josphat Igadwa, Nzila Charles, Oyondi Eric, Githaiga John; Department of Manufacturing, Industrial and Textile Engineering, Moi University.

glycerin supplied by Desbro Uganda limited, before testing. Glycerin was selected over other plasticizers as it is a by-product waste material in the bio-fuel industry that prevents brittleness and increase flexibility of the final bio-product. [15], [16]

B) Banana peels bio-resin characterization

The pycnometer, Mettler Toledo balance, measuring cylinders, glass containers and oven for bio-resin characterization were obtained from The Uganda Industrial Research Institute. Various resin, glycerin and water ratios were mixed in glass containers. The test samples were introduced to controlled temperatures in an oven over set time intervals. The density of starch samples was determined using a pycnometer according to ASTM standard D854-2010. This is a flask with a close-fitting ground glass stopper with a fine hole through it, so that a given volume can be accurately obtained. This enables the density of a fluid to be measured accurately, by reference to an appropriate working fluid such as water, using an analytical balance. If the flask is weighed empty, full of water, and full of a liquid whose density is desired, then the density can easily be calculated. Density was measured in grams/cm^3 [17] Three readings per experiment were taken and the average density considered.

Table I presents density properties of selected commercial resins used globally in composites development. This provides a basis for comparison between these synthetic and bio-resins with the locally made bio-resin from raw banana peels. As can be noted, the densities range between 0.7g/cm^3 to 1.46g/cm^3 that provides a comparison range for the developed and optimized bio-resin. This will also be critical in determining the bio-resin end uses in relation to the density properties of other commercially available resins.

Table I: Density properties of common commercial resins

Matrices/Resins	Density (g/cm^3)	Reference
THERMOSETS		
Epoxy @ 25^{0}C	1.06 – 1.18	[18]
Green epoxy @ 25^{0}C	-	[19]
Polyester	1.12 - 1.46	[20]
Phenolic	-	[21]
THERMOPLASTICS		
Urea formaldehyde	1.0 – 1.3	[22]
Polypropylene	0.85 – 0.96	[20]
Poly vinyl alcohol	1.3	[20], [23]
Cornstarch	1.21	[20], [23]
Tapioca @ 113^{0}C	0.7	[20], [23]

C) Bio-resin experimental design and optimization

Previous studies reveal that modern design of experiments, regression analysis and optimization of various responses can be achieved through computer software programs including Matlab, SAS, Design Expert, Monte Carlos and Minitab. [24] – [27] Therefore, using design of experiments under Minitab 17.0.1, response surface designs were selected. However, the central composite half unblocked rotatable design was preferred over other experimental designs because of a few factors involved and optimization of a new experimental method required. [28] 5 factors at 5 levels were employed according to the design display to obtain a total of 32 experimental runs. In order to achieve a wider sample size for better regression and optimization analysis, 3 replicates were considered hence a total of experimental 96 runs were used. Each run was weighed three times using a pycnometer and the average density recorded. Table II represents the relationship between factors and levels relating to the input data. The alpha (α) value was generated by Minitab automatically as 2.

Table II: Relationship between factors and levels

Factors		Levels				
		-α	**Low**	**Optimum**	**High**	**+α**
Coding		2	-1	0	1	2
Temperature (^{0}C)	X_1	25	40	60	80	100
Time (min)	X_2	20	30	40	50	60
Resin (mls)	X_3	20	40	60	80	100
Glycerin (mls)	X_4	0	10	15	20	25
Water (mls)	X_5	0	10	15	20	25

The effects of several factors as outlined in the experimental design and table II can be investigated using multiple regression models, a well-established statistical tool. [29] The second order polynomial regression equation below was used to fit the model whereby Y = Density, b_0 = Constant, b_1 to b_{20} = Model coefficients and X_1 to X_5 = Factors.

$$Y = b_0+b_1X_1+b_2X_2+b_3X_3+b_4X_4++b_5X_5+b_6X_1^2+b_7X_2^2+b_8X_3^2+ b_9X_4^2+b_{10}X_5^2+b_{11}X_1X_2+b_{12}X_1X_3+b_{13}X_1X_4+b_{14}X_1X_5+b_{15}X_2X_3+ b_{16}X_2X_4+ b_{17}X_2X_5+ b_{18}X_3X_4+ b_{19}X_3X_5+ b_{20}X_4X_5 \ldots\ldots\ldots\ldots(1)$$

III. RESULTS AND DISCUSSION

A) Banana peels bio-resin experimental data

From design of experiments under Minitab 17.0.1, an experimental datasheet at 5 factors and 5 levels was obtained. The entire test samples were subjected to different ratios of temperature (X_1), time (X_2), resin (X_3), glycerin (X_4), and water (X_5) as the input to study their effect on density (Y) as the output of the locally made bio-resin from banana peels. It was noted that each individual combination yielded different results of density. Central rotatable composite design was used to identify the five parameter combination sets that produced the most optimized sets in terms of yield. Modeling of the influence of the above factors and sensitivity analysis on the bio-resin properties was done using multiple regression analysis. A multiple regression model was developed for the yield in density of the bio-resin. According to the multiple regression report card obtained, the sample data of 96 points was a precise estimate of the strength of the relationship. There were no unusual data points to have a strong influence on the results. Furthermore, the normality test was passed since more than 15 data points were used.

B) Density of developed banana peels bio-resin

The objective of the density was to minimize yield attributed to reduction in final product density and costs. Therefore, the generated second order polynomial regression equation below, was employed for density yield minimization.

$$\mathbf{Y} = 1.0566 - 0.000479X_1 - 0.005639X_2 - 0.001164X_3 - 0.00699X_4 + 0.01604X_5 + 0.000010X_1^2 + 0.000051X_2^2 + 0.000011X_3^2 - 0.000210X_5^2 + 0.000017X_1X_2 - 0.000007X_1X_3 - 0.000038X_1X_4 - 0.000057X_1X_5 + 0.000122X_2X_4 - 0.000094X_2X_5 + 0.000068X_3X_4 - 0.000051X_3X_5 \quad (2)$$

According to the density model summary report, the model strength (R^2) exhibited was acceptable at 83.4%. This means that 83.4% of the variations in density (Y) could be explained by the regression model. The regression model was used to design a prediction and optimization report for density of the developed banana peels bio-resin to minimize density yield. Optimal settings (table III), the top five alternative solutions closest to the optimum settings (table IV) and sensitivity for the optimum solution (Fig. 1) below were also obtained.

Table III: Density prediction and optimization report

Goal: Minimize density		**Solution: Optimal settings**			
Predicted density	0.834	X1	75.5	X4	0
95% PI	(0.796, 0.872)	X2	60	X5	25
		X3	100		

Table IV: Density values close to optimal settings

X1	X2	X3	X4	X5	Predicted Y_1
60	40	60	15	25	0.915
80	30	30	20	20	0.925
80	50	80	20	20	0.929
80	30	80	10	20	0.932
40	50	80	10	120	0.933

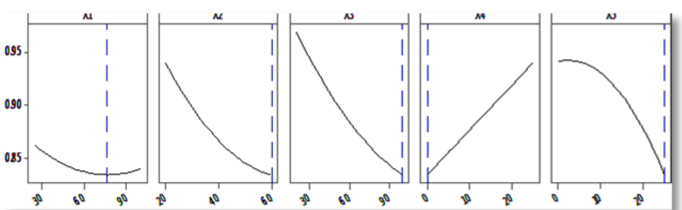

Fig. 1: Settings and sensitivity for density optimal solution

From table III and IV, the optimal settings required for obtaining the minimum density for this banana peels bio-resin, which was 0.83g/cm^3 between predicted intervals of 0.796g/cm^3 to 0.872g/cm^3 were presented. The top five predicted alternatives are between 0.92g/cm^3 to 0.93g/cm^3 hence fall in the range of polypropylene thermoplastic resins. The alternatives could be considered in case the optimal settings were not viable in reality. From the predictive model, it was evident that to obtain the density objective of yield minimization, temperature (X_1), time (X_2), resin (X_3) and water (X_5) quantities had to be increased up to the optimal values. However, glycerin quantity (X_4) required to be eliminated from the model since increase leads to increase in density as evidenced by fig. 1 above.

1) Bio-resins density results discussion

Lower density yields relate to reduction in final product density and costs. This is according to [30], [31]. Therefore, a bio-resin with optimum properties would be termed as one with relatively low-density range of values. The density value of 0.83gms/cm^3 within a predicted interval of 0.796 g/cm^3 and 0.872 g/cm^3 is above tapioca bio-resin density and also falls in the range of low density polypropylene employed in composites development. However, the top five alternative solutions ranging between 0.92gms/cm^3 and 0.93gms/cm^3 are in the same range as High Density Polypropylene (HDPE). These facts are stipulated in table I above. Tapioca and polypropylene are commercial resins that have been used in natural fibre reinforced composites. [32, [33]

IV. CONCLUSION

A viable locally made bio-resin from raw banana peels has been developed and characterized. The predictive regression used exhibited an R^2 value of 83.4% implying that 83.4% of the variations in the density yield could be explained by the model. An optimum density value of 0.83g/cm^3 within a predicted interval of 0.796 g/cm^3 and 0.872 g/cm^3 was obtained. This bio-resin's density is above that of tapioca and in close proximity to polypropylene that have been used in bio-composites development.

ACKNOWLEDGEMENT

We are grateful for the financial assistance extended to us by the European Commission through the Mobility for Enhancing Training of Engineering Graduates in Africa (METEGA), without which this research work will not have been undertaken.

REFERENCES

[1]. R. Kažys, R. Rekuvienė. Viscosity and density measurement methods for polymer melts. 2011. pp. Vol. 66, No. 4.
[2]. A. Puttmer, P. Hauptmann, H. Henning. Ultrasonic density sensor for liquids/ IEEE transactions on ultrasonics, ferroelectrics and frequency control. 2000. Vol. 47. P. 85-91.
[3]. Zahra, A. N. In-process density control of extruded foam PVC using wavelet packet analysis of ultrasound waves. s.l. : Mechatronics. Vol. 12. pp. 1083- 1095., 2002.
[4]. A. N. Zahra. Measuring melt density in polymer extrusion processes using shear ultrasound waves. s.l. : Int. J. of Adv. Manufac. Tech, 2004. Vol. 24. No. 9-10. pp. 661-666.
[5]. Jasiūnienė, E. Ultragarsinė medžiagotyra: Mokomoji knyga. Kauno Technologijos Universitetas. 2007.
[6]. Recent Development in Natural Fibre Reinforced Polypropylene Composites. Malkapuram. R, Kumar, V and Yuvraj, S N,. 2008, Journal of Reinforced Plastics and Composites, pp. Vol. 28, Pg. 1169-1189.
[7]. Review on comparative evaluation of fiber reinforced polymer matrix composites. Arpitha.G.R, Sanjay.M.R and Yogesha.B. 2014, Advanced Engineering and Applied Sciences: An International Journal , p. 4 (4): Pg. 44.
[8]. Arikan, A. "Bio-plastics.". s.l. : Packaging Bulletin., 2009.
[9]. Y. Lourdes, A. Miguela, E. Efrain, and G. Porfirio. Production Practices and Quality Assessment of Food Crops: Integral Handling of Bananas. New York, Boston, London, and Moscow : Kluwer Academic Publishers, 2004. p. Pg.139.
[10]. P. Wachirasiri, S. Julakarangka, and S. Wanlapa. "The effects of banana peel preparations on the properties of banana peel dietary fibre concentrate.": Songklanakarin Journal of Science and Technology., 2008.
[11]. Elif, B. Using banana peels in production of bio-plastic as a replacement of traditional petroleum based plastics. Istanbul, Turkey : Google Science Fair, 2014.

[12]. A.K Mohanty, M. Misra, and L.T Drzal. Natural fibers, bio-polymers and bio-composites. s.l. : CRC Press: Taylor and Francis Group, LLC: ISBN 0-8493-1741-X., 2005, pp.4, 15-16.

[13]. Yu, Long. Biodegradable polymer blends and composites from renewable resources. [book auth.] A.Z. Anali & V. Alejandra. Starch - cellulose fiber composites. New jersey & Canada : Copyright # 2009 by John Wiley & Sons, Inc. All rights reserved., 2009.

[14]. K. Susheel, B.S. Kaith, and K. Inderjeet. Cellulose Fibers: Bio and Nano-Polymer Composites. London, New York : Springer Heidelberg Dordrecht: ISBN 978-3-642-17369-1, 2011. p. Pg.V.

[15]. S.S. Yazdani, and R. Gonzalez. Aerobic fermentation of glycerol: a path to economic viability for the biofuels industry. s.l. : Current Opinion in Biotechnology, 2007. 18, 213-219..

[16]. S. Thomas, S.A. Paul, L.A. Pothan, and B. Deepa. Natural Fibres: Structure, Properties and Applications. [book auth.] Susheel Kalia l B. S. Kaith l Inderjeet Kaur. Cellulose Fibers: Bio- and Nano-Polymer Composites: Green Chemistry and Technology. New York, London : Springer Heidelberg Dordrecht: ISBN 978-3-642-17369-1, 2011, p. Pg.6.

[17]. Properties and performance of natural fibre composites. [book auth.] Kim L.Pickering. Cambridge : Woodhead Publishing Limited, 2008.

[18]. Atur Limited, Polymers Division. Lapox A-31; Epoxy Resin. Gujarat (India) : Atur Limited, 2015.

[19]. Spolchemie Limited. Green Epoxy Resins. Ústí nad Labem (Czech Republic) : Spolchemie Limited, 2014.

[20]. Expert Process Systems. Fluid Viscosity. Hackettstown, NJ : Expert Process Systems, 2014.

[21]. Sumitomo Ltd. Properties of Phenolic Resins. Japan : Sumitomo Bakelite Company Limited, 2015.

[22]. Aime Suurpere, Peep Christjanson and Kadri Siimer. Rotational viscometry for the study of urea-formaldehyde resins. s.l. : Proc. Estonian Acad. Sci. Eng., 2005.

[23]. S.S Yazdani, and R. Gonzalez. Aerobic fermentation of glycerol: a path to economic viability for the biofuels industry. s.l. : Current Opinion in Biotechnology, 2007. 18, 213-219..

[24]. Fibers from Cotton Stalks. Narendra Reddy, Yiqi Yang. s.l. : Innovative Biofibres from Renewable Resources, October 23, 2014.

[25]. A.C. Meira Castro, M.C.S. Ribeiro, J. Santos, J.P. Meixedo, F.J.G. Silva, A. Fiúza, M.L. Dinis, M.R. Alvim. Sustainable waste recycling solution for the glass fibre reinforced polymer composite materials industry. s.l. : Elsevier Ltd. All rights reserved, 2013.

[26]. S. Alwani, H.P.S. A. Khalilab, Md. N. Islamac, O. Sulaimana, A. Zaidond & R. Dunganiae. Microstructural Study, Tensile Properties, and Scanning Electron Microscopy Fractography Failure Analysis of Various Agricultural Residue Fibers. s.l. : Journal of Natural Fibers: 12:2, 154-168, DOI: 10.1080/15440478.2014.905216, 2015. 12:2, 154-168, DOI: 10.1080/15440478.2014.905216.

[27]. A.W. Mburu, J.I. Mwasiagi and E.O. Anino. Optimisation of cotton wax removal using bacteria isolate from gin trash. s.l. : The Journal of the Textile Institute, UK, 2015.

[28]. R. G. Brereton, P. W. Araujo. Experimental design: Optimisation. Bristol, UK : Trends in analytical chemistry, vol. 15, no. 2, 1996.

[29]. B.L. Bowerman, R.T. O'Conell and M.L. Hand, Business Statistics in Practice. New York : McGraw-Hill Irwin, 2001.

[30]. Viscosity and density measurement methods for polymer melts. R. Kažys, R. Rekuvienė. 2011, ISSN 1392-2114 Ultragarsas (Ultrasound), pp. Vol. 66, No. 4.

[31]. A. N. Zahra. In process density control of extruded foam PVC using wavelet packet analysis of ultrasound waves. s.l. : Mechatronics, 2002: Vol. 12. Pg.1083- 1095.

[32]. R. Malkapuram, V. Kumar and S.N. Yuvraj. Recent development in natural fibre reinforced polypropylene composites. 2008. pp. Vol. 28, Pg. 1169-1189.

[33]. A. Venkateshwaran, and N. Elayaperumal. Banana fiber reinforced polymer composites - A review. Chennai, India : Journal of reinforced plastics and polymers, Vol. 29, No.15, 2010. p. Pg.1: http://www.sagepub.co.uk/journalsPermissions.nav.