Available online www.ejaet.com

European Journal of Advances in Engineering and Technology, 2015, 2(11): 10-14

Research Article ISSN: 2394 - 658X

Heat Transfer Properties of Hibiscus Sabdariffa (Zobo) Extract in a Heat Exchanger

Gideon Majiyebo Adogbo and Mozie Mary

Department of Chemical Engineering, Ahmadu Bello University Zaria, Nigeria
adogbogm@yahoo.com

ABSTRACT

In furtherance of the exploitation of the vast potentials of Hibiscus Sabdariffa and to improve the efficiency of its drink production, the analysis of heat transfer properties of Hibiscus Sabdariffa (H.S) extract using a shell and tube heat exchanger was carried out in this study. The extraction of the H.S calyces was done using hot water between the temperatures 58^{o}C – 82^{o}C. The specific heat capacities for different concentration of H.S extract were obtained using Copper calorimeter. For concentration from 1.25-6.25g/cm^3, the values of the C_{pz} were found to vary from 4.485-3.324J/g^{o}C. It implies that concentration of 6.25g/cm^3 loses heat about 1.35 times faster than that at a concentration of 1.25g/cm^3. The overall heat transfer coefficient of the H.S extract were obtained with values ranging from 2621.73-10486.88J/g^{o}C as H.S extract flowrate increased from 23-102cm^3/sec. On varying the cooling water flowrate from 10-50cm^3/sec, the overall heat transfer coefficient of the H.S extract also varied from 1607.30-5340.78J/g^{o}C.

Key words: Heat Transfer, Hibiscus Sabdariffa, Specific Heat Capacity

INTRODUCTION

Roselle (*Hibiscus sabdariffa*) belongs to the malvacea family, it is an erect, mostly branched annual shrub that is widely grown and cultivated in tropical and subtropical regions of the world [1-2]. It is known by many names such as ‘Florida Roselle’, ‘Florida cranberry’ and ‘Indian sorrel’ in Florida, USA; ‘asam susur’, ‘asama paya’ and ‘asam kumbang’ in Malaysia; ‘sorrel’ or ‘Jamaican sorrel’ in the Caribbean; ‘karkade’ or ‘carcade ’in Sudan, ‘bisap’ in Senegal and Zobo in Nigeria [3-6]. Two botanical types of Roselle are recognized: *Sabdariffa varaltissima* (a tall, vigorous, practically un-branched plant with fibrous spicy and inedible calyxes mainly cultivated for fiber and *Hibiscus sabdariffa* var (a bushy, branched sub-shrub with red or green stem and red to yellow inflate edible calyx, the shoots and leaves of the latter Roselle variety are usually cooked and eaten as vegetables while the fleshy, swollen red calyxes and the flowers are used to colour and season other foods as well as in the preparations of a fruit drink [7-8]; it has been reported as being a popular soft drink with daily consumption in many countries including Egypt, Sudan, Mexico and Nigeria [9]. Different products have been developed from sorrel calyces such as wines [10] sorrel sauces [11], stirred-sorrel yoghurts [12], sorrel cheese [13], seed cake [14] and jam [15]. The flower contains anthocyanins, sugar, flavonoids, vitamins, minerals, and bioactive compounds, such as organic acids, phytosterols, and polyphenols [16-18], some of them with antioxidant properties and is used in curing minor stomach ailments, sore throat and strengthening the heart among other uses [19-20]. The juice drink, which is usually obtained by extraction of the calyx of *Hibiscus sabdariffa* with hot water, contains about 1% solid [21-22]. Its extract is found to have high medicinal value, which can be produced at industrial scale using a plant with unit such as a heat exchanger to enhance energy efficiency of the extract during production. After extraction, the temperature of the extract has to be reduced before the addition of additive, traditionally; *Hibiscus Sabdariffa* drink is cooled in open air which takes a lot of time and can be contaminated. It is therefore necessary to obtain the best heat transfer properties for the extract which can be used for the design of a heat exchanger. The aim of this work is to determine the best heat transfer properties of *Hibiscus Sabdariffa* extract using a one-tube pass, one-shell pass, shell and tube heat exchanger to find the overall heat transfer coefficient during cooling.

METHODS AND MATERIALS

The sample was collected from the market and sorted, it was then dried in an oven at 60^{o}C for 8 hours in order to retain important nutrient. 200g of ground calyces was soaked in 16 liters of hot water for one hour. This was repeated with different mass of ground calyces of 400g, 600g, 800g and 1000g in the same volume of hot water (16 liters) for the same 1 hour to obtain different concentration of the extract. After the extracts were obtained, spectrophotometric analysis was carried out. The flowrate of the *Hibiscus Sabdariffa* extract was obtained using centrifugal pump connected to a variable transformer. The hot extract was passed through a shell-and-tube heat exchanger; the extract was passed through the tube of the heat exchanger to be cooled by the cooling water in the shell. The inlet and outlet temperature of the *Hibiscus Sabdariffa* extract with the inlet and outlet temperature of the cooling water from the shell were measured using a thermometer. At a constant extract flow rate, different cooling water flow rates were taken to obtain the best cooling water rate during the cooling process. Also, at different extract flow rate for a constant cooling water flow rate, the individual heat transfer coefficient were also obtained and a plot of these individual heat transfer coefficient were plotted against *Hibiscus Sabdariffa* extract flow rate at constant cooling water flow rate. The overall heat transfer coefficient was obtained from the plots made. The specific heat capacity of the *Hibiscus Sabdariffa* extract (Cp) was also determined for different concentration using a Copper calorimeter. The equation below was used to determine specific heat capacity of *Hibiscus Sabdariffa* extract after the analysis:

$$Heat\ lost\ by\ Copper = Heat\ gained\ by\ Zobo\ extract$$

$$MC_{pc}(T_2 - T_1) + m_z C_{pz}(T_2 - T_1) = m_c C_{pc}(T_3 - T_1)$$

$$\boldsymbol{m_z C_{pz}(T_2 - T_1) = m_c C_{pc}(T_3 - T_2) - MC_{pc}(T_2 - T_1)}$$

$$C_{pz} = \frac{m_c C_{pc}(T_3 - T_2) - MC_{pc}(T_2 - T_1)}{m_z(T_2 - T_1)} \quad (1)$$

Where: M = Mass of calorimeter, m_c = mass of copper metal, m_z = mass of extract,
C_{pz}, C_{pw} = Specific Heat Capacity of *Hibiscus Sabdariffa* Extract & Copper respectively.(J/g^{o}C)

RESULTS AND DISCUSSION

From the analysis carried out the following results were obtained. The Fig.1 above shows the plots of specific heat capacity of *Hibiscus Sabdariffa* extract for different concentrations of the extract. As the concentration of the extract was increasing, its specific heat capacity was decreasing this is because the heat capacity of a body is directly proportional to the amount of substance it contains, with increase in the degree of freedom, the larger the specific heat capacity of the substance. For concentrations of the *Hibiscus Sabdariffa* extract ranging from 0.0125-0.0625g/cm^3, the specific heat capacity was 4.485-3.324J/g^{o}C respectively. The decrease in the specific heat capacity accounts for the rate at which the extract loses heat, thus the highest concentration of 6.25g/cm^3 with C_{pz} =3.324J/g^{o}C loses heat at about 1.35 times faster than that of lower concentration of 0.0125g/cm^3 with C_{pz} =4.484J/g^{o}C. Comparing the C_{pz} which ranges from 4.485-3.324J/g^{o}C for this experiment, it can also be seen that at lower concentration, *Hibiscus Sabdariffa* extract loses heat almost at the same rate as that of water and at higher concentration loses heat faster than water. A similar trend was reported for *Hibiscus Sabdariffa* seeds [14] where analysis was carried out on the thermal properties of *Hibiscus Sabdariffa* seeds, the specific heat capacity of the seeds showed a linear decreasing trend in value with an increase in moisture content but constant mass of seeds. The modeling of the curve gave the relationship between the specific heat capacity and concentration of the extract to be:

$$C_{pz} = 4.873 - 26.336C \quad (2)$$

$$R^2 = 0.946$$

Where C is the Concentration of the extract
The regression analysis gave a high value indicating that specific heat capacity is greatly affected by the concentration of the extract.

From Fig. 2, it was observed that as the concentration of *Hibiscus Sabdariffa* extract increases from 0.0125 – 0.0625 g/cm^3, the density of the extract increases from 1.0161 – 1.0262g/cm^3 which is not a significant increment since density is an intensive property and increase in concentration increases the mass but has no significant effect on the density of the substance. The density is the same as the density of water 1g/cm^3 which was used in the exraction process.

As shown in Fig. 3, the rate of the individual heat transfer coefficient increased with increase in the *Hibiscus Sabdariffa* extract flowrate at different concentrations. Upon analysis of the plots, it was observed that for various concentrations of the extracts, as the flowrate varies from 23 – 102g/cm^3, the values of the overall heat transfer varies from 2621.73 – 10486.88J/g^{o}C. Since the overall resistance is the inverse of overall heat transfer coefficient, the higher the overall heat transfer coefficient, the lower will be the resistance to heat transfer. Thus, the increase in the overall heat transfer coefficient is as a result of decrease in resistances between the exchange fluids as the flowrate increases. The higher the value of heat transfer coefficient, the faster the rate of heat transfer, this is because higher flow rate increases Reynolds number which increases turbulence leading to higher heat transfer, higher efficiency and greater temperature change.

As shown in Fig.4, the individual overall heat transfer coefficients were plotted against the flowrate of cooling water at constant Hibiscus *Sabdariffa* extract flowrate. It was observed that as the flowrate of the cooling water increases ranging from 10 – 50cm^3/sec, the individual heat transfer coefficient is also increasing as it varies from 1607.30 – 5340.78J/sm^{2o}C. Upon analysis, for the various concentrations, the lower concentration loses heat faster with highest magnitude of the overall heat transfer coefficient of about 5340.78J/sm^{2o}C than those of higher concentrations.
Comparing the result obtained for the variation of *Hibiscus Sabdariffa* extract flow rate at constant cooling water flow rate and variation of cooling water flow rate at constant *Hibiscus Sabdariffa* extract flow rate with the individual heat transfer coefficient; it was observed that the magnitude of the overall heat transfer coefficient obtained at various *Hibiscus Sabdariffa* extract flow rate are greater than those obtained at various cooling water flow rate. Thus it is preferable to cool the *Hibiscus Sabdariffa* extract by varying the *Hibiscus Sabdariffa* extract flow rate because it yields higher magnitude of overall heat transfer coefficient and therefore loses heat at faster rate thereby saving cost.

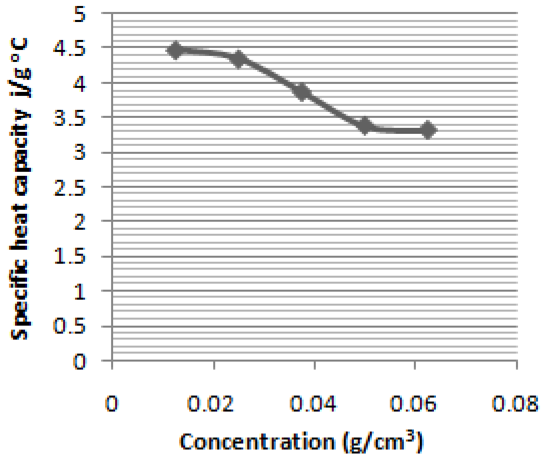

Fig. 1 Variation of specific heat capacity with concentration of extract

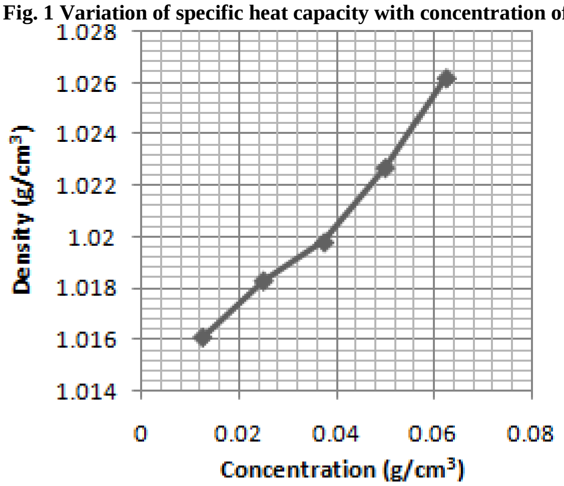

Fig. 2 Variation of density with concentration of extract

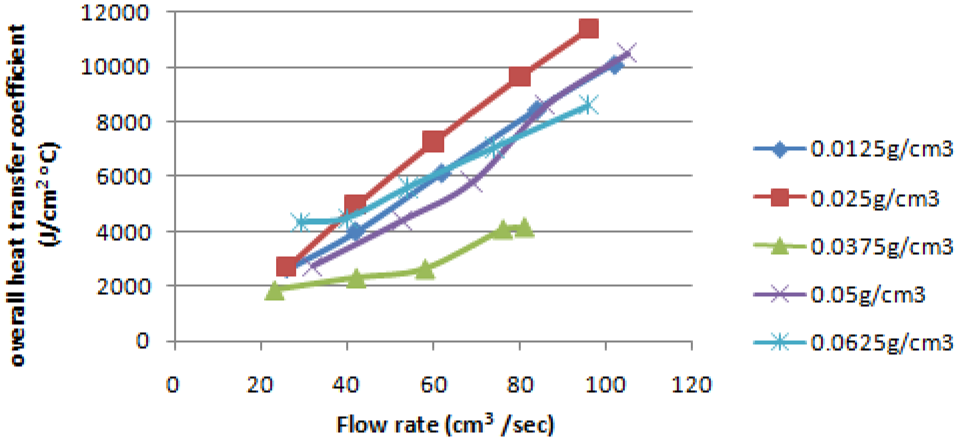

Fig. 3 Variation of H.S. flowrate with overall heat transfer coefficient

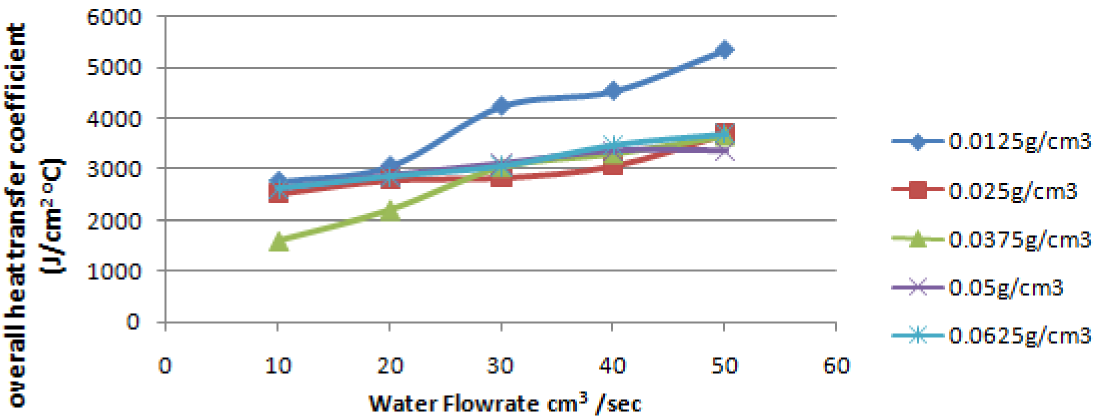

Fig. 4 Variation of cooling water flowrate overall heat transfer coefficient

CONCLUSION

The specific capacity for the different concentrations of the H.B extract decreased as the concentration increased indicating that high concentration increases the rate of heat loss. As the flow rate of H.S extract increased at a constant flow rate of cooling water, the individual heat transfer coefficient also increased due to decrease in resistance in the exchange fluid. The overall heat transfer coefficient increased when the cooling water flow rate was varied at a constant flow rate of H.B extract while the overall heat transfer coefficient values gotten at a constant H.B extract flow rate were lower than the values gotten when the H.B extract flow rate was varied thus, it is economical to vary the flow rate of the H.B extract during cooling. Heat exchangers can be used for cooling of H.B extracts for large scale production in industries as it yields high efficiency thereby reducing the time needed for cooling compared to using the traditional method; as a result, more production would be done in lesser time compared to using the traditional method of cooling.

REFERENCES

[1] OE Nwafor and MJ Ikenebomeh, Effects of Different Packaging Materials on Microbiological, Physio-chemical and Orgaleptic Quality of Zobo Drink Storage at Room Temperature, *African Journal of Biotechlogy*, **2009**, 8(12), 2848-2852.

[2] MK Bolade, IB Oluwalana and O Ojo, Commercial Practice of Roselle (*Hibiscus sabdariffa* L) Beverage Production: Optimization of Hot Water Extraction and Sweetness Level, *World Journal of Agricultural Sciences*, **2009**, 5 (1), 126-131.

[3] P Mounigan and N Badrie, Physicochemical and Sensory Quality of Wines from Red Sorrel/Roselle (Hibiscus Sabdariffa L) Calyces: Effects of Pretreatments of Pectolase and Temperature/Time, *International Journal of Food Science and Technology*, **2007**, 42, 469-475.

[4] J Broomes and N Badrie AK, Effects of Low- Methoxl Pectin on Physicochemical and Sensory Properties of Reduced Calorie Sorrel /Roselle (Hibiscus Sabdariffa L) Jams, *The Open Food Science Journal*, **2010**, 4, 48-55.

[5] N Mahaderan, Shirali and P Kamboj, Habiscus Sabdariffa Linn- An Overview, *Natural Product Radiance*, **2009**, 8 (1), 77-83.

[6] AM Omemu, MO Edema, AO Atayese and AO Obadina, A survey of the Microflora of Hibiscus Sabdariffa (Roselle) and the resulting Zobo Juice, *African Journal of Biotechnology*, **2005**, 5 (3), 254-259.

[7] Q Yadong, LC Kit, M Fatemah, B Mila and G Janet, Biological Characteristics, Nutritional and Medicinal Value of Roselle, *Hibiscus Sabdariffa* Circular – Urban Forestry, *Natural Resources and Environment*, **2005**, 604.

[8] SB Fasoyiro, OA Ashaye, A Adeola and FO Samuel, Chemical and Storability of Fruit-Flavoured (*Hibiscus sabdariffa*) Drinks, *World Journal of Agricultural Sciences*, **2005**, 1 (2), 165-168.

[9] AA Abou-Arab,FM Abu-Salem and EA Abou-Arab, Physio-Chemical Properties of Natural Pigments (anthocyanin) Extracted from Roselle Calyces (Hibiscus Sabdariffa), *Journal of American Science*, **2011**, 7 (7), 445-456.

[10] P Mounigan and N Badrie, Roselle/sorrel (Hibiscus sabdariffa L)Wines with Varying Calyx Puree and Total Soluble Solids: Sensory Acceptance, Quantitative Descriptive and Physicochemical Analysis, *Journal of Food Service*, **2007**,17, 102-109.

[11] F D'Heureux-Calix and N Badrie, Consumer Acceptance and Physicochemical Quality of Processed Red Sorrel/Roselle (Hibiscus sabdariffa L) Sauces from Enzymatic Extracted Calyces, *Food Serv Technology*, **2004**, 4, 141-148.

[12] H Henry and N Badrie, Utilisation of Sorrel/Roselle (Hibiscus sabdariffa L) Nectar in Stirred Yoghurts: Physiochemical and Sensory Quality, *Journal of Food Technology*, **2007**, 5 (1), 55-66.

[13] M Jueanville and N Badrie Processed sorrel/roselle (Hibiscus sabdariffa L) Leather from Pectolase-Treated Calyces, Effects of Xanthan Gum on Physiochemical Quality and Sensory Acceptance, *Journal of Food Technology*, **2007**,5 (2),164-168.
[14] AI Bamgboye and OI Adejumo, Thermal Properties of Roselle Seeds, *International Agrophysics*, **2010**, 24, 85-87.
[15] OE Nwafor and MJ Ikenebomeh, Effects of Different Packaging Materials on Microbiological, Physio-chemical and Orgaleptic Quality of Zobo Drink Storage at Room Temperature, *African Journal of Biotechnology*, **2009**, 8 (12), 2848-2852.
[16] S Tantipaibulvut, C Soontornsophan and S Luangviphusavanich, Fermentation of Roselle Juice by Lactic Acid Bacteria, *Asian Journal of Food and Agro- Industry*, **2008**, 1(4), 213- 222.
[17] LO Ajala, GO Oyeleke and EO Olagunju, Nutritional Assesment of Juice Extract from Hibiscus Sabdariffa, *International Journal of Biological, Pharmaceutical and Appplied Sciences*, **2013**, 2 (1), 10- 19.
[18] HH Tzu- Lilin, CC Chen, MC Lin, MC Chou and CJ Wang, Hibiscus Sabdariffa Extract Reduces Serum Cholesterol in Men and Women, *Nutritional Research*, **2007**, 27, 140-145.
[19] AC Miranda, RC Miranda and JM Jimenez, Solar Drying System for the Agro-Products Dehydration, *Journal of Agriculture and Social Sciences*, **2008**, 4,135–140.
[20] J Meza-Jimenez, JJ Raminez-Ruiz and JJ Diaz-Nunez,The Design and Proposal of a Thermodynamic Drying for the Dehydration of Rosell (*Hibiscus Sabdariffa*) and other Agro-industrial Products, *African Journal of Biotechnology*, **2008**, 3 (7), 477-485.
[21] MM Ramirez-Rodrigues, ML Plaza, AAzeredo, MO Balaban and MR Marshall, Physicochemical and Phytochemical Properties of Cold and Hot Water Extraction from *Hibiscus sabdariffa*, *Journal of Food Science*, **2011**, 76, 428–435.
[22] I Amin, HK Emmy and SM Halimatul, Roselle (Hibiscus sabdariffa L)Seeds–Nutritional Composition, *Protein Quality and Health Benefits Global Science Books*, **2008**, 1-13.