Journal of Engineering and Applied Sciences 14 (22): 8297-8300, 2019
ISSN: 1816-949X

Development of a Screw Conveyor Essential Oil Extractor

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Abstract: In Nigeria, most essential oil bearing materials are at present, underutilized. These vast resources, if properly harnessed could be a huge source of income of hard currency for national development. It could also, be a ready source of livelihood for essential oil dealers. At present, efforts and extraction methods used limited, rudimentary and hence, unattractive as a business venture. Consequently, the sector remains untapped and wasted. The needs to redress this situation lead to development of a continuous flow oil extractor that is capable of extraction of oil from ginger rhizome and lemon, grass, respectively. The whole unit was powered by a single phase 15 W, 220 V AC geared motor and a steam generator fitted with a 2.2 kW heating element, the average speed of the screw shaft that conveys materials was 10 rpm given a mass conveyance rate of 0.41 kg/sec while the volumetric flow rate of water turned to steam and condensed within the system was 1.39×10^{-6}m^3/sec. For each extraction require 21 L of water was consumed which yielded extracts of an average of 8.1 mL of ginger oil and 1.65 mL of lemon grass oil extracts for three batched samples at 37.4 and 0.36% MCDB. The yield obtained compared favourably with those obtained in other conventional methods. The adoption of this new method would bring a significant improvement in oil extraction and promote development in the area of essential oil extraction. This would reduce wastage in the exploration of essential oil resources in Nigeria.

Key words: Essential oil, continuous fed, extraction, ginger rhizome, lemon grass, development

INTRODUCTION

Essential oils are volatile liquids, freely soluble in alcohol, ether, vegetable and mineral oils but mostly insoluble in water. These mostly sweet fragrance oils found in plants makes them precious and sought after for the various uses (Lyth, 2015; Olle and Bender, 2010; Kabuba and Huberts, 2009).

In Nigeria, resources from these oils wasted yearly are of economic value that could boost the Nigerian economy (Olayanju, 2003). Currently, in many industries all over the globe, the extracted oil have found great use in manufacturing companies that deal with products such as perfumery, toiletries, paints and pharmaceuticals, cosmetic and soap, agriculture and livestock, food and drink, petroleum and aromatherapy industries.

The yearly demand of essential oil was reported to be about USD 5.51 billion (1.989 trillion naira) in 2014 (Anonymous, 2019). In the same report a projection of an income of USD 13.94 billion (5.032 trillion naira) was estimated for essential oil sector for the year 2024.

In view of all these great investment accruable to essential oil productions, there is need to develop a better extracting method for local producers both in Nigeria and nations beyond where all these vast resources were being wasted (Chemat and Boutekedjiret, 2015; Jayashree and Visvanathan 2011; Akinoso and Olayanju, 2010; Akinoso *et al*., 2008). These would generate great revenues and overall improvement in the livelihood of peasant stake holders still practicing the traditional batch method which is cumbersome, time and energy consuming limited to wood combustion.

MATERIALS AND METHODS

Conceptual design of the extractor: The basic underlining principles and concept of the machine development for extraction was to design: a rig handling a solid mass transfer of raw materials from which oil is to be extracted from temporal storage bin to the extracting chamber, a heat exchanger involving the thermodynamic extraction of the plant materials using steam with appropriate machine

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Table 1: Design equations and specifications of component parts of the continuous screw fed extractor

Machine parts	Design equation	Specifications	Material types
Screw conveyor	$Q_t = \frac{(D^2 - d^2) \times P \times n}{36.6}$	Shaft diamater = 20 (mm)	Stainless, outer casing made of mild steel
	Otto	Screw diamater = 70 (mm) Screw pitch = 70 (mm) Conveyor length = 500 (mm)	
Screw conveyor chamber	$V = \frac{\pi D^2 H}{4}$	Diameter = 72 (mm)	Stainless, outer casing made of mild steel
		Length = 300 (mm) V_C = 0.0024 (m^3)	
Steam generator	$t = \frac{P_v D}{2\sigma\varnothing}$ (Rajput, 2012) $_m C_{pavg} \Delta T$	Shell thickness = 0.063 (mm)	Stainless, outer casing made of mild steel
Condenser	$q = {}_m C_{pavg} (t_{h1} - t_{h2})$ $N_{u_1} = \frac{h_1 D_h}{k_1}$ Bergman *et al.* (2011)	2 (m) Ø copper pipe	Copper pipes and mild steel
Separator	$V_s = 0.07 \left[\frac{\rho_l - \rho_v}{\rho_v}\right]^{\frac{1}{2}}$ $D_m = \sqrt{\left[\frac{4\dot{V}_c}{\pi V_s}\right]}$		Glass
Motor	P = FV	1.5 (kW) single phase 220 (V)	-
Frame			Mild steel
Steam hose		20 (mm) Ø rubber hose	Rubber
Heating element	$Q = m_w C_{p,water} \Delta T$ Nurul	2.2 kW (energy Q = 6279 kJ)	-
Control valve			Plastic
Hopper	$V_h = \frac{\pi h}{3}(R^2 + Rr + r^2)$		Mild steel

techniques in manipulating the feedstock heat for adequate heat transfer from machine interface to the materials being extracted (Bergman *et al*., 2011; Rajput, 2012). Differential modelling of rate of flow of plant mass, mass residence time, fluid flow, heat energy of fluid impacting plant mass adequately and uniformly and proximal extraction point and timely harvesting of extracts from the heat exchanger unit into the condenser, mass flow rate of coolant in the condensing unit.

The conceptual design of the extraction plant which was basically a heat exchanger is shown in Fig. 1. The equipment comprises of the following parts, screw conveyor chamber and screw, steam generator, condenser and separator. The specifications and design equations for sizing each part are summarized in Table 1. The detail design of all these parts is given by Sulaimon (2018). The extraction plant has a theoretical conveying capacity of 1.61 kg/h.

Machine testing and operation: The extractor was tested to evaluate the extraction efficiency determined using

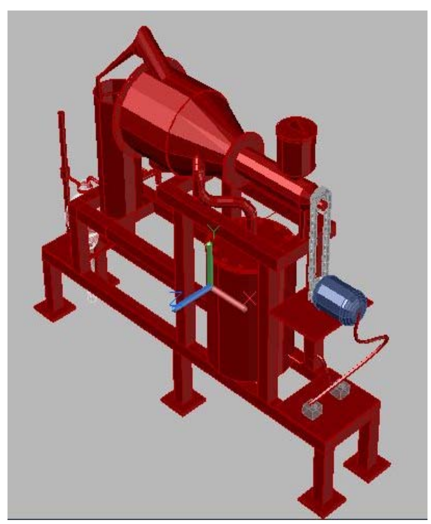

Fig. 1: Conceptual design of the extraction plant

Eq. 1. The percentage oil yield was determined by dividing the weight of the oil collected with the initial weight of the sample used.

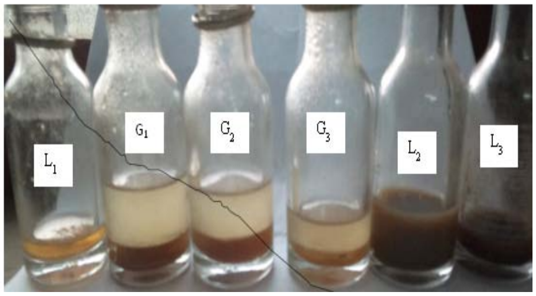

Fig. 2: Ginger ($G_{1\text{-}3}$) and Lemon grass ($L_{1\text{-}3}$) oil extract

$$\text{Yield}(\%) = \frac{\text{Weight of oil collected (g)}}{\text{Initial weight of sample (g)}} \times 100\% \quad (1)$$

The steam generator was filled with 21 L of water and the heater was switched on while the start time was noted with a stop watch and recorded. The raw materials fed into the machines were three different samples of ginger rhizome and lemon grass prepared in three modes as chopped, blended and dried of varied moisture contents from wet and bone dried samples. Sample prepared in this manner were weighed before loading into the hopper and the machine was operated to obtain extracts from each samples. These materials fed into the hopper are conveyed into the extracting chamber by means of electrically powered screw auger. At the extraction chamber, materials filling the space were continuously agitated to create a continuous and uniform exposure of materials to the incoming steam. A control valve was used to control in flow of steam from the steam generator into the extraction chamber. This valve was opened when the thermometer read 70°C at exactly 30 min into the 4 h of machine operation. The steam vapour interacting with the materials extracted the essential oil in vapour form into the condenser. As the oily vapour got into the condenser it was super cooled by water circulating outside the condenser pipes thereby turning the oily vapour into liquid form (condensation). The liquid form in the condenser was a mixture of oil and water known as hydrosol. The hydrosol gravitated to the bottom of the separator while the oil stayed on top (since, the oil is less dense). The hydrosol was collected at intervals as the experiment progressed while the oil was allowed to stay in the separator until final need to empty the separator to decant off the oil at the end of the test. The time of extraction and when no extraction was forth coming were recorded. These procedures were repeated for other samples operated in batches. During experimentation the temperature and pressure of the steam generator was maintained at 100-110°C and 103 kPa, respectively with aid of the control pressure release valve indicated in Fig. 2.

Fig. 3: The continuous-fed steam distillation essential oil extractor

RESULTS AND DISCUSSION

The designed and constructed essential oil extractor is shown in Fig. 3. All the major components of the equipment were fine-tuned to perform well.

The average speed of the screw shaft that conveyed materials was 10 rpm giving a mass conveyance rate of 0.41 kg/sec. The volumetric flow rate of water turned to steam and condensed within the whole system was 1.39×10^{-6} m^3/sec. The average total volume of hydrosol yielded was 2.05 L. The mass ratio of material type to water for the system was 2 kg of sample to 20 L of water. From all the different tests performed using the extractor an average of 8.1 mL of ginger oil and 1.65 mL of lemon grass oil extracts were obtained from 2 kg of ginger (37.4%) dryness and 200 g lemon grass (0.35 %) dryness for 4 h extraction time in 3 batches, respectively.

CONCLUSION

The equipment performed to the required standard that was obtainable in similar works in that the extraction was in the range of that of Mohamed (2005). However, the yield was quite significant of 5.47 mL/2000 g extraction efficiency which makes the system better and more promising in creating livelihood and untold wealth for national use.

RECOMMENDATION

A further researcher in advancing this new method to facilitate the continuous mode of this machine would require further development of the hopper metering section to an injection system mode. With this development, the continuous process mode of this extractor would be accomplished. Adopting this new method would bring development and a great change in yearly lost, untapped vast essential oil resources all over Nigeria.

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