International Journal of Current Science Research and Review
ISSN: 2581-8341
Volume 07 Issue 11 November 2024
DOI: 10.47191/ijcsrr/V7-i11-05, Impact Factor: 7.943
IJCSRR @ 2024
www.ijcsrr.org

Thermal Conductivity, Density and Calorific Value of *Sargassum fluitans* and *Sargassum natans* Species

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ABSTRACT: In this study, we obtained the values of the thermodynamic properties of sargassum that includes *S. fluitans* and *S. natans species,* which are the ones that most arrive at the coasts of the Mexican Caribbean. The sargassum samples, collected at the coast, were dried in a direct type of solar dryer and their final relative humidity was 15% dry base. Two physical models were designed to construct biscuits of 0.0127 m in diameter and 0.0063 m in length, which were used to obtain the density and calorific value and those used for thermal conductivity, were 0.069 m in diameter and 0.008 m thick. The density resulted in $660.62\ kg/m^3$. To determine the calorific value, a commercial calorimetric pump was used, and the value obtained was $17{,}950\ kJ/kg$. For thermal conductivity, a device that employs the hot plate and guard method was designed and built and its value was $0.346\ W/m°C$. These values indicate that it is possible to use dehydrated sargassum to produce energy, which has approximately a value of 75% of that obtained for sugar cane bagasse. With these three values and using the thermal diffusivity definition equation, this last parameter was calculated in $2.917 \times 10^{-11}\ m^2/s$.

KEYWORDS: *Sargassum fluitans, Sargassum natans,* thermal conductivity, density, calorific value

INTRODUCTION

The massive influx of sargassum has caused a great deterioration of the coastal environment and has affected the tourism industry. The first record of the massive arrival of sargassum in Caribbean waters and in particular to the coasts of Quintana Roo, Mexico, was in the summer of 2011; the predominant species were *Sargassum fluitans* and *Sargassum natans* [1, 2]. These two species, being pelagic, grow and divide without contact with the coast or the seafloor, which makes them very different from other species of sargassum that grow rooted in shallow waters. Therefore, they can be observed drifting after storms, so they have spread throughout the world and their accumulation on the coasts is becoming a problem in many areas [3].

Sargassum is formed by thin-branched stems, with small spines that can support long and thin-toothed leaves, without prominent central veins. The clusters have an average length of 0.40 m, they are made up of small spherical vesicles, which are filled with gas and at the tips they have tiny spines that functions as projections to keep the plants on the surface. A cluster and its details can be observed in Figures 1 and 2.

Between May and September 2018, some organisms belonging to 78 faunal species died because of this massive event, with demersal neritic fish and crustaceans being the most affected groups [4]. This same year, about 900 thousand people visited the northern area of Quintana Roo, Mexico; the excessive arrival of sargassum changed the water of the beaches to a brown colour, with a rather unpleasant smell due to its decomposition and the proliferation of organisms harmful to health. This made it impossible for tourists to find the mythical turquoise colour of the Caribbean Sea and changed their paradisiacal perception of the region [2].

The vast majority of sargassum species have a high capacity to absorb heavy metals; therefore, their leachate can contribute to contamination by potentially toxic metals when they reach the beaches [5, 6]. The valorisation of sargassum would contribute to its sustainable management; therefore, knowledge about the content of potentially toxic metals is necessary to define their possible uses [6]. Several sustainable applications have been proposed for sargassum biomass, namely: in agriculture as fertilizer, for the bioremediation of marine and industrial effluents based on the biosorption of heavy metals, in the manufacture of food products, the extraction of biomolecules with use in the pharmaceutical industry and of course, for the generation of bioenergy. The main disadvantage is that some processes require dry raw material. It has been reported that the energy required to dry seaweed with a moisture content greater than 88% may exceed the amount of energy available in the dried seaweed. Therefore, methods in which wet biomass can be used directly to produce biofuels may encounter moisture limitations, in these cases anaerobic digestion might be the best option. For example, the solid-liquid separation from sargassum biomass on biodegradability and methane yield has reported great feasibility due to its profitability [7].

- **Figure 1. *Sargassum fluitans* cluster**

- **Figure 2. Detail of the vesicles and spines at the tips of the leaves**

Solar energy has been used to dry the red sargassum [8]. *Sargassum muticum (Fucales)* has also been dried, using a drying tunnel with air heated with electrical resistances, but the final product required a considerable amount of energy [9]. In a previous work, it was possible to dry the brown sargassum from the coasts of Cancun, Mexico, in a direct solar dryer [10]. Seaweed is a potential source of renewable energy and can be converted into energy such as biofuel, oil, and gas, can be used to produce bio-oil, biodiesel, ethanol, methane, and hydrogen [8]. In Mexico, 79% of the consumed electricity is produced through conventional technologies and for the remaining 21%, alternative technologies are used, within which biomass represents 1%. This comes from sugarcane bagasse (0.75%) and biogas (0.25%) [11, 12]. The thermodynamic properties that are required to know if any product is a suitable source of energy are: density, specific heat, diffusivity, and thermal conductivity. This paper presents the values of these properties, experimentally obtained, to analyse the feasibility of using these dehydrated algae as a source of thermal energy, the process in dehydration was performed in a direct type of solar dryer with air in forced flow.

METHODOLOGY

For the drying of the sargassum, a fully instrumented, direct solar dryer was used, which works in forced flow conditions. It consisted of a $1.00\ m$ −long and $0.60 -\ m$ wide box, which had a perforated sheet, painted black with matte finish at the bottom, through which the air entered at a velocity of $3.00\ m/s$, driven by a fan. Above this at $0.10\ m$, there was a 20-gauge steel mesh, in which the product to be dried was placed, finally covered with a glass $0.005\ m$ thick. The hot air exited through an opening of $0.10\ m$ high and $0.30\ m$ wide, the description of this prototype is in [10].

The sargassum was collected in the sea before reaching the beach in Cancun, Mexico. It was washed and drained completely before packaging. Samples of $100\ g$ (wet mass) were taken, frozen at $-12\ °C$ and transferred to Mexico City the same day. In the laboratory, they were kept in the freezer at $-18\ °C$ for preservation. For the drying process, each sample was thawed at room temperature, approximately 23 °C, crushed and allowed to drain for two hours. The $0.100\ kg$ sample was evenly distributed over the tray mesh and the drying process was carried out. The maximum solar radiation for the months of March and April of the year 2023 was $7.1\ kW/m^2\ h$ on average, the tests began at $10{:}00\ h$ and ended at $15{:}00\ h$. Sargassum ended up with a relative humidity of $0.15\ (dry\ base)$, approximately.

To determine the bulk density of dry sargassum the same tablets that were used for the measurement of calorific value were used. The device used to make them consists of three elements that were machined from a cylindrical aluminium bar of $0.0254\ m$ external

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diameter. The cylinder was $0.0254\, m$ in length and $0.0127\, m$ in inner diameter; the base had a diameter of $0.0127\, m$ and $0.00635\, m$ in length. Above this was the piece that worked as a compressor punch of $0.0127\, m$ in diameter and equal length. The cylinder was placed on the base, and filled with dried sargassum, and then it was taken to a hydraulic press, which would apply a force of $30\ tons$ to form the tablets. These tablets were $0.0127\, m$ in both diameter and length; in Figure 3 a photograph of these elements is shown. The mass of the tablet was measured with an electronic balance with an accuracy of $0.001\, g$ and its physical dimensions with a digital micrometer of $1.27\, x\, 10^{-6}\, m$, ($0.000005\, in.$) resolution. For the thermal conductivity tablets, the three elements were built in a cylindrical Teflon bar, the outer diameter of which was $0.106\, m$; the diameter of the punches was $0.070\, m$. The formed biscuit had a diameter of $0.069\, m$ and a thickness of $0.008\, m$, the cross-sectional area was $0.00374\, m^2$.

The calorific power, C, was determined with a calorimetric oxygen pump (PARR 1341) [13], burning a tablet of sargassum and monitoring temperature variations before and after combustion. The test was performed six times and the dehydrated sargassum in the solar dryer presented a maximum moisture content of $14.00\ \%$; the tablets were the same as those used for the determination of the density. Mexican Standard NMX-AA-33-85 was used to carry out the evaluation [14].

The thermal conductivity of a material is a measure of its ability to transfer thermal energy by imposing a temperature gradient on it. A "Hot Plate Apparatus with Guard" was used, which was designed, built, and evaluated for this purpose. It consisted of: an electrical resistance that controls the energy supplied with a rheostat; in direct contact, a biscuit of the material to be evaluated with known diameter and thickness was placed and introduced into a case of insulating material to prevent heat leakage. The device used is presented in Figure 4; it is constructed entirely of Teflon. The measuring instruments were a voltmeter, an ammeter and four thermocouples, two at the bottom of the sample and the other two at the top. This device was designed, built, and evaluated according to ASTM-C-177-97 [15]. Thermal conductivity, k, was evaluated using equation (1).

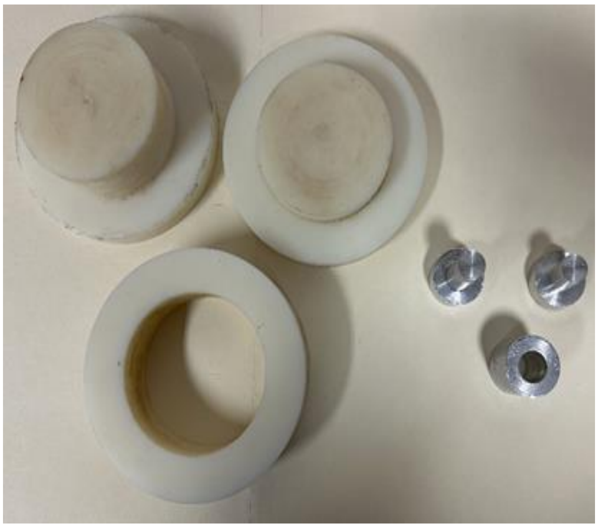
$$Q = -kA\frac{dT}{dx} = -kA\frac{\Delta T}{L} \qquad (1)$$

wherein the heat supplied, Q, is determined by the product of the current intensity times the voltage, $Q = VI$.

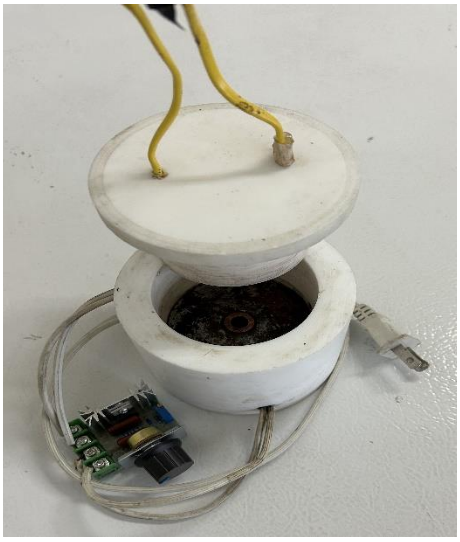
The thermal diffusivity was calculated according to its definition, (equation 2):

$$\alpha = \frac{k}{\rho\, C} \qquad (2)$$

in which α is the thermal diffusivity; k is the thermal conductivity; ρ, is the density and C, is the calorific power or specific thermal capacity, which are determined experimentally, therefore, this will also have an experimental value.



- **Figure 3. Models for sargassum tablets to determine thermal conductivity, density, and specific heat**



- **Figure 4. Prototype of the hot plate and guard device**

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RESULTS

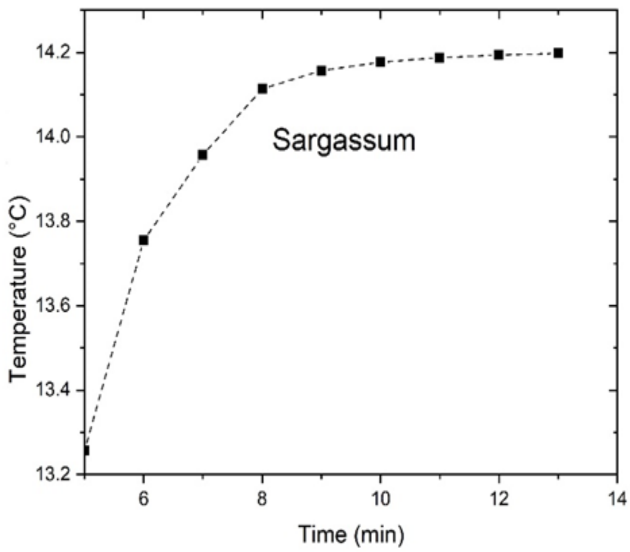
For the small cylinder of compressed sargassum of $0.0127\ m$ in both, length and diameter, it was found that the average density of the six samples was $660.62\ kg/m^3$. This value could be verified with the density of the biscuits used for thermal conductivity, which average dimensions were $0.038\ mm$ in height and a diameter of $0.069\ m$.

The calibration of the heat pump available with benzoic acid was obtained, as it is the most used reference in this equipment, the value was $24950\ kJ/kg$ that it is slightly lower than that reported in the consulted literature of $26{,}410\ kJ/kg$ [15]. Subsequently, the sargassum tablet was evaluated, finding a specific heat value of $17{,}950\ kJ/kg$; the graph obtained from the calorimeter of the temperature increase against time is shown in Figure 5.

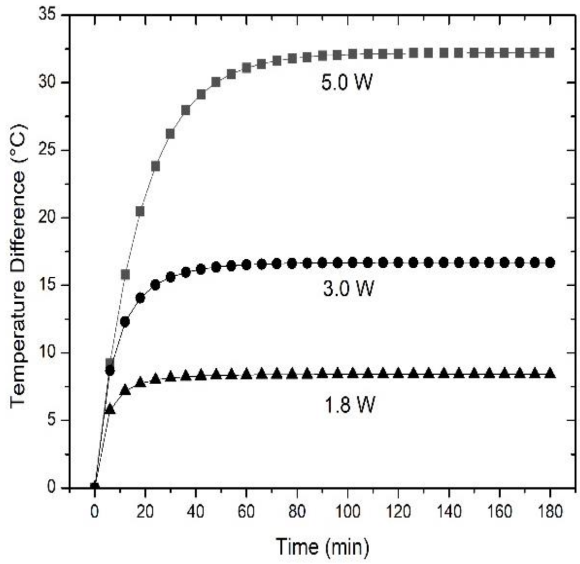
When comparing the value obtained with respect to that of sugarcane bagasse, whose specific heat is $19{,}469\ kJ/kg$ [17], with which $0.75\ \%$ of the electrical energy in Mexico is produced [11], it follows that sargassum could provide $92\ \%$ of this kind of renewable energy. In addition, sargassum has a higher calorific value than that of rice husk, which is $15,640\ kJ/kg$ [18].

To find the value of the thermal conductivity of dry sargassum, the above-mentioned biscuit of $0.008\ m$ thickness and $0.069\ m$ in diameter was manufactured. The values electrical power supplied to the resistor were $1.8, 3.0$, and $5.0\ W$; the maximum temperature reached on the wall of the resistor side was $80\ °C$, which remained constant during the test. The temperature on the other side of the sample was recorded every two minutes for $3\ h$. At the beginning of the test a rapid increase was observed until temperature stability was achieved on the side opposite the power supply. For the powers of 1.8, and $3.0\ W$, the temperature difference was already constant before $60\ min$, and for $5.0\ W$, a time of $75\ min$ was required, this is shown in the graph of Figure 6. From equation (1) the average thermal conductivity for sargassum resulted in $0.346\ W/m°C$

To find the value of the thermal diffusivity equation (2) was used, substituting the experimental values obtained previously, resulting a value of $2.917\ \times 10^{-11} m^2$/s.



- **Figure 5. Graph of the calorimeter for sargassum with relative humidity of 0.15 (dry base)**



- **Figure 6. Temperature difference against time for sargassum biscuit**

CONCLUSIONS

Samples of sargassum formed mainly of *Sargassum fluitans* and *S. natans* species, which are the ones that arrive preferably at the coasts of the Mexican Caribbean, were dried in a solar dryer of the direct type; their final relative humidity was $15\ \%$, dry base. Two models were designed to form the biscuits to obtain the density and the calorific power, and for the one used to determine the thermal conductivity it was necessary to use a hydraulic press for its formation. The experimental values of were $660.62\ kg/m^3$

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for the density, which was corroborated using the biscuits prepared for the thermal conductivity experiment; the calorific power was $17{,}950\ kJ/kg$. To obtain it, a commercial calorimetric pump was used, and the conductivity value was $0.346\ W/m°C$. With these values, it was concluded that it is possible to use dehydrated sargassum to produce energy of approximately 75 % of that obtained with the same mass of cane bagasse. Finally, with these three experimental values and using the thermal diffusivity definition equation, this last parameter was calculated in $2.917 \times 10^{-11}\ m^2/s$.

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Cite this Article: R López, M Vaca, A Lizardi, A Lara, H Terres, S Chávez, R Rodríguez (2024). Thermal Conductivity, Density and Calorific Value of Sargassum fluitans and Sargassum natans Species. International Journal of Current Science Research and Review, 7(11), 8178-8183, DOI: https://doi.org/10.47191/ijcsrr/V7-i11-05