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Development of thermal insulation material using coconut and kenaf fiber for heat recovery enhancement

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Abstract. In line with the world's Sustainable Development Goals (SDG), Malaysia aims to have a clean future energy. The main problem facing the energy revolution is the low conversion efficiency of low-grade heat to useful energy. During the process, a significant fraction of thermal energy is generally lost to the environment as waste heat. Waste heat accounts for 20-50% of industrial energy use, with Southeast Asia processing 40 million tonnes of oil equivalent. Heat losses especially in engines can reduce efficiency, leading to extensive studies to reduce heat loss and improve thermal performance. Heat recovery systems are being studied to recover lower-grade energy, but to the extent of the authors' knowledge, the majority of them are not economically effective for low temperature waste heat. Therefore, the objectives of this study are to develop low thermal conductivity material for thermal insulators based on natural fibre and investigate their impact on thermal performance. The natural fibre-based materials that were chosen in this study are coconut husk and kenaf fibre due to their supposedly low thermal conductivity level and availability in the Southeast Asia region. The specimens were prepared using two different methods; the first two specimens using needle felting method and for the other two specimens epoxy resin was reinforced to bind the material together to become a polymer. The results revealed that coconut husk fibre reinforced with resin has the lowest thermal conductivity value among the four specimens with 0.0410 W/m.K and the lowest overall heat transfer coefficient of 2.73 W/m².K, making it a possible thermal insulator to be proposed for heat recovery.

Keywords: Coconut fiber, Kenaf fiber, Heat recovery, Thermal insulation, Waste heat

1. Introduction

Among the top three global energy users is the industrial sector. The amount of industrial waste heat produced as a result is probably substantial. This heat can be captured and used for various on-site tasks, such heating incoming water, combustion air, and furnace loads. It can also be transformed into cold, electricity, or another type of heat. An estimated 20–50% of the energy used in industry is released as waste heat [1].

A machine that uses heat as a source of energy may become less efficient if heat is lost to the environment. This is now a concern for the majority of combustion engine types. Waste heat recovery is a crucial technology for the strategic deployment of energy as it has the potential to effectively alleviate energy scarcities and reduce emissions of pollutants. Based on their capacity to tolerate a broad range of temperatures, waste-heat sources may be broadly categorised into three categories: low-grade waste-heat (<230°C), medium-grade waste-heat (230-650°C), and high-grade waste-heat (>650°C) [2]. While there are a number of waste heat recovery devices on the market, none of them are cost-effective for recovering waste heat at low temperatures. Even though 63% of waste heat is of low temperature, it is challenging to recover this energy, hence the issue may go unnoticed [3].

Therefore, increasing heat transfer efficiency is a crucial method for raising the engine's heat transfer efficiency [4]. Many researches have been conducted to reduce heat loss and enhance engine thermal performance by methods such as employing nanofluid, increasing surface area for heat transfer, etc. [5-8]. It has been common practice to insulate heat transmission surfaces, such as the valves, piston, cylinder head, combustion chamber, and cylinder wall, in order to increase engine performance and eliminate the cooling system. The insulation that keeps heat from escaping to the cooling system allows the engine's cylinder walls to become hotter and generate more energy from exhaust gases [9].

As thermal insulators, natural fiber-based materials made from sustainable raw materials sources are gaining popularity. This comprises naturally occurring fibres from agricultural goods including palm fibre, coconut husk, and several more. Because of their low mass density and cell structure, they offer very good sound and heat insulation qualities, usually better and more advantageous than synthetic fibres. Not only does natural fibre insulation have low heat conductivity, but the natural quality of the input fibres is also a significant benefit. Its renewable nature and lack of environmental effect are other benefits. For instance, natural fibre insulation gives comparable, if not better, thermal technical qualities than mineral wool [10].

It has been demonstrated that agricultural by-products are efficient heat insulators. The thermal insulation decreases with increasing heat conductivity. Since the thermal conductivity of the agricultural by-products P S Dhivar and A R Patil [11] examined is significantly lower than that of artificial insulators, they offer good thermal insulation properties. Low heat conductivity in every specimen under examination indicates superior thermal insulating capabilities. The maximum thermal conductivity, 0.077 W/m.K, is found in rice husk, while the lowest, 0.0378 W/m.K, is found in sunflower stalks. The rest, in increasing order of heat conductivity, are palm, hemp, banana, bagasse, and coconut fibres.

Another recent work by N Nadir et al. [12] looked experimentally at the energy efficiency of a solar collector with glass wool and date palm wood thermal insulation. A petiole containing gypsum can function as an efficient thermal insulator for the solar air collector, according to an analysis of the impact of vegetable components on the air design of the collector. The Petiole + gypsum insulated collector was shown to have a 37.7% greater thermal efficiency than the glass wool insulated collector, making it a more efficient option for thermal insulation in the solar air collector.

Agricultural by-products, which have never been used as an insulator in a waste heat recovery system, will eventually be the focus of this article as a means of reducing heat losses in the sector. Using these resources will result in a sustainable product that is also less harmful to the environment and less polluting. The ability of these materials to achieve the two main objectives—minimizing heat losses to the environment and, above all, determining the heat transfer coefficient—will be assessed.

2. Methodology

2.1. Experimental procedures

The materials chosen for this experiment were kenaf fibre and coconut husk, and samples were made using the needle felting method and the fiber-resin mixing method. The thermocouple and heat flux sensor were calibrated by heating the system without the specimen until the sensors' values were constant or did not vary. After then, the system is continuously heated, and temperature data is gathered and recorded on a regular basis. Plotting graphs to show trends and computing temperature differences are examples of data analysis techniques. After that, the various samples were examined, and the ideal

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insulator was determined using the thermal conductivity value and heat transfer rate. In the event if the specimens' thermal conductivity is not less than 0.07 W/m.K., a replacement material with better thermal insulation qualities must be recommended. This is due to the fact that the best materials for thermal insulation applications are those with thermal conductivity values of 0.07 W/m.K. or less [11].

The AGILENT 34970A® data logger was employed in this investigation. A range of characteristics may be precisely measured with the AGILENT 34970A® data recorder. Data is acquired every ten seconds in order to offer a more accurate and thorough analysis.

2.2. Preparation of the specimens

To symbolise the hot part or the heat-absorbing walls of the heat recovery systems, a cylinder pipe made of stainless steel was employed. After that, it is divided into three pieces using a circular saw that is 10 cm long. The stainless-steel cylinder has a 5 cm diameter.

Two distinct processes were employed to create the two distinct agriculturally produced materials used in this investigation. Coconut husk and kenaf fibre have poor heat conductivity values, according to earlier research [11]. The initial method that was employed was needle-felting. Because so little fibre was used, the needle felting procedure was carried out by hand. The second technique included mixing glue and hardener with the powdered fibres. The four specimens that will be created and used in this experiment are coconut husk needle felted (CHN), kenaf fibre needle felted (KFN), coconut husk powder reinforced epoxy resin (CHER), and kenaf fibre powder reinforced epoxy resin (KFER). For the sake of simplicity, the remainder of this paper will use the code below to address these specimens.

By measuring the stainless-steel cylinder's dimensions, the thermal insulator's measurements were ascertained. In order to provide a more accurate reading and that heat does not escape from the gaps, this is done to ensure that the cylinder was completely covered. Using a weighing scale, the mass was calculated based on the quantity of fibre required to cover the cylinder. Because the thermal insulating materials have varying densities, their masses varied as well. The size of the stainless-steel cylinders that were on sale in the stores and an analysis of earlier trials were used to calculate the mass and dimensions of the thermal insulator. The stainless-steel cylinder's diameter is 5 cm, and the four specimens are 10 cm in height, 22 cm in breadth, and 1.5 cm in thickness. 20 g for CHN, 19 g for KFN, 37 g for CHER, and 34 g for KFER is the mass of each specimen.

The fibre sheet measured 10 centimetres by 22 centimetres. The kenaf and coconut fibres were cleansed and let to dry in the sun for five to six hours in order to eliminate any remaining moisture. After the drying phase, the felting process was done by hand. The ultimate felting results of kenaf and coconut fibre are shown in figure 1. Since the fibre is now in sheet form, it is simple to mould into a cylindrical shape that fits the experiment's stainless-steel cylinder.

Figure 1. After felting, coconut husk with kenaf fibre.

In the second technique, the fibres were combined with glue and hardener to create the sample. Using a pulverizer, the fibres from the coconut and kenaf were crushed into a powder. For five to six hours, the powder is dried in the sun. Following the drying process, a mechanical mixer was used to fully combine the fibre, resin, and hardener in a 1:2:1 ratio. Subsequently, the mixture and the stainless-steel cylinder were placed into a cylindrical mould measuring 10 cm by 7 cm. After that, the mixture is cured for a day to solidify. The final product of the created sample is seen in figure 2.

Figure 2. Coconut husk and kenaf fibre after blending with resin.

2.3. Set up of the testing

A heat flux sensor model 27160 and a type-K thermocouple were used in this experiment. Strong corrosion resistance and a wide working temperature range characterise the standard Chromel/constant Type K thermocouple. It is less costly than other varieties with a wider temperature range and can withstand temperatures as high as 1260°F. Its partial radiation hardness has a usual accuracy of 2.2°C, a standard accuracy of 0.75%, and a particular error limit of 0.4% [13].

Four thermocouples were used in this experiment and positioned differently, as figure 3 illustrates. The coconut husk experiment setup with resin acting as an insulator is shown in figure 3. To monitor the temperature of the heat exiting the combustion chamber, one thermocouple was attached. Together with the heat flux sensor, two more thermocouples were mounted at the cylinder's entry, one on the insulator material, and the other at the cylinder's end.

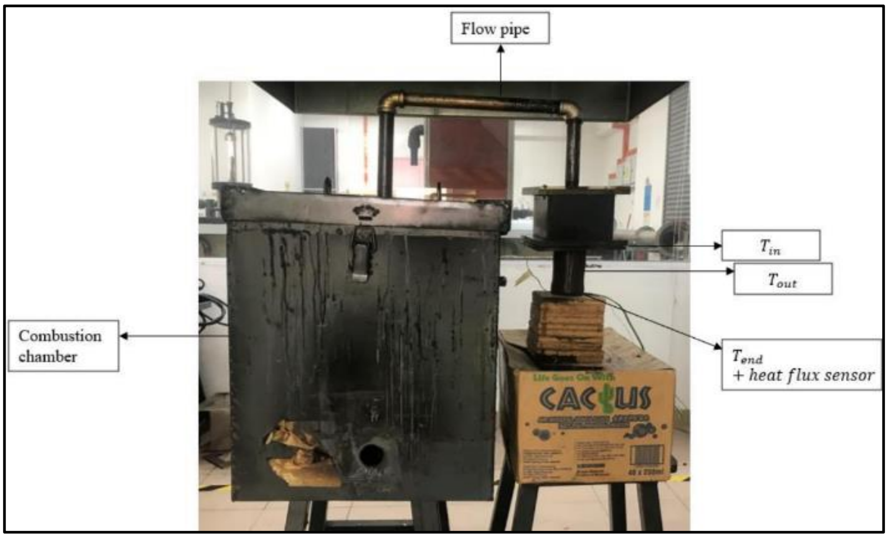

Figure 3. Setup for the experiment.

In order to record the temperature of the insulator, the thermocouple is positioned as indicated in figure 3. This is done to figure out the thermal conductivity of the insulator and the system's overall heat transfer coefficient. Wood was the substance that was used in the combustion process. For each test, one kilogramme of wood was used. Butane gas was used to burn the wood and heat the system.

3. Results and discussion

3.1. Temperature and thermal conductivity

The heat from the combustion chamber that enters the cylinder is represented by the T_{in}. T_{end} indicates the temperature as it leaves the cylinder, whereas T_{out} indicates the temperature of the insulating materials. We saw from the experiment technique that while the temperature of the combustion chamber rises, the insulator's temperature stays relatively constant. 33.4°C was the maximum T_{out} value. T_{in} experiences a decrease in temperature as the temperature differential grows. T_{end}, on the other hand, rises in time with T_{in}. T_{end} reached a highest value of 38.9°C. In the meanwhile, the trend for temperature difference and the trend for T_{in} are the same, indicating that the trend is stable.

We can confirm that the kenaf fibre sheet has certain shortcomings in terms of its ability to insulate against heat based on the testing as well. The insulator's temperature increases in tandem with the heat emanating from the combustion chamber. The experiment shows that the kenaf fibre absorbs heat from the cylinder walls. 36.6°C was the highest T_{out} value recorded. In addition, the T_{end} is somewhat higher than the sheet of coconut husk. T_{end} reached a highest value of 47.8°C.

In addition, when the T_{in} hits its maximum, the T_{out} for the coconut husk with resin insulator increases. Nevertheless, because it maintains a low temperature as the temperature rises, the coconut husk with resin insulator exhibits superior thermal insulating qualities than the coconut husk sheet. 34.6°C was the greatest T_{out} value. As the T_{in} rises, the T_{end} also exhibits a consistent increase. T_{end} reached a highest value of 42.1°C.

Conversely, when T_{in} rises, there is a little increase in the T_{out} of the kenaf fibre with resin insulator. 35.0°C was the maximum T_{out} value. But when the T_{in} rises, we can see that the T_{end} essentially stays the same with just little fluctuations. The capabilities of heat insulation demonstrated by the kenaf fibre with resin were nearly identical to those of the kenaf fibre sheet. T_{end} reached a highest value of 47.1°C. The temperature and voltage readings from the carried out experiment that were utilised in the computation procedure are displayed in Table 1.

Table 1 Temperature and voltage values for calculation.

Specimens	T_{in} (°C)	T_{out} (°C)	T_{end}(°C)	Voltage (V)
CHN	81.4	31.2	37.4	3.98 x 10^{-5}
KFN	92.2	32.8	47.7	5.82 x 10^{-5}
CHER	85.2	32.1	40.1	3.77 x 10^{-5}
KFER	84.9	32.9	47.0	5.58 x 10^{-5}

Because it was believed that at the greatest temperature, the system starts to stabilise before progressively falling in temperature, the maximum temperature was chosen as the data for the computation. Furthermore, the negative value, which just shows the direction of heat transport, has been ignored and all voltage values have been converted to absolute values. The sensitivity value of the heat flux sensor is 0.26 × 10−6 V/W.m2, as stated in the manufacturer's specifications for that particular model [14].

The heat transfer rate and thermal conductivity of the four specimens are shown in figure 4. Equations (1) and (2) were utilised to derive the values. Coconut husk has a thermal conductivity value between 0.046 and 0.068 W/m.K., according to earlier studies [11]. Kenaf fibre has a thermal conductivity ranging from 0.051 to 0.058 W/m.K [15]. The experimental values of the materials' thermal conductivity, which were computed using the experiment's data, are shown in figure 4. Every thermal conductivity value is within the reference value's range, as the figure illustrates. The coconut husk with resin exhibited the lowest thermal conductivity when compared to the other samples, indicating that it will function well as a thermal insulator. This is because, as compared to kenaf fibre, coconut husk often has a higher density and porosity. Additionally, combining natural fibres with epoxy can result in stronger and more durable thermal insulators as well as a lower heat conductivity rating. Since it was thought that the system starts to stabilise at its peak temperature before progressively dropping, the values at the maximum temperature were utilised in the calculations.

The results of the analysis also show that the maximum heat transfer coefficient, 4.21 W/m^2.K, is achieved by kenaf fibre with resin acting as a thermal insulator, whilst the lowest value, 2.85 W/m^2.K, is achieved by coconut husk with resin insulator. This experiment has shown that the best material to utilise as a heat insulator is coconut husk combined with resin.

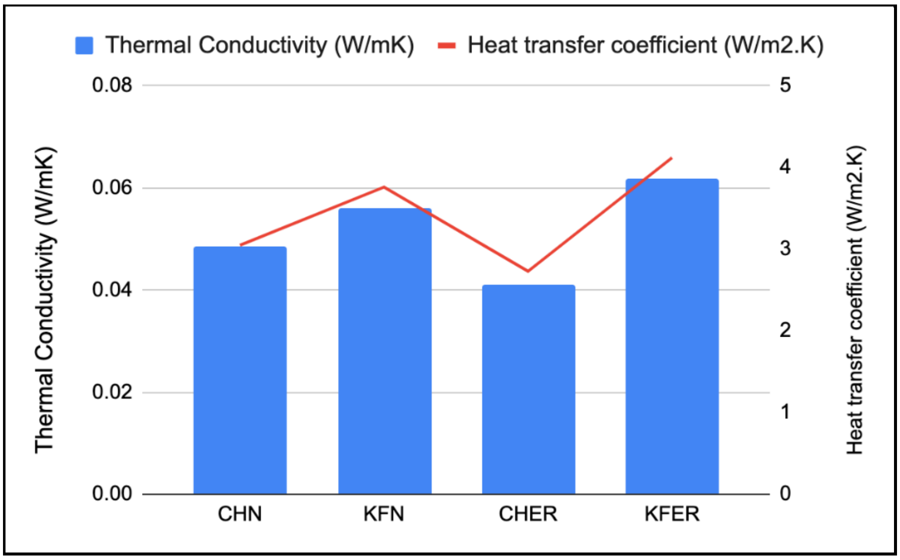

Figure 4. Thermal conductivity and the coefficient of heat transfer for each of the four specimens.

4. Conclusion

Two types of agricultural waste, coconut husk and kenaf fibre, were used in an experiment. Two different techniques were used to construct the specimens: resin mixing and needle felting. The purpose of this experiment was to develop a low thermal conductivity agricultural-based thermal insulator and investigate how it affects the coefficient of overall heat transfer.

The best substance to use as a thermal insulator might be chosen. The experiment's findings show that the combination of coconut husk fibre and resin has the lowest thermal conductivity value (0.0410 W/m.K.), while the combination of kenaf fibre and resin has the highest thermal conductivity value (0.0619 W/m.K.). This ultimately suggests that due to its low heat conductivity, coconut husk bonded with epoxy resin is the best material to employ as a thermal insulator.

This substance may be able to stop the system from absorbing too much heat and lessen heat losses to the environment, which is a problem that many waste heat recovery systems have nowadays. It also shows a low total heat transfer value, which suggests a slower rate of heat transfer and efficient heat preservation within the system. Therefore, using this material can greatly improve a waste heat recovery system's performance and efficiency.

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