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Conference paper

Thermal performance and Feasibility Study Using a Straw-Based Thermal Insulation in Geothermal systems

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ABSTRACT

Straw is the part of the stem (or stubble) of certain grasses, known as "straw cereals", and is most often a by-product or waste product of cereal production. In northern Algeria, it is produced in all cereal growing regions. It is generally used for animal feed. In this study, straw waste is used as a bio-material for thermal insulation in bioclimatic constructions and especially in geothermal applications, and the thermal insulation needs in a geothermal system is discussed. Furthermore, thermal performance of wheat straw aggregates bio-based material is tested for several thicknesses until stable results are achieved, using conduction heat transfer tests or heating flat plate. This method is based on the temperature difference measuring across the sample (inlet and outlet) and finally, compared it with other commercial geothermal insulation materials. Obtained results give us an idea of the energy gains to be expected from the bio-based materials manufacture to be used in geothermal systems comparing to conventional materials. It is noted that, the optimum thickness of the insulation material based on straw is 2cm, giving a temperature gradient around 9°C versus 16°C for conventional materials. Straw organic waste material is a promising candidate as an alternative insulating material for low-carbon and green buildings targets. Which are in line with the objectives set by the Algerian government as part of the fight against climate change, in particular the development of renewable energies, the promotion of energy efficiency as well as clean technologies and waste recycling.

1. INTRODUCTION

Cereal products occupy an important strategic place in the food system and the Algerian economy.

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During the two periods 2000-2009 and 2010-2017, the area of cereals occupies an annual average of 40 % of total agriculture area (Belkhiri, 2021). From 2000 to 2009, the total cereal cultivation area was estimated at 3,200,930 hectares, with durum wheat and barley comprising 74% of this area (Belkhiri, 2021). During the period 2010-2017, this area reached an average of 3385,560 ha, indicating an in-crease of 6 % compared to the previous period (2000-2009) (Belkhiri, 2021). The production of cereals during the period 2010-2017 is estimated at 41.2 million quintals on average, indicating an increase of 26% compared to the period 2000-2009 when the production is estimated on average of 32.6 million quintals (Belkhiri, 2021). In the period 2010-2017, the production consists mainly on 51% wheat durum and barley, and 29 % of all cereal production (Belkhiri, 2021). About 30 % of this cereal weight is lost or wasted (Viganó et al., 2015; Negreanu et al., 2019) in the processing and manufacturing chain, where it generates a huge amount of waste (Fărcaș et al., 2022). The Algerian cereal production currently stands at 41 million quintals (4.1 million tonnes) for the 2021/2022 season, and it is expected to increase. The Government notes that production forecasts for 2025 are around 55 million quintals, with a cultivated area of 3.75 million hectares. Currently, the total area dedicated to cereal cultivation is estimated at 2.9 million hectares. Fortunately, straw is indeed a by product of cereal production, making it a readily available and often abundant resource.

Several research papers investigate the use of this organic waste matter. A study by Madival et al. (2023) investigated a sustainable composite material made from rice straw agro-waste natural fibers. The research found that a composite with 20 wt % rice straw, combined with a hardener at a 1:10 ratio to epoxy, exhibited the lowest thermal conductivity. Additionally, stubble and straw from crops such as rice, barley, and wheat have long been used as insulation materials, notably in the form of straw bale walls for building construction (Marques et al., 2020; Peng et al., 2021). The porous structure, low density, thermal conductivity, and specific heat of straw make it highly effective for thermal insulation applications (Noha et al., 2019; Bouasker et al., 2014; Alshndah et al., 2023).

Additionally, it is found that the organic materials are beneficial for geothermal applications, which could assist to enhance the thermal conductivity and heat transfer performance by their low density and high porosity (Huo et al., 2022). Furthermore, it is important to take in consideration the structure of the thermal insulation layer and the nature of thermal insulation materials (Luo et al., 2023), in order to used it for geothermal heat exchanger especially in pipes and thermal storage tank for greenhouse gas reduction and enhance heat transfer efficiency (Cui et al., 2024).

Recovering straw as natural matter to produce a new thermal insulation material for used in the heat recovery and distribution networks in geothermal systems is a promising solution for moving towards environmentally friendly and low energy consumption technologies.

2. THERMAL INSULATION IN GEOTHERMAL SYSTEMS

There are several designs of geothermal applications, the double-cycle power generation and industrial hot processing require a temperature range of 100-200°C, heating, soil heating and dehydration processing needs a temperature range of 20-100°C (Xu et al., 2022; Li et al., 2023; Bendaikha et al., 2011a; Bendaikha et al., 2012). In this section, we are going to describe low enthalpy geothermal application that need insulation materials in order to improve the efficiency of the system. In the previous papers (Bendaikha et al., 2011b; Ngo et al., 2022; Khandouzi et al.; 2021), using domestic geothermal application need thermal insulation in the heat recovery sub-system (Bendaikha et al., 2011b), it needs insulation materials in order to reduce temperature spread from pipes and storage tank and to store thermal energy as a heat sources (fig. 1). The heat recovery system is mainly composed of thermal storage tank (2), pipes (3) and heat exchanger (4), which are well recovered by insula-tion material (1), as well as pumps (5) to ensure the fluid's circulation and therefore the heat transfer from geothermal spring to thermal storage tank.

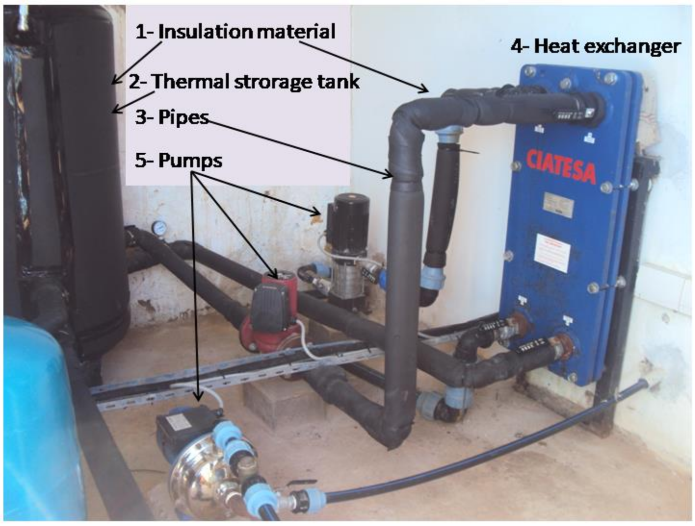

Fig 1. Domestic geothermal system schematic diagram (Saida, Algeria) (Bendaikha et al., 2011b)

Efficient thermal insulation is required, in order to reduce energy consumption of the system by reducing the pumping system activation, as well as the supplementary heating provided by the heat pump.

3. MATERIALS AND METHODS

In this section, the wheat straw aggregates are mixed with vinyl glue to obtain a mixture suitable for moulding. The thermal performance of this bio-based material is tested for different thicknesses.

3.1 Materials Preparation

Milled straw sample is obtained through a compression process, then it is drying with natural convection in a solar greenhouse (see fig.2). This sample is finely ground (≈2 mm) to be ready for experimentation.

The milled straw is mixed with (30 wt %) well mixed Aloe Vera plant in order to obtain a soft sample preparation, and (10 wt%) of sodium bicarbonate (as fire Extinguishing Agent), than coated in vinyl glue.

Fig 2. Milled straw block sample drying with natural convection in a solar greenhouse

The block sample is prepared with varying thicknesses and random assembly to achieve optimal efficiency. Fig 3 illustrates the different stages of this process.

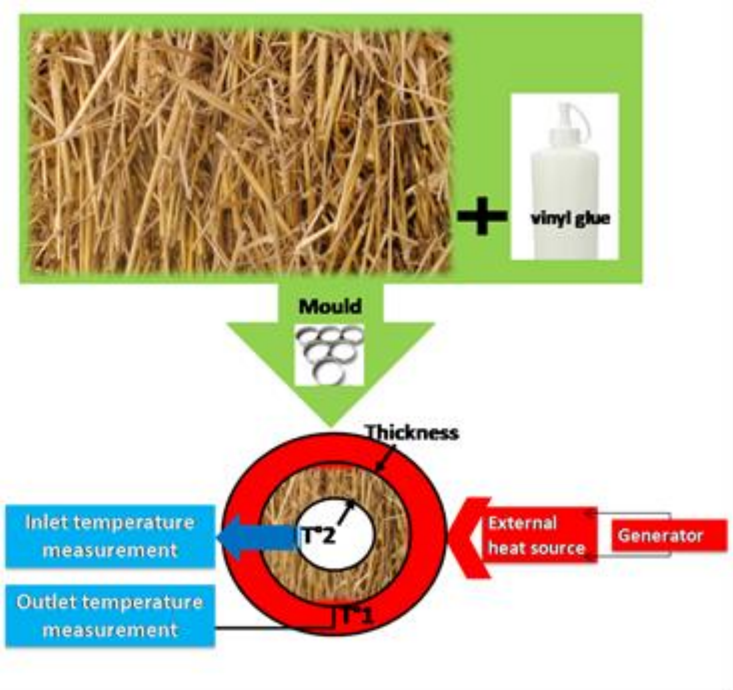

Fig 3. Wheat straw aggregates moulding technique and experimental set-up

For material selection: The process begins with selecting straw as the primary material with removing any dirt. The straw was dried and finely ground to no more than 2 mm, size suitable for the intended application.

Subsequently, the blocks are randomly assembled with 30 wt% of thoroughly mixed Aloe Vera plant material. This random arrangement helps to improve the thermal insulation properties and flexibility of the final product by creating irregular air pockets within the structure. We then added 10 wt% of sodium bicarbonate and coated both sides with vinyl glue to take shape.

Each sample is studied with the flat plate method, in order to identify experimentally the temperature evolution at a point of the prepared sample, so that, it can identify the transient and steady state temperature evolution.

Experiment requires an external circular heating flat plate made by aluminum which is heated by an electrical resistance reached to two cables connected to voltage (0 to 30 V)/current (0 to 6 A) generator. During the test, generator displays voltage of 21 V and current 0.2 A. Inlet and outlet temperatures measurement is carried out using thermometer with thermocouples type K, the Extech Instruments SD200, Three Channel Data Logging Thermometer. This device displays and stores on an SD card the temperature data taken on both sides of the straw sample. The measurement duration taken is 60 seconds between each value until the temperature's variation reaches a steady state.

It involves generating a temperature gradient across the sample thickness and characterizing it by measuring temperatures on two sides: the outlet, where the heat source applied at the boundary side diffuses, and the inlet temperature measurement zone.

This experiment is also conducted for conventional geothermal pipe insulations such as nitrite foam insulation, polyethylene foam insulation, and polyurethane foam, each with a thickness of 2 cm, as illustrated in Figure 4.

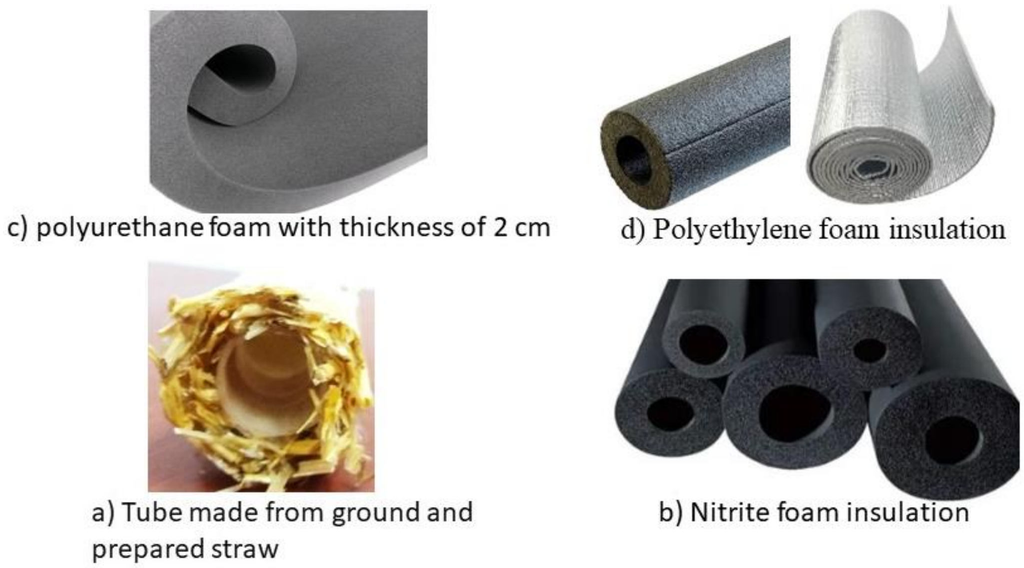

Fig 4. Conventional insulation materials and straw bio-based material

4. RESULTS AND DISCUSSION

Conduction heat transfer of the prepared straw sample is investigated by comparing the transient and steady temperatures evolution (T °C) from outlet to inlet the straw sample as function of time.

The inlet temperatures are measured for different thicknesses of the material (10-15-20-25-30 mm), and outlet temperature is diffused by the heat source applied at the boundary side and taken at the same time as inlet temperature, ambient temperature remains relatively constant throughout the experiment set up (T amb ≈ 22°C).

Fig. 5 shows the inlet temperatures evolution (°C) of the prepared material in the different thicknesses as function of time (min).

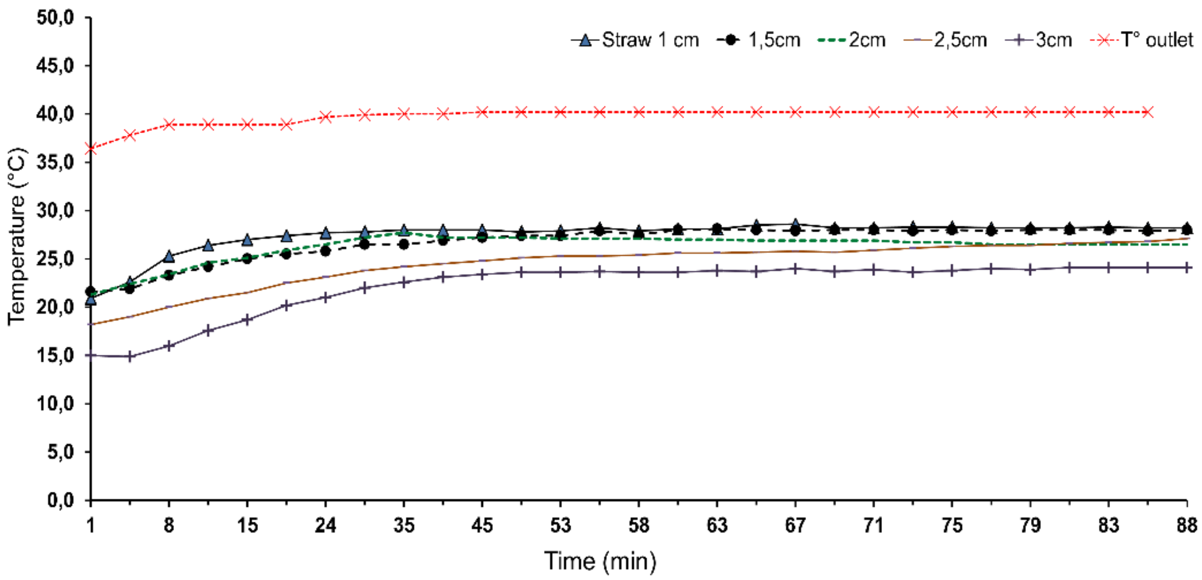

Fig 5. Inlet temperature measurement at different thicknesses

Figure 6 illustrates the temperature evolution (T °C) of the prepared straw material. It can be observed that temperatures (T° outlet, straw thicknesses of 1 cm, 1.5 cm, 2 cm, 2.5 cm, 3 cm) increase from 0 min to 25 min, indicating the transient state. Subsequently, temperatures stabilize during the steady-state period from 26 to 87 min, with temperature differences of approximately 2.5 °C between each thickness until reaching stability, suggesting that 2 cm thickness of the prepared insulation material is optimal. Therefore, increasing the thickness beyond this point does not significantly enhance efficiency. Indoor temperature measurements are compared with conventional geothermal pipe insulations such as nitrite foam insulation, polyethylene foam insulation, and polyurethane foam, each with a thickness of 2 cm (see Figure 6).

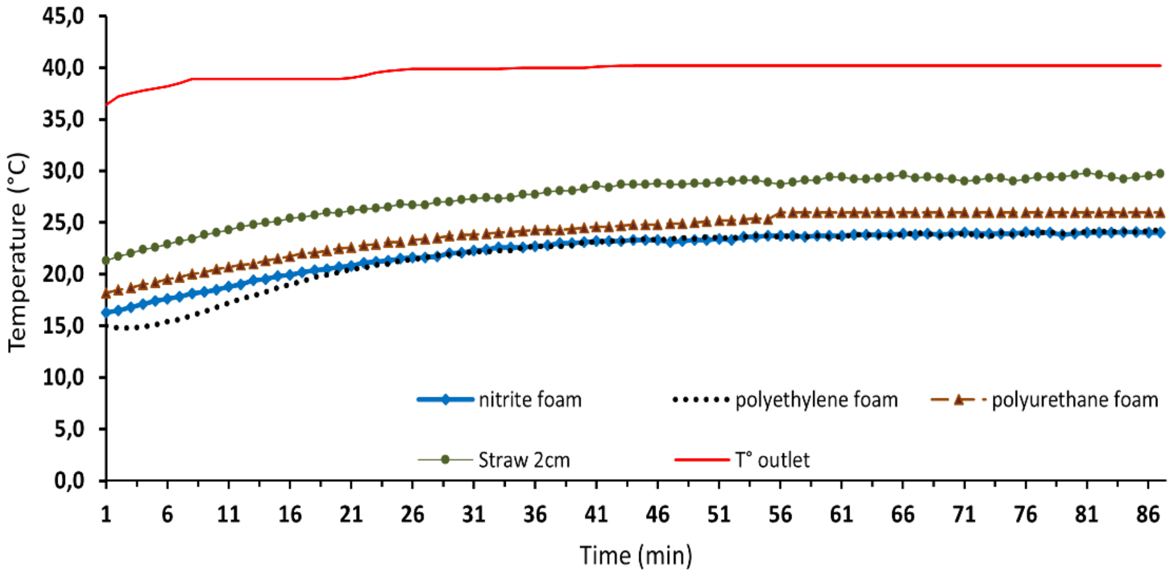

Fig 6. Conventional insulation materials used in geothermal systems tests

It can be observed that temperature gradient for conventional foams varies by 16°C between the outlet and inlet temperatures, which is greater than the straw material with a thicknesses of 2 cm, Where the measured ΔT is approximately 9°C. Despite the efficiency gap between conventional materials and the sample developed in this paper being evident, it can be concluded that straw material is a promising candidate for achieving low-carbon and environmentally friendly building objectives.

5. CONCLUSION

Thermal insulation plays a crucial role in geothermal systems. Therefore, hot water recovered by the pumps is transported through pipes and stored in a thermal storage tank. Therefore, the inlet temperature of the circuit must be maintained to avoid heat loss through the system. In the conventional geothermal systems, the most insulating materials used are derived from chlorine and petroleum chemistry, they are produced from non-renewable materials using energy intensive processes. These insulating materials contain substances that deplete the ozone layer (such as HCFCs) and release toxic gases that are fatal in the fire. In Algeria, straw organic waste is estimated more than 95% of organic matter from cereal production. These wastes can be recovered and recycled through an ecological process for a very high value use in the reduction of energy losses "thermal insulation material". In this study, a substitute for CFCs recycled from waste green materials, which is renewable and has a very low-energy process, is tested as a suitable candidate for pipe insulation in geothermal systems in order to reduce the overall cost of the heating system. Experimental results show that the straw-based prepared material is suitable as a thermal insulation material, with thermal tests revealing stability with a temperature gradient of 9

°C between outlet and inlet of the prepared sample, compared with conventional systems that give a temperature gradient of 16 °C.

In summary, the study demonstrates that straw material, prepared with a thickness of 2 cm, exhibits favorable thermal insulation properties compared to conventional foam materials. While thicker straw samples do not significantly improve efficiency. These results could be improved by using supplementary ingredients that give this material flexibility, resilience and more efficiency, towards environmental and economic sustainability.

Straw-based insulation can play a crucial role in optimizing heat recovery and distribution within geothermal systems. By insulating pipelines, tanks, and other infrastructure components, straw-based materials help to minimize heat loss during transport and storage, thereby maximizing the efficiency of heat exchange processes. This not only improves the overall performance of geothermal systems but also reduces energy waste and operating costs associated with conventional heating and cooling systems.

Moreover, the use of straw-based insulation aligns with broader sustainability goals by reducing reliance on fossil fuels and promoting the adoption of renewable energy sources. By incorporating environmentally friendly insulation materials into geothermal systems, we can contribute to the transition towards a more sustainable and resilient energy infrastructure.

In conclusion, leveraging straw natural matter to produce thermal insulation materials represents a practical and environmentally sound approach to enhancing energy efficiency and reducing carbon emissions in geothermal systems and beyond. Through innovation and collaboration, we can harness the potential of agricultural waste to drive positive change towards a greener and more sustainable future.

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