CFD investigation of a combined biomass furnace and solar drying system for paver blocks

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Abstract. Paver blocks have been widely used as concrete materials for exterior flooring. The process of producing paver blocks consumes a lot of time as the drying period takes at least eleven days. This paper had aimed to design a drying mechanism, a combined biomass furnace and solar collector drying system for paver blocks, and simulate the flow of the system through computational fluid dynamic analysis using SolidWorks Flow Simulation (SWFS) 2018. Desired results had been achieved as temperature, pressure, and velocity fields generated by simulation were accounted to observe fluid distribution in the drying system using contour plots. The temperature in the chamber had increased and uniformly distributed as the heat inputs from the two heat sources converged in the drying chamber. It was observed that the pressure varied from 101,331.72 Pa to 101,327.83 Pa with the highest temperature peaking at 600K and velocity was 1.5 m/s. The theoretical heat produced in the solar collector, biomass furnace and combine system were 191.70 W, 1290.66 W and 1482.36 W, respectively.

1. Introduction

Paver block manufacturing has been associated with construction-related industries extensively used in some applications. Due to modernization, materials used in making paver blocks had been modified in time. Having plastics as inseparable materials which are frequently used by the society, these objects have low density, long lifespan, and low cost of production which serve as key factors that support the rapid growth of plastic usage [1]. According to [2], these wastes and their industrial by-products should be considered as potentially valuable resources merely waiting for appropriate treatment and application. Given the situation, a number of researches were done to integrate plastic wastes as an aggregate material in block manufacturing and were introduced to compensate for the disadvantages in the old block manufacturing. Despite the improvement on the material science of paver blocks, its production is dependent on sun drying where large amounts of production time are consumed in the drying process. Sun drying is a slow process since it takes for about three (3) to four (4) drying days and is affected by weather conditions [3]. The importance of reducing the drying time of this is necessary and for it to happen, moisture should be removed. However, eliminating moisture in the blocks is critical as hasty moisture removal may result in the shrinkage on the surfaces of the paver blocks. The internal pressure experienced by the block material and immediate environment of the block within the system of the drying chamber may result in rupture. This has been proven by [4] as they have stated that severe stresses in bricks will result in cracking and rupturing. The drying phase is factored in by air temperature, relative humidity, and air velocity due to their contribution.
to moisture reduction [5,6]. Temperature rates are operated gradually to prevent brick cracking which is mainly due to the contraction rate difference between the core and the surface of the bricks. Safe ranges for air velocity need to be accounted for as well as high velocities aid low condensation but can lead to hasten drying. One of the efficient ways to evaluate the quality of airflow inside the dryer is by applying Computational Fluid Dynamics (CFD) to predict the flow pattern [7,8]. CFD simulations have been generally carried to process the most appropriate parameters to maximize efficiency and minimize production cost [9]. Moreover, the potential of CFD was strengthened by the fact that it can be adopted to minimize the costly experiment because users can generate visual results in similitude to real life situations [10].

In this study, CFD Analysis had been used to determine the drying conditions of the paver blocks by generating temperature, pressure, and velocity fields of the designed drying system– a combined biomass furnace and solar collector drying system under simulation, which appeared to predict significant heat in the system and quantify heat transfer observed at different drying configurations: use of the biomass furnace only, use of the solar collector only, and a combination of both drying systems. This study had determined the condition of the drying prototype before fabrication.

2. Materials and Methods
The project had been modified by the researchers to have forced convection while the absorber was to be coupled to a biomass furnace. Given this, the drying system subjected in simulation had been designed for handling paver blocks with plastic as its aggregates. The study focuses on atmospheric air as input and heater air as its output. The estimated temperature limits of the paver blocks ranges from 38°C to 204°C [11]. The biomass furnace was assumed to have constant heat while it varies in the case of the solar collector since it is dependent on time. The research had aimed to determine the condition of the drying system, to map heat patterns, and to account theoretical heat transfers from drying configurations of the system through CFD Analysis with the use of SolidWorks 2018 Flow Simulation. The flow analysis of the system had been done for monitoring pressure, temperature, and velocity fields. Moreover, as the system was simulated, heat mapping was done to determine the sections of the drying mechanism where significant heat values have been located. Considering drying configurations as biomass furnace only, solar collector only and both drying schemes combined, the system was simulated to determine each theoretical heat given. For the boundary conditions, there had been three (3) configurations of the system using the CFD analysis for the hybrid biomass for drying paver blocks. Physical parameters and air properties are seen below on Table 1.

| Physical Parameters                              | Remarks    |
|-------------------------------------------------|------------|
| Fluid                                           | Air        |
| Velocity Magnitude (Outlet)                     | 1.11 m/s   |
| Gage Pressure inside the Chamber                | 101.325 kPa|
| Heat Produced by the Biomass Furnace            | 1290.66 W  |
| Heat Produced by the Solar Collector            | 191.70 W   |
| Mass Flow Rate in the Biomass Furnace           | 0.0022 kg/s|
| Mass Flow Rate in the Solar Collector           | 0.0119 kg/s|
| Specific Heat (Cp)                              | 1 kJ/kg-K  |

3. Results and Discussion
The following had been the fields generated through simulation with heat produced at 1290.66 W by the furnace and a velocity of air at 1.11 m/s attached at the exhaust part of the system.
In Figure 1, the temperature, pressure, and velocity distributions inside the chamber without paver block were simulated. The contour plot in Figure 1a had shown that the heat was mostly concentrated in the middle of the drying chamber where the fire of the furnace was closest. The temperature of the other parts of the drying chamber were shown to be in uniform at 413 K. Figure 1b had shown that closing the solar collector had yielded to a lesser temperature in accordance with the reduced pressure in the drying chamber. Highest pressure had been seen in the furnace at around 101,335.61 Pa and diminished to 101,329 Pa at the top part of the drying chamber. Pressure difference was caused by the height and heat source placement in the system. With the solar collector outside in the field of computation, the velocity focused on the circulation of air near the exhaust and near the tube which had acted as a connection for the furnace and solar collector. A peak of 1.393 m/s can be seen at the said locations as shown Figure 1c. There was a peak velocity that had occurred in the connecting tube of the furnace and drying chamber that is caused by the change of area coming from the furnace to the tube itself. Since the heat produced by the solar collector was heavily dependent on time because of the effect of the temperature difference, the researchers had made five (5) trials from Figures 2 to 6a-c. Trials were time dependent to determine the heat produced at the given time. The outlet temperature of the solar collector was based on the study of [12] as shown in Table 2.

**Table 2. Inlet and Outlet Temperature of the Solar Collector**

| Time        | Temperature, °C | Inlet | Outlet |
|-------------|-----------------|-------|--------|
| 10:00 AM    | 36.11           | 100   |        |
| 11:00 AM    | 36.67           | 106   |        |
| 12:00 PM    | 37.77           | 90    |        |
| 1:00 PM     | 38.89           | 80    |        |
| 2:00 PM     | 38.89           | 55    |        |
Figure 2. Second Configuration: Solar Collector Only at 10 AM a) Temperature field b) Pressure field and c) Velocity field of the solar collector as the only heat source of the drying system for paver blocks.

Figure 3. Second Configuration: Solar Collector Only at 11 AM a) Temperature field b) Pressure field and c) Velocity field of the solar collector as the only heat source of the drying system for paver blocks.

Figure 4. Second Configuration: Solar Collector Only at 12 NN a) Temperature field b) Pressure field and c) Velocity field of the solar collector as the only heat source of the drying system for paver blocks.
Figure 5. Second Configuration: Solar Collector Only at 1PM a) Temperature field b) Pressure field and c) Velocity field of the solar collector as the only heat source of the drying system for paver blocks.

Figure 6. Second Configuration: Solar Collector Only at 2PM a) Temperature field b) Pressure field and c) Velocity field of the solar collector as the only heat source of the drying system for paver blocks.

Figure 7. Solar collector heat generation.

Figure 7 above had shown that the heat generation of the solar collector with respect to time, being the time at the 2nd trial had yielded the largest generation of heat and the last or fifth trial was the lowest to yield heat. Hence, for the combined biomass furnace and solar collector drying configuration, the lowest heat yield had been considered to avoid overheating in the system as the heat input from the biomass is high. Both sources had produced heat into the system for the last configuration. Also, the temperature inside the drying chamber can be seen to be almost uniformly distributed. The pressure in the system heavily differs.
based on the placement of the brick in the drying chamber that might affect the drying time of the brick. The pressure inside the drying chamber ranges from 101,331.72 Pa to 101,327.83 Pa.

The exhaust part of the system was the area with significant result due to the fan attached. The flow rate inside the drying chamber had focused mainly on the middle part and had shown that there was forced convection in the drying chamber. Figure 8 had shown that both heat sources have significant temperature readings and as they have converged in the drying chamber, the temperature inside increased to a uniform value of 535 K. The highest temperature is 600 K which is located at the connecting tube as seen in Tables 3 and 4. It was also observed that the highest pressure occurred in the upper area of the chamber and the highest velocity attained in the dryer is about 1.50 m/s

![Figure 8. Third Configuration: Combined Biomass Furnace and Solar Collector for a) Temperature field b) Pressure field and c) Velocity field in the solar collector as the only heat source of the drying system for paver blocks.](image)

**Table 3. Parameter Readings Based on Simulation**

| Parameters      | Temperature, K | Pressure, Pa   | Velocity, m/s |
|-----------------|----------------|---------------|---------------|
| Highest Value   | 600            | 101,331.72    | 1.50          |
| Lowest Value    | 297            | 101,327.83    | 0             |

**Table 4. Location of the Parameter Readings Based on Simulation**

| Location         | Temperature, K          | Pressure, Pa               | Velocity, m/s |
|------------------|-------------------------|----------------------------|---------------|
| Highest Value    | Connecting Tube         | Upper area of the chamber to the exhaust | Exhaust |
| Lowest Value     | Tip of the Solar Collector | Lowest area of both heat sources | Side areas of the chamber |

The theoretical heat transfer based on the simulation was obtained for each configuration. The biomass furnace yielded 1290.66 W of heat while the solar collector provided 191.70 W. It was found out that the combine or hybrid system has the largest heat transfer produced at 1482.36 W.
After the simulation, the solar dryer was fabricated with material specifications and technical information. For the design of the system as shown in Figure 9, the solar collector had contained a solar heat absorber for air heating, a drying chamber for accommodation of wet products to dry, and a chimney for the air exhaust. The width of the dryer is 612 mm while its height is about 1.35m. The absorber had an area of 1.0 m² composed of two corrugated aluminum sheets painted with matt-black paint to increase its heat absorption. A 50 mm thick cork plate had been added which minimized heat loss at the bottom of the solar air collector. In addition, air heated had crossed the channels of the absorber to reach the drying chamber by natural convection. The drying chamber had been insulated from all sides with glass wool with a thickness of 5.0 mm. At the back of the drying chamber, a double-swing door had been installed for easy loading and unloading of products to dry. Four rectangular trays had been made of galvanized iron wire of dimensions 955 mm by 262 mm. The first tray had been fixed at 32.0 cm from the bottom of the drying chamber and the last at 13.5 cm from the top. The upper part of the drying chamber had been equipped with a vertical chimney made of aluminum of 70.0 cm height. The whole had been supported by a metal frame located at 86.0 cm above the ground.

4. Conclusions
The combined biomass furnace and solar collector drying system for paver blocks had been tested through computational fluid dynamic analysis with the use of software simulation. By means of SolidWorks Fluid Simulation, mapping was conducted to observe the behavior of specific parameters when the system is operated. Temperature, pressure, and velocity fields were accounted for in the simulation process to determine the condition that the paver blocks would be situated during operations. The highest temperature, pressure and velocity observed were 600K, 101,331.72Pa and 1.50 m/s, respectively. The simulation showed that the temperature inside the drying chamber increased with heat inputs from the biomass furnace and the solar collector as heat sources. The temperature differences in the system had been confirmed by the variation in contour plots. Moreover, the direct relationship of pressure and temperature in the system as shown in the simulation could affect the drying time of the paver blocks when the prototype would be fabricated. Pressure is non-uniform inside the drying chamber where it varies with elevation. For the velocity, forced convection had contributed significantly to improving the air circulation in the drying system. With the use of a fan in the design, forced convection can be initiated and enhanced. Mapping through simulation can greatly help a system under designing. The heat variations in the system are quantified which can improve or predict possible errors before having a prototype be fabricated. The
researchers had observed the uniform distribution of heat in the system due to heat mapping. In connection, heat values from each configuration had been considered where the heat value of the hybrid system yielded the highest heat transfer among the three configurations. This could also help in the designing phase of a project.

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