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Development of Greenhouse Prototype for Drying Wet Paperboard for EverLantern Sdn Bhd

Problem Statement

Recycling is expressed as a critical component in reducing the quantity of trash produced. Recycling may attain environmental sustainability by diverting the waste output of an item's lifespan back into the input to replace raw material inputs. As a result, the firm is responsible for producing paperboard from recycled materials for consumers' benefit. Therefore, the firm has prepared wastepaper products as raw materials and goes through multiple procedures to produce paperboard. At the end of the process, the paperboard was produced and dried using different techniques. Some of the conventional drying techniques are sun drying and condebelt drying technique. The Sun drying method is preferred to the mentioned technique as it causes high-cost electricity bills, requires a high-level technical skill, and the safety of employees. However, some problems encountered at this sun drying stage are: (1) Due to the unfavorable weather condition, the drying period of a wet paper takes a long time which is not desirable. (2) When it is dried in an open area, it affects the quality of the paper and (3) Open-air drying has low efficiency.

Introduction

This study's goal was to investigate the optimal drying process method of recycled wet paperboard in a greenhouse, which can save money and time. The study's primary objectives were to propose how to increase the efficiency of the drying process for the wet paperboards in the greenhouse by considering innovation, environmental-friendly, material selection, cost-effectiveness, sustainable development, and safety. Through this, various programme outcomes have been achieved, such as recognise the significance of sustainable development when devising professional solutions to engineering problems with a clear understanding and displaying the capability to work competently in the context of a diverse team within a multidisciplinary environment, as an individual member with a teamwork fortitude or as an inspiring leader with practical management skills.

In terms of design, the maximum solar radiation received by the dryer is determined by the geometrical characteristics of the greenhouse dryer, such as form and direction. Mathematical modelling was used to investigate the impacts of the form (even or uneven, vinery, modified arch, or Quonset), direction (east-west and north-south), and latitude on the greenhouse air temperature produced by the dryer and is founded that, the uneven form received more solar radiation, whereas the Quonset shape got the least solar radiation [1]. Some researchers suggested that unevenly shaped greenhouse dryers oriented in the east-west received the most solar incident radiation from north-south orientation. Moreover, the uneven shape of greenhouse drier was observed to have reduced energy and heating requirements. Since the free-standing with even-span (symmetrical roof) shape of a greenhouse is widely used in many applications due to its multiple advantages, the same design goes for the greenhouse, which has the function of drying the wet paper. By implementing this design, the receiving amount of solar radiation and greenhouse internal temperature is maximized. The east-west orientation greenhouse can cause temperature rise inside the greenhouse [2]. Furthermore, the greenhouse cladding material, also known as cover material, is vital. Therefore, a low-cost and lightweight polyethylene material is used as the cover for the greenhouse. Polyethylene is a transparent material which allows maximum light to pass through, promoting the drying process. However, continuous exposure to the sun can deteriorate the cover material. Hence an ultraviolet-inhibited and anti-drop polyethylene cover is preferred to prolong the life cycle of polyethylene. The inhibitor prevents the rapid breakdown of polyethylene caused by ultraviolet light and reduces the frequency of changing the cover material.

The variation in solar energy during the day causes a change in the temperature of the heated air. Moreover, it is difficult to continuously dry goods in the greenhouse drier at night. Therefore, the incorporation of a thermal energy storage device such as sensible heat storage material is needed. These materials are inexpensive, and the floor of the drying room is covered with heat-sensitive materials. Ahmad and Prakash (2020) experiment examined the performance of different bed conditions in a greenhouse dryer. The examined sensible heat storage material is gravel bed, ground bed, black painted gravel bed, and concrete bed and found that the greenhouse dryer with black painted gravel type bed reported a maximum heat gain (53%), overall heat transfer coefficient (3.88 $W/m^2 °C$), and temperature (64 ◦C) followed by gravel bed (49%), concrete bed (34%) and ground bed (29%) type respectively [3]. Since gravel is more expensive than concrete and black gravel has higher heat gain than gravel, a black concrete bed is suggested to cover the floor of the greenhouse. It is predicted that the black concrete bed would have a higher heat gain than the concrete bed (more than 34%). A concrete slab can retain the heat in the greenhouse dryer, together with a steel plate which is used as a heater for the environment in the greenhouse due to its high thermal conductivity. Thus, it can help create a higher temperature condition and increase the greenhouse temperature at daytime.

Project Outcomes

An exhaust fan is a part of the ventilation system used in a greenhouse. The drying process needs to avoid pest disturbance, remove moisture and maintain humidity in the greenhouse. It is also used for air movement in the greenhouse so that the wet paperboard can dry faster. A double-decker stand will be used to hang the paperboards in the greenhouse. The vertically hanged board can dry faster as it will be fully exposed to the air, ensuring numerous paperboards are dried simultaneously. Some considerations were taken note of in the design of the stand, such as utilizing the maximum space of the greenhouse and drying the maximum number of wet paperboards. The Figs. 1 and 2 show a greenhouse set up with the features mentioned above.

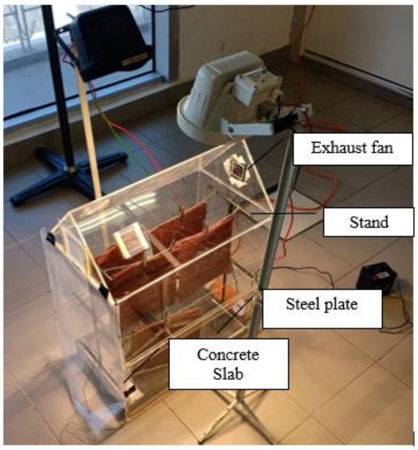

Figure 1: Greenhouse setup for drying the wet paperboards

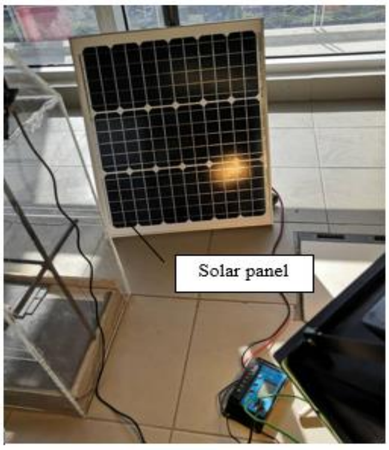

Figure 2: Solar panel connected to exhaust fan

Based on the literature review, the wet paperboard is dried due to the heat trapped inside the greenhouse and the airflow. Hence, the mechanism involved in the drying process of wet paperboard is discussed with the heat flow and air movement.

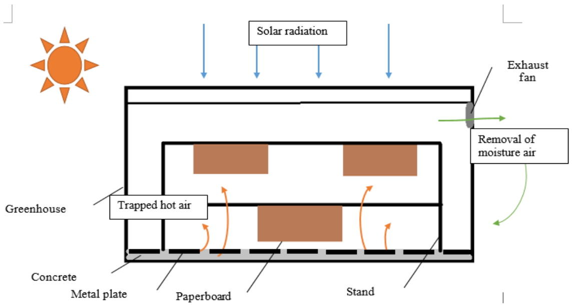

Figure 3: Heat flow at daytime

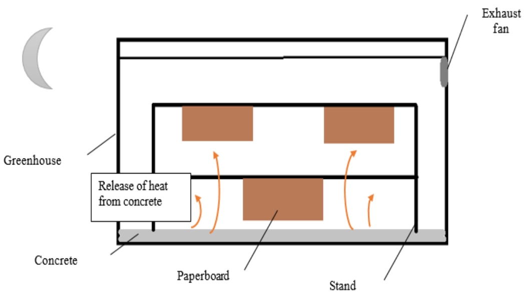

Figure 4: Heat flow at night

Fig. 3 shows the airflow in the greenhouse at daytime (12pm-3pm). The blue line indicates heat energy transmitted through the roof and wall cover. The solar radiation from the Sun, which has a value of around 420 W/ m^2 – 625 W/m^2, passes through the polyethylene cover and warms up the paperboard, concrete, and steel plate inside the greenhouse. The orange arrow indicates the heat trapped from the ground by the concrete floor and metal plate. The heat is nearly entirely absorbed by the floor, raising the temperature of the materials. The polyethylene film also acts as an effective thermal insulator, protecting it from cold air. The greenhouse structure keeps the heated air within it. During the day, no heat is transmitted outside via air convection, and the film permits low heat loss owing to heat conduction through its substance, and all heat energy will be used to dry the wet paperboards. The green line indicates the moisture air removed from the greenhouse by the exhaust fan. At night, the metal plate is removed. Since concrete has the function of releasing heat, it helps the paperboard to dry as shown in Fig. 4. It prevents heat loss and maintains a high temperature inside the greenhouse at night.

When the experiment was conducted with spotlight condition, concrete slab condition, steel plates, and exhaust fan, the estimated drying time improved to an average of 3.77 days while in the conventional drying of the open-air drying method, the estimated drying time is an average of 6.36 days. In the experiment condition, the highest temperature is 39.8 ℃, while the average drying rate is 39.44%/3 h, while in conventional drying, the highest temperature is 30.4 ℃, with the average drying rate of 22.99%/ 3 h. From Fig. 5, it is observed that the weight of wet paperboard in greenhouse conditions is much lesser than the conventional drying technique during the 6 hours of drying duration. It indicates that the drying rate is high, resulting in lower weight content. Thus, it can be concluded by saying that, the drying rate of wet paperboard in greenhouse conditions is significantly improved by 16.45 % while reducing 39.46 % of the weight.

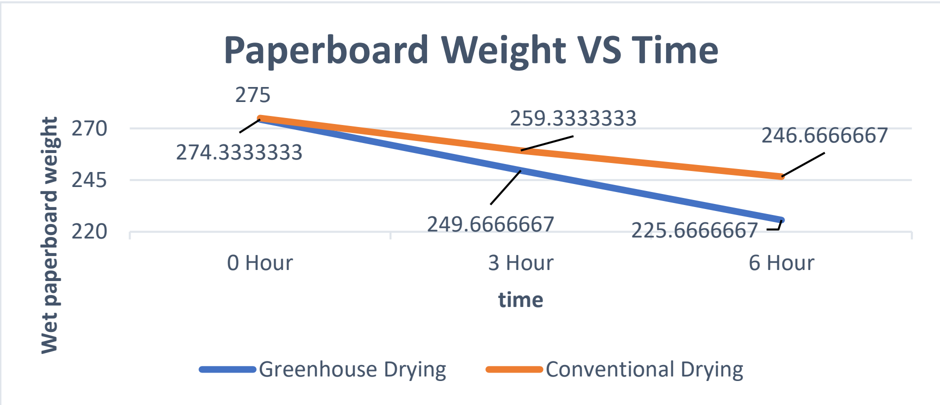

Figure 5: Results obtained under different conditions.

<u>Environment and Sustainability Aligned to United Nation's Sustainable Development Goals</u>

The development of solutions complies with the consideration of the environment and sustainability. It is vital to consider the 17 Sustainable Development Goals (SDGs) to produce a sustainable future. Sustainable Development Goals related to design development are as follows: (1) Goal 9 - Industry, Innovation, and Infrastructure. It focuses on constructing flexible infrastructure, maintainable industrialization, and cultivating development. Initially, greenhouses were used for agricultural purposes but nowadays are used for drying other goods such as paperboard. The greenhouse drying process involves less energy consumption with cost-effectiveness. (2) Goal 12 represents responsible consumption and production. Renewable energy such as solar energy acts as the heat source for the drying process where the heat production increases by using reused steel plates, and it is also utilized to function the exhaust fan and solar panels. The whole drying process is to dry recycling old paperboard. Hence, deforestation can be reduced to produce more raw materials for paper making. (3) Goal 13 reflects climate action, where spontaneous actions are taken to tackle climate change and its impacts. Solar energy is used in the proposed design instead of fossil fuels. Consumption of fossil fuels can produce harmful greenhouses gas such as carbon dioxide, and methane can cause a negative impact on the climate. (4) Goal 15 represents life on land. Protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, reverse land degradation, etc. Deforestation can disrupt ecosystems, which also affects the habitat of wild animals, food sources, etc.

Project Management and Finance

Table 1.0 presented a Gantt chart of the Integrated Design Project from week 1 to week 13.

Table 1: Gantt Chart.

No	Project Activities	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13
1	Literature Studies	■	■											
2	Finalize Design			■	■									
3	Prototype Fabrication					■	■							
4	Prototype Testing							■	■	■	■	■		
5	Greenhouse Construction												■	
6	Greenhouse Launch													■

Table 2: Estimated Budget for the real-scale greenhouse (W-3.5m × H-8m × L-6m)

Component	Labour Fee (RM) Real scale	Material Fee (RM)	Total Fee (RM)
(1) Concrete Floor	720 (10 wage × 3 worker × 8 hour × 3 days)	670	1390
(2) Exhaust Fan	20 (10 wage × 2 hour)	130	150
(3) Greenhouse	80	300	380
(4) Steel component	20 (10 wage × 2 hour)	120	140
(5) Polyethylene	120 (10 wage × 4 worker × 3 hour)	880	1000
		Grand Total:	3060

For financial analysis, the suggested component modification for this project is adding a concrete slab, exhaust fan, greenhouse, and steel component, which can be any shape. The total cost for all components (1), (2), (3), (4) and (5) combined is RM 3060 for building one greenhouse (As shown in Table 2.0). Assume the original design of the drying method (without a greenhouse) have a profit of RM 0.50 for each paperboard and can hang up to 40 pcs in one batch, with the average drying duration of 7 days per batch profit gets around RM 1042.86 yearly. Meanwhile, the same profit and number of paperboards can be hung in one batch, but the drying duration can reduce to 4 days per batch, and the payoff can reach up to RM 1825 per year. The added profit for the greenhouse design can be used to cover the cost of greenhouse building, in which the return on investment can be achieved in 4 years.

Conclusions

Greenhouse drying method implementation can result in good impacts on the environment by using natural renewable resources compared to the conventional method. In addition, it also gives better results where within 6 hours of drying in the greenhouse can cause the weight of the wet paperboard to reduce by 48.66g meanwhile conventional drying causes a weight reduction of 28.33g. The improvement percentage is 16.45 %. It has proven that the greenhouse drying method is a cost-effective and efficient way to dry wet paperboard as well as promote sustainable development, which creates positive impact to social, economic and environmental sustainability.

References

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