**Optimum Design of a PV Driven Transpired Plate Solar Air Heater for Drying Woodchip in Scotland.**

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**Abstract**

The design and operation of a PV driven solar air heating system for drying woodchip is considered. For a given weight and moisture content of the woodchip sample, the effect of the dryer unit configuration on drying rate, that is, either operating with a thick or thin layer of woodchip, is discussed. Six alternative collector designs, based on absorber plate hole spacing and diameter, absorber material type, and the use of a collector cover are presented in relation to the ability of the complete system to dry the given sample. It is found that the system operating with the thin layer dryer in combination with the covered collector with aluminium absorber comprising 3mm holes at 3.0 cm pitch provides the highest annual yield of dried woodchip.

*Keywords: Solar air heaters, Drying woodchip, PV driven*

**1. Introduction**

Forced drying of woodchip for use in both large and small scale heating operations is an energetically intensive process. Typically, raw softwood chip has a moisture content of approximately 60%.[1] Many appliances and automatic feed systems require a maximum moisture content of 30% for effective operation. Existing large scale production schemes can use up to 20% of the feedstock as fuel to dry the product. [2] This, clearly, has a significant economic impact on the supply chain. The present work considers, on a small scale, the potential of a simple solar air heating system to dry woodchip. The relative performance of six alternative designs of transpired plate solar air heater is evaluated. All collectors considered have an aperture area of 2 m2. The first three of these collector designs are; 1.6 mm thick aluminium absorber plate, painted matt black, with 2mm holes at 2cm spacing and double skinned polycarbonate cover ( type 1w), the same absorber material and cover but with 3mm holes at 3.0 cm spacing ( type 2w) and, thirdly, an absorber of woven black polythene (Mypex), again with cover ( type 3w). The second three designs considered comprise the three above noted configurations, but each without the polycarbonate cover. These are termed 1n, 2n, and 3n respectively. Figure 1 shows a schematic representation of a transpired plate solar air heater, with air flow provided by means of a PV driven fan. A 10Wp BP Solar PV module and PAPST [3] 5W, 12V DC fan were used for all collector configurations studied.



Figure 1. Transpired plate solar air heater (no cover) with PV driven fan.

**2. Woodchip Drying Characteristics**

Previous work, [4], found that the type 2w collector provided the highest outlet temperatures. While air temperature is a key factor in determining the drying rate, the volume flow rate and air velocity through the woodchip are, naturally, also significant. The thickness of any given woodchip sample to be dried has an effect on system performance. For a thicker layer, overall system pressure drop will be greater, implying reduced flow rates and hence, also, velocity. However, drying air residence time will be increased which, provided it does not become saturated, provides a better utilisation of its moisture carrying capacity.

An initial study on the drying characteristics of different thicknesses of woodchip was therefore undertaken to define relative impact of velocity and temperature on drying rate. Four drier configurations were considered. Figure 2 shows a schematic representation of the thin layer dryer, with appropriate instrumentation, while Figure 3 shows the thick layer drier. The thin layer drier comprises a 5cm thick woodchip sample, initially at an MC of 60% and weighing 3kg. The thick layer drier was tested with three sample weights and thicknesses, namely, 10 cm and 1kg, 20 cm and 2 kg and 30 cm 3kg woodchip samples, all, again, initially with an MC of 60%



Figure 2. Schematic representation of the thin layer dryer, indicating position of sensors.



Figure 3. Thick layer drier showing position of thermocouples and humidity sensors in the wood chip layer.

Through consideration of previously defined collector flow rate profiles and thermal performance [4], each drier configuration was tested for an appropriate range of flow rates and heat input (i.e. air temperature and velocity). Figure 4 shows a plot of moisture content against time, for the thin layer drier, for a range of air velocities for a fixed temperature of 22C.



Figure 4 Evolution of woodchip Moisture Content as a function of 4 different velocities for a temperature of 22 C.

Moisture Content is defined, as shown in Eq. 1, on a wet basis, as the mass of water in the sample at any given time, divided by the total mass of the product.

$MC=\frac{W-W\left(dried\right)}{W}$ (1)

Similar tests were undertaken for a range of temperatures and flow rates. Through a detailed statistical analysis of gathered data, the drying characteristics for the thick and thin layer woodchip samples were determined. The model thus derived for moisture ratio, for the thin layer dryer, is given in Eq. 2. Moisture ratio is defined as (MC –MCeq)/(MCo-MCeq), where MCo is the initial moisture content ( 60%), MC the moisture content at any given time, and MCeq, the equilibrium moisture content.

 (2)

Where V is the average air velocity through the sample (m/s), T the air delivery temperature (C), and t, the duration (s)

Clearly, as velocity, time and temperature increase, the Moisture Ratio decreases. Similar models were developed for the Moisture Ratio for the three thick layer drier configurations. As the pressure drop increases with woodchip layer thickness, for a given collector configuration, system flow rates will be lower for thicker layers. While this will necessarily increase collector outlet temperatures, a detailed analysis of system pressure drop, and drying velocities and temperatures is required to determine the optimum configuration of drier and collector. The following section therefore considers the performance of the PV module and fan combination, system pressure drop and collector performance.

**3. Fan and System Flow Rate Characteristics**

Analysis of the respective fan and PV module operating characteristics showed that the relationship between fan voltage and irradiance was as given in Eq 3

V = -9.5x10-6 G2 + 0.0251G -0.4694 (3)

Where: V is fan voltage (V), and G, irradiance (W/m2). Equation 3 implies a full sun (1000 W/m2) operating voltage of 15.13 V. A series of tests were run to determine the fan pneumatic characteristics for a range of voltages. The results are shown in Figure 5.



Figure 5. Fan pneumatic characteristics for a range of operating voltages.

Through consideration of this relationship, for a given voltage, by measuring the volume flow rate through each drier configuration, it was possible to determine the pressure drop across each woodchip sample. For the thin layer drier, with 5cm thick layer of woodchip, with the fan operating at 16 V, the flow rate was found to be 225 m3/hr. This, as can be seen from Figure 5, implies a pressure drop of approximately 12 Pa. For the thick layer drier, the volume flow rates, as expected, were lower.

A theoretical analysis of the pneumatic characteristics for the six alternative collector designs, including the flexible connecting duct work and its degree of extension [5], showed that the greatest resistance to flow is afforded by the type 1w collector (2mm holes at 2cm spacing and double skinned polycarbonate cover). The unglazed collector comprising the Mypex fabric absorber will deliver the highest flow rates for a given drier configuration.

This analysis, in association with the previously determined drier unit pressure drop allows a determination of the pneumatic characteristic for the combined system, namely; collector, connecting ductwork and drier unit.

Theoretical analysis of collector performance in relation to the operational flow rates predicted implied that the optimum combination for drying the woodchip sample was the type 2w collector, operating with the thin layer drier. These findings were borne out through experimental validation. Table 1 shows the full sun (1000 W/m2) thermal efficiency of the alternative collector/drier configurations. Solar Drier 1 refers to the thin layer drier, while Solar Drier 2 refers to the thick layer drier. For the latter, results for the system operating with only the types 2w and 2n collector are shown for the different thickness of wood chip studied. The optimum system full sun thermal efficiency, 78.1 %, is obtained using the type 2w collector, operating with thin layer drier.

Table 1 System thermal efficiencies for alternative collector and drier configurations



**4. Conclusion**

While the addition of a glazing cover increases pneumatic resistance, thermal efficiencies are higher due to a proportionately greater reduction in heat loss. This effect is more marked when operating with the thick layer dryer. Considering system flow and outlet temperature profiles in relation to the Moisture Ratio drying models for the alternative drier configurations reveals that the same optimum thermal configuration of collector and drier will also provide the greatest drying rate. In analysing potential annual outputs, it is assumed that a batch process system could be in operation to remove the chip once MC had been reduced to 30%. On this premis, this configuration can dry approximately 3100kg of chip per year.

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