CHAPTER 7

Summary and Conclusion

7.1 Summary

Solar energy is fast becoming an alternative source of energy. One of the most potential applications of solar energy is the solar drying of agricultural products. The post-harvest losses of agricultural products in rural areas of developing countries can be drastically reduced by using well designed solar drying system. Since solar air collector is the most important component of solar drying, improvement of designs of collector would lead to better performance of the system. In this work an attempt is made to design and fabricate solar dryer with a thermal storage unit with three different solar air heater designs. The scope of the project is to improve the thermal performance of the solar air heater and to use the same for off-sunshine hours using thermal storage unit and also for possible drying applications and find a solution to the severe energy shortage existing in many parts of the developing world.

Three different solar air heaters with thermal storage and solar dryer are successfully designed and fabricated.

Type I : Flat plate type solar collector with storage and solar dryer.
Type II : Parallel type solar collector with storage and solar dryer.
Type III : v-groove type solar collector with storage and solar dryer.

The experiment was performed from August 2012 to August 2013 at Coimbatore (11.0183° N, 76.9725° E). The experiment was done for both natural flow and forced flow of air. The mass flow rate was set from 0.02 kg/sec to 0.06 kg/sec. About 150 kg of white and black pebbles are used in thermal storage. Food products are dried using solar dryer and compared the results with open sun drying.
Experimental analysis has been carried out in three phases

Phase I : Thermal performance of solar air heaters.
Phase II : Testing of Thermal Storage.

7.2 Phase I: Thermal performance of solar air heaters

Thermal performance analysis is carried out based on operational parameter such as air mass flow rate and climatic parameters such as solar radiation, ambient temperature, relative humidity and wind speed.

The average ambient temperature during the experiment period was 34.4°C. The average solar radiation measured during experimental study is 772.7 W/m². Average wind speed recorded during the study was 0.2 m/sec.

The average collector outlet temperature with natural air flow for flat plate, parallel type and v-groove collector are found to be, 50.8 °C, 51.7 °C and 54.2°C respectively. Average collector outlet temperature obtained for 0.02kg /sec mass flow rates for flat plate, parallel plate and v-groove are 74.5°C, 77.5°C and 80.5°C respectively. For 0.03 kg/sec mass flow rate collector outlet temperature are 71.9°C, 75.8°C and 78.4°C for flat plate, parallel plate and v-groove respectively. Outlet temperature are 68.7°C, 72.6°C and 75.4°C for 0.04 kg/sec mass flow rate and 65.8 °C, 68.4°C and72.6°C for 0.05 kg/sec respectively for flat plate, parallel plate and v-groove collectors. Average collector outlet temperature obtained for 0.06 kg /sec mass flow rates for flat plate, parallel plate and v-groove are 61.4°C, 65.2 °C and 70.5 °C. It is seen that the collector outlet temperature in forced convention flow was found to be higher when compared with the natural flow. This is because the manually adjustable fan pushes more air from outside to flow inside the collector and available for heating. It is seen that as the mass flow rate increases the collector outlet temperature decreases irrespective of climatic parameters.
Average absorber temperature obtained for 0.02 kg/sec mass flow rates for flat plate, parallel plate and v-groove are 52.5°C, 54.2°C and 55.7°C, respectively. For 0.03 kg/sec mass flow rate absorber temperature 52.0 °C, 53.6 °C and 55.04 °C are for flat plate, parallel plate and v-groove respectively. Absorber temperature are 51.3 °C, 52.7 °C and 54.1°C for 0.04 kg/sec mass flow rate and 51.2 °C, 52.8 °C and 54.6 °C for 0.05 kg/sec respectively for flat plate, parallel plate and v-groove collectors. Average absorber temperature obtained for 0.06 kg/sec mass flow rates for flat plate, parallel plate and v-groove are 50.9°C, 52.7°C and 54.3°C. The monthly average absorber temperature throughout the study was 52°C, 54°C and 55°C for flat plate, parallel plate and v-groove respectively.

Average cover temperature obtained for 0.02 kg/sec mass flow rates for flat plate, parallel plate and v-groove are 30.9°C, 32.5°C and 34.0°C, respectively. For 0.03 kg/sec mass flow rate cover temperature are 36.5 °C, 37.9 °C and 39.5 °C for flat plate, parallel plate and v-groove respectively. Cover temperature are 37.9 °C, 39.4 °C and 40.5 °C for 0.04 kg/sec mass flow rate and 44.5°C, 44.7°C and 44.9°C for 0.05 kg/sec respectively for flat plate, parallel plate and v-groove collectors. Average cover temperature obtained for 0.06 kg/sec mass flow rates for flat plate, parallel plate and v-groove are 40.0°C, 41.5°C and 43.1°C. Only after 8 a.m, there is an appreciable rise in absorber and glass temperatures and after 6 p.m temperatures decreases gradually.

The collector efficiency for mass flow rate from 0.02 kg/sec, 0.03 kg/sec, 0.04 kg/sec, 0.05 kg/sec and 0.06 kg/sec are 30%, 34%, 39%, 42% and 46% respectively for flat plate collector. Similarly the efficiency for parallel plate are 35%, 38%, 41%, 43% and 47% and 39%, 41%, 43%, 45% and 50% for v-groove collector for different mass flow rate. It is clear that increased air flow rate significantly increases the efficiency of solar air heater because at low flow rate of air into the collector there was high temperature of absorber. V-groove solar air heater was found to have better performance compared to other solar air heaters. The efficiency of v-groove is higher than the other designs. The use of v-groove absorber in the place of flat absorber
obviously provides a large surface area for heat transfer to the air stream. The convective heat transfer from plate to cover increases in this case but the loss is largely compensated by the increased heat transfer to the flowing air. The efficiency of parallel plate solar air heater is higher than flat plate collector.

From the observations, the average performance parameters obtained are as under

a) Flat plate collector
   Overall loss coefficient ($U_L$) is 7.40 W/m$^2$, collector removal factor ($F_R$) is 0.66, radiative heat transfer between absorber plate and glass cover ($h_{1r}$) is 6.47 W/m$^2$, radiative heat transfer between glass cover and ambient ($h_{2r}$) is 4.72 W/m$^2$ and convective heat transfer between glass cover and ambient ($h_{1c}$) is 3.72 W/m$^2$.

b) Parallel plate collector
   Overall loss coefficient ($U_L$) is 7.40 W/m$^2$, collector removal factor ($F_R$) is 0.67, radiative heat transfer between absorber plate and glass cover ($h_{1r}$) is 6.45 W/m$^2$, radiative heat transfer between glass cover and ambient ($h_{2r}$) is 4.72 W/m$^2$ and convective heat transfer between glass cover and ambient ($h_{1c}$) is 3.72 W/m$^2$.

c) v-groove collector
   Overall loss coefficient ($U_L$) is 7.38 W/m$^2$, collector removal factor ($F_R$) is 0.67, radiative heat transfer between absorber plate and glass cover ($h_{1r}$) is 6.45 W/m$^2$, radiative heat transfer between glass cover and ambient ($h_{2r}$) is 4.72 W/m$^2$ and convective heat transfer between glass cover and ambient ($h_{1c}$) is 3.72 W/m$^2$.

7.3 Phase II: Testing of Thermal Storage

Performance of pebble bed storage was done with varying mass flow rate from 0.02 kg/sec to 0.06 kg/sec. The average storage temperature in flat plate, parallel plate and v-groove collectors are 47.8°C, 49.8°C and 51.2°C respectively. The higher temperatures above the ambient temperature exhibited by the storage during the night periods indicated that the storage contributes significant heat to the dryer during off-
sunshine hours and therefore provides the dryer the ability to undertake drying process into the hours of night.

Average energy stored from 150 kg of pebbles with flat plate, parallel plate and v-groove type collectors are 321.23 KJ, 359.46 KJ and 406.1 KJ respectively. Average energy released from 150 kg of pebbles with flat plate, parallel plate and v-groove type collectors 308.61 KJ, 356.38 KJ and 387.61 KJ respectively.

**7.4 Phase III: Application – Solar drying**

Performance of the dryer was studied for different mass flow rate and drying of products was done at constant mass flow rate 0.05 kg/sec which is the optimum air mass flow rate.

Average dryer temperature obtained in solar dryer with Flat plate, Parallel plate and v-groove collectors are 53.5°C, 55.6°C and 56.06°C respectively. It was observed that the average relative humidity inside the, flat plate, parallel plate and v-groove was around 52.46%, 51.53% and 51.26% respectively compared to the average ambient air humidity of 68.07%. The low air humidity inside the solar drier indicates that the air inside the drier was having higher drying potential compared to the ambient air and therefore the product placed inside the dryer dried much faster compared to open sun drying. The average humidity of drying chamber started decreasing from 50 percent at 9:00 am in the morning to 30 percent at 12:00 noon. The humidity ranged from 20 to 50 percent for 7 hours (9:00 am to 4:00 pm).

Average efficiency of solar dryer with flat plate, parallel plate and v-groove collectors are 41.1%, 41.2% and 41.9% respectively. This is found to be higher than the dryer efficiency recorded in the literature.

High drying rate of about 6.1 was observed during the initial stages of drying. Drying rate gets decreased with increase in drying time. Drying occurs in the falling
rate period with steep fall in moisture content in initial stages of drying and becomes very low in the later stages. The reason for sudden increase in drying rate during second day is due to increase in collector outlet temperature. During off sunshine hours and nights, drier utilizes the heat stored in heat storage materials. Drying rate decreases due to decrease in collector outlet air temperature and gets increased due to increase in collector outlet air temperature.

At the initial stages of drying, moisture content was high and more moisture was evaporated from the surface. As the drying process proceeded, the moisture on the surface decreased and the evaporation zone moved from the surface to the inside of the product and less evaporation took place. Thereafter, there is linear drop in drying rate with the reduction in moisture content.

A financial analysis that includes the cost of dryer (fixed cost), cost of drying (operating expenses) and payback is carried out. The payback period was found to be 3 years when the dryer was used for drying of Curry leaves, Onion and Red Chilli. The payback period was found to be 5 years when the dryer was used for drying of Potato, Grapes and Carrot. The payback period was found to be 5 years when the dryer was used for drying of Apple, Cauliflower and Tomato.

### 7.5 Conclusions

- Of the three solar air collectors designed and fabricated, flat plate absorber collector is the simplest. However parallel plate absorber collector shows better results than flat plate absorber collector. But v-groove absorber type shows the best performance.
- Better thermal performance for v-groove absorber could be achieved by reducing the size of v-groove and also by maintaining small gap between absorber and bottom plate.
✓ Drying efficiency of all dryers studied was better than those recorded in the literature which implies that the design and fabrication of the dryer studied is laudable.

✓ Employing Pebble bed as thermal storage gives considerable amount of energy for drying during off-sunshine hours.

✓ Drying time is considerably reduced.

✓ Quality of dried products is remarkably better in solar drying compared to open sun drying.

7.6 Suggestion for future study

➢ Similar studies can be carried out using different energy storage materials.

➢ Dryers of large dimensions can be designed and fabricated for commercial purposes.