DESIGN AND DEVELOPMENT OF ON FARM SOLAR DRYER FOR DRYING OF GROUND NUT PODS FOR LONGER STORAGE

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ABSTRACT

A low cost solar assisted dryer was developed to eliminate constraints of traditional sun drying viz., weather dependent, inferior quality, longer drying time, hazards of aflatoxin and post harvest losses faced by groundnut growers of Saurashtra region. The solar dryer (120 kg capacity) for drying of groundnut pods was comprised of drying chamber (12 trays), solar collectors (8 solar collectors), blower (1.5 hp), wheel valve and chimney. The performance evaluation of the developed dryer was carried out on the basis of temperature and relative humidity profile at five different selected ports under no load and full load condition (120 kg of groundnut pods) at 0.50 m/s and 1.0 m/s air velocities. The highest temperature and the lowest relative humidity were obtained in port 3 (in between blower and heating unit) in both the levels of air velocity (i.e., 0.50 and 1.0 m/s air velocity). However, the highest values of relative humidities were obtained in port 5 (exhaust air) for both the level of air velocity under full load condition. The developed dryer could be able to raise the temperature up to 26.9 ^{o}C during 13.00 hours in the winter season. The solar dryer required only 7 hours to reduce the moisture contents of groundnut kernels with better quality to desired moisture contents in just 7 hours (i.e., 10.00 am to 17.00), whereas sun drying took five days (50 hours) with inferior quality. In addition to this, better retention of biochemical parameters (protein, carbohydrate, fat) was observed in groundnut dried by solar dryer as compared to sun drying. Furthermore, the recovery level of dried groundnut pods was higher in the developed dryer as compared to traditional sun drying method in terms of quantity 14.30 kg and in terms of Rs. 572 per 100 kg of groundnut pods.

KEY WORDS: Economics, Groundnut pods, Performance evaluation, Solar dryer

INTRODUCTION

The groundnut production in India was 7180.5 thousand tons in 2015-16. There were 9 States having groundnut production of more than 100 thousand tons *viz*., Gujarat, Rajasthan, Tamil Nadu, Andhra Pradesh, Karnataka, Madhya Pradesh, Maharashtra, West Bengal and Telangana in 2015-16.

Gujarat is one of leading groundnut production and producing about 2892 thousand tons of groundnut under 16.25 lakh hectares area in 2015-16 (Anonymous, 2017).

In Gujarat, groundnut farming involves two cropping seasons. One is generally harvested at the peak of the rainy season. At digging time, groundnuts generally contain about 35 to 45 per cent (wb) moisture, Without reducing moisture content to about 7 to 8 per cent (wb), the produce is quite susceptible to contamination by moulds, especially at the warm temperatures and high humidities in the tropics. This condition leads to decrease the shelling efficiency and milling quality and also development of aflatoxin when spoilage occurs. Several researchers recommended storing the unshelled ground nut rather than kernel. It becomes necessary to reduce the initial moisture content of ground pods to 5 per cent (wb) or less and that of groundnut kernel to 7 to 8 per cent (wb) or less for safe storage. Most of the farmers have poor drying and storage facilities. If such moisture levels are maintained, unshelled groundnuts can be stored without significant loss in quality for long storage period. Groundnut drying systems and aflatoxin contamination have been the main constraints in improving peanut quality to meet industrial market standards. There is high demand for toxin free produce in the international market.

Chavda (2010) studied the aspirations of the farmers for scientific post harvest techniques in groundnut crop for 10 villages of South Saurashtra Agro-climatic Zone, Gujarat. There is no information available on aspirations of farmers toward scientific post harvest techniques of groundnut crop. It was concluded that the majority of the groundnut growers had aspiration to increase their production and to increase their land in next three years. Majority of the groundnut growers were expected to purchase of pod plucking machine and to reduce the losses of groundnut production during the post harvest practices of grading of pods, marketing place for better price, storage method, advanced drying method, and cleaning and winnowing of pod.

Solar drying is a good alternative to sun drying, especially for farmers in developing countries. In comparison with sun drying, solar dryers can generate higher air temperatures and consequently lower air relative humidities, both of which are conducive to improved drying rates and lower final moisture contents of the dried product. This advantage reduces the risk of spoilage both during the actual drying process and in storage. The higher temperatures attainable are also a deterrent to insect and microbial infestation, and protection against dust, insects, and animals is enhanced by drying in an enclosed structure (Bassey and Schmidt, 1986).

Peanut is one of the most important oil and protein producing crops in the world. Most peanuts grown in the world are used for oil production, peanut butter, confectionaries, roasted peanuts and snack products, extenders in meat product formulations, and soups and desserts. Being a source of good fat namely poly and monounsaturated fatty acids; they are also used in weight management diets as they provide satiety. The substantial amounts of by-products are generated in the process of peanut harvest and peanut oil extraction. A large portion of peanut meals, skins, hulls and vines is regarded as the agriculture wastes. With respect to its high nutritive value especially being an excellent source of protein, it can also be incorporated in many food preparations as supplementary food and emergency foods which can be supplied to populations suffering from hunger and malnutrition especially in the developing and underdeveloped countries (Bindhya and Kochhar, 2015).

These constraints of traditional sun drying could be eliminated by adopting mechanical drying of groundnut pods. Presently, mechanical dryers *viz*., cabinet dryer, belt dryer, tray dryer, tunnel dryer, etc. available in the market are of high cost. In addition to this, the operating cost of these dryers is higher. This limits the use of mechanical dryer at on farm level. So, there is need to develop a low cost dryer, which would have low operating cost for drying of groundnut pods at farm level immediately after threshing. The hot air drying of groundnut pods immediately after threshing could eliminates the growth of aflatoxin, bruchid, etc., which could not be eliminated in traditional sun drying method. The adoption of hot air drying after threshing could also reduce the post harvest losses of groundnut pods, i.e., up to 15 to 40 per cent.

In view of above constraints, present investigation was undertaken to develop a low cost solar dryer operated by renewable energy sources in order to reduce the post harvest losses, to improve the overall qualities of ground kernel, to increase the storage life, and to inhibit the attacks of moulds, afflatoxin, bruchid, etc.

METHODS AND MATERIALS

The fabrication of solar dryer was carried out in the Department of Processing and Food Engineering, College of Agricultural Engineering and Technology, JAU, Junagadh. The design and fabrication for each component of solar dryer, materials used and its cost, instruments / equipments used, performance evaluation and cost economics are reported as per following details.

Design and development of solar dryer

The solar dryer was designed and fabricated as the following theoretical considerations. The dryer was fabricated in the workshop of Processing and Food Engineering Department, CAET, JAU, Junagadh. The theoretical considerations were made on the basis of local climatic conditions, physical and biochemical properties of groundnut pods, heating load, and germination characteristics as mentioned below.

Theoretical considerations

- Capacity of dryer = 120 kg
- Bulk density of groundnut pod = 240 kg/m^3
- Moisture content of groundnut pod after time of threshing : 14 - 15 % (wb)
- Final moisture content of groundnut pod : 6 to 7 % (wb)
- Size of tray = 85 cm x 50 cm x 10 cm
- Capacity of tray = 10 kg per tray
- Total number of tray = 12
- Expected temperature : 52 ± 2 ^{0}C
- Density of air at 52 ^{0}C =1.17 kg/m^3
- Ambient air temperature - 28° C.
- Relative humidity - 65 % (November - December)
- Average wind speed - 1.5 m/s
- Mean percent possible sunshine - 40 %
- Mean intensity of solar radiation – 450 W/m^2
- Air flow rate = 0.05 kg / s
- Total number of solar collector : 8
- Size of solar collector : 1 m x 2 m
- Blower capacity : 28 m^3/min

Components of solar dryer

A solar dryer was designed and developed for drying of groundnut pods as per the following details.

Solar dryer comprises of following components

- Drying chamber
- Solar collector
- Wheel valve
- Blower unit
- Heating unit

Drying chamber (Plate 1)

- Capacity of drying chamber : 120 kg
- No of trays : 12 trays
- No of trays per tier : 2 (total 6 tier)

- Size of the tray : 85 cm x 50 cm x 10 cm
- Capacity of tray : 10 ± 0.50 kg

Solar collector (Plate 2)

- Total numbers : 8
- Size of collector : 1 m x 2 m
- Raise of temperature : 24.7 ^{0}c (during winter)

Wheel valve (Plate 3)

- Size : 6" in diameter
- Location : Between solar collector and blower assembly
- Function : To adjust the air velocity

Blower unit (Plate 4)

- Capacity : 1.5 hp
- Location : Between solar collector and heating box

Heating unit

- Output : 8 kW
- No. of heating coils : 6
- Raise of temperature : 38 ^{0}C (during winter)

Performance evaluation of solar dryer

Performance evaluation of the developed dryer was carried out under no load and full load conditions.

Performance evaluation of solar dryer under no load condition (Plate 6)

The performance evaluation of solar dryer on the basis of temperature and relative humidity at five different ports were measured at different air velocities (i.e., 0.50 m/s and 1.0 m/s) under no load condition during 7th November - 2017 to 10th November-2017 using digital temperature indicator and digital rh meter, respectively. The experiment was repeated two times for each of the air velocity. Five different ports were selected at different places on the developed dryer as per following details.

Port 1: Mounted on the trapezoidal section connected between the one row (4 solar collectors) and main duct (M.S. pipe of 150 mm and 1.6 mm thick covered with glass wool and aluminum sheet) (Plate 6).

Port 2: Mounted on the trapezoidal section connected between the second row (4 solar collectors) and main duct (M.S. pipe of 150 mm and 1.6 mm thick covered with glass wool and aluminum sheet) (Plate 6).

Port 3: Mounted on the connecting section between blower and heating box (Plate 6).

Port 4: Mounted on the connecting duct between heating box and plenum chamber (Drying Chamber) (Plate 9).

Port 5: Mounted on upper conical section of chimney of drying chamber (Plate 6).

The experiment was started from 10:00 AM in the morning, the air velocity of drying air was kept 0.50 m/s in the drying chamber by adjusting wheel valve mounted in between solar collector and blower assembly.

Performance evaluation of solar dryer under full load (120 kg) condition

The performance evaluation of solar dryer on the basis of temperature and relative humidity at different ports were measured at different air velocities. Five different ports were selected at different places on the developed dryer as mentioned above.

The drying chamber comprises of 12 nos of trays, each tray loaded with 10 kg groundnut pods (GG 20), i.e., total 120 kg of groundnut pods loaded in a batch of performance evaluation on 12th November, 2017.

The experiment was started from 10:00 AM in the morning, the air velocity of drying air was kept 0.50 m/s in the drying chamber by adjusting wheel valve mounted in between solar collector and blower assembly. The temperature and relative humidity of air at different ports were measured with digital temperature indicator and digital rh meter, respectively. Similarly, the performance evaluation of solar dryer was carried out at 1.0 m/s air velocity on 13th November, 2017.

Economic feasibility of the solar assisted dryer

The different components of solar dryer, *viz*., drying chamber along with 12 nos of trays, chimney, solar collector (8 nos.) with stand, heating unit, blower unit, connecting ducts / pipes were fabricated as per their design successfully. The details of materials and accessories used for each component with their fabrication charges were calculated and the total cost was to be worked out. The drying cost for drying of groundnut pods (GG 20) at full load condition (120 kg) was worked out on the basis of fixed cost and variable cost of the developed dryer.

The sun drying of groundnut pods was carried out at Village Kanadipur of Junagadh district as per the followed by local farmers. A sample of 1000 kg of groundnut pods immediate after threshing was spreaded over the field during 8.00 hours in the morning to 18.00 hours under direct exposure of sun radiation. Then after 18.00 hours, grooundnut pods were heaped and covered with plastic cover in order to protect from dew. Next day, heaps of groundnut pods were spreaded over the field under direct sun radition for further sun drying. The cost of sun drying was also calculated on the basis of numbers of labour required per day for handling 1000 kg of groundnut pods at farm level.

RESULTS AND DISCUSSION

The different components of solar dryer, viz., drying chamber along with 12 nos of trays, chimney, solar collector (8 nos.) with stand, heating unit, blower unit, connecting ducts / pipes were successfully designed and fabricated as per their capacity. During the all the experiments, solar dryer could easily accommodate 120 kg of groundnut pods in 12 trays, i.e., each tray should be capable to hold 10 kg of groundnut pods. The developed could be efficiently maintaining the desired temperatures. In addition to this, air velocities at different ports could be successfully adjusted by using wheel valve and blower unit. The developed dryer required only 7 hours of drying time to reduce the initial moisture contents of threshed groundnut pods (i.e., 11.00 to 11.25 per cent (wb)) to desired moisture contents (i.e., 6 to 7 % (wb)) (i.e., 10.00 am to 17.00).

Performance evaluation of solar dryer

The performance evaluation of the developed dryer was carried out under no load and full load conditions.

Performance evaluation of solar dryer under no load condition

The performance evaluation of solar dryer on the basis of temperature and relative humidity at five different ports were carried out at different air velocities (i.e., 0.50 m/s and 1.0 m/s) under no load condition. The experiment was repeated two times for each of the air velocity.

The results of temperature and relative humidity at different ports for two experiments for 0.50 m/s air velocity on different days are reported Table 1 and 2, whereas the that is for 1.0 m/s air velocity on different days are reported in Table 3 and 4.4. However, temperature profiles and relative humidity of air under no load condition at 0.50 m/s air velocity on different days are graphically illustrated in Figure 1.and Figure 2, whereas that of 1.0 m/s air velocity on different days are graphically illustrated in Figure 3 and Figure 4.

The higher temperatures were obtained in Port 3 (in between blower and heating unit) in both the levels of air velocity (i.e., 0.50 and 1.0 m/s air velocity). This might be due to higher temperature of blower assembly may results in rise of temperature.

The temperature difference between ambient and drying air was increased with increase in drying time, i.e., 10.00 to 13.00

hours, then after it decreased with increase in further drying time, i.e., 14.00 to 17.00 hours. The maximum temperature difference of 20.9 ^{0}C (Table 1) and 24.1 ^{0}C (Table 2) were obtained at 13.00 hours between ambient and drying air for 0.50 m/s.

Similar kind of pattern was observed at 1 m/s air velocity under no load condition. The maximum temperature difference of 26.9 ^{0}C (Table 3) and 24.4 ^{0}C (Table 4) were obtained at 13.00 hours between ambient and drying air for 1.0 m/s.

The highest temperature difference of 24.1 ^{0}C and 26.9 ^{0}C were obtained at 13.00 hours between ambient and drying air for 0.50 m/s and 1.0 m/s air velocity, respectively.

The lower temperatures and higher relative humidities were obtained in Port 5 (Exhaust air) as compared to other four ports in both the levels of air velocity (i.e., 0.50 and 1.0 m/s air velocity). This might be attributed to gain of moisture by hot air when passes through the groundnut pods (11 % (wb)).

The statistically analyzed data of temperature and relative humidity under no load condition with their interactions are reported in Table 5. It was observed that the effect of port (P) over temperature and relative humidity was found non-significant during 10.0 to 17.0 hours of drying period. Similarly, the effect of interaction, i.e., P x I was also found non-significant throughout the drying period (i.e., 10.0 to 17.0 hours). Effect of air velocity (A) over temperature was found significant during 11.0, 14.0, 15.0, 16.0 and 17.0 hours, whereas effect of air velocity over relative humidity during 11.0 and 14.0 hours was found significant.

It could be concluded that the highest temperature difference of 24.1 ^{0}C and 26.9 ^{0}C were obtained at 13.00 hours between ambient and drying air for 0.50 m/s and 1.0 m/s air velocity, respectively under no load condition.

Performance evaluation of solar dryer under full load condition

The performance evaluation of solar dryer on the basis of temperature and relative humidity at different five ports were measured at different air velocities under full load condition (i.e., 120 kg per batch). Five different ports were selected at different places on the developed dryer as per above details.

The experiment on performance evaluation of the developed dryer under full load condition was started from 10:00 AM in the morning; the air velocity of drying air was kept 0.50 m/s in the drying chamber by adjusting wheel valve mounted in between solar collector and blower assembly. The temperature and relative humidity of air at different ports were measured with digital temperature indicator and digital rh meter, respectively.

The different values of temperature and relative humidity at an interval of 1 hour are reported in Table 6. Also, the graphical presentation of temperature and relative humidity profile at constant air velocity 0.50 m/s are illustrated in Figure 5 and Figure 6.

Similarly, the performance evaluation of solar dryer under full load condition was carried out at 1.0 m/s air velocity. The different values of temperature and relative humidity at constant air velocity 1.0 m/s are reported in Table 7. The presentation of temperature and relative humidity profile at constant air velocity 1.0 m/s are illustrated in Figure 5 and Figure 6.

The temperature difference between ambient and drying air was increased with increase in drying time, i.e., 10.00 to 13.00 hours, then after it decreased with increase in further drying time, i.e., 14.00 to 17.00 hours for 0.50 m/s and 1.0 m/s air velocity. The highest temperature difference of 24.7 ^{0}C and 21.9 ^{0}C were obtained at 13.00 hours between ambient and drying air for 0.50 m/s and 1.0 m/s air velocity, respectively.

The higher temperatures were obtained in Port 3 (in between blower and heating unit) in both the levels of air velocity (i.e., 0.50 and 1.0 m/s air velocity). This might be due to higher temperature of blower assembly may results in rise of temperature.

Highest values of relative humidities were obtained in port 5 (exhaust air) for both the level of air velocity under full load condition. This might be attributed to gain of moisture when it passes through the groundnut pods.

The lower temperatures and higher relative humidities were obtained in Port 5 (Exhaust air) as compared to other four ports in both the levels of air velocity (i.e., 0.50 and 1.0 m/s air velocity). This might be attributed to gain of moisture by hot air when passes through the groundnut pods (11 % to 11.25% (wb)).

The lower temperatures and higher relative humidities were obtained in Port 5 (Exhaust air) as compared to other four ports in both the levels of air velocity (i.e., 0.50 and 1.0 m/s air velocity). This might be attributed to gain of moisture by hot air when passes through the groundnut pods (11 % to 11.25% (wb)).

The statistically analyzed data of temperature and relative humidity under full load condition with their interactions are reported in Table 8. It was observed that effect of different ports (P) over temperature and humidity during 10.00 to 17.00 hours was found significant, whereas effect of air velocity (A) over temperature during 10, 11, 12, 13, 14 and 16 hours was found significant. The effect of air velocity over relative humidity during 10, 12, 13, 14, 15, 16 and 17 hours was found significant (Table 4.10.). The effect of interaction between port and air velocity (PXA) on temperture during 10, 12, and 16 hours was found significant. Whereas, the effect of interaction over relative humidity of air was found significant during 10.00 to 17.00 hours. It could be concluded that the highest temperature difference of 24.7 0C and 21.9 ^{0}C were obtained at 13.00 hours between ambient and drying air for 0.50 m/s and 1.0 m/s air velocity, respectively under full load condition (i.e., 120 kg per batch). It could be also concluded that highest temperature and lowest relative humidity were obtained in Port 3 (in between blower and heating unit) in both the levels of air velocity (i.e., 0.50 and 1.0 m/s air velocity). However, highest values of relative humidities were obtained in port 5 (exhaust air) for both the level of air velocity under full load condition.

Economic feasibility of the solar assisted dryer

The different components of solar dryer, viz., drying chamber along with 12 nos of trays, chimney, solar collector (8 nos.) with stand, heating unit, blower unit, connecting ducts / pipes were fabricated as per their design successfully. The details of materials and accessories used for each component with their fabrication charges are reported in Table 9. The fabrication charges were considered 15 % of total cost of different components by excluding the cost of blower and wheel valve. The total cost of the dryer along with fabrication charges is Rs. 3,60,000/- (Table 9).

Drying of groundnut pods could be completed in 7 hours to reduce the initial moisture content (11 to 11.25 %(wb)) of threshed groundnut to the desired storage level moisture content (6 to 7 %(wb)). Only two unskilled labour could be able to handle one batch of groundnut pod (i.e., 120 kg) drying. The cost of drying per kg of groundnut pods (fresh as well as dried) is worked out on the basis of fixed cost and variable cost as reported in Table 10.

The cost of drying per kg of groundnut pods (fresh as well as dried) is worked out on the basis of fixed cost and variable cost as reported in Table 10. The cost of drying per kg of threshed groundnut was found Rs. 7.50, whereas the drying cost per kg of dried groundnut pods was Rs. 7.90. The comparison of cost for drying of groundnut pods by developed dryer and traditional sun drying method was carried out and reported in Table 11.

It was remarkably observed that there is no any kind of loss of groundnut pods was occurred during drying process. The recovery level of dried groundnut pods was higher in the developed dryer as compared to traditional sun drying method in terms of quantity 14.30 kg and in terms of Rs. 572 per 100 kg of groundnut pod. So, farmers of Saurashtra region will get benefited in minimizing about 14 to 15 % post harvest loss of groundnut pods occurs during drying process.

In addition to these benefits, aflatoxin level (11.4 ppb) of groundnut kernels before drying was eliminated after drying of these groundnut pods using the developed dryer.

CONCLUSION

1. The highest temperature difference of 24.7 ^{0}C and 21.9 ^{0}C were obtained at 13.00 hours between ambient and drying air for 0.50 m/s and 1.0 m/s air velocity, respectively under full load condition (i.e., 120 kg per batch).
2. The highest temperature and lowest relative humidity were obtained in Port 3 (in between blower and heating unit) in both the levels of air velocity (i.e., 0.50 and 1.0 m/s air velocity). However, highest values of relative humidities were obtained in port 5 (exhaust air) for both the level of air velocity under full load condition.
3. It could be concluded that the highest temperature difference of 24.1 ^{0}C and 26.9 ^{0}C were obtained at 13.00 hours between ambient and drying air for 0.50 m/s and 1.0 m/s air velocity, respectively under no load condition.
4. The highest temperature and lowest relative humidity were obtained in Port 3 (in between blower and heating unit) in both the levels of air velocity (i.e., 0.50 and 1.0 m/s air velocity). However, highest values of relative humidities were obtained in port 5 (exhaust air) for both the level of air velocity under full load condition.
5. The cost of drying per kg of threshed groundnut pods was found Rs. 7.50 using the solar dryer, whereas the cost of sun drying per kg of groundnut pods was found Rs. 5.60.
6. The recovery level of dried groundnut pods was higher in the developed dryer as compared to traditional sun drying method in terms of quantity 14.30 kg and in terms of Rs. 572 per 100 kg of groundnut pod. So, farmers of Saurashtra region would be benefited in minimizing about 14 to 15 % post harvest loss of groundnut pods occurs during drying process.
7. Finally, it could be concluded that the use of developed solar dryer reduced the drying time (i.e., 42 hours), reduced hazard of aflatoxin, eliminated post harvest losses (15 to 16 %), higher retention of biochemical parameters, less area required and gave benefit of land preparation for next crop.

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Table 1: Temperature and relative humidity profile at various ports in solar assisted dryer under no load condition at 0.5 m/s air velocity (Date: 07.11.2017)

Sr. No.	Time (IST), h	Temperature (°C)						Relative Humidity (%)					
		Ambi. Air	1 (Solar Collector)	2 (Solar Collector)	3 (After Blower)	4 (Drying Chamber)	5 (Exhaust air)	Ambi. Air	1 (Solar Collector)	2 (Solar Collector)	3 (After Blower)	4 (Drying Chamber)	5 (Exhaust air)
1	10:00	26.2	28.0	28.5	30.0	29.0	27.8	45.0	35.0	35.5	32.0	32.2	36.0
2	11:00	28.1	36.2	36.6	39.2	36.5	34.2	34.0	33.2	37.5	33.7	34.5	34.9
3	12:00	29.4	49.5	48.0	50.2	46.0	41.5	34.0	30.5	36.4	25.7	24.9	26.7
4	13:00	30.1	51.0	50.0	51.0	49.0	45.0	27.0	28.6	31.0	28.4	22.5	23.3
5	14:00	31.5	50.0	49.5	51.0	50.0	47.5	25.0	24.2	21.0	34.9	22.0	22.1
6	15:00	31.2	45.0	45.0	48.0	47.0	44.6	24.0	26.0	22.9	20.9	21.0	21.7
7	16:00	31.3	38.0	37.0	42.0	40.2	38.8	26.0	28.0	28.8	25.0	27.1	25.7
8	17:00	29.1	36.0	38.0	40.3	38.4	36.4	28.6	25.0	26.5	28.0	28.2	30.0

Table 2: Temperature and relative humidity profile at various ports in solar assisted dryer under no load condition at 0.5 m/s air velocity (Date: 08.11.2017)

Sr. No.	Time (IST), h	Temperature (°C)						Relative Humidity (%)					
		Ambi. Air	1 (Solar Collector)	2 (Solar Collector)	3 (After Blower)	4 (Drying Chamber)	5 (Exhaust air)	Ambi. Air	1 (Solar Collector)	2 (Solar Collector)	3 (After Blower)	4 (Drying Chamber)	5 (Exhaust air)
1	10:00	28.0	28.3	29.0	34.6	35.4	32.1	29	36.4	28.1	21.8	31.5	42.5
2	11:00	30.2	46.7	47.3	50.2	47.0	42.5	31	21.9	20.9	31.2	32.2	23.0
3	12:00	32.1	51.0	53.0	55.0	52.0	49.3	23	14.0	12.0	23.6	11.2	11.6
4	13:00	33.7	55.0	56.0	57.8	55.0	53.0	21	14.2	13.9	23.6	11.5	10.7
5	14:00	33.6	53.3	53.0	55.2	54.0	51.6	20	15.5	14.8	22.6	19.7	19.8
6	15:00	32.1	46.0	47.0	49.0	48.2	47.7	22	14.9	14.2	12.4	12.0	10.0
7	16:00	32.4	40.0	41.5	44.0	42.8	40.9	22	16.5	16.7	22.6	15.3	16.0
8	17:00	31.1	34.0	36.0	38.5	35.8	34.1	22	25.0	23.4	17.3	17.2	18.4

Table 3: Temperature and relative humidity profile at various ports in solar assisted dryer under no load condition at 1.0 m/s air velocity (Date: 09.11.2017)

Sr. No.	Time (IST), h	Temperature (°C)						Relative Humidity (%)					
		Ambi. Air	1 (Solar Collector)	2 (Solar Collector)	3 (After Blower)	4 (Drying Chamber)	5 (Exhaust air)	Ambi. Air	1 (Solar Collector)	2 (Solar Collector)	3 (After Blower)	4 (Drying Chamber)	5 (Exhaust air)
1	10:00	25.5	32.5	32.4	36.7	35.4	30.8	29	35.8	42.1	21.8	40.8	42.5
2	11:00	29.4	47.6	48.0	53.0	51.6	48.6	40	15.2	16.8	29.9	26.8	29.3
3	12:00	31.2	51.0	52.2	56.0	58.0	55.0	33	14.0	15.2	23.2	25.4	27.1
4	13:00	32.1	54.3	53.0	59.0	58.0	54.6	30	9.8	14.8	19.0	19.5	21.8
5	14:00	33.5	54.0	53.6	55.8	54.0	52.8	20	15.3	14.0	22.6	19.7	19.8
6	15:00	32.3	53.6	53.8	56.4	57.0	51.3	26	10.1	8.9	8.2	7.3	12.9
7	16:00	31.1	51.0	52.4	53.8	53.0	51.0	25	23.9	23.0	22.6	25.9	30.0
8	17:00	30.2	44.9	45.0	48.0	47.2	46.2	22	31.2	29.1	25.3	24.4	29.5

Table 4: Temperature and relative humidity profile at various ports in solar assisted dryer under no load condition at 1.0 m/s air velocity (Date: 10.11.2017)

Sr. No.	Time (IST), h	Temperature (°C)						Relative Humidity (%)					
		Ambi. Air	1 (Solar Collector)	2 (Solar Collector)	3 (After Blower)	4 (Drying Chamber)	5 (Exhaust air)	Ambi. Air	1 (Solar Collector)	2 (Solar Collector)	3 (After Blower)	4 (Drying Chamber)	5 (Exhaust air)
1	10:00	25.2	29.0	28.0	32.5	31.0	30.6	40	35.0	36.2	37.2	36.0	40.0
2	11:00	29.1	45.0	46.2	48.0	46.0	45.0	37	14.0	12.9	20.8	20.4	21.6
3	12:00	31.0	49.0	48.9	51.0	50.2	49.2	33	15.5	16.7	17.9	18.1	19.2
4	13:00	31.2	54.5	53.8	55.6	53.1	50.1	30	12.5	13.2	16.3	15.1	16.0
5	14:00	31.1	53.1	54.2	56.8	54.6	51.6	25	14.7	15.5	15.9	15.9	14.9
6	15:00	32.4	50.5	49.0	52.0	50.5	48.2	28	16.3	17.3	14.1	14.0	14.2
7	16:00	30.2	48.7	48.2	51.4	48.6	46.2	30	20.3	18.0	15.9	18.3	20.4
8	17:00	29.4	44.2	41.7	43.0	41.0	40.2	32	20.0	21.0	19.3	18.2	23.0

Table 5: Effect of air velocity and port location on temperature and relative humidity of air at different drying time under no load condition of solar dryer

Treatment	Temperature (°C)								Relative Humidity (%)							
	Drying time (IST), h								Drying time (IST), h							
	10.00	11.00	12.00	13.00	14.00	15.00	16.00	17.00	10.00	11.00	12.00	13.00	14.00	15.00	16.00	17.00
Port Number (P)																
Port 1 (Solar Collector 1)	29.45	43.875	50.12	53.70	52.60	48.77	44.42	39.77	35.55	21.07	18.50	16.27	17.42	16.82	22.16	25.3
Port 2 (Solar Collector 2)	29.47	44.525	50.52	53.20	52.57	48.70	44.77	40.17	35.47	22.02	20.07	18.22	16.32	15.82	21.62	25.00
Port 3 (After Blower)	33.45	47.600	53.05	55.85	54.70	51.35	47.80	42.45	28.20	28.90	22.60	21.82	24.00	13.90	21.52	22.47
Port 4 (Drying Chamber)	32.70	45.275	51.55	53.77	53.15	50.67	46.15	40.60	35.12	28.47	19.90	17.15	19.32	13.57	21.65	22.00
Port 5 (Exhaust Air)	30.32	42.575	48.75	50.67	50.87	47.95	44.22	39.22	40.25	27.20	21.15	17.95	19.15	14.70	23.02	25.22
S.Em.±	1.36	2.74	1.87	1.78	0.98	1.22	1.17	1.29	2.513	3.074	4.236	3.302	2.127	2.914	3.064	2.93
C.D. at 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Air Velocity (A)																
A_1 (0.50 m/s)	30.27	41.640	49.55	52.28	51.51	46.75	40.52	36.75	33.10	30.30	21.66	20.77	21.66	17.60	22.16	23.90
A_2 (1.0 m/s)	31.89	47.90	52.05	54.60	54.05	52.23	50.43	44.14	36.74	20.77	19.23	15.80	16.83	12.33	21.83	24.10
S.Em.±	0.864	1.73	1.18	1.12	0.62	0.77	0.74	0.81	1.589	1.944	2.679	2.088	1.345	1.843	1.938	1.85
C.D. at 5%	NS	5.47	NS	NS	1.96	2.45	2.34	2.58	NS	6.126	NS	NS	4.238	NS	NS	NS
P x A																
S.Em.±	1.93	3.88	2.65	2.52	1.39	1.73	1.66	1.83	3.554	4.347	5.991	4.670	3.008	4.121	4.333	4.14
C.D. at 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
C.V.%	8.80	12.28	7.39	6.68	3.73	4.97	5.17	6.40	14.40	24.08	41.45	36.13	22.11	38.95	27.86	24.43

Table 6: Temperature and relative humidity profile at various ports in solar assisted dryer under full load (120 kg) condition at 0.50 m/s air velocity (Date : 12.11.2017)

Sr. No.	Time (IST), h	Temperature (°C)						Relative Humidity (%)					
		Ambi. Air	1 (Solar Collector)	2 (Solar Collector)	3 (After Blower)	4 (Drying Chamber)	5 (Exhaust air)	Ambi. Air	1 (Solar Collector)	2 (Solar Collector)	3 (After Blower)	4 (Drying Chamber)	5 (Exhaust air)
1	10:00	28.3	28.5	29.0	34.6	35.4	28.1	36	36.4	37.5	34.5	40.8	42.0
2	11:00	29.1	46.1	47.2	49.8	47.0	41.3	34	24.5	22.4	30.9	32.5	33.6
3	12:00	31.2	50.9	53.2	55.4	52.0	46.6	23	15.5	14.8	24.2	23.5	22.1
4	13:00	33.1	54.6	55.7	57.8	56.5	50.8	21	16.2	15.9	23.6	15.3	17.2
5	14:00	34.6	53.1	52.7	55.5	53.6	48.7	20	15.5	13.4	22.6	19.7	19.8
6	15:00	33.1	45.8	46.5	48.9	48.4	42.1	22	16.8	14.2	12.4	12.0	14.0
7	16:00	32.2	43.0	42.7	44.5	43.7	38.4	22	16.5	16.7	22.6	15.3	16.0
8	17:00	32.1	36.6	37.2	40.4	38.6	34.1	23	25.0	22.0	17.3	17.2	18.4

Table 7: Temperature and relative humidity profile at various ports in solar assisted dryer under full load (120 kg) condition at 1.0 m/s air velocity (Date : 13.11.2017)

Sr. No.	Time (IST), h	Temperature (°C)						Relative Humidity (%)					
		Ambi. Air	1 (Solar Collector)	2 (Solar Collector)	3 (After Blower)	4 (Drying Chamber)	5 (Exhaust air)	Ambi. Air	1 (Solar Collector)	2 (Solar Collector)	3 (After Blower)	4 (Drying Chamber)	5 (Exhaust air)
1	10:00	27.2	29.5	29.0	33.0	31.2	25.0	44	36.2	36.9	33.1	32.0	36.0
2	11:00	28.1	32.5	33.2	37.0	34.6	29.1	32	28.0	28.5	27.0	26.3	32.4
3	12:00	30.3	39.3	40.1	44.2	43.0	39.2	31	27.0	26.2	25.4	25.2	29.8
4	13:00	31.1	49.3	50.0	53.0	49.0	44.0	27	26.2	26.0	24.8	24.7	29.3
5	14:00	32.4	50.0	49.5	51.5	49.6	43.2	25	24.2	23.0	22.5	22.6	26.9
6	15:00	32.5	46.0	46.2	49.0	47.0	43.0	27	26.0	26.7	25.6	25.4	29.3
7	16:00	32.1	38.0	37.8	42.0	40.2	37.7	28	26.3	26.4	25.1	25.9	30.6
8	17:00	33.3	36.0	37.0	40.3	38.4	34.2	29	25.0	26.5	28.0	28.2	30.0

Table 8: Effect of air velocity and port location on temperature and relative humidity of air at different drying time under full load condition of solar dryer

Treatment	Temperature (°C)								Relative Humidity (%)							
	Drying Time (IST), h								Drying Time (IST), h							
	10.00	11.00	12.00	13.00	14.00	15.00	16.00	17.00	10.00	11.00	12.00	13.00	14.00	15.00	16.00	17.00
Port Number (P)																
Port 1 (Solar Collector 1)	29.29	39.69	45.55	52.47	52.06	46.35	40.90	36.66	36.66	26.513	21.46	21.41	20.04	21.61	21.59	25.25
Port 2 (Solar Collector 2)	29.29	40.60	47.11	53.37	51.61	46.81	40.65	37.47	37.57	25.70	20.70	21.16	18.38	20.65	21.76	24.49
Port 3 (After Blower)	34.14	43.83	50.29	55.95	54.03	49.44	43.68	40.75	34.13	29.240	25.04	24.44	22.77	19.19	24.08	22.87
Port 4 (Drying Chamber)	33.63	41.20	47.97	53.27	52.11	48.17	42.37	38.88	36.76	29.694	24.59	20.20	21.36	18.88	20.80	22.92
Port 5 (Exhaust Air)	26.82	35.55	43.32	47.87	46.41	42.97	38.43	34.49	39.39	33.330	26.21	23.48	23.58	21.86	23.53	24.44
S.Em.±	0.216	0.285	0.330	0.369	0.359	0.327	0.289	0.264	0.2592	0.203	0.168	0.158	0.151	0.150	0.160	0.171
C.D. at 5%	0.619	0.9000	1.041	49.79	1.132	1.032	0.910	0.831	0.816	0.6422	0.530	0.500	0.476	0.474	0.506	0.538
Air Velocity (A)																
A_1 (0.50 m/s)	31.43	46.74	52.13	55.63	53.24	46.80	42.88	37.75	38.62	29.068	20.22	17.81	18.38	14.01	17.58	20.18
A_2 (1.0 m/s)	29.84	33.61	41.57	49.55	49.24	46.70	39.53	37.55	35.18	28.724	26.98	26.46	24.07	26.86	27.12	27.81
S.Em.±	0.136	0.1807	0.209	0.233	0.227	0.207	0.182	0.167	0.1639	0.128	0.106	0.100	0.095	0.095	0.101	0.108
C.D. at 5%	0.430	0.5692	0.658	0.735	0.716	NS	0.576	NS	0.5165	NS	0.335	0.316	0.301	0.299	0.320	0.340
P x A																
S.Em.±	0.305	0.404	0.467	0.522	0.508	0.463	0.408	0.373	0.3666	0.288	0.238	0.224	0.213	0.212	0.227	0.241
C.D. at 5%	0.961	NS	1.473	NS	NS	NS	1.288	NS	1.1550	0.908	0.750	0.707	0.673	0.670	0.716	0.762
C.V.%	1.41	1.42	1.41	1.40	1.40	1.40	1.40	1.40	1.40	1.41	1.43	1.44	1.42	1.47	1.44	1.43

Table 9: Cost of solar dryer for different components with the details of materials and fabrication charges

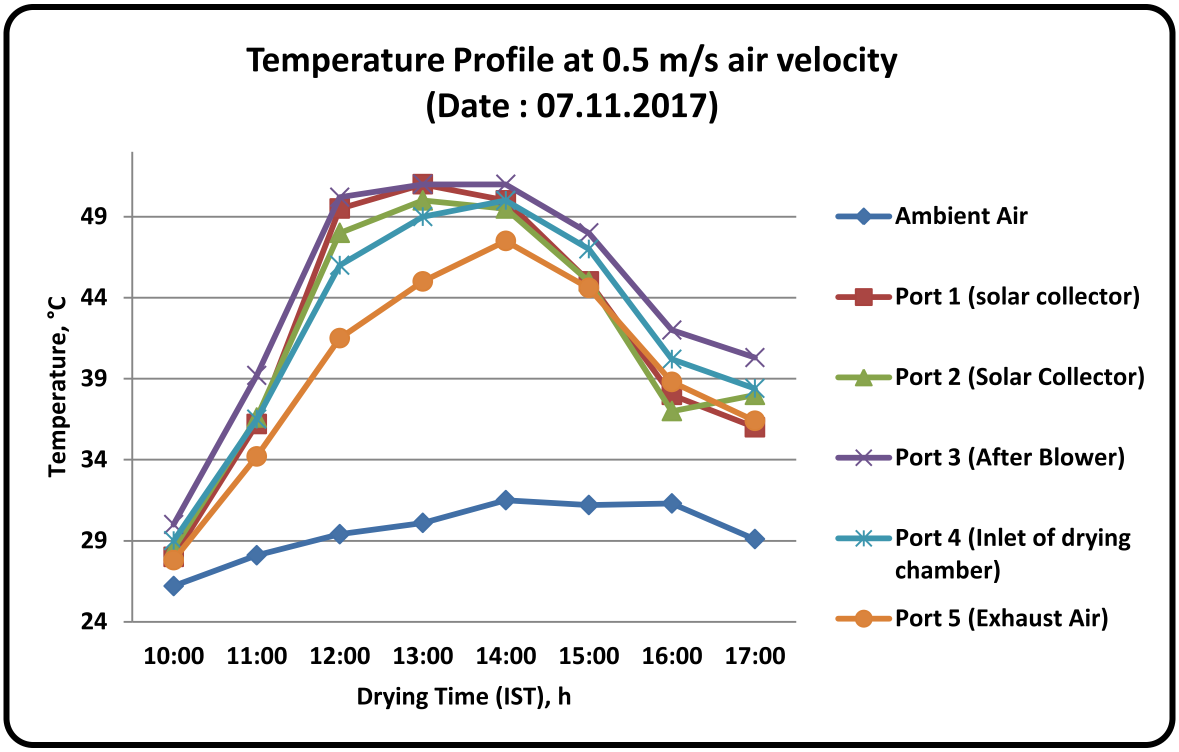
Sr. No	Name of Component	Materials Used	Total Cost Including Fabrication Charges
01	Drying Chamber (a) Drying Cabinet including chimney (b) Drying Tray (12 nos)	CRC Sheet, M.S. Sheet, M.S. angle, Glass Wool, Angles, Nut, Bolts, Screw & Other accessories including 15 % fabrication charges	175000/-
02	Solar Collector (8 nos) with trapezoidal connecting ducts.	Toughened Glasses, Aluminum Sheet (0.50, 1.0 mm & 1.2 mm thick), Aluminum angle (35x35x2 mm), M.S. angle (35x35x5 mm), glass wool, neoprene rubber, Nut, Bolts, Screw & Other accessories including 15 % fabrication charges	94000/-
03	Heating unit including all the connecting ducts (drying chamber, solar collector, heating unit)	M.S. Pipe (150 mm diameter, 1.6 mm thick), Heating coils (6 nos, total – 8 kW), Aluminum Sheet (1.0 & 1.2 mm thick), Flanges (8 nos) – 6”, M.S. angles (35x35x5 mm & 50x50x5 mm), M.S. Sheet (2 mm thick), wheel valve (6”), Blower (1.5 hp), electric wires, switch boards & electric accessories, glass wool, couplines, Nut, Bolts, Screw & Other accessories including 15 % fabrication charges	91000/-
	Total Cost		**360000/-**

Table 10: Cost estimation of solar dryer for drying of groundnut pods

Sr. No.	Particular	Cost (Rs.)
01	**Initial Cost**	360000.00
02	**Fixed cost**	
	(a) Depreciation @ 10 % per year	36000.00
	(b) Interest @ 18 % on half the initial cost	32400.00
	(c) Maintenance @ 5 % of initial cost per year	18000.00
	(d) Housing cost @ 3 % per year	10800.00
	(e) Total fixed cost	97200.00
	(f) Fixed cost / day	266.30
03	**Variable cost**	
	(a) 2 Labous required per day @ Rs. 300 per day (Total working hours = 2 x 8 = 16 hours)	600.00
	(b) Electricity charges @ Rs. 4.50 per unit, total units 8 per day (7 hour)	31.50
	(c) Variable cost / day	631.50
04	Total cost of drying of 120 kg threshed groundnut pods {[Fixed cost + Variable cost]/day}	897.8 say 900
05	**Drying cost per kg of threshed groundnut pods**	**7.50**
06	**Drying cost per kg of dried groundnut pods (114 kg)**	**7.90**

Table 11: Comparison of cost for drying of groundnut pods by traditional sun drying and solar dryer

Sr. No.	Particulars	Drying Methods	
		Solar Dryer	Sun Drying
01	Initial Cost, Rs.	360000	--
02	Capacity, kg	120 (by 2 labour)	1000 (by 3 labour)
03	Labour, man-h	16	120
04	Power requirement, hp	1.5	--
05	Drying time, h	7	50
06	Dried weight of groundnut pods, kg	114	807.00 {(950 – 143 (loss)}
07	Drying cost, Rs. / kg of dried pods	7.90	5.60
08	Percent recovery of dried groundnut pods, % (in terms of kg/100 kg)	95 (95 kg)	80.70 % (80.70 kg)
09	Market value of dried groundnut pods @ Rs. 40 per kg	3800	3228
10	Benefits in terms of Rupees / 100 kg of dried groundnut pods, Rs.	572	---



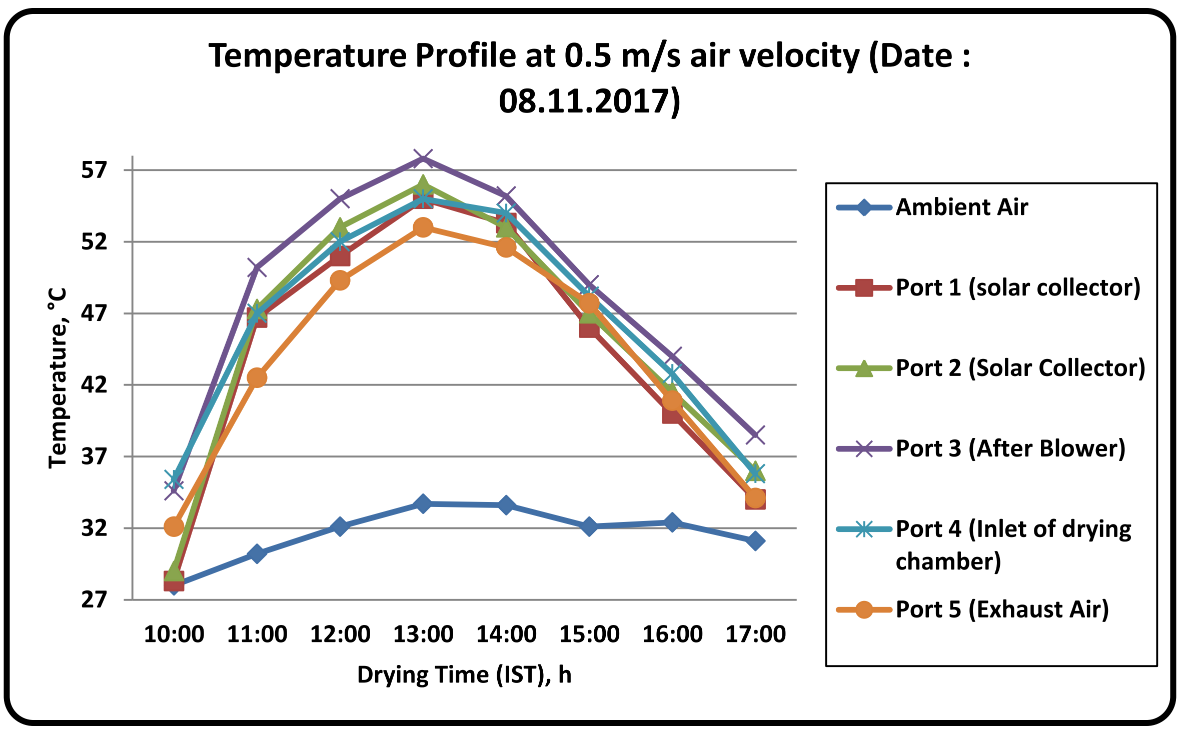


Figure 1: Temperature profile at different ports under no load condition of solar assisted Dryer at 0.50 m/s air velocity

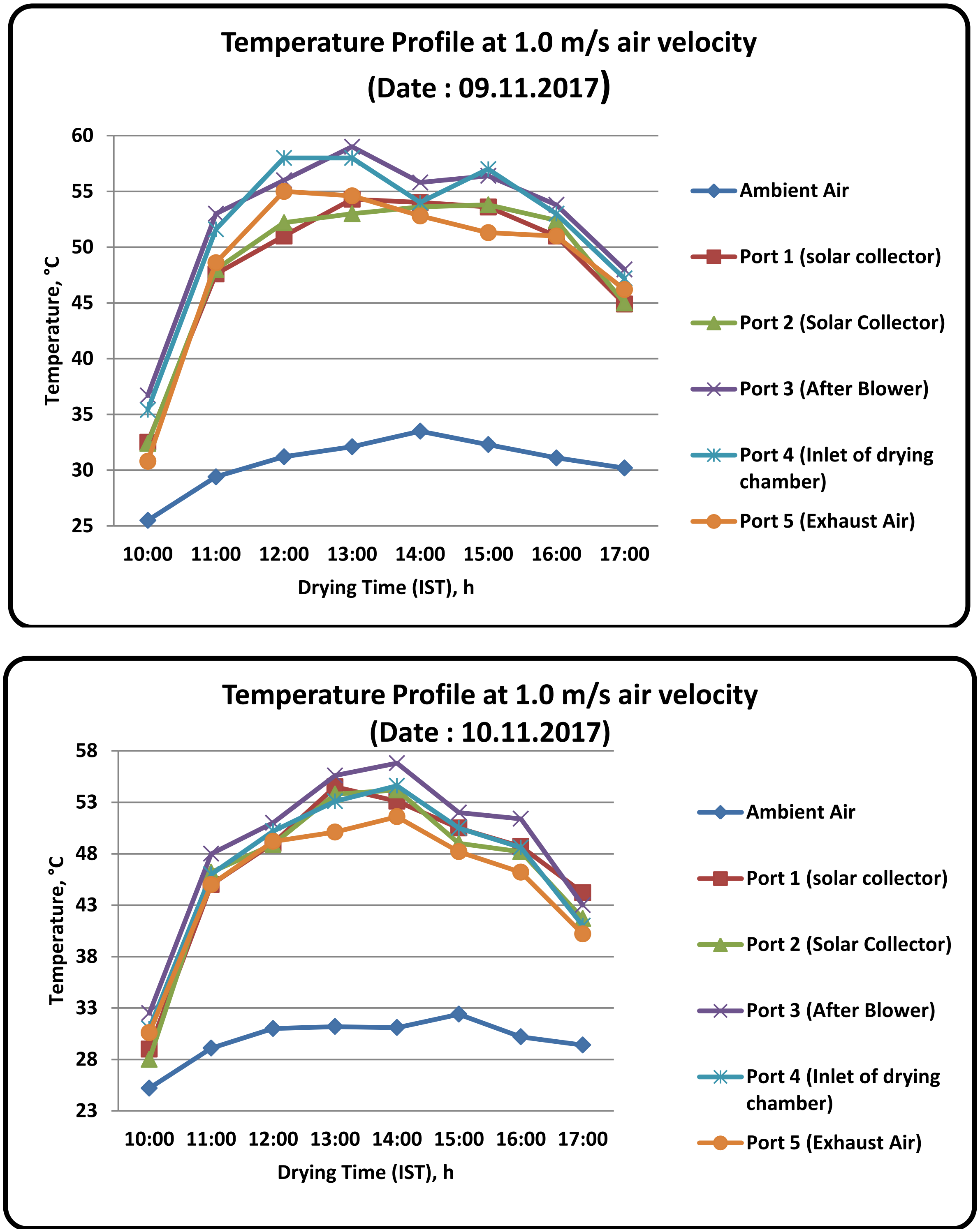
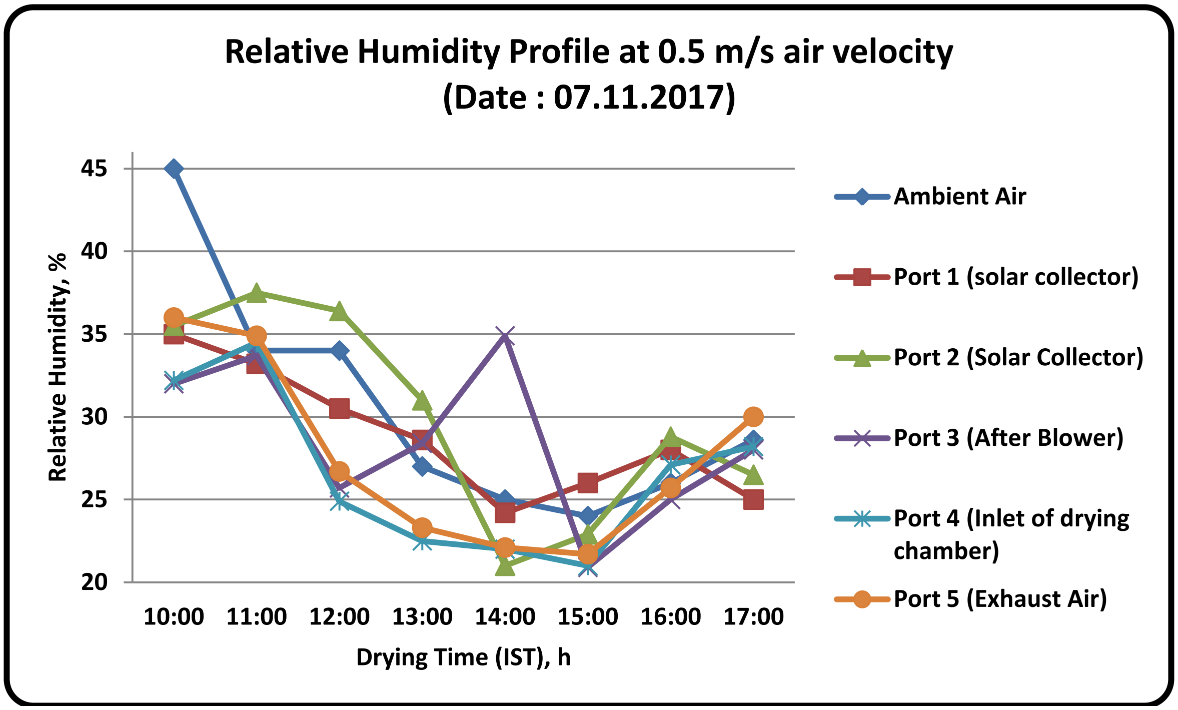


Figure 2: Temperature profile at different ports under no load condition of solar assisted Dryer at 1.0 m/s air velocity



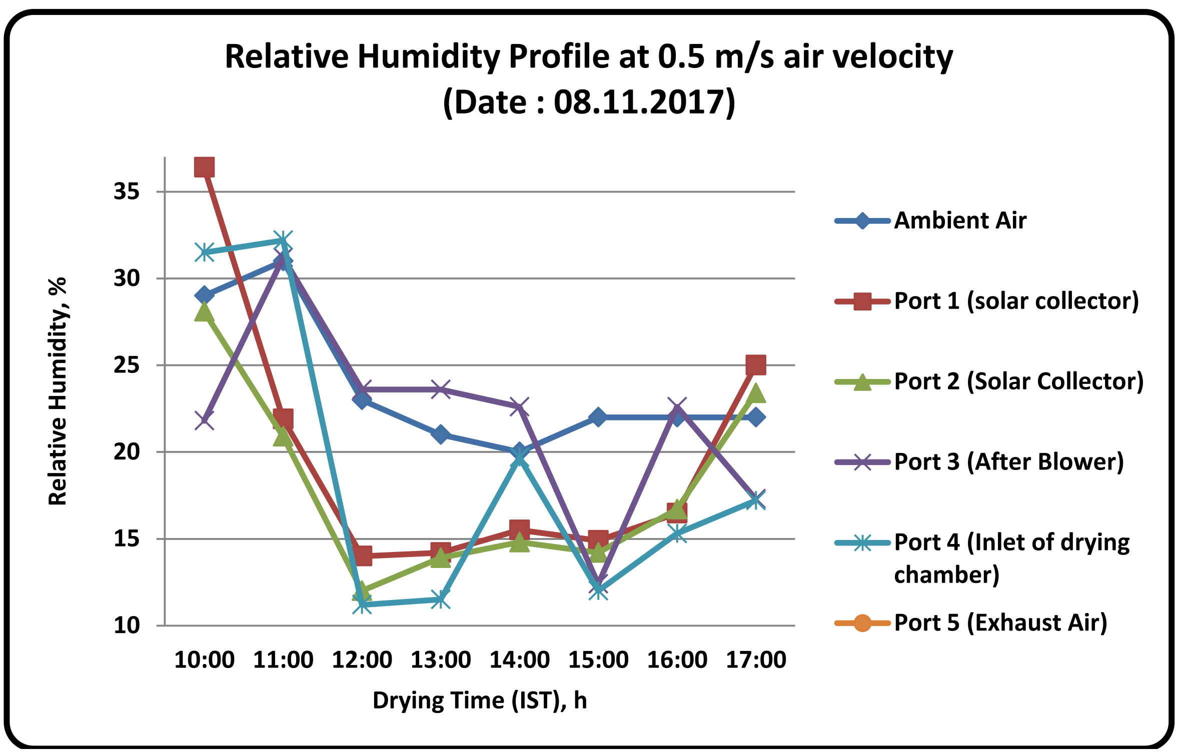
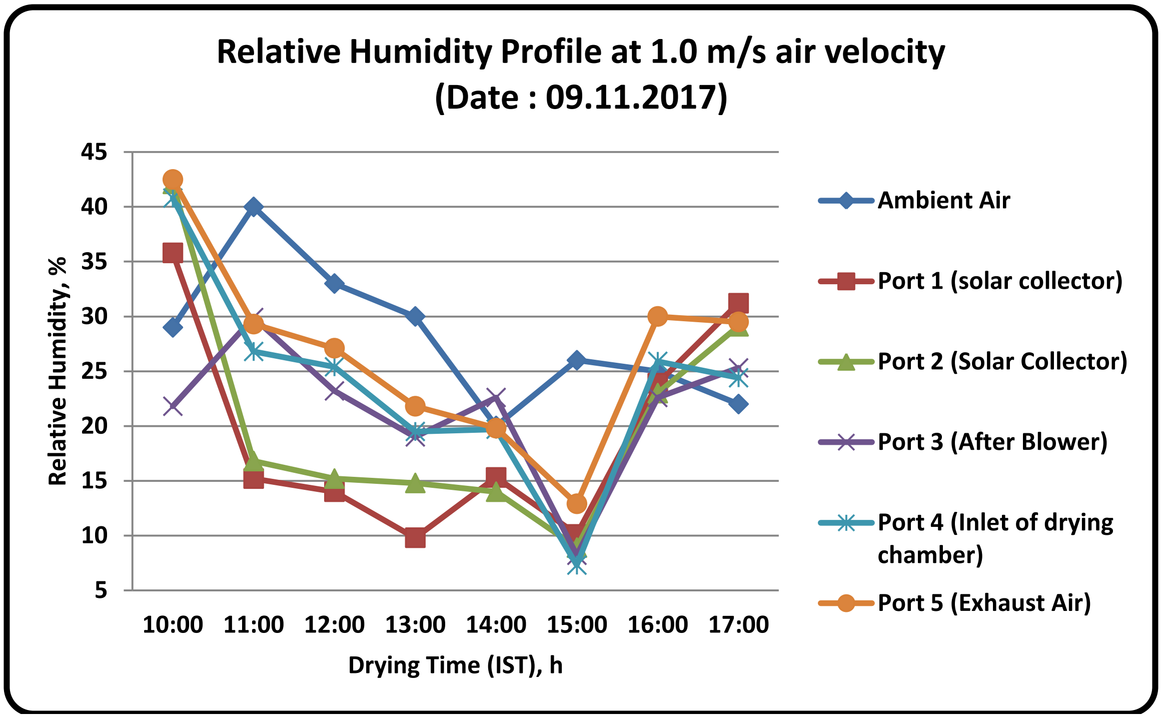


Figure 3: Relative humidity profile at different ports under no load condition of solar dryer at 0.5 m/s air velocity



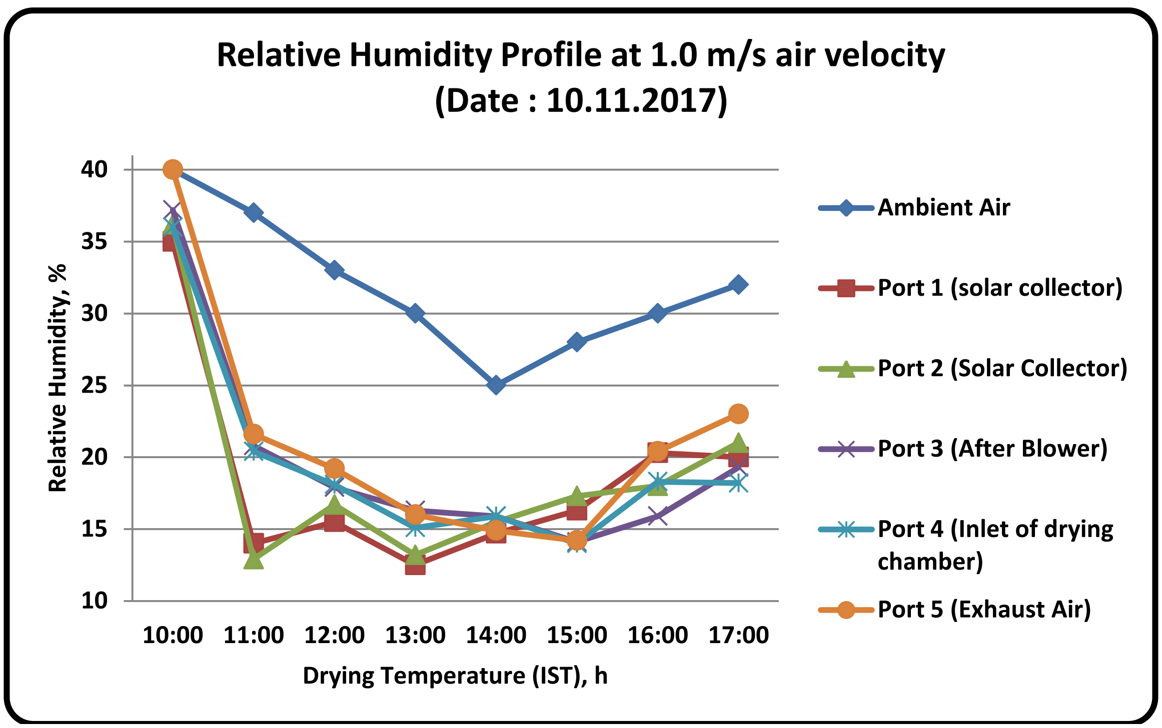


Figure 4: Relative humidity profile at different ports under no load condition of solar dryer at 1.0 m/s air velocity

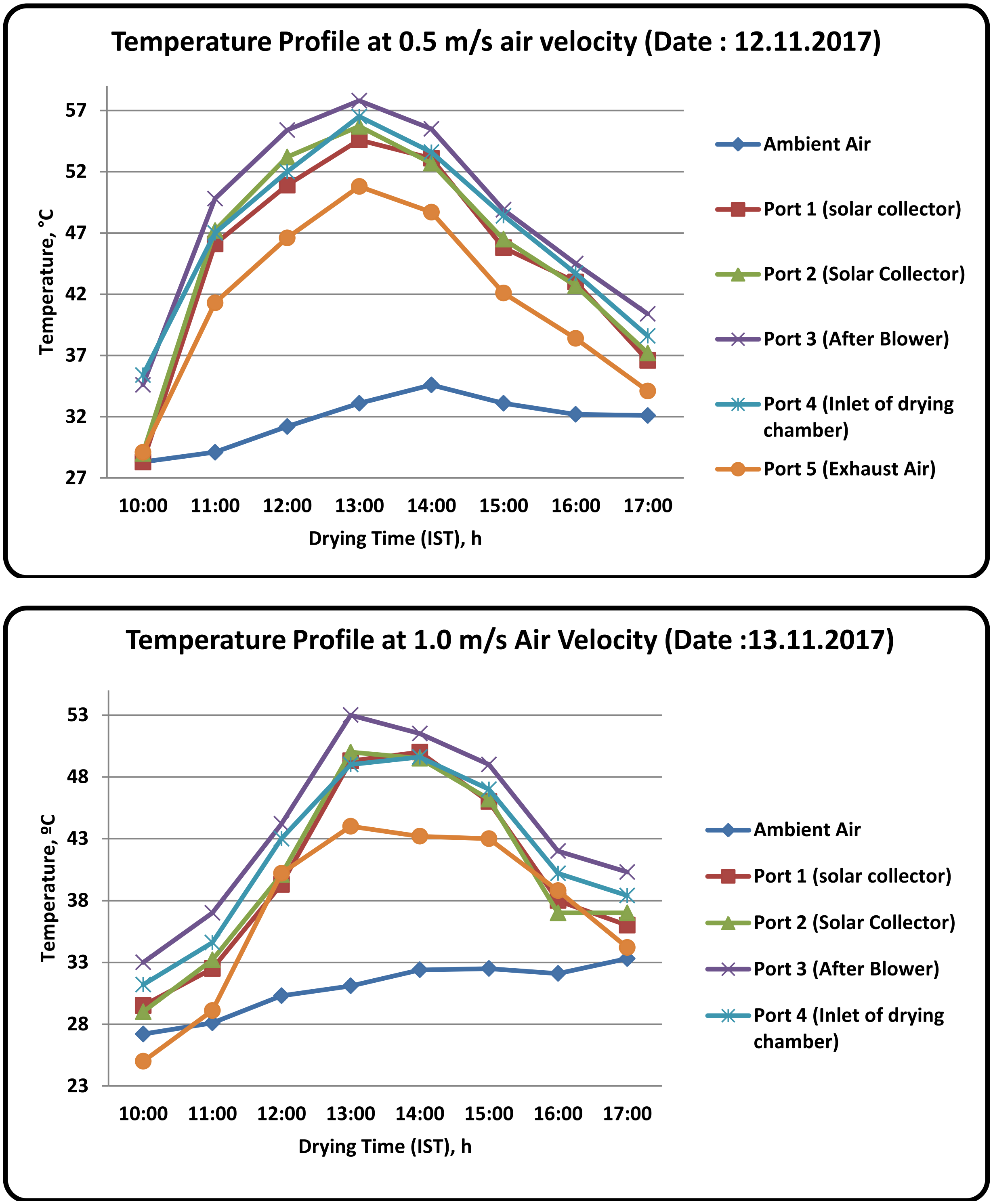
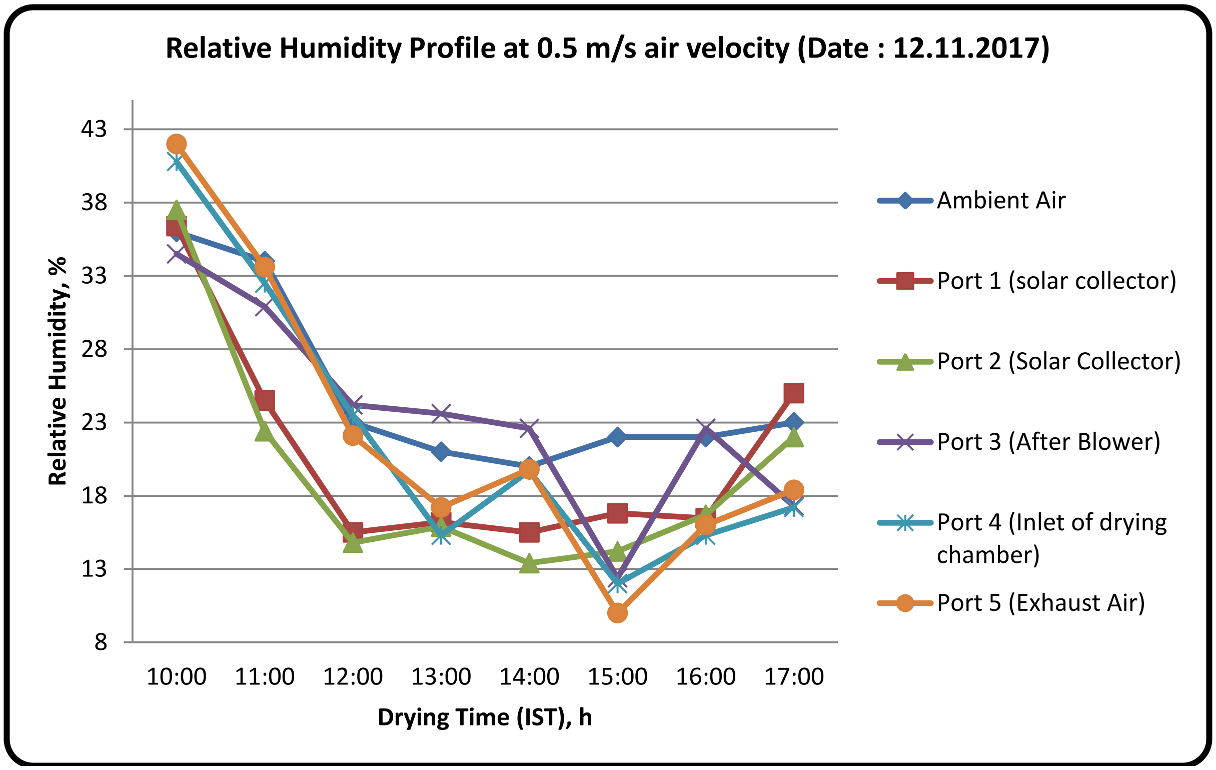


Figure 5: Temperature profile at different ports under full load condition of solar dryer at different air velocity



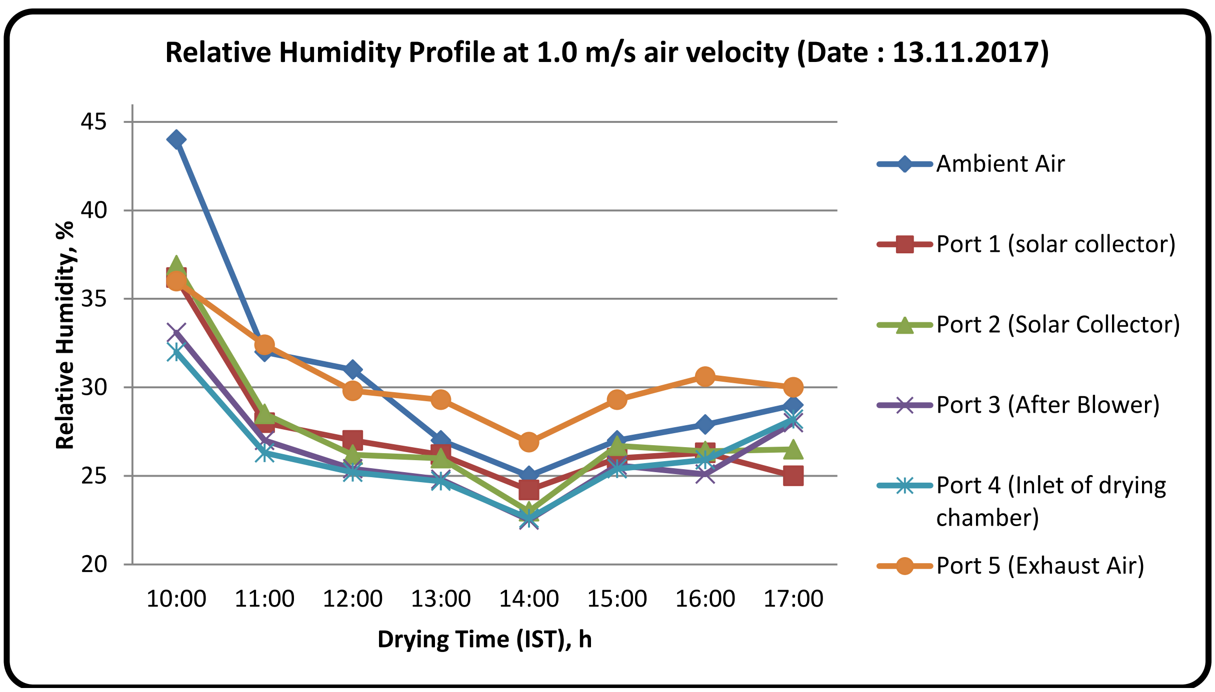


Figure 6: Relative humidity profile at different ports under full load condition of solar dryer at different air velocity

Plate 1: Drying Chamber along with 12 trays

Plate 2: Solar collector (8 Nos.)

Plate 3: Wheel valve (6"Ø)

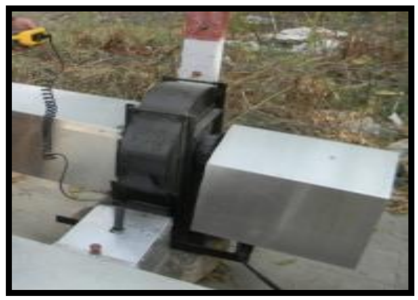
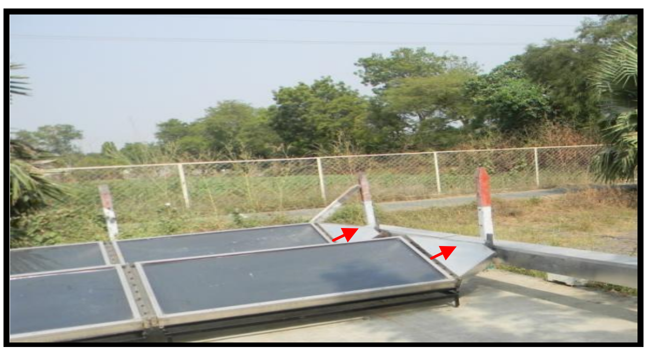


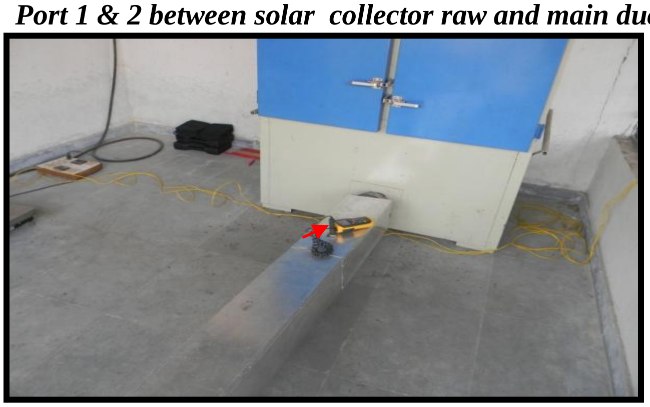
Plate 4: Blower unit (1.5 hp)

Plate 5: Heating unit (8 kW)



Port 1 & 2 between solar collector raw and main duct

Port 3 between blower unit and heating box



Port 4 between heating box and drying chamber

Port 5 at the top of drying chamber (exhaust end)

Plate 6: Performance evaluation of solar dryer at different ports

[MS received : March 21, 2018] *[MS accepted : March 26, 2018]*