Journal of Engineering and Applied Sciences 3 (7): 553-559, 2008
ISSN: 1816-949X

Determination of Maximum Number of Layers of Solar Collector for Fish Solar Dryer

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Abstract: This study presents experimental determination of maximum number of layers of solar collector for fish solar dryer. To investigate into this, four geometrically similar boxes each with an internal volume of 0.07 m^3 (i.e., 0.6×0.4×0.2 m) were constructed and named Dryer 1, 2, 3 and 4. Dryer 1, 2, 3 and 4 has one layer of solar collector, two layers of solar collector, three layers of solar collectors and four layers of solar collector, respectively. Each of the solar collectors has a thickness of 0.5 mm. Each of the dryers was loaded with 0.4 kg of fish with temperature between 27 and 31°C, the ambient temperature being between 20 and 25°C. The experiments were conducted between 1000 and 1700 h for 2 days. The results of the experiments revealed that the fish temperature in Dryer 1, 2, 3 and 4 rose to 47, 52, 46 and 44°C, respectively. The percent moisture loss of the fish in Dryers 1, 2, 3 and 4 were 33.0, 38.0, 36.5 and 32.5%, respectively. The Dryers 1, 2, 3 and 4 gave a drying rate of 0.014, 0.02 , 0.017 and 0.013 kg h^{-1}, respectively. Thus, the arrangement of the fish solar dryer in descending order of performance is Dryer 2, 3, 1 and 4. This indicates that a maximum of two layers of solar collector is required for a fish solar dryer to enhance its performance.

Key words: Dryer, solar collector, performance, temperature, moisture loss, drying rate

INTRODUCTION

The need for provision and availability of food to cater for the global population has necessitated the need for preservation of the food to avoid wastage through spoilage. The problem of wastage has been combated in developed countries through the provision of preservation techniques such as canning, refrigeration, chemical preservatives, etc. (Carneige and Pohl, 1978; Bansal *et al.*, 1998). This is not the case in some developing countries where there is no stable and reliable supply of electricity to carry out the preservation techniques. This has left a large portion of population in some developing countries to depend on other alternatives of preservation techniques among which are drying, smoking, salting, cooking and frying.

Fish is a source of protein, vitamins, minerals and calcium, hence its importance to man. Fish is an extremely perishable food. For example, most fish become inedible within 12 h at tropical temperatures. Spoilage begins as soon as the fish dies and processing should therefore, be done quickly to prevent the growth of spoilage bacteria. Fish is a low acid food and is therefore, very susceptible to the growth of food poisoning bacteria. This is another reason why it should be processed quickly (Fellows and Hampton, 1992).

Traditionally, whole small fish or split large fish are spread in the sun on the ground, or on mats, nets, roofs, or on raised racks. The heat of the sun and movement of air remove moisture which causes the fish to dry. Sun-drying does not allow very much control over drying times and it also exposes the fish to attack by insects or vermin and allows contamination by sand and dirt. Such techniques are totally dependent upon the weather conditions. The ideal is dry weather with low humidity and clear skies. Alternatives to sun-drying involve the use of solar or artificial dryers (Fellows and Hampton, 1992).

In solar drying, the sun energy is harnessed for drying of food such as fish. There has been a great deal of research on the development of solar dryers as an improved method of drying fish. This has shown that by achieving increased drying temperatures and reduced humidities, solar dryers can increase drying rates and produce lower moisture content in the final products, with improvements in fish quality compared with the traditional sun-drying techniques (Sayigh, 1988).

Solar energy is generally defined to include energy directly from sunlight and it is the most abundant energy source available to human race. In the case of solar fish dryer, the solar energy of sun is converted into thermal energy (heliothermal process) (Bansal *et al.*, 1998). Man in his search for more knowledge has been harnessing the solar energy in various ways to improve his living condition (Sayigh, 1988; ILO, 1986). In consideration of possible extinction of non-renewable energy sources such as petrol and diesel, it becomes very imperative that activities should be geared towards the use of energy from sun, a renewable energy source, for drying fish.

Solar drying of fish is cheap and affordable. The effectiveness of a solar dryer that will carry out the drying needs to be optimized. One of the means of achieving this is to increase the number of layers of solar collector for the solar dryers. It is therefore, the scope of this research that a maximum number of layers of solar collector be determined so as not to waste money on increasing the layer of solar collector of the solar dryer to unnecessary number.

MATERIALS AND METHODS

Four geometrically similar fish solar dryer were constructed with each having an internal volume of 0.07 m^3 (i.e., 0.6×0.4×0.3 m). Each of the dryers is made of wood painted black outside with its interior lined with aluminum sheet coated with foil of 1.5 mm as given by (Ashrae Handbook, 1997; Kreider and Kreith, 1981). The space between the wood and the aluminum foil is lagged using sawdust to reduce heat loss by conduction. A pictorial view of the dryer is shown in Fig. 1.

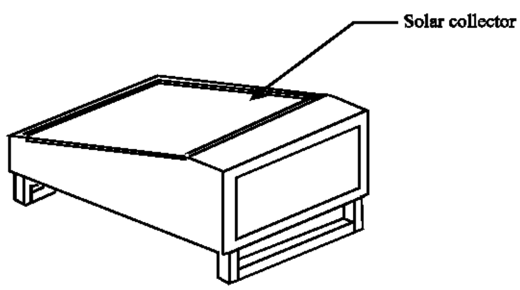

Fig. 1: Pictorial view of the fish solar dryer

The dryers have different layers of solar collector of 5 mm thickness as follows: Dryer 1-layer of solar collector, Dryer 2-layers of solar collector, Dryer 3-layers of solar collector, Dryer 4- four layers of solar collector. The solar collectors collect solar radiation from sun and they are tilled at an angle of 17° for optimum solar collection.

Table 1: Measurement of fish temperature (Day 1)

Local time, t (h)	Ambt. temp., t_a/°C	Fish temperature, t_f (°C) Dryer 1	Dryer 2	Dryer 3	Dryer 4
10:00	23	30	29	29	27
10:30	24	31	30	30	29
11:00	24	33	32	31	31
11:30	22	33	32	31	31
12:00	21	32	35	34	30
12:30	21	40	42	42	38
13:00	20	45	48	46	44
13:30	23	45	45	46	43
14:00	22	46	50	46	43
14:30	25	46	51	46	43
15:00	23	47	52	45	44
15:30	22	40	43	40	37
16:00	25	38	42	40	37
16:30	24	38	41	39	38
17:00	23	36	40	38	36

Table 2: Measurement of fish temperature (Day 2)

Local time, t (h)	Ambt. temp., t_a/°C	Fish temperature, t_f (°C) Dryer 1	Dryer 2	Dryer 3	Dryer 4
10:00	22	31	29	29	27
10:30	23	31	30	30	29
11:00	24	32	31	30	31
11:30	22	33	32	31	31
12:00	22	31	34	34	30
12:30	21	39	41	42	38
13:00	20	44	46	46	44
13:30	22	45	46	45	43
14:00	23	45	50	45	43
14:30	24	46	50	45	43
15:00	23	46	52	45	44
15:30	22	40	43	40	37
16:00	24	39	42	40	37
16:30	24	38	41	39	37
17:00	23	36	41	38	37

Table 3: Determination of percent moisture loss of fish (Day 1)

	Dryer 1		Dryer 2		Dryer 3		Dryer 4	
Local time, t (h)	*Final mass of fish, m_f (kg)	**Percent moisture loss of fish, m_L (%)	*Final mass of fish, m_f (kg)	**Percent moisture loss of fish, m_L (%)	*Final mass of fish, m_f (kg)	**Percent moisture loss of fish, m_L (%)	*Final mass of fish, m_f (kg)	**Percent moisture loss of fish, m_L (%)
10:00	0.400	0.000	0.400	0.000	0.400	0.000	0.400	0.000
10:30	0.392	2.000	0.392	2.000	0.393	1.750	0.393	1.750
11:00	0.392	2.000	0.389	2.750	0.391	2.250	0.393	1.750
11:30	0.390	2.500	0.386	3.500	0.388	3.000	0.390	2.500
12:00	0.389	2.750	0.379	5.250	0.387	3.250	0.390	2.500
12:30	0.370	7.500	0.360	10.000	0.374	6.500	0.375	6.250
13:00	0.365	8.750	0.342	14.500	0.358	10.500	0.368	8.000
13:30	0.350	12.500	0.298	25.500	0.300	25.000	0.351	12.250
14:00	0.341	14.750	0.286	28.500	0.298	25.500	0.343	14.250
14:30	0.300	25.000	0.265	33.750	0.284	29.000	0.325	18.750
15:00	0.292	27.000	0.259	35.250	0.270	32.500	0.293	26.750
15:30	0.286	28.500	0.254	36.500	0.266	33.500	0.278	30.500
16:00	0.277	30.750	0.252	37.000	0.260	35.000	0.276	31.000
16:30	0.275	31.250	0.250	37.500	0.256	36.000	0.273	31.750
17:00	0.268	33.000	0.248	38.000	0.254	36.500	0.270	32.500

*Initial Mass of Fish, m_i (kg) = 0.400 kg, **$m_L = (m_i - m_f)/m_i \times 100\%$

Table 4: Determination of percent moisture loss of fish (Day 2)

	Dryer 1		Dryer 2		Dryer 3		Dryer 4	
Local time, t (h)	*Final mass of fish, m_f (kg)	**Percent moisture loss of fish, m_L (%)	*Final mass of fish, m_f (kg)	**Percent moisture loss of fish, m_L (%)	*Final mass of fish, m_f (kg)	**Percent moisture loss of fish, m_L (%)	*Final mass of fish, m_f (kg)	**Percent moisture loss of fish, m_L (%)
10:00	0.400	0.000	0.400	0.000	0.400	0.000	0.400	0.000
10:30	0.392	2.000	0.392	2.000	0.393	1.750	0.393	1.750
11:00	0.392	2.000	0.389	2.750	0.391	2.250	0.393	1.750
11:30	0.390	2.500	0.386	3.500	0.388	3.000	0.390	2.500
12:00	0.389	2.750	0.379	5.250	0.387	3.250	0.390	2.500
12:30	0.370	7.500	0.360	10.000	0.374	6.500	0.375	6.250
13:00	0.365	8.750	0.342	14.500	0.358	10.500	0.368	8.000
13:30	0.350	12.500	0.298	25.500	0.300	25.000	0.351	12.250
14:00	0.341	14.750	0.286	28.500	0.298	25.500	0.343	14.250
14:30	0.300	25.000	0.265	33.750	0.284	29.000	0.325	18.750
15:00	0.292	27.000	0.259	35.250	0.270	32.500	0.293	26.750
15:30	0.286	28.500	0.254	36.500	0.266	33.500	0.278	30.500
16:00	0.277	30.750	0.252	37.000	0.260	35.000	0.276	31.000
16:30	0.275	31.250	0.250	37.500	0.256	36.000	0.273	31.750
17:00	0.268	33.000	0.248	38.000	0.254	36.500	0.270	32.500

*Initial Mass of Fish, m_i (kg) = 0.400 kg, **$m_L = (m_j - m_f)/m_i \times 100\%$

Table 5: Determination of drying rate of fish (Day 1)

	Dryer 1				Dryer 2			
Local time, t (h)	*Final mass of fish, m_f (kg)	**Moisture loss of fish, Δm_f (kg)	Duration of drying, t_d (h)	***Drying rate, t_r (kg h^{-1})	*Final mass of fish, m_f (kg)	**Moisture loss of fish, Δm_f (kg)	Duration of drying, t_d (h)	***Drying rate, t_r (kg h^{-1})
10:00	0.400	0.000	0	0.000	0.400	0.000	0	0.000
10:30	0.392	0.008	0.5	0.016	0.392	0.008	0.5	0.016
11:00	0.392	0.008	1	0.008	0.389	0.011	1	0.011
11:30	0.390	0.010	1.5	0.007	0.386	0.014	1.5	0.009
12:00	0.389	0.011	2	0.006	0.379	0.021	2	0.011
12:30	0.370	0.030	2.5	0.012	0.360	0.040	2.5	0.016
13:00	0.365	0.035	3	0.012	0.342	0.058	3	0.019
13:30	0.350	0.050	3.5	0.014	0.298	0.102	3.5	0.029
14:00	0.341	0.059	4	0.015	0.286	0.114	4	0.029
14:30	0.300	0.100	4.5	0.022	0.265	0.135	4.5	0.030
15:00	0.292	0.108	5	0.022	0.259	0.141	5	0.028
15:30	0.286	0.114	5.5	0.021	0.254	0.146	5.5	0.027
16:00	0.277	0.123	6	0.021	0.252	0.148	6	0.025
16:30	0.275	0.125	6.5	0.019	0.250	0.150	6.5	0.023
17:00	0.268	0.132	7	0.019	0.248	0.152	7	0.022

Table 5: Continued

	Dryer 3				Dryer 4			
Local time, t (h)	*Final mass of fish, m_f (kg)	**Moisture loss of fish, Δm_f (kg)	Duration of drying, t_d (h)	***Drying rate, t_r (kg h^{-1})	*Final mass of fish, m_f (kg)	**Moisture loss of fish, Δm_f (kg)	Duration of drying, t_d (h)	***Drying rate, t_r (kg h^{-1})
10:00	0.400	0.000	0	0.000	0.400	0.000	0	0.000
10:30	0.393	0.007	0.5	0.014	0.393	0.007	0.5	0.014
11:00	0.391	0.009	1	0.009	0.393	0.007	1	0.007
11:30	0.388	0.012	1.5	0.008	0.390	0.010	1.5	0.007
12:00	0.387	0.013	2	0.007	0.390	0.010	2	0.005
12:30	0.374	0.026	2.5	0.010	0.375	0.025	2.5	0.010
13:00	0.358	0.042	3	0.014	0.368	0.032	3	0.011
13:30	0.300	0.100	3.5	0.029	0.351	0.049	3.5	0.014
14:00	0.298	0.102	4	0.026	0.343	0.057	4	0.014
14:30	0.284	0.116	4.5	0.026	0.325	0.075	4.5	0.017
15:00	0.270	0.130	5	0.026	0.293	0.107	5	0.021
15:30	0.266	0.134	5.5	0.024	0.278	0.122	5.5	0.022
16:00	0.260	0.140	6	0.023	0.276	0.124	6	0.021
16:30	0.256	0.144	6.5	0.022	0.273	0.127	6.5	0.020
17:00	0.254	0.146	7	0.021	0.270	0.130	7	0.019

*Initial Mass of Fish, m_i (kg) = 0.4000 kg, **$\Delta m_f = m_i - m_f$ ***$t_r = \Delta m_f / t_d$

Table 6: Determination of drying rate of fish (Day 2)

	Dryer 1				Dryer 2			
Local time, t (h)	*Final mass of fish, m_f (kg)	**Moisture loss of fish, Δm_f (kg)	Duration of drying, t_d (h)	***Drying rate, t_r (kg h^{-1})	*Final mass of fish, m_f (kg)	**Moisture loss of fish, Δm_f (kg)	Duration of drying, t_d (h)	***Drying rate, t_r (kg h^{-1})
10:00	0.400	0.000	0	0.000	0.400	0.000	0	0.000
10:30	0.392	0.008	0.5	0.016	0.392	0.008	0.5	0.016
11:00	0.392	0.008	1	0.008	0.389	0.011	1	0.011
11:30	0.390	0.010	1.5	0.007	0.386	0.014	1.5	0.009
12:00	0.389	0.011	2	0.006	0.379	0.021	2	0.011
12:30	0.370	0.030	2.5	0.012	0.360	0.040	2.5	0.016
13:00	0.365	0.035	3	0.012	0.342	0.058	3	0.019
13:30	0.350	0.050	3.5	0.014	0.298	0.102	3.5	0.029
14:00	0.341	0.059	4	0.015	0.286	0.114	4	0.029
14:30	0.300	0.100	4.5	0.022	0.265	0.135	4.5	0.030
15:00	0.292	0.108	5	0.022	0.259	0.141	5	0.028
15:30	0.286	0.114	5.5	0.021	0.254	0.146	5.5	0.027
16:00	0.277	0.123	6	0.021	0.252	0.148	6	0.025
16:30	0.275	0.125	6.5	0.019	0.250	0.150	6.5	0.023
17:00	0.268	0.132	7	0.019	0.248	0.152	7	0.022

Table 6: Continued

	Dryer 3				Dryer 4			
Local time, t (h)	*Final mass of fish, m_f (kg)	**Moisture loss of fish, Δm_f (kg)	Duration of drying, t_d (h)	***Drying rate, t_r (kg h^{-1})	*Final mass of fish, m_f (kg)	**Moisture loss of fish, Δm_f (kg)	Duration of drying, t_d (h)	***Drying rate, t_r (kg h^{-1})
10:00	0.400	0.000	0	0.000	0.400	0.000	0	0.000
10:30	0.393	0.007	0.5	0.014	0.393	0.007	0.5	0.014
11:00	0.391	0.009	1	0.009	0.393	0.007	1	0.007
11:30	0.388	0.012	1.5	0.008	0.390	0.010	1.5	0.007
12:00	0.387	0.013	2	0.007	0.390	0.010	2	0.005
12:30	0.374	0.026	2.5	0.010	0.375	0.025	2.5	0.010
13:00	0.358	0.042	3	0.014	0.368	0.032	3	0.011
13:30	0.300	0.100	3.5	0.029	0.351	0.049	3.5	0.014
14:00	0.298	0.102	4	0.026	0.343	0.057	4	0.014
14:30	0.284	0.116	4.5	0.026	0.325	0.075	4.5	0.017
15:00	0.270	0.130	5	0.026	0.293	0.107	5	0.021
15:30	0.266	0.134	5.5	0.024	0.278	0.122	5.5	0.022
16:00	0.260	0.140	6	0.023	0.276	0.124	6	0.021
16:30	0.256	0.144	6.5	0.022	0.273	0.127	6.5	0.020
17:00	0.254	0.146	7	0.021	0.270	0.130	7	0.019

*Initial Mass of Fish, m_i (kg) = 0.4000kg ** $\Delta m_f = m_i - m_f$ *** $t_r = \Delta m_f / t_d$

Table 7: Average values of ambient temp., fish temp., percent moisture loss of fish and drying rate of fish for day 1 and day 2

	Day 1				Day 2			
	Dryer 1	Dryer 2	Dryer 3	Dryer 4	Dryer 1	Dryer 2	Dryer 3	Dryer 4
Avg. Amb temp., t_{av} (°C)	22.8	22.8	22.8	22.8	22.6	22.6	22.6	22.6
Avg. Fish temp., t_{fv} (°C)	38.667	40.800	38.867	36.733	38.4	40.533	38.6	36.733
Avg. (%) moist. Loss, m_{Lv}	15.217	20.667	18.683	14.700	15.217	20.667	18.683	14.700
Avg. drying Rate of fish, t_{rv} (kg h^{-1})	0.014	0.020	0.017	0.013	0.014	0.020	0.017	0.013

The same mass of fish (0.4 kg) was put inside each of the 4 dryers. The temperature of the fish and ambient temperature were measured by means of a digital thermocouple. The masses of the dryers and their contents were also measured. Readings in all cases were measured and recorded on half-hourly basis over a period of seven h between 1000 and 1700 h for two days. The final mass of the fish in each dryer at each half- hourly interval is determined by the difference between the mass of the dryer and its content at the start of the experiment (1000 h) and its mass at a specified time. They are shown in Table 1 and 2. The moisture loss, percent moisture loss and drying rate of the fish at half- hourly interval for the four dryers for the two days were determined and tabulated in Table 3-6.The average values of ambient temperature, fish temperature, percent moisture loss of fish and drying rate of fish are shown in Table 7.

RESULTS AND DISCUSSION

The results of the experiments are presented in Fig. 2-7. Figure 2 and 3 show that Dryer 2 with 2 layers

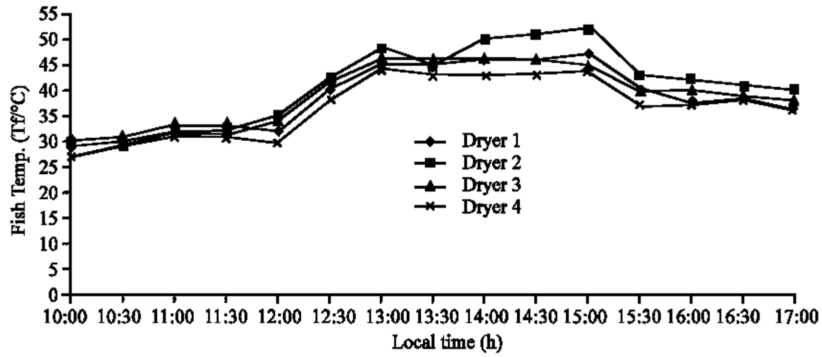

Fig. 2: Graph of fish temperature vs local day time for day 1

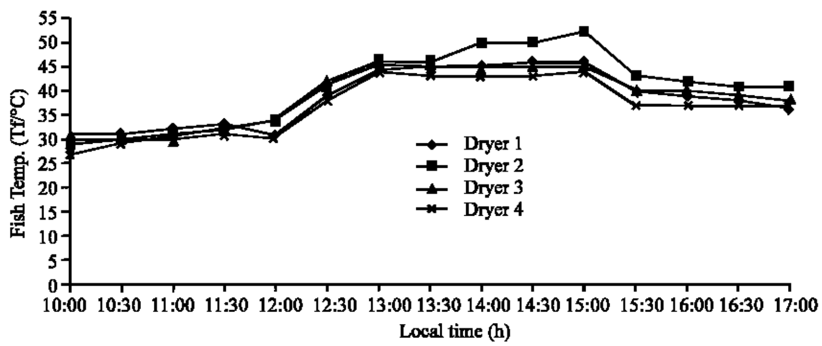

Fig. 3: Graph of fish temperature vs local day time for day 2

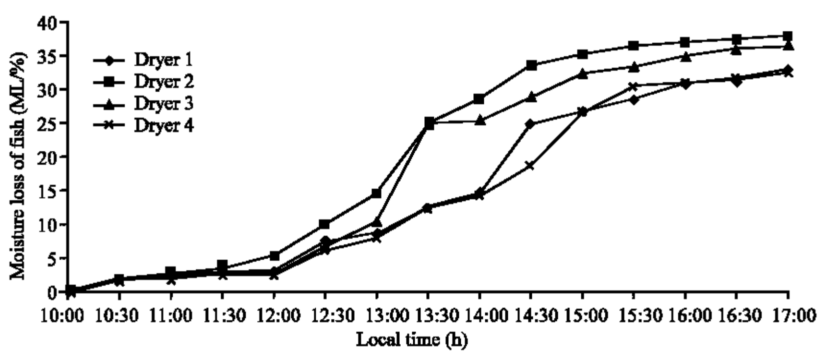

Fig. 4: Graph of percent moisture loss fish vs local day time for day 1

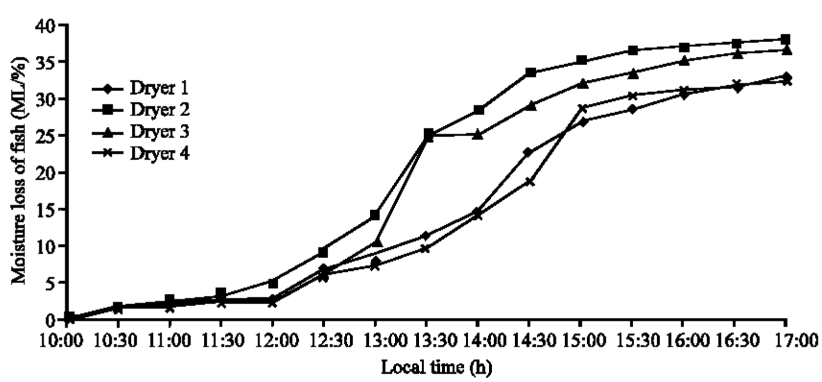

Fig. 5: Graph of percent moisture loss fish vs local day time for day 2

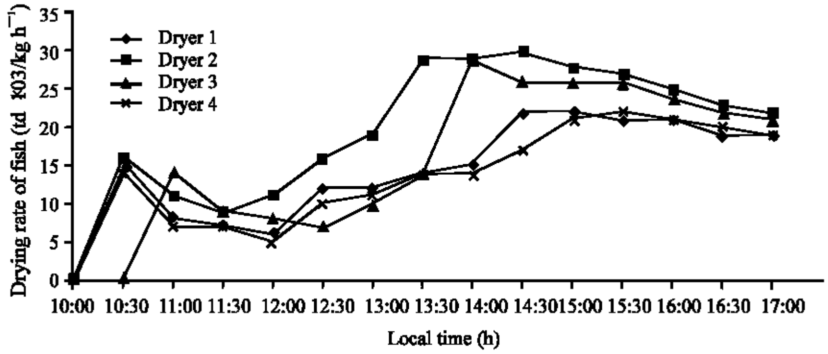

Fig. 6: Graph of drying rate of fish vs local day time for day 1

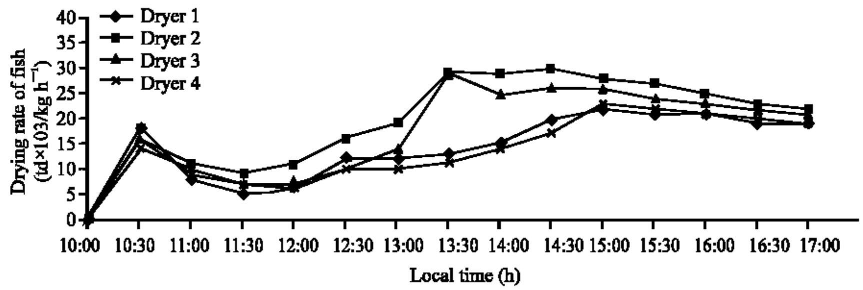

Fig. 7: Graph of drying rate of fish vs local day time for day 2

of solar collector has the maximum fish temperature of 52°C for the 2 days. The performance is followed by Dryer 3 (46°C), Dryerl (47°C for Day 1, 46°C for Day 2) and Dryer 4 (44°C).

Figure 4 and 5 show that the percent moisture loss of fish in Dryer 2 was the highest with a value of 38.0% followed by Dryer 3 (36.5 %), Dryer 1 (33.0 %) and Dryer 4 (32.5 %).

On the basis of drying rate of fish, Fig. 6 and 7 depict that Dryer 2 had the highest drying rate of 0.02 kg h^{-1}, followed by Dryer 3 (0.017 kg h^{-1}), Dryer 1 (0.014 kg h^{-1}) and Dryer 4 (0.013 kg h^{-1}).

CONCLUSION

Considering the trends in the values of fish temperature, moisture loss, percent moisture loss and drying rate of fish as given in Table 1-7 and Fig. 2-7, it can be inferred that a fish solar dryer using 2 layers of solar collector gives a better performance than any of dryers with single layer, 3 layers or 4 layers of solar collector. Although, the performance of the dryer with 2 layers of solar collector and that of three layers of solar collectors are close, yet that of 2 layers of solar collector is better. Thus, it will be a waste of resources if 3 or 4 layers of solar collector are used for the fish solar dryer. The research also revealed that that by achieving increased drying temperatures fish solar dryers can increase drying rates and produce lower moisture content in the final products.

Notations:

m_f = Final mass of fish (kg).
m_i = Initial mass of fish (kg).
m_L = Percent moisture loss of fish (%).
m_{Lv} = Average percent moisture loss of fish (%).
t = Local time (h).
t_a = Ambient temperature (°C).
t_{av} = Average ambient temperature (°C).
t_d = Drying period (h).
t_f = Fish temperature (°C).
t_{fv} = Average fish temperature (°C).
t_r = Drying rate of fish (kg h^{-1}).
t_{rv} = Average drying rate of fish (kg h^{-1}).
Δm_f = Moisture loss of fish (kg).

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