Tropical Agriculture (Trinidad), 49, 4, 319-3

THE DEVELOPMENT OF A FORCED CONVECTION SOLAR DRYER FOR RED PEPPERS

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ABSTRACT

The construction of a solar dryer of a double-skin tent design, (the inner skin of black plastic sheet, the outer of clear sheet), with forced air draught provided by an electric fan, is described.

The performance of the solar dryer in the drying of capsicum peppers was compared with traditional sun drying; drying times with the solar dryer were reduced by some 65%. The quality of the solar dried peppers was found to be fully acceptable.

INTRODUCTION

The sun drying of crops is still the most widely practiced form of preservation in many parts of the world, especially so in the developing countries. Usually this practice consists of merely spreading the crop on the nearest available surface such as a relatively flat area of ground, roofs of buildings, scrap metal sheet, woven mats, plastic sheet, concrete, or even roads. The limitations of this practice are many. Long periods of dry sunny weather are required, and large drying areas are necessary. There is a need for labour to be always on hand during inclement weather to protect the crop from rain. The crop being dried is susceptible to damage from insects, birds and animals and to dust contamination. The general quality of the dried crop is likely to be low with some being under-dried and some over-dried. Microbiological quality is also likely to be poor because of the large degree of handling involved and microbal contamination from both the farmer and pests.

The use of solar dryers can avoid or reduce these limitations. The drying time can be considerably shortened, thus lessening the need for long sunny periods, and increasing the throughput per unit area of land. By employing either through-flow deep bed drying techniques or by using tiers of drying trays within the dryer, the land area required can be reduced still further. Since solar dryers afford a great deal of shelter to the crop, the need for labour to be on hand during inclement weather is considerably reduced. The design of the majority of solar dryers renders the likelihood of contamination by either pests or dust very low indeed and the relatively high temperatures attainable within some dryers reduce the rate of microbial proliferation, so improving product quality. The higher temperatures possible also tend to result in lower final moisture contents of the dried product compared with those achieved by sun drying this can be of importance for subsequent processing and storage.

Numerous versions of solar dryers have been constructed and operated in many countries. They can be classified according to several principles of design and operation. Perhaps one of the more useful distinctions is that of the mode of air movement through the dryer, which can ~~be~~ by either natural or forced convection. Natural convection designs, which depend upon temperature gradients within the dryer for air movement, do not require an external source of motive power and thus are the type most appropriate to those areas with no ready power supplies. The degree of air movement produced by natural convection is however invariably considerably less than that produced by forced convection, and since the rate of air flow over and around the drying material exerts a controlling influence over the drying rate, especially so in the initial stages of drying, forced convection dryers usually achieve shorter drying times than do natural convection dryers. In relatively developed countries such as Korea, electrical power supplies are generally available in all but the most rural of areas and forced convection dryers can be feasible propositions in such localities.

Of the various designs of forced convection dryers that have been developed one of the most effective and popular has been the design orginally investigated by Buelow, (1958, 1961). This design has the drying chamber positioned under a roof-cum-solar collector. Air is drawn through ducts under the roof by a fan and then blown into the drying chamber. Bose, (1978), Johnston, (1979), Lawand, (1967) and Phillips, (1965) amongst others, have reported on the further development and application of this system for various crops. Foster and Peart, (1976) have described the somewhat more sophisticated employment of such dryers in the grain growing regions of the

USA.

The technique of constructing the collector of a solar dryer from two concentric plastic tubes has been used by Foster and Peart, (1976) for grain drying and by Bolin, Stafford and Huxsoll, (1978) for the drying of fruit. In the design the inner tube is of black plastic and the outer of clear plastic. Air flow can be either through the inner tube or through the annular gap between the two tubes. Both clear and black plastic sheet are becoming increasingly available in most developing countries, such as Korea.

The solar dryer described here was constructed at the Food Research Institute near Suweon. Air movement through the dryer was by forced convection provided by an electric fan. It was designed to combine the principle of the roof-cum-collector with that of the all plastic collector but using local construction techniques.

Korea has the highest per capita consumption of red peppers (Capsicum annum L.) in the world, (Park and Chun, 1977). Peppers are therefore one of the major cash crops grown by Korean farmers. The peppers are harvested from August to October, and the majority of the crop is dried by traditional sun drying methods, although in recent years some have been dried using artificial hot air dryers. The shortcomings of sun drying have been outlined above and artificial drying is becoming increasingly expensive because of the rapidly rising cost of fuel. The need arose therefore for an improved but inexpensive drying technique, and it was decided to investigate the potential of the solar dryer as an alternative to other techniques for the drying of red peppers.

CONSTRUCTION AND METHOD OF OPERATION

A basic sketch of the solar dryer is shown in Figure 1. Essentially it consisted of a double-skinned plastic tent, 4.25 m long, and semi-circular in cross-section with a radius of two metres. Both inner and outer skins were constructed of plastic sheet fastened to a framework of bamboo poles, the inner skin of black plastic and the outer of clear plastic. The bamboo framework for the inner skin was made by embedding bamboo poles, each approximately four metres long, in two parallel rows, four metres apart, at a spacing of 0.5 m. Each opposite pair of poles was then bent over and tied

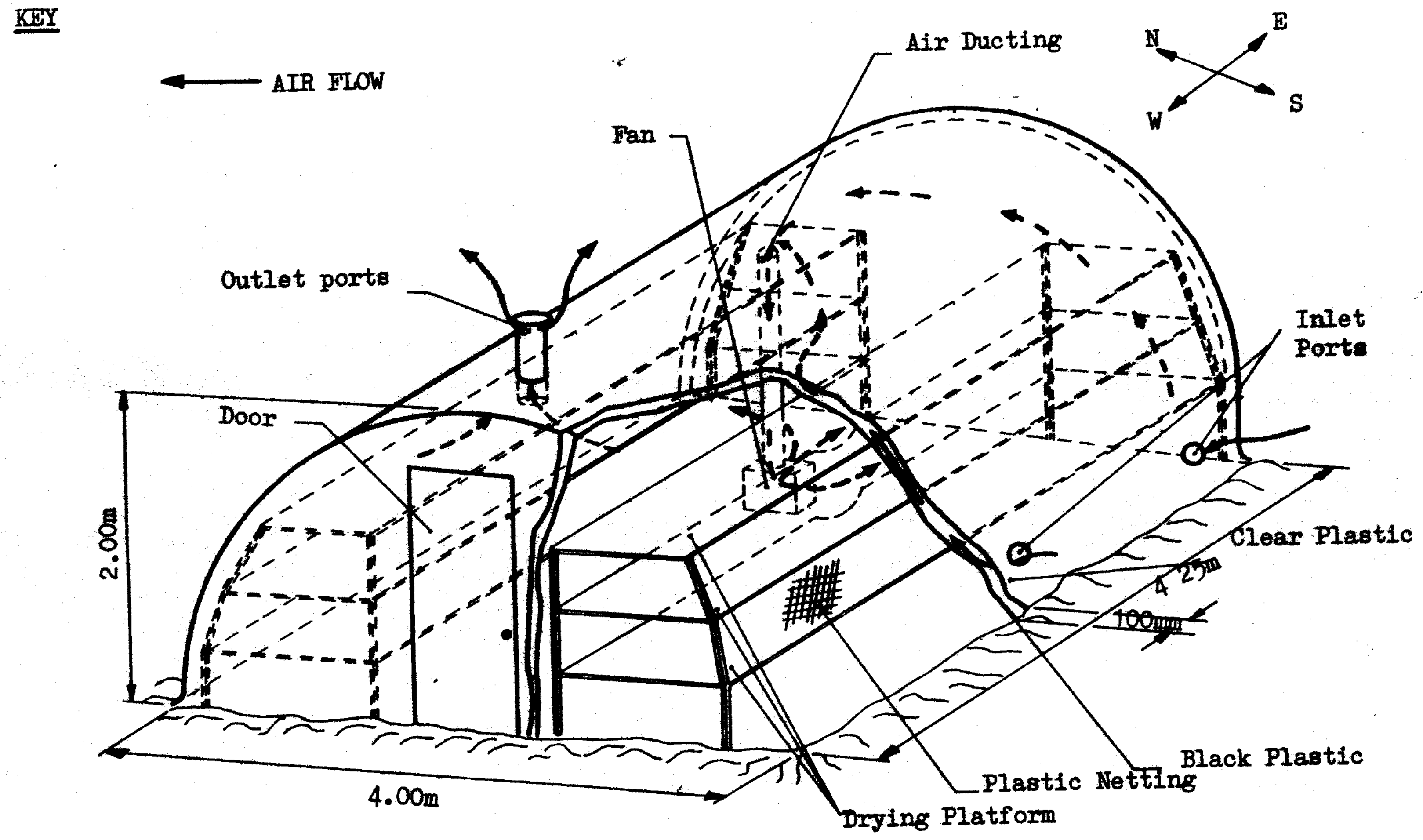

Figure 1: Forced Convection Solar Dryer

together to form a semi-circular arch. Additional poles were fixed lengthwise along the sides and across the two ends to provide increased structural stability. Black plastic sheet was cut to the required size and shape and then fitted over the framework, with all bottom edges being buried to form an effective seal. The outer skin was constructed in an identical manner but to a slightly larger radius which resulted in an annular spacing of approximately 0.1 m between the two skins. A doorway 1.7 m high by 0.7 m wide was left in one end of the structure. The dryer was built such that its longitudinal axis lay on the east-west line with the door being at the western end.

On the southern side of the dryer three equi-spaced openings were cut into the outer skins and fitted with circular air inlet ports. These were short lengths of plastic piping approximately 200 mm in diameter. As shown in Figure 1 a similar opening was cut into the centre of the inner skin, and connected via ducting to a centrifugal fan positioned directly beneath. The ducting was made of plastic sheet over a bamboo frame. At the top of one end of the dryer an air outlet port was made by fitting another length of plastic piping into an opening cut through both inner and outer skins. A cowl was fitted over the end of the outlet port to prevent rain entering the drying chamber. The 0.19KW (0.25Hp) fan was capable of a throughput of 7.58 kg.min^{-1} of air under the operating conditions employed. Three drying racks were built along the complete length of each side of the dryer at heights of 0.4 m, 0.8 m, and 1.2 m respectively. The racks were made of plastic netting stretched across a bamboo frame. The total drying area of the racks was approximately 22 m^{2}.

The principle of operation of the solar dryer was extremely simple. Air was drawn through the three inlet ports into the annular space between the inner and outer skins which effectively acted as a curved surface solar collector. The incident insolation which passed through the transparent outer skin was absorbed by the black plastic of the inner skin. Most of this absorbed energy was transferred either to the air flowing through the annular space or to the air within the drying chamber. The air in the annular space was thus heated considerably during its passage from ground level to the top of the dryer before it was drawn into the drying chamber. The air flow pattern within the drying chamber was as shown in Figure 2, with the air initially directed by the fan to one end of the chamber exhausting through the outlet port at the other end. With this simple arrangement the flow of air around the drying racks was far from ideal.

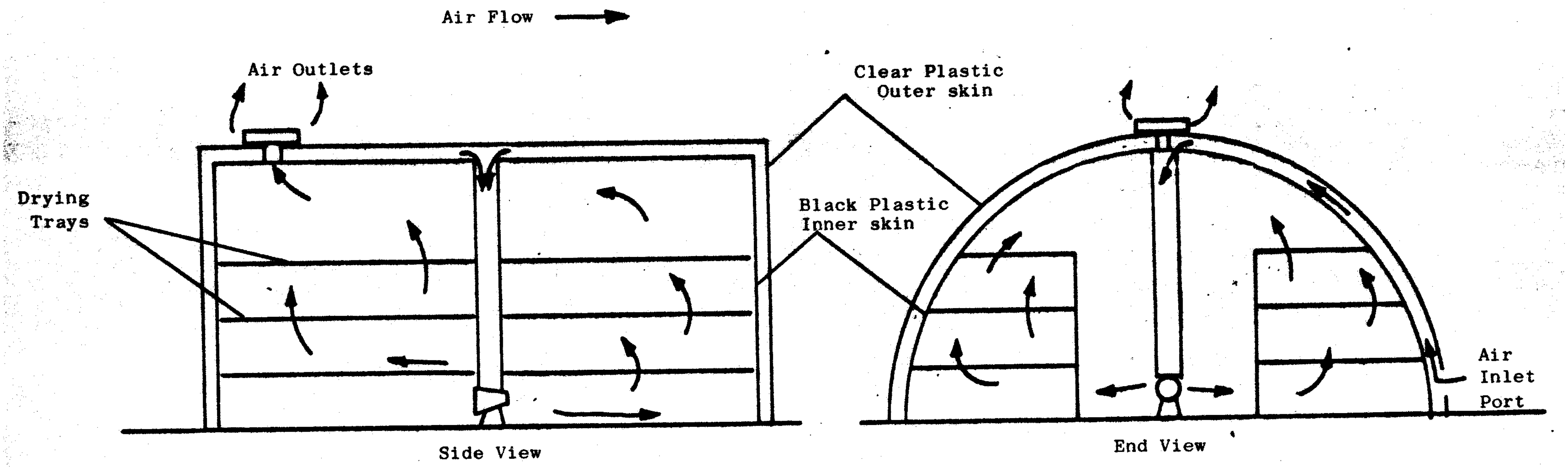

Fig. 2. Air Flow Distribution within Solar Dryer.

However to have employed a system of baffles etc to obtain an improved air distribution would have been relatively complex and such a system would have been an impediment to easy access to the drying racks.

The northern side of the dryer and the two ends were not used as solar collectors because large parts of their surfaces were in shade for most of the day and heating of the air by these collectors would have been minimal. If all surfaces had been employed, then for a given fan delivery the resultant temperature of the combined air streams would have been considerably lower than that achieved by the southern side along. However, the presence of a double skin on the northern side and the two ends was technically advantageous because of the insulation properties of the relatively stagnant air contained within the skins. At other times of the year or at other locations, the use of only one side as the solar collector may not be the most efficient. It would be but a simple matter to insert inlet ports into the base of the northern side and use either or both of the sides as collectors as appropriate.

COMMISSIONING OF THE DRYER

The commissioning trials consisted of a controlled comparison of the performance of the solar dryer with that of the local sun drying technique. Three trials were carried out. In the first trial freshly harvested whole peppers were dried in the solar dryer and also on a sun drying rack, identical to those within the solar dryer but completely exposed to the elements; it had previously been established that rack drying was compatible to drying on flat solid surfaces. At night or during inclement weather, the peppers were covered with plastic sheet. In the second and third trials, longitudinally sliced peppers as well as whole peppers were dried in the solar dryer and on the sun drying rack.

For both sun drying and solar drying, the rate of drying was monitored by placing a proportion of each batch of prepared peppers in open mesh baskets with a loading of 14 kg m^{-2}. The loaded baskets were weighed before the start of drying and then at frequent intervals until successive weighings showed little or no change in weight. The peppers in the baskets and the bulk of each batch that were spread on the racks were turned at intervals to promote even drying. Within the solar dryer the baskets of peppers were moved around the drying chamber to minimise any variation in drying conditions. Moisture contents of the dried peppers were evaluated by grinding and then drying to constant weight in an oven at 105°C. Colour estimates were made according to the method of Chun and Park, (1979) using a Tri-stimulus XL-10 Colorimeter, with the reference Red colour for comparison. Pungency (capsaicine content) was measured using the method of Trejo-Gonzales and Wild-Altamirano, (1973).

RESULTS AND DISCUSSION

Collection Efficiency

Since the latitude of Suweon is approximately 37°N and the commissioning of the solar dryer took place during the equinoctial months of September and October, the angle of incidence of insolation upon the dryer had a mean value of effectively 53° over the period of investigation. The projected solar collection area was therefore 19.24 m^2. The solar collection efficiency, defined as the ratio of the heat collected by the air in its flow through the collector to the insolation incident upon the collector was thus easily calculated.

Table 1 shows the total daily insolation, the mean ambient and internal drying chamber temperature, the total heat collected by the air, and the solar collection efficiency for a number of days of operation. The solar collection efficiency is seen to vary from a minimum of 32% to a maximum of 52%. This compares well with efficiencies of 35% - 40% reported by Lawand, (1967), and is significantly greater than that of 13% reported by Bolin, Stafford and Huxsoll, (1978), obtained with systems employing inflated plastic tube collectors with longitudinal flow.

Table 2 illustrates the variation in ambient temperature and mean internal drying chamber temperature, (averaged from measurements at the six locations within the chamber), over a seven hour period. A maximum temperature of 55°C was attained within the drying chamber when the ambient temperature at that time was 22°C. Such temperatures were by no means uncommon, internal temperatures as high as 66°C were recorded inside the drying chamber on occasions and increases in air temperature of 35°C over the collector were achieved. Despite the simplicity of the air distribution system the variation in temperature within the drying chamber was slight; mean daily temperatures measured at the six locations within the chamber differed by a maximum of only 5°C.

TABLE 1. Thermal Performance of Solar Dryers

Daily Insolation, kJ m^{-2} day^{-1}	Temperature. °C		Total Heat Collected, kJ day^{-1}	Collection Efficiency, %
	Ambient	Solar Dryer		
15170	26	42	92810	31.8
10400	22	33	63410	31.7
17630	25	45	114110	33.6
17330	27	48	118540	35.5
16800	24	46	123990	38.4
15030	22	41	103890	35.9
14990	20	44	130260	45.2
15300	21	41	108170	36.7
6950	19	32	68770	52.2
12820	22	44	115760	46.9
15390	17	43	136100	46.5

TABLE 2. Hourly Variation in Ambient and Solar Dryer Temperatures

Time	Temperature °C	
	Ambient	Solar Dryer
10.00	21	37
11.00	23	51
12.00	23	52
13.00	22	55
14.00	23	52
15.00	23	47
16.00	20	34
17.00	18	22

Drying Performance

The relative performance of the solar drying of peppers in comparison with sun drying for the three commissioning trials is represented graphically in Figures 3, 4 and 5. Irregularities in these drying curves are directly

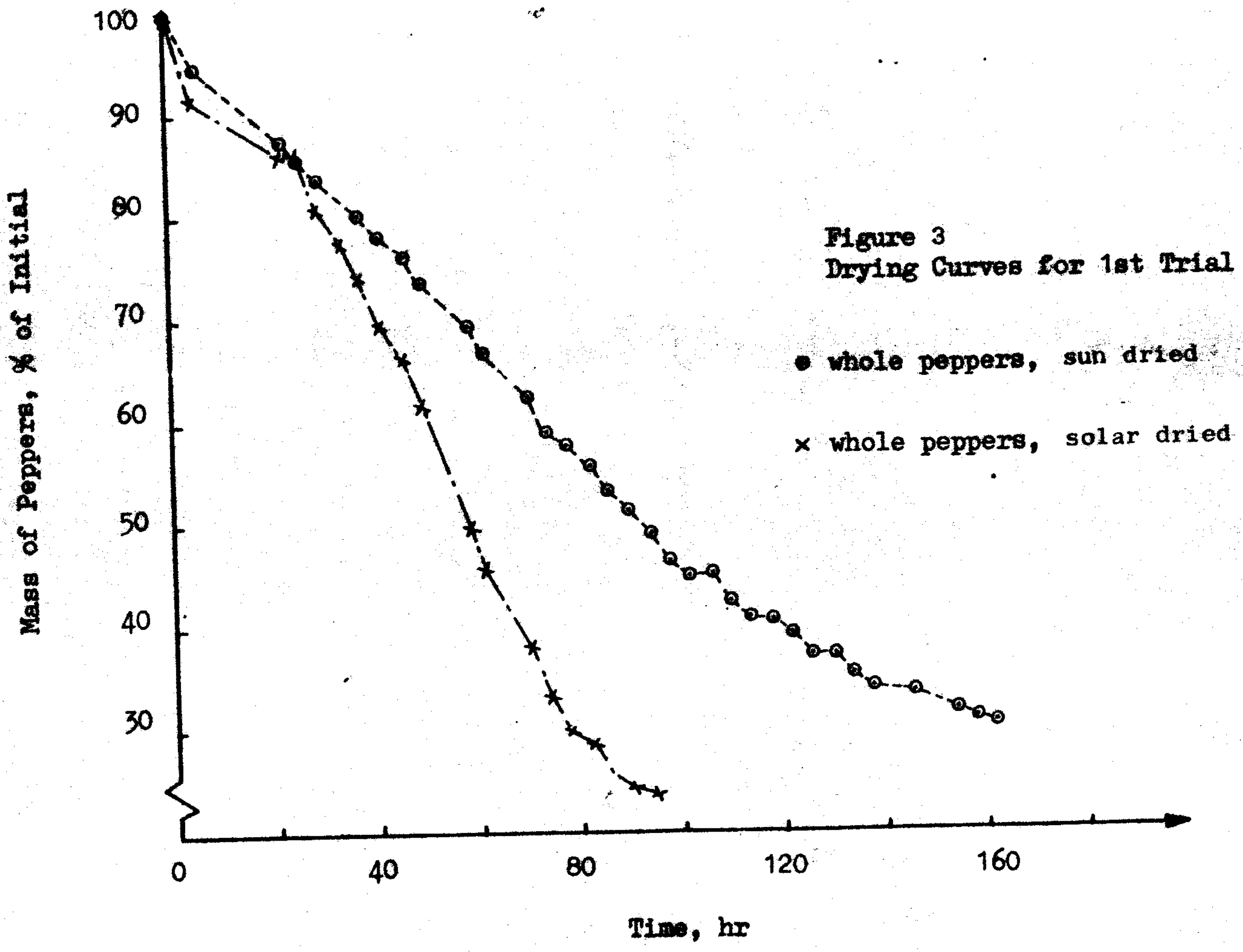

Figure 3
Drying Curves for 1st Trial

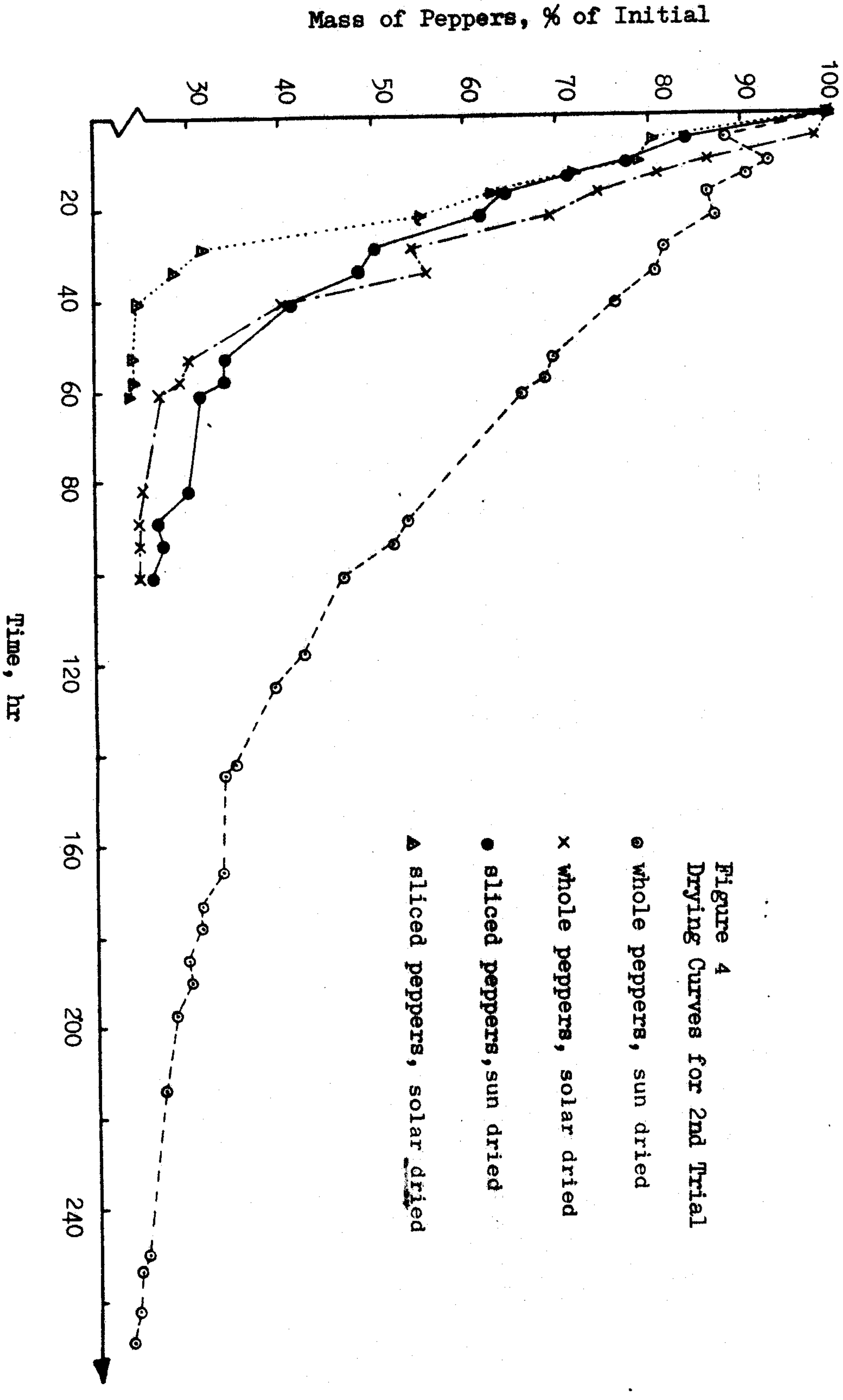

Figure 4
Drying Curves for 2nd Trial

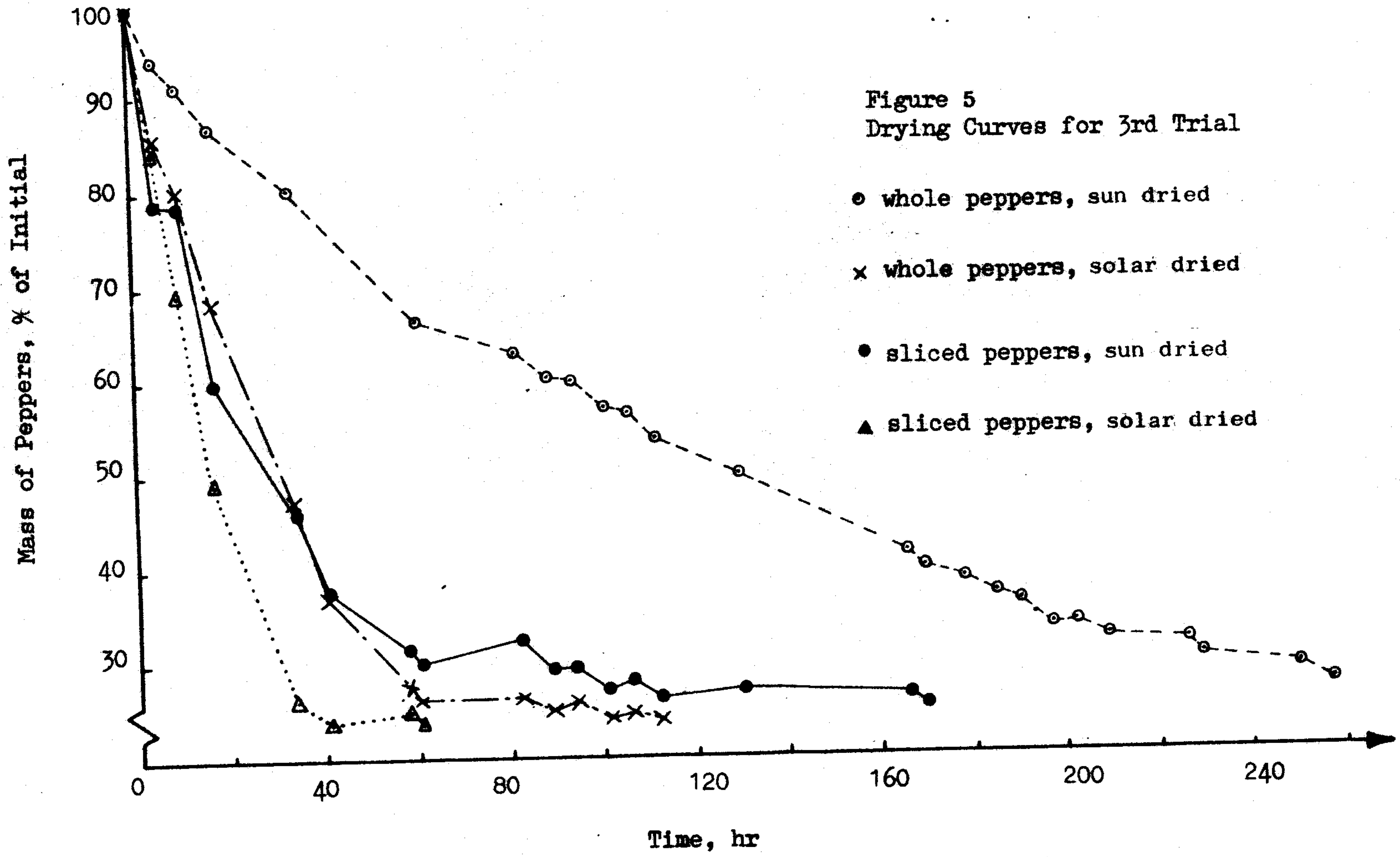

Figure 5
Drying Curves for 3rd Trial

attributable to insolation and climatic variations. The final moisture contents of the dried peppers produced in the three trials are shown in Table 3.

TABLE 3: Final Moisture Content of Dried Pepper

Drying Method	Form of Peppers	Final Moisture Content, % (d.b)		
		First Trial	Second Trial	Third Trial
Sun	Sliced	-	13.3	15.2
	Whole	44.6*	17.1	15.3
Solar	Sliced	-	7.2	8.4
	Whole	9.1	9.1	8.7

* Moisture content as measured at termination of trial.

From these results it is immediately obvious that peppers dried considerably faster in the solar dryer than by sun drying. From the Figures it can be seen that, in the first trial, for whole peppers to dry to 30% of their initial weight required 78 hours in the solar dryer but 162 hours when sun dried; in the second trial, solar drying took 54 hours, and sun drying 190 hours, and in the third trial, solar drying required 55 hours and sun drying 235 hours respectively; the mean reduction in drying time for whole peppers achieved by the solar dryer was 67%. For sliced peppers in the second trial 31 hours were required to dry to 30% of the initial weight in the solar dryer but 81 hours when sun dried, and in the third trial solar drying took 32 hours and sun drying 88 hours respectively. From these results, the mean reduction in drying time for sliced peppers achieved by the solar drying was 63%.

This improvement in the rate of drying was more pronounced in the later stages of drying. For example, in the first trial the times required to dry from 80% to 70% of initial weight were 19 hours and 13 hours for sun dried and solar dried peppers, whereas to dry from 40% to 30% required 43 hours and 9 hours respectively. A possible explanation for this observation is that in the early stages of dehydration the degree of air movement around the peppers is of major importance, (Sherwood, 1936). Natural air currents would provide for a reasonable initial rate of drying for sun dried peppers comparable to that obtained by forced air circulation within the solar dryer, but in the final stages of drying at low moisture contents the rate of drying tends to be controlled by the rate of moisture movement from the interior of the drying body to the surface. This in turn is controlled by the temperature of the body which is of course governed by the temperature of the surrounding air. It can be postulated, therefore, that the higher rate of solar drying at low moisture contents is attributable to the higher air temperature attained within the solar dryer.

Slicing of the peppers had a very significant effect upon the drying rate, particularly so for sun drying. From Figures 4 and 5 it can be seen that the times required to sun dry sliced peppers to 30% of their initial weight in the second and third trials were 81 hours and 88 hours compared with 190 hours and 235 hours respectively for whole peppers. Solar drying times in the same trials were 31 hours and 32 hours for sliced peppers and 54 hours and 55 hours respectively for whole peppers. This is almost certainly due to the exposure of the internal surfaces of the pepper berries which not only effectively doubles the surface area available for the evaporation of moisture, but also exposes a surface differing in composition from that of the external surface with its waxy bloom.

As whole peppers required a solar drying time of about 65 hours to obtain a moisture content of around 10% and sliced peppers about 40 hours, it can be calculated that the power consumption for the drying of a 300 kg batch of whole peppers was about 12 kWh and for a batch of sliced peppers about 7.5 kWh.

Product Quality

From Table 3 it can be seen that the final moisture contents of the solar dried peppers were appreciably lower than those of the sun dried peppers, even though both were dried to constant weight, (with the exception of sun dried whole peppers in the first trial). Moisture content is of great importance for reasons of subsequent storage and for ease of milling, and therefore solar dried peppers would be superior in this respect. Samples of dried peppers purchased in the market place at Seoul had moisture contents ranging from 10% to 12%.

Colour estimations as shown in Table 4 indicated no significant difference between solar dried and sun dried peppers; neither did visual assessment indicate any difference. This is of obvious importance for a product directly sold to the consumer.

TABLE 4: Colour Estimation of Dried Peppers

Drying Method	Form of Peppers		Hunter Value	
		First Trial	Second Trial	Third Trial
Sun	Sliced	-	1.45	1.43
	Whole	1.40	1.62	1.67
Solar	Sliced	-	1.52	1.55
	Whole	1.45	1.37	1.25

Capsaicine contents as shown in Table 5 indicated that the pungency of solar dried and sun dried whole peppers was very similar, but that of solar dried sliced peppers was a little lower. Preliminary organoleptic tests did not indicate any significant differences between the method of drying or between whole or sliced peppers.

TABLE 5: Capsaicine Content of Dried Peppers

Drying Method	Form of Peppers	Capsaicine Content, % (db)
Sun	Sliced	-
	Whole	0.~~426~~ 213
Solar	Sliced	0.~~346~~ 173
	Whole	0.~~406~~ 203

Putrefaction of individual berries was observed, although not quantified, amongst peppers on the sun drying racks, especially so during inclement weather; but not observed amongst peppers dried in the solar dryer. Putrefaction is an obvious cause of losses during drying and is most likely to occur with peppers that are dried slowly, as can happen with sun drying in cloudy or inclement weather.

CONCLUSIONS

It can be said that the solar dryer was of an efficient and effective design. The collection efficiencies obtained, ranging from 32% to 52% were high compared with those reported for other designs. Temperatures attained within the drying chamber were ideal for the drying of red peppers and would be so for the drying of many other crops.

From the results obtained the dryer would be capable of drying a batch of 300 kg of whole peppers in four to five days and a similar quantity of sliced peppers in about three days. Such a dryer would offer a considerable advantage over the traditional practice of sun drying peppers for the medium-scale farmer in Korea and also be a feasible and cheaper alternative to artificial hot air dryers.

The principles of construction and operation of the dryer are such that it would be suitable for the drying of other crops grown in Korea, such as paddy and tobacco, and also for application in other countries where a source of motive power is available.

ACKNOWLEDGEMENTS

The authors are grateful to the managements of both the Tropical Products Institute and the Food Research Institute for permission to publish this paper, and also to their colleagues at both Institutes for assistance and advice readily and generously provided.

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