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COMMERCIAL DEHYDRATION OF VEGETABLES
Part I. Design and Development of Dehydration Unit

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A dehydration unit has been designed and developed for the production of dehydrated vegetables. The unit has been fabricated by using local materials of construction and makes use of a gas fired furnace and heat exchanger for heating air. The vegetable, after pretreatment, is dehydrated under controlled conditions of temperature and humidity using counter and con-current arrangement of hot air flow followed by the removal of residual moisture in a finishing dryer. The processing capacity of the plant is from 3 to 5 tonnes per 3 shifts a day, depending upon the particular vegetable used. Data on the bulk dehydration of various vegetables has been described and discussed. Figures on the labour requirement, electricity, natural gas and water consumption are given. Consideration has also been given to the economics of the process.

Key words: Dehydration; Vegetables; Design.

INTRODUCTION

Pakistan produces a large quantity of seasonal vegetables, of which a substantial portion is lost either due to the lack of facilities for transporting them to the centres of consumption or due to the glutting of markets in periods of peak production. These losses, however, can be minimized by preserving the surplus produce of the glut season into non-perishable products. Dehydration is regarded the most economical and satisfactory method for extending the shelf life of various vegetables [1-5].

This paper deals with the fabrication and operation of a tunnel dehydration plant for processing 3 to 5 tonnes of fresh vegetables per 3 shifts a day. Several designs of the tunnel dehydrators have been described by Kilpatrick *et. al.* [1]. The present design is, in fact, a modified version which suits the local technology and conditions of processing. It may be mentioned that this unit owing to its deversity of application, can be easily adapted/modified to dehydrate fruits, fish, feeds, fodders, cereal products, food foams and concentrates.

MATERIALS AND METHODS

The process. A general sequence of unit operations involved in the process of dehydration is shown in the flow sheet (Fig. 1).

A standard procedure has been adopted for the initial preparation of vegetables [2, 4, 6]. In general, the fresh vegetable is first of all sorted carefully to remove the blemished/damaged pieces. It then passes through a washer into a peeler. The peeled vegetable is trimmed, washed and sliced mechanically. The sliced/cut material, which may be sulphited and blanched, if necessary, is spread on trays and stacked on trolleys. The trolleys are then passed through the twin tunnel dehydrator at regular intervals of time. At the end of the cycle, partially dried material containing 15-20 % residual moisture is taken out of the dehydrator and stacked in a finishing dryer (cabinet type) for lowering the moisture level to about 5%. The final product is packed in polythene bags and stored in hermetically sealed containers.

The twin-tunnel unit. The essential features of the dehydrator are shown in Fig. 2.

The unit consists of two drying tunnels 30 ft. long by 3.5 ft. wide by 5 ft. high (inside diamensions) with a central hot air chamber of equivalent length and height and a width of 9 ft. Ordinary brick structure was used in the construction. A direct fired furnace and a double entry centrifu-

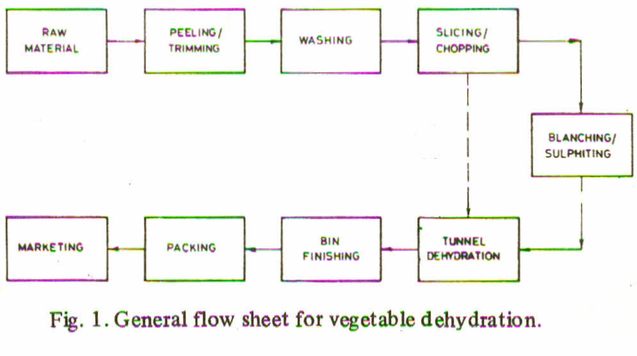

Fig. 1. General flow sheet for vegetable dehydration.

gal blower are located in the central chamber. Air heating is achieved through natural gas burning. The products of combustion are mixed with the outside air and discharged by the blower into the two drying tunnels. Upon leaving the tunnels, a part of the hot air is recycled through the cold end side-ports opening in the central chamber, while the rest is exhausted to the atmosphere via overhead discharge ducts. About 4 ft of space is left empty at the hot end of each tunnel for the air to straighten out before entering the trays after making a smooth turn from the central chamber into the drying tunnels. A set of deflectors and dampers helps in the uniform and even flow of air across the section of both the tunnels. Wooden doors with inside protection by galvanised steel sheets have been used for the tunnel inlets and outlets.

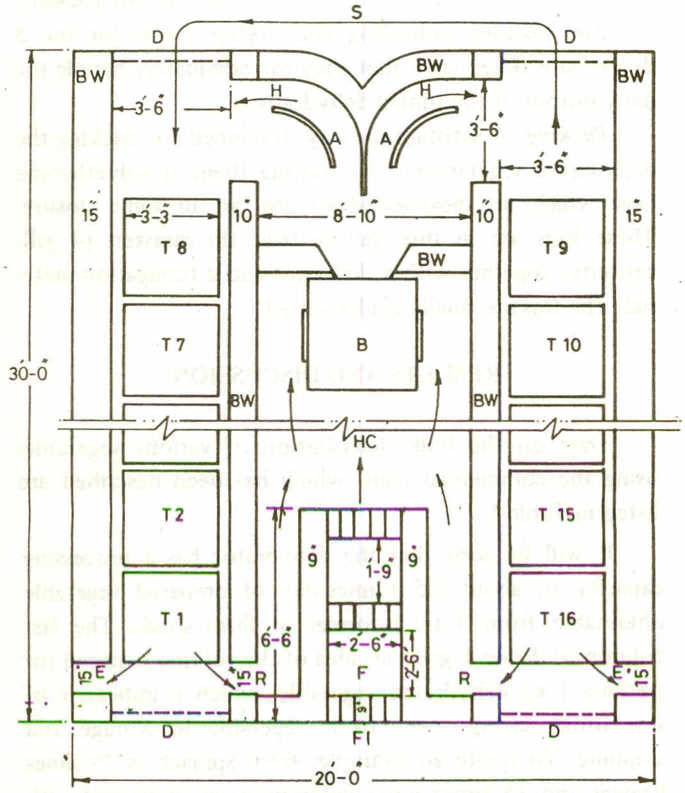

Fig. 2. Twin tunnel dehydrator. A. Air deflector; B. Centrifugal blower; D. Doors; E. Exhaust air; F. Furnace; Fl. Fresh air inlet; R. Return air duct; H. Hot air delivered by blower to tunnels; HC. Hot air chamber; BW. Burnt-brick walls; S. Trolley shifting; T1-16. Drying trolleys.

The unit accommodates in each drying tunnel 8 trolley-loads of trays, so that there is an equivalent of about 800 kg of fresh material at any one time in the tunnels during full load operation.

Trays and trolleys. The drying tray consists of a steel frame of size 3.0 ft by 1.5 ft. and *sarkanda* network firmly held by the sides. A useful surface of the tray is 4 sq. ft. Free space for upward passage of air consists of one-third of the total tray area. The drying material does not stick to the uneven surface and is easily scraped off during detraying operation at the end of a drying cycle. These trays can be easily fabricated and the plant personnel can repair the trays during the off-season. Drying trays, containing the material, are conveyed through the tunnels and to the loading and unloading stations on trolleys.

The trolley consists of a cubical frame made of angle-iron with steel bands fixed to the sides for supporting the trays. 40 trays can be stacked on 20 flights of a trolley, each flight having a pair of trays placed side by side. There are 16 trolleys, 8 for each tunnel, and two additional trolleys are available for loading the wet material.

Air heating system. A standard refrectory brick furnace of the internal size of 2½' x 5' x 2' has been used for achieving direct combustion heating. The furnace has a central chequered work of fire bricks which helps in breaking up the flame and favours complete combustion, serving also to confine the radiant heat to the primary zone. The size of the furnace is large enough to serve as a heat reservoir. This together with a large pilot burner helps to keep the temperature fluctuation to a minimum. The flue gas temperature which is usually above 500° is too high for the food products. The gases are, therefore, diluted with cold fresh air at the furnace together with a part of the spent air from the tunnels.

Hot air blower. A double-entry centrifugal blower with backward inclined wheel blades making them non-overloading, has been used for circulating air in both the tunnels. An axial fan has also been incorporated at the exhaust outlet of each tunnel for increasing the air velocity inside the tunnels. The air velocity in the empty tunnels, measured by means of an anemometer, is around 500 ft/min, the air handling capacity of the blower being 25.000 cu. ft. per min.

Instrumentation and control of variables. It is necessary to have a satisfactory control of temperature, air velocity and relative humidity in a dehydrator. The dry bulb temperature of the air entering the tunnels has been automatically controlled by a simple on-off control system. This consists of a thermostatic switch opening and closing an electric solenoid valve fitted in the gas supply line. Dial thermometers with long leads are fitted at the hot and cold ends of each tunnel to indicate temperatures at these points. By adjusting the deflectors in the central chamber, it is possible to adjust the temperature and the flow rate of hot air to be equal in both the tunnels. An optimum setting for most purposes is around 80° and 500 ft/min for each tunnel. Dial hygrometers are also fitted at each end to indicate the relative humidity of air. A relative humidity of 10% is always maintained at the hot end by recirculating a part of exhaust air, the rate of flow being controlled by dampers fitted in the recirculation ducts.

A variation in air velocities can be achieved by replacing the pulleys for blower and/or electric motor. However, the drive system has been set to give an average velocity of 500 ft/min as mentioned earlier.

Operation of tunnel dehydrator for a typical run. The pilot burner is ignited and the main blower started. The temperature regulator is set at 80° and switched on, so that the main burner is ignited automatically. The dehydrator is allowed to heat up empty of trolleys for about 90 min. When the hot end temperature of both the tunnels approach 80°, the exhaust blowers are started. Trolleys loaded with the prepared vegetable are now passed one after the other, first against the hot air draft in the countercurrent tunnel and then parallel with the air in the concurrent tunnel. During a full load operation, there are 8 trolleys in each tunnel of the dehydrator at any one time.

Under conditions of continuous dehydration, each trolley loaded with the vegetable enters the cold end of the countercurrent tunnel after an interval of 30 min and at the same time partially dried trolley is withdrawn from the hot and of the same tunnel. This is now pushed into the concurrent tunnel at the hot end in a manner that the back of the trolley now faces the hot air draft. Simultaneous with this entry, a dried trolley load of the material is withdrawn from the cold end of the concurrent tunnel. The operation of introducing and withdrawing the trolleys is performed as quickly as possible to minimize heat losses.

If the dehydrator is not to be run continuously for 24 hr then the starting and ending of dehydration cycle requires some careful manipulation with respect to the temperature and movement of trolleys, so that each trolley load receives identical treatment and is dried to the required level of moisture. Normally, the moisture content of vegetables after residence of 8 hr in the dehydrator falls below 20%. The material is taken out and transferred to the finishing dryer.

Finishing dryer. Three cabinet type finishing dryers each with inside dimension of 12 ft. x 3½ ft. x 6½ ft. have been separately built using burnt bricks. Two independent heat exchangers (fin type) are fitted at the right and left sides of each drying chamber. Fin plates are heated by burning natural gas and using products of combustion which pass through the pipe assembly of the heat exchangers. An axial fan fitted above the RHS heat exchanger draws fresh air through the inlet port situated under the LHS heat exchanger. The air receives heat from the heat exchangers and the hot air is circulated over the material in the drying chamber, a part being continuously exhausted to the atmosphere from the rear of the fan via an outlet port in the roof. The temperature of the finishing dryer is automatically controlled by a regulator which is normally set at 60°.

Partially dried material with about 20 % moisture content (obtainable from ½ tonne fresh vegetable) received from the tunnel dehydrator is detrayed and reloaded on two trolleys capable of accommodating 160 drying trays. Both trolleys containing the partially dried material are parked side by side in the finishing dryer and the door is closed. The material is allowed to stay in the dryer for about 8 hr after which period its moisture content lowers to below 6%. The product is then taken out for packing.

The loading, unloading and drying cycles for the 3 dryers are timed such that they can adequately handle the daily output of the tunnel dehydrator.

Packing. A satisfactory way developed for packing the dehydrated vegetables is by putting them in polyethylene bags which are heat-sealed to give an air tight closure. These bags are in turn put in large tin canisters (4 gall. capacity) together with a desiccant and a fumigation material. The tins are finally solder-sealed.

RESULTS AND DISCUSSION

Data on the bulk dehydration of various vegetables using the commercial plant which has been described are listed in Table 1.

It will be seen that the dehydrator has a processing capacity of about 2.5 tonnes/day of prepared vegetable obtainable from 3 to 5 tonnes of farm stock. The last column of Table 1 gives an idea of the volume required for packing 1 kg dehydrated vegetable, which is indicative of severalfold savings over fresh vegetable in storage and shipping. To quote an example, fresh spinach is 25 times heavier and 15 times more voluminous as compared with the dry product. This has an economic significance to the processor and the consumer.

The final moisture content has a strong bearing on the shelf life of dehydrated products, an optimum value being around 5% (Table 2), which is in accordance with the manufacturing practice [2, 3]. It has been observed that prolonged dehydration for further reduction of moisture besides being uneconomical, results in the overheating of the product. Nutrient losses and poor reconstitution characteristics of the heat scorched product render it unsuitable for human consumption. Similarly a product with moisture content higher than 10% would end up in browning and cake formation in a matter of few weeks. Further shelving of this product intensifies the deterioration of quality due to microbial attack.

Dehydration and rehydration capacity. Dehydration and rehydration ratios are important parameters in the determination of the quality of a dehydrated product.

Table 1. Weight and volume reduction of various vegetables by dehydration.

Vegetable	Average moisture content (%)	Wt. of raw material (kg)	Weight of dehydrated material (kg)	Volume occupied by one kg. dehydrated product (cm^3)
Garlic	70	3000	750	1200
Tomato	94	3000	150	1800
Bitter gourd	92	3500	140	6000
Okra	90	3000	250	4500
Onion	88	3000	300	5100
Potato	80	3000	500	3600
Carrot	90	3000	188	3600
Turnip	91	3500	233	4500
Spinach	92	5000	200	6000
Pea	74	5000	556	1400

Using the data from Table 1, dehydration ratio (DR) values have been expressed on the basis of fresh vegetable as obtained from a local market. These values have been listed in Table 2. The left hand side figures under the DR column represent the weight of the raw vegetable which after dehydration would yield 1 kg of finish-dried product. A slight variation in DR values in comparison with those quoted in the literature may be attributed to differences in the seed variety, ecological conditions and stage of harvesting/maturity [2]. The higher ratios for tomatoes, bitter gourd and spinach are due to larger losses in the preparatory operations coupled with a low parcentage of dry matter for these vegetables.

Rehydration ratio (RR) is the index of the reconstitutability of the product; the higher the ratio the better the quality of the product [2, 4, 8]. It will be seen that dehydrated vegetables do not absorb as much water as was removed during dehydration. The increase in weight upon rehydration is only 4-5 times the original product (except for peas) as against an average of tenfold reduction during dehydration. These findings are in accordance with the values quoted in the literature [2, 4, 8, 9]. It can be said that the original weight and volume of fresh vegetable cannot be regained because of physico-chemical changes brought about by the process of dehydration. These changes continue to play their part during subsequent storage as is evident from the tendency of further reduction in RR values, the effect being highest during initial period of 3 months.

Table 2. Dehydration and rehydration ratios for various vegetables.

Vegetable	Dehydration* ratio	Rehydration ratio** after storage for				
		0-time	3-months	6-months	9-months	12-months
Garlic	4:1	–	–	–	–	–
Tomato	20:1	4.0	3.6	3.4	3.2	3.2
Bitter gourd	25:1	5.2	4.0	3.9	3.8	3.8
Okra	12:1	4.2	3.8	3.8	3.6	3.5
Onion	10:1	5.0	4.7	4.5	4.5	4.4
Potato	6:1	4.0	3.5	3.4	3.4	3.3
Carrot	16:1	4.8	4.3	4.1	4.0	3.9
Turnip	15:1	5.0	4.4	4.1	3.8	3.8
Spinach	25:1	4.8	4.7	4.7	4.6	4.6
Pea	9:1	3.1	3.0	2.8	2.8	2.7

*Dehydration ratio (DR) = $\frac{\textit{Wt. of fresh vegetable}}{\textit{Wt. of dehydrated vegetable}}$

**Rehydration ratio determined according to the method of Mohammad, *et. al*, 1973 [7].

Table 3. Summary of investment production cost and profit.

Fixed capital cost = 17,50,000
Working capital = 11,75,000
Total investment = 29,25,000
(Value in Rs.)

Production cost = 45,07,000
Fixed cost = 8,80,000
Variable cost = 36,27,000
Sales = 54,05,000
Contribution = 17,78,000
Break-even (49.5 % to sales/capacity)

Item	Cost per kilogram of dry product (in Rs.)									
	Garlic	Tomato	Bitter gourd	Okra	Onion	Potato	Carrot	Turnip	Spinach	Pea
Raw material and packing	15.76	31.67	41.79	21.12	18.43	10.96	18.67	10.64	29.10	14.50
Direct manufacturing cost	6.10	30.75	33.32	18.63	15.24	9.33	24.88	20.02	22.79	8.40
Indirect manufacturing cost	2.20	11.00	11.79	6.60	5.50	3.30	8.80	7.08	8.25	2.97
Manufacturing cost	24.06	73.42	86.90	46.35	39.17	23.59	52.35	37.74	60.14	25.87
General expenses	4.27	14.63	16.77	9.03	7.62	4.61	10.76	8.01	11.65	4.83
Total production cost (rounded)	28.35	88.10	103.70	55.40	46.80	28.25	63.15	45.80	71.80	30.75
Estimated sale price	34.00	106.00	124.00	66.00	56.00	34.00	76.00	55.00	86.00	37.00
% profit on sales	16.62	16.89	16.37	16.06	16.43	16.91	16.91	16.73	16.51	16.89

Routine quality tests, supported by organoleptic assessment, were regularly carried out soon after dehydration and then on stored samples for a period of one year. It was found that the samples generally ranked very high with respect to quality and acceptability.

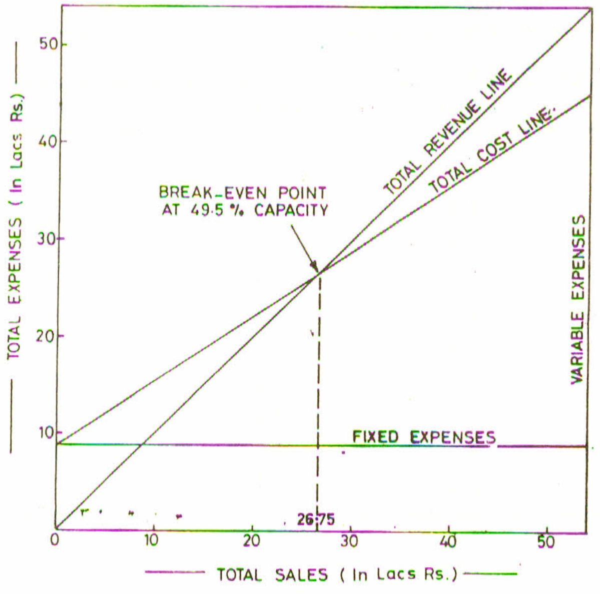

Fig. 3. Break-even chart.

Economics of the process. Total electricity consumption for operating the plant per 3 shifts a day lies within the range of 840 to 960 kW depending upon the particular vegetable being processed. Potable water requirement for the purpose of vegetable washing, equipment cleaning etc. is to the tune of 30,000 to 50,000 gall per day. The average consumption of fuel (natural gas) is around 12,600 cu. ft. which represents 38% energy efficiency on the average for the plant. This figure compares well with those reported in the literature [2]. Total labour requirement for 3 shifts is 54 persons besides the normal supervisory and managerial day staff.

A detailed account of the cost economics of the process has been prepared and published [10], the results having been summarised in Table 3 and break-even chart shown in Fig. 3. It will be seen that a revenue of Rs. 54,05,000 yields a return of 16.6% against the production cost of Rs. 45,07,000 and based on the fixed cost of Rs. 8,80,000 and variable cost of Rs. 36,27,000, a break-even is reached at Rs. 26,75,000 which represents 49.5% to sales.

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