THE DEHYDRATION OF FRUITS AND VEGETABLES
with Special Reference to Hot Air Methods.

Thesis submitted in partial
fulfilment of the requirements
of the Degree of Master of Science.

By

MICHEL CORTAS

American University of Beirut

Beirut, Lebanon. May, 1943.

TABLE OF CONTENTS.

(references are listed within the body of the thesis)

PREFACE

Much can be learned in trying to adopt text-book methods, or methods written up in books and journals, to actual factory practice. The topic of dehydration was chosen for my thesis in order that I might put all my effort into the construction of a suitable dehydrator to serve civilian and army needs during war-time, after two such had burned to the ground within a period of six-weeks. The third plant was completed in January 1943. Trials have shown it to be technically sound although it will not have been subjected to actual production until the summer months of this year.

Thanks are due Prof. R. J. Pauly for the critical reading and correction of this thesis.

M. Cortas

I. INTRODUCTION

A. PRESERVATION OF FOODSTUFFS IN GENERAL

The preservation of foodstuffs for out of season consumption is a very ancient practice and one may with confidence say that it grew up with primitive man and dates to time immemorial. Collecting dried cereals, the drying of fruits and vegetables, the salt-curing of fish and meats, the smoking of meats and alcoholic or acetic fermentation processes are no innovations of modern times. The problem of controlling foods from the time they are picked, prepared or first handled until they are consumed, has accompanied the advance of science. Since microbiological factors and chemical activity are at the basis of every case of food spoilage (except for accidental spoilage issuing from fires, floods or the acts of God) Pasteur and Appert may be thought of as laying the foundations for the scientific control of food preservation.

Preservation is concerned with the elimination of the causes of spoilage and may be divided into two parts, namely:-

1. Temporary Preservation.

In such preservation the nature of the product determines in many cases the kind of treatment it may receive. There are numerous ways in which temporary preservation may be attained, e. g.:

a. By asepsis, or the avoiding of the contamination of the food product with the organisms that cause spoilage by the use of a definite techique for it is well known that the greater the microbe count the faster will be the spoilage. In attaining asepsis, for example, fruits must be carefully handled, kept clean and placed in clean recepticles to keep them from spoilage. Washing fruits and vegetables before they are used in manufacture, removes a great part of the dirt and organisms that may cause trouble later on. With milk the shed where the cows are housed must be kept spotless. If the milker washes his hands, and if the udder of the cow is cleaned before milking a better keeping milk free from odours is obtained and the sources of contamination are greatly reduced.

b. By low temperatures. Low temperature does not kill organisms but reduces their activity. It also affects chemical changes and enzyme activity in like manner. Within the last decade a whole new industry has been built around the "Quick-freezing" of foods and their distribution in frozen form direct to the consumer.

c. By the use of mild antiseptics to hold raw materials until the manufacturing process is complete. Mould growth is not completely prevented without antiseptics if the soluble solids are below 65 per cent. In dried products or sugar solutions, if moisture is allowed to reduce this figure the product is liable to mould growth unless antiseptics are present. Many chemical changes are also favored by moist atmosphere. Therefore the control of humidity is an important factor in the preservation of dried products such as cereals, flour, dehydrated foods and the like.

d. By pasteurization, or the killing of the greater part, but not all, of the organisms which delays the activity of the organisms not killed.

2. Permanent Preservation

To carry food products over longer periods of time than that made possible by the methods mentioned above, techniques must be used which result in a more permanently preserved product. Among such may be briefly mentioned:

a. Sterilization by Heat:

(1) At temperatures below 100°C. (For acid products where the acidity helps to kill the organisms, i.e. "pH effect".)

(2) At 100°C. (Besides being sterilized, the product is cooked and made ready for use. Such treatment does not kill spores.)

(3) Fractional or Intermittant Sterilization at 100°C. (Here, any spores are given the chance to change to the vegetative form in which state they are killed immediately.)

(4) Pressure Sterilization. (Use is made of an autoclave with temperatures up to 126°C. Heat resistant bacteria (spores) are easily killed, if given ample time, without spoiling the product.

b. Use of Preservatives:

For this, preservatives are added in such quantities to prevent the growth of organisms. The substances that are usually used in the preservation of foods are:

(1) Sugar. The action of sugar is mainly due to the osmotic effect of highly concentrated solutions rather than to toxic effects of the sugar on the organism.

(2) Salt. Salt has two effects:- It acts as a poison and is also used for its osmotic effect. A concentration of 15% is required whereas 70% sugar would be necessary to obtain the same results.

(3) Chemical preservatives. The most commonly used are:

(a) Benzoates and Salicylates.

(b) Sulfur Dioxide.

(c) Acetic Acid.

The use of such substances falls under strict government regulation.

c. Drying: Preservation by drying depends on reducing the moisture content to a degree which will prevent the growth of microorganisms. Since the total dissolved solids necessary for preservation must be at least 65%, the amount of drying will depend on the nature of the product.

The general methods of drying are two:

(1) Sun Drying, and

(2) Dehydration - which may be accomplished by means of a stream of hot air, steam, inert gases, or by drying in vacuo.

d. Preservation by Fermentation: Certain constituents of food materials, especially the carbohydrates, are subjected to controlled fermentation where either alcohol or lactic acid is produced as the preservative agent. The carbohydrates, which are a necessary medium for the growth of putrefactive organisms, are thus eliminated at the same time.

e. Exclusion of Air: The elimination of air or oxygen has two main effects: the prevention of the growth of aerobic organisms and the preclusion of oxidation reactions. This may be accomplished by "vacuum packaging" or by the replacement of air by inert gases such as nitrogen or carbon dioxide.

3. Discussion.

Of the five main methods for preserving food products sterilization by heat, such as is practised in canning and bottling, and drying or dehydration stand out as the most important from a commercial point of view.

In spite of the fact that refrigeration has developed greatly in recent years as a means of preserving the natural flavor and appearance (form and color) of fruits and vegetables, the initial cost of outlay, the running expenses and the necessity of having a refrigeration plant at every stage of the handling of the product augments the price to a point which off-sets the advantage of superior quality.

Canning may at all times compete with other methods of preservation when the containers and the machinery for canning are available. It offers the most convenience to the consumer in furnishing ready-to-serve products, whereas dried foods have to be soaked for some time before they can be cooked and rendered palatable and even then the finished product is never as appetizing as food prepared by the other methods. Drying methods have their place in the economics of food handling, however, and sometimes become the method of choice due to the inherent advantages of cheapness, low bulk and light weight of the product.

Since it is the purpose of this paper to present the theories and practice of dehydration by hot air, a comparison of the general drying methods is in order.

B. HOT AIR DEHYDRATION VERSUS SUN-DRYING.

Of the two methods for drying fruits and vegetables - hot air dehydration and sun-drying - control is obtained in the former by the use of artificial heat having the proper humidity and air flow, whereas control in the latter is left to the vagaries of climatic conditions.

Hot air dehydration has the following advantages over sun-drying:-

a. The quality of the product is nearer to that of the original.

b. There is less contamination with external factors that may cause spoilage (flies, dirt, etc.)

c. The space required and the number of trays to be handled is much less.

d. Dehydration can also be carried on the year round whereas sun-drying is limited to the dry season.

Although sun-drying in general may be less expensive than dehydration, the superior cooking qualities of the product obtained by the latter method outweighs the extra expense.

In sun-drying there is always fear of fermentation in spite of the fact that the fruit or vegetable may have been treated to prevent it. Fermentation spoils the quality and may be a cause of 100 per cent loss of the product.

One advantage of sun-drying is the fact that in case fruits or vegetables are picked that have not developed their natural colors the drying process continues the synthesis of pigment, whereas in dehydration only mature fruits and vegetables may be used.

Of the various methods of dehydration, i.e. by hot air, steam, inert gases, or in vacuo; drying by air is the cheapest and easiest, requires less complicated apparatus and the factors of overheating may be controlled. The latter is an important point to keep in mind, especially with delicate articles such as fruits and vegetables.

II. THEORY CONNECTED WITH THE PROCESS OF DRYING BY HOT AIR.

A. GENERAL

Dehydration, or drying, is essentially an evaporation process. For its proper accomplishment the following facts must be known:

1. The capacity of the plant or installation. (The quantity of material that can be dried within a certain time.)
2. The weight of the water to be evaporated, (or the smallest quantity of water that need be evaporated to give the proper amount of solids necessary to preserve the product.)
3. The highest temperature that the product will withstand. (Such limitation is dependent on the nature of the product.)

Factors that need determination and which are dependent on the nature of the product are:

1. The quantity of heat, or fuel, required.
2. The exposed surface.
3. The volume of air needed to vaporize and to carry away the moisture.

Since considerations are for atmospheric pressure, the factor that changes is temperature. A change of temperature involves a change in volume, especially as the fruit or vegetable to be dried enters at the cold end of a dehydrator and is removed at the hot end.

With a change in temperature the amount of water vapor carried by a cubic meter of air[1] varies thus:

1 cu. M. water vapor at	0°C.	weighs	0.00504 Kgs.
1 " " " " "	5°C.	"	0.00696 "
1 " " " " "	10°C.	"	0.00951 "
1 " " " " "	15°C.	"	0.01319 "
1 " " " " "	20°C.	"	0.01753 "

The same quantity of water is held in a cubic meter whether moisture saturated air or water vapor alone fills the space.

If the air is completely saturated the relative humidity is said to be 100%. If it contains $\frac{3}{4}$, $\frac{1}{2}$ or $\frac{1}{4}$ the amount that it could contain, then the relative humidity is 75%, 50%, or 25% respectively.

1 Kgm. of water when changed to vapour has a volume of:-

$$V \text{ (Litres)} = 22.4 \times \frac{1000}{18} \times \frac{T(^\circ abs.)}{273} \times \frac{(P_2)}{(P_1)}$$

The pressure factor need not be considered as it is taken as constant or equal to 1.

By simplifying:

$V = 4.543 \times T$ or, $V = 4.543 \times (273 + t)$ where t is degrees centigrade.

The weight of water in 1 cu. M. of saturated water vapour (Kd) may be expressed:

$$Kd = \frac{1}{V} = \frac{1}{4.543} \times \frac{1}{(273 + t)}$$

Almost the same result is obtained from density measurements. If dry air is taken as 1 the relative wt. of 1 cu. M. of water vapour is 0.623.

(1) Hansbrand, E.,- Drying by means of Air and Steam. London, 1924. Page 7.

In practice the weight of 1 cu. M. of air at different degrees of saturation is given in tables.

B. SPECIAL

1. Air Flow.

Now, although the humidity in the air may vary between 10-100%, in working out the quantity of air necessary to carry away a definite weight of water a high relative humidity is assumed. At the exit of the drier the most economical results are attained if the air is saturated with water vapour. This is seldom the case, greater volumes of air are used to make up for the unsaturation. A loss in heat is thus encountered. Combining the two, i.e. the assumption of high humidity of the incoming air and unsaturation at its exit a thermal efficiency of 45-50% is thought to be a good figure for many driers. This, of course, assumes that heat losses are also incurred due to bad insulation.

If the external air (L Kgms.) containing Ld_a Kgms. of moisture (d_a being the quantity of moisture in 1 Kgm. of air) enters the heating chamber at temperature t_a, and leaves at a temperature t_h. In the drier it picks up w Kgms. of water and is cooled to t_n. A fan drives the warm air through, the air being now loaded with Ld_n Kgms. of water vapour

$$Ld_n = w + Ld_a$$

(1) The quantity of heat carried by L Kgms. of air must at least be enough to raise the temp. of the material in the drier from its initial temp. t_n to its final temp. t_z and evaporate w kgms. of water.

(2) The temp. of the air at its exit t_n must be high enough to carry $Ld_a + w$ kgms. of moisture.

Thus if r (the specific heat of air) = 0.2375 Cal.

and S (" " " H_2O vap) = 0.475 Cal.

and C_n is the amount of kilo-calories used in the drier.

Then, in the drying room

$$(Lr + Ld_aS)(t_h - t_n) = C_n \qquad (1)$$

$$L(d_n - d_a) = w \qquad (2)$$

or L (Kgms. of air that enter drier) $= \dfrac{w}{d_n - d_a}$ (3)

or Quantity of air in Kgms. that enters drier = $\dfrac{\text{Quantity of water necessary to be evaporated in drier}}{\text{Quantity of water vapour in 1 Kgm. of air at } t_n \; - \; \text{Quantity of water vapour in 1 Kgm. of air at } t_a}$

Inserting (3) in (1)

$$\frac{w}{d_n - d_a}(r + d_aS)(t_h - t_n) = C_n.$$

w may be taken as the weight of water to be evaporated in a unit of time.

To evaporate 1 Kgm. of water at t_u, $640 - t_u$ Calories are needed, or

$C_n = w(640 - t_u)$
t_u = Initial temp. of material

In the above formula it is assumed that only the water of the material to be dried is being heated.

t_u and d_n are the quantities to be determined by experiment.

C_g is the actual heat absorbed into a drier.

$C_g = L(0.2375 + d_a \times 0.475)(t_h - t_a)$

The larger C_g is in proportion to C_n the less economical is the work of the drier.

Fuel actually used $> C_g > C_n$

2. <u>Size of Drier and Heating Surface.</u>

There are three limiting factors in estimating the size of a drier, namely:-

a. The temperature of the air and its humidity which depends on the season and location.

On a cold day more heat is required to raise the temp. of the air and of the material to be dried.

On a cold day the volume of a certain weight of air is less than the volume of the same weight on a hot day; therefore, a smaller volume of air is required for drying on a cold day.

In a dry district, where the relative humidity is low, a smaller quantity of air passes through the drier.

b. The highest temperature to which the material can be raised.

The higher the temperature the more is the capacity of a certain amount of air to carry moisture; therefore, the drying is very much faster. But if the drying is too quick the surface of the product may dry up while the interior remains wet - this condition is called "case hardening" and must be avoided. The best humidity for drying purposes is between 20-30%.

c. The rate of flow of air through the drier.

The time given for the air to flow over the material and pick up moisture is a primary consideration; if too slow, the drying time is slow; if too fast, it is not economical from the fuel point of view. A velocity between 2-5 meters per second is the accepted range. A greater velocity than 5 m. per sec. does not give the moisture enough time to diffuse into the air, thus the air does not become saturated or nearly so in its passage.

At this stage it is best to mention that the heating surface must be large enough to warm up the air on the coldest days when a certain weight of air has its smallest volume.

The air circulating apparatus must be of sufficient size to handle greater volumes on hot days.

"The area of the heating surface in square meters is determined by the mean difference in temp. (t_m) between the air and the hot surface, and the coefficient of transmission (K)."[2] The coef. of tramsmission K is given by the expression:

$$K = 2 + 10\sqrt{C}$$ where C is the velocity of the air in meters per second.

The area of the heating surface in square meters is given by the expression:

$$H = \frac{C_g}{t_m\,(2 + 10\sqrt{C})}$$ where C_g is the number of Calories transferred per hour, t_m is the mean temperature.

(2) Ibid., page 62.

The greater the velocity the more heat is taken up, and the smaller is the value of H, but too high a velocity is not economical as was mentioned previously.

On cold days, all factors remaining the same, the efficiency of the heating surface is greater than on hot days - t_m being greater.

$$t_m = \frac{t \text{ heating surface} - t \text{ outside air}}{2}$$

Since the quantity of heat to be transferred in 1 hour to the drying material is:

$$C_n = O \times t_m \times K = O \times t_m (2 + 10\sqrt{C})$$

the surface of drying in square meters (O) is:

$$O = \frac{C_n}{t_m (2 + 10\sqrt{C})}$$

and t_m is given by the equation:

$$t_m = \frac{(t_h - t_z) + (t_n - t_u)}{2}$$

where, as before,

t_h = Temp. of air at entry into drier,

t_z = Temp. of material at its exit,

t_n = Temp. of air at exit of drier,

t_u = Temp. of material at entry into drier,

and C = Velocity of air in drier.

3. Summary

A summary of the facts may be of help.

(a) From the drying ratio of the material (the quantity of water to be evaporated per unit time) and the max. temp. that the material withstands, C_n can be calculated.

(b) C (the velocity of the air) is more or less fixed.

(c) The quantity of air to pass through the drier depends on the initial relative humidity and therefore varies at all times.

(d) C_g is greater than C_n but smaller than the actual heat produced in the furnace.

C_n is the theoretical minimum heat required.

C_g accounts for the extra heat necessary to keep the drier on the + side of C_n and changes with the velocity of the air.

The total heat used accounts for C_g plus losses due to improper insulation, loss of heat in the flues and loss due to improper burning of the fuel.

III. TYPES OF DRIERS

There are two classes of driers:- Natural draught driers and forced draught driers.

A. NATURAL DRAUGHT DRIERS.

These are simple in structure, the drier being generally of two stories. In the lower story the air comes in contact with a radiating surface, the hot air then passes to the upper story where the material to be dried is spread on trays. A draught is developed by placing a chimney stack at the end of the drier.

The natural draught drier is easy to construct, but its efficiency is low as the quantity of fuel consumed is high. The more economical types, both in fuel consumption and the time required for drying, are the forced draught driers.

B. FORCED DRAUGHT DRIERS.

Of these there are two types, the ordinary air drier and the recirculating air drier.

In structure both types are not very different from the natural draught drier - the difference is in the circulation of the air. As mentioned previously in the theoretical considerations, calculation is made for the size of the drier, the velocity of the air and other details. A fan with a changeable speed device is placed either before the heating chamber, if of the blower type, or at the head of the stack at the end of the drier, if of the aspirator type.

1. In the ordinary forced-air drier the drying compartment is generally built in the form of tunnels, the fruit or vegetable passing in counter current to the air where the fresh raw material enters at the cold end, gradually heats up and leaves at the hot end of the tunnel.

The material to be dried is put on trays the bottom of which is made of metal gauze. The trays are either pushed along shelves or a trolley loaded with trays may be pushed from one zone to the other until the final stage of drying is reached.

2. In the recirculating forced-air driers the hot air is moving at a certain speed in the tunnels where in its passage it picks up moisture and is gradually cooled. In general as it reaches the end of the tunnel it is still hotter than the air outside and has a relative humidity below saturation. If this air before leaving the tunnel is allowed to go back to the heating chamber, great economy in fuel is obtained. After some time this air becomes more and more saturated and part of it has to be let out and fresh air with a lower humidity introduced. The forced draught drier with air recirculation works on this principle.

IV. EXPERIMENTAL

A. CONSTRUCTION OF A DRIER.

In the previous sections no mention is made of the materials used for the construction of a dehydrator or drier.

Because of conditions imposed by the war the policy of using local materials as much as possible had to be adopted for the construction of a drier suitable to our purposes. Thus, wherever wood could be used instead of iron, no iron was included. As the United States Department of Agriculture (3) gives plans for the construction of a dehydrator using only wood such construction was tried.

Their plan was followed to the letter, putting up a plant of 3 tunnels to handle 10 tons of fresh material with a drying area of 250 sq. meters and with a fan included to create a forced draught. As a precautionary measure we thought of impregnating the wood with materials that would render it non-inflammable. Unfortunately no such material could be found on the market. An ordinary resinous wood (قطراني) was used. This dehydrator proved to be a complete failure for, after working the plant for 2 weeks, fire broke out and the whole construction was burnt to the ground. The cause of the fire was attributed to some leakage in the radiating surface of the fire tunnel leading to the chimney. A second plant was built with wood, as our demand for iron was refused by the authorities. More precautions were taken

(3) Caldwell, J.S., - U.S. Dept. Agr., Farmer's Bulletin, No.984, 1933.

in having a tight chimney. However, at the end of 17 days fire again broke out. The cause this time, as given by the insurance expert, was due to the kind of wood used in the construction and the recommendation was made that should a third experiment be tried only iron or some other non-inflammable material should be used. Acting upon this advice we searched for angle iron on the black market. Some was found at exorbitant prices and we constructed a plant of 4 tunnels having a drying surface of approximately 400 sq. meters or a capacity of from 10 to 15 tons of green material every 24 hours. By the time the tunnels were finished, the fruit and vegetable seasons were over so the finished plant has not yet seen service.

B. HEAT

1. Kind:-

Both wood and solar oil were tried out, the latter proved much more satisfactory because of the regularity of the flame and easy control. With wood it is difficult to make a correct estimate of the cost, unless the wood is perfectly dry when bought.

2. Quantity:-

Considering the capacity of the third drier as 15 tons of green material with a drying ratio of 7:1 the quantity of water to be evaporated per 24 hours is around 13 tons or a little over ½ ton per hour.

Initial atm. temp. = 20° C.

Final temp. of drying = 70° C.

Thus ½ ton of water has to be heated through 50°

and evaporated at a temp. of 70° C.

The number of Kilo-Calories required =

500 x 50 + 500 x Sp. H. of Evap. at 70°C.

= 25,000 + 500 x 540 (considering 540 as S. H. of evaporation)

= 295,000 Kilo-Calories.

1 Kgm. of solar oil is normally said to yield the equivalent of 10,500 Kilo-Calories, or

$\frac{295,000}{10,500}$ = 28.0 Kgm. solar oil required to evaporate 500 of water every hour.

If the thermal efficiency of the dehydrator is 50%, approximately 60 Kgms. of solar oil must be used every hour, provided the volume of air that passes through the dehydrator is enough to carry away the heat generated and the radiating surface large enough to transmit the heat furnished. The economic limit of air flow is 250 - 300 meters per minute. Should this not be attained the velocity of the air must be increased to get the maximum output of the dehydrator. In the case of forced recirculation the quantity of fuel may be decreased and the fuel efficiency increased.

In brief, the quantity of fuel consumed is a good indicator for the efficiency of a dehydrator, provided the velocity of the air and its volume are correct. The volume of air that should be used depends on the temperature of drying and on the relative humidity. Every factor counts in the efficiency of drying and is a quantitative indicator and check on the other factors. Yet the time required for drying a particular product cannot be estimated beforehand since this depends, to a considerable extent, on the nature of the material, the size, shape and thickness of the slices and the degree to which they must be dried. For one type of product a fair average could be drawn only after running a few experiments.

3. Results.

In actual experiments run on the first drier the following figures were obtained:

Drying Ratio on Bekaa September potatoes	5:1
Water required to be evaporated per hour	333 Kgs.
Calculated amount of wood required for above	2400-2900 Kgs.
Actual amount of wood used in trials	700-900 Kgs.
Calculated amount of solar oil required for above	800-950 Kgs.
Actual amount of solar oil used in trials	250-300 Kgs.

The observations made showed:

a. Low quantity of fuel used in comparison to calculations.

b. Superheating of heating surface, indicated by reddening of tubes.

c. Drying time was longer than that recommended.

d. Night output was greater than the day output.

e. Output in general was less than the calculated figure.

The quantity of air entering the heating chamber was recognized as being too small, but by the time a larger ventilator fan was installed the first fire occurred.

With a larger ventilator the second drier (which was the same size and capacity as the first) showed better results almost immediately. Even though the consumption of fuel was greater than before yet the time of drying was still longer than that recommended. With the ventilator turning at the rate of 400 r.p.m. 450-500 Kgs. solar oil were used per hour and the output reached almost 1 ton per day. Superheating was still noticeable to a small extent, however, showing that the fan was still not giving enough air volume.

C. OPERATION

The experiments tried out in drying foodstuffs in our plant were restricted to potatoes - with a few experiments on onions.

1. <u>Treatment of product to be dried</u>.

   a. <u>Potatoes</u>: The potatoes are washed to remove sand, rotten parts are removed, then they are peeled by mechanical peelers. After peeling they are again sorted and passed through mechanical cutters or slicers. The thickness of the slices is adjusted to 0.4-05 cms. The slices are given a dip in hot water in order to "blanch" them, the purpose of which is to help break the cellular structure at the surface. Thorough rinsing in cold water is now necessary to remove any soluble starch from the surface of the slices, otherwise proper drying later is delayed. The slices are now spread on trays and are either subjected to an atmosphere of sulfur dioxide for an hour or put straight into the dehydrator. The sulfur dioxide acts as a preservative while, at the same time, it prevents darkening on standing, as well as afterwards in storage, as the chips retain part of the sulfur dioxide.

b. Onions: The drying of onions is very similar to that of potatoes except that the maximum temperature for drying is 60° C. (140° F.) whereas with potatoes 76° C. (170° F.) does not adversely affect the product. Onions do not need blanching. A dip in cold 5% salt solution for 3-5 minutes helps to reduce the tendency to darken on storage.

c. Carrots: Carrots and other root vegetables are dried between 74-76° C. (165-170° F.). They are blanched before drying.

d. Cabbages: The cabbage heads are cored and the outer leaves removed and the head sliced as for the manufacture of sauerkraut - the cut cabbage is blanched for 1 min. in 1% $NaHCO_3$ which intensifies and sets the color. A temp. of 62.5° C. (145° F.) should not be exceeded in drying, otherwise the color changes. Exposure to air tends to darken the cabbage. A vacuum seal helps in the keeping qualities of dried cabbages.

2. Measuring the relative humidity.

This is best done by the use of the wet and dry bulb thermometric method.

3. Flow of Air.

No measurements for the speed of flow of air were made. However, in the coming season, as I have no instrument to measure the velocity of air, I propose to use the following device:

A thin piece of metal, say 5 x 5 cms., very light in weight, is fitted with two rings along one edge. The metal piece is then suspended, by means of these rings, on a smooth horizontal rod fixed to a portable framework which should be marked off with a scale graduated in angular degrees. With 0^o as the natural position that the metal piece takes, the deviations are marked by supporting the framework on a car moving at known speeds on a very calm day and marking the position that the metal piece takes at various speeds. This will give us a very good way of measuring the velocity of the air in the dehydrator.

4. Volume of Air.

From the velocity of the air flow and the size of the openings the volume of air that passes in the dehydrator can be ascertained. Also from factory specifications for the output of standard fans the volume given under a certain static pressure could be found.

D. RESULTS WITH POTATOES.

The following results were obtained before the second dehydrator plant burned using potato slices 4-5 mm. thick for which a drying time of 5 to 6 hours at a temperature of 65 - 68^o C. (150 - 155^o F.) is recommended. The relative humidity ran between 60 - 80% during the period of the experiment.

The figures given are based on 100 Kgs.of fresh product.

Experiment No. Max. Temp. °F.	(1) 150/155°F.	(2) 150/155°F.	(3) 150/155°F.
1. Weighing	100 Kgms.	100 Kgms.	100 Kgms.
2. Cleaning	✓	✓	✓
3, Weighing	97	97	97
4. Peeling	✓	✓	✓
5. Weighing	92	92	92
6. Sorting	87/89	87/89	87/89
7. Slicing	86	86	86
8. Blanching	--	2 min.	2 min.
9. Washing	--	--	3 min.
10. Weighing	--	84	80 ±
11. Spreading on trays	✓	✓	✓
12. Sulfuring	--	--	--
13. Allow to stand in sun.	--	--	--
14. In drier	9-10 hrs.	9-10 hrs	8-9 hrs.
15. Weighing	20 Kgms.	19 ±	18 ±
16. Recirculation of chimney flue air	--	--	--
17. Colour	Slightly dark	Slightly lighter than (1)	Even colour Translucent
18. Degree of moisture	10/12%	9/10%	9%
19. Soaking	Satisfactory	Satisfactory	Satisfactory
20. Flavour	Good	Good	Good
21. Shelf life	Risky	Risky	--
22. Drying ratio	5/1	5.6/1	5.6/1
23. Remarks	Inside not as dry as outside.	Uneven drying, white spots - starch granules.	Even drying no white spots.

	(4) 160°F.	(5) 160°F.	(6) 170°F.	(7) 175°F.	(8) 170°F.
1.	100 Kgms.	100 Kgms.	100 Kgms.	100 Kgms.	100 Kgms.
2.	✓	✓	✓	✓	✓
3.	97	97	97	97	97
4.	✓	✓	✓	✓	✓
5.	92	92	92	92	92
6.	87/89	87/89	87/89	87/89	87/89
7.	86	86	86	86	86
8.	2 min.	4 min.	4 min.	4 min.	4 min.
9	3 min.	3 min.	3 min.	3 min.	3 min.
10	80 ±	75 ±	75 ±	75 ±	75 ±
11	✓ --	✓	✓	✓	✓
12	~~✓~~ --	--	--	--	✓(*)
13.	1-2 hrs.	1-2 hrs.	1-2 hrs.	1-2 hrs.	1-2 hrs.
14.	7-8 hrs.	6-7 hrs.	5.5-6 hrs.	5-5.5 hrs.	5-5.5 hrs.
15.	18 ±	16 ±	16 ±	16 ±	16 ±
16.	--	--	--	--	✓
17.	Slightly darker than (3) Translucent	Same as (4) more translucent	Same as (4)	Same as (4)	Product lost in fire.
18.	9%	8%			
19.	Satisfactory	Satisfactory			
20.	Good	Good			
21.	--	Good after 9 months in open container			
22.	5.6/1	6/1			
23.	Above 2 hrs. in sum the potatoes change color turning into dirty black accompanied w. fermentation.	Drying more even than in 2, 3 or 4.			

(*) Sulfuring for 1 hr. or recirculation of fuel oil fumes from furnace gave a very white product as good as when freshly cut. In case of chimney fumes there is danger of catching petrol flavour.

V. KEEPING QUALITIES AND THE PROSPECTS OF DEHYDRATED PRODUCTS AS AN INDUSTRIAL VENTURE.

A. KEEPING QUALITIES

There are four points to consider under this topic:

1. <u>The relation of the moisture content to the deterioration of raw dried vegetables upon common storage.</u>

By "common storage" is meant the packing of the dried product in air tight containers. From the work of Mangels and Gore(4) published in 1921, and tabulated in the Appendix I of this thesis, we find that the approximate maximum moisture content permissible for seal-packed products which are to be kept longer than 6 months runs as follows:

Cabbage -	3.5%
Carrots -	6.0%
Onions -	5.5%
Spinach -	4.0%
Turnips -	5.0%

2. <u>Heat as an insecticide</u>.

According to Cruess(5), heating for from three to four hours at a temperature range of 62.5 -76°C. (145-170°F.) is enough to kill insect eggs. Reinfestation is possible only if the product is not packed immediately in air-tight containers. The container ordinarily referred to is the sealed four-gallon petrol tin, which will hold 9 lbs. of Potatoes or 4 lbs. Cabbage(6). Paraffined paper bags are not recommended as they are not 100% moisture proof. Dried products quickly absorb moisture if permitted to do so. A tabulation of products injured by heat is found in Appendix II.

(4) Mangels, C.E. and H.C. Gore, - Ind. Eng. Chem. Vol. 13, Pg. 523, June 1921.
(5) Cruess, W.V., - Commercial Fruit and Vegetable Products, New York, 1924.
(6) Crosbie-Walsh, T., - Food Manufacture, Vol.17, p.217, Aug.1942

3. Preservation in an inert gas atmosphere.

Such has been recommended(6) as a means of enhancing the keeping qualities of dehydrated products. The air is expelled from the container which is then immediately sealed. This is done by pumping in an inert gas, such as nitrogen or carbon dioxide, which drives out the oxygen.

4. Fumigation.

The following are recommended(5): (a) CS_2 (b) HCN (c) SO_2.

(a) Carbon Disulfide is the most extensively used but its vapors are explosive and great care must be taken in handling it.

(b) Hydrocyanic acid is very poisonous and only experienced and dependable persons should use it.

The above two chemicals are applied to the dried products.

(c) Sulfur Dioxide is extensively used but since it is absorbed by the vegetable tissues it is restricted to those products that could be sold in the sulfured state. The SO_2 is applied to the fresh fruit or vegetable before drying, generally after the blanching stage. SO_2 also acts as a bleaching agent and helps to keep the product from darkening on storage.

B. PROSPECTS OF THE INDUSTRY.

As stated by Crosbie-Walsh(6), "the requisites for dried vegetables are as follows:-

1. The finished product should be palatable.
2. Its nutritive properties with reference to the

original product should be unimpaired, especially with regard to its vitamin content.

3. Its storage life must be reasonably long.

4. The cost of production must not be too high."

A few of the advantages and disadvantages of the use of dried products have been mentioned in the introduction. The most important fact to keep in mind is that the dried products should cook properly, otherwise the product loses its value. Overdrying is not good while scorching changes the flavor.

From a nutritive point of view, dried vegetable products may be used as a substitute for fresh meat. The following is a table giving the comparison:

	Dried Vegetables[7] %	Lean meat[8] %
Water	10.30	76.71
Protein	18.20	20.78
Carbohydrate and fiber	61.84	---
Fat	1.49	1.50
Ash	8.44	1.07

Again if the drying is carried out between 36-42°C. under vacuum little destruction of the vitamin content occurs. Experiments carried on in Italian laboratories[7] show that vitamins B and C are retained in dried vegetables after storage from 6-8 months and the physiological effects are the same as fresh vegetables. There are many recommendations for powdered soup preparations.

Regarding storage life this has already been dealt with

(7) L'Industrie Italiana della Conserva Alimentari through Food Manufacture. Vol. 7, p. 346, Nov. 1932.

(8) Tibbles,- Book on "Foods". Same as ref. No. 7.

to show that dehydrated products can be made to keep well over long periods. (Edible wheat has even been taken from the Tomb of Tut-Ankh-Hamoun after at least 2500 years of storage.)

As a war time policy it seems obvious that dehydration of fruits and vegetables should be given preference over canning as transport and economy in raw materials are basic factors to be considered. In peace time dried fruits are still in demand in certain sections of the world, but I cannot visualize it as a profitable industry for this country where fresh fruits and vegetables of some kind may be found on the market at all seasons of the year and where the individual family needs for off-season fruits and vegetables are often furnished by using a home-dried product, unless, of course, the industry were undertaken to supply the export trade. Cereals are always on the market. The practice of sun-drying carrots, cabbage, onions, spinach, tomatoes, in the home has not taken a strong foothold. How much scientific recommendation can influence the whims of the consumer is something for the future to tell. The demands of the consumer will ultimately influence production.

APPENDIX I.

Relation of moisture content to the deterioration of raw dried vegetables upon common storage (cf. ref. 4 on page 27).

<u>Cabbage</u> (Dried Jan.2, 1918).

A. Dried 6 hrs. at 122° F.
B. " 10 " " 122° F.
C. " 10 " " 122° F. + 1 hr. at 140° F.
D. " 10 " " 122° F. + 1 hr. at 140° F. + 1 hr. at 150°/160° F.

Days of Storage	A 11.15% H_2O	B 5.49% H_2O	C 3.54% H_2O	D 3.00% H_2O
33	Slightly browned	...	...	...
80	Browned. Peculiar taste and odor.	No change	No change	No change
232	Quite dark unpleasant aroma.	Slightly darkened flavor good	Slightly darkened, flavor good	Same as C
588	Same as previous examination.	Distinctly browned	Slightly darkened, flavor good	Same as C
940	Same as previous examination	Distinctly browned, unpleasant aroma.	Same as previous examination	Same as C

<u>Carrots</u> (Dried Dec. 31, 1917)

A. Dried 6 hrs. at 122° F.
B. " 6 " " 122° F. + 2 hrs. 140° F.
C. " 6 " " 122° F. + 3 " 140° F.
D. " 6 " " 122° F. + 3 " 140° F. + 1 hr. at 150° F.

Days of Storage	A 11.11% H_2O	B 7.39% H_2O	C 4.99% H_2O	D 5.54% H_2O
40	No color change Strong carrot odor.	No change	No change	No change
68	Distinct fading of color noticeable.	No change	No change	No change

APPENDIX I.

Relation of moisture content to the deterioration of raw dried vegetables upon common storage (cf. ref. 4 on page 27).

Cabbage (Dried Jan.2, 1918).

A. Dried 6 hrs. at 122° F.
B. " 10 " " 122° F.
C. " 10 " " 122° F. + 1 hr. at 140° F.
D. " 10 " " 122° F. + 1 hr. at 140° F. + 1 hr. at 150°/160° F.

Days of Storage	A 11.15% H_2O	B 5.49% H_2O	C 3.54% H_2O	D 3.00% H_2O
33	Slightly browned	...	...	...
80	Browned. Peculiar taste and odor.	No change	No change	No change
232	Quite dark unpleasant aroma.	Slightly darkened flavor good	Slightly darkened, flavor good	Same as C
588	Same as previous examination.	Distinctly browned	Slightly darkened, flavor good	Same as C
940	Same as previous examination	Distinctly browned, unpleasant aroma.	Same as previous examination	Same as C

Carrots (Dried Dec. 31, 1917)

A. Dried 6 hrs. at 122° F.
B. " 6 " " 122° F. + 2 hrs. 140° F.
C. " 6 " " 122° F. + 3 " 140° F.
D. " 6 " " 122° F. + 3 " 140° F. + 1 hr. at 150° F.

Days of Storage	A 11.11% H_2O	B 7.39% H_2O	C 4.99% H_2O	D 5.54% H_2O
40	No color change Strong carrot odor.	No change	No change	No change
68	Distinct fading of color noticeable.	No change	No change	No change

Carrots (Con'd)

Days of Storage	A 11.11% H_2O	B 7.39% H_2O	C 4.99% H_2O	D 4.54% H_2O
86	Color faded. Odor & flavor still distinctive	Color slightly faded.	----	----
235	Carrot color faded. Sample darkened.	Color faded no darkening. Odor & flavor still distinctive.	Color faded slightly less than B.	Like C
690	Color faded & browned. Distinctive aroma & flavor lost.	Color faded & darkened	Color faded no darkening.	Sample lost.
942	----	Distinctive color & aroma lost.	Color faded. Distinctive flavor still present.	Sample lost.

Onions (Dried Jan. 6, 1918)

A. Dried 10 hrs. at 113° F.
B. " 20 " " 113° F.
C. " 24 " " 113° F.
D. " 24 " " 113° F. + 0.5 hrs. at 113 - 122° F.

Days of Storage	A 9.35% H_2O	B 6.64% H_2O	C 5.74% H_2O	D 5.34% H_2O
29	Slight darkening onion odor.	No change	No change	No change
76	Same as previous	" "	" "	" "
227	Color light brown. Flavor poor.	Sample lost, jar defective.	Slightly yellow, flavor good.	Same as C.
554	Color dark brown. Flavor poor.	----	Distinctly browned. Flavor & odor good	----
905	Same as previous examination.	-----	Color light brown. Flavor deteriorated but still distinctive	----

Spinach (Dried May 13, 1918)

B. Dried 1.25 hrs. at 140° F.
C. " 1.50 " " 140° F.
D. " 2.50 " " 140° F.
E. " 3.00 " " 140° F.

Days of Storage	B 8.9% H_2O	C 5.38% H_2O	D 3.81% H_2O	E 2.03% H_2O
103	Flavor poor, hay-like	Color slightly faded. Flavor fair.	Color unchanged. Flavor fair	Like D
778	Color slightly browned. Flavor poor, hay-like	Sample as previous examination.	Color very slightly faded, flavor fair.	Like D

Turnips (Dried Jan. 2, 1918)

A. Dried 6 hrs. at 122° F.
B. " 10 " " 122° F.
C. " 10 " " 122° F. + 1 hr. at 140° F.
D. " 10 " " 122° F. + 2 hrs. at 140° F.
+ 2 hrs. " 140° F.

Days of Storage	A 11.51% H_2O	B 6.57% H_2O	C 5.00% H_2O	D 4.55% H_2O
33	Browned distinctly strong turnip odor.	No change	No change	No change
65	Darker than above. Still has strong turnip odor.	Darkened very slightly. Very little odor.	No change	No change
80	----	----	No change	No change
233	Color dark brown. Strong turnip odor.	Darkened & has strong turnip odor.	Slightly darkened, turnip odor.	Same as C.
588	Color dark brown. Lacks distinctive flavor.	Color brown, slight turnip odor.	Slightly browned.	Same as C.
940	Same as previous examination.	Same as previous examination.	Same as previous examination	Same as C.

APPENDIX II

Injury Due to Heat.
(also taken from ref. 4 - see page 27)

Class I. Very easily injured.

Onions:	In dry air for 6 hrs. at 55° C. In moist air at 60° after 4 hrs. 70° C. injures onions.
Turnips:	(data not available)
Celery:	" " "
Tomatoes:	" " "
Cabbage:	Injured in a moist atm. in 5 hrs. at 60° and within 3.5 hrs. at 70° C.

Class II. Fairly resistant.

White Potatoes:	60 - 70° C.	
Carrots:	Withstand 70 - 80° C.	
String beans:	At 90° C.	In dry atm. injured within 1-2 hrs. In moist atm. the same.
	At 60° C.	Dry - no injury after 20 hrs. Moist - injured within 9-11 hrs.
	At 50° C.	Dry - no injury. Moist - After 20 hrs.
Sweet Corn:	(data not available)	

Class III. Very resistant.

Sweet Potatoes: 80 - 90°C. Injury after 5 hrs. exposure.

With high humidity injury at lower temperature.

BIBLIOGRAPHY

1. Caldwell, J.S., U.S. Dept. Agr. Farmer's Bulletin, No. 984, 1933.

2. Cruess, W.V., Commercial Fruit and Vegetable Products, New York, 1924.

3. Hansbrand, E. Drying by Means of Air and Steam, London, 1924.

4. Tibbles, Foods - through Food Manufacture, Vol. 7, p. 346, Nov. 1932.

5. Crosbie-Walsh, T. Food Manufacture, Vol. 17, p. 217, Aug. 1942.

6. Mangels, C.E. and H.C. Core, Ind. Eng. Chem., Vol. 13, p. 523, June 1921.

7. .... L'Industrie Italiana della Conserva Alimentari through Food Manufacture, Vol. 7, p. 346, Nov. 1932.