THESIS

On

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INTRODUCTION

There are many influences along the lines of research, scientific experimentation, and practical experimentation that are contributing to the accomplishments of the day. One of the most important facts to note is the kind of influence, whether direct or indirect. The more indirect the influence the less the interest shown and the more difficult it is to receive business and financial cooperation. Consequently there is a marked increasing popular interest taken consecutively in : -- research, scientific experimentation and practical experimentation. The former is a field in which it is impossible to receive sufficient business and financial backing and the latter presenting a field in which billions of dollars have been spent, either wisely or unwisely.

The material presented in this paper is a part of the work on scientific experimentation conducted by the Experiment Station of the Oregon State Agricultural College on the drying of fruits and vegetables. Although considerable work was done in obtaining the data presented herein and the material and equipment approximated that of a commercial plant, the work is basic and comparative only. In other words, the results of the experiments were obtained without consideration for economical construction and financial returns. The proper relation of the factors involved are basic and the results as presented in this paper are comparative, that is, capable of commercial application.

HISTORY

Much could be written on drying from a historical standpoint. It is not a new art. Sun drying dates back to ancient times, and the modern evolution of drying or evaporating had its origin about the year 1865. Since that time many types of evaporators and methods of evaporating have been tried.

As early as the year 1895, in Wayne County, New-York, the pioneer state of evaporated fruits, it was estimated that there were two thousand two hundred evaporators in operation. According to L. H. Bailey the types of evaporators used could be placed in five catagories;--the kilns, horizontal evaporators, towers, steam tray evaporators, and air blast evaporators. He further states that due to the undesirability of large commercial plants the air blast evaporator would naturally be eliminated on the ground of its high cost. From this it does not seem as though there were a proper correlation of the greatest recognized difficulty or obstacle in evaporating and a possible means of remedy. This obstacle has grown with the industry and like a cancerous growth it has been eating and gnawing away until the one possible and plausible source of remedy has been recognized and is now on trial.

H. P. Gould most forcibly and pointedly presented the obstacle when he said, "If atmospheric conditions are heavy and damp, the drying is retarded. Under some conditions it is hardly possible to thoroughly dry the fruit". It was early recognized that air movement, circulation, or draft was a most important factor in satisfactory drying. Yet in spite of this recognition we find a divided opinion which was early voiced and is still a matter of more or less controversy, although the opposition to rapid drying is not as marked as in the past.

Henry E. Dosch, responsible for a good many things in the early advancement of the evaporating industry in Oregon said, "Rapid evaporation as claimed by some patentees as a point of merit is a great mistake; nature if left to her good offices, will dry fruit very slowly in order to develop the saccharine matter, and the closer we follow her the nearer right we are; nature makes no mistakes; french prunes should never be evaporated in less than 24 to 30 hours; Italian and silver prunes 36 to 42 hours; apples in 6 hours; peeled pears in 24 hours and unpeeled pears in 48 hours to 60 hours." In the same paper H. E. Dosch quotes Dr. J. F. Simonds on the chemistry of the evaporation of apples, as follows:--"The chemical change which belongs to truly evaporated fruit will now begin and the albumen instead of being slowly dried coagulates precisely the same as in an egg when boiled. The soluble starch existing in all the fruit and composed of $C_5 H_{10} O_5$, will, if the heat is high enough combine with one equivalent of water so that now we have an entirely different combine, towit: glucose or fruit sugar which will assist in the preservation of the fruit instead of being liable to decomposition as the dried product."

He further states, "Apples will cook in boiling water at a temperature of only 212 degrees Fahr., or bake in an oven at 225 degrees Fahr., but, if the heated air is circulated fast enough the fruit will not cook or burn, or become itself heated to the temperature indicated by the thermometers, even at 300 degrees Fahr., for the evaporation of the water is a cooling process and every particle of vapor leaving the minute cells which contained it carries with it also a large amount of calories in a latent form and this keeps the heat of the apple far below the surrounding air."

In one case rapid evaporation is not alone accepted from an economic standpoint but also as an improver of the quality of the product, while, in the other case slow drying is accredited with the better quality and the economic factor is not considered. Both seem to be of the opinion that the carbohydrate content is influenced by the method of drying. A more recent article written by J. J. Dillion in 1917 favors rapid evaporation. He says, "In the trade there appears to be a tendency to make a distinction between evaporated products and steam dried products and dehydrated products. There is, however, but little difference between the products although the systems differ greatly. Yet in each of the systems the object is to drive out the moisture as quickly as possible."

Evidently, then, with the object in mind to eliminate as nearly as possible this obstacle of atmospheric conditions, to economically produce and to improve the quality of the product, hundreds of types of evaporators have come and gone and are still coming and going. It has not been until the last year or two that institutions such as The Oregon State Agricultural College and The University of California have carried on sufficient experimental work to be able to make any definite statement as to the best construction of a dryer.

An apparent reason for the confusion of type and the hesitancy in recommending an evaporator is suggested in a recent statement by W. V. Cruess. In referring to temperature he says, "This factor has been fully taken into account in the design of the evaporator to be described." In a previous publication he stated, "A large volume of air of low humidity is necessary for rapid evaporation. Many evaporators do not provide this." Evidently then, a certain knowledge of a relation of conditions is a necessary prerequisite to type or construction of dryer.

The above statement is true when referring to the evaporation of grapes, but, is it not, as he states elsewhere, that grapes approximate a free water surface, which is undoubtedly true of other fruits and vegetables ? This does not take into consideration those fruits that are more resistant to the forces of evaporation, which leads finally to the conclusion that, if at all possible, the ideal evaporator should be constructed to meet the requirements of all fruits and vegetables.

A further statement is made--"In designing an evaporator provision must be made for--

a. Sufficient heat production;

b. Sufficient radiating surface;

c. Good air circulation, and

d. Control of temperature."

No mention is made of humidity. In a later publication the statement is made--"Because of the vital importance of controling the humidity of the air used in drying prospective purchasers and manufacturers of evaporators are advised to install in their plants some means of effectively regulating the moisture content of the air." This leads to recirculation which is a very important factor to consider in the type or construction of an evaporator.

Other opinions and statements on the importance of the factors involved in drying, that are more or less representative of the past and present sentiment, will be given in the form of quotations from articles written on the subject.

> *"The time necessary for drying fruit depends upon several factors. The more important are type of evaporator; depth to which fruit is spread; method of preparing--whether sliced quartered or whole; temperature maintained, conditions of the weather and to a certain extent the construction of the evaporator. A probable temperature which has been suggested by some of the operators in 150 degrees F. or more when fruit is first put into the drying compartment, dropping to about 125 degrees F. as the drying process nears completion.
>
> For most satisfactory results, however, in all types, thorough ventilation is essential to insure a good circulation of heated currents of air."

*H. P. Gould------Evaporation of Apples.
Farmers' Bulletin 291----------1915.

*"Necessary to thorough and perfect evaporation is thorough and rapid circulation of heat in the evaporator, beginning at a low heat and finish at a high heat. As stated by me before and so scientifically explained by Dr. Simonds the two principal requisites in the evaporator are heat and circulation."

**"By the strong draft the surface of the prunes becomes dry and the pores closed up before the interior water has all evaporated thus rendering evaporation slower than it would be by a moderate circulation. By the stack system, however, this condition is obviated by the steam of the lower trays passing up through the upper fruit, thus keeping the surface moist and allowing this interior moisture to pass off and hence in this system the stronger the draft the better."

*H. E. Dosch------------------Fruit Evaporation.
Fifth Biennial Report----
Board of Horticulture Ore. 1898.

**R. D. Allen--------------The Prune and the Methods of Evaporation.
Fifth Biennial Report-----
Board of Horticulture Ore. 1898.

*"According to the dehydration system the material is placed on trays in thin layers and the trays arranged one above another with spaces between them. Hot air at about 125 degrees F. is blown horizontally from one side of a heated chamber through the spaces between the trays and is automatically discharged from the opposite side of the chamber. According to this system the moisture from one tray is not driven through the trays above it and probably there is a quicker driving out of the moisture due to the fact that there is no absorption of moisture in the compartment.

The temperature within this tower is about 300 degrees F. which drives off the moisture much quicker than any of the other systems above mentioned."

**"As for making his choice between the two methods afforded by flues or by fans for securing the necessary circulation of air the writer has still to be convinced that the economy afforded in using a fan blower operated at high mechanical efficiency is not to be preferred over flue draft.---------Moist air produces the

*B. C. Coons---J. J. Dillion-----Drying of Food Products
New York State Food Supply Commission--Bulletin 5, 1917

**C. V. Ekroth--Fruit and Vegetable Dehydration from a technical Standpoint.
American Journal of Public Health----1917.

very best results in dehydrating, not alone in saving of time but also in securing an even and thorough drying, since the moisture laden air keeps the outer layers of the vegetable cells soft and permeable and so permits the easy escape of the internal moisture."

This brief summary of opinions and ideas, though incomplete, is fairly representative of the situation both past and present. To crystallize or to even conjure from these statements a plausable plan of procedure in dehydration would necessitate an undiscovered faculty on the part of the successful individual. This I will not endeavor to do, but will, in brief, present the points of controversy and arrange them so as to most forcibly lead to a justification of the work presented in this thesis.

FIRST----Standardization.

In the beginning it should be understood that the economic laws governing the drying or evaporating industry are no exceptions to the laws governing other successful industries. The product, besides being most economically produced, must be standardized, and this will necessitate the adopting of the proper system whether it be adaptable to the single grower or not. The home spun clothes days have long past and the drying industry cannot afford to retain its present status of a supporter of tradition and expect to gain a sympathetic patronage. Consequently if the mechanical draft tunnel is the one that will make possible the production of a uniform product, it must be adopted; if not it must be rejected. At all events we must desert this false objective of constructing a tunnel primarily to meet the demands of the single grower.

SECOND-----Economic Relation.

If the drying industry is to stand on its own footing and progress, it must wake from the nightmare of a one product affair. The evaporator that will produce a standard product must, if at all possible, be adaptable to the evaporating of all fruits and vegetables. This will enable it to run the year round. The kiln evaporator, the most popular evaporator in the state of New York, is adaptable to apples and apples only, that is, when quality is considered along with economic production.

THIRD----Natural Draft Tunnel.

The consensus of opinion is that the natural draft tunnel is always more or less subject to atmospheric conditions, consequently the time of drying, as well as the quality, is a varying factor. If this is true the natural draft tunnel is of necessity, and of necessity only, filling a place until a better type of tunnel can be found, or until this difficulty can be overcome.

FOURTH----Rapid vs. Slow Drying.

This is not such a big question today in the United States, although in Europe there is a tendency to emphasize slow drying. Those supporting the slow drying claim for it a superior quality, as Dosch puts it, ---- referring to nature and her slow drying---"The closer we follow her the nearer right we are."

FIFTH----Quality.

There is a difference of opinion on quality:--- some seem to prefer a rapidly dried fruit or vegetable and others one that has been dried slowly. Some prefer the original flavor, as near as possible, and others prefer a distinct flavor. There seems to be the same divergence of opinion on this phase of the subject as on the other phases.

SIXTH----Factors Involved in Dehydration.

The factors as mentioned in the historical review are---temperature, circulation, humidity and volume. As to whether all these are essential or not there is a varying opinion. The relations of each and their specific influence are only known in an imcomplete way.

SEVENTH----Type.

This has been the one outstanding feature of the history of evaporating. The type of dryer has been foremost in the minds of those interested in the industry. This is a natural turn to take and is not a mistake. It is and was simply a matter of meeting conditions under circumstances.

There can be no just criticism of those who have worked from economic necessity to keep their industry going, and at the same time solve the problems that faced them. The path of evolution has been run and today the evaporating industry has reached the point where it can begin to command the necessary expenditure of time and money toward the solution of some of the difficulties confronting it. Scientific experimenting has just begun, and it will be several years before much improvement can be made, as there is only a beginning interest shown in fostering and encouraging this type of work.

The advancement made in the evaporating industry has been slow, but sure. There is not a better illustration, possibly, of the still existing problem of problems, than that furnished by these two quotations:---

The first by R. D. Allen in 1898----

"One thinking of purchasing an evaporator should in-investigate as many styles as possible; he should see them in operation; talk with operator----"

And the second by W. V. Cruess in 1920-----

"It is obviously impossible to describe all of the different forms of evaporators in this short paper or even to discuss fully the fundamental principles which should guide us in the selection of an emergency evaporator. There are several good types and many bad ones. Our advice to the prospective builder is that before the evaporator is built he consult every evaporator owner in reach; that he even spend a hundred or more dollars and a week or two of his time to visit dryer owners outside of his district."

Practically all that we have to date on the evaporating industry we owe to such men as those herein sighted. They have done considerable practical experimenting but the problem has bean too large and complex. The key note to progress is voiced in a statement by W. V. Cruess--- "Evaporators of many types have been used with varying degrees of success for many years. From the experience gained in the use of these evaporators and from observations and measurements taken by scientific investigators certain principles have been recognized. To this existing knowledge new information is being constantly added and some of the older theories are being discarded or seriously modified."

The problem that I have taken in this thesis is most aptly introduced by one of the pioneers of the dehydrating industry, R. D. Allen, who has been quoted several times before.

"I believe it is proper and pertinent to continue the discussion to the end that out of the proplexity we may blow the chaff and gather the golden grains of information formed of experience the foundation of all useful knowledge."

Problem

Experience or observation is the foundational step to every possible means of advancement. Practical experimentation follows it closely and in a good many cases will lead to a satisfactory end.

When the problem is complex, involving special equipment and the expenditure of considerable time and money, there is only one recourse, scientific or systematic work. This is, in brief, the popular reason for the work presented in this paper. But, going further into the study of evaporation there appears to be a center about which the whole problem revolves; the specific influence on different tissues of the factors concerned.

The various stages of substances whether solid, liquid or vapor and the medium in which they exist and their reaction thereto are all governed by laws. These will be taken up later under the theory of evaporation.

The proper relation of temperature, humidity, circulation and volume in the evaporating of apples is a simple statement of a rather involved problem. The first obvious step and the first step taken was to make runs of apples with different combinations of the factors. It was plain, at the start, that there would not be sufficient time to make the necessary runs to cover all possible combinations. This would require around a thousand runs or about three years steady work involving the attention of at least two men and would be impractical, if not, impossible to do. It then was necessary to simplify; and, from the results obtained there is every reason to believe that the short cut was not alone expedient from necessity but was a proper and economical course.

There are other problems of importance in drying which have a decided influence on the interpretation of the results, and which must be taken into consideration. Economy or time and quality are the final ends and constitute the basis upon which the best combination of factors can be determined. Both economy and quality are influenced by other conditions than temperature, humidity, circulation, and volume. The treatment of the fruit, the construction of the tray, and the size and shape of the prepared apple must be considered in a proper interpretation of results.

It might be added for emphasis that as long as all these influencing factors are constant throughout all the experiments the comparative value of the results is maintained. It therefore is obvious that the results must be interpreted in the light of the conditions under which the drying was done and that if these conditions of temperature, humidity, circulation, volume, shape of tray, treatment of fruit, and cut of fruit could be obtained commercially the results in time and quality would be the same.

THEORY OF DRYING

Water, the outstanding substance involved in all drying work, has some very characteristic physical properties. Its maximum density is reached at 39.2 degrees F.; expansion taking place either above or below this temperature. In the evaporation of water heat is used, requiring 537 calories to change one gram of water to vapor. This is called heat of vaporization.

There is a similar heat relation in the melting of ice called latent heat which does not raise the temperature of the melted ice or water. It requires 80 calories to melt one gram of ice. The specific heat of water is greater than that of any other substance and is taken as the standard, 1.0. Water possesses the property of viscosity, or fluidity, this property varying with the temperature. In conductivity water is low, although it is a better conductor than air.

In the drying of fruits and vegetables we are concerned with tissue, the unit of which is the cell. The water is in the cells, in intercellular spaces and in special water carrying organs. Obviously there is a distinct difference in the influencing factors in drying from a free water surface, from organic tissue, and from inorganic matter. Water, as it exists in the various kinds of tissues and inorganic materials is influenced by other factors than those influencing a free water surface. A more complex condition exists ---- especially is this true when the different kinds of treatment are taken into consideration. Furthermore, the rate of evaporation is not the only desired end, but, is equaled if not exceeded in importance by the quality of the finished product.

According to Millikan and Gale the rate of evaporation depends:

1. On the nature of the evaporating liquid;
2. On the temperature of the evaporating liquid;
3. Onthe humidity of the space into which the evaporation takes place;
4. On the density of the air or other gas above the evaporating surface;
5. On the rapidity of the circulation of the air above the evaporating surface;
6. On the extent of the exposed surface of the liquid.

Rate of evaporation is indirectly influenced by the specific gravity of the liquid and humidity; directly by the temperature, by circulation and by the exposed surface. From this it is evident that for quick evaporation from a free water surface a high temperature, low humidity, high circulation and a large exposed surface are necessary.

Evaporation is due to molecular motion. The more rapid moving molecules are able to overcome the cohesive force and fly into space. This is the explanation for the existence of the three states of matter---solid, liquid and gas.

Humidity always decreases evaporation from a free water surface or from a soil surface.

Considerable work has been done with soil waters. There are three kinds of water existing in soils:

1. hygroscopic, acted upon by the force of cohesion;
2. capillary or film, acted upon by the force of surface tension;

and 3. hydroscopic, acted upon by the force of gravity.

Hygroscopic water surrounds the soil and at ordinary temperatures is always present. It requires a very high temperature to remove this moisture.

The most abundant form of soil water is capillary water. It surrounds the soil particles with films and evaporates at ordinary temperatures. The capillarity of water from wet soil into dry soil is very slow making dust mulches very effective. The viscosity of the soil water has a decided effect upon evaporation. A high viscosity increases the surface tension or pull, but retards the rate of movement by lessening the fluidity. By far the greatest amount of water leaving the soil is capillary water which is lost by evaporation and transpiration. Surface tension or the pull of a water-air surface is the force at work. In soil particles the capillary movement increases with the difference of thickness of the film surrounding the particles. Rapidity of capillarity is very marked from a saturated lower strata in the soil, but as the water travels upward the films become thinner and the movement slower. The passage of water through a dry surface layer is very slow.

In living organic matter transpiration or the evaporation of water through stomatal openings takes place. It is influenced by the physiological functions of the plant.

High wind velocity, low humidity, high temperature, and intense light facilitate transpiration. When evaporation is too rapid transpiration is checked by a concentration of the cell sap and a closing of the stomatal openings.

On a large free surface of water there is practically no adhesive force to retard evaporation as there would be in fruits or vegetables, neither would the forces of capillarity, imbibition or osmosis be present to complicate matters.

A very important phenomena accompanying evaporation is the cooling effect that it has on the liquid itself and on bodies with which it is in contact. There is very little if any data on the cooling effect of evaporation upon the different fruit and vegetable tissue. It is a recognized physical fact that the temperatures of ether, alcohol, and even water, contained in a shallow vessel are lower than the surrounding air. This is due to evaporation from the surface of the liquid. The more rapid the evaporation the cooler the liquid. This would also be true of fruit and vegetable tissue. The relation of increase in temperature and the cooling effect of the evaporating surface would tend toward equalization, the cooling taking heat away, and the heat of the air conducting heat into the tissue. This ratio, would, most probably, be constantly changing as the atmospheric temperature increased; the tissue temperature increasing faster than the cooling caused by evaporation. Quite opposite to this would be the influence of circulation. Increased circulation would have no equalizing effect on temperature, as the only condition disturbed is evaporation. A decided cooling would be the result.

Air is a poor conductor. Air space is used in various ways as an insulator. This means that heat in air would tend to travel by convection or air movement, resulting in a noticeable difference in air temperature within a small space. Humidity or moisture in the air increases its heat conductivity. At the same time it lessens the evaporating power of the air.

In both the fields of soils and plant physiology very accurate and detailed work has been done on the factors influencing evaporation. The capillary pull in actual inches of water has been determined, also the influence of minerals, colloids, and the fineness of the soil particles.

In summary, the factors acting on the movement of water in soils and plants are--gravity, osmosis, surface tension, cohesion, adhesion and imbibition. Molecular activity is back of all these forces and is influenced by light, heat, circulation and humidity. And, finally the specific influence of the tissue or the material itself must be considered.

It has taken years to work out the exact relation of water in the two fields of soils and of plant physiology, and it will take years to do the same in the field of non-living organic tissue. There is altogether a different situation to meet, and while some points can be taken from other fields, their actual place and influence must be determined in the specific field itself.

At present we should be concerned with the influence of the above factors in a grosser way. This will not give the basic action of the unit involving pure theoritical laws but it will give the foundational material for guiding in the actual drying of fruit and vegetables.

The grosser theory of drying applied to organic tissue will be discussed after the experimental data has been presented.

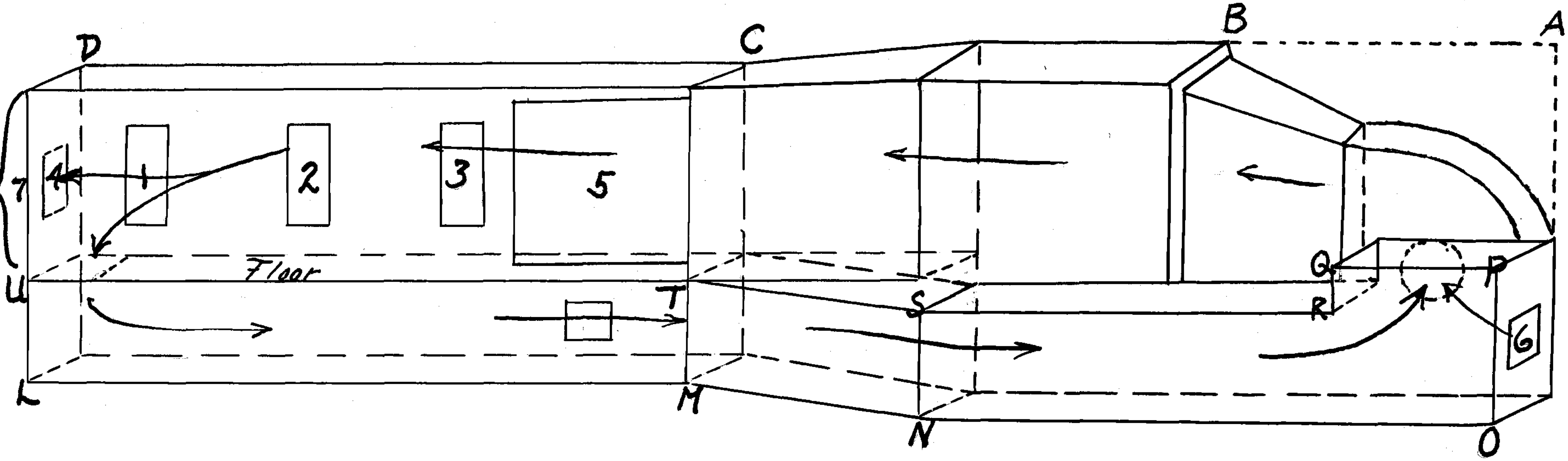
DESCRIPTION OF TUNNEL

The sketch on page number 27 divides the tunnel into four parts; A-B, B-C, C-D, and L-M-N-O-P-Q-R-S-T. The latter will be referred to hereafter as the return duct. A-B includes the fan and the approach to the steam coil; B-C includes the coil and the approach to the evaporator, C-D is the evaporating chamber.

When running on a commercial scal e the large trays, 31 by 38 inches, enter the evaporator through '7' and are removed from the door '5'. In the experimental work small trays 10 by 31 inches were used. They are put in and removed at doors 1, 2 and 3. This gives the rate of drying at the middle and both ends of the tunnel.

The air is blown from the fan in the direction of the arrows and is sucked back into the intake through the return duct. The slides '6' and '4' regulate the amount of outside air taken in and the amount of inside air blown out, which has a decided influence on the humidity and temperature. In order to control humidity and eliminate channeling the air upon emerging from the coils is steamed and made to pass through three sections of screens. This divides the steam and mixes the air making uniform conditions.

In the construction of the evaporator mechanical efficiency was not a matter of first importance. The object was to be able to regulate and control temperature, circulation and humidity. This, we were able to do to a fairly satisfactory degree without control instruments, although more work was required. Also the tunnel can be used for both small and large lots. The large lot or full tunnel will approximate commercial conditions; holding when full about 36 of the large trays. Absolutely no claims are made for the mechanical efficiency of the tunnel as its construction is in some respects far from ideal. That is a separate problem and must be handled in its turn.



Drawing of Tunnel

Instruments used In Tunnel.

The thermometer, wet and dry bulb thermometer, and the anemometer were the instruments used in the tummel to record conditions of temperature, humidity and circulation.

Temperature or heat has the qualities of intensity and quantity. Intensity of heat is measured by the thermometer. The quantity of heat is called the B. T. U. or calorie, and is the amount of heat required to raise a certain amount of water a certain number of degrees. Heat is a form of energy and its exact identity is not known, although it is known to have a decided influence on molecular activity which enables certain measurements to be made of it. Heat travels by radiation, conduction, and convection. Radiation is the travel of heat in a straight path, accompanying and obeying as a rule the laws of light. Conduction is the travel of heat from one body or from one part of a body to another. Convection is the travel of heat by currents.

The thermometers used in the experimental work had been recently checked by the Bureau of Standards, Washington, D. C. All other thermometers were checked to them.

The moisture content of the air was obtained by wrapping a thermometer bulb with silk and furnishing a reservoir to give a constant moisture supply. Recording instruments were also used for both wet and dry bulb.

Air movement in lineal feet per minute was obtained with the anemometer. The instrument reads fairly accurate within a radius of 25 feet up to the velocity of 1200 lineal feet per minute. Readings above this rate are inaccurate due to increased friction.

The amount of water vapor that a space will hold depends on temperature and pressure, and is entirely independent of the presence or absence of air. Absolute humidity is the weight of a cubic foot of water vapor at a given temperature and percentage of saturation. Relative humidity is the ratio of water vapor in a given space to the weight which the same space will hold when saturated.

Air at freezing temperature absorbs 1/160 part of its weight of moisture. For every 27 degrees F. rise in temperature the moisture capacity is doubled.

In reference to the amount of air necessary for maximum evaporation Professor W. V. Cruess makes the following statement, "It will require 63,000 cubic feet of air dropping one degree F. to furnish 965 B. T. U., the heat necessary to evaporate one pound of water". From this physical fact he further states, referring to the drying of 5 tons of grapes, "If the drying period is 12 hours, approximately

14,500 cubic feet of air per minute will be needed". This, however, would vary with the texture and thickness of material or tissue. There is a marked difference in drying from a free water surface and from organic matter or tissue.

Method of Proceedure.

The apples used were pealed, cored and trimmed according to the practice in commercial canning or drying. At first the apples were dropped from the pealing machine into a weak salt solution to prevent oxidation. They were then run into a half inch dicer, dropped into the salt solution again, spread on the small experimental trays and sulphured.

The above proceedure was changed when it became evident that a large error was introduced by dropping into the salt water. This error was noticed upon weighing the trays during the experiment and computing the percent of moisture in the apples from these weights. It was thought that this error would not be very great but figures showed it to be from 5 to 8 per cent of the total moisture content of the apples.

The proceedure was then carried on as above stated but the apples were not dipped in a salt solution. It was found that by rapid work the apples oxidized but a very little, and a ten minute light sulphuring was sufficient.

The trays with the apples were weighed before putting in the tunnel, in hundreths of a pound. They were removed and weighed every half hour during the experiment until dry.

For each experiment a certain temperature, humidity, and circulation was desired. Steam was admitted to the coil and the fan started about an hour before the fruit was put in. This gave plenty of time to warm the tunnel and obtain the proper regulation. When the tunnel was warmeded to the desired temperature, providing the pressure in the boiler was fairly constant, the temperature could be maintained by regulating the slides '3' and '4'. The humidity could also be controlled by this means, although it would be necessary at times to use the valves.

For obtaining the desired air circulation a variable speed motor was used, and for extreme conditions the pully on the main shaft was changed either to a smaller or larger one according to the speed desired.

During the period of operation temperature readings were taken at varying intervals, including both wet and dry bulb. These readings were always the average of two or three thermometers.

Tray readings were taken every half hour, it taking about two to three minutes to weigh the trays and record the data for each reading.

The rate of air movement remained reasonably constant at any set speed of the fan. At low speeds there was a slight difference in drying time due to air currents, but this condition did not exist at higher speeds.

From a separate tray in each run material was taken for oven determinations. The samples were not very large and consequently did not give entirely satisfactory results.

The data obtained for a single experiment includes--wet and dry bulb readings, anemometer readings, oven moisture determinations, and tray moisture determinations or readings.

Following is a possible system upon which the factors for each run can be determined so as to best cover the ranges of temperature, humidity and circulation:

Temp.	Hum.	Cir.		Temp.	Hum.	Cir.		Temp.	Hum.	Cir.
130	10	250	:	130	20	250	:	130	35	250
150	10	250	:	150	20	250	:	150	35	250
170	10	250	:	170	20	250	:	170	35	250
130	10	700	:	130	20	700	:	130	35	700
150	10	700	:	150	20	700	:	150	35	700
170	10	700	:	170	20	700	:	170	35	700

Temp.	Hum.	Cir.		Temp.	Hum.	Cir.		Tem.	Hum.	Cir.
130	10	1400	:	130	20	1400	:	130	35	1400
150	10	1400	:	150	20	1400	:	150	35	1400
170	10	1400	:	170	20	1400	:	170	35	1400

This was the form of proceedure adopted at the start, but due to lack of time and material and unforeseen difficulties it was not strictly followed. A check experiment should be run for each of the above making a total of fifty four experiments. Such a proceedure would take from three to four months depending on the help and losses of time that naturally occur.

Data.

The data recorded in this thesis includes experiments ten to twenty-eight. Each experiment was condensed and the data recorded in the manner noted.

The first column of figures refers to time of readings in tenths of hours for humidity and temperature. This is not of any significance other than to show that the readings were taken over the entire drying time and at fairly equal intervals.

In the second and third column figures on temperature and humidity are recorded, each figure being an average of two or more readings. While the variation is, in some cases, as much as seven or eight degrees the comparative range of conditions is great enough to allow the same without any apparent error.

The fourth and fifth columns contain the exact weight of fruit from all the trays at definite time intervals. The number of trays used is usually six or twelve and the time interval for weighing was one half hour. In the sixth column the weight of fruit has been changed to the common basis of per cent taking the original weight to be 100.

The last two columns including moisture oven determinations are not used in this paper.

Final average conditions and results obtained in time are quality are briefly summarized for each experiment directly below the summarized data. The time of drying was computed on a basis of 20% moisture content for each experiment, but the actual per cent of moisture in the apples when taken out was a little above or below this figure.

The basis of twenty- per cent refers to the weight of the fruit when dried to the weight at the start. This gives between a twenty and twenty five per cent moisture content for the dried product.

In the following presentation of the data the two divisions, time and quality, will be discussed in turn.

Experiment X

Apples (Yellow Newtown) February 4, 1921

Hours	*Temp. Fahr.	% Rel. Humidity.	Hours	** Lbs.wt. Fruit (tray)	Per-cent	Hours	*** % Moisture (oven)
0.0	151	34	0.0	27.7	100	0.0	84.6
0.5	148	37	1.1	16.8	61	1.1	79.9
1.0	146	35	1.6	13.5	49	1.0	73.1
1.5	147	37	2.1	11.0	40	2.1	67.1
2.0	149	40	2.6	8.5	31	2.6	55.6
2.5	146	34	3.1	6.9	25	3.1	40.1
3.0	146	40	3.6	5.8	21	3.6	26.9
3.5	149	38	4.1	5.1	18	4.1	16.1
4.0	146	38	4.6	4.7	17	4.6	11.9
4.5	152	31					

Average Circulation...........750-800L. F. M.
Average Temperature...........148 Degrees Fahr.
Average Relative Humidity..... 36%
Time of drying................3.7 hours
Moisture content..............20%
Quality....................... --

* Average of two thermometer readings.
*** Average of four determinations.
** Sum of the weights of fruit on ten trays.

Experiment XI

Apples (Yellow Newtown) February 5, 1921.

Hours	*Temp. Fahr.	% Rel. Humidity.	Hours	** Lbs. wt. fruit (tray)	Per-cent	Hours	*** % Moisture (oven)
0.0	149	27	0.0	13.29	100	0.0	84.6
1.0	150	19	0.5	9.33	70	1.0	74.1
2.0	149	14	1.0	6.13	46	1.5	55.9
3.0	150	20	1.5	4.10	31	2.0	41.7
			2.0	3.18	24	2.5	27.9
			2.5	2.53	19	3.0	17.2
			2.95	2.23	17		

Average Circulation...........750 - 800 L. F. M.
Average Temperature...........150 Degrees Fahr.
Average Relative Humidity.....20%
Moisture Content..............20%
Quality....................... --
Time of Drying................2.4 hours.

* Average of two thermometer readings
** Sum of the weights of fruit on five trays.
*** Average of two determinations

Experiment XII

Apples (Spitzenberg) February 8, 1921

Hours	*Temp. Fahr	% Rel. Humidity	Hours	** Lbs. wt. Fruit (tray)	Percent	Hours	*** % Moisture (oven)
0.0	177	28	0.0	10.69	100	0.0	84.0
0.5	178	28	0.5	6.96	65	o.5	77.1
1.0	178	32	1.0	4.24	40	1.0	59.0
1.5	178	23	1.5	2.81	26	1.5	39.2
2.0	173	22	2.0	2.19	20.5	2.5	13.1
			2.5	2.09	19.5		

Average Circulation.........750 -800 L. F. M.
Average Temperature.........177 Degrees Fahr.
Average Relative Humidity...26%
Time of Drying..............2.2 hours
Moisture Content............20 %
Quality.....................Poor

*Average of two thermometer readings
**Sum of the weights of fruit on five trays.
***Average of two determinations.

Experiment XIII

Apples (Yellow Newtown) February 8, 1921

Hours	*Temp. Fahr.	% Rel-Humidity	Hours	** Lbs. Wt. Fruit (tray)	Per-cent	Hours	*** % Moisture (oven)
0.0	167	32	0.0	13.30	100	0.0	85.5
0.5	162	37	0.5	9.64	72	0.5	79.7
1.0	166	33	1.0	6.98	53	1.0	72.6
1.5	168	34	1.5	4.48	38	2.0	58.8
2.0	167	32	2.0	3.51	28	2.5	23.5
2.5	164	33	2.5	2.74	21	3.0	17.4
3.0	161	25	3.0	2.43	18		

Average Circulation..........750 - 800 L. F. M.
Average Temperature..........165 Degrees Fahr.
Average Relative Humidity.....32%
Time of drying...............2.8 hours
Moisture Content.............20%
Quality......................Fair

* Average of two thermometer readings
** Sum of the weights of fruits on five trays
*** Average of two determinations.

Experiment XIV

Apples (Spitzenberg) February 19, 1921

Hours	*Temp. Fahr.	% Rel. Humidity.	Hours	** Lbs. wt Fruit (tray)	Per-cent	Hours	*** % Moisture (oven)
0.0	147	36	0.0	11.12	100	0.0	84.6
0.5	149	32	0.5	6.21	56	0.5	76.5
1.0	148	35	1.0	4.21	38	1.0	68.2
1.5	154	38	1.5	2.89	26	1.5	43.6
2.5	149	36	2.0	2.22	20	2.0	38.5
			3.0	1.77	16	3.0	6.7

Average Circulation..............1400 L. F. M.
Average Temperature..............149 Degrees Fahr.
Average Relative Humidity.......35 %
Time of Drying...................2 hours
Moisture Content.................20 %
Quality..........................Fair

* Average of two thermometer readings.
** Sum of the weights of fruit on five trays
*** Average of two determinations.

Experiment XV.

Apples (Spitzenberg) February 21, 1921

Hours	*Temp. Fahr.	% Rel. Humidity	Hours	** Lbs. wt. Fruit (tray)	Per-cent	Hours	*** % Moisture (oven)
0.0	169	28	0.0	13.50	100	0.0	84.6
0.8	169	28	0.5	7.23	54	0.7	59.1
1.2	171	32	1.0	4.12	31	1.0	38.1
1.6	169	27	1.5	3.01	22	1.5	16.7
2.0	166	31	2.0	2.58	19	2.0	11.5

Average Circulation.................1400 L. F. M.
Average Temperature.................169 Degrees Fahr.
Average Relative Humidity...........29%
Time of Drying. ....1.8 hours
Moisture content....................20%
Quality.............................Fair

* Average of two thermometer readings.
** Sum of the weights of fruit on six trays
*** Average of two determinations.

Experiment XVI

Apples (Spitzenberg) February 22, 1921.

Hours	*Temp. Fahr.	% Rel. Humidity	Hours	** Lbs.wt Fruit (tray)	Per-cent	Hours	*** % Moisture (oven)
0.0	135	8.0	0.0	14.43	100	0.0	84.6
0.6	145	5.0	0.5	9.06	63	0.5	75.3
1.2	130	8.0	1.0	5.90	41	1.0	59.6
1.8	128	9.0	1.5	4.58	32	1.5	49.9
2.4	141	6.0	2.0	3.83	26	2.0	33.4
			3.0	3.01	21	2.5	16.8
						3.0	12.7

Average Circulation...........1400 L. F. M.
Average Temperature...........134 degrees Fahr.
Average Ralative Humidity.....7%
Time of Drying................3.2 hours
Moisture Content..............20%
Quality...................... Excellent

* Average of two thermometer readings.

** Sum of the weights of fruit six trays

*** Average of two determinations.

Experiment XVII

Apples (Spitzenberg) February 23, 1921.

Hours	*Temp. Fahr.	% Rel. Humidity	Hours	** Lbs.wt fruit (tray)	Per- cent	Hours	*** % Moisture (oven)
0.0	118	13	0.0	13.48	100	0.0	84.6
0.6	120	12	0.5	8.79	65	0.5	72.7
1.2	118	12	1.0	6.54	49	1.0	66.5
1.8	117	11	1.5	5.24	39	1.5	59.6
2.4	116	11	2.0	4.40	33	2.0	51.3
3.5	115	10	2.5	3.83	28	2.5	47.9
			3.0	3.47	26	3.0	31.8
			3.4	3.30	24.5	3.3	26.9

Average Circulation............1400 L. F. M.
Average Temperature............117 Degrees Fahr.
Average Relative Humidity......12%
Time of Drying.................4.6 hours.
Moisture Content...............20%
Quality........................Good

*Average of two thermometer readings.
**Sum of the weights of fruit on six trays.
***Average of two determinations.

Experiment XVIII

Apples (Spitzenberg) February 25, 1921.

Hours	*Temp. Fahr.	% # Rel. Humidity	Hours	** Lbs. wt. fruit (tray)	Per-cent	Hours	*** % Moisture (oven)
0.0	170	4	0.0	12.29	100	0.0	84.6
0.5	176	5	0.5	5.28	43	0.5	59.7
1.0	177	9	1.0	3.13	25	1.0	27.2
1.5	166	5	1.5	2.54	21	1.5	14.7
2.0	169	4	2.0	2.34	19	2.0	9.9

Average Circulation.........1400 L. F. M.
Average Temperature.........171 Degrees Fahr.
Average Relative Humidity...5%
Time of drying..............1.8 hours.
Moisture content............20%
Quality.....................Fair

* Average of two thermometer readings.

** Sum of the weight of fruit on six trays.

*** Average of two determinations.

\# Humidity below 10% not certain.

Experiment XIX

Apples (Yellow Newtown) February 26, 1921.

Hours	*Temp. Fahr.	% Rel. Humidity.	Hours	** Lbs. wt. Fruit (tray)	Per-cent	Hours	*** % Moisture (oven)
0.0	139	29	0.0	19.08	100	0.0	84.6
0.2	132	30	0.5	14.06	74	0.5	76.4
1.8	131	36	1.0	10.07	53	1.0	70.1
2.3	134	31	1.5	7.76	41	1.5	52.8
2.9	136	32	2.0	6.14	32	2.0	43.3
3.5	136	31	2.5	5.11	27	2.5	36.5
			3.0	4.40	23	3.0	22.3
			3.5	4.10	21	3.5	14.5

Average Circulation............1400 L. F. M.
Average Temperature............135 Degree Fahr.
Average Relative Humidity..... 31%
Time of drying.................3.6 hours
Moisture content...............20%
Quality........................ Good

* Average of two thermometer readings.
** Sum of the weights of fruit on seven trays.
*** Average of two determinations.

Experiment XX

Apples (Yellow Newtown) February 28, 1921.

Hours	*Temp. Fahr.	% Rel. Humidity	Hours	** Lbs. wt fruit (tray)	Per-cent	Hours	*** % Moisture (oven)
0.0	144	9	0.0	15.26	100	0.0	---
1.0	137	10	0.5	10.64	70	0.5	73.8
2.0	141	9	1.0	8.14	53	1.0	66.9
3.0	144	7	1.5	6.00	39	1.5	57.5
4.0	134	9	2.0	4.81	31.5	2.0	43.7
			2.5	3.89	25.5	2.5	34.9
			3.0	3.44	22.5	3.0	28.6
			3.5	3.18	21	3.5	18.5
			4.0	3.02	20	4.0	14.6

Average Circulation............675 - 700 L. F. M.
Average Temperature............140 Degrees Fahr.
Average Relative Humidity...... 9%
Time of drying.................3.8 hours
Moisture content...............20%
Quality........................ Fair

* Average of two thermometers readings.
** Average of two determinations.
*** Sum of the weights of fruit on six trays.

Experiment XXI

Apples (Yellow Newtown) March 1, 1921.

Hours	*Temp. Fahr.	% Rel. Humidity	Hours	** Lbs. wt Fruit (tray)	Per-cent	Hours	*** % Moisture (oven)
0.0	171	29	0.0	15.18	100	0.0	---
1.4	173	25	0.5	11.74	77	0.5	78.9
2.1	174	24	1.0	8.18	53	1.0	68.6
2.8	168	25	1.5	5.71	38	1.5	54.4
3.5	169	29	2.0	4.33	28	2.0	40.7
			2.5	3.44	23	2.5	23.7
			3.0	3.03	20	3.0	15.8
			3.5	2.88	19	3.5	9.9

Average Circulation.......675 - 700 L. F. M.
Average Temperature........170 Degrees Fahr.
Average Relative Humidity..25.5%
Time of Drying.............3 hours.
Moisture content...........20%
Quality.................... Good

* Average of two thermometer readings.
** Average of two determinations.
*** Sum of the weights of fruit on six trays.

Experiment XXII

Apples (Yellow Newtown) March 1, 1921.

Hours	*Temp. Fahr.	% Rel. Humid-ity	Hours	** Lbs. wt Fruit (tray)	Per-cent	Hours	*** % Mois-ture (oven)
0.0	155	30.0	0.0	14.74	100	0.0	---
1.8	150	36.0	0.5	11.73	80	0.5	78.3
2.7	151	37.0	1.0	9.09	62	1.0	74.8
3.6	149	33.0	1.5	6.98	47	1.5	67.3
4.5	151	28.0	2.0	5.38	37	2.0	60.5
			2.5	4.43	30	2.5	40.8
			3.0	3.58	24	3.0	24.4
			3.5	3.18	21	3.5	13.9
			4.0	2.92	20		

Average Circulation.........675 - 700 L. F. M.
Average Temperature ....151 Degrees Fahr.
Average Ralative Humidity...33%
Time of drying..............4 hours.
Moisture content............20%
Quality.....................Fair

* Average of two thermometer readings.
** Average of two determinations
*** Sum of the weights of the fruit on six trays.

Experiment XXIII

Apples (Yellow Newtown) March 2, 1921.

Hours	*Temp. Fahr.	% Rel. Humidity	Hours	** Lbs. wt Fruit (tray)	Per-cent	Hours	*** % Moisture (oven)
0.0	135	38	0.0	15.81	100	0.0	---
1.7	133	30	0.5	13.77	87	0.5	78.7
2.5	133	38	1.0	11.56	73	1.5	72.4
3.3	132	31	1.5	8.85	56	2.0	66.8
4.2	136	32	2.0	7.68	49	2.5	60.5
3.0	131	39	2.5	6.51	41	3.0	44.3
			3.0	5.24	33	3.5	40.6
			3.5	4.27	27	4.0	28.9
			4.0	3.85	24	4.5	18.5
			4.5	3.43	22	5.0	16.6
			5.0	3.26	21		

Average Circulation............675 - 700 L. F. M.
Average Temperature............133 Degrees Fahr.
Average Ralative Humidity.....34. 7%
Time of drying.................5.3 hours.
Moisture content...............20%
Quality........................Fair

* Average of two thermometer reading.
** Average of two determinations.
*** Average sum of the weights of fruit on six trays

Experiment XXIV

Apples (Yellow Newton) March 3, 1921.

Hours	*Temp. Fahr.	% Rel. Humid-ity	Hours	** Lbs.wt. Fruit (tray)	Per-cent	Hours	*** % Mois-ture (oven)
0.0	116	19	0.0	15.29	100	0.0	---
1.4	117	16	0.5	11.76	77	0.5	78.6
2.1	116	17	1.0	9.40	61	1.0	73.7
2.8	120	15	1.5	7.52	49	1.5	64.0
3.6	115	16	2.0	6.11	40	2.0	54.1
4.3	114	17	2.5	5.22	34	2.5	49.5
5.0	116	15	3.0	4.54	30	3.0	39.5
			3.5	4.06	27	3.5	32.5
			4.0	3.72	24	4.0	30.9
			4.5	3.46	23	4.5	24.1
			5.0	3.28	21.5	5.0	19.8

Average Circulation..........674 - 700 L. F. M.
Average Temperature..........116 Degree Fahr.
Average Ralative Humidity....16.4%
Time of drying...............5.5 hours.
Moisture content.............20%
Quality...................... Fair

*Average of two thermometer readings.
**Average of two determinations.
***Sum of the weights of fruit on six trays.

Experiment XXV

Apples (Yellow Newtown) March 4, 1921.

Hours	*Temp. Fahr.	% Rel. Humid-ity	Hours	** Lbs. wt Fruit (tray)	Per-cent	Hours	*** % Mois-ture (oven)
0.0	165	8	0.0	14.32	100	0.0	---
1.0	173	8	0.5	9.04	63	0.5	74.1
1.5	173	8	1.0	5.60	39	1.5	57.2
2.0	177	8	1.5	3.69	26	2.5	23.1
2.5	174	8	2.0	2.84	20	3	13.1
			2.5	2.44	17		

Average Circulation.......675 - 700 L. F. M.
Average Temperature.......174 Degrees Fahr.
Average Ralative Humidity.8%
Time of Drying............2 hours.
Moisture content..........20%
Quality...................Good

* Average of two thermometers readings
** Average of two determinations
*** Sum of the weights of fruit on trays.

Experiment XXVI

Apples (Yellow Newtown) March 7, 1921.

Hours	*Temp. Fahr.	% Rel. Humidity	Hours	** Lbs. wt. Fruit (tray)	Per-cent	Hours	*** % Moisture (oven)
0.0	141	12	0.0	14.62	100	0.0	---
1.1	137	14	0.5	12.33	84.5	0.5	80.6
2.6	135	13	1.0	10.06	69	1.0	71.3
4.1	134	13	1.5	8.47	58	2.0	68.4
5.2	132	13	2.0	7.19	49	2.5	64.2
			2.5	6.13	42	3.0	54.0
			3.0	5.21	36	3.5	48.0
			3.5	4.46	30.5	4.0	37.8
			4.0	3.88	26.5	4.5	26.8
			4.5	3.49	24	5.0	21.2
			5.0	3.21	22		
			5.5	3.03	20.5		

Average Circulation...............250 L. F. M.
Average Temperature...............135 Degrees Fahr.
Average Ralative Humidity.........13%
Time of drying....................5.8 hours.
Moisture content..................20%
Quality...........................Fair

* Average of two thermometer readings.
** Average of two determinations.
*** Sum of the weights of fruit on six trays.

Experiment XXVII

Apples (Yellow Newtown) March 8, 1921.

Hours	* Temp. Fahr.	% Rel. Humidity	Hours	** Lbs. wt. Fruit (tray)	Per-cent	Hours	*** % Moisture (oven)
0.0	138	30	0.0	15.87	100	0.0	84.6
1.4	138	30	0.5	14.74	92	0.5	82.1
2.8	131	33	1.0	13.51	85	1.0	80.0
4.2	138	34	1.5	12.17	77	1.5	78.6
5.6	137	30	2.0	11.22	71	2.0	73.7
7.0	141	26	2.6	9.90	62	2.5	71.6
			3.0	9.07	57	3.0	63.3
			3.5	7.83	41	3.5	48.5
			4.0	6.93	44	4.5	35.3
			4.5	6.18	39	5.5	31.0
			5.0	5.44	34	6.5	16.1
			5.5	4.73	30		
			6.0	4.20	26		
			6.5	3.70	24		
			7.0	3.49	22		

Average Circulation ....250 L. F. M.
Average Temperature............137 Degrees Fahr.
Average Relative Humidity 32%
Time of drying.................7.5 hours
Moisture content...............20%
Quality.........................Fair

* Average of two thermometer readings
** Sum of the weights of fruit on six trays
*** Average of two determinations.

Experiment XXVIII

Apples (Spitzenberg) March 9, 1921.

Hours	*Temp. Fahr.	% Rel. Humidity	Hours	** Lbs. wt Fruit (tray)	Per-cent	Hours	*** % Moisture (oven)
0.0	171	25	0.0	11.35	100	0.0	84.6
1.1	168	30	0.5	9.89	87	0.5	78.9
2.1	167	32	1.0	8.23	72.5	1.0	75.3
3.2	167	32	1.5	6.95	61	1.5	73.2
4.3	172	24	2.0	5.70	50	2.0	67.4
			2.65	4.01	35	2.5	45.5
			3.1	3.17	28	3.0	40.0
			3.65	2.65	23	3.5	24.7
			4.15	2.39	21		

Average Circulation..........250 L. F. M.
Average Temperature..........169 Degrees Fahr.
Average Relative Humidity....29%
Moisture Content.............20%
Time of drying...............4.3 hours
Quality......................Very Good.

* Average of two thermometer readings
** Sum of the weights of fruit on five trays
*** Average of two determinations.

Discussion of Time.

From column six of the preceeding data the time curves were obtained. They are divided on the following pages into three groups, representing the influence of temperature, humidity, and circulation. Sufficient data was not obtained to make the grouping complete, nevertheless there are distinct differences in time which undoubtedly are due to the factors involved.

In each of the three major groupings there are sub-groupings with two factors constant and the third varying. For example, the factor--'temperature' page--- 62 has, under the sub-grouping 'medium circulation and high humidity'--circulation and humidity practically identical, with temperature varying. Therefore, any difference in drying time in these three runs must be due to temperature.

Horizontal readings on the graph represent time and vertical readings weight. The more abrupt the curve the quicker the time of drying and the smoother the curve the more constant were the conditions throughout the experiment.

GROUP 1--CIRCULATION

Sub-groups:

	Temp.	Cir.	Hum.	Hrs.	Exp.		Temp.	Cir.	Hum.	Hrs.	Exp.
1.	135	250	13	5.8	26	2.	116	700	16	5.5	24
	140	750	9	3.8	20		117	1400	12	5.0	17
	134	1400	7	3.3	16						
3.	174	700	8	2.0	25	4.	148	750	36	3.7	10
	171	1400	5	1.8	18		151	700	33	4.0	22
							149	1400	35	2.0	14
5.	137	250	32	7.5	27	6.	169	250	29	4.3	28
	133	700	35	5.3	23		170	700	26	3.0	21
	135	1400	31	3.6	19		165	750	32	2.8	13
							169	1400	29	1.8	15

Sub-Group 1--Medium temperature and low humidity.

At a medium and a low humidity increased circulation decreases the time of drying. There is a greater decrease from the low to the medium circulation than from the medium to the high circulation although the increase in lineal feet per minute is greater in the latter. This would indicate that the maximum is below 1400 L. F. M.*

Sub-Group 2--Low temperature and low humidity.

Circulation again decreases drying time but does not materially do so above 700 L. F. M. This verifies the above results at a low temperature.

Sub-Group 3--High temperature and low humidity.

Results again verify the above at an extremely high temperature.

Sub-Group 4--Medium temperature and high humidity.

Here, circulation above 700 L. F. M. has a decided influence on drying time, decreasing it by one half.

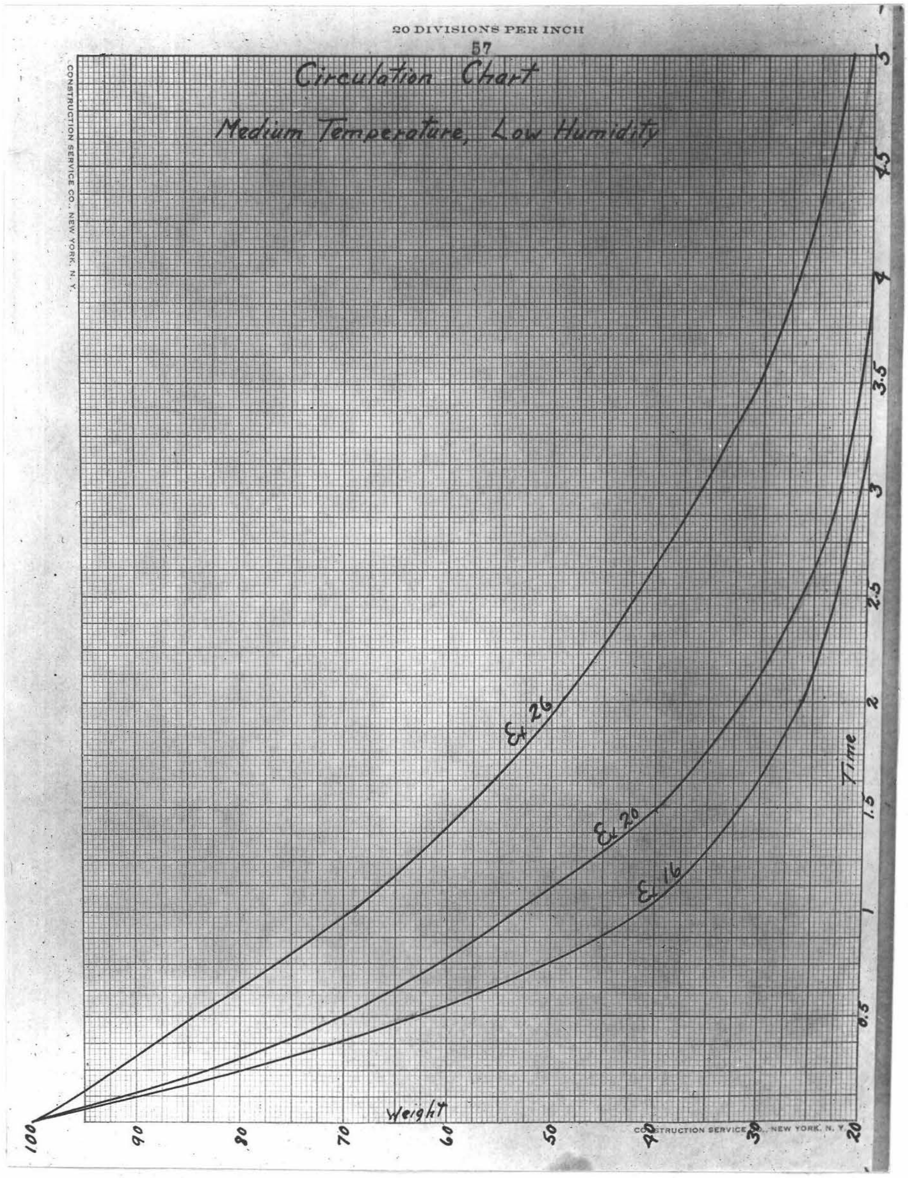
Sub-Group 5--Medium temperature and high humidity.

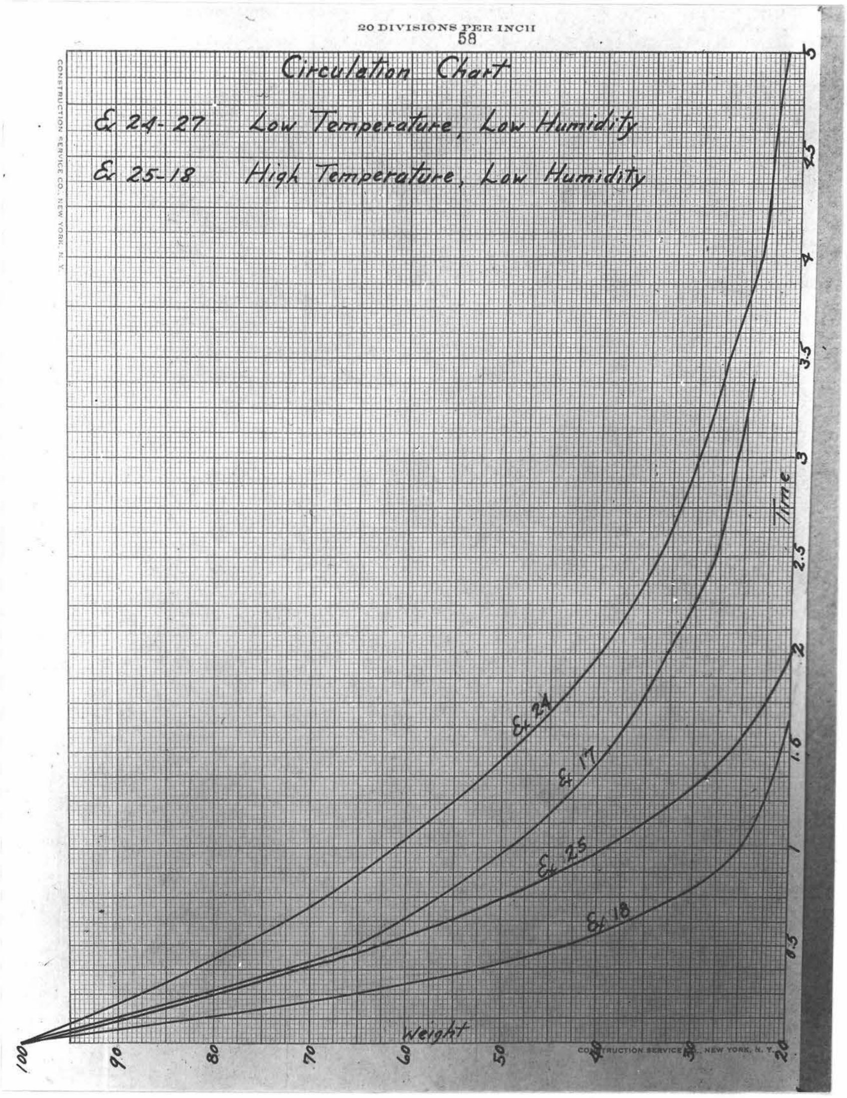
Again the drying time is materially reduced by a high circulation when the humidity is high.

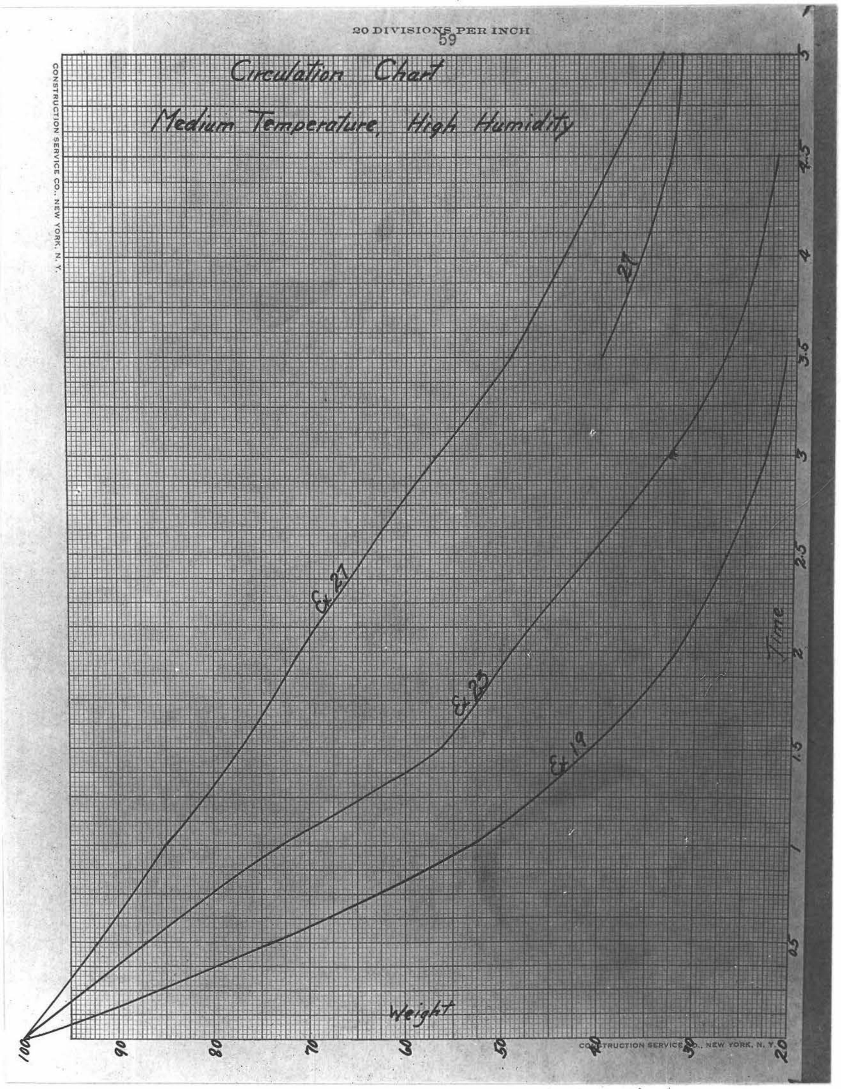
Sub-Group 6--High temperature and high humidity.

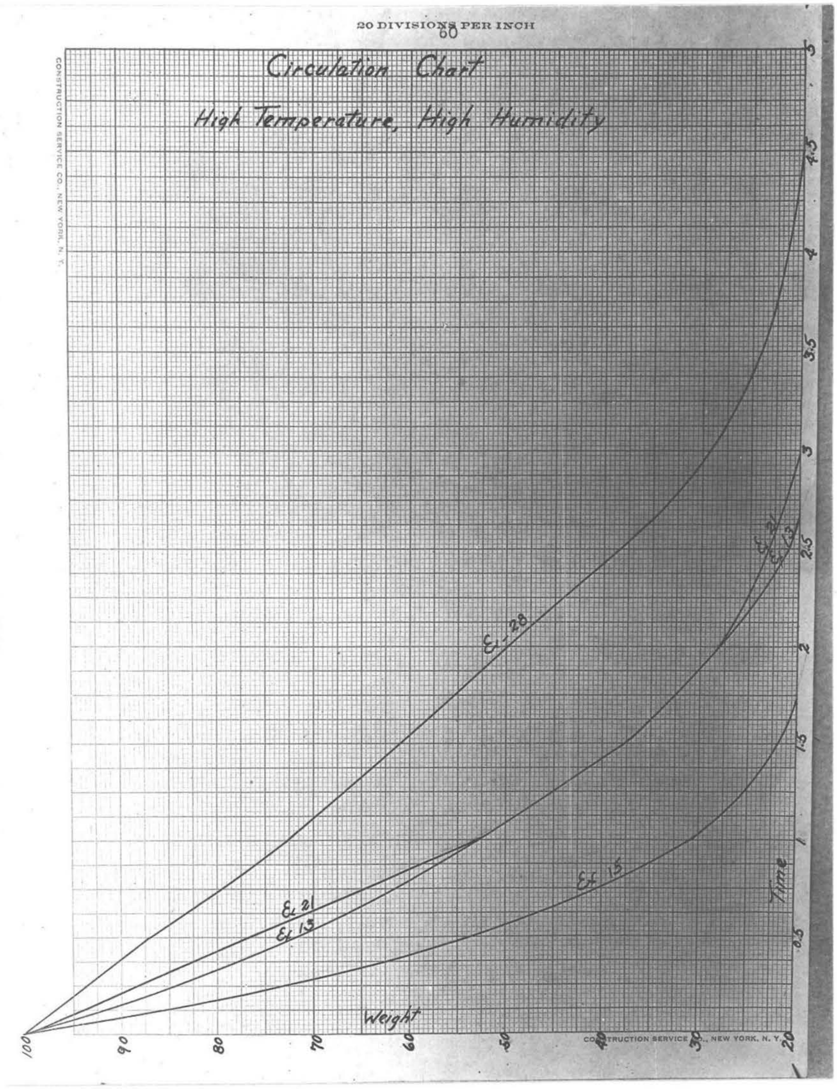
At an extremely high temperature there is not as marked an influence of air movement from either the low to the medium or medium to high circulation.

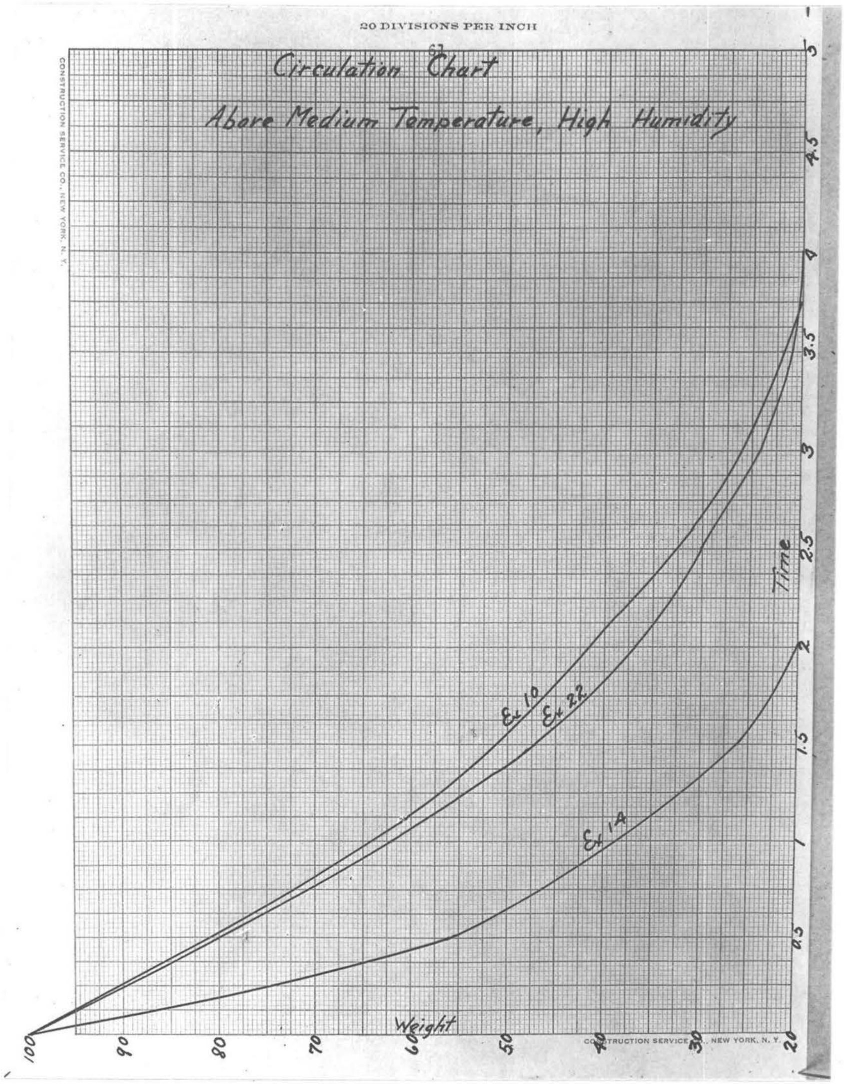
Drying time is not appreciably decreased by circulation at low humidities irrespective of what the temperature is. At higher humidities high circulation is somewhat of a factor in the time of drying. Circulation can be stated to have a decided influence on decreasing drying time.


20 DIVISIONS PER INCH
57
Circulation Chart
Medium Temperature, Low Humidity
CONSTRUCTION SERVICE CO. NEW YORK, N. Y.
Ex 26
Ex 20
Ex 16
Time
Weight
100
90
80
70
60
50
40
30
20
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5


20 DIVISIONS PER INCH
58
Circulation Chart
Ex 24-27 Low Temperature, Low Humidity
Ex 25-18 High Temperature, Low Humidity
Ex 24
Ex 17
Ex 25
Ex 18
Time
Weight
100
90
80
70
60
50
40
30
20
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
CONSTRUCTION SERVICE CO., NEW YORK, N. Y.


20 DIVISIONS PER INCH
59
Circulation Chart
Medium Temperature, High Humidity
Et 27
Et 23
Et 19
27
Weight
Time
100
90
80
70
60
50
40
30
20
.5
1
1.5
2
2.5
3
3.5
4
4.5
5
CONSTRUCTION SERVICE CO., NEW YORK, N. Y.


20 DIVISIONS PER INCH
60
Circulation Chart
High Temperature, High Humidity
CONSTRUCTION SERVICE CO., NEW YORK, N. Y.
Ei 28
Ei 21
Ei 13
Ei 15
Ei 21
Ei 13
Time
Weight
100
90
80
70
60
50
40
30
20
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5


20 DIVISIONS PER INCH
Circulation Chart
Above Medium Temperature, High Humidity
Ex 10
Ex 22
Ex 1A
Time
Weight
100
90
80
70
60
50
40
30
20
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
CONSTRUCTION SERVICE CO., NEW YORK, N. Y.

GROUP 2--TEMPERATURE

Sub-groups.

	Temp.	Cir.	Hum.	Hrs.	Exp.
1.	133	700	35	5.3	23
	151	700	33	4.0	22
	165	750	32	2.8	13
2.	135	1400	31	3.6	19
	169	1400	29	1.8	15
	149	1400	35	2.0	14
3.	117	1400	12	5.0	17
	134	1400	7	3.3	16
	171	1400	5	1.8	18
4.	116	700	16	5.5	24
	140	750	9	3.8	20
	174	700	8	2.0	25
5.	137	250	32	7.5	27
	169	250	29	4.3	28

Sub-Group 1--Medium circulation and high humidity.

An increase in temperature, both from a low to medium and medium to high, has a decided influence on drying time.

Sub-Group 2--High Circulation and high humidity.

Temperature again shows a very marked influence on drying time.

Sub-Group 3--High circulation and low humidity.

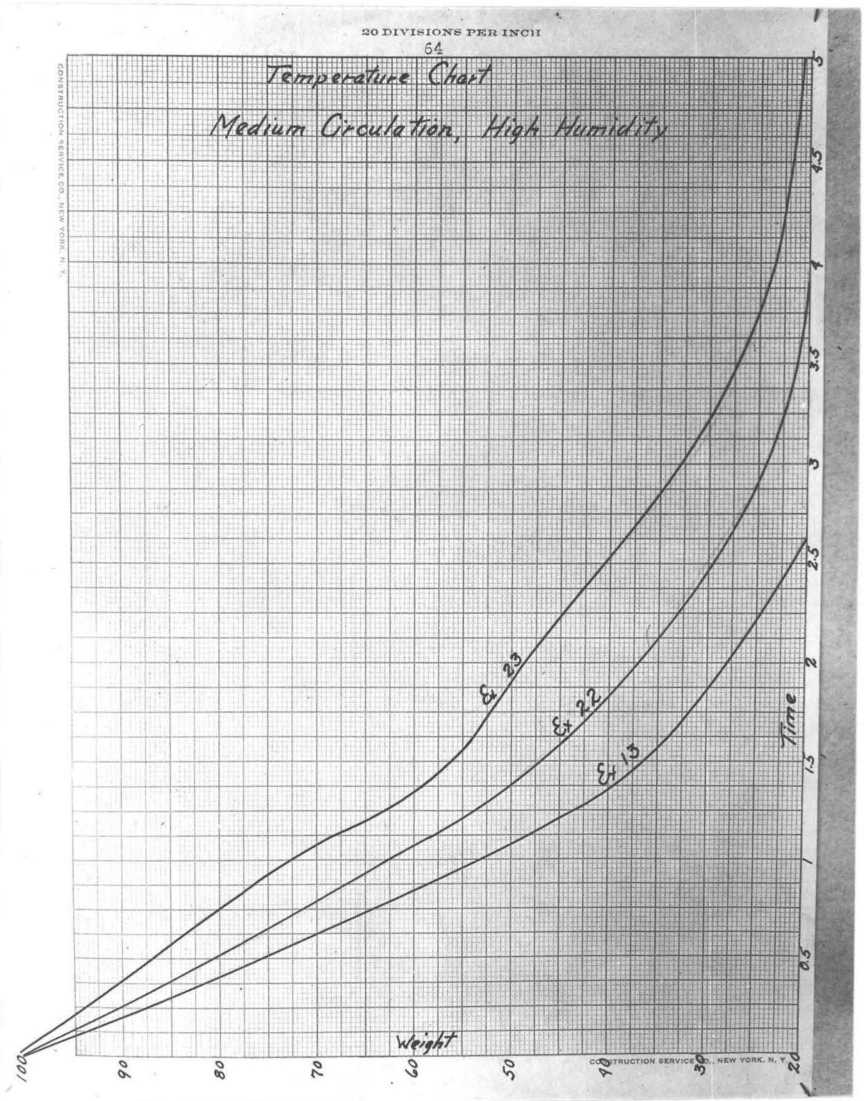
There is practically the same influence on drying time whether a low or a high humidity.

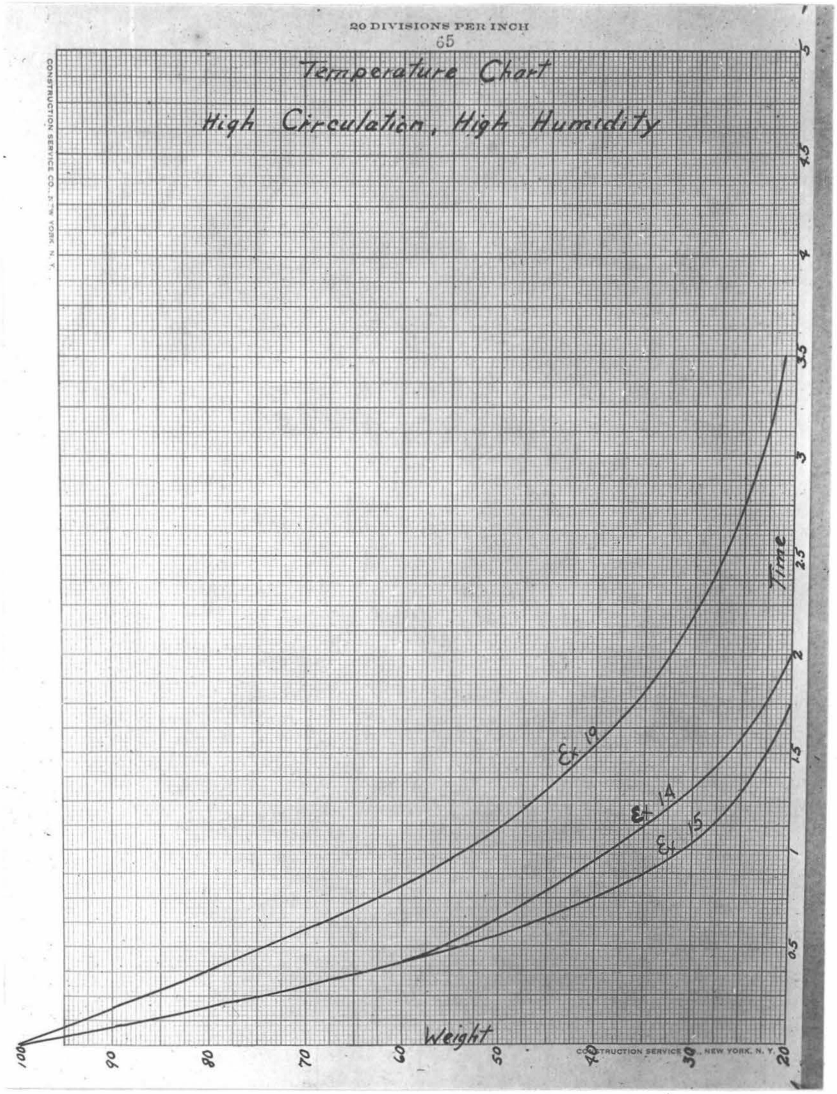
Sub-Group 4--Medium circulation and low humidity.

Here, the influence of temperature seems to verify the results under circulation, that an increase in air movement above 7 or 8 hundred L. F. M., at a low humidity has no decided influence on drying time.

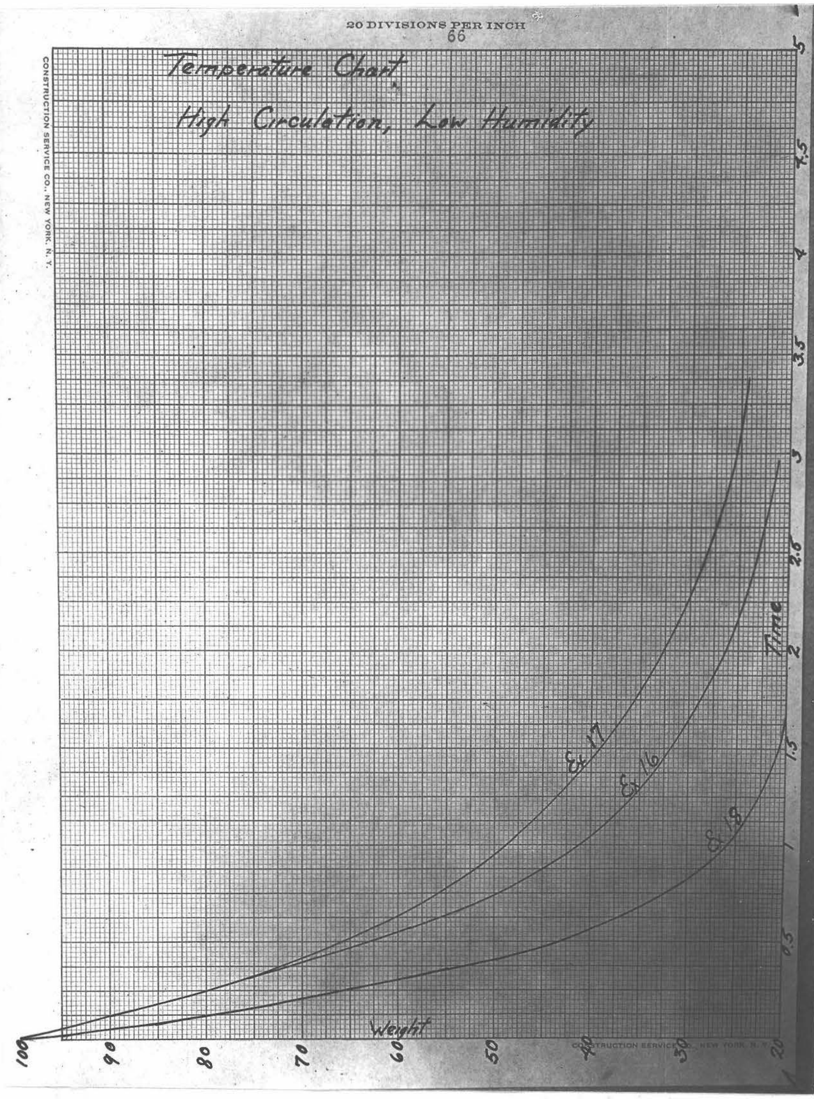
Sub-Group 5--Low circulation and high humidity.

Temperature has a decided influence although not to the extent that it offsets the influence of circulation.

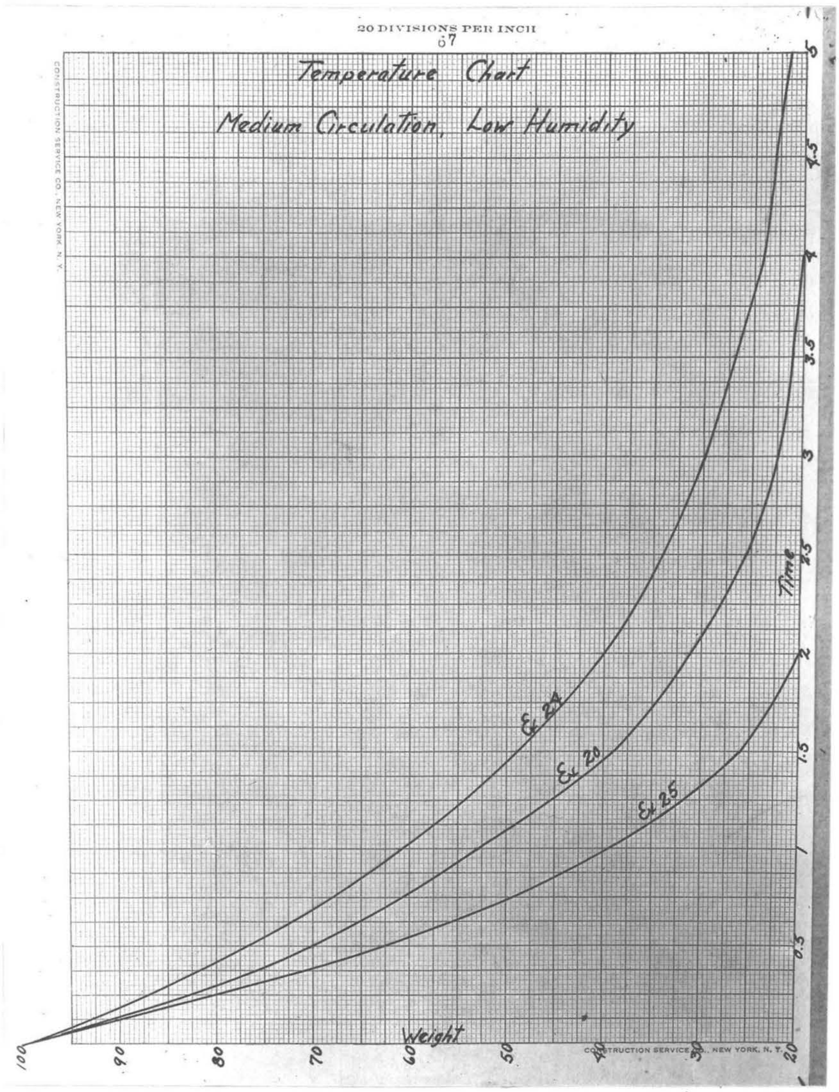

20 DIVISIONS PER INCH
64
Temperature Chart
Medium Circulation, High Humidity
Ex 23
Ex 22
Ex 13
Time
Weight
100
90
80
70
60
50
40
30
20
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
CONSTRUCTION SERVICE CO., NEW YORK, N. Y.

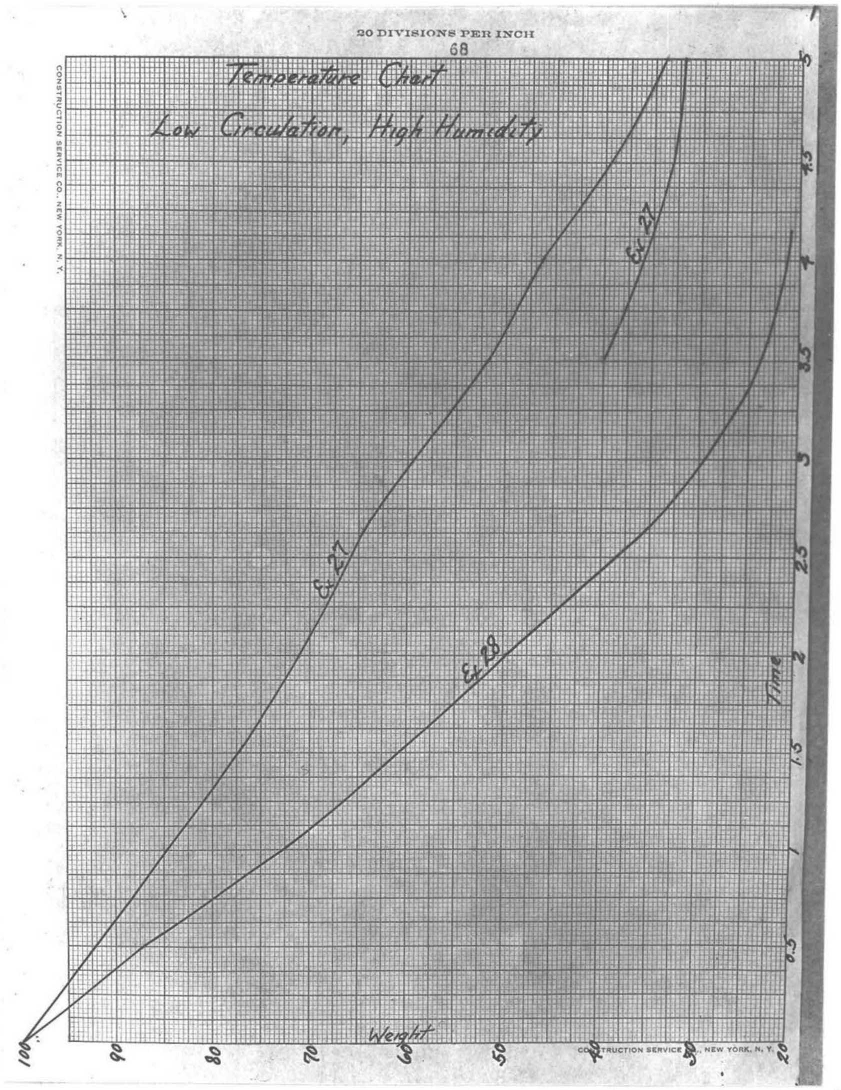


20 DIVISIONS PER INCH
65
Temperature Chart
High Circulation, High Humidity
Ex 19
Ex 14
Ex 15
Time
Weight
100
90
80
70
60
50
40
30
20
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
CONSTRUCTION SERVICE CO., NEW YORK, N. Y.



20 DIVISIONS PER INCH
66
CONSTRUCTION SERVICE CO., NEW YORK, N. Y.
Temperature Chart
High Circulation, Low Humidity
Ex 17
Ex 16
Ex 18
Time
Weight
100
90
80
70
60
50
40
30
20
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5


20 DIVISIONS PER INCH
67
Temperature Chart
Medium Circulation, Low Humidity
Ex 27
Ex 20
Ex 25
Time
Weight
100
90
80
70
60
50
40
30
20
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
CONSTRUCTION SERVICE CO., NEW YORK, N. Y.



20 DIVISIONS PER INCH
68
Temperature Chart
Low Circulation, High Humidity
Ex 27
Ex 27
Ex 28
Time
Weight
100
90
80
70
60
50
40
30
20
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

GROUP 3-- HUMIDITY

Sub-Groups.

1.	Temp.	Cir.	Hum.	Hrs.	Exp.	2.	Temp.	Cir.	Hum.	Hrs.	Exp.
	171	1400	5	1.8	18		140	750	9	3.8	20
	169	1400	29	1.8	15		133	700	35	5.3	23
3.	134	1400	7	3.3	16	4.	135	250	13	5.8	26
	135	1400	31	3.6	19		137	250	32	7.5	27

5.	Temp.	Cir.	Hum.	Hrs.	Exp.
	170	700	26	3.0	21
	174	700	8	2.0	25

Sub-Group 1--High Circulation and high temperature.

It is evident, here, that humidity has absolutely no influence on drying time, i. e., when the factors of temperature and humidity are high.

Sub-Group 2--Medium circulation and medium temperature.

With this set of factors a high humidity decidedly increased the drying time.

Sub-Group 3-- High circulation amd medium temperature.

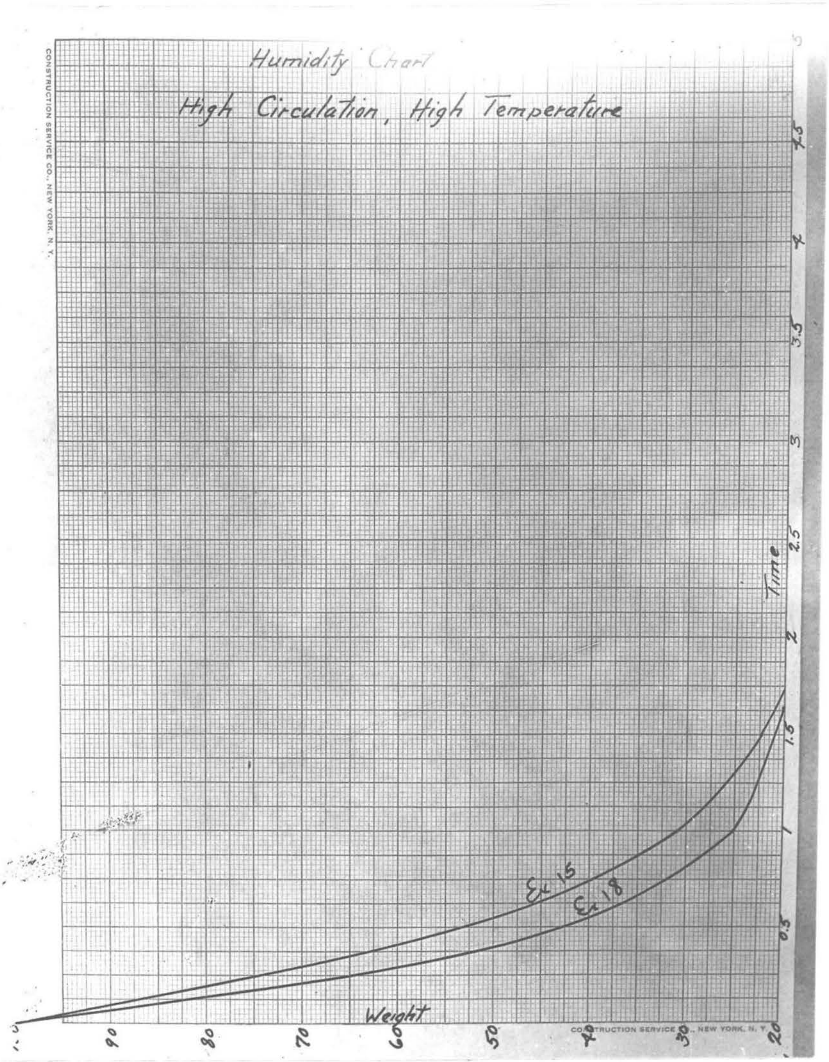
Again, with high circulation humidity has no decided influence on drying time.

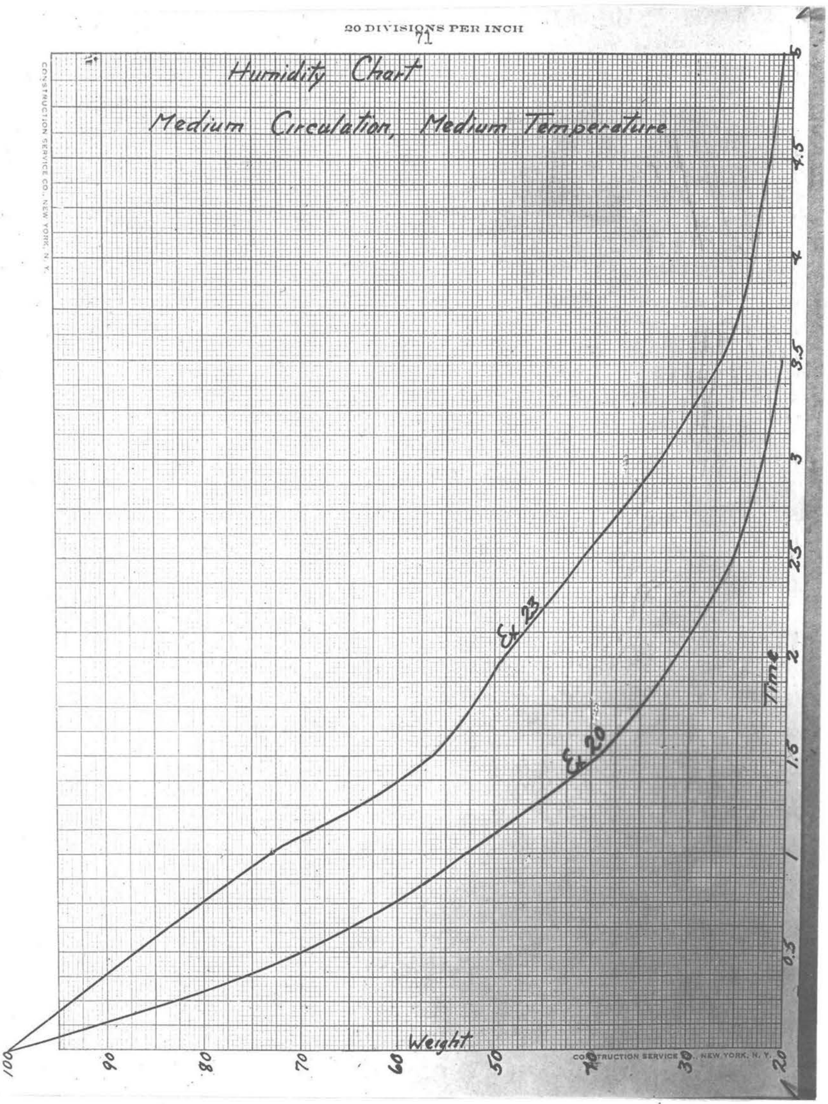
Sub-Group 4-- Low circulation and medium temperature.

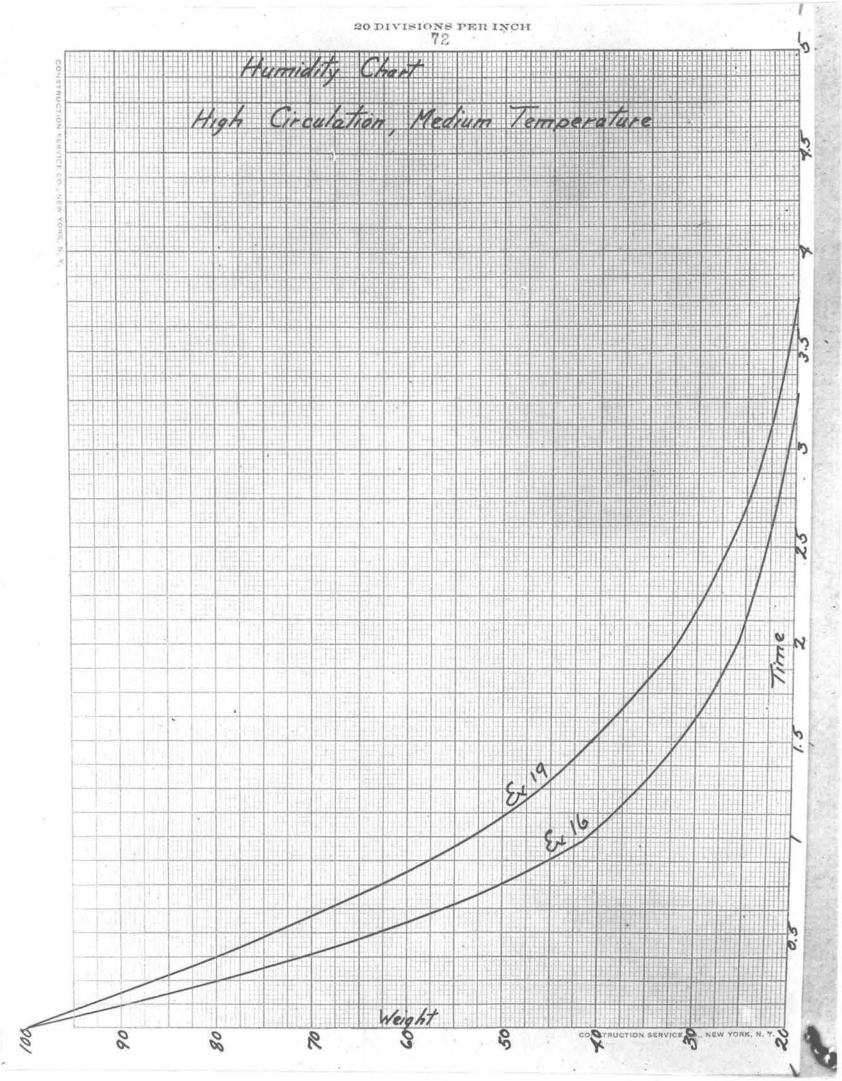
High humidity increases drying time.

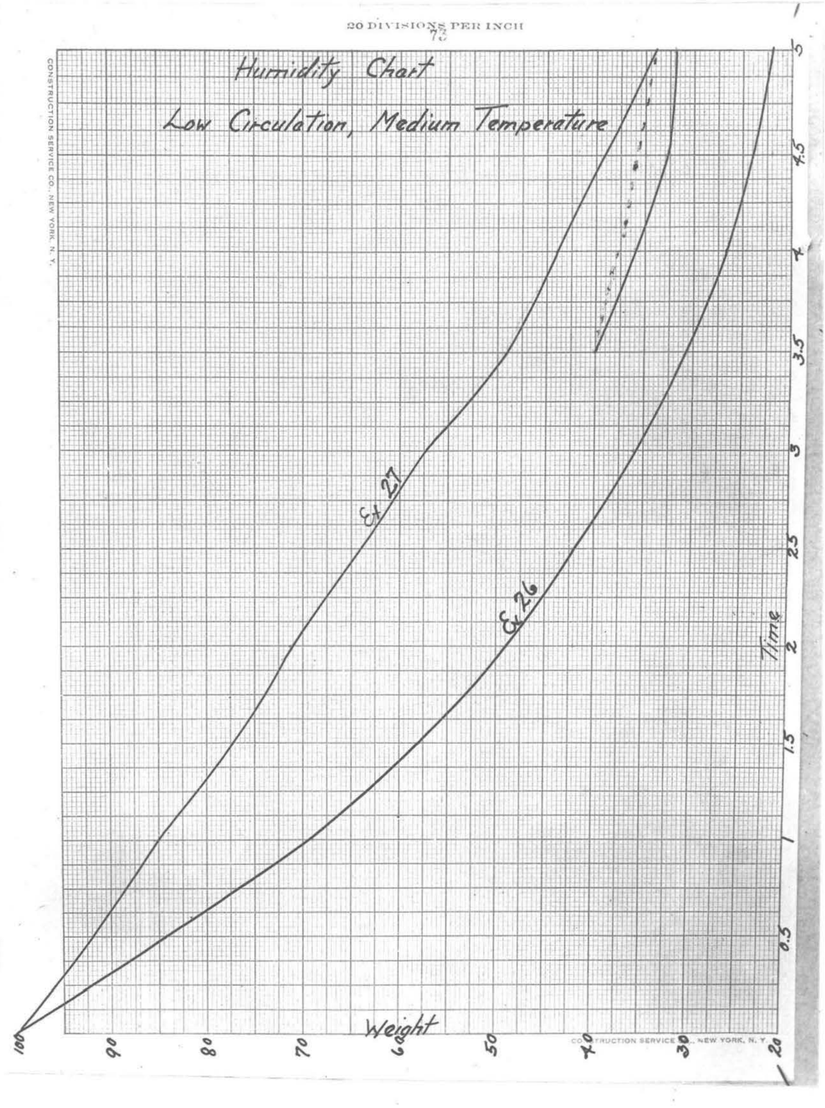
Sub-Group 5--Medium circulation and high temperature.

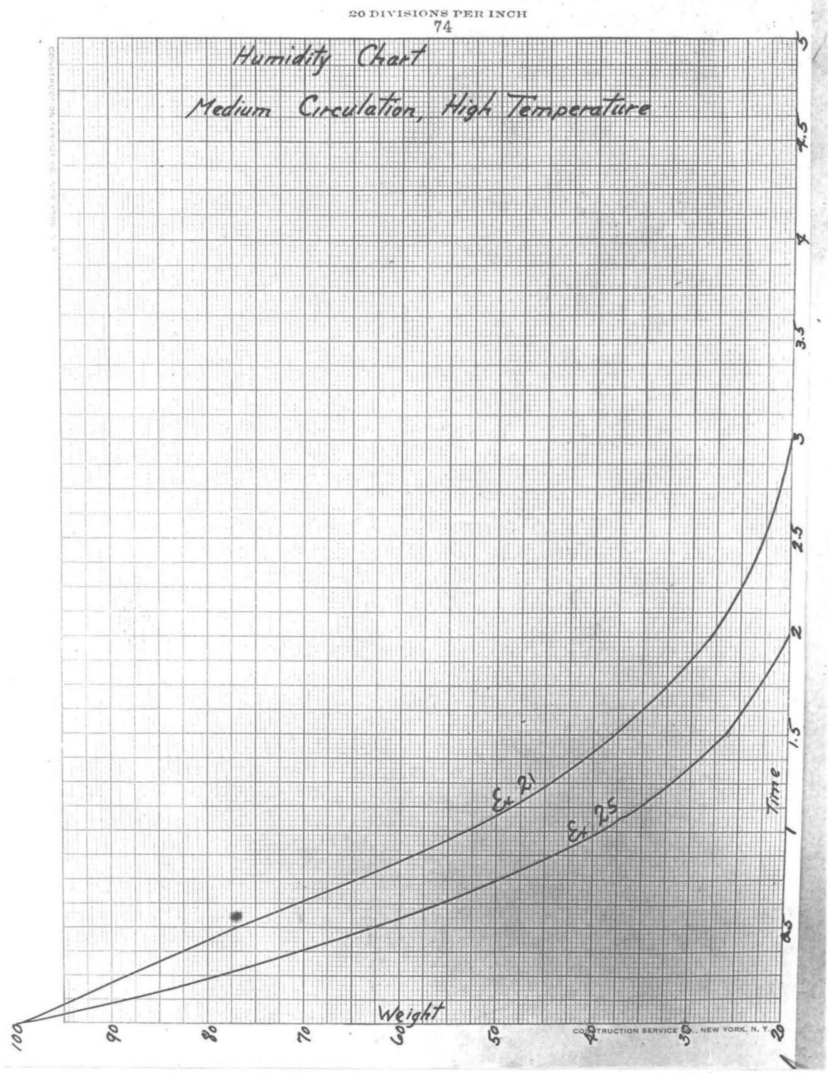
Again high humidity increases drying time.


Humidity Chart
High Circulation, High Temperature
Ex 15
Ex 18
Weight
Time
90
80
70
60
50
40
30
20
0.5
1
1.5
2
2.5
3
3.5
4
4.5
CONSTRUCTION SERVICE CO., NEW YORK, N. Y.


20 DIVISIONS PER INCH
71
Humidity Chart
Medium Circulation, Medium Temperature
Ex 23
Ex 20
Time
Weight
100
90
80
70
60
50
40
30
20
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
CONSTRUCTION SERVICE CO., NEW YORK, N. Y.


20 DIVISIONS PER INCH
72
Humidity Chart
High Circulation, Medium Temperature
Ex 19
Ex 16
Time
Weight
100
90
80
70
60
50
40
30
20
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
CONSTRUCTION SERVICE CO., NEW YORK, N. Y.


20 DIVISIONS PER INCH
Humidity Chart
Low Circulation, Medium Temperature
Et 27
Et 26
Time
Weight
100
90
80
70
60
50
40
30
20
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
CONSTRUCTION SERVICE CO., NEW YORK, N. Y.


20 DIVISIONS PER INCH
74
Humidity Chart
Medium Circulation, High Temperature
Ex 21
Ex 25
Time
Weight
100
90
80
70
60
50
40
30
20
1
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
CONSTRUCTION SERVICE CO., NEW YORK, N. Y.

Summary of Influence of Factors on Time.

To select the best combination of temperature, humidity and circulation from the work done is not possible, but an approximation can be made. Efficiency or cost of operation is most important and the set of factors that gives the shortest drying time with the least fuel cost is, from a production standpoint, the best. This choice would be subject to another deciding factor --that of quality.

Temperature has the most decided influence on decreasing drying time. Under all conditions of high or low humidity or high or low circulation its influence is felt.

Second to temperature is the influence of circulation. At high temperature it does not decrease drying time to any extent, except where a high humidity is maintained.

The only influence from humidity was found to be a slight increase in drying time.

In other words, apple tissue though subject to other laws than those governing a free water surface is influenced in a similar way, except by a decreasing ratio instead of by a direct constant ratio. The same time of drying can be obtained by several combinations of the factors and the desired one is the most economical one.

Humidity has no noticeable influence on apple tissue in maintaining capillarity and thereby, as often stated, facilitating evaporation. Several experiments were run to further substantiate this result. Whole apples, halved apples, quartered apples and cubed apples were run with and without humidity. Upon comparing the drying time no difference was found.

There is no doubt a limit to the rapidity of drying, or at least a limit to any marked influence that a further increase in favorable conditions would give.

Theoretically this would be reasonable with any form of work as friction usually increases by the square or cube. The molecule could be pictured as some larger moving body such as a train or ship. There is a point reached where friction exacts more power than can be furnished or that can be made to advantageously work. Such is the case undoubtedly with the water molecules that are bound inside the apples.

The best times made and their factors are:

Hours	Temp.	Circ.	Hum.	Experiment
2	174	700	8	25
1.8	171	1400	5	18
2	149	1400	35	14
1.8	169	1400	29	15

With both temperature and circulation limits have been reached. In the light of the incomplete work a possible suggestion of a successful combination would be--

Temp.	Circ.	Humidity
165 to 170	900 to 1000	15 to 20

As previously stated medium humidity is not an important factor in the drying time of apples when high air movement accompanies it. Its amount could be gaged by the proper and economical demand for heat re-circulation.

A proceedure much discussed is that of entrance and exit temperatures. Some claim advantages for a high and some for a low exit and entrance temperature. With apples the point is not of great importance from a time stand-point, i. e., within reasonable range. Theoretically, it would be better to have the higher heat last in order to overcome the increased resistance offered by the last 5 or 10 per cent of moisture. In the experiments referred to, no definite work was done on this problem yet it is safe to say that a difference of 10 degrees F. would do no harm, and could be obtained in an average length Oregon Tunnel with re-circulation and an air movement of 1000 L. F. M.

For commercial application undoubtedly the relation of the fruit to space would be considered. This would deal with construction, the distance between trays, and would, therefore, be out of the range of this work. This would also involve channeling and proper means to prevent it, the thickness of the spread of fruit, the size of tray rim, etc.

Influence of Factors on Quality.

There is possibly no other one thing upon which opinions differ so widely than that of quality. Methods of proceedure are established by certain definite laws of economical production. This can not be said of quality, which, dealing with the abstract, the flexible, must needs be in the field of education of tastes--of likes and dislikes. Nothing could be further from the truth than a possible inference that people can be educated to like anything. There is a wide range of choice of quality. Within this range there is a particular taste that will be acquired more readily by the general public. It is this flavor or taste that should be worked for whether it be an approximation of the fresh flavor or an altogether different flavor.

Clarence V. Ekroth speaking on the subject says, "Dehydration would thus, as the writer sees it, be definable as the process of removing all of the moisture from fruits and vegetables in such a manner as to leave the other properties, such as flavor and texture, almost wholly intact."

David Fairchild commenting along the same line says, "It seems to be instictive to ridicule a new flavor of any kind----" These opinions show that quality is variable and that it might be preferable in the drying of fruits and vegetables to change the quality, not necessarily to a superior quality but to a different quality and that by establishing this new distinct taste and flavor the product will no longer be a counterpart of the fresh article but will be a distinct commodity in itself. Such is the case with the fig and the raisin.

There is a serious objection to the present non-uniformity of dried fruits and vegetables. No product can create a popular demand on the world's markets unless it is uniform--a constant standard quality product.

Quality varies with the treatment previous to drying. Sulphuring must be reduced to a minimum as a certain bitterness seems to come from over-sulphuring.

The variety of the fruit or vegetable will more or less influence the quality of the dried product, as will also the stage of ripeness.

Taking all these things into consideration the selection of the best quality dried product can be seen to be very difficult.

There are three phases upon which the dried product may be judged: First, the appearance when dried;

Second, the color and quality upon cooking;

Third, the sugar content.

COOKING TEST.

The following cooking test of the dried samples was made by Miss Sybil Woodruff of the Home Economics Department of the Oregon State Agricultural College.

Cooking Quality of Dried Apples--

Standards for cooked dried-apple sauce--

Color--should be like fresh and recently cooked sauce; should be neither darkened nor pale.

Flavor--should be like fresh apple sauce, tart and with body; should taste neither bitter nor washed out.

Texture--should be tender and easily mashed to a smooth juicy pulp.

Experiment 1.

Method--

50 grams of each sample were weighed into a white enamel sauce pan of medium depth. Covered with 300 grams of cold tap water. Soaked one hour.

To obtain water absorption: after soaking, the apples were drained through a wire strainer until no more liquid dripped (3 minutes) and the liquid reserved.

Example	weight	of dried apple	50 grams
	"	of soaked "	173.2 grams
	"	of water absorbed	123.2 grams
	percent	of water absorbed	246.1 grams.

Liquid was replaced on soaked apples for cooking. Cooked 20 minutes in covered sauce pan, boiling moderately fast. No liquid was added or drained off.

After they had cooled they were tasted and scored:--

They were also scored the next day as check.

The apples were in the white enamel sauce pans or in white dishes while being examined.

Results:

Fine gradations of color and flavor were very difficult to record.

In many cases the flavor was quite good but the color rather dark. In only one case, No. 10, was the color exceptionally good when the flavor was poor. A sauce such as No. 20, in which the color was a little dark was preferable to No. 9, which had a good color but an inferior, tasteless flavor. With the exception of No. 12, which was pale-colored, if the color was scored lower than 35 it was because the product was darkened. There was no noticeable difference in the texture of the cooked sauces or in the length of time required for cooking.

Twenty minutes of cooking was more than was actually needed. They cooked tender in a reasonably short time.

One hour seemed plenty long for the soaking. The actual scoring was done by one individual only but several others tasted the sauces and expressed opinions which agreed with the scores.

The following table gives the results of Experiment 1.

Quality of Sauce Made from Dried Apples.

Experiment 1.

Exp. No.	Sample No.	Variety *	Water absorption (Based on: dry wt.)%	Score for Cooked Sauce: Color (35)	Flavor (45)	Texture (20)	Total (100)
5	1	N	246.1	15	20	20	55
		Remarks:Circulation 750-Temp. 150-Hum. 22 Bitter					
7	2	N	229.6	25	30	20	75
		Remarks:Circ. 750- Temp. 147- Hum. 9.					
8	3	N	236.8	30	25	20	75
		Remarks: Circ. 750 - Temp. 150. Hum. 7, Bitter					
12	4	S	180.4	25	30	20	75
		Remarks: Circ. 750- Temp. 177. Hum. 26					
13	5	N	176.8	25	40	20	85
		Remarks: Circ. 750- Temp. 165- Hum. 32					

S =

N =

Exp. 1 (continued)

Exp. No.	Sample No.	Water absorption (Based on dry wt.)%	Score for Cooked Sauce:-- Color (35)	Flavor (45)	Texture (20)	Total (100)	Variety *
14	6	214.8	25	35	20	80	S
		Remarks: Circ. 1400-Temp. 149-Hum. 35					
15	7	195.4	30	30	20	80	S
		Remarks: Circ. 1400-Temp.169-Hum.29					
16	8	203.8	35	45	20	100	S
		Remarks: Circ. 1400-Temp.134-Hum.7 Decidedly the best.					
17	9	194.8	35	35	20	90	S
		Remarks: Circ.1400-Temp.117-Hum. 12					
18	10	204.0	35	25	20	80	S
		Remarks: Circ. 1400-Temp.171-Hum. 5 Very flat and tasteless					
19	11	200.0	30	40	20	90	N
		Remarks: Circ.1400-Temp.135. Hum. 31					
20	12	198.4	30	35	20	85	N
		Remarks: Circ.700-Temp.140.Hum.9 Cool pale rather than darkened					
21	13	180.0	30	40	20	90	N
		Remarks: Circ.700-Temp.170-Hum.26					
22	14	182.8	25	40	20	85	N
		Remarks: Circ.700-Temp.151-Hum.32					
23	15	178.4	30	35	20	85	N
		Remarks: Circ.700-Temp.133-Hum.34					
24	16	201.8	30	30	20	80	
		Remarks: Circ.700-Temp.116-Hum.16					

Experiment 1 (continued)

Exp. No.	Sample	Water absorption (Based on dry wt.)%	Score for Cooked Sauce Color (35)	Flavor (45)	Texture (20)	Total (100)	Variety
25	17	218.1	30	40	20	90	N
		Remarks: Circ.700-Temp.174-Hum.8					
26	18	190.6	25	35	20	80	N
		Remarks: Circ.250-Temp.135-Hum.13					
27	19	176.8	25	40	20	85	N
		Remarks: Circ.250-Temp.137-Hum.32					
28	20	174.8	30	40	20	90	N and S
		Remarks: Circ.250-Temp. 169-Hum.29 Second choice, color somewhat dark					

Experiment 2.

Because the apples seemed to cook in less time than 20 minutes the proceedure in Experiment 1 was repeated in all details except the cooking was of only 10 minutes duration. Only samples 8, 9, 12, 17, and 20 were used as they had been found to be quite satisfactory in Experiment 1.

They cooked tender in the 10 minutes and were mashed through a sieve and made into a puree'. The flavor and color of the puree' coincided with that of the sauce in Experiment 1.

The puree' was sweetened by adding 12 grams of sugar to each sample in order to see if the flavors could be improved or more nearly equalized. However, the same differences were still noticeable in the sweetened products though all were improved.

Experiment 3.

Samples were cooked and canned for future observation.

50 grams of apple and 300 grams water.

Soaked one hour and boiled 5 minutes.

Placed in jars and heated at 5 lbs. pressure for 15 minutes.

(There were only 43 grams of apple No. 3.
" 26 " " " No. 2.)

The darkening of the color was not so pronounced in the apples cooked in the jars as in the apples cooked in the open sauce pan. This darkening is probably due to some oxidative changes which occur when exposed to the air.

Each sample was carefully gone over by three or four individuals and placed according to appearance. The first three were given their place by all who judged them.

A...........Exp. No. 20, 24, 16

B...........Exp. No. 23

C...........Exp. No. 21

D...........Exp. No. 22, 26

E...........Exp. No. 27

F...........Exp. No. 18, 19

G...........Exp. No. 25, 28

H...........Exp. No. 17

I...........Exp. No. 14, 15, 13

J...........Exp. No. 5, 4

K...........Exp. No. 2, 1

L...........Exp. No. 3

A, B, C, D are grouped as satisfactory (A, etc., being best.)

E, F, G, H, I, are rated as fair. in the order of the letters.

Sugar Content.

Although time and equipment did not permit a complete chemical examination to be made, some points were roughly observed. Tests on the carbohydrate content of experiments 14 and 16 were made, including total and reducing sugars. Experiment 14 showed a higher sugar content. As the samples were kept under similar conditions and were not analyzed for two or three months after drying there can be no positive statement made.

Summary of influences of factors on quality.

Exp. 16 gave by far the best product; Exp.28 second.

	Temp.	Hum.	Circ.	Time
Ex. 16	134	7	1400	3.3
Exp.28	169	29	250	4.0

In the cooking report the color for experiment 28 was somewhat dark. From observations made on color this could be due and probably is due to a high humidity. All three of the experiments placed first in color, before cooking, had a low humidity as well as a low or medium temperature.

Experiment 16 has a combination of factors that evidently retains color and flavor and dries in a reasonably short time. It is a case of velocity taking the place of temperature, resulting in a product dried under cooler conditions. Experiment 17 gives the extreme conditions where the actual temperature of the fruit would possibly not be much over a hundred degrees F. The quality is good but evidently not as good as in Experiment 16. Without having run a check it would not be of any importance to endeavor to conclude a definite reason for the difference.

There is a difference of 20% between the best product and the poorest, not including the first four experiments.

In comparing drying time, temperature, humidity, and circulation, no uniformity exists for the best and the poorest. No doubt there is a reason for the difference-- this reason being more or less a specific influence of moisture, circulation and heat on the chemical substances that constitute color, flavor and carbohydrate ratio, that is, sugar to starch. One set of conditions would have a good influence on flavor, another on color, and still another on sugar content while at the same time they would have a detrimental influence on the other desired qualities.

Color and appearance of dried product.

For desired color, uniformity of color, and for retention of color Experiment 16 was superior. The better color was observed to go with a medium temperature and a low humidity.

Chemical Test.

Samples from experiments 14 and 16 gave a marked difference in sugar content. This may be attributed to high humidity and high temperature being more favorable for sugar formation, although this has not been definitely proven. In tasting the dried product before the cooking the experiment 16 gave a distinct fresh acid flavor which was not as marked in the others. Experiment 14 tasted sweeter and had a milder acid flavor.

SUMMARY

1. The past and present of the evaporating industry shows a need for standard and uniform conditions of drying which means a uniform product.

2. Proper knowledge for obtaining the above can best come from scientific experimenting of which this thesis is a part.

3. In the drying of fruits and vegetables there are two objectives--time and quality. They are both influenced by the factors humidity, temperature and circulation.

4. The influence of the factors can be more easily obtained by considering their specific effect on color, flavor, sugar content and time of drying.

5. An increase in air movement above seven or eight hundred L. F. M. at a low humidity has no decided influence on drying time, whether low medium or high temperature. With high humidity increased circulation has a more decided influence.

6. Humidity increases drying time, except where the factors of temperature and circulation are high enough to overcome it.

7. Humidity has no apparent influence on maintaining capillarity and thereby decreasing drying time.

8. Indications are that high temperature and high humidity increase the sugar content.

9. Every precaution must be taken to have variety, condition, and treatment of apple the same.

10. The following factors gave the best quality product--- (from cooking test)

Temperature	Circulation	Humidity
134	1400	7

11. The following factors are selected to give the best drying time.

Temperature	Circulation	Humidity
165 to 170	800 to 1000	15 to 20

12. A proper combination for both quality and time can be given, from a general weighing of results, to be the same as under No. 11, above.

13. A high humidity tends to discolor the product.

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