

# ON THE THEORY OF WATER EVAPORATION AND ITS APPLICATION TO WITHERING AND DRYING OF TEA.

SVEN STRÖMGREN.

During the process of water evaporation, changes take place continuously both in the condition of the vapour and in the condition of the body from which the water escapes.

More important than the condition of the vapour is the condition of the body which is to be dried. Whatever method may be applied to study a process of this kind, it must aim at a disclosure of the phenomena concerning the body exposed to the drying action. In order to limit this discussion, I shall deal only with bodies of vegetable nature and of a type similar to the tea leaf.

It is known that the drying of a piece of wet cloth can be achieved by allowing air to pass over it, even if the air has a very high degree

of humidity but is not saturated. On the other hand, if fully fired tea be soaked with water and exposed to humid air, it will dry only to a certain extent, and a comparatively big amount of water will be left in the leaf. Such a residue can be dried off by passing a *very dry* air over it. From this, one may conclude that bodies behave in two different ways during drying, and in what follows I shall term a body similar in behaviour to the cloth above, as a "wet" body, and one comparable in behaviour to tea, as a "hygroscopic" body.

A body at a certain degree of moisture may behave as a "wet" body, whereas at a lower degree it may become "hygroscopic". This is actually what happens with tea leaf, although the passage from the "wet" to the "hygroscopic" state is not very marked.

Every wet or hygroscopic body exerts a pressure termed the elastic force of water vapour. In the case of a "wet" body this elastic force depends upon the temperature only, while in a hygroscopic body it is also influenced by several other factors, such as capillarity, concentration of solutions, etc. The hygroscopicity of tea leaf thus depends upon the temperature, the structure of the leaf and the concentration of the juice. The elastic force of vapour in a hygroscopic body is always lower than in a "wet" body at the same temperature. A "wet" body always has an elastic force of vapour equal to that which would exist in air were it saturated at the same temperature. The degree of hygroscopicity may, therefore, be determined by the difference in elastic force of vapour inside the body and the force in saturated air at the same temperature as the body.

An important factor in all evaporation processes is the *rate* of evaporation, i.e., the weight of the water which is evaporated from a square inch of the surface of the body per second. This rate depends firstly, upon the difference in elastic force of vapour between the body and the surrounding atmosphere, and within practical limits it is proportional to this difference. Secondly, it is influenced by the atmospheric pressure, and is approximately inversely proportional to the barometric pressure. Thirdly, it depends upon the amount of air that passes over the body per second and the area of the surface of the body exposed to the air. It is thus influenced by four factors in all, and I would like to stress that not one of these factors is either

the dry temperature of the air or its relative humidity, the latter being the ratio between the elastic force of vapour in the air present and the elastic force of the air when saturated at the same temperature. In further stressing this point, one may say that neither the relative humidity nor the temperature of the air, measures directly the capability of drying which the air may possess; to use these values to determine the drying capacity of the air to which they refer, one requires a table to find out actually what water carrying capacity the air has left.

In an evaporation process, the temperature of the body is, however, of great importance. We all know that certain materials have to be dried at low temperature, and unfortunately tea is of this type. On the contrary, certain materials can be dried regardless of temperature. If a material during the whole drying period is a "wet" body, its temperature will remain practically the same as the wet bulb temperature of the surrounding air. If at a lower moisture content, i.e., when partially dry, the material becomes hygroscopic, its temperature will have to be raised above that of the wet bulb thermometer, otherwise evaporation will cease. The drier the hygroscopic substance becomes, the higher one must raise its temperature above that of wet bulb. If, therefore, the temperature of the substance must not exceed a certain limit, the wet bulb temperature of the surrounding air may have to be lowered in order that the material can be dried to the desired degree without raising the temperature of the body.

As tea leaf at the beginning of the drying process behaves like a "wet" body, it has a temperature approximately equal to that recorded by the wet bulb thermometer in the surrounding air, but during the latter part of the drying (when the leaf becomes hygroscopic) its temperature will rise and approach that recorded by the dry bulb thermometer. In actual tests, one finds that the rise in temperature of the leaf mainly takes place in one section of the dryer or on one tray of the dryer. In reality, tea leaf is a hygroscopic substance the whole way through the dryer, but from a practical point of view it deviates in behaviour so little from that of a "wet" body in the beginning of the drying, that we may consider it during that period as "wet". Careful measurements of the temperature of the tea inside a dryer have shown that the tea on the first three trays in a 4 ft. conveyor dryer very closely follows the wet bulb temperature, the deviation being not more than 5 per cent.



hygroscopic condition takes place when there is about 30 per cent moisture left in the leaf. The actual shape of this curve will probably vary with different types of leaf, such as young leaf or old leaf, tipplings, and probably also with high-grown and low-grown leaf.

During the withering also, the leaf becomes more and more hygroscopic towards the end, although the degree of hygroscopicity is small compared to the degree reached in the drying process.

As in case of drying, the rate of evaporation during the wither depends upon the following four factors only:—

- (1) The difference in elastic force of vapour between the leaf and the air.
- (2) The barometric pressure.
- (3) The volume of air that passes through the lofts per second.
- (4) The surface exposed by the leaf to the air.

Of these factors, the first and the third are of equal importance, that is to say that a big amount of air and a small difference in elastic force of vapour are, from the drying point of view, equal to a small amount of air and a bigger difference in the elastic force of vapour. As in the case of drying, the temperature or the relative humidity of the air is of no direct interest from an evaporation point of view, especially when the withering is carried out between reasonable temperature limits, say 50 to 100°F.

So far, I have tried to derive the physical laws of water evaporation from knowledge which is common to most planters, the drying and withering processes having been used to illustrate the laws. In the following pages I shall try to describe the two processes more completely, but it may be necessary to repeat some of what has already been written in other connections.

*The Physical Process of Tea Drying.*—The curves given in Figure 2 show the physical relations between the air and the tea during a drying process. On the ordinate are plotted the temperature and the moisture contents, while on the abscissa is given the time in percentages of the total drying time. It is not intended that these curves should give more than a general idea of the process.

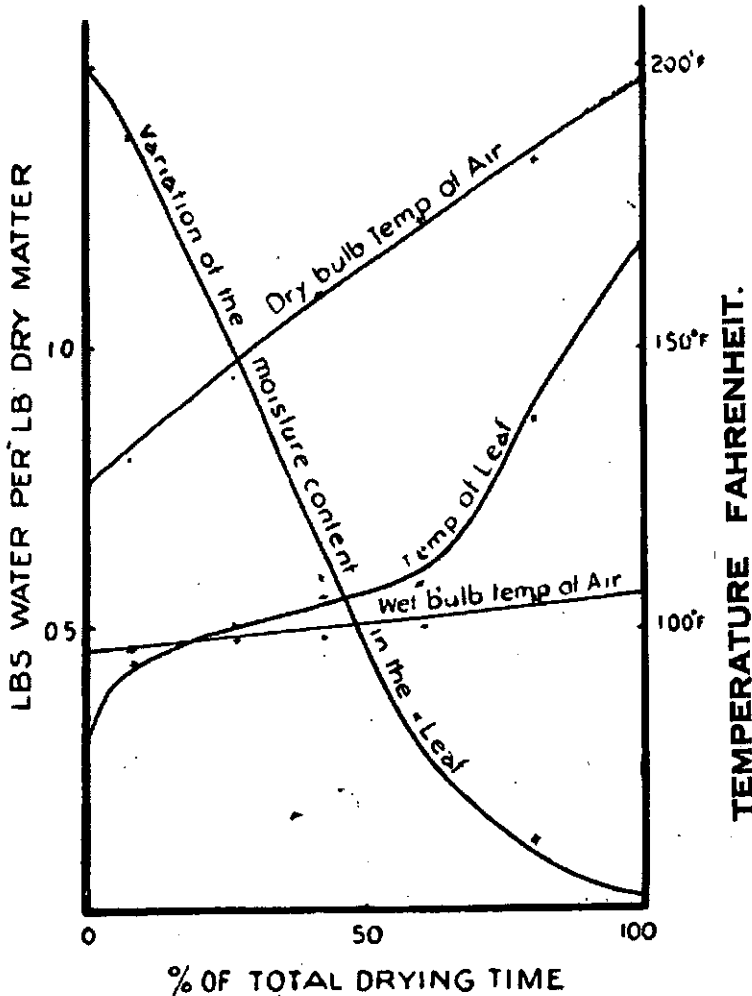


FIG 2. CURVE SHEWING CHANGES IN THE CONDITION OF THE LEAF & THE AIR DURING DRYING

The water content of the tea as well as that of the air is not counted in percentages, but in the amount of water per pound of dry air and dry tea respectively. These curves refer to a drying process where the air travels in an opposite direction to the leaf, such as occurs in a tilting tray type. In a dryer of the conveyor type, such as an E.C.P. or Empire dryer, where this is not actually the case, the process of drying is more difficult to study.

From these curves one finds that the wet bulb is practically constant through the whole drying process, while the dry bulb of the air alters considerably.

When drying tea, the question of quality has always to be borne in mind, but the relationship between quality and drying has not yet been completely elucidated. One may, however, consider that the tea leaf in the dryer should not exceed a certain temperature at any time and also that the leaf entering the dryer should be exposed to a rapid drying action in order to prevent further fermentation.

Like chemical processes in general, fermentation is mainly influenced by the temperature of the leaf and its moisture content. It is probable that the fermentation proceeds most rapidly at a certain temperature, and that its rate diminishes when the temperature rises or falls from that optimum. It is probably also correct that fermentation proceeds more rapidly with a solution of certain concentration in the leaf, and that with a more concentrated or less concentrated solution, the rate of fermentation falls off. The problem of stopping fermentation or preventing stewing (whichever term is used) is, therefore, to balance the two factors, the temperature of the leaf and the dryness of the leaf, in such a way that the rate of fermentation is sufficiently decreased at an early stage of the drying process.

Much has been written about temperatures of the air in the dryer which will prevent stewing. From a theoretical point of view and as stated above, the temperature of the air has no direct relation to either the dryness of the leaf or the temperature of the leaf. The only thing that can give us a clue whether the dryer is working properly or not, is the difference between the elastic forces of vapour in the leaf and in the air at each point in the dryer; in order to simplify matters later on, I will here introduce a term and call this

difference the "drying potential". In order to find out whether the rate of evaporation and the temperature of the leaf combine to prevent stewing or stop fermentation, one must therefore study the drying potential of the air, and the simplest method will be to determine the drying potential of the air as it leaves the dryer.

The prevention of stewing can be achieved by keeping a certain drying potential in the exit air provided that other conditions in the dryer are normal. If the air escaped from the dryer fully saturated, it would mean that the tea on the top trays, while carrying a fair amount of moisture, was undergoing a very slow drying action and being kept at a comparatively high temperature for a considerable time. The result would be similar to that of increasing the temperature in the fermenting room.

In tea gardens at high elevations, however, for tea drying purposes the climatic conditions of the air, as regards the elastic force of vapour, vary very little, provided that the inlet temperature of the air is kept constant within reasonable limits. The dry bulb temperature alone gives a fairly good measure of the drying potential and so we reach the old statement in the literature that a temperature of 120°F. at the exit will prevent stewing. This statement, however, only holds good if the wet bulb remains constant. To take an example; if tea was to be dried at a low elevation *with the air entering the stove at a temperature of 100°F. and fully saturated*, this tea would be badly stewed if fully dried with a temperature of 120°F. at the exhaust. To prevent stewing in this case, the volume of air must be increased to such an extent that the exit temperature reaches somewhat near 150°F.

As previously mentioned, a low barometric pressure helps the water evaporation, and one may therefore expect less difficulty in preventing stewing at high elevations.

There are mainly three means by which one can control the drying potential in the exhaust: (1) by varying the volume of air and this is probably the method which is most usually adhered to; (2) by varying the thickness of the spreading or the speed of the trays, the first method being the more sensitive one; and (3) (which so far as I am aware has never been used in tea drying) by regulating

the wet bulb temperature of the incoming air, or in other words, by regulating the elastic force of vapour in the air that enters the dryer. This latter method is probably the most rational one, because variation of the air volume very often disturbs the distribution of the air in the dryer, whereas variations in the amount of leaf fed into the dryer upsets the out-turn of the machine.

If the conditions of the air that enters the drying chamber proper is constant as to temperature, humidity and barometric pressure, the condition of the exhaust will vary with the amount of evaporation that takes places inside the dryer, i.e., with the amount of water that passes through the dryer per unit of time, or still better with the moisture content of the incoming leaf. If one has decided upon a certain rate of evaporation and the temperature at which the tea leaf is to be maintained during the first period of drying, he will have to regulate the condition of the expelled air in such a way that these conditions in the leaf are satisfied.

One very often hears the expression "case-hardening" used in conjunction with tea drying. I have several times purposely tried to produce this effect, but have so far only succeeded with a coarse bulk, and in order to do this the air has had to leave the dryer with a drying potential of .4 in. of mercury or more, and with the trays running at maximum speed to avoid burning later on.

Before I enter into a discussion on the practical problem of regulating the drying process, I will deal in a few paragraphs with the second half of the process, i.e., after the leaf has become hygroscopic.

It may be seen from the curves in Figure 2 that the temperature of the tea leaf during this period rapidly increases while the decrease in its moisture content is comparatively slow. While the temperature of the leaf during the first period must always be considered in conjunction with its dryness and rate of evaporation, the temperature of the leaf alone during the later period is of importance. This is because the temperature of the leaf gradually approaches that of the dry air, and the leaf, having a low specific heat, may get its temperature raised more quickly should the drying not be properly looked after. It is therefore of importance that during this period the leaf

must be exposed to air with low elastic force of vapour. This is always the case in the ordinary drying process, where the air travels in an opposite direction to the tea. Where one deals with leaf with big moisture contents, however, it may be advisable to divide the drying into two steps and carry out the first period down to 30 per cent moisture content in one dryer and to finish off in another dryer, in which case the latter process may have to be controlled in a different manner from the first.

In this connection, I should like to mention a statement which one very often hears planters put forward as a reason for so-called double firing, and that is, that the double firing increases the capacity of the dryers. This is not the case. On the contrary, double firing considerably decreases the amount of water which may be evaporated in the two dryers combined, and consequently the out-turn of tea from the two dryers also when compared with the out-turn at full firing in both machines. The only reasons for double firing are, therefore, high moisture content in the leaf and also in the atmosphere, which necessitate a separate control of the second period of the drying to prevent the leaf from reaching too high a temperature. With double firing one can also reach a lower moisture content in the tea, but it is possible that the chemical processes, which take place during the latter part of the drying, proceed in a slightly different way. Whether this is beneficial or otherwise I do not know.

Dryers consisting of two chambers in which the condition of the air can be individually controlled are in use for materials other than tea. For certain types of vegetable matter in S. America one uses a dryer consisting of a revolving drum, which for the first period is worked with heated air, whereas for a later period it is worked with cool air which has been dried over a water absorbing substance. By this method one is able to complete the drying process without raising the temperature of the material itself to such a high degree as would be necessary if the whole of the drying was done with hot air. However, I believe it has been proved that tea has to reach a certain temperature in the drying in order to "fix" its qualities.

When the tea leaves the drying chamber, it still contains a certain amount of moisture. This moisture content depends upon various factors such as the amount of air used per unit of time, its drying potential and the type of leaf such as fine dhools and bulk. In general, one may say that the higher the drying potential, the drier the leaf will be. The element of time, however, is in this respect of more importance, as the tea will become drier if it is exposed to the air longer during the later period.

If tea is kept in a container with air, it finally reaches an equilibrium when the moisture content of the tea corresponds to the elastic force of vapour in the air. At the same time, the tea will acquire a temperature equal to, or just below, that recorded by a dry bulb thermometer in the air. These conditions, however, are never reached in the dryer where the tea always has a higher temperature than that one which corresponds to its dryness.

In practice, I have found that the drying potential of the exit air is a fairly good measure of the dryness of the outgoing tea, and this is particularly so with a dryer which is doing only the second firing. Therefore, if one can control the drying potential of the air leaving the dryer, one can also control the dryness of the outgoing tea.

*(To be continued.)*