WITHERING BY HEATED AIR

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Considerable attention is now being given to the increase in the capacity of withering fans in tea factories but very little appears to be paid to the amount of heated air available from the driers. Methods of using fans and hot air are still mostly carried out by rule of thumb; the connection between the volume of air delivered by the driers and that by the fans is seldom or never taken into account. Neither is the economy resulting from running an empty drier at a high temperature seriously considered. An understanding of some of the principles involved is therefore essential if the best possible results are to be obtained from the bulking of hot air from driers and cold air from the atmosphere.

In studying the various changes that take place when air is heated, cooled or mixed it must be remembered that barometric pressure has to be taken into consideration, because the density of air varies with altitude. For withering computations, however, precise results are not required and what follows is only an illustration of the manner in which the properties of air vary under the conditions normally experienced in artifical withering.

In order to follow these psychrometric changes in a tea factory it is first necessary to know a few fundamental rules. These are given below with examples.

(1) Wet bulb temperature:—When air is heated the wet bulb temperature also rises but in some definite relation to the increase in the dry bulb temperature and the moisture content of the air.

Example:— Table 1.

Air at temp. °F.		Heated to	Final wet bulb temp. °F.
Dry	*Wet*		
65	63	80 (dry)	68
,,	,,	160 ,,	88
,,	,,	190 ,,	93
70	66	190 ,,	94
80	71	190 ,,	95

(2) Relative humidity:—Heating of air does not alter its moisture content, but its relative humidity is lowered. In other words its capacity for taking up moisture is increased.

Example:— Table 2.

Air at temp. °F. *Dry* *Wet*	Relative Humidity	Moisture content per 1000 c. ft.	Extra water 1000 c. ft. of air can take up at the existing dry bulb temperature
(*a*) 65 63	90%	0.88 lbs. water	0.10 lbs. (approx.)
(*b*) same air heated to 190° (Dry); 93° (Wet)	3%	,,	23 lbs. (,,)

(3) **Absorption of moisture:**—When air takes up moisture its *dry bulb temperature drops,* but the *wet bulb temperature remains constant.* This is what happens in a tea drier or withering loft. The drop in temperature depends on the amount of moisture absorbed. Saturation is obtained when the dry bulb temperature has dropped to the wet bulb temperature. It will thus be seen that the maximum amount of water a certain quantity of air can take up without addition of heat corresponds to saturation at *wet bulb temperature.*

The evaporative capacity of air is, therefore, not, as it is sometimes understood to be, the figure given in column 4 of Table 2. It is actually much less, as the following figures show:—

Table 3.

(Actual evaporative capacity of air)

Air at temp. °F (*Dry*, *Wet*)	Extra water 1000 c. ft. of air can take up to reach saturation
(*a*) 65 63	0.03 lbs. (approx.)
(*b*) same air heated to 190° (Dry): 93°(Wet)	1½ ,, (,,)

There should be no difficulty in understanding the difference between the two sets of figures given in Tables 2 and 3 so long as it is remembered that whereas the former refers to saturation at dry bulb temperature the latter deals with saturation at wet bulb temperatures. The distinction should be clearly understood because of its application to the drying and withering of tea.

(4) **Cooling by absorption of water:**—The drop in the dry bulb temperature after air has been used for drying or withering is explained by the foregoing remarks. The greater the amount of moisture taken up by the air the bigger the fall in the dry bulb temperature. At ordinary temperatures, the absorption of only 0.1 lbs. of water per 1,000 cubic feet is sufficient to lower the dry bulb temperature approximately 6°F. At high temperatures, the fall in the dry bulb temperature is slightly greater and for the same absorption of moisture is nearly 7°F.

In theory, therefore, the passage of air through a drier operated at say 190°F (inlet) and 130°F (exhaust) results in the air absorbing 0.85 lbs. of moisture per 1,000 cubic feet. Actually, it is less since the drop in temperature of 60° is not entirely due to moisture absorption. If radiation losses are accounted for and corrections made for the change in the density of the air, it will be found that under normal firing conditions the evaporation is equivalent to a little over ½ lb. of moisture per 1,000 cubic feet.

(5) **Cooling by abstraction of heat:**—When air is cooled by this method, both the dry-bulb and wet-bulb temperatures are lowered, till dew point is reached after which point if further cooling takes place surplus moisture is condensed. This phenomenon has been actually observed in some factories and is usually brought about by the employment of air at a high dew point. If the temperature outside is low, and insulation poor a considerable amount of heat is abstracted from the air in a loft. In the early stages of withering, especially when leaf is wet, the evaporation is so rapid that the air is almost saturated. If 100 per cent. saturated the dew point becomes that of the wet-bulb temperature, and any subsequent cooling causes condensation.

It must be remembered that dew point is entirely dependant on the moisture content of the air. For example, air at 65°F (dry) 63° (wet) has the same dew point temperature of 62°F (approx.) as air at 80° (D), 68° (W) or air at 190° (D), 93° (W). The exhaust air of a drier while in use for the drying of tea has a much higher moisture content and its dew point is therefore higher. That of air at 125°F (D), 93° (W) is nearly 85°F.

(6) **Mixture of air—dry bulb temperature:**—When air quantities at two different dry bulb temperatures are mixed, the dry bulb temperature of the mixture depends on the proportions in which they are mixed together.

Example:—Air at 160°F mixed with air at 60°F.

If in equal proportions the temperature of the mixture is

$$\frac{160+60}{2} = 110^\circ$$

If in the proportion of 1 to 10, the temperature of the mixture is

$$\frac{(1\times160) + (10\times60)}{1 + 10} = 69^\circ$$

Air at	mixed with	*Air at*	*in proportion*	*Temperature of mixture.*
190°F		60°F	1 to 10	72°F
120°F		70°F	1 to 10	75°F

(7) **Mixture of air—wet bulb temperature:**—The wet bulb temperature of a mixture is not so easily calculated since this depends on the moisture contents of the two quantities of air that are mixed together. The aid of a psychrometric chart has to be resorted to.

The following Table 4, calculated from a psychrometric chart, may serve as a guide for estimating the temperature in a withering loft when mixing hot and cold air in different proportions.

The dew point of the mixture and percentage relative humidity are also given as a matter of interest.

Table 4.

A. *Hot air from a drier NOT being used for firing of tea.*

Temperatures °F			Mixed in proportion of	Mixture			
Hot air.	Cold air. D.B.	W.B.		Temperature D.B.	W.B.	Dew Point	% Relative Humidity (approx.)
160	65	63	1 to 5	81	68	62	50
,,	,,	,,	1 to 10	74	66	62	65
,,	,,	,,	1 to 15	71	65	62	70
,,	75	71	1 to 5	89	75	69	50
,,	,,	,,	1 to 10	83	73	69	65
,,	,,	,,	1 to 15	80	72	69	70
190	65	63	1 to 5	86	70	62	45
,,	,,	,,	1 to 10	76	67	62	60
,,	,,	,,	1 to 15	73	66	62	70
,,	75	71	1 to 5	94	76	69	45
,,	,,	,,	1 to 10	85	74	69	60
,,	,,	,,	1 to 15	82	73	69	70
B. *Hot air from the drier exhaust while tea is being fired.*							
125	65	63	1 to 5	75	70	67°	75
,,	,,	,,	1 to 10	70	66	65°	80
,,	,,	,,	1 to 15	69	66	64°	85
,,	75	71	1 to 5	83	76	74°	70
,,	,,	,,	1 to 10	80	74	72°	75
,,	,,	,,	1 to 15	78	73	71°	80

In practice indentical results are unlikely to be obtained but from the data provided information is available concerning the conditions under which a withering system can best be employed. A large proportion of the methods now used are crude and empirical; further some of the present withering systems leave much to be desired and if the principles of air-conditioning were properly understood a higher degree of success could be achieved.

One fundamental fact stands out from these data and it is that the exhaust air from a drier, has, contrary to popular belief, further drying capacity. Although it contains the additional moisture picked up from the leaf during drying, it can be usefully employed for withering. But it may be readily seen from table 4 that the amount of cold air that has to be mixed with the exhaust air to provide sufficient drying capacity is much less than that required for an empty drier. It is obvious, therefore, that the valuable heat from drier exhaust will be wasted by indiscriminately letting in too much cold air.

A further study of the figures in table 4 also reveals the following information.

(*a*) No matter what outside temperature conditions exist or at what temperature the drier is run, an increase of about 10°F in the dry bulb temperature is sufficient to give conditions suited for withering purposes.

(*b*) The drying capacity of the mixture is influenced to a much greater extent by the amount of outside air admitted than the temperature of the hot air.

(*c*) If the capacity of the withering fans is more than 15 times that of the drier and they are worked at their maximum efficiency the hygrometric difference of the conditioned air may at times be lower than the figure of 7°F generally accepted.

(*d*) The wet bulb temperature of a mixture of outside air and hot air from an empty drier rises approximately 1° for every 3 to 4° increase in the dry bulb temperature.

This relationship does not hold true when the exhaust air from a drier is used.

In the light of the foregoing information and the knowledge that the dry bulb temperature drops when air takes up moisture it is not difficult to understand why a minimum hygrometric difference of 7°F is recommended in artificial withering. It is therefore, obvious that the smaller the volume of air delivered into a loft the bigger should be the hygrometric difference and vice versa. It is uneconomical of course to have too large a volume of air with too small a wet bulb depression. In any case, the amount of air is limited to some extent by the speed at which it travels through a loft. Neither is a low volume of air satisfactory because apart from the fact that there will be very little air movement the temperature will have to be raised unduly to give the necessary drying capacity.

It is evident, therefore, that temperature is not the most important consideration in artificial withering. The amount of air available is equally important and it would appear that many factories to-day possess inadequate fan capacity. This probably explains the increasing tendency to employ high temperatures in withering. The figures given in table 5 may be used to estimate fan requirements in relation to crop and size of drier.

Table 5

Drier for withering	Total fan capacity (cu. ft. per min.)	No. of bulking chambers	Average daily green leaf in-take	Annual crop. (made tea)
3′	50,000 to 80,000	1	5,000 lbs.	300,000 lbs.
4′	80,000 to 120,000	1	8,000 ,,	500,000 ,,
5′	120,000 to 180,000	1 or 2	12,000 ,,	750,000 ,,
6′	160,000 to 240,000	1	16,000 ,,	1,000,000 ,,

It must not be concluded that more fan capacity is not desirable but anything lower is certainly inadequate. If the capacities of fans and driers are so related as given in Table 5, no difficulty should be experienced, even under adverse monsoonal conditions, in getting a reasonable hygrometric difference in the conditioned air. There is no necessity for high temperatures to get a mixture of suitable drying capacity when sufficient fan capacity is available.

One limiting factor in increasing the size or speed of fans is of course the velocity of air flow through one single loft. But this is not so serious as it is made out to be. If air speeds are so high as to blow leaf off the tats, the bank nearest the bulking chamber can be kept free. In the alternative, a part of the air can be diverted into an empty loft, or all of it reversed into the section containing the leaf; or for that matter, only one fan can be operated.

It is strange, however, that no attempt has yet been made to provide variable speed fans to meet contingencies as the one just mentioned or when crops are low. Such a scheme will not only make control of the withering process easier but will also save power. The delivery of air from the fans could then be varied according to crop, and in this way the loss of heat, due to excess air, uncontrollable on the present systems, could be reduced to a minimum.

While on the subject of heated air for withering it may be well to consider the measures to be taken to secure the most satisfactory results. No hard and fast rules can be set down because of the numerous variable factors. The following practical hints, however, may prove helpful to those factories where the process is being haphazardly carried out.

(1) Although the efficiency of most of the present schemes has been considerably improved by boosting the air and reversing it, thicker spreading of leaf nearer the bulking chamber is strongly recommended.

(2) Spreading of wet leaf should always start furthest from the bulking chamber.

(3) The loft should always be warmed before wet leaf is spread.

(4) The highest possible temperature should be used for removal of surface moisture. Many observers recommend large hygrometric differences for this purpose, but it is quite apparent from Table 4 that in practice they cannot be obtained. Generally, the driers are being used for the firing of tea at the times wet leaf is received and the only source of heat is the drier exhaust. To obtain the maximum temperature the minimum amount of cold air must be admitted but care must be taken in doing so to see that the fans are not too scantily supplied with air. A part of their demands in such circumstances might be met from the driers themselves causing erratic firing.

(5) Hygrometers are necessary for control but they should be placed in the correct places, not in the middle of a loft or behind a bank of tats, as is customarily done. That recording the temperature of the inlet should be in front of the first bank and the one at the exit end directly opposite the window through which the air is discharged.

When air is led from one loft to another below or above it the hygrometer should be placed behind the last bank of tats. If the hygrometric difference is found to be less than 3°F after it has passed over the leaf little will be gained by passing it through another loft. If after traversing two lofts or more, air is discharged into the atmosphere with a hygrometric difference of over 4°F excess heat is just being wasted.

(6) If the capacity of fans is found to be inadequate the air used for artificial withering should have a hygrometric difference greater than 7°F. A 10°F wet bulb depression or even more is possible without having to raise the dry bulb temperature beyond a point where quality is likely to be seriously impaired.

(7) In a factory possessing adequate fan capacity there should be no difficulty in creating conditions at night approaching natural conditions in the day time. By a suitable adjustment of drier temperature and airflow through the drier, the maintenance of temperatures not exceeding 75°F(dry) with a satisfactory wet bulb depression is not at all a formidable task.

(8) A higher drier temperature with less air is more economical than a lower temperature and more air. Every effort should therefore be made whenever circumstances permit, to run an empty drier when used for artificial withering at the highest possible temperature, using the fan-damper to regulate the temperature of the mixture of the air in the lofts. This is an easier and more economical form of control than the empirical method of shutting and closing windows opposite the fans or in the drying room.

(9) Just as important as allowing sufficient openings for air to leave the lofts it is equally necessary not to starve the fans. The area of air entry should not be less than the area of the fan inlet. Table 6 gives the minimum free area required for fans of different sizes.

Table 6.

Diameter of fans	Minimum area for 2 fans.
6'	60 sq. ft.
7'	80 ,, ,,
8'	100 ,, ,,
9'	130 ,, ,,

It is not intended in this article to discuss the wider aspects of artificial withering. The main purpose has been to give an insight into a process which would appear to be the one least understood in tea manufacture. There is a common notion for instance that a hygrometric difference of over 6-7°F in withering is harmful. Another view that has no foundation is that natural withers cannot be obtained in a reasonable time if the hygrometric difference is lower. In consequence, artificial withering has become a habit in most estates. The poorer results that followed from the indiscriminate use of heated air naturally gave rise to the erroneously held belief that artificial withering is an evil. Without question, a natural wither does give better results provided the period is not unduly lengthened, but for a greater part of the year the use of heated air is a necessity in some factories. It is hoped these notes will enable better results to be obtained from a process against which a deep-rooted prejudice still exists.

Photo by B. N. Webster