

FERMENTATION IN RELATION TO HEAT DEVELOPED IN ROLLING

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Of all the external factors influencing the fermenting process in tea manufacture temperature is undoubtedly one of the most important because fermentation is an enzymic process. According to work carried out on the biochemistry of tea, in which the activity of the enzyme extracted from tea leaf was studied, it was found that under *in vitro* conditions the temperature for optimum enzyme activity was 81°F, and that above this temperature its rate diminished rapidly. It does not necessarily follow, however, that at this optimum temperature the characteristics of a tea liquor are at their optimum.

Even should an ideal temperature be determined, the batch process of rolling and subsequent operations of roll-breaking and extraction of dhool preclude any such Utopia being realised for the present. For it must be remembered that fermentation is not confined only to that period during which the leaf lies on a fermenting rack; fermentation commences from the time leaf is bruised in the rollers. Thus each dhool is not only subject to a different temperature, but to a variable temperature in the course of fermentation. To maintain a constant temperature throughout rolling, roll-breaking and the final stage of fermentation would indeed be a costly undertaking.

It would appear, therefore, that, under the existing system of tea manufacture, the determining of an ideal temperature in fermentation is not of much practical value. It would really be far more useful to know what temperature is harmful and the period for which its influence is most marked. With this knowledge the way should be clearer to an understanding of what changes take place in the warmer conditions induced by rolling.

The fact that most of the fermentation proceeds in the rollers at temperatures considerably higher than at room temperature makes this question all the more important. The vital part that the heat generated in rolling plays in fermentation is recognised, but there appears to be little information available on the extent to which this heat affects the individual characteristics of a tea liquor.

The term heat can be interpreted in many ways as it is only a sensation which is entirely relative to the conditions under which it is noted. For example, leaf leaving a roller at a temperature of 70°F in the early hours of a very cold morning may feel just as hot to the touch as, say, when it is at 90°F in a room temperature of 80°F. But the fermentation will be obviously significantly different in the two cases. Unless, therefore, there is a clearer insight into this question, which can only be obtained by actual temperature measurements, this so-called heat will continue to be a 'bugbear' in tea manufacture. What is perhaps meant by the popular phrase 'Heat is the enemy of quality' is unnecessary heat, but even so the phrase is vague and perplexing.

As the scope of this article is to show the influence of high temperatures in fermentation, which generally prevail during the rolling process, no attempt is being made to set down any specific critical temperature below which fermentation is inhibited. But a word or two about low temperatures may not be out of place.

Tea leaf is known to ferment at exceptionally low temperatures, but the action is so slow that the period has to be unduly prolonged for the leaf to approach any semblance of the fermentation associated with that obtained at normal temperatures. The use of chilled rollers² has shown that fermentation proper takes place only after the leaf is exposed to the higher temperature in the rolling room. It has also been shown that in the range of 50°F to 68°F the best all round tea is obtained when fermented at the higher temperature³. Further evidence of slowing down in fermentation as a result of low temperatures is provided by the experimental rollers at St. Coombs each of which has a capacity of only 30 pounds of withered leaf. On account of their small charges the rise in temperature of leaf rolled in these machines is so small that a considerably longer period of fermentation than what is considered normal is found necessary. In spite of the extended period the liquors are sometimes inclined to be greenish.

From the foregoing observations it may be concluded that low temperatures are not very favourable to fermentation. How then can a satisfactory explanation be given for the success obtained in up-country factories at certain times of the year when the temperature of the atmosphere goes down to very low levels? The answer lies in the fact that the leaf itself during these periods possesses such marked quality and flavour that these two virtues, if present to a high degree, swamp the chief characteristic developed in fermentation, namely, colour. Nevertheless, a certain amount of fermentation does occur because of a noticeable rise in temperature of the leaf during rolling. This also helps to keep the leaf at a temperature higher than that of the rolling room for a considerable time after it has been sifted. Reference to the appendix to this article will convey an idea of the effect of rolling and roll-breaking on the temperature of leaf under different conditions. It will be evident from the figures given that, if not for the heat generated during rolling, very little fermentation will take place at low room temperatures.

Thus the tea roller, although regarded as a cumbersome part of factory equipment, is fulfilling a very useful purpose besides rupturing the cells of the leaf. In the slow process of extracting the juice from the leaf it provides the heat necessary for fermentation, but it can, however, not be used to the best advantage in the absence of knowledge of the actual effect of the temperatures normally reached by the leaf in the rolling process.

To assess accurately the effect of any particular temperature from the time the leaf is bruised and fermentation starts is, of course, extremely difficult, because rolled leaf in the first place is not subject to a fixed temperature during the period of rolling and, secondly, the rise in temperature of the leaf is dependent on the pressure applied and the degree of circulation. Other factors from day to day which can affect the rate of fermentation are the type of leaf, the period and degree of wither, roller charge, and the rolling room temperature. The most that can be done, therefore, is to find out how the characteristics of a tea liquor are altered at some pre-determined temperature in the course of fermentation after leaf is discharged from a roller.

In these studies the material worked with was the second dhool, which was chosen for three reasons:—

(1) It is much more uniform than the first dhool, which generally contains a higher proportion of tip and flaky leaf.

(2) It has not been subject to too high a temperature for too long a period.

(3) The influence of a high temperature of this dhool would give a reliable estimate of the effect of the heat generated in later rolls.

Since any approach to a study of the influence of temperature in fermentation must take period into consideration, it should be borne in mind that the material used for these experiments would already have been fermented for a period of an hour during rolling at a temperature higher than room temperature and for half an hour at room temperature during the roll-breaking intervals. It is a factor not to be overlooked, as will be seen from the results obtained from leaf rolled in a commercial roller in comparison with the effect produced on leaf from an experimental roller. In the former case temperatures as high as 90°F were recorded, whereas leaf rolled on an experimental scale never attained a temperature higher than 80°F. Table 1 gives the mean temperatures observed.

Table 1. Room temperatures and temperatures of the leaf at end of rolling and after roll-breaking.

	Room temperature	TEMPERATURE OF LEAF	
		At end of rolling*	After roll-breaking
<i>During flavoury season</i>			
(a) Commercially rolled leaf	60°F	83°F	68°F
(b) Experimentally rolled leaf	60°F	70°F	65°F
<i>During off-quality season</i>			
(a) Commercially rolled leaf	68°F	88°F	76°F
(b) Experimentally rolled leaf	68°F	76°F	72°F

*Two 30 minute rolls, the first dhool being 15% and second 20% through a No. 5 roll-breaker mesh.

The significant point to note from these figures is that the temperature of the leaf after roll-breaking did not fall to room temperature. In the case of (a) it was approximately 8° higher and in the case of (b) 4° higher. These temperatures showed practically no change during the whole of the period the leaf was fermented on the racks in the atmosphere of the rolling room.

It is not necessary to go into the details of the technique employed for comparing the leaf fermented at room temperatures with leaf fermented at higher temperatures. Suffice it to say that all precautions were taken to minimize the effect of outside factors and to ensure as far as possible that the result obtained was primarily due to the effect of the particular temperature under investigation, and that temperature alone. However, it is advisable to accept the results with some reserve until they are confirmed by the use of apparatus more suitable than that used for these studies.

The following points require to be noted:—

(1) As previously stated, period must be considered in conjunction with temperature for judging the effect of the latter. The standard chosen for these experiments was leaf fermented at normal room temperatures. It was necessary, therefore, in the first instance, to determine the optimum period at ordinary temperatures.

(2) Higher temperatures were compared with the standard for the same length of fermentation as the optimum period at normal temperatures.

(3) The effect of a shorter period at the higher temperature was also studied.

(4) The temperatures hereafter referred to are those of the leaf, unless otherwise stated.

(5) Any period mentioned is the actual time during which the leaf had been subject to the temperature under discussion. It does not include the periods of rolling and roll-breaking over which operations the time taken was $1\frac{1}{2}$ hours.

RESULTS

Optimum period at Room Temperature:—(a) DURING FLAVOURY SEASON:—

(Temperature of leaf about 68°F)

(Room temperature about 60°F)

(1) When flavour was present the optimum period was found to be 1 hour. A shorter period resulted in liquors that were too green and raw.

(2) Flavour definitely declined after 1 hour. Quality also had a downward trend, but not to the same extent.

(3) The most valuable tea was 1 hour, when compared with 2 and 3 hours, despite the least amount of colour.

(b) OFF QUALITY SEASON:—(Temperature of leaf about 76°F)

(Room temperature about 68°F)

(1) There was very little to choose between 1, 2 and 3 hour periods. The better quality as a result of a shorter period compensated for the poorer colour.

(2) The preference for any particular period was entirely governed by the market requirements existing at the time the teas were tasted.

(3) Colour and quality are so closely related that both features have to be taken into consideration.

(4) On the whole, 2 hours gave the best all-round tea. 1 hour was thinner and 3 hours had slightly less quality.

Effect of Higher Temperatures:—(a) 80-85°F:—For a period of 2 hours quality was slightly worse than normal. The slight gain in colour did not compensate for the slight loss in quality. During a very low quality season colour, it must be noted, increases in importance in proportion to the drop in quality.

On shortening the period to 1 hour, however, quality improved and was about the same as that for the best tea at normal temperatures.

Strength and infusion were not affected by the higher temperature.

During the flavoury season, the effect of the higher temperature was more strongly marked. Compared with the normal for a period of 1 hour (the optimum for room temperature) the higher temperature for a similar period resulted in appreciably worse flavour, slightly worse quality and appreciably better colour. The normal though possessing much less colour was the more valuable tea.

(b) 85-90°F:—Results were very similar to those obtained at 80-85°F.

(c) 90-95°F:—The effect of this higher range of temperatures was clearly significant. Compared with the normal for the same period of 2 hours, quality was appreciably worse and despite improved colour the liquor was described as not quite true. A slight dullness in the infusion was also noted. Strength of the liquor, as in the lower range of temperatures, was unaltered.

The shortening of the period to 1 hour resulted in a distinctly improved tea. Yet, the normal was slightly preferred as it had more point and a little more character. The difference in quality was, however, so small that the extra colour in the tea fermented at the higher temperature might have made it more valuable in certain markets. The shorter period also improved the infusion but it was slightly greenish and not as bright as the normal.

The effect on flavour and quality, when these two features were present at a high level, was to make the former characteristic inferior and the latter appreciably worse. They were not counter-balanced by the appreciably better colour and the tea as a whole was considered inferior.

(d) 95-105°F:—These high temperatures have actually been recorded in commercial rollers, usually in later rolls in low-country factories and sometimes even in factories at higher elevations when leaf is rolled under very heavy pressure.

Their effect for 2 hours was to produce a tea definitely worse than at normal temperature for the same period. The liquor was described as having a peculiar metallic character and was plain and unattractive with a dull infusion.

There are two remarkable influences of these very high temperatures worth mentioning. Colour of the liquor had not improved to the same extent as that in the range 80-95°F, and strength that had shown no change was slightly reduced.

A shorter fermentation of 1 hour gave results very similar to those obtained at 90 to 95°F, but the liquor was a little green.

A still shorter period of 30 minutes was tried out but the liquor was not quite true though it possessed the same amount of quality as a tea fermented at normal temperatures for a period of about 2 hours.

Flavour, of course, declined rapidly with the lengthening of the period and at 3 hours was absent.

High Temperatures followed by periods of Fermentation at Normal Temperatures:—This aspect of the influence of high temperatures was specially investigated in order that some information might be obtained on the changes that took place after a 30 minute period of heavy rolling. The same material as that used for the foregoing experiments, namely, dhool 2, was taken, and subjected for half an hour to temperatures of 90 to 100°F. The leaf was then fermented for periods varying from $\frac{1}{2}$ to $1\frac{1}{2}$ hours at room temperature.

The extension of the fermentation resulted only in a slight increase in colour with a proportionate loss in quality. The character of the liquor was barely changed and, compared with the standard fermented for 2 hours at room temperature, all these teas were not so 'round' in liquor.

Other effects of High Temperature:—(1) It is not quite clear whether 'greenness' of liquor is reduced by a higher temperature. When intrinsically present this feature may be accentuated under the influence of very high temperatures for long periods. At the same time, bright, rosy liquors have been obtained at a temperature of 90°F. The evidence was inconclusive.

(2) Creaming in some instances was better at higher temperatures.

(3) It would also appear that slightly blacker teas result from higher temperatures.

Effect of High Temperatures on Leaf from Experimental Rollers:—The foregoing results refer to commercially rolled leaf and it will be of interest to see how these same temperatures have affected leaf rolled under cooler conditions. The experimental rollers at St. Coombs provided the necessary material. Working with 2nd. dhool again, which incidentally was rolled at a temperature approximately 10° less, the following results were obtained:—

80-90°F:—Compared with the standard fermented for 3 hours, the normal period which the experimental 2nd. dhool receives, the higher temperatures for a shorter period of 1½ hours produced a distinctly better tea. It was more fully fermented than the standard, which was inclined to be thin. Flavour also was more prominent in the tea fermented at the higher temperature. For a longer period than 1½ hours quality and flavour were not so pronounced in the high temperature teas.

95-105°F:—Flavour and quality were hardly affected for very short periods, but on account of the thin, hard liquors produced, the teas were substantially worse in value than the normal.

It was noted again that colour did not improve to the same extent as at 80-90°F. Even for a period of 1½ hours colour was slightly worse than the standard fermented for 3 hours. Though the liquors compared favourably with the standard as regards individual characteristics, they lacked the 'smoothness' of the liquors from the normal temperature fermentation and were, therefore, valued lower.

SUMMARY OF RESULTS

In order to get a clearer understanding of these results a summary is given of the influence of temperature on each of the main characteristics. It must be repeated that temperature refers to that of the leaf.

Quality:—(1) High temperatures up to about 90°F are not detrimental to quality, provided periods are suitably adjusted. A total over-all period of more than 1½ hours at this temperature brings about liquors that are not quite true, accompanied by a significant loss in quality.

(2) Temperatures over 95°F even for a short period of half an hour are harmful.

(3) For equal periods, no matter of what length, a lower temperature produces better quality.

(4) At normal temperatures quality takes some time (approximately an hour on the racks) to reach its optimum level, after which it gradually declines. In the case of high temperatures no such optimum was noted. The level of quality was inversely proportional to the period.

Colour:—(1) A very close relationship exists between colour and quality.

(2) High temperatures improve this character considerably.

(3) But if the temperature is in the region of 95°F development of colour is not so rapid.

(4) There is not a very significant difference in fermentation at temperatures between 70°F and 80°F.

(5) Below 70°F fermentation is slow.

(6) It is most active between 80°F and 90°F.

Strength:—(1) At normal temperatures period has no effect.

(2) There are indications that it is not affected appreciably by higher temperatures as well.

(3) Strength is affected only if the period is unduly lengthened to many hours.

Flavour:—(1) The influence of high temperatures on flavour is very similar to that on quality up to a period of about $1\frac{1}{2}$ hours, after which it is affected to a much greater extent.

(2) It can be lost if leaf is exposed to a high temperature for a long period.

(3) Its rate of development depends on the temperature of leaf in the rollers.

(4) If high, that is over 80°F, a further period of fermentation, however short, at this temperature adversely affects it.

(5) If the temperature of leaf in the rollers is considerably below 80°F, a higher temperature subsequently is not unfavourable.

(6) A temperature of over 90°F, however, is harmful at any stage.

Infused Leaf:—(1) Below 90°F temperature influence was small.

(2) Lower temperatures as a rule gave slightly brighter infusions.

(3) Above 95°F infusion is liable to be dulled and becomes greener.

TENTATIVE CONCLUSIONS

Though some of these results remain to be proved by the use of better controlled equipment the points of significant importance which emerge are:—

(a) High temperatures are harmful only if uncontrolled.

(b) For preservation of quality and flavour temperatures of over 90°F must be avoided.

(c) The shortest possible fermentation is advisable when flavour is present.

(d) The period of fermentation on the racks depends on the temperature the leaf has been exposed to in the rollers, the higher the temperature the shorter the period.

(e) If the temperature is too high, *i.e.* above 95°F, even a short period of half an hour or less results in no improvement.

(f) Quality and colour are very closely related in the temperature range of 70 to 90°F. At higher temperatures there is no relationship.

(g) At about 70°F and below, fermentation is so slow that the period has to be appreciably lengthened to obtain colour. Quality is not unduly sacrificed in achieving this objective, but a decline in flavour occurs.

(h) Strength is not appreciably affected by temperature or period.

(i) Though high temperatures may reduce greenness, there are indications that when this character is intrinsically present in the leaf it is accentuated by high temperatures of over 90°F for periods of half an hour or more.

(j) Creaming, usually associated with strength, does not appear to be affected by temperature. But at about 100°F and over there seems to be a slight loss, indicating the formation of a higher proportion of insoluble products. The darkening of the infused leaf strongly suggests this.

(k) Temperatures of over 95°F are inadvisable even for a short duration during rolling.

(l) Temperatures of 80 to 90°F are not harmful to quality provided the overall period does not exceed 2 hours.

(m) During the flavoury season, temperatures of 80 to 90°F are permissible, but the period must be as short as possible. Lower temperatures are, however, preferable.

(n) During the off-quality season high temperatures in rolling are advantageous, but a temperature higher than 90°F cannot be recommended.

Although it is realized that the experimental work on the influence of high temperatures has been carried out under conditions that vary greatly from those actually encountered in practice, the knowledge acquired throws some light on the influence of heat developed in the rolling process. The details given in the appendix should assist in making the picture clearer.

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APPENDIX

Table 1. *Heat developed in rollers under different conditions*

Situation of factory	Type of rolling	No. of roll	Pressure application	Period of rolling	Dhool outturn %	Rolling room temperature °F	Temperature of leaf at end of rolling period °F	Rise in temperature °F
Low-country	Light	1	Nil 5 on 5 off " "	25 mins. " " " "	7	79 79 81	90	11
		2			18		94	15
		3			19		95	14
"	"	5	" "	30 mins. " "	—	78 80	90	12
		6			—		95	15
"	"	5	Continuous	20 mins.	—	86	98	12
Mid-country	Very light	1	5 on 5 off " " " " " " " "	30 mins. " " " " " " " "	2	71 71 72 73 73 (48% B.B.)	82	11
		2			5		83	12
		3			16		84	12
		4			15		86	13
		5			14		83	10
"	"	1	Nil "	40 mins. 30 mins.	—	72 72	80	8
		2			—		78	6
"	Somewhat heavy	1	5 on 5 off " "	40 mins. 30 mins.	—	72 72	87	15
		2			—		84	12
Up-country	Heavy	1	5 on 5 off " " " "	30 mins. " " " "	15	65 65 65	85	20
		2			21		88	23
		3			20		89	24

Up-country	Light	1	5 on 5 off	30 mins.	8	71	80	9
		2	" "	"	9	70	81	11
		3	" "	"	16	70	83	13
		4	" "	"	15	70	84	14
		5	" "	"	16 (38% B.B.)	70	84	14
"	"	1	Continuous	45 mins.	5	65	82	17
"	Very heavy	3	5 on 5 off	25 mins.	23	68	92	24
		4	" "	"	33 (11% B.B.)	68	98	30
"	Heavy	1	8 on 2 off	30 mins.	—	53	70	17
"	"	2	3 on 2 off	35 mins.	—	49	77	28
"	More dhool in early rolls	1	8 on 2 off	30 mins.	26	68	83	17
		2	4 on 1 off	"	23	66	83	17
		3	" "	"	20	66	85	19
		4	" "	"	17	66	84	18
		5	3 on 2 off	25 mins.	9 (5% B.B.)	66	82	16
"	Harder rolling in early rolls	1	8 on 2 off	30 mins.	35	67	81	14
		2	4 on 1 off	"	26	67	82	15
		3	" "	"	17	68	84	16
		4	" "	"	16 (6% B.B.)	68	82	14

NOTE:—Roll-breaker mesh—Low country No. 4 or thereabouts.

Mid-country No. 5 "

Up-country No. 6 "

Table 2. *Effect of degree of wither on temperature rise.*
(Low-country factory).

Rolls	Rolling room temperature	Temperature of leaf at end of rolling period		Rise in temperature	
		Hard wither	Soft wither	Hard wither	Soft wither
1st.	81°F	89°F	89°F	8°F	8°F
2nd.	81°F	96°F	90°F	15°F	9°F
3rd.	77°F	97°F	91°F	20°F	14°F

Table 3. *Comparison between two methods of pressure application in relation to rise of temperature of leaf (Up-country factory).*

(a) 2nd. rolls—40 minutes—25% dhool		
	5 mins. on, 5 mins. off	15 mins. on, 5 mins. off
Rolling room temperature	63°F	65°F
Temperature of leaf fed into roller	74°F	74°F
Temperature of leaf after 15 minutes of rolling	81°F	82°F
At end of rolling (40 mins.)	84°F	86°F
Final rise in temperature	21°F	21°F
(b) 3rd. rolls—20 minutes—15% dhool		
	5 mins. on, 5 mins. off	15 mins. on, 5 mins. off
Rolling room temperature	66°F	68°F
Temperature of leaf fed into roller	76°F	77°F
Temperature of leaf at end of rolling	82°F	86°F
Final rise in temperature	16°F	18°F

NOTE:—Pressures adjusted to give the same dhool outturns.

Table 4. *Effect of three methods of rolling on rise of temperature of leaf.*
(Up-country factory).

Method of rolling	No. of roll	Dhool outturn %	Rolling room temperature °F	Temperature of leaf at end of rolling period °F	Rise in temperature °F
(a) Epicyclic pressure (no pressure cap)	1	20	67	90	23
	2	32	67	91	24
	3	38 (10% B.B.)	68	91	23
(b) Battens, pressure cap (5 on, 5 off)	1	13	67	92	25
	2	16	67	90	23
	3	25	68	92	24
	4	35 (11% B.B.)	69	98	29
(c) Battens, pressure cap (Continuous pressure)	1	13	66	91	25
	2	16	66	90	24
	3	25	66	95	29
	4	35 (11% B.B.)	67	100	33

NOTE:—Each roll of 25 minutes duration, and pressures adjusted in (b) and (c) to give equal dhool outturns.

Table 5. *Effect of roll-breaking on temperature of leaf.*
(A few observations).

Rolling room temperature °F	Temperature of leaf at end of rolling °F	Temperature of leaf after roll-breaking °F	Cooling effect °F
46	75	63	12
46	77	58	19
61	88	68	20
62	83	70	13
63	87	71	16
67	93	75	18
69	88	76	12
69	90	74	16
70	92	76	16