TEA FERMENTATION.—Part II.

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THE DEVELOPMENT OF AROMA DURING FERMENTATION.

The aroma and flavour of tea has been ascribed to the presence of volatile constituents, and several attempts have been made to isolate the essential oil of tea by distilling large quantities of fermenting leaf with steam, but the amount of oil separated has been too small for its proper study. Van Romburgh and Lohmann (*Meded. v.h. Proefstation v. Thee*, 1912, 19.) are reported to have obtained 1 c.c. of oil from 15 kilos (30 lb.) of freshly fermented leaf. The oil obtained was a yellow liquid, with a smell resembling that of tea but so strong as to be disagreeable and even objectionable. Romburgh and Lohmann, contrary to Crole who also investigated the essential oil, asserted that the oil did not resinify readily but remained liquid when kept in a stoppered bottle exposed to diffused light. The reactions of the oil marked it as alcoholic in nature, and on fractionation they obtained methyl alcohol, acetone, and methyl salicylate which is an ester found in many essential oils, especially oil of wintergreen. They also isolated salicylic acid from the residue left after distillation by neutralising with dilute alkali, evaporating it down, acidifying and then extracting this with ether. They found no difference between the essential oils of Java and Assam tea, and noticed that fermentation altered the amount of essential oil which is rapidly produced during this process.

Deuss (*Meded. v.h. Proefstation v. Thee*, 1915, 42.) describes his method of separating an oil from tea leaves and gives a short account of the product obtained. He distilled large quantites of fermenting old tea leaves with water in an improvised apparatus made of drums and kerosene tins. The large volume of distillate obtained was re-distilled from the cleaned still until a quarter of the original distillate passed over. This process was repeated four times, when small drops of oil separated out on the surface of the distillate. It was necessary to repeat the distillations because the first distillates were only turbid and did not show any separation of oil. It was also essential to carry out the distillations very slowly and with efficient cooling to avoid loss of oil. The oily drops on the surface of the distillate were removed with ether or acetic ether and the resulting solution dried over calcium chloride. On evaporating off the solvent a yellow oil with a disagreeable tea smell was obtained which gave a colourless liquid when distilled under reduced pressure. The oil remained colourless for some time if kept in the dark, but after a while it became yellow again. Deuss found that the oil did not solidify for years if it was pure, and that it could be separated into two fractions on distillation. The main fraction boiled over at 156°C, and appeared to consist of an alcohol with six carbon atoms. The higher boiling fraction passed over at 220°C, and was composed of methyl salicylate.

Finally, Gildemeister and Hoffmann are reported by Neuville (*Technol. du The*, 1926.) as claiming to have isolated an alcohol of the formula $C_6 H_{12} O$ from the main factor.

The essential oil is found exclusively in the leaves, but it only exists in very small amount, if at all, in fresh leaves. Green tea, accordingly, does not contain any essential oil, its aroma being due to the presence of other substances. This view, however, is not universally accepted as Mulder (Neuville, *Technol. du The*) states that the green tea Hyson contains more essential oil than the black tea Congou. He found 0·79 per cent. essential oil in Hyson from China, and 0·98 per cent. in Hyson from Java, but only 0·6 per cent. in Congou from China, and 0·65 per cent. in Congou from Java.

Whether it is present in green tea or not, it is rapidly produced during fermentation, and Deuss suggests that it is formed by the decomposition of a glucoside tannin which breaks up into tannin and sugar. The sugar then decomposes to form an alcohol and essential oil.

As stated before, the amount of essential oil obtained from tea is very small, and if only small samples of tea are used the distillate itself does not exhibit any separation of oily drops, but is slightly turbid. When this is shaken with ether the oil is removed, but the quantity obtained is too small to be weighed and estimated. Mann (*The Fermentation of Tea*, 1907, No. 1) tried to overcome this difficulty by determining the amount of oxygen necessary to oxidise the distillate obtained. The method, which consisted in oxidising the volatile substances with permanganate, is described in his paper and it is claimed that, although it gives no measure of the absolute amount of essential oil, it gave comparative results which were trustworthy. He found that Darjeeling teas required more oxygen for the oxidation of the material distilled from 10 gms. of tea than Assam teas. It was found possible to pick out a flavoury tea from one which had no marked flavour in accordance with a tea broker's opinion of flavour, but the method could not be applied to fresh or withered leaf because the distillates obtained with these were acid. The figures obtained for fresh leaf on the other hand were so different from those obtained with fermented leaf that it was considered possible to draw certain conclusions from them. According to Mann, very little flavour is produced during a normal wither, but a rapid development of essential oil takes place as soon as the leaf is rolled. This development continues during fermentation, but the rate slows up in time, so that the maximum flavour is developed at an early stage of the fermentation. The usual period necessary to attain maximum development of essential oil under the conditions of his experiment was three hours. After that there was, generally, a decline in amount. This was not always true, but at times the decline was very rapid. It was suggested that this loss in flavour observed in practice was due to micro-organisms, since such a decline was not observed in experiments carried out in the presence of chloroform so as to exclude micro-organisms. The temperature at which fermentation was carried out did not seem to affect the yield of essential oil, provided it was below 86°F., but any stewing of the leaf during the firing operation caused a rapid reduction in the amount of essential oil. A tray temperature of 212°F. and over, or prolonged drying at temperatures well below the boiling point of water, also resulted in loss of flavour.

Mann sums up the result of his experiments as follows:—

(1) The whole of the flavour is very rapidly developed after the cells of the leaf are broken.

(2) The quantity of oil does not materially increase after three hours' fermentation.

(3) There is generally a decline in flavour after three hours' fermentation though occasionally the amount remains constant.

(4) This decline may, it is possible, be connected with the action of microbes in the fermenting leaf.

(5) The temperature, at any rate up to 86°F. has little influence on the formation of flavour during fermentation.

(6) Firing above 212°F. means loss of flavour, and long continued firing even below that temperature, and even with almost dry tea, also means loss of flavour.

According to Mann the time required to produce maximum flavour does not coincide with the time necessary to produce the maximum thickness of liquor. If flavour is the primary consideration, then the fermentation should be as short as possible, but if liquor is more important, a longer fermentation should be allowed. If absolute cleanliness is maintained then it is possible to prolong the fermentation in order to improve liquors without serious detriment to the flavour produced, and in this way turn out flavoury and good liquoring teas.

The methods of investigating the production of essential oil in the above work seem to have been eminently successful. It is, however, difficult to decide how many of the results obtained could be reproduced, and there are many objections to the analytical methods used. Although the results agree well with experience gained in practice, no further estimations carried out in this way have been reported from India, and Deuss (*ibid*) makes the disconcerting statement that he was never able to get duplicate results to agree by the permanganate method in spite of all precautions taken. This detracts somewhat from the merit of Mann's work, and makes it difficult to decide what is the true value of it, so that the problem of the development of essential oil is still far from being solved.

THE TEMPERATURE RELATIONS DURING FERMENTATION.

(a) *Heat production by the fermenting leaf.*—Another characteristic of fermenting leaf is that of the production of heat. When the leaf is crushed, the oxidative change is accompanied by the evolution of heat energy. The leaf mass when emptied from the rollers is at a much higher temperature than the surrounding atmosphere, and although some of the heat is undoubtedly the result of friction, the greatest proportion of it is due to the chemical change which takes place when the leaf is crushed. In an actual test, carried out on leaf emptied from the rollers after the first light roll, the temperature of the leaf was 84°F. while the air temperature was 73°F., and after the fourth roll when fairly heavy pressure was applied the temperature of the leaf had risen to 88°F. By the time the leaf had passed over the roll-breaker and sifter the temperature had dropped to 79°F., and the fine leaf spread out for fermenting had a temperature of 73°F. The process of roll-breaking has thus materially cooled the leaf before it goes back to the roller, so that the more efficient is the roll-breaking, and the cooler the room is maintained by means of proper humidification, the greater is the cooling effect on the leaf before it goes back to the rollers. Roll-breaking thus serves the double purpose of removing the fine leaf from the coarse, and of cooling the leaf quickly at the same time, and is a process which needs careful supervision lest it be scamped. According to Deuss (*Meded. v.h. Proefstation v. Thee*, **1917**, **42**.) the temperature rise is greater during the first roll than during the second roll, so that the heat is developed with almost explosive force when the cell walls are crushed and the mixed juices come in contact with the oxygen of the air. This increase in temperature is also considerable in open top rollers in which the only pressure effect is that of the weight of the leaf itself.

Further, when the leaf is spread for fermentation heat is still evolved, and sometimes a rise in temperature can be observed in the fermenting leaf. The observed rise in temperature, however, depends on the thickness of spread and the rate at which this heat can be dissipated into the surroundings. When the fermenting leaf is insulated in a receptacle in the way described by Boscha and

Brzesowsky (*Meded. v.h. Proefstation v. Thee*, 1916, 47.) the production of heat is clearly demonstrated by the rise in temperature observed, as will be seen from the following data calculated from the curves given in their paper.

Table II

Temperature of tea leaf during fermentation

Period of fermentation in hours.		Temperature of the leaf in °F.
0·0	...	71·6
0·5	...	77·0
1·0	...	78·8
1·5	...	79·7
2·0	...	80·2
3·0	...	80·6
4·0	...	81·0
5·0	...	80·6
6·0	...	80·2
8·0	...	78·8

According to Carpenter and Harrison (*The Manufacture of Tea in North-East India*, 1927.) the temperature of fermenting leaf rises during the first 2½-3 hours, and then remains steady for 2½ hours before showing a decline. An aroma which they term "the first nose" develops just before the maximum under normal plains' conditions in India, and if the tea is fired at this point a brisk and pungent tea results. A "second nose" appears if the tea is allowed to ferment for another hour, but the temperature change has been slight during this period. This tea is stronger but less brisk than the former, and if allowed to ferment for another 1½ hours a "third nose" is observed. The temperature may show a decline at the end of this period, but the strong coloury tea obtained is flat and lacks pungency and briskness.

Deuss (*Meded. v.h. Proefstation v. Thee*, 1917, 42.) determined the temperature of the fermenting leaf on various estates at different elevations ranging from 600-4,900 ft. above sea level. The temperatures recorded were plotted against time so that a series of curves were obtained for various elevations. The curves were very irregular, but there was a remarkable similarity between them and the curves obtained by Boscha and Brzesowsky (*ibid*). On estate A at 600 ft. the temperature of the leaf increased from 80·2°F. to 87°F. in 2¼ hours; on estate O at 3,600 ft., the temperature increased from 73°F. to 80·6°F. in 3 hours; while on estate U at 4,500 ft. the temperature varied from 65·3°F. to 77·5°F. in 3 hours. Twenty estates were investigated and as a result of this work he divided them into four groups and constructed hypothetical curves for temperature changes in fermenting leaf at various elevations. It will be seen from the examples given that the period of fermentation does vary with the temperature, and although the theoretical temperature curves are not to be taken as the course of events at any particular elevation, it is suggested that they may help estates in determining the period of fermentation necessary in their locality. In his Handbook of Tea Manufacture (*Handleiding v.d. Thee bereiding*, 1922.) Deuss recommends that the fermentation should be followed by taking the temperature of the leaf every 15 minutes, when it will be seen that the temperature of the leaf rises to a maximum, and it is stated that the best time to dry the leaf is generally 15 minutes after the maximum temperature is reached. Incidentally, the temperatures given for estates A, O and U illustrate the different temperature conditions under which fermentation is carried out at various elevations, and when this is realised it will be understood why fermentations varies from place to place.

Although a rise of temperature during fermentation is thus definitely recorded from India and Java, this is not always found to occur under Ceylon conditions. In a cool, well ventilated fermenting room the temperature change observed has been very small, and fermentation proceeded at the Tea Research Factory, at a time when very fine teas were produced, unaccompanied by any appreciable rise in temperature above that of the floor on which it fermented. A rise in temperature has been observed in other factories as will be seen from the following table.

Table III.

Temperatures observed in fermenting leaf in °F.

Period of fermentation in minutes.	Estate A	Estate B Temp. in leaf	Estate B Temp. of air
0	74·0°	73·0°	72·0°
15	—	74·0	72·0
30	75·0	75·0	72·0
45	76·0	76·0	72·0
60	—	76·0	73·0
75	—	76·0	73·0
90	76·5	77·0	74·0
120	76·5	—	—
165	76·4	—	—

The rise in temperature is therefore very much less than that recorded by Deuss, although normal fermentation appeared to have taken place and the teas produced were of required standard. It is possible that there is some heat production as in other countries, but that it is lost by conduction and radiation. The loss of heat must be very great when it is spread in a thin layer where there is a proper movement of the air surrounding the leaf. This will be particularly so when fermentation is carried out on a concrete floor, and, since fermentation is carried out successfully under such conditions, it may be that the most suitable condition for fermentation is that which tends to prevent any temperature change in the leaf. If this is so, then a big rise in temperature in the leaf mass is an indication that the fermentation is not carried out under the best conditions possible. In this connection it is to be remarked that many planters prefer to ferment their leaf on the floor, and in so doing they use the coolest place in the factory and also attain the greatest loss of heat by conduction, since a concrete floor is generally one or two degrees cooler than the air a few feet above the floor.

From what has been said about the temperature change in the fermenting leaf it will be realised that there is no conclusive evidence that the increase in temperature is to be desired, and when this occurs, it may be an indication of unfavourable fermenting conditions. There is no question but that heat is developed during the process, and the problem is whether this heat should be conserved or dissipated. The solution of this problem depends on the question of the temperature at which the leaf should be kept during fermentation.

(b) *The temperature at which fermentation should be carried out.*—The beneficial effect of cooling on fermentation led Nanninga in Java to study the temperature conditions suitable for fermentation and a series of experiments was carried out in order to throw some light on this question. I have not been able to study the original papers, but a short account of this work appears in Neuville's *Technologie du The* and in *Meded. v.h. Proefstation v. Thee*, **1914**, 31. Nanninga completely dried fresh tea leaf over lime in a desiccator and then moistened the powdered leaf with water. The wet powder was found to develop the brown colour and aroma of fermenting tea, and on analysis it appeared to have undergone all the changes which green leaf undergoes during fermentation. Heating the powder to 158°F. rendered it incapable of undergoing these changes and on heating the powder to 104°-113°F., the action was strongly retarded. If the temperature was below 68°F. then the fermentation was very slow or did not take place at all, but an active fermentation occurred between 68°F. and 86°F. These laboratory experiments were followed by factory investigations in which the leaf was fermented at different temperatures, the variation in temperature being conditioned by the thickness of spread. Thus in one set of experiments the leaf was put out to ferment under the following conditions.

(a) The leaf was spread in a layer 2 cms. thick. The temperature of the leaf remained constant at 75·2°F. for 2½ hours during which the fermentation was carried out.

(b) The leaf was spread 8-9 cms. thick, the temperature in this series running from 75·2°F. to 78·8°F. during the first hour and to 80·6°F. within 3½ hours which marked the end of the experiment.

(c) The leaf was placed 8-9 cms. thick on a warm receptacle (ajakan). The temperature increased from 77°F. to 86°F. in 3½ hours which was the duration of the experiment.

At the end of each experiment the leaf was dried at a temperature of 192°F. to 201°F., and the resulting tea critically examined. The method may be criticised because varying the thickness of spreading introduces unknown factors, one of which is the effect of aeration on fermentation. It is impossible to avoid such complications when experiments are being carried out in factories where every factor can never be brought under proper control, but, in spite of this, Nanninga was able to draw certain very interesting conclusions. The infusion obtained from (a) was light in colour and rather green, while the liquors were also greenish showing the tea to be under-fermented. The infusion from (b) was light and still somewhat green, but the liquor was dark and highly coloured although tinted with green. The development of aroma was more pronounced in (b) than in the others, and this experiment produced the best tea in spite of a long fermentation. The tea made from (c) was over-fermented, the infusion being much darker in colour than the others.

In the next series of experiments the period of fermentation was subjected to a greater variation as will be seen from the following data relating to the experiments:—

Table IV.

General conditions of Nanninga's Fermentation Experiments.

Series No.	Duration in hours.	Temperature F.	Spreading
a	4	73·4-75·2	Fine layer
b	6	,, ,,	,,
c	8	,, -77·	,,
d	4	75·2-80·6	Thick layer
e	6	,, -83·4	,,
f	3½	,, -87·8	,,

The best result was obtained under conditions (b), although the 8-hour fermentation in (c) did not appear to result in over-fermentation. The tea made in 6 hours (b), however, was superior in strength of liquor and aroma, and was much better than (f) which was made under the usual estate conditions. A better fermentation is thus obtained with a fairly long fermentation at a low temperature than in a shorter period at a high temperature. The experiments also show that an improvement on estate practice can be carried out by paying attention to the temperature of fermentation.

In the third series of experiments an attempt was made to ferment the leaf in the sun outside the factory, but a peculiar taint developed in the tea, and the conclusion was arrived at that fermentation in the open air was not feasible.

The former experiments were carried out at a fairly high elevation, but the fourth series were carried out on an estate at about 1,500 ft., and the results obtained supported the former conclusion that a relatively long fermentation at a comparatively low temperature gave the best results. The most suitable condition found in these experiments was a fermentation of 4 hours at 78·8°F.-80·6°F.

The final set of experiments was carried out at an elevation of 1,100 ft., low temperature conditions being obtained by means of a refrigerator. The temperature range varied from 57·2°F. to 97°F. but the tea fermented at the lowest temperature was still green after 2 hours, and only tinted with brown after 4 hours. Although it was difficult to decide which of the teas fermented between 68°F. and 77°F. was the best, there was no doubt that the tea fermented at the higher temperature of over 86°F. was inferior in quality.

The conclusions arrived at were:—

(1) Fermentation is very slow at low temperatures.

(2) Fermentation above 86°F. is bad, especially if the spread is thick, as the aroma developed is not pure.

(3) Too long a fermentation at low temperatures (below 68°F.) is harmful to the aroma which becomes less pronounced.

(4) When high temperatures are met with it is advisable to instal some arrangement by means of which the temperature may be maintained around 77°F., which is the most suitable temperature.

Mann (*The Fermentation of Tea*, Pt. I, 1906) also carried out experiments on the effect of temperature on fermentation, and came to the conclusion that the temperature of the fermenting room must be kept down to 82°F. The effect of high temperature on the amount of soluble extract in the made tea is clearly shown in his results. In one experiment the percentage soluble matter in tea fermented for 4 hours at 87°F. was 36·17 and the percentage tannin was 12·94, whereas the tea fermented for the same period at 113°F. gave 30·93 per cent. soluble extract and 8·27 per cent. tannin. Such a high temperature would represent an extreme and unlikely condition, but serves well to show in what way increase of temperature affects the resulting tea, and according to Mann a second action comes into play as soon as the temperature exceeds 82°F. This action is independent of the presence of any enzyme and it gives rise to insoluble, dark brown products, resulting in loss of pungency, colour and body in the liquors. This effect is slight up to 84°-85°F. but is very marked at 90°F., and the most suitable temperature for fermentation is 82°F. or below.

On comparing the conclusions of these two investigators, it will be found that they are in close agreement, although Mann did not determine the lowest temperature suitable. They agree that temperatures above 85°-86°F. are unsuitable, but the temperature recommended by them for carrying out the fermentation is higher than that at which the process is successfully carried out on up-country estates in Ceylon.

Carpenter and Harrison (*The Manufacture of Tea in North-East India*, 1927) state that 82°F. is a practical maximum room temperature for average gardens in the plains during Monsoon weather but lower temperatures are better if they can be obtained, and Deuss (*Handleiding v.d. Thee bereiding*, 1922) who advises a temperature of 68°F.-77°F. thus modifies Nanninga's conclusion by extending the suitable temperature range to lower temperatures, and this is more in keeping with our experience in Ceylon. This temperature is aimed at in the fermenting rooms in Java, and it is customary on some of the estates at high elevations to warm their fermenting rooms when the temperatures are low (See *Tea Quarterly*, 1930, 3, 34), while warm fermenting rooms are cooled by some suitable scheme of humidification.

The evidence gained from these investigations agree with practical experience that a high temperature is detrimental to a proper fermentation, but this critical temperature of 85°-86°F. appears at first sight to allow a wide margin of safety, at least for up-country estates, where the temperature of the rolling and fermenting rooms may be from 70°-75°F. It is true enough that the leaf sifted out and spread for fermentation is doing this at a low temperature but it has been long accepted as a fact that a big proportion of the fermentation takes place in the rollers, especially in the later dhools. In spite of this little attention has been paid to what it means, and how we should adjust our policy to this altered viewpoint. In the first place, it is very evident that there is no *one* temperature of fermentation adopted in practice; the leaf spread on the fermenting table is fermenting at one temperature while the leaf in the rollers is fermenting at a higher temperature, which is very often considerably higher than the highest temperature advocated by Nanninga, Mann and Deuss. The difference in temperature between the leaf fermenting on the floor and the leaf fermenting in the rollers can be seen from the data already given for the Tea Research Factory in connection with the development of heat. There, the leaf on the floor was fermenting at 73°F. while the leaf in the rollers was fermenting at

84°-88°F., and I have seen factories where considerable ingenuity was spent in keeping cool the leaf on the fermenting tables, but where the rolling was carried out in such a way that the rolled leaf left the rollers in compressed flat cakes whose temperature I judged to be between 95°F. and 100°F. It must, therefore, be concluded that either tea fermentation allows a good deal of latitude in the temperature range suitable for its proper accomplishment, or else, one or other or both of these fermenting conditions is incorrect. It may be stated that when the temperature in the rollers rises above 85°-86°F., then the high temperature fermentation condemned by all the investigators comes into play, and if the leaf is maintained at this temperature for any length of time a loss of quality will be the result. It will be seen, therefore, that it is necessary to watch the temperature of the leaf in the rollers carefully, and to do everything to keep it down. This can be done by having a cool, humid rolling room, efficient roll-breaking, short rolls, and periodic application of pressure. I do not think it is quite realised how much humidification tends to improve conditions during rolling by maintaining a low temperature, and making it possible to have proper cooling of the leaf during the sifting, thus counteracting the effect of high temperature in the rollers. On referring to the figures given by Deuss for the heat production in fermenting tea, it will be seen that there is a tendency for the effect to be greater at the higher temperature. This is a natural consequence of the acceleration of the reactions by heat, so that in warm factories the fermentation initiated in the roller proceeds more rapidly than in a cool factory and results in a more rapid evolution of heat. Heavy rolling in so far as it bruises more cells in a shorter period of time thus increases the mass of material undergoing oxidation and augments the heat production. This is a well-known fact which most teamakers have had to adjust by rule of thumb and explains the benefit obtained from short rolls and periodic application of pressure. In this way the leaf is cooled by lifting up the pressure cap, and fresh leaf sap brought into action gradually during the whole of the rolling period. A cool atmosphere in the rolling room will materially help these expedients to keep the temperature of the leaf down, but full advantage of the cooling effect can only be obtained by careful roll-breaking.

Although Nanninga's work indicates a limit of low temperature at which fermentation can be carried out, the evidence is not very definite as to what is the lowest suitable temperature. If Deuss' limit of 68°F. is correct then the present tendency of fermenting and rolling in the same room is not always the best system. It is quite true that the coolest possible conditions are required for rolling in order to prevent the temperature of the rolled leaf going above 85°F., but in attaining this the temperature of the rolling room may be reduced below 68°F., which is said to be too low for fermentation. Extreme temperature conditions of this kind may be met with up-country during the coolest months when the cold morning temperatures are ideal for rolling as the leaf does not get too hot during the process, but the fermentation of the leaves on the table is very slow and, according to Deuss, could be improved by a proper temperature adjustment. This can only be carried out when the rolling and fermenting rooms are separate units. The fermentation of the leaf is thus habitually carried out at two temperatures and it is difficult to decide what is the best temperature to aim at. It is hardly possible that the best temperature will be the same on every estate but it should be possible to determine a practical working range, the actual temperature within the range varying according to the quality of the leaf, fineness of plucking and degree of wither.

(*To be continued.*)