COFFEE

Botany, Biochemistry and Production of Beans and Beverage

EDITED BY M.N. CLIFFORD AND K.C. WILLSON

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14 THE TECHNOLOGY OF CONVERTING GREEN COFFEE INTO THE BEVERAGE

R.J. Clarke

Introduction

Though infusions of green coffee, and fermented drinks made from the whole fruit, have been prepared at different times in history, only after roasting the green coffee beans is the beverage as we know it brewed and consumed today. The large-scale roasting of green coffee has been established for some considerable time, leading to the sale of roasted whole beans in suitable packages, in which form the product is reasonably stable. The advent of vacuum packaging machinery allowed coffee roasters to make their product in the pre-ground form which then has considerable stability to deterioration on storage. The housewife has the responsibility for brewing the roasted coffee with water, to obtain her final desired product in the cup, and since now she has a variety of appliances at her disposal, different grinds of coffee from fine to coarse, suiting the appliance, have also to be offered. The roaster must also offer different coffee blends and degrees of roast. The housewife will however finally have to dispose of the spent grounds.

As a further development in convenience, it was no longer necessary to dispose of the grounds after the introduction of soluble or instant coffee. Furthermore, this product was much more flavour stable in opened packages. Whilst historically, particularly in the USA, there have been numerous soluble coffee ventures, really large-scale manufacture for the retail market took place after World War II. Since then the technology of manufacture has become increasingly sophisticated, and with it, a corresponding increase in the quality of instant coffees available. Liquid coffee extracts have also been offered from time to time, including one long-selling product in the UK. Without additions of such substances as sugar, however, they are not sufficiently stable at ambient temperatures, though attempts have also been made to market deep-frozen products.

The literature on the science and technology of roasted coffee, and particularly instant coffee manufacture, is relatively sparse excepting that of patents, and of publications of a trade journal character, which is extremely large. The two volumes by Foote and Sivetz (1963), and its single volume update by Sivetz and Desrosier (1979), served as a prime source of information, not least to patentees, but have been criticised for some controversial and non-scientific elements. The proceedings of the biennial

International Colloquia on Coffee published by the Association Scientifique Internationale du Café (Paris) are also a fruitful source of information. The Noyes Data Corporation in their food technology reviews provide useful US patent reviews, though non-critically assessed, and not comprehensive; Pintauro (1975) has collated review No. 28 on Coffee Solubilization.

The following description of current technology, within the short compass available, guides the scientific reader to issues, problems and solutions devised by others. The patents quoted are usually only a fraction of those published on any particular subject, with some preference being given to British patent numbers.

Selection and Pre-Preparation of Green Coffee

Green coffee imported from the various producing countries of the world is the basic raw material for the manufacture of roasted and of soluble coffee. There is, however, also substantial manufacture, which takes place in the producing countries themselves (e.g. Brazil), and therefore uses mainly indigenous green coffee. The preparation of green coffee for export has already been fully described in Chapter 10 with a description of the types and grades that are available to importers.

The selection of green coffees for roast (and ground) coffee manufacture is primarily a matter of blending though many roasters also market individual coffees, designated by country of origin (e.g. 100 per cent Columbian, etc.), but all designed for consumer taste requirements. There are various principles of blending, but with considerable skill, experience and art required in practice, which have been typically described (Davids, 1980) together with close consideration of cost factors in the final product. Various combinations of 'Mild' coffees may be used, but with Brazils (dry processed arabicas) generally included, characterised by their 'blendability' and lower cost. Speciality considerations may also apply, by the selection of maragogipes, peaberries, large sized beans, and Mocca coffees, by smaller roasters. National and regional tastes are important in selection, so that, for example, the cheaper robusta green coffees, usually darkly roasted, are very popular in France and Italy. It is fair to say that the Swedish and German manufacturers offer the highest proportion of high quality coffees for their markets, despite the fact that in Germany, there are considerable extra governmental taxes on coffee. Similar principles of blending green coffee apply in the manufacture of instant coffee, again with the important considerations of cost factors, and of quality factors determined by the overall process used, which are of increasing sophistication as subsequently described. The older processes of drum or simple spray drying would not

always justify the use of better qualities rather than poorer, (judged initially by liquoring tests on the brewed roast and ground coffee). Robusta coffees are widely used in blends for instant coffee, dependent on market brand factors of cost and consumer taste requirement in different countries.

After selection, the pre-preparation of the green coffee for subsequent conversion into roasted or soluble coffee is very little. Green coffee is delivered in bags (usually of 60 kg content weight, but see Chapter 11, p. 251). It is important that such coffee should be properly warehoused in the factory, in respect of environmental conditions, indeed at all times through transportation from the overseas source to usage. Many of these factors are well described in a National Coffee Association (USA) booklet (1979), and Guidelines being developed by the ISO Coffee Subcommittee. Commercial green coffee may well however contain fractional percentage weights of foreign matter, such as dirt and stones, tending to settle to the bottom of the bags. As in large scale manufacture, storage silos are used immediately prior to blending and roasting, it is usual to tip the contents of the bags onto conveyors, leading to cleaning and de-stoning equipment, which are typically described by Foote and Sivetz (1963: 187-93).

There is however, a distinct form of pre-preparation required in the manufacture of decaffeinated roasted or soluble coffees. The extraction of caffeine to a very low level (less than 0.1 per cent dry basis, which will give less than 0.3 per cent in the resultant instant coffee) will either be carried out by companies specialising in these techniques (e.g. Coffex AG), or in the premises of the roasted or instant coffee manufacturers. Decaffeination was first practised as early as 1905 by the Hag Company in Bremen, Germany who took out a patent on their process. The process of decaffeinating green coffee is essentially one of solvent extraction for caffeine, followed by removal of caffeine and re-use of the solvent. Organic solvents are effective, provided the green coffee is first well moistened with water, typical solvents are methylene chloride and ethyl acetate. Residual solvent in the coffee is removed to very low levels (ppm) by steaming/drying the extracted beans. Other processes are used, e.g. water extraction only followed by organic solvent contact of the extracting water to recover the caffeine, and re-use, first described in US patent 2,309,092 (1943); and more recently the use of supercritical carbon dioxide as the solvent, first patented in 1971 (GP 2,005,293). Solvents will not be equally or totally selective for caffeine; some aroma precursors of the green coffee may be extracted to a greater or lesser extent, though with good decaffeination practice, the brew difference between decaffeinated and non-decaffeinated coffees of the same type will be small. The technology is again complex, with a large patent literature, developing the various processes outlined. Direct decaffeination of roasted coffee or coffee extracts is much less usual in practice, though a number of patents also cover this technique. Detailed descriptions of decaffeination processes are also available in the general literature by Foote and Sivetz (1963: 207-215 Vol. 2), Katz (1980) and Rothmeyr (1980: 82-6).

A more limited form of pre-treatment is that used by a number of German manufacturers, by solvent washing or steaming and other processes to remove the outer coffee 'wax', 5-hydroxytryptamide, and/or other substances claimed responsible for gastric upsets by some consumers (see Chapter 13).

Roasting

Process Factors

Roasting is a time-temperature dependent process, whereby chemical changes are induced in the green coffee, with a loss of dry mass primarily as gaseous carbon dioxide and other volatile products of the pyrolysis. About half of the total carbon dioxide generated will be retained within the roasted coffee, together with a major proportion of the important volatile flavour substances. Roasting is normally carried out under atmospheric pressure with hot air and combustion gases as the primary heating agent, though heat may also be provided by contact with hot metal surfaces, solely or supplementarily. After the initial removal of moisture, roasting proper starts at a green bean temperature of about 200°C, after which through exothermic reactions, escalation of effect readily occurs requiring considerable control of the process for a given degree of roast. These exothermic reactions have been studied recently in the laboratory by differential thermal analysis methods (Quijano Rico, 1975: Raemy and Lambelet 1982). Other methods of applying heat have been used in limited practice.

Degree of roast plays a large part in determining the flavour characteristics of extracts subsequently brewed from the roasted coffee, whatever the blend. The degree of roast is qualitatively assessed from colour, for example, simple categorisation as a light, medium or dark roast. Various sub-divisions have been devised, such as French or Italian roasts; but in large-scale commercial practice, a final quantitative assessment is made by colour reflectance readings of the roasted coffee surface, shortly after roasting but after grinding in a clearly specified manner. There are various commercial instruments available for reporting this colour in arbitrary units, of the prepared sample (Smith, 1963, Sivetz and Desrosier, 1979). Roast colour will also be broadly correlated with percentage loss of coffee matter, expressed on a dry basis; so that, a light roast will show about 3-5 per cent loss, medium 5-8 per cent, dark 8-14 per cent together with the moisture (variable) that the green beans will have contained. More specific correlations can be developed for particular roasting methods and blends.

Clearly, chemical composition, in respect of both volatile and involatile substances will be strongly determined by the degree of roast. These

changes have been studied in detail by many workers and summarised by Clifford (see Chapter 13) and Maier (1981). Both chlorogenic acid(s) and trigonelline are destroyed, according to the degree of roast, and may indeed be used as a measure of it (Kwasny, 1978 see also Chapter 13). Of commercial interest also, are any differences in extractable soluble solids, whether by home brewing, laboratory (including exhaustive) extraction or in instant coffee manufacture, though reliable published information is hard to come by (Kroplien, 1963; Wilbaux 1967).

In roasting, times of heating range in practice from a few minutes to about 30 minutes; beyond that time is generally regarded as undesirable for flavour. For any given degree of roast, the time is determined by conventional heat transfer factors, i.e. the relative movement of the beans-air (velocities), bean-bean and bean-contact surfaces together with any internal radiative heat effects. Air temperatures may range from 540°C in older roasters, to 430°-480°C and to 370°C or lower, often reflecting differences in air velocities used. These considerations in design are especially discussed in detail by Foote and Sivetz (1963: 203-39).

The physical changes in the coffee beans during roasting are also technically important. Expansion of the beans takes place, including a 'popping' phase, leading to considerably decreased density, as a function of degree of roast but also of the speed of roasting. This decrease of density is followed through into the ground roasted coffee, as a decrease of bulk density. This feature is an important determinant in deciding subsequently, the size of packages, particularly cans. Green coffees from different sources and age start with different bean densities, and furthermore roast somewhat differently, for example, 'harder' beans roast more slowly to a given colour. Though a matter of taste opinion, optimum flavour is developed by different green coffees at different roast colours, so that whereas single roasting of a green coffee blend is general, it is often recommended that different coffees are roasted separately and subsequently blended. Uniformity of roast colour is generally desired, though this may be frustrated by individual differences in beans, e.g. immature beans giving rise to 'pales'; control of roasting avoiding individual charred beans is important.

The roasting process is followed by immediate cooling, in which the addition of water by a few per cent plays a part. This addition of water, however, enables much greater uniformity of particle size in subsequent commercial grinding. A further by-product of roasting is the variable production of 'chaff', which is the 'roasted' silverskin released when present from the surface of the bean into the conveying air. Robusta coffees tend to have more than arabica; a further small quantity left in the cleft or centre-fold of the beans will be released on air-veying and grinding. The overall amounts are small, but arrangements are made to separate, usually by a cyclone, from the discharging gases.

Process Equipment

Large-scale roasting plant, or roasters, are now largely of US or German manufacture, with several companies being old-established from the nineteenth century. The most generally used principle is that of the horizontal rotating drum, for tumbling the green coffee beans in a current of hot air, either batch or continuously operated. Once through air flow was general, but hot air re-circulation is now more usually adopted. The former is, however, generally associatd with further combustion (after-burners) to minimise atmospheric pollution by the discharged gases, so that re-circulation of these gases is a logical extension for fuel economy. It may still be necessary to have an 'after burner' or catalytic system to lower the emission of organic carbon compounds, (Anon 1975).

The horizontal drum principle is typified by the Probat-Werke roasters (series GO) in a standard 4-bag roaster (240 kg batch) with a roasting time of some 10-12 minutes, and turn-round of 15-18 min. Hot air is provided by direct fuel oil/gas combustion, with air intake controlled by a damper, which enters the back-end of the double-walled solid drum, and leaves to a stack. Probat in the RR series, adopt re-circulation of the gases through the main burder. Barth, also of Germany, manufacture batch drum roasters (Tornado models).

The drum principle is also used in the 'Thermalo' roasters of the original Jabez Burns Company (US) or Neotec in Germany. These roasters, are either batch, with a perforated drum, to allow cross hot air flow also, or continuous, first introduced in 1940. In batch roasters, the cessation of roasting is determined apart from the control of the temperature programme applied, by the addition of quench water and then discharge into a cooling tray with up-draft of cool air. With continuous roasters, there is a cooling section of the rotating drum, separated by a heat lock, through which the roasted beans pass. Gas velocities in the roasting section are high, the roasting times down to five minutes or so, with consequent high throughputs (up to about 3,000 kg/hour). Details of practical operation of these roasters are described by Foote and Sivetz (1963: 210-220).

Other mechanical principles have been adopted, in particular the Gothot roaster (Rapido and Rapido Nova) which uses a fixed vertical vessel but with rotating paddles to assist heat transfer from the hot air to the green coffee, again providing short roasting times (i.e. about 6 min in the Rapido-Nova). Discharge takes place into a second vessel, with cooling air. A recirculation system for the roaster gases can be readily incorporated. In recent years, Probat have marketed a batch roaster, on yet another principle, the Radial-Turbo Roaster (RZ series) in which a rotating bowl is used for intimate contact of hot gases and beans. Discharge is arranged after a short roasting time from the periphery of the bowl. Again a recirculation system is incorporated. The logical extension of the use of high velocity air is in fully 'fluidised bed' roasting, where various designs and performance have been described (Sivetz, 1975; Vincent, 1977). For example, a fully commercial unit is the Wolverine Jet Zone Roaster.

The Smithern roaster differs from all others, in that roasting takes place under pressure (50-150 psig) with a closed circulation of nitrogen gas (USP 3,615,688 (1971) and 3,825,221 (1975)). Closed pressure systems are generally reported to increase brew acidity of such roasted beans. A study has been made on its performance (Sivetz, 1973) together with a report of other pressure roasting systems.

Grinding

Process Factors

Grinding of roasted coffee, whether by the manufacturer or the housewife, is necessary to allow sufficiently rapid infusion or percolation of its soluble content by 'boiling' or hot water. Clearly the finer the particle size, the more rapid will be this rate of infusion, but in practice, the method of brewing and equipment used will dictate the degree of grinding which is desirable. This is equally true in the process of grinding roasted coffee, subsequently to be extracted in large-scale plant for instant coffee manufacture. Degree of grind is usually assessed from result of screen or sieve analyses, using a number of different mesh sizes.

It is not possible to grind coffee to a single uniform particle size, a distribution of particle size around an average is to be expected. This distribution is best expressed graphically in a plot of cumulative oversize by weight for each screen used on a probability scale versus the corresponding mesh size (aperture, in microns) on a linear scale. The average particle size may be assessed as the aperture at which there is 50 per cent cumulative oversize. The slope of the straight line plot (except at the extremes) indicates the degree of uniformity of particle size, which may be quantitatively assessed as a coefficient of variation (CV). The CV is in fact, the percentage ratio of the aperture for 16 per cent over-size minus aperture for 50 per cent retention divided by aperture for 50 per cent retention (or average). The screens chosen in a nest, usually not more than 5, should be chosen from a $\sqrt{2}$ series of screen sizes, now internationally standardised (British Standard 410, 1976).

In general, single stage grinding (i.e. once through a single grinding device) will give a relatively high CV figure, and show a high proportion of fine particles. Multi-stage grinders (e.g. with a series of grinding rolls, progressively reducing particle size) will be found to give lower CV figures, typically $\pm$ 30 per cent for roasted coffee. Similarly, closed circuit grinding with return of oversize to a single grinding device will decrease CV figures. Uniformity of grinding is also dependent upon the condition or brittleness of the roasted coffee, its moisture content and degree of roast. For this reason, grindability is improved by increasing moisture content of roasted coffee by so-called quenching in the roaster. Really fine grinding (i.e. an average of about 50 μm or less, average particle size) is best achieved by cryogenic grinding (i.e. at sub-zero temperatures by use of solid CO_2 or liquid nitrogen), which can have other advantages (BP 2,006,603B (1982)).

Really fine grinding, however, is not required in roast and ground coffee for brewing or large-scale percolation. Practical grinds for home-brewing purposes may be divided qualitatively by the terms 'coarse', 'medium', 'fine' or 'very fine', or according to the brewing device for which they are intended, e.g. 'jug', 'percolator', 'drip-pot', 'filter' or 'espresso'. Recommended standards characterising degree of grind by screen analyses (often in terms of percentage oversize at two screen sizes only, which is adequate) have been published from time to time in various countries (Clarke, 1965; IEC 661; BS 3999 Part 8). Home percolators and 'jugs' will tend to require 'coarse' to 'medium' grinds, in order to minimise the amount of fines finding their way into the cup, typically the average size will be between 1100 and 600 μm, whilst modern filter devices (automatic) use finer grinds, typically in Europe at 500-400 μm though coarser in the USA (between 600 and 700 μm). With filter papers, the problem of sedimenting fines in the cup is negligible, but the coffee bed should not consist of such fine particles as to impede percolation.

Roasted and ground coffee for large-scale extraction generally require relatively coarse grinds, dependent upon the plant design and operation. Allowable pressure drops in long percolation beds have to be considered.

The grinding of coffee will release a further quantity of chaff. This material can be disposed of, though it does contain a substantial proportion of coffee soluble solids. Often however, it is incorporated with the ground coffee in a so-called 'normaliser', by mixing under the action of rotating blades in a trough-shaped vessel. Particularly with dark-roast coffees, this process is an advantage to absorb any exuding oil on the surface, and keep the ground coffee reasonably flowable in subsequent handling. 'Normalising' has a further function in that it is a means of controlling the bulk density of roast and ground coffee, though only within certain limits, by variation of blade speed and disposition. This is of importance in subsequent packing for retail sale, though less so in large-scale extraction. The combination of grinding, and 'normalising' can be referred to as 'granulising'. The grinding of coffee will also release its inherent CO_2 and some of its more volatile components, at the time of grinding and subsequently but at a declining rate. The release of CO_2 is again of importance in subsequent packing operations (see page 389). The release of volatile components necessitates rapid transfer of the roasted and ground coffee to extraction equipment in instant coffee manufacture.

Process Equipment

For large-scale production of ground roasted coffee at whatever grind for retail sale or subsequent instant coffee manufacture, the multi-stage grinding machine is almost essential. The best known and probably most used type is the Gump Grinder, which has been manufactured in different models for a large number of years. It is a multiple-roll grinder, with two to four sets of rolls below a feeding roll, according to degree of grind required. The cutting surfaces of these rolls are especially serrated for grinding coffee based on the original LePage patented (1905) design for each roll. Roasted coffee beans require a cutting, rather than a tearing or crushing action. The construction of this grinder, operation and important aspects of its maintenance is described by Foote and Sivetz (1963: 239-50, Vol. 1).

Extraction

Process Factors

After grinding, the large-scale extraction of roast and ground coffee is the next stage in the manufacture of instant coffee. Both soluble solids and volatile aroma and flavour compounds need to be extracted. Liquid water is the only solvent used in practice for extracting the soluble solids, which however, will also extract the volatile components. The latter, being present in quite small quantities, will generally be found solubilised in the extracting water, though some components (e.g. non-polar) will require larger operating ratios of water to coffee than others (polar) for complete extraction. Prior passage of steam through roasted and ground coffee in a bed, with collection of a volatile-containing condensate, has been recommended in numerous patents (e.g. BPs 982,521 (1965); 1,206,296 (1967); 1,424,263 (1976); 1,466,881 (1976); 1,525,808 (1978)). Organic solvents are not used for extracting volatile or soluble solids for instant coffee though there are patented processes. Since roasted coffee contains coffee oil, in which many of the volatile components are located, mechanical pressing or expelling has also been recommended as a means of separately isolating these components, prior to water extraction. Inert gases, like CO_2, whether supercritical or not, have also been described for this purpose (e.g. BP 1,106,468, (1968)).

Contact between an extractable solid foodstuff and water may be arranged by any one of three main methods. In all these methods, however, unlike single-stage home brewing, in order to obtain efficient extraction with an adequately high concentration of soluble solids in the final extract (to lessen amount of water to be subsequently handled, and removed to form a dry product), it is necessary to arrange multi-stage or continuous counter- or co-current operation. So-called 'slurry' extraction is obtained by the use of tanks or vessels for contacting, and separating devices such as centrifuges between the stages. Slurry extraction does enable the use of relatively fine grinds for the roasted coffee. The most largely used method is that of percolation batteries, deriving from the 'Shanks' battery in which the coffee is held as a bed in vessels (or vertical columns) with internal separation of liquor from one stage or column to the next. The flow of water to the solid foodstuff is countercurrent, though the draw-off of extract is intermittent. As each column is exhausted, so it is replaced in the battery by a 'fresh' column. A truly continuous countercurrent system can be established within a single horizontal cylindrically shaped vessel, by movement of the solids by screw conveyor against the flowing water. The grind of coffee in these two methods needs to be relatively coarse. Other designs are possible, but these are the main methods used in extracting coffee.

Coffee extraction has a number of features which distinguish it from other extractions of materials. Roasted coffee is a cellular substance, with matrix of carbohydrate material and oil, and can become compressible on extraction. Extraction of coffee soluble solids by water at 100°C provides a yield from the roasted coffee of up to about 30 per cent, depending upon the conditions and number of stages used. It was generally recognised however, that such extracts did not provide very satisfactory powders on drying, with problems in producing adequate flavour retention and free-flowing and 'non-tacky' powders. Corn syrup solids or other similar carbohydrate materials were therefore often added (up to about 50 per cent) to give 'soluble coffees with added carbohydrates'. It was then realised that roast coffee itself was a source of suitable carbohydrates (see Chapter 13), readily solubilisable by use of extracting water at higher temperatures up to 175°C (USP 2,324,526 (1943)); and also by use of dilute acids (USP 2,687,355 (1954)) at 100°C. The first large-scale use of such elevated temperatures developed about 1950, for which a percolation battery with columns operable under pressure (to keep water liquid at all times) was particularly suitable. In this way instant coffee made from 100 per cent coffee could be satisfactorily manufactured. The effective yield of coffee solubles was then well beyond 30 per cent, figures primarily dependent upon the feed water temperature used (and pressure rating of the system). In fact, a controlled temperature regime has to be established across a battery percolation set, the most 'spent' coffee is contacted with the feed water, whilst the 'fresh' coffee is contacted with liquor from previous stages at a temperature around 100°C. Continuous extractors have similarly to be designed, in which the required complete temperature profile is either built into a single unit or into two separate units, operating at two different temperatures (one high, the other low), with external transfer of partially extracted grounds from one unit to the other.

As a unit operation of chemical engineering, extraction is based upon the mass-transfer of diffusible components from a solid phase to a liquid phase. The fundamentals are extremely complex, especially reflected in the mathematical equations needed to model these systems, as will be noted from the various recent studies that have been made (Schwartzberg, 1976; Bruin and Spanninks, 1979; Spanninks, 1979; Besson, 1983). In the same way, the operation in practice has many elements of craft, skill and experience. In optimising their operation for extract quality, yield from coffee, concentration of extract and productivity factors, numerous variants of procedure have been described, largely in the patent literature (e.g. USP 3,655,398 (1972); BP 1,547,242 (1979).

It is probable that roasted coffee extraction is not a completely physical operation, with some chemical changes taking place, as for example, some cleavage of large molecular mass polysaccharides at the temperatures conventionally used for commercial extraction. Like roasted coffee the composition of coffee extracts is complex, (see Chapter 13), and the proportions of different soluble components extracted will differ somewhat with yield of solubles taken. Caffeine, chlorogenic acids and numerous constituents are very easily extracted, whilst the use of higher temperatures will cause increasing solubilisation of less-diffusible substances. Extract composition in respect of polysaccharide content has been experimentally studied in detail (Thaler, 1979) and does not show any substantial monosaccharide formation by hydrolysis (Kroplien, 1974). Only a negligible amount of free coffee oil enters into the extract.

Extraction of roasted coffee requires also a number of ancillary processes. Coffee extracts as drawn off, may still contain a proportion of fine suspended coffee grounds and other insoluble matter, which generally need to be removed by centrifugal filtration procedures. The finally spent grounds have to be disposed of; pressure percolation systems are particularly convenient for their discharge. The hydraulic pressure in a spent column (e.g. 200 lb/in^2) after its isolation from the rest of the battery is available for pushing out its contents on release to atmospheric pressure. In the course of this expansion, some 10-15 per cent of this water will be vapourised, but the spent-grounds will still contain some 80 per cent of water, which are then usually mechanically pressed to around 60 per cent w/w moisture content. The spent grounds will then appear dry and be capable of easy further handling. Coffee extract as it emerges hot from an extractor, has to be immediately cooled through heat exchangers, and kept cool before proceeding to subsequent operations.

Process Equipment

A description of typical large-scale percolation battery plants is given by Foote and Sivetz (1963: 261-319), together with the important various items of ancillary equipment that are required. Percolation batteries will consist of 5-8 columns, one of which will be out of stream to allow discharge of the spent contents and re-filling with fresh coffee. Such equipment is supplied by Niro A/S; but it is probable that most large-scale manufacturers of instant coffee will have fabricated plant to their own particular designs, and requirements. The overall time of contact of coffee with water is variable, of the order of 180 minutes or less; though the cycle time (30 min or less) of batch intermittent percolators is important in determining output per hour.

Various types of continuous extractors are available for solid-liquid contact; but the continuous extractors supplied also by Niro A/S (Kjaergaard and Andresen, 1973) are those which have been especially designed for coffee extraction. There is advantage in such extractors, in that unlike percolation batteries, substantial interstage piping and valving is not required. The substantial contact times required are similar to those of percolation batteries.

Slurry systems consisting of tanks or pressure vessels, and interstage separating devices (centrifuges) are not now widely used, except that they have a use in dealing separately with coffee fines, in secondary streams, from grinding and screening out 'unders' and from oil expelling. Their really large-scale use in a large number of stages would represent high capital expense compared with percolation batteries, for similar performance.

Drying Coffee Extracts

Drying Processes

Whereas early ventures into instant coffee employed drum-drying, spray-drying quickly established itself on account of favourable appearance and easy control of bulk density of finished powder that can be effected. Conventional spray-drying however, causes high losses of the flavour volatile substances from the original extract. In the 1950s and early 1960s, freeze-drying equipment became available and suitable for large-scale use on coffee extracts, providing greater retention of flavour and other product advantages. Even so, freeze-drying should be operated to produce granules, and not fine powder. The increasing consumer preference for granules then spurred the marketing of so-called agglomerated instant coffee, that is, granules formed by adhesion of spray-dried particles by water or steam-wetting techniques, followed by finish-drying. There was a corresponding development in milk powders, for 'instant milks'. Such granules have essentially the flavour characteristics of the original spray-dried powders, which due to further technical developments in this process, can, and usually have markedly improved flavour retention over the older products.

Coffee extraction techniques as previously described, lead to extracts

with solubles concentrations of less than about 25 per cent, and often much less. Direct spray-drying at these concentrations will lead to substantial flavour loss. The effect of various variables (including concentration) in spray drying on the retention of different volatile substances, of different relative volatilities and other relevant physical characteristics have been studied in depth by Professor Thijssen and colleagues from 1965 onwards, as reported in numerous papers (see for example, Bomben, Bruin and Thijssen, 1973: 65-74). Other workers have also studied these variables, including effects on particle morphology (Karel, 1973; King, 1980).

Whilst freeze-drying can be conducted effectively at these concentrations, higher concentrations are again advantageous, especially since the cost of removing water by freeze-drying is high compared with other methods. Volatile retention is also determined by various operational factors including the rate of freezing prior to the drying itself (Bomben *et al.*, 1973; Karel, 1973). The characteristics of the freezing curve are also important for freeze drying (e.g. see enthalpy-concentration diagram for coffee extract, Riedel, 1974) and process conditions must be chosen to ensure sublimation of the ice. Operating vacuums of less than 1 mm Hg are required.

Increased solubles concentration as with other foodstuffs liquids can be achieved by two main methods, evaporation and freeze-concentration, both well-studied scientifically and technically, especially well covered in a 1971 Symposium on Foodstuffs Evaporation held in London (Clarke, 1971; Gray, 1971; Shinn, 1971; Wiegand, 1971). Evaporation, however, is also responsible for loss of volatile substances, according to the percentage water evaporated (Bomben *et al.*, 1973; 19-25) especially significant with coffee extracts. Due to the viscosity of coffee extracts, however, final concentrations possible are limited depending upon the type of evaporator. Wiped film evaporators are capable of achieving concentrations up to 70 per cent. When evaporation is used, two stages may be employed, a preliminary stripping and condensation of required volatiles, followed by bulk evaporation and condensate discarded. The desired condensate, together with other flavour distillates from other sources in the soluble coffee process, can then be added to the bulk evaporate for feed to the drier, whether spray or freeze. Numerous variants of this kind of technology are clearly possible, well-testified to by the considerable patent literature, (typically USP 3,244,530 (1966); BP 1,265,206 (1972); BP 1,563,230 (1980)) though evaporation may also be used merely as a means of increasing solubles concentration for economy reasons. Freeze concentration is an alternative to evaporation, though probably much less used, but with the advantage that flavour volatiles are retained within the concentrate (Bomben *et al.*, 1973: 45-50). Extract viscosity factors are again limiting, to around 40 per cent for coffee extracts. Reverse osmosis is probably even less used, except for concentrating very dilute extract streams.

Whilst improved spray and freeze-drying techniques have led to greatly improved flavour retention, some coffee volatile substances (of low molecular mass and high volatility) especially those responsible for characteristic coffee headspace aroma, are very difficult to retain, so that direct addition of coffee oil to the dried powder is recommended (e.g. BP 1,525,808 (1978)), thus by-passing drying systems.

Spray Drying Equipment

Spray drying of coffee extracts demands finished powders for direct marketing of a desired colour, and appearance and moisture content, but a bulk density (either assessed free flow or packed) such that a typical-sized teaspoon dispenses about 2 g or less. The latter requirement in turn demands particle sizes and distribution, averaging about 300 μm which is not possible to obtain in the type of drier conventionally used in the production of fine milk powders, that is, spray driers of wide diameter and relatively low height, fitted with spinning disc 'atomisers'. In general, therefore spray driers for coffee extract are relatively narrow in relation to height (or drying path), into which 'atomisers', or spraying devices, providing small spray angles, especially centrifugal nozzles, need to be fitted. Such driers are manufactured by a number of companies such as Niro A/S, Stork-Bowen and Anhydro A/S, but it is probably true to say that most large instant coffee manufacturers will provide themselves with driers and 'atomisers' of their own specific design. There are a number of other features of general importance; the supply of hot air (usually direct combustion gases from refined fuel oils or gas) and its entry arrangements into the drier (usually co-current or radial); the discharge of dried powder from the bottom of the tower, and the separation (either internal or external) of the dustier fractions from the main product, together with a final collection of very fine powder from the outlet air, otherwise a pollutant to the atmosphere. A good detailed description of spray driers is provided by Masters (1972), though not really covering important points of operation for coffee extracts, for which the other references should be consulted. Any subsequent or simultaneous process of agglomeration is carried out in equipment, of which a wide variety of designs and operable plants are available for coffee, and other foodstuffs generally (Jensen, 1975). The patent literature is again replete with methods (Pintauro, 1975: 177-90).

Freeze-Driers

Small-scale and laboratory freeze driers became widely available in the 1950s and used in the pharmaceutical industry. From about 1960, large freeze driers became available, from such companies as Leybold, Atlas and Stokes. Numerous experimental marketings of various foodstuffs both solid and liquid were initiated. Most of these ventures eventually lapsed, due to the high capital and running costs of freeze-drying, though its application

to coffee extracts prospered, by the quality and appearance advantages offered. Freeze driers, in the batch mode, consist of a cylindrical chamber, carrying trays of the deeply frozen product resting on hollow shelves, through which heating water can be passed. The chamber is kept however under a high vacuum, so that the ice in the product sublimes off, and the water vapour allowed to condense on suitably positioned condensers. The frozen extract may be in thin slabs, and after being freeze-dried, removed from the chamber and ground to a powder. The preferred type of procedure, outlined in a number of patents (Pintauro, 1975: 134-54) is, however, to grind the frozen slabs into still frozen granules, which are then loaded onto the trays. The under-sized particles are recycled by a number of different methods. In this way, the required sized granules are ready made. It is important that either slabs or granules remain frozen during drying, determined by the vacuum used and the temperature programme. The time of drying is often long, 8 hours or more dependent upon equipment design, including that of the trays. A further commercial variant is the foaming of the extract, immediately prior to freezing, especially when high concentration extracts are being dried, also described in patent and other literature (Pintauro, 1975: 139-54; Petersen, 1977). Some driers instead of using conductive heat transfer, use radiant heat (Atlas A/S, Copenhagen). Semi-continuous freeze driers also became available, e.g. Leybold tunnel driers. These use an intermittent feed into, and discharge of product from a compartmented tunnel of chambers with interlocks, operating at different temperature regimes as required. Truly continuous freeze driers have also been made (Lurgi, GmbH).

The overall economics of operation of concentration-drying systems has been described in a number of papers (e.g. Van Pelt, 1977).

Packing Roast Coffee and Soluble Coffee

Roast Coffee

Both roasted whole beans, and roasted and ground coffee contain large amounts of gas, primarily carbon dioxide, immediately after manufacture, which is only slowly released, with time. This phenomenon is of importance in the packing of, and the packaging required for these products, presenting problems which have been overcome in a variety of ways. The initial content of carbon dioxide in roasted beans depends upon the type of green coffee (primarily whether arabica or robusta), and importantly on the degree of roast. This content can be measured (by collection to 'infinite' time), and is of the order of 2-6 ml CO_2 (at NTP)/g of roast whole bean. On grinding, dependent upon grind size, a large proportion is, however, immediately released, but a high amount of gas may still remain especially with coarse grinds. The remaining 1-3 ml is then slowly released to the atmosphere in an exponential manner, and many hours may pass before the amount reduces to say 5 per cent of its original. The rate of release will also be dependent on grind size, temperature and external pressure. It can be readily seen therefore that attempts to pack a roast and ground coffee (or whole beans) before sufficient CO_2 has been allowed to escape, in a package of limited total take-up volume for gas may well cause the package (even cans) to burst eventually, due to excess internal pressure. The conventional solution to this problem, is to vacuum pack, i.e. to maintain some initial vacuum within the pack. this solution, however, still requires close consideration of the vacuum to be applied, the size of the package in relation to weight/volume of the contents, and whether any period of holding after grinding for 'degassing' is still required. In practice, it may be found with fine grinds and the use of a high vacuum (e.g. 15 mm Hg pressure absolute), packing can be commenced very shortly after grinding. This solution has been practised for many years with metal cans; or more latterly with so-called 'hard-packs', which are laminate flexible bags, collapsing on the contents under high vacuum. There is however, less surplus volume available for take-up of released carbon dioxide, before such packs would become undesirably soft.

There are, however, other considerations; roasted coffee is very sensitive to effect on quality by oxygen; for example, some 70 ml of oxygen pick up per pound of coffee is enough to cause the roasted coffee to become stale. More scientific investigations (Heiss and Radtke, 1977) have suggested a maximum in-pack level of 0.12 mg oxygen/g of coffee. Certainly the aim is to have an in-pack oxygen content of less than 0.5 per cent for a shelf-stability of up to one year. The use of a very high vacuum helps to achieve this, but the conditions surrounding the holding of roasted and ground coffee for many hours before packing can allow the absorption of oxygen, which may not be readily released in the vacuum packing operation. A lower vacuum can be used in packaging, together with a pre-inert gas flushing stage, in order to reduce the oxygen level. All these matters have been closely examined at the Packaging Institute of the Technical University of Munich in a series of papers (Radtke, 1973, 1975, 1982; Heiss and Radtke, 1977). A further solution to the problem of potential deterioration during de-gassing has been offered by a process of controlled vacuum de-gassing (BP 1,200,635 (1967))); whilst another uses a simple non-return valve, the Goglio valve, for the release of gas in the package itself (Heiss and Radtke, 1977).

The stability of roast and ground coffee in packages is also dependent upon its initial moisture content (usually recommended to be not more than 4 per cent). The package itself should be impermeable to the ingress of further moisture, and oxygen, and not allow egress of volatile aroma compounds. These conditions are of course, readily possible with metal cans; but with flexible packages, careful selection is needed for the package material. The types of packing machinery in general use are described by Sivetz and Desrosier (1979: 279-314).

Instant Coffee

The packing of instant coffee presents fewer problems. Instant coffee in Europe and the USA is now generally packed in glass jars, with a sealed diaphragm at the mouth of the jar and closing lid, the pack is then impermeable to moisture ingress. With instant coffee processed to have a high proportion of retained aroma/flavour volatiles such as freeze-dried, it is also necessary to pack these coffees in an atmosphere of inert gas, either carbon dioxide or nitrogen or mixtures of both, so that residual oxygen content is as low as possible (less than 4 per cent). The operation of filling machinery for large-scale manufactured instant coffee, is necessarily high speed (Foote and Sivetz, 1963: 548-81, Vol. 1).

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