Counter-Current Extraction of Food Industry Wastes

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The ideal approach to the problem of agricultural residues is to maximize recoveries and if possible achieve complete utilization and hence have no residue problem. At the worst, the residue should not be associated with a difficult disposal problem either in terms of bulk or in terms of environmental implications. For example, the residual solids remaining after the mechanical expression of juice from apples (pomace) or citrus fruit (peels) is high in sugar and therefore attracts vermin and is subject to microbial spoilage, producing odours and other environmental pollution problems. Residue from the seafood industry are extremely prone to microbiological degradation and therefore should be treated before deterioration commences.

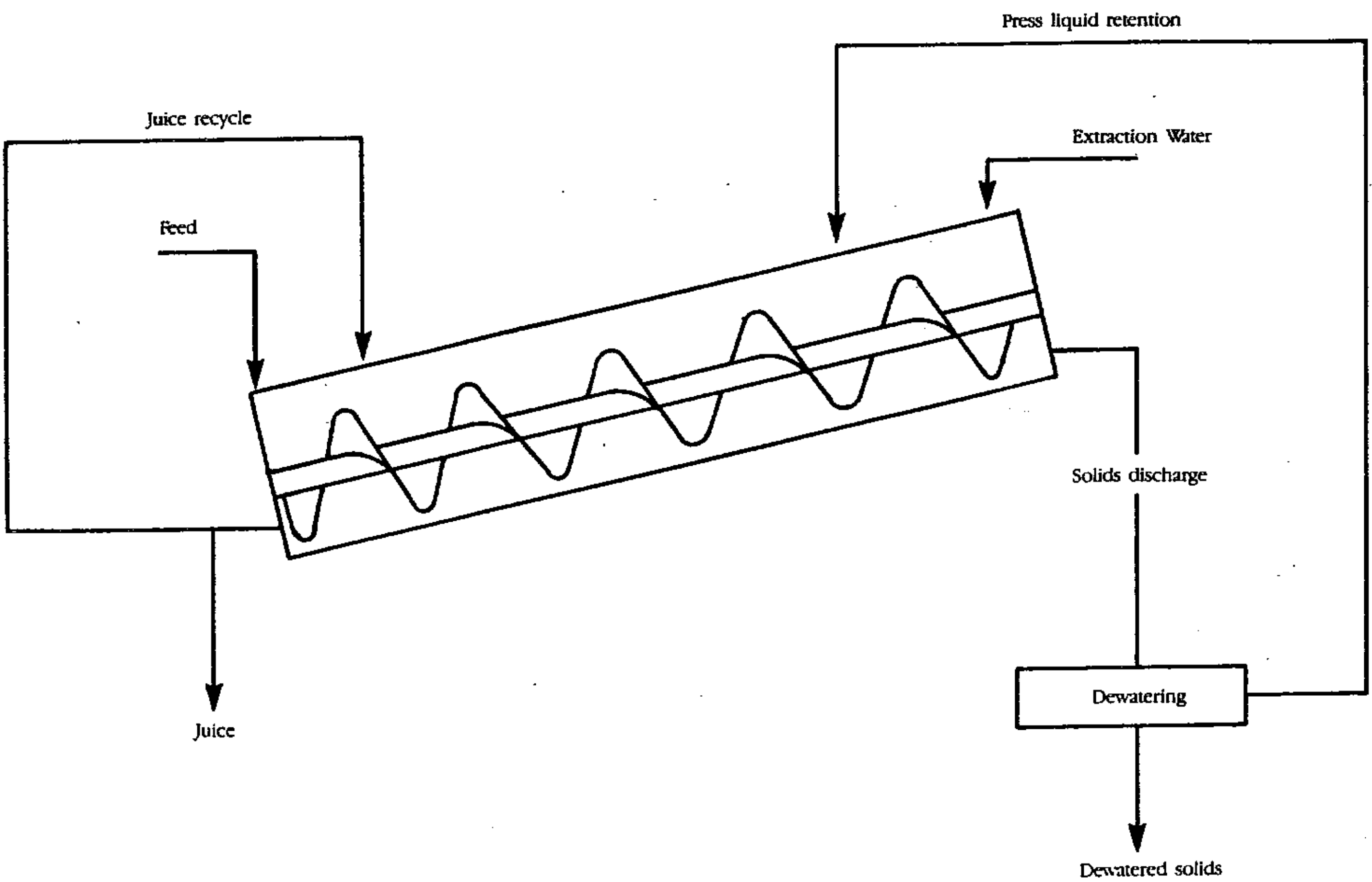
If the ideal situation of complete utilization cannot be achieved, food industry residues should be treated as quickly as possible to recover all the useful edible material, leaving as little as possible of a residue which can be disposed of easily.

The maximization of recoveries and the reduction of residues has been the objective of a program undertaken in Australia by CSIRO and Bioquip Australia Pty Ltd, a firm licensed to manufacture and sell the CSIRO-developed counter-current extraction (CCE) equipment.

The CCE process is a simple and efficient continuous extraction which outperforms conventional pressing extractors with respect to yield, energy efficiency and level of sanitation.

In the CSIRO/Bioquip CCE (Figure 1), the solids to be extracted are moved up an inclined trough by a conveying screw. At the same time, a counter-current flow of extracting liquid flows down the trough. The liquid stream containing the soluble materials extracted (sugars, colours, flavours, etc.) is removed at the bottom end of the trough and the particulate solids which have been extracted are discharged over the top end. The solids as discharged are saturated with the extraction liquid. These are normally dewatered to make disposal easier and recover the remaining small amounts of solubles dissolved in the liquid present in the discharged solids. This dilute liquid stream is

Figure 1.
Diagrammatic layout showing feed and discharge streams to counter-current extractor.



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returned at an appropriate concentration point in the screw to join the extraction liquid flowing down the screw.

Counter-current extraction, or diffusion extraction as it is sometimes called, was conceived some 60 years ago for the extraction of sugar from sugar beets. However, it was not until the 1960s that serious interest was awakened in the use of this technique for the extraction of fruit juices. It is only recently that this technique has been applied to the extraction of animal products and residues by the CSIRO in Australia using the reversing screw extraction developed in Australia.

With extractors in which the screw rotates continuously in the same direction, the solids being extracted tend to ride up one side of the trough while the extracting liquid flows relatively unimpeded down the other without percolating through the solids being extracted. Also, the solids tend to move up the inclined trough compacted, which also inhibits percolation of the liquid through the bed of solids.

The patented CSIRO/Bioquip design overcomes these problems of inefficient contacting by intermittently reversing the direction of rotation of the screw. To obtain a resultant progression of solids being extracted up the incline, the rotation causing progression up the incline must of course be greater than that causing progression down the incline. The ratio of forward to reversing rotation can be used to control the retention or extraction time.

The change in direction of rotation causes the mass of compacted and drained solids being conveyed high along one side of the trough to move down through the extraction liquid in the bottom of the trough and up the other side where they again drain and are subjected to compaction until the direction of screw rotation is again reversed. This action results in a very efficient counter-current contacting of the solid and liquid phases and hence very efficient extraction.

Apple juice. When apple juice is extracted using this process the efficient contacting between the extraction water and the sliced apples results in a juice with a soluble solids level approaching that of the fruit cells. The juice contains less suspended solids than pressed juice, clarifies readily, and can be concentrated without problems.

The cell wall structure must be disorganized for optimum extraction. This is achieved by carrying out the extraction at an elevated temperature, e.g. 60°C, so that the soluble materials within the cells can diffuse out into the counter-flowing stream of extraction liquid. That is, the cells must be killed, but not necessarily mechanically damaged. When the cell walls are not ruptured they act as a filter, reducing the transfer of suspended solids to the juice stream.

An elevated extraction temperature also means that:

- Diffusion rates are increased
- Growth of spoilage microorganisms is inhibited
- Enzyme activity is controlled
- Oxygen solubility is reduced

Thus the extractor can operate for long periods before downtime for cleaning is required, enzymic reactions due to naturally occurring enzymes can either be eliminated or utilized, and oxidative degradations can be minimized.

The particulate form of the solids being extracted should be such that the diffusional path for the soluble materials is short and the surface area for mass transfer is large. Thin slices are an ideal particle shape for fruit such as apples. The slicing operation is not as energy intensive as milling. As only a small proportion of the cells is damaged, the juice which is low is suspended solids is easy to clarify.

Grapes. Grape marc can be defined as the residue remaining after the "juice" has been removed from the grapes by mechanical means. The mechanical means is usually pressing, which may be severe or light. There may or may not have been a degree of fermentation before the pressing operation. The marc frequently does not contain stems as they are often removed in a destemming operation prior to the crushing and juice process.

As in many fruits, constituents important to the character of the fruit, such as aroma, flavour, colour and acid, occur in higher concentrations in the skin fraction. The skin tissue, being more mechanically rigid, retains liquid and other soluble components. These are not as efficiently removed from this tissue in pressing operations and hence are lost with the marc.

The weight of marc varies from 5 to 20% of the grapes crushed and the further extraction of marc using the CCE process produces an extract which can be as high as 16-18% grape sugar. The extract also contains valuable aroma compounds, tartrates, and colour (enocyanin in the case of red varieties). These pigments are becoming of increasing importance in a world demanding natural foods.

Citrus. During the extraction of juice from citrus fruit by mechanical means only about half of the fruit weight is collected as juice, that is, liquid from the endocarp. Depending upon the setting of the extractor, either some of the liquid is expressed from the peel (albedo/flavedo) fraction or some of the juice is absorbed into the spongey albedo tissue and is thus lost with the peel.

The peel discharged from mechanical extractors is about half the fruit weight and contains approximately as much sugar and vitamin C as the juice. Hence, when peel residues are extracted in the CCE a liquid containing up to 10% soluble solids can be obtained. This liquid extract can be evaporated to produce a drink base concentrate or may be fermented and distilled to give citrus liqueurs. The extracted peel solids contain essentially only insoluble carbohydrate which includes the major portion of the pectin, which can then be solubilized and extracted using an acid.

Poultry residues. The poultry processing industry produces a number of residues such as carcases, feet, heads and eviscera which, if processed before deterioration commences, can result in a number of products useful in the formulation of human or animal foods.

The CCE process allows the recovery of stock, fat and soluble proteins from these materials. This is a rendering type process allowing the extraction of water-soluble materials and permits the lipid materials which liquify at the extraction temperature to be separated from the aqueous and solid phases.

After separation of the lipid phase, the aqueous phase may be concentrated to produce a flavour concentrate and/or dried to be used for the preparation of chicken stock cubes or for incorporation in low-moisture foods, such as dehydrated soups or dips, or as a flavoring for potato crips and extruded or puffed foods.

The stock or aqueous fraction obtained from the CCE of chicken carcases was of light brown colour, had a characteristic flavour and aroma, and a total solids of 3%, of which 81% was protein.

Fish and crustacean residues. As with poultry residues, fish and crustacean residues contain valuable protein and flavoring materials. Certain species of fish also contain sufficient quantities of lipid materials to make the separation of an oil fraction possible. The protein containing stock can be concentrated and/or dried to produce high-protein flavoring materials which can be used in formulations for dehydrated seafood bisques and puffed or extruded seafood products.

The concentrated aqueous fraction from the CCE extraction of fish skeletons (heads and backbones) had a grey-brown colour, a characteristic fish-like aroma, and an insoluble solids content of 2.3%, of which 72% was protein.

The extraction of shrimps heads resulted in an aqueous extract having a solids content of 6%. This "prawn juice" had a very characteristic shrimp flavour and mixed tomato juice resulted in a "prawnato" juice, which is a pleasant drinking seafood cocktail.

Crayfish bodies were similarly processed to obtain a "crayfish juice" which, when combined with tomato juice, resulted in a "craymato" juice. The solids residue remaining after the extraction of soluble materials from crustacean residues contains large amounts of chitin (poly-beta [1:4]-N-acetyl-D-glucosamine) which can be used as an emulsifying or flocculating agent.

Mushroom-growing residues. The peat moss in the casing soil, which is used to cover the beds of mushrooms compost prior to fruiting, is nearly all imported into Australia, the best quality material coming from West Germany. The concentration of salts, which retards the growth of the mushroom mycelium, builds up so that this material has not been able to be reused. It has been found possible to leach out these salts in the CCE using hot water at 60-70°C. This treatment also results in undesirable organisms such as fungi, bacteria, nematodes and insect pests being destroyed so that the peat moss can be used again for further crops.

Not all the peat moss from the beds is recovered as there are losses when the mushrooms are picked and during the recovery stage. However, more than 50% is normally recovered and this is blended with new peat before reuse. Because of the extensive leaching in the CCE it is only necessary to add sufficient lime to control the pH of the newly added peat.

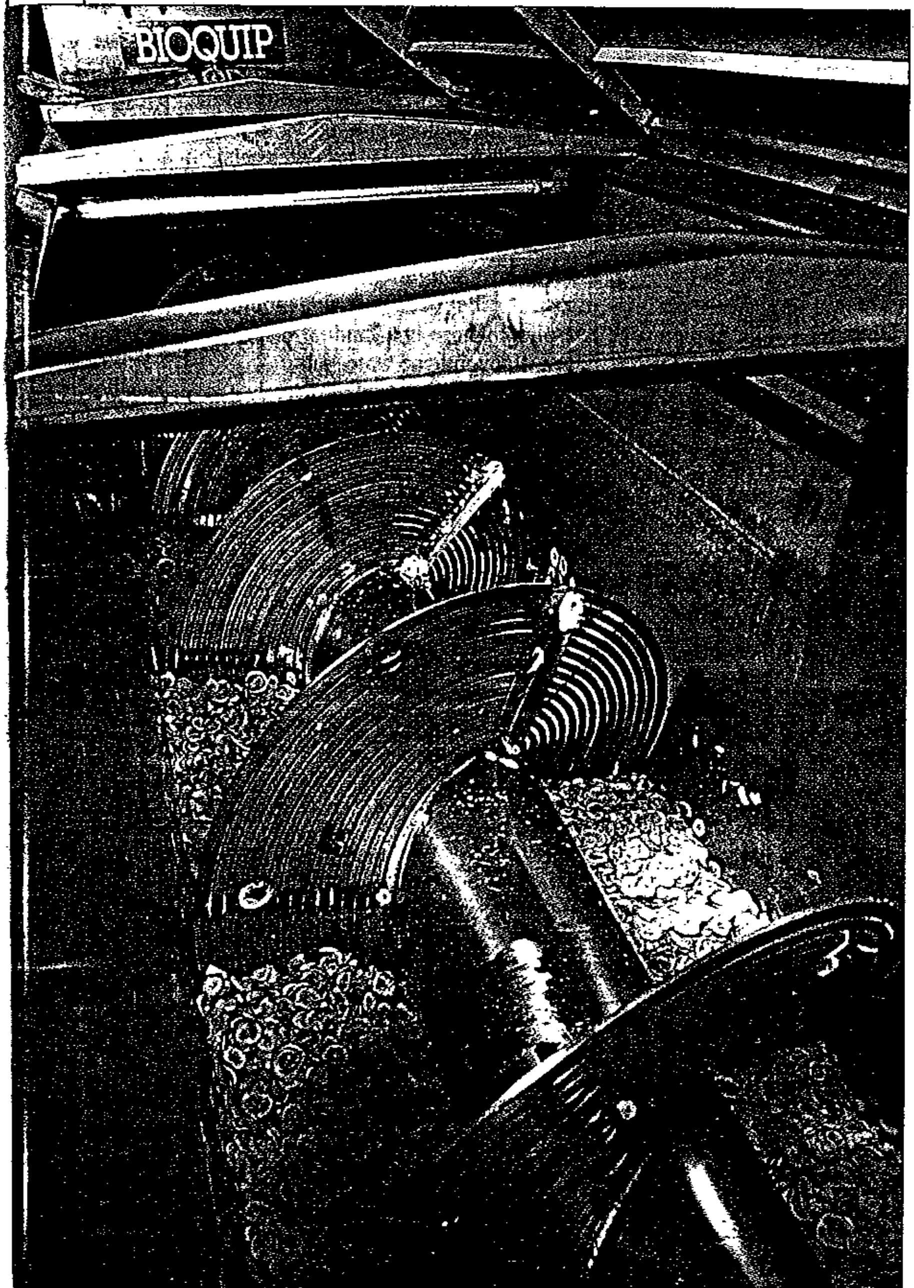
Fibre recovery from fruit residues. The trend to diets with more fibre and less calories suggests that the extracted solids discharged from the CCE process could be a valuable component of these diets. This is especially so as the non-digestible carbohydrate in extracted fruit residues is high in pectin, which is now considered to lead to a lowering of the blood cholesterol levels.

To sum up, this new technology and equipment developed and commercialized by CSIRO and Bioquip Australia Pty Limited can be used for the extraction of soluble materials from waste materials. This allows valuable materials to be recovered and reduces the disposal problems with the remaining fraction.

New applications for this technology are coming forward continuously. Many areas such as the production of vegetable juices from off-cuts, for example celery butts, and the use of non-aqueous extractants for the recovery of lipid materials and essential oils have yet to be developed.

COUNTER CURRENT EXTRACTION INCREASES YIELDS

Counter current extraction methods can dramatically increase the yields of soluble solids in fruit processing. The method extracts the soluble solids by presenting the material to a counter current flow of a suitable solvent to wash them out of the fruit.



Removal of soluble solids from a large variety of organic materials is an objective common to many food manufacturing processes. Several conditions must apply to achieve this objective satisfactorily.

- The product must be readily capable of further economical and convenient processing;
- The soluble solids recovered must be very close to the total soluble solids in the feed material, or at least closer than other methods;
- The process should be continuous, not a batch operation;
- Residue from the process should be easy and inoffensive to handle as well as potentially saleable;
- The process must deliver a product that conforms with food laws.

Bioquip Australia Pty, Ltd.'s continuous diffusion extraction by means of a counter current extractor satisfies all of these criteria in four stages.

1. **Feed Delivery.** Feed material is delivered to the extractor in the form that makes the particular material most suitable for diffusion extraction. Some materials are sliced; others are crushed, chopped or minced; some require no pre-treatment. Washing, sieving or mixing is done at this stage.

2. **Extraction.** The soluble solids are extracted in a continuous process which presents the feed material to a counter current flow of a suitable solvent, usually water, for a sufficient time for the soluble solids to be washed out.

3. **Product.** The extracted liquor is drawn off

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Laboratory tests are made for brix measurements, turbidity, solids by volume, pH measurement, pectin and starch determinations and micro checks.

When applied to oranges, a profit increase of $89.67 (Australian) per ton is realized from the counter current extraction process over traditional methods.

for further treatment.

4. **Residue.** The residue from the process is discharged continuously. During discharge, it is subjected to further treatment to remove most of the few remaining soluble solids. After treatment it is almost dry, friable, not readily putrescible and may be saleable.

The equipment

The Bioquip counter current extractor is an inclined jacketed trough in which rotates a ribbon flight screw, driven by a variable speed hydraulic motor. The screw has the ability to rotate in either the forward or reverse direction for periods set by timers in the control panel. These times are set so that the apple slices are held in the trough for the required residence time while they move from the lower (feed) end to the upper (discharge) end of the trough. The ratio of forward to reverse times is also set to give the optimum contacting between solid and liquid phases.

At the lower end there is a self-cleaning screen for separating the product stream from the mass of apple slices and an adjustable weir for controlling the operating liquid level in the machine.

A circuit comprising a pump, heat exchanger, spray manifold and connecting pipework and fittings is supplied to allow a quantity of the product juice to be heated up and returned to the process via the spray manifold. The hot juice sprays assist in rapidly raising the temperature of the fruit to the operating level.

At the upper end, the extraction water enters the machine at a constant flow rate, maintained by a flow control valve via a similar spray manifold. The sprays promote uniform and efficient cooling of the spent slices prior to discharge.

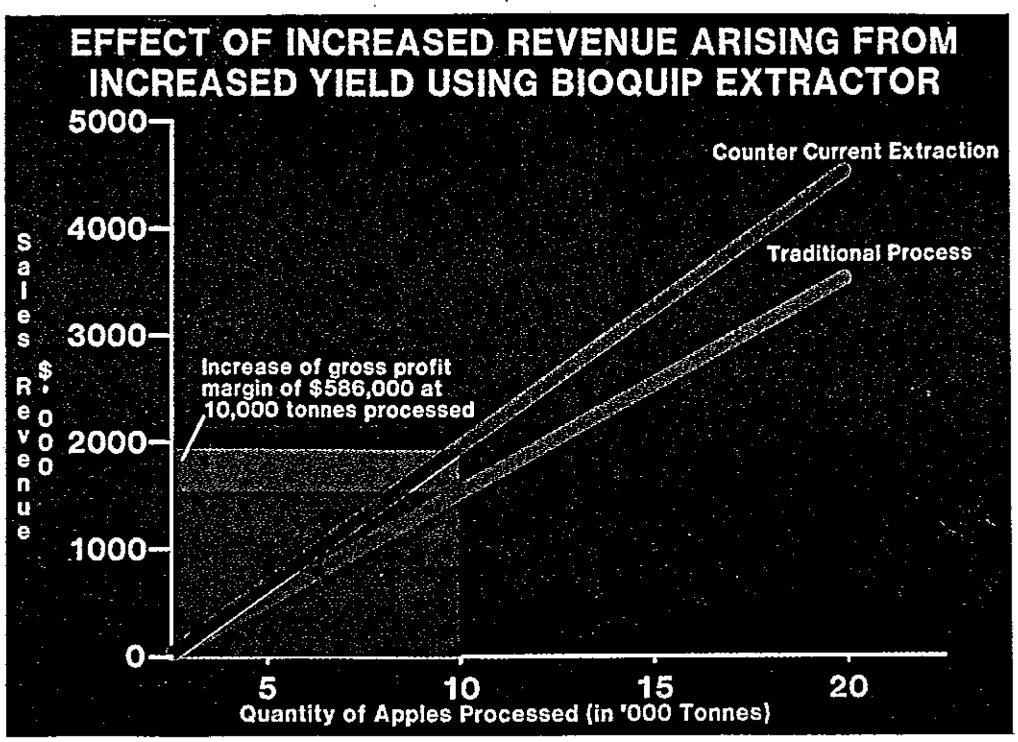
The spent slices which still contain some residual traces of dissolved solids are removed from the trough by an elevator across a sieved screen. There is a further dewatering operation in an inclined drainer. The press liquor so obtained may be wholly or partially returned to the process through a nozzle manifold some distance from the upper end.

The process for apples

Apples stored in bins are transferred to a water bath at the rate of one bin every three minutes using two rotating head forklifts. Heavy foreign objects are removed from the apples in the water bath.

The apples are taken from the water bath by an elevator and conveyed to the slicer, passing through high pressure water jets on a roller system to ensure complete and thorough washing of the apples, and removal before extraction of any damaged sections. The elevator can include a weighing facility, enabling the feed rate to be continuously monitored or controlled. There is a manual inspection area at a point beyond the water jets.

The slicer is mounted directly above the slice inlet of the extraction unit. A crinkle cut slice approximately 2.5mm thick is used, ensuring minimum diffusional path and a large surface for mass transfer while maintaining the struc-



tural strength of the slice.

The slices are brought quickly to the extraction temperature (58-60°C). The rapid heating: kills the cells, disorganizing their structure and allowing solubles to diffuse out; prevents enzymatic browning by reducing solubility of oxygen and eliminating the need for antioxidents; controls microbiological growth; and increases the rate of diffusion.

The operating temperature is critical — if it is too low, diffusion is inefficient; if too high, a "cooked" flavor develops.

The heated slices are conveyed through the extractor by means of a single screw. The screw rotation is intermittently reversed and is operated with more forward motion than reverse. The resultant action provides very efficient contacting between the solids and liquids and eliminates maceration of the slices.

As the slices are conveyed through the extractor, they are exposed to a counter current stream of extraction water. During the passage of a slice, soluble solids diffuse from the cells within the slice into the counter current liquid stream. Between 93% and 96% of the soluble solids in the fruit are extracted and recovered.

The resultant juice is discharged from the machine through an overflow tube which maintains the desired liquid level. It then flows over a vibrating screen to remove coarse solids and into a balance tank. Because of the filtering action of the cell walls, counter current extracted juices tend to contain less suspended solids than pressed juices.

Because lower solids are generated in the juice and because of the temperature of the product off the extractor, the level of finings, diatamaceous earth and enzyme additions can be significantly reduced. These levels can be further reduced through the use of microfiltration. In addition, holding time on finings and enzyme can be shortened considerably.

Outcoming juice temperature is adjusted to 50°C and pectolytic enzymes are added continuously in-line. Fining additions are made and at this temperature, reaction and settling time will not normally exceed three hours.

The supernatant is then racked and passed through a microfiltration system. The clarified juice produced is less than 1 ppm suspended particulate matter, turbidity less than 1 NTU, microbial plate count 0-10 CFU per 100 mg. and meets all standard quality tests.

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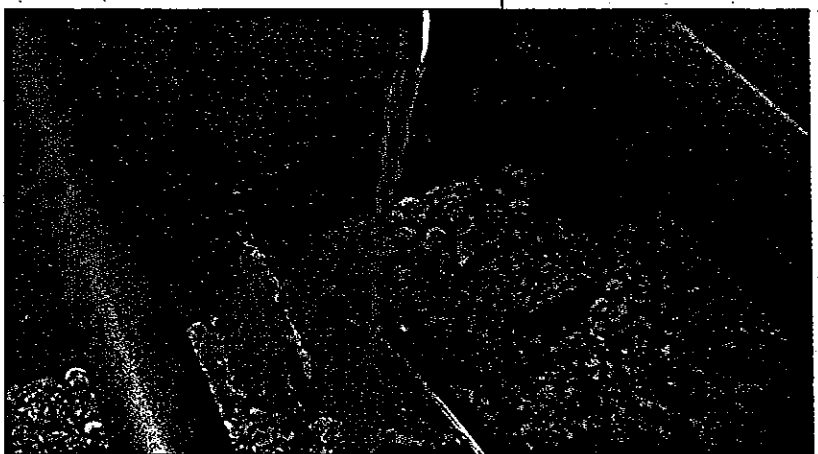
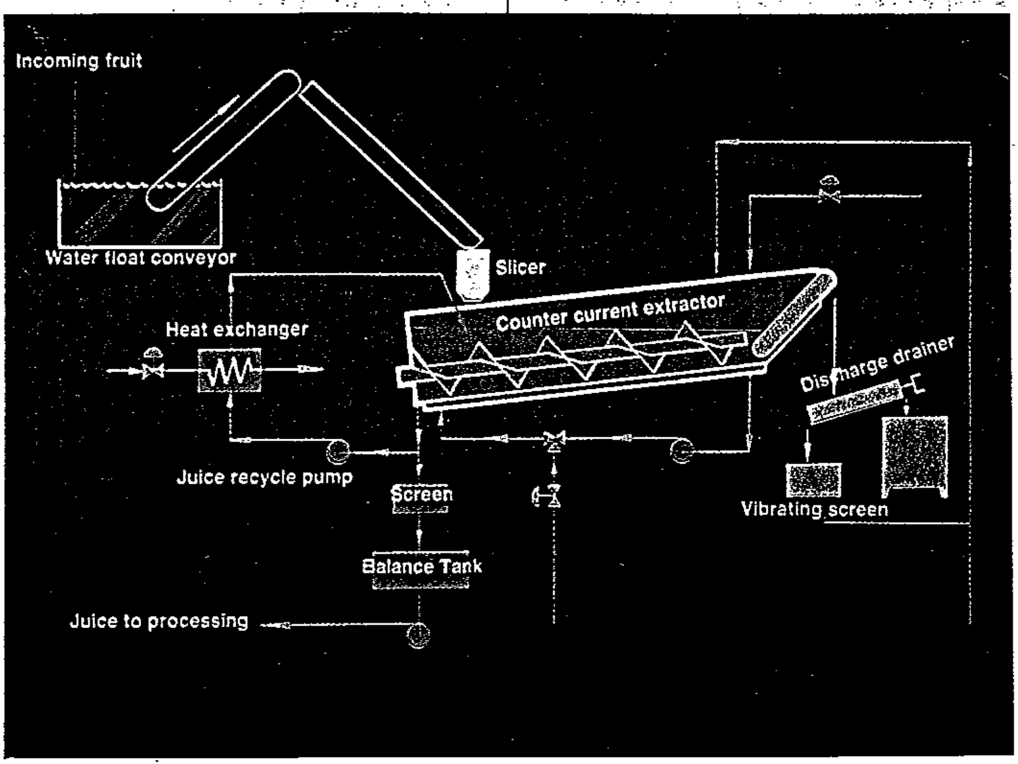
Part of the product juice is heated and returned to the process. The hot juice assists in rapidly raising the the temperature of the fruit to the operating level.





The schematic shows the progress of the apples through the extraction process. The rotating ribbon flighted screw moves the product forward and back for a prescribed amount of time before discharging the product.

A rotary drum vacuum filter provides further recovery from enzyme settlings as well as discharge from the microfiltration unit. The clear juice from this operation is fed back into the microfiltration system along with the supernatant, ensuring a fully polished product and maximum yield.

Reverse osmosis

Some dilution is intrinsic to the counter current extraction process. The polished juice leaving the microfiltration unit has a brix reading of approximately 10° depending on the brix of the incoming fruit. Reverse osmosis is then used to remove the water used in the counter current extraction process and carry out a partial concentration.

The water removed by the reverse osmosis is used as the elution water in the counter current extraction process, so there is no net water addition. Pre-concentration to 20° Brix, using the reverse osmosis process is performed, prior to evaporation.

Concentration is done using an Alfa-Laval multiple effect cassette evaporator. Waste heat from the evaporator is recovered and used in the counter current extractor. Ester recovery is included, meaning that no pasteurization is required pre-concentration.

In order that apple concentrate can be stored at ambient temperature, aseptic filling is provided. Multi-ply flexible bags incorporating an aluminum foil layer are used. The bags are housed in metal drums or paperboard containers. The aseptic technique consists basically of product heating, deaerating, sterilizing, cooling and filling under aseptic conditions. The technique results in significant savings in the capital cost of cold storage and in operating costs, particularly power and labor.

For oranges, the process is similar, with resulting juice yields of 70-87% of the total soluble solids in the fruit. This is 59-113% greater than is achieved by traditional processing, according to Bioquip.

The mass of the apple slices leaving the process is only 50% of the mass of the apples entering the extractor.

Benefits of C.C.E.

The use of counter current extraction technology results in an increased yield of 25.7 liters (28.7%) of concentrate per ton of apples processed. Expressed in Australian dollars at $2.28 per liter, this results in an increased gross profit of $58.60 per ton.

Additionally, according to Bioquip, operating costs are reduced by $3.20 per ton as compared to traditional methods, mostly due to lower labor costs.

Item	C.C.E.	Traditional
Labor	$5.40	$10.80
Power	0.36	0.72
Consumables	7.81	8.13
Evaporating Costs	7.31	4.43
Total	$20.88	$24.08

This table assumes:

1. Labor—$9.00 per man hour
2. Power—$0.06 per kilowatt hour
3. Steam—$0.025 per kilogram
4. Assumed evaporation to be 3-effect, i.e. ratio of kilograms of steam to kilograms of water evaporated is 0.3:1.

Hence, if 10,000 tons of apples were processed, the total cost saving is $32,000. In processing oranges, while operating costs are increased, net revenue, including these costs improves by $89.67 per ton.

There are currently four commercial counter current extractor installations in Australia and one in New Zealand, processing apples, pears, grapes, oranges, blackcurrant and dried fruit residue. In addition, a wine plant in New South Wales is processing grapes for the production of low alcohol wine. Other applications which have been successfully tested include; berry fruits, pineapples, mangoes, prunes (fresh and de-hydrated), tomatoes, guavas, raisins and other dried fruits (to reduce sugar levels). Other successfully tested products include meat and fish, brewery products (for extraction of wort and of grain), vegetables (for extraction of their juices), pine bark (for tannin extraction), potatoes (to reduce sugar levels prior to frying) and for the production of alkaloids and pectins.