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recovery of by-products from the treatment of whey

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Introduction

As in other process industries, there are many cases of food processing where relatively low-value by-products are inevitably made with the main products. In such cases, it is often simplest to consider these by-products as waste and to discharge them into sewers. However, if they have a high pollution level, it is often necessary to carry out some type of pre-treatment before discharge.

In recent years, legislation relating to effluent disposal has become increasingly severe, with the result that treatment of food waste materials to acceptable standards is becoming very expensive. Given the right circumstances it can thus become more attractive to consider such food wastes as sources of saleable by-products and therefore to recover them, rather than treat the ste as an effluent. Whey is a typical mple of a highly polluting food waste product from which saleable by-products could be recovered, as an alternative to disposal as effluent.

Cheese Production and Whey Disposal

When milk is cultured and processed to make cheese, liquid whey is separated from the cheese curd. Whey may be considered as milk which has had the casein and butter fat removed. Water soluble minerals and vitamins, lactose (milk sugar) and the non-casein proteins (mainly lactalbumin and lactoglobulin) remain in the whey. Only 10% of the milk is converted to cheese, whey representing the balance of 90%. A typical whey from cheddar cheese would have a total solids content of 6–6½%, of which lactose is about 4.5% and whey proteins about 0.75%, the balance being variable quantities of fats, mineral salts, and minor constituents.

Traditionally, liquid whey has been used as a cheap animal feed, particularly for pigs and calves, and any whey not required for this purpose was discharged to adjacent water-courses. Advancing industrialisation has brought about the manufacture of cheese in increasingly larger units, which are often far from pig or calf rearing farms. This has led to the development of whey recovery processes, for instance by drying, and to the separation of specific components such as lactose. In spite of these recovery processes, a large proportion of whey is still discharged as effluent to streams, either directly or after some treatment to reduce its very high BOD value (approximately 30 000 ppm).

The entire whey situation is currently changing drastically in view of two factors:

(1) The severe restrictions being imposed by most European governments prohibiting the discharge of untreated whey into streams.

(2) Since the entry of the UK into the Common Market, imports of cheese from Australia and New Zealand are being phased out. This means that considerable quantities of cheese will have to be produced for the UK market by the members of the enlarged EEC. Consequently, cheese-making capacity is being significantly increased in Britain, Ireland, France, Holland, and Denmark. Table A gives estimated figures of cheese production and consumption in 1965, 1970, and projected 1980 for the UK and the old EEC countries. While the projections have to be treated with reserve, it is clear that there is considerable scope for increased production in Britain and Ireland as well as in other European countries.

As a consequence of this additional projected capacity, cheese producers are currently evaluating the feasibility of various methods of treating whey in order to reduce its very high pollution level and to recover saleable by-products.

Since most cheese-making plants are situated far from sewage works, it is not usually possible to overcome the pollution problem by using the treatment service provided by a municipal sewage authority. Separate biological oxidation plants will therefore have to be installed by the cheese producer if he merely wishes to decrease the pollution load of his whey for discharge into local streams. Effluent treatment of whey yields no saleable by-product and, depending on circumstances, could entail high capital and operating costs. On the other hand, the recovery of whey by-products is not always an attractive economic proposition so that in certain cases effluent treatment of whey may well be the lesser of two evils.

In the following sections various conventional and novel techniques of whey treatment will be discussed. These methods can produce saleable by-products as well as bring about a decrease of the pollution level.

Conventional Processing Methods

While the pollution load can be reduced by aerobic oxidation in conventional plant, this does not recover a saleable by-product. Most whey processing operations for this purpose comprise a number of conventional unit operations or biological processes used singly or in combination. The following have been tried in practice.

TABLE A—*Estimated Production of Cheese in old EEC and UK*

000 Ton

	Belgium	France	W. Germany	Italy	Netherlands	UK	Total
1965							
Production	35	580	370	450	220	115	1,770
Demand	60	570	490	460	100	260	1,940
Surplus or Deficit	−25	+10	−120	−10	+120	−145	−170
1970							
Production	35	730	470	400	260	120	2,015
Demand	75	700	550	540	100	285	2,250
Surplus or Deficit	−40	+30	−80	−140	+160	−165	−235
1980							
Production	35	950	620	500	350	145	2,600
Demand	100	820	690	705	125	335	2,775
Surplus or Deficit	−65	+130	−70	−205	+225	−190	−175

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Concentration and drying

Multiple effect evaporators are used to raise the solids content of the whey to between 20% and 50% total solids. Concentration is carried out either to reduce transportation costs (if the whey is to be processed elsewhere) or as a first step prior to drying or other processing operations.

Roller driers have been used traditionally, but they produce a hygroscopic whey powder. Spray drying gives a whey with improved flowing characteristics but does not produce a really non-caking material because the caking is caused by the presence of amorphous lactose, which is formed when rapid drying conditions prevail.

This difficulty can be overcome by inducing the formation of nuclei of alpha and/or beta type lactose crystals in varying proportions in the concentrated whey solution fed to the spray drier. The properties of the product powder can thus be controlled by the extent and conditions of the pre-crystallisation treatment adopted. Some commercially available spray drier installations incorporate additional conditioning aids, usually within the final cooling operation.

Separation of protein

The proteins present in the whey (mainly the lactalbumins) are separated by acidification followed by filtration or centrifuging.

Extraction of lactose

Whey is an important source of lactose. Its extraction involves deproteination of the whey, followed by vacuum concentration in several stages, and crystallisation with recovery of the crude lactose by centrifuging. Subsequent purification involves various stages of recycling of the crystals and mother liquor. The grade of lactose produced—whether food or pharmaceutical—depends on the number and details of the extraction and purification stages to which the crystals are subjected.

Fermentation

The lactose constituent of whey (which has been previously deproteinated as mentioned above) can serve as a fermentation medium for producing yeast. This process is a very elegant method of increasing the protein content, while at the same time reducing the pollution load.

Whey is pasteurised and passed into a fermenter together with other nutrients such as ammonia, mineral salts, *etc.* A strain of *Saccharomyces fragilis* is injected into this fermentation medium. Propagation of the yeast then proceeds rapidly whilst the fermentation medium is subjected to a high degree of aeration. Although there are many commercial yeast production plants in the world, most of them produce yeast of the species *Saccharomyces cerevisiae* (grown on molasses) or *Candida utilis* (grown on spent sulphite liquor). There are only two commercially viable processes in the world for the production of *Saccharomyces fragilis* on whey. One of these, pioneered in France, involves a continuous fermentation followed by separation and recovery of the yeast by centrifuging, filtration, washing, drying, *etc.*

Novel Separation Techniques

A number of new methods of separation have been applied in recent years to the treatment of whey. In general such methods have only been used experimentally and in most cases large scale industrial operation may still be hazardous. Nevertheless many pilot plants are in operation, and rapid progress is being made in meeting and overcoming the problems associated with continuous operation. At the same time efforts are being put into scaling up the design of commercial plants. Thus it is likely that even in the near future a number of medium to large scale plants using these techniques will be in commercial operation.

Reverse osmosis and ultrafiltration

These are two separation operations using membranes which were first developed for water desalination and similar applications.

In reverse osmosis, as the name implies, a pressure greater than the osmotic pressure is applied to one side of the membrane and thereby the whey can be concentrated to a solids content of up to four or five times its original concentration. Because the energy consumption is relatively low, reverse osmosis could provide an economic replacement of thermal concentration, but the separation is not perfect and at the higher concentrations (*e.g.* 30% solids) a substantial proportion of the lactose present in the raw whey passes through the membrane and leaves with the "filtrate" which thus retains a high BOD.

By using different membranes, ultrafiltration applied to whey treatment is essentially a method of separating the protein. Here again there are several limitations. While virtually all the protein can be separated from the whey, a proportion of the lactose will inevitably accompany it. The protein/lactose ratio of the so-called protein stream depends on its concentration and the nature of the membranes, but at best it will be in the 60/40—70/30 range, at a total solids content of 20–30%.

Neither of these membrane techniques gives a saleable product when used by itself, but one can envisage more complex process sequences in which one or both of these operations can be accommodated as viable process steps. As new membranes are developed by several competing suppliers, their field of application should widen, especially if they will become less subject to damage through maloperation (mechanical damage, bacterial contamination, *etc.*).

Electrodialysis

This technique also makes use of special membranes but the objective is the removal of the mineral salts from the bulk of the whey. It uses an electric potential difference as the driving force, and varying degrees of demineralisation are possible. Up to 90% of the mineral salts can be removed in the form of a salt solution.

Electrodialysis is probably in a more advanced state of readiness for large scale industrial application than either reverse osmosis or ultrafiltration, but like these techniques its separation capacity is directly proportional to the number and/or size of units or modules employed. While this type of modular construction makes installation and expansion easier, it also means that the capital cost is very high without the cost benefits usually associated with large scale operation.

Gel Filtration

This is a unit operation which, like reverse osmosis and ultrafiltration, achieves separation of whey components according to thei[r] molecular weight. The filtration medium a crossed-linked polysaccharide gel containing "pores" the size of which can be controlled. These "pores" can trap molecules of smaller size and then separate them from the larger ones in a cyclic method of operation. Gel filtration could be used for whey concentration or for protein/lactose separation, but it still requires much practical development.

The various by-products will now be considered in the light of their manufacturing and marketing possibilities.

Marketing Considerations

As seen from the above, a number of different products can be made from whey. Bearing in mind the big increase in the supply of whey requiring either effluent treatment or processing for by-products recovery, one can discern three groups of products as follows:

(1) Lactose.

(2) Various grades of whey powder.

(3) High-protein products.

The first group comprises the various grades of lactose currently used in baby foods and for pharmaceutical purposes. In broad terms the demand for these products is fairly steady. For economic reasons the recovery of high-grade crystalline lact[ose] requires a relatively large scale of ope[ra]tion, so that new facilities will have to be carefully matched to new demand.

Conversely, the consumption of whey powder for animal feed purposes is increasing rapidly, partly due to certain effects of EEC price regulations. This increasing demand is being satisfied through a number of new spray drying installations. This trend has been encouraged on the one hand by the pressure of the greater availability of whey and the need to treat it, and on the other hand by the advanced state of the spray drying technique compared to some of the other processing methods. It is hard to gauge how this combination of factors will affect the price of dried whey and hence the economics of further drying installations. Obviously, premium products such as demineralised whey will have a much wider field of application and will command higher prices. These, and the higher plant investment costs, must be allowed for in any project evaluation.

For the high-protein products comprising the third group (protein fractions, yeast, protein-enriched whey powder, *etc.*) the situation is governed by the recent sharp rise in the price of proteins for animal feeds. This is the combined effect of the temporary disappearance of fishmeal, the decline in soya bean harvest in the USA, a drop in the world groundnut production, and poor grain harvests in the USSR and China. The world shortage of protein l

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