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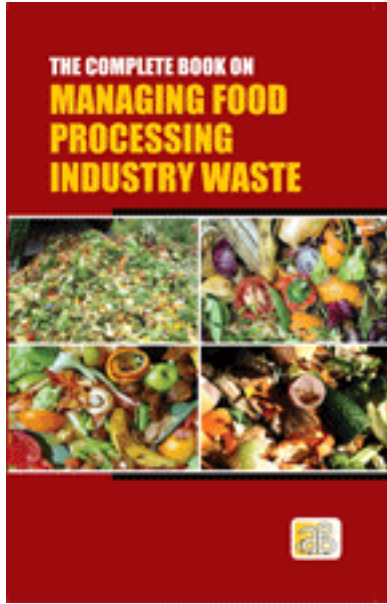
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The Complete Book on Managing Food Processing
Industry Waste



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Food industry produces large volumes of wastes, both solids and liquid, resulting from the production, preparation and consumption of food. These wastes pose increasing disposal and can pose severe pollution problems and represent a loss of valuable biomass and nutrients. Many standard industrial waste treatment texts sufficiently address a few major technologies for conventional in plant environmental control strategies in the food industry. Environmental legislation has significantly contributed to the introduction of sustainable waste management practices worldwide. Considering the challenges in the area of food industry, efforts are to be made to optimize processing technologies to minimize the amount of waste. Food processing wastes have a potential for conversion into useful products of higher value as by product, or even as raw material for other industries, or for use as food or feed after biological treatment. There are many examples of utilizing waste materials from plant material processed by canneries, there are many other types of waste that can be utilized. In many canneries, the organic from the processing system is combined with the other types of non usable wastes, such as hardware, glass, cans, nails etc. Food industry should also have to concentrate on waste avoidance as well as utilization of process wastes. All the combined efforts of waste minimization during the production process, environmentally friendly preservation of the product, and utilization of by products would substantially reduce the amount of waste, as well as boost the environmental aspect of food processing industry.

This book basically deals with utilization of food industry wastes, ultra filtration in the recovery of food waste, recovery of fruit and vegetable wastes, recovery of protein, the screening of vegetable wastes, fat extraction, treatment of fatty effluents, recovery and utilization of protein, conversion of bone to edible products, utilization of waste in animal feeds, production of earthworm proteins, use of microbiological agents in upgrading waste for feed and food, underutilized proteins for beverages, coffee and tea wastes, utilization of food waste in pet food industry, etc.

Readers, technical institution, food technologists, technocrats, existing industries and new entrepreneurs will find valuable material in this book. This book gives a complete detail on invaluable waste management concepts, utilization of by-products and the practical methods to implement them. This book deals on the techniques and methods for food processing wastage. Comprehensive in scope, the book provides solutions that are directly applicable to the daily waste management problems specific to the food processing industry.

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Sample Chapter:

This paper will consider some of the problems that arise in utilizing food industry wastes. My concern is specifically with utilization rather than disposal; the effluent considerations will be discussed later. The wastes which are of interest are those emerging from food processing factories and this defines the first characteristic of the problem, namely that the raw materials for any utilization process are very varied. Not only may that nature to the waste differ from site to site but it also may vary, on one site, from one time of the year to another-as in canning units. Additionally the volume and concentration of the waste material will not be constant. So the first problem is to ensure that a process can work consistently in spite of the major fluctuations in the nature and quantity of the raw material. This situation is one which is anathema to the more classical fermentation physiologists and technologists; in practice, the usual response has been to construct relatively large units of plants, which incorporate substantial 'holding' capacity in order to even out the fluctuations and introduce some stability.

Which product is to be made by utilization of waste? Here there seem to be two basic choices, namely to modify the waste to produce an upgraded material of higher value than the waste itself or to produce something quite distinct by using the waste. With regard to upgrading, there are clear possibilities, which apply, however, only to a relatively small proportion of the waste produced in Britain. Good examples are production of animal feeding stuffs from distillers' solubles, the ensilage of rape seed meal to reduce toxicant level and so obtain a more useful product and, perhaps the most common, the simple drying of wastes such as brewery grains to make a more useful product. In all such cases the research approach must be to determine the disadvantages of the waste as a product and then to devise remedial action. Of much more general interest is the second alternative, the production of a completely different product from waste and, in this context there are basically two choices: to produce microbial biomass and to produce fuel.

Biomass, or single cell protein, is used as either animal or human food, and this imposes particular limitations on the processes which are to be used. The first of these is that biomass which is to be consumed must be acceptable to regulatory authorities as a component of diet even if animal food is to be produced, and the number of unusable organisms may be rather small. The present UK restrictions are relatively minor but it seems likely that EEC regulations will soon be in force and these will be much more rigorous. A second limitation which naturally follows is that the product must not be contaminated with other organisms and for this reason the waste, which is almost inevitably contaminated with a range of microorganisms, must be sterilised for biomass production. Furthermore, the process used must avoid introducing other organisms during production and there must be rigorous tests to confirm the purity of the biomass product. All these steps are expensive. Biomass as a product from waste seems to me to be unlikely to be a viable proposition except in specialised conditions. The production of Pruteen from methanol and of Candida yeast from confectionery wastes may be practicable but it seems unlikely that the production of biomass will find general application as a widespread method of utilising food industry wastes. For this reason I do not propose to consider this approach further today.

The situation seems more promising with regard to fuel production. There is a substantial need for energy in the world and, although the supply situation in Britain is less serious than in many other countries, the cost of energy is sufficiently high to make the production of energy from waste very attractive. Energy from waste means producing either ethanol or methane. These substances are both volatile and thus are products which can readily be separated from the mixture of organisms and residual waste which produced the fuels. Problems of toxicology and public health anxieties accordingly do not arise to anything like the same extent as they do with biomass production.

Microbial ethanol production on the industrial scale is well known and very large quantities are currently being produced from surplus carbohydrate, or from carbohydrate-rich crops, in 'gasohol' projects in a

number of countries. Even in these circumstances there is some doubt about the true value of the process in energy terms as well as economically and this reflects, in part, the energy costs of distillation, necessary in order to remove ethanol from the treated waste. This difficulty becomes greater as the concentration of ethanol diminishes; as a rule of thumb, it is generally held that the production of ethanol by distillation from a microbiological 'broth' is unlikely to be economical unless the ethanol concentration is 5% or more. This in turn suggests that carbohydrate concentration in the waste material must be of the order of 10%. There are relatively few wastes that meet this requirement so that, as was the case with biomass, ethanol production from waste seems to be applicable only in special circumstances.

The production of methane seems to be much more attractive. The best advantage is that methane is liberated as a gas and can be collected without to need to use energy in a distillation process. Furthermore there is substantial experience of its utilization as a fuel, since it is the principle component of natural gas. Additionally, there is much experience of the production of methane by the process of anaerobic digestion in effluent disposal plants at sewage works. There seems to be no reason why anaerobic digestion should not, in principle, be applicable to a very wide range of waste materials. If a given stream of waste could be utilised for methane production, the advantages of utilization of the gas as an energy source together with the reduction in COD and thus the costs of effluent disposal, arising from the utilization of polluting substances to produce methane would seem likely to produce a worthwhile process.

At this stage one may ask why anaerobic digestion is not more widely employed for waste utilization, particularly as it is quite widely used at sewage disposal plants. There are, I believe, two reasons for this. First the process has always been a lengthy one and second, it has always been subject to disruption by any change in operating procedures or nature of the waste supplied. The consequences of this have been that anaerobic digestion plants have been large- big enough in some sewage works, for example, to allow a residence time of 30 days- and have been inflexibly operated. In terms of waste utilization, therefore, they have been expensive to install and difficult to run when load is fluctuating.

Looking at the situation from the viewpoint of a researcher with personal experience in the operation and in the control of industrial fermentations, the problem is that there is so little information about the detailed microbiology of the process. There is some information available which relates to the broad aspects of the process- the necessity for a variety of organisms to be present and to successively convert polymeric material first to monomers, second to fatty acids, hydrogen and CO₂ and finally to methane. To work satisfactorily the process depends on the presence of an appropriate mixture of at least three types of organisms and, clearly, the difficulties which follow a change in conditions arise from the disturbance of this desirable balance. Equally the long period needed to fully utilize the organic matter and obtain the maximum yield of methane is a reflection of an inadequate level of one of the three types of activity listed above. When difficulties arise, there are no microbiological tests to allow operators to determine the broad area in which there is a problem and, apart from measures to correct acidity, there is little that can be done to remedy problems. Procedures to increase the total load of bacteria have been introduced, and this somewhat accelerates the conversion of organic matter to methane. Again, though, we have no detailed knowledge of the procedures needed to regulate this process.

In these circumstances it is my judgement that the prime research need is to establish a corpus of knowledge about the basic microbiology of waste conversion to methane, so that trouble-free, rapid and economic operation of a waste utilization plant can be achieved.

Recovery of Protein

The recovery of protein in waste fluids from food processing plants is a difficult problem especially when the protein concentration is low and the fluid contains relatively high concentrations of non-protein constituents. An example of the problem is represented by the efforts to reclaim protein in whey from cheese and casein manufacturing in which the protein content is 0.5% or less while other solids constitute

as much as 6-7%, principally in the form of lactose, milk salts and lactic acid. Considerable advances have been recorded over the last decade for whey protein recovery through a number of processes, including ultrafiltration. These processes have largely been directed towards the treatment of sweet whey from cheese manufacture (pH 6.0 - 6.5). Recovery of protein from acid whey (pH 4.5), resulting from cottage cheese or caseinate production, presents additional problems arising from the presence of mineral or organic acids, which limit the acceptability of the recovered protein product, unless, by special efforts, the acid constituents have been eliminated. In this respect, complexing of proteins by anionic polyelectrolytes including polysaccharides, polyphosphates and polyacrylic acid, is an alternative approach for protein reclamation which would appear to be particularly suited for acid whey systems since the complex formation requires a low pH environment to allow the isoelectric precipitation to occur.

A number of polyelectrolytes are already in use for the treatment of sewage, the clarification of industrial wastewater and the purification of contaminated streams, rivers and lakes. Treatment of water with polyelectrolytes for purification is primarily designed for removal of suspended or dispersed solids and not for the purpose of reclaiming the constituents for further use. However, it should be recognized that the availability of food grade polyelectrolytes, including a variety of food gums, offers the possibility of applying the principles of complex formation for reclamation and upgrading of proteins from food waste fluids. Early work by Smith demonstrated nearly complete protein recovery from soybean whey by the use of edible food gums and detergents under controlled conditions, with a corresponding reduction of 8-18% in biological oxidation demand (BOD). A similar approach, using carboxymethyl cellulose (CMC) has been used in our laboratory for the recovery of proteins from sweet and acid whey. A patent for the continuous fractionation of whey by CMC treatment has been issued to the DeLaval Separator Co.

Interactions between proteins and anionic polysaccharides are pH dependent and involve the formation of complexes at a pH usually below the isoelectric point of the protein. The complexes are least soluble when the proteins and the polyanions are matched in predetermined amounts and the pH is adjusted to form isoelectric aggregates. Excess of polyanion in the mixture causes formation of soluble complexes, whereas high salt concentration interferes with complex formation. In a series of papers, Hill and Zadow have described the mechanism of interaction between whey protein and carboxymethyl cellulose and its derivatives. These investigators reported that the efficiency of precipitation was increased with increasing degrees of substitution of CMC, and more importantly, that the tolerance of the induced complex towards high salt concentration was also increased. Thus, at a degree of substitution of CMC of 1.4 i.e. with, on average, 1.4 of the three available sites per monomer substituted, a 90% efficiency in protein recovery was recorded, without resorting to dilution of the whey system. In the USA. Specific regulations prevent the use in food of carboxymethyl cellulose with a degree of substitution greater than 0.95. However, it is worthwhile to note that the Australian authors have observed that derivatives of CMC modified with substituents of increasing hydrophobicity were also increasingly effective as protein precipitants. Thus, selection from these various types may make it possible to meet the requirements of effectiveness within the limitations of the current food regulations.

Isolated whey protein complexes typically contain 70-80% Water, and on a dry weight basis, approximately 65% protein and 35% of hydrocolloid. Although in some cases it may be possible and desirable to separate the complexes into their constituent protein and precipitant, separation may not be warranted if it were possible to utilize the intact complex for edible or technical purposes. Complexes of a nutritious protein with an edible food stabilizer, having specific functional properties, would be of interest to the food industry, for example for ice-cream stabilization. Such complexes may also have application in biomedicine in treatment of ulcer patients and for other special dietary needs.

While whey protein reclamation, using CMC as a precipitant, offers advantages with respect to low cost for investment in equipment, there have been up to now certain limitations to this approach. These relate to

(1) lack of salt tolerance of food grade CMC for complex formation which necessitates dilution of the whey system to counter this effect, and

(2) problems in spray drying of the neutralized complex because of the extremely high viscosity of the product due to the presence of CMC.

In this chapter it is not intended to review the whole of protein recovery by charged polysaccharides because, as indicated earlier, several such reviews are already available. Rather the development of a scheme by which the acidification step is accomplished by the use of a cationic exchange resin in order to minimize the effect of ionic strength on directly acidified whey will be discussed. Furthermore, a method by which the isolated complex is dried conventionally or by freeze drying and subsequently converted to a soluble product by exposure to anhydrous ammonia is reviewed.

Materials and methods

Cottage cheese whey (pH 4.4) was obtained from a local dairy plant at the day manufacture and kept refrigerated until use. Carboxymethyl cellulose was obtained from Hercules, Inc., Wilmington, Delaware. Four types of CMC were used differing in their degree of substitution (DS): 9M31 F with a DS of 0.9 and of medium viscosity; 7 LF with a DS of 0.7 and of low viscosity; 4 M6F with a DS of 0.4 and of medium viscosity; and 4 H1F with a DS of 0.4 and of high viscosity.

For protein precipitation the whey was warmed to ambient temperature (23° C) and mixed with a cationic wet resin (Amberlite G - 120. 100 - 200 mesh, H +) in sufficient quantities (approximately 12% wet weight) to reduce the pH to 3.2. The whey was then decanted and the resin reclaimed for further use. Solutions of CMC at 0.25% concentration were prepared in tap water and added to the acidified whey in predetermined quantities to yield maximum precipitation. Following the addition of CMC, the protein CMC complex was permitted to settle by gravity and the supernatant decanted and discarded. The complexed protein was resuspended in water and recovered by gravity sedimentation. The resuspension/sedimentation procedure was repeated for a total of three times. The wet sediment was dried by freeze drying and the dry material treated with anhydrous ammonia gas as follows: the complex was placed in a vacuum chamber and a vacuum was drawn by aspirator to approximately 98 kPa (29 inHg). Dry ammonia gas was admitted to reduce the vacuum to approximately 17-34 kPa (5-10 in Hg) which was maintained for approximately 30 min. The chamber was then degassed and flushed with air to remove excess ammonia and the product was retrieved.

The nitrogen content of dry complexes, receiving different treatments, was determined by the Dumas method using a Coleman Nitrogen Analyzer, Model 29. The total nitrogen content was converted to protein using the factor 6.38.

Results and discussion

A pilot plant process capable of handling 1 m³ (1000) of whey was previously developed in our laboratory for reclamation of protein by utilizing carboxymethyl cellulose and other hydrocolloids. While the pilot plant experiments demonstrated the feasibility of the process, using in most instances CMC with a DS of 0.70, it became evident that improvements would be needed to decrease the ionic strength of the mixture so as to exert better control over the complex formation and, more particularly, to circumvent the need for spray drying. This was desirable because of the extraordinary difficulties encountered in processing the highly viscous material resulting from neutralization of the acid complex.

Since Hill reported improved efficiency in protein precipitation using CMC of high DS value, it was decided to examine the performance of a number of available food grade CMC types. The results in Table 1 confirm that the protein content of the complex increases with increasing DS value, with type 9 M31 F with a DS of 0.9 showing the highest value. However, viscosity grade is apparently also an important factor, at least for gravity

Table 1. Yield and protein content of complexes obtained by different types of CMC

CMC type	Mixing ratio ^a	Yield ^b (g/l)	Protein in dry complex ^c (%)
9M31F	0.6	5.00	69.0
7LF	0.7	6.03	67.4
4HIF	0.8	4.67	54.4
4MGF	1.0	5.07	61.1

aml of 0.25% CMC per ml of whey (pH 3.2) required for maximum precipitation.

bg of dry complex perof whey

cmmeans of duplicate determination, standard deviation (means) 1.60%

sedimentation, as shown by the improved yield and protein content for the medium viscosity grade, 4MGF, over the high viscosity grade, 4 H1F, both with a DS of 0.4. The total protein recovery (3.9 g/) was highest for type 7 LF (DS 0.7 and of low viscosity), possibly because of the viscosity factor.

Figure. 1 illustrates a possible approach that should lead to an improvement of the industrial process.

Acidification with a cationic resin is readily achieved and controlled and results in an overall reduction in the electrolyte content, and thus in ionic strength, as indicated by the specific conductivity values listed in Table 2. The need for a regeneration cycle to reactivate the resin has been indicated in the diagram.

Fig. 1. Flow diagram for manufacture of soluble CMC/whey protein complex

The complex recovered by centrifugation in the solids discharging separator may, if desired, receive a first wash prior to solids ejection. The purpose of this wash is to remove lactose and other soluble constituents, by diverting rinse water to the separator in a controlled manner. The curd, which is normally well compacted, can be subjected to additional washing in a tank and subsequently collected by centrifugation or gravity sedimentation.

Table 2. Specific conductivity of acid whey before and after treatment

Whey	pH	Specific conductance (10 ⁻⁵ mhos/cm)
Untreated	4.4	452
Acidified, 1N HCl	3.2	607
Cation exchanged	3.2	326

The proposed ammonia treatment of the dry complex was adapted from the process used by Girdhar for the treatment of dry, isoelectric casein by a column arrangement operating at a positive pressure. The conversion, however, is more conveniently accomplished in a vaccum tank under slightly reduced pressure, an approach which is also better suited for larger scale operation. The treatment results in the adsorption of ammonia to the dry matrix and apparently also in ammonium salts formation with carboxyl groups on the protein and the CMC.

The treated product exhibits a pungent odor of ammonia which may be partly eliminated by degassing. The effect of degassing on the pH of

Fig. 2. Change in pH of ammonia-treated CMC / whey protein complex during degassing in stream of ambient air and by prolonged vacuum treatment (pH of 5% solution)

the complex is shown in Fig. 2. It may be observed that the ammonia is rapidly lost when the product is exposed to a stream of ambient air. In contrast, ammonia is retained under simple vaccum exposure, even after 24 h. This suggests that removal and loss of ammonia occurs through contact of the treated complex with moist air.

The values in Table 3 show that ammoniation followed by degassing to pH 7.0 resulted in a 7 - 11% increase in nitrogen, corresponding to a total retention of approximately 1.2% ammonia.

Ammoniation of complexed whey protein, dried by conventional means, would be expected to be an energy conserving process compared to alkali conversion in the wet state followed by spray drying. The

question of food safety and nutritive value of proteins treated in this manner has been addressed found no significant differences in growth of weanling rats fed high levels of ammoniated casein.

Table 3. Nitrogen content of whey and whey protein/CMC complexes before and after ammonia Treatment

Product	Nitrogena		Ammonia
	Untreated (%)	Ammoniated (%)	uptake (%)
Freeze dried whey	1.68	-	-
Complexes			
9M31F	10.81	11.54	0.89
7LF	10.57	11.76	1.45
4HIF	8.52	9.48	1.17
4M6F	9.58	10.60	1.24

Means of duplicate determination, standard deviation (mean) 0.15%

The market potential for complexed whey protein has not been explored to any large extent. In the early stages of development of the pilot plant process it was observed that the complexes provided adequate stability for milk fat emulsions over a wide range of pH and calcium ion concentrations. Complexes of whey protein and CMC as well as other hydrocolloids may have application as whipping agents and foam stabilizers.

The Treatment of Dairy Wastes

The importance of the Dairy industry may be judged from the fact that dairy products provided some 24% of the protein content of the national diet at a cost of approximately 18% of the total food costs.

During 1978 some 15 x 10⁶ m³ of milk was produced in the UK which was used as follows:

Liquid milk	89%	Condensed milk	4%
Butter	24%	milk powders	1.4%
Cheese	14%	Other products	0.6%
Cream	7%		

Over the last 20 years rationalisation has resulted in large units both in terms of dairy herds, bulk collection of milk, larger reception depots and production complexes which are tending to specialise in particular products, which in turn have brought special effluent problems.

Many of these manufacturing units are located in rural areas where the problem of effluent disposal is that much more different because it might results in the effluent discharge being to a river or stream. Peak production periods at such dairies are usually in the summer months when the dilution water available in the water course is at its lowest.

The pollution potential of dairy effluents' is high with a typical average sized unit producing an effluent load equivalent to a population of the order of 14 000. In general terms it can be said that the volume of milk of milk equivalent carried away in milk washing is of the order of 2% and the volume of effluent is within the range of 0.5-1.5 times the volume of milk handled, depending on the product being manufactured.

The magnitude of the problem becomes apparent when it is realised that the BOD of whole milk is of the order of 110 000 mg/litre.

Most countries have legislation which enables the appropriate government authority to control discharge of trade effluent. India is no exception to this- the 1974 control of pollution Act being the latest of acts of parliament controlling the quality of the environment, and it is the main instrument of the Regional water Authorities.

There may be two courses of action open to the discharge:

1. To discharge to the public sewer without prior treatment.
2. To install on-site treatment plant for either the partial treatment of the effluent prior to discharge of sewer

or for the full treatment of the effluent prior to discharge to a water course.

The choice between these two options will depend on:

1. Availability of sewers.
2. Capacity of water authority plants to deal effectively with the discharge.
3. Economics.

In normal circumstances the water authorities will want to charge an economic rate for the transport/reception of the effluent. These charges are commonly in the UK based on a formula similar to:

$$C = R + V +$$

where C = total charge per m³ of effluent

R = reception and conveyance (1.56 pence/m³)

V = volumetric and primary treatment cost (1.97 pence/m³)

O_t = COD of effluent

O_s = COD of settled sewage (499 mg/litre)

B = biological oxidation cost (2.88 pence/m³)

S_t = suspended solids of effluent

S_s = Suspended solids of domestic sewage (288 ppm)

S = treatment and disposal costs of primary sludges

S = treatment and disposal costs of primary sludges

(2.27 pence/m³)

() average UK figures for 1978/79

If this formula were applied to a typical dairy complex producing yoghurt with an effluent discharge as follows:

Volume	550m ³ /day
BOD	1500 mg/litre
COD	25000 mg/litre
Suspended solids (ss)	300 mg/litre

this would equate to an annual charge of £ 40 792.

In addition, if the sewers or treatment plant required extensions to accommodate the effluent, a capital contribution may also be levied. Sums in the region of £ 60 000 - 100 000 are not uncommon in such circumstances.

It is therefore of the utmost importance for the dairy industry to reduce its pollution load to the bare minimum thus lowering purification and disposal costs.

To reduce the pollution load means:

1. To reduce the volume of water used.
2. To reduce the volume of milk, raw materials and product lost either as a result of accident or deliberate acts.

The wastage arising from various dairying operations is usually of the order shown in Table 1.

Table 1.

Kg BOD/m ³ milk processed	
Milk reception	0.26
cooling milk	0.2
washing tankers	0.25
pasteurising and storage	0.29
Bootling	0.11
Cheesemaking	0.89

Butter manufacture	0.46
Clotted cream	1.2
Condensed milk	1.4
Evaporated milk	0.75

Once all reasonable precautions have been taken to minimise effluent production there remains the problem of disposal of what cannot be eliminated. It can be seen that the decision to treat, and to what level, is essentially based on economics, although local political factors could influence the decision.

Pre-Treatment systems

Dairy wastes, with the exception of detergents, caustic cleaning agents and bactericides used in hygiene control, are not difficult to treat and providing that suitable dilution with other streams is practised these materials usually have no adverse effect on treatment rates. However, the dumping of batches of these materials causes complete havoc to any treatment plant.

The discharge of dairy effluents can cause special problems in relation to treatment plants due to:

1. Variation in volume.
2. Variation in strength.
3. Temperature.
4. pH value.
5. Nutrient levels.
6. Fat and curd levels.

As a consequence some pre-treatment is required prior to biological systems.

1. Fat Removal

Settlement and skimming to remove fat may be carried out in a single tank with suitable baffles. Usually 20 minutes retention at peak flow is adequate.

2. Screening

This operation should be carried out as soon as possible to prevent the solubilisation of biochemical oxygen demand from the solid material resulting in increasing in the polluting load from the liquor. Mechanically brushed and inclined screens of 40 mesh are equally successfully used for this operation.

3. pH Control

Biological treatment plants most efficiently when the pH value of the feed liquid is in the range 7.0-8.5. However, feed liquids with a pH value of up to 10 can be tolerated, since acids produced by fermentation and carbon dioxide formed by oxidation of organic matter reduce the pH value in the biological stage of treatment.

However, acid pHs of crude effluent should be adjusted with caustic soda to minimise fermentation and the production of odours by the reduction of sulphates. The use of sulphuric acid for pH correction should be avoided.

It is preferable to carry out a coarse pH adjustment prior to balancing and then a fine pH adjustment prior to biological treatment to be absolutely sure the pH is not going to present a problem.

4. Flow and composition balancing

The rate at which effluent is produced over the 24 h day is by no means constant. Large quantities of effluent arise from the washing of plant and equipment. As a result most of the effluent will be discharged during two of three short periods of the day. Flow balancing therefore becomes a prime requisite if any subsequent biological process is to operate at optimum efficiency. Flow balancing also tends to even out the biological composition and load.

If the screening operation is carried out effectively it is possible to combine the operations of flow balancing and solids removal so that they can take place in the one tank. This means equipping the tanks with a method of withdrawing sludge and the use of a floating arm take-off for the effluent.

Often in the past, flow balancing tanks have not been equipped with solids removal facilities and spasticity has developed within the tank to the extent that increases in biochemical oxygen demand (BOD) have been recorded after flow balancing, coupled with complaints of foul odours.

Biological treatment

Biological treatment systems can be categorised into two types: (a) anaerobic and (b) aerobic. Anaerobic systems operate in the absence of oxygen and aerobic systems in the presence of oxygen.

Anaerobic systems have not been used to any significant degree for the treatment of dairy wastes as in general terms they are more suited to the treatment of high strength and high solids containing wastes. In addition anaerobic systems, particularly digestion, are not suitable for the production of high quality effluents.

Where the discharge of an effluent is to a watercourse, usually high standard on purification are required. Effluents of 20 ppm BOD and 30 ppm SS are quite common and in some case higher standard are required. Such standard are usually achieved by the use of anaerobic biological treatment plant.

However, before feeding a pre-treated dairy waste to an aerobic treatment plant, attention should be paid to the nutrient content of the wastewater.

Biological treatment systems required for satisfactory operation a variety of elements (e.g/ Ca, mg, Na, K, Fe). However, it is fortunate that these need only be present at the 'trace' level and usually appear naturally at these low levels. Most attention is therefore paid to the provision of nitrogen and phosphorus which must be present (or added) in appreciable quantities. While low rate systems may require the minimum of addition, for high rate treatment is usually necessary to have a relationship BOD:N:P of 100:5:1. It is important to stress that both nitrogen and phosphorus should be in a form readily available for assimilation by the bacteria, etc. (i.e. nitrogen as ammoniacal nitrogen and phosphorus as ortho phosphate).

Normally dairy effluents do not require the additions of nutrients. However, if by-product recovery is being practised, using either reverse osmosis or electro dialysis system, ammonia levels can be low and will need supplementing.

Percolating flitters (mineral media)

This is one of the oldest methods of biological treatment for the production of high quality effluents and the general design features are well known. Understood and documented. Many factors affects the performance of a filter, e.g. physical characteristics of the medium, the rate and periodicity of dosing the liquid, the depth of media and degree of ventilation, and the operating temperature.

It is not normal to apply liquids stronger than 300-400 mg/litre BOD to this type of filtre and this means that recirculation is usually employed for the treatment of dairy wastes where no other biological treatment system is employed prior to the filters. If recirculation is not employed the medium becomes choked with heavy growths of biological films and fat.

The only viable method of using mineral media filters for the sole biological treatment of dairy effluents is to employ the system known as alternating double filtration based on work by whitehead O'Shaughnessy in 1935. In this process the wastewaters after settlement are diluted with recirculated final effluent so that their BOD is of the order of 300/mg/litre and are then passed through two filters in series with settlement after each filtration stage. At weekly intervals the order of the filters, but not the settlement tanks, is usually reversed. In this way the film accumulation in the primary filters is minimised. Overall organic loads of 0.28-0.3 kg BOD/m³ day can usually be applied to filter plant operating on this principle treating dairy wastes.

Activated Sludge

This is a process developed in 1913 by Arden and Lockett for the production of high quality effluents. Basically it is a process in which the wastewaters are mixed and aerated over a period of time with a flocculent suspension of micro-organism. The various types of activated sludge plant differ mainly in the

method adopted for aeration of the mixed liquor, the design of the tank and the period of contact of the wastewater with the 'activated sludge'. The most common difficulty with the system is that the sludge tends to bulk. When this occurs sludge does not settle efficiently and may be lost in the final effluent. The results in a reduced concentration in the sludge recycled or returned to the aeration tank, which leads to a progressive decrease in concentration of activated sludge in the mixed liquor and often results in a further deterioration in performance. Such problems are usually associated with effluents of low pH and high nitrogen contents.

Variations on the conventional activated sludge process introduced over the years have included extended aeration, contact stabilisation, the oxidation ditch and more recently the pure oxygen injection systems and 'Deep Shaft'.

Extended aeration is usually employed without primary removal of suspended solids, and extended aeration times are required to stabilise aerobically the suspended material present. In addition low loading rates are employed to minimise sludge production from the system.

The contact stabilisation process involves treatment in four distinct stages. In the first stage, sewage is aerated in contact with activated sludge for a short period (usually $\frac{1}{2}$ -2h), the mixed liquor then passing to a settlement stage where the sludge is separated and the clarified effluent (final effluent) is discharged.

The separated sludge is then transferred to a third stage (the reaeration or stabilisation stage) where it is aerated for a period of several hours during oxidation of observed organic material occurs. A larger proportion of the activated sludge is then recycled to the first 'contact stage, surplus passing to the fourth stage (the aerobic digester) where it is aerated before being removed for disposal.

The oxidation ditch consists essentially of a continuous shallow channel 1-1.5 m deep usually forming an oval circuit of uniform width in plant: It is normally constructed by excavation in the ground. Aerations is provided by means of brush aerators which maintain a velocity of flow in the ditch of about 0.3 m/s, which is sufficient to keep the activated sludge flocs in suspension. Provision is required for settlement of sludge before discharge of final effluent.

The Deep Shaft is essentially a very efficient oxygen transfer device comprising a shaft 50-150 m deep, vertically partitioned into a downflow section (downcomer) and an upflow section (riser) and surmounted by a gas disengagement tank. The shaft can be 0.5-10m in diameter depending on the duty.

The influent is fed to the top of the Deep shaft and air is injected into the downflow section from a standard compressor at a sufficient depth to cause the mixed liquor to circulate at a velocity of 1-2 m/s. This velocity is much greater than the rate of rise of the air bubbles, which are, therefore carried down by the liquid towards the bottom of the shaft. Provision is required for degassing the effluent prior to settlement of sludge before discharge of the final effluent.

One development of the activated sludge process has taken place in Japan, namely the Morinaga process which is a version of extended aeration. The process has been tried at three dairy locations in the UK and it is claimed to have a comparatively low capital cost; however, the energy costs appear to be very high. The process consists of a large aerated lagoon split in the ratio of 3:1. The effluent from the production complex after fat separation and screening is fed to the larger of the lagoons where it is continually aerated. Twice a day, aeration in the smaller lagoon is stopped and the contents allowed to settle and then discharge to a water course. The solids that have settled in the smaller part of the lagoon are then reaerated with the next batch and the claim is that these solids are then partially digested. However, based on UK experience, the rate of solids production appears to be higher than that indicated in Japan.

High Rate Biofiltration

Until the early 1960s the dischargers of dairy effluents who, by virtue of location, were forced to treat their effluent prior to discharge to a water course, had to choose between either percolating filters using mineral media or a variant of the activated sludge process for the treatment of their effluent, with the inherent

operating difficulties. The introduction of plastics media and their application to the process of high rate bio-filtration, and their use in combination with conventional processes, offered considerable advantages to the dairy industry in the solution of its effluents problems.

It is not uncommon in the UK for the average BOD of the crude dairy effluent to be of the order of 1500 mg/litre, of which up to 85% is soluble. One of the main advantages of plastics pickings over conventional biofiltration media is that they remove high weights of BOD per unit volume of media, usually of the order of a factor of 10 times. A typical load curve for the use of plastics pickings treatment dairy effluents is shown in Fig. 1. The application of plastics media to the treatment of dairy effluents has been detailed by Askew and Hemming.

Fig. 1. Typical design curve for high rate biofiltration systems. (crude BOD concentration 1500 -2000 mg/litre)

The majority of plants using plastics media for the treatment of dairy wastes have used ordered plastics media. A more recent development has been the introduction of random plastics media. This latter type of medium is used in a similar manner to mineral media and often as a replacement. Organic loads of the order of three times the mineral media can be applied for the production of equivalent effluents.

Sludge Disposal

One of the consequence of aerobic biological treatment is a nett increase in the solids for disposal known as sludge. In general the dairy industry has not been faced in the past with a major sludge disposal problem other than the inconvenience and cost of transporting the material as the major part of dairy sludges are disposed of by spreading on the land. A typical cost is £7/m³.

However, faced with increasing transport costs and public opinion demanding that sludge disposal to land be at least restricted, many dairy installations are being forced to consider alternative means of disposal of their sludge.

The sludge production figures of the various aerobic unit operations at now being considered more carefully, particularly, if the dairy is considering the dewatering of its sludges prior to disposal. The mechanical dewatering of sludges can represent 50% of the total operating cost for effluent disposal and up to 50% of the capital cost of the oxidation stage.

In view of the costs involved it is essential that before a sludge handling and disposal plant can be designed the expected sludge characteristics, e.g. specific gravity, solids concentration, settling characteristics, particle size, rheology, fuel value, fertiliser value and food value, are considered. In the light of this information the most appropriate system can be designed based on both technical and economic considerations.

It is not often appreciated that any change in process, raw materials or operation which may affect any one of these properties could result in a sludge which will not thicken, dewater or be acceptable for the ultimate disposal previously arranged.

Accumulation of sludges on site, particularly organic sludges, can lead to serious odour problems. Sludge should be treated and disposed of while fresh.

Treatment and disposal costs

In these times of rapid inflation it is difficult to quote meaningful figures for both capital and operating costs. Therefore, in Table 3 relative costs are shown for the main process combinations used for dairy effluent treatment.

While capital costs do vary as a consequence of scale and topography of the site available, which may favour one process rather than another, a typical capital cost order of magnitude would be £ 150/ kg BOD load for an activated sludge plant of 1000 kg BOD/day scale. On the same scale of plant, a typical power requirement for an activated sludge system would be 1 kW/hour/kg BOD removed.

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