APPLICATION OF DISSOLVED AIR FLOTATION (DAF) TO THE TREATMENT OF DAIRY WASTEWATERS

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-by-

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I dedicate this thesis to
my brother and sister-in-law, SRIDHAR and GAYATRI SUSARLA

ABSTRACT

An investigative work was carried out to examine the process performance of dissolved air flotation to remove suspended solids and fat from dairy wastewaters. Suspended solids and fat inhibit advanced treatment systems and cause lot of problems like clogging etc. Traditionally dairy industry uses sedimentation and fat traps to remove solids and fat. Dissolved air flotation is a novel treatment method to purify dairy wastewaters.

A laboratory bench scale flotation unit was used to carry out the flotation experiments. The wastewater was collected from a dairy factory manufacturing milk powder and butter. Two types of wastewater was collected, one type (Type-I) of wastewater was used when the plant was manufacturing only milk powder. Type-II wastewater contained discharge from butter plant, thus exhibiting a overall characteristics of the discharges from the plant. The effects of change in pH, temperature and the usage of coagulant alum were examined to assess the process performance of flotation.

Experiments with changing the pH showed that pH plays an important role in the treatment of dairy wastewaters. When the pH was lowered to 4 from original pH of wastewater of 11.3, the solids and fat in the wastewater precipitated. High removal efficiencies were obtained at pH 4. Flotation tests were carried out at pH 4, 5, 7, 8 and original pH of wastewater. Considerable removal efficiencies were obtained at pH 7 and 8. This pH range is considered to be effective for further treatment like biological treatment. Temperature studies were carried out at pH 7 and 8.

Removal efficiencies were average and were comparable to the removals with pH studies, at temperatures 25° C and 34° C. At a higher temperature of 48° C removal efficiency decreased considerably. Maximum removal efficiencies were obtained for solids and fat at a temperature of 34° C.

Coagulant alum was used to increase the removal efficiency of solids and fat. Jar tests indicated that high dosage of alum was necessary to obtain optimum removal efficiencies. Alum was used in the concentrations of 150 mg/l to 400 mg/l. Removal efficiencies upto 92% were obtained for fat and solids.

From the experiments it can be concluded that dissolved air flotation is a suitable method for the removal of fat and solids from the dairy wastewater. Scale up experiments can be undertaken before application for large scale treatment system.

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Finally, I acknowledge my family for their constant encouragement and support throughout my life.

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CHAPTER I

INTRODUCTION

The disposal of industrial wastes has become an environmental concern and the public regulating bodies are increasingly involved with the establishment of water quality criteria. Substances present in the waste discharged into water can degrade the water quality to an extent which makes the water unusable for ordinary purposes. Stream water is polluted by the release of different types of toxic substances by process industries.

The New Zealand Resource Management Act (1991) requires that industries which produce and dispose of waste regulate production and keep the discharges under the regulatory limits. All the process industries come under the purview of this Act in New Zealand. The penalties and liabilities under the Act have been increased dramatically with the possibility of a fine of $ 200,000 and imprisonment up to two years.

The dairy industry is one of the major industries in New Zealand and a lot of emphasis is put on the treatment of dairy wastewater (Barnett, 1991). The wastewater treatment methods currently practised by the New Zealand dairy industry are spray irrigation, disposal to natural waterways and a few biological treatment systems.

The main components of dairy waste are milk and various milk products including: whey, casein, washings, cheese, butter and anhydrous milk fat. The appropriate treatment of wastewaters depends on the products manufactured and the waste generated from them. Milk and its products are organic materials and organic waste is characterized by biochemical oxygen demand (BOD), chemical oxygen demand (COD), and total organic carbon (TOC). Dairy wastes do not contain significant quantities of toxic compounds.

The wastes from these products are of relatively low pH, because the pH of cultured products is normally around 4.5-4.7 (Marshall and Harper, 1975). The characteristics of the effluent vary greatly because of the highly seasonal nature of milk production (Marshall, 1978).

Waste treatment options in the New Zealand dairy industry

The options currently used for waste treatment in New Zealand are balancing, land disposal and aerobic biological treatment systems. Prior to treatment the wastewater is balanced in silos. The balancing tanks are utilised to obtain a degree of mixing of waste streams especially when presented with a high and low organic strength waste and acidic and alkaline wastes.

Land disposal has been the main method of treatment for dairy wastewaters in New Zealand. The spreading of whey onto land as a fertilizer is used extensively in New Zealand (Barnett, 1991). In a survey Galpin (1981) found that spray irrigation is the most popular method of effluent disposal. In spray irrigation soil type is important to ensure adequate metabolism of the waste. The nutrient quantity in the waste is also of importance as the nutrients can leach through soil and contaminate ground water. The land treatment systems are used to cope with peak waste water loadings in spring when rainfall can be high (Parkin et al, 1984). The problem encountered in land disposal is that after a certain period the soil becomes saturated and also causes odour problems in nearby areas.

In biological treatment systems aerated lagoons are popular and are commonly used in New Zealand (Marshall, 1978). Other types of aerobic treatment systems used for treatment are oxidation ponds, activated sludge plants, oxidation ditches, biological filters, and rotating biological contactors. Of these only oxidation ponds/ditches have lower capital cost requirements than aerated lagoons, but are known for odour problems when treating dairy wastewater. It is favourable to use aerated lagoons where land is available in plenty. The main problems encountered in the biological systems are operational difficulties and interference of fat.

In the New Zealand dairy industry fat traps have been used to remove milkfat from the wastewater. The traps consist of rectangular tanks with series of baffles to obtain laminar flow and retain milkfat. Some systems now use mechanical scrapers in the tanks to aid removal of recovered fat. Fat recovered by this process is used as animal feed.

New alternative treatment systems currently considered by the dairy industry to recover fat and solids are dissolved air flotation and diffused air flotation. Fat and protein recovered from these systems can be used as animal feed. In New Zealand diffused air flotation is used at only a few sites, since it is not effective in removing fat efficiently. For protein and lactose recovery from whey, ultrafiltration, reverse osmosis and demineralisation processes are being used.

This thesis investigates "Dissolved air flotation" as an alternative treatment for the purification of dairy wastewaters by removing solids and recovering fat. The removal of fat helps tertiary treatment systems to operate efficiently. The effect of pH, temperature and the usage of coagulant on flotation performance were observed. The efficiency of dissolved air flotation for removal of suspended solids (SS), volatile suspended solids (VSS), fat and COD was determined.

Chapter 2 reviews the literature on the process of dissolved air flotation and dairy waste treatment by dissolved air flotation. A brief description of the dairy wastewater used in the experiments is given in Chapter 3. Also the detailed analytical methods for the analysis of suspended solids, volatile suspended solids, fat and COD are presented in Chapter 3.

In Chapter 4, experimental results and discussion are presented. A detailed study of the effects of changing the pH and temperature are presented. After these studies the coagulant alum was used to optimise the process performance. Finally, in Chapter 5 conclusions and recommendations from this study are presented.

CHAPTER II
LITERATURE REVIEW

2.1 Introduction

Traditionally dairy industry wastewater was treated by a biological treatment process or by land application. With recent developments in technology alternative treatment methods are being looked into for the treatment and disposal of dairy wastewater. The treatment processes are similar to those used for domestic sewage, but the difference is that dairy wastewater is characterised by high organic strength. This chapter looks into the treatment of dairy wastewaters, the suitability of flotation for dairy wastewaters, and the process of dissolved air flotation.

2.1.1 Dairy industry wastes

As discussed in the previous chapter dairy wastewater varies a lot in character and mainly depends on the products being manufactured in the factory. The treatment methods also depend on the type of waste being generated. So the treatment methods vary from each manufacturing site. The methods that are generally followed in New Zealand to treat dairy wastewater are given in Table 2.1,

Table 2.1 Methods for treatment of dairy wastewaters in New Zealand (Barnett, 1991).

Year	1972	1980	1991
No. of manufacturing units	144	81	34
Natural Waterways	139	52	13
Spray Irrigation	39	82	17
Biological treatment	2	3	5
Municipal Sewers	13	7	4

The technological developments in dairy processing resulted in generating a waste of variable character. Protein manufacturing plants have high nitrogen and phosphorus contents which require treatment before discharge into the waterway. Milk powder and butter plants are characterized by significant quantities of cleaning compounds and sanitizers being present in the wastes. The wastes are essentially organic and methods used for treating domestic sewage are being practised for the treatment of dairy industry wastes. Table 2.2 below gives the characteristics of wastewaters from dairy plants in New Zealand (Barnett, 1991).

Table 2.2 Characteristics of wastewaters from dairy plants in New Zealand (Barnett, 1991).

Characteristic	Product		
	Casein/cheese	milkpowder/butter	whey
BOD$_5$ g/m^3	8000	1500	35000
pH	4.5/6.0	10-12	4.6-6
Na g/m^3	380	560	430
K g/m^3	160	13	1500
Mg g/m^3	14	1	110
Ca g/m^3	95	8	1250
Fat % W/W	0.04	0.04	0.08
N g/m^3	200	70	1400
P g/m^3	100	35	640

There are few reported studies of volume and strength of wastewaters from New Zealand dairy factories. The effluent from nearly half of the factories was discharged through grease traps to natural waterways or to the sea, while wastewater from one-third of the factories was spray irrigated on to pasture or waste land (Marshall, 1975). The temperature and pH of the dairy effluent vary from each factory. Marshall (1978),

summarizing the characteristics of effluents, presented the following data regarding temperature and pH from representative factories which produce dairy effluent. Table 2.3 shows the variation in temperature and pH,

Table 2.3 Temperature and pH of dairy effluents (Marshall, 1978).

Type of effluent	Temperature ° C	pH
1. Butter and roller-dried butter-milk	19-46	2.1-12.3
2. Lactic casein	20-65	3.3-10.5
3. Butter, powder, casein	17-42	4.5-10.5
4. Cheddar cheese	19-62	5.9-11.3
5. Cheddar cheese	19-54	7.6-11.0
6. Cheddar and colby cheese	12-32	4.2-12.2

2.1.2 Suitability of flotation for dairy wastewater

Removal of fat is important for biological treatment systems to work efficiently as fat interferes with the process. Traditionally fat traps and fat separators are used to remove fat before further treatment. Dissolved air flotation is a novel method of treatment by which fat and solids present in the wastewater are removed. The application of dissolved air flotation to the treatment of dairy wastewater is fairly new. But it has been extensively used to treat meat industry wastewaters which are characterised by proteins, fat and solids. It is mainly used for the removal of solids and fat. Previously dairy wastes were disposed of by land spreading, spray irrigation and biological treatment such as aerated lagoons (Barnett, 1991).

Flotation is advantageous over sedimentation in that it is capable of removing extremely fine particles or globules which do not have significant settling or rise rates, (Vrablik, 1959). Flotation can be applied to both clarification and thickening. In

clarification the objective is to remove suspended solids, whereas in thickening the solids from secondary treatment are concentrated (Bratby and Marais, 1977).

Rusten *et al.* (1990) carried out experiments on food industry wastewaters. Their results showed that wastewater composition greatly influences the maximum removal efficiencies and also the optimum conditions for coagulation and flocculation. Their studies pertained to the dosage of coagulant and optimum pH. By using $FeCl_3$ greater removal efficiencies were obtained than by using alum. The efficiency of purification ranged between 67-90% of total COD. Variations were due to wastewater composition. The optimum pH was found to be between 4.5-5.0. The fat removal efficiency was around 78%. Experiments with pilot scale and full scale plants gave similar results to that of jar tests.

Ecalard (1984) described the use of physico-chemical treatment followed by low load biological treatment. The pH is controlled by sulphuric acid and an alkaline starch is used as coagulant. The experiments were carried out by using a recycle ratio of 30-40%. The removal efficiencies reported were in the range of 65-85% for COD and fat. He emphasized the fact that the sludge after dissolved air flotation, (i.e. the float), after drying, can be used as animal feed. These sludges are of interest from the economical point of view. The lysine content of the sludges is around 7.8 mg/l, which is equal to that of milk, thus making the sludges significantly better than soya, as animal feed.

Hopwood (1984) reported that proteins can be recovered from dairy effluent by precipitation with lignosulphate, as coagulant, and treating the waste with dissolved air flotation. He observed that even though the lignosulphate process is well established for meat industry effluents, achieving good removal efficiencies, it's usage in dairy industry is limited. By using the process BOD removal is fairly low around 30-40%, while fat removals are upto 70%.

Pengilly (1978) described the viability of dissolved air flotation as an alternative treatment to sedimentation. The advantages were speed of the flotation process and the continuous aeration of biological material throughout the process. When this process is

used after alternate double filtration, the area required for the flotation process is less than that for sedimentation. The efficiency of the flotation process is greater when operated under optimum design conditions.

Wang and Guss (1988) in their project report on food industry wastewater treatment reviewed the technique of "high-rate" dissolved air flotation, known as 'supra-cell', to remove total suspended solids, fats, oil and grease. They found that for cocoa plant effluent results with high-rate flotation system compared well with conventional dissolved air flotation results. The BOD reduction was over 85%. Also, they reported similar efficiency for a dairy-based food ingredients waste. Wang and Guss (1988) observed that a two-stage wastewater treatment system involving the use of a high rate dissolved air flotation clarifier for the first stage physico-chemical treatment, and a package unit for the second stage aerobic biological treatment, is ideal for treating dairy wastewater.

Pretreatment for dairy waste is necessary before biological treatment as the fat can inhibit the growth of micro-organisms (Synnott et al., 1978, Wang and Guss, 1988). Synnott et al. (1978) reported the usage of dissolved air flotation to remove fat, in the first stage treatment, in a three stage treatment system for dairy wastewater in Ireland.

If further treatment is required, which is in general biological treatment, the pH of the effluent should be around 7.0-8.5. When a discharge of an effluent is to a water course, the authorities require high standards of purification. These can be achieved using biological treatment systems with dissolved air flotation as pre-treatment.

2.2 The process of flotation

Air flotation has been used for many years in the mineral industry for the benificiation of the ores. Its first application in the wastewater treatment field was in the removal of suspended solids, fibres and other substances of comparable densities. Recently air flotation has been applied to the removal of the oil and greases from wastewaters (Bennett, 1988).

In flotation, the wastewater is pressurised in the presence of sufficient air to achieve saturation. When the pressurised air-liquid mixture is released at atmospheric pressure into the flotation unit, minute air bubbles are released from the mixture of the solution. The suspended solids, flocs, and fat, oil and grease are floated to the top by the air bubbles which form bubble-particle agglomerates with particles present in the wastewater. The float is removed from the top and the clarified effluent is removed from the bottom of the flotation cell (Vrablik, 1959; Eckenfelder, 1989).

2.3 Types of flotation

There are four of types flotation. They are, 1) Dispersed air, 2) Dissolved air, 3) Electro flotation, 4) Micro flotation. This thesis deals mainly with Dissolved air flotation which is discussed in detail. The details of other flotation methods are discussed elsewhere (Bennett, 1988).

Dissolved air flotation can be categorised as dissolved air pressure flotation and vacuum flotation. In dissolved air pressure flotation air is dissolved under pressure and bubbles are released when the liquid saturated with air is exposed to atmospheric pressure, On the other hand in vacuum flotation bubbles are released when a vacuum is applied on to the pressurised liquid in the flotation unit (Bratby and Marais, 1975).

Distinction between dissolved air and dispersed air flotation can be made in the size of the bubbles produced (Vrablik, 1959). Dissolved air flotation produces bubbles of size 30-120 microns (Vrablik, 1959; Eckenfelder, 1989), whereas dispersed air flotation produces a size of 1000 microns. Bratby and Marais (1974) and Ramirez (1979) observed that the dissolved air flotation is more efficient than dispersed air flotation due to the production of smaller air bubbles and better bubble-particle agglomeration.

Ramirez (1979), in his studies on dispersed, dissolved, and electro flotation treatment of wastewaters, found the relative sizes of the bubbles to be 75 microns for dissolved, 110 microns for dispersed and 100 microns for electro flotation with bubble

densities of 3.2, 0.2, and 1.0 million respectively. He concluded that dissolved air flotation produces largest number of smallest bubbles and hence provides the largest surface area for efficient removal of suspended matter. In recent years only dissolved air and electrolytic flotation have became increasingly used (Bennett, 1988).

2.4. Theory of dissolved air flotation (DAF)

Dissolved air flotation involves the study of the three phases: gas, liquid, and solid. A flotation process brings the solid, gas, and liquid phases together for a reaction to be carried out. DAF involves the dissolving of a gas phase into a liquid phase and the precipitation of the gas from the liquid in the form of bubbles when the pressure is reduced. The amount of gas soluble in the liquid follows Henry's law which gives the relationship between gas solubility and pressure,

$$C = kP \tag{2.1}$$

where,

C = concentration of the gas in solution, mg/l

P = absolute pressure above the solution at equilibrium, KPa

k = Henry's law constant

The value of k is taken as 0.22 mgl^{-1} kPa^{-1} for air in water at 20°C . Bratby and Marais (1975) have demonstrated that k is not altered due to the presence of suspended solids, On the other hand, Vrablik (1959) has reported that k varies with the concentration of dissolved solids.

The amount of air dissolved in solution and consequently the amount of air released upon reduction of the pressure are both direct functions of the initial air pressure applied to the system. This highlights the fact that the gas phase is the ''work horse'' of the system (Bratby and Marais, 1975).

Vrablik (1959) suggested three types of mechanism by which bubble-particle adhesion will occur which makes flotation possible. They are,

1)   adhesion of gas bubble to a suspended liquor or solid phase,

2)   the trapping of gas bubbles in a floc structure as the gas bubble rises and

3)   the absorption of a gas bubble in a floc structure as the floc structure is formed.

The mechanism of bubble-particle adhesion is shown in Figure 2.1.

The forces acting on the suspended particle in wastewater are gravitational force, drag force and buoyancy. These three forces act on the particle at the same time and keep the particle in a state of suspension. The forces acting on the particle are shown in Figure 2.2.

Separation of particles in flotation adheres to the same laws as sedimentation but in a reverse field of force. The governing equation is Stokes' law, which is derived based on the above forces and is used to calculate the rise rate of bubble flocs, agglomerates and bubble-oil aggregates (Vrablik, 1959; Eckenfelder, 1989), and is given by,

$$V_t = \frac{gD^2(\rho - \rho_o)}{18\mu} \tag{2.2}$$

where, V_t is the terminal rise velocity of the particle, g is the gravitational constant, D is the diameter of the bubble, μ is viscosity, ρ_o and ρ are initial and final densities of the particle. Stokes' law is applicable for determining the rise rate of the bubble particle agglomerate, below a bubble size of 130 microns.
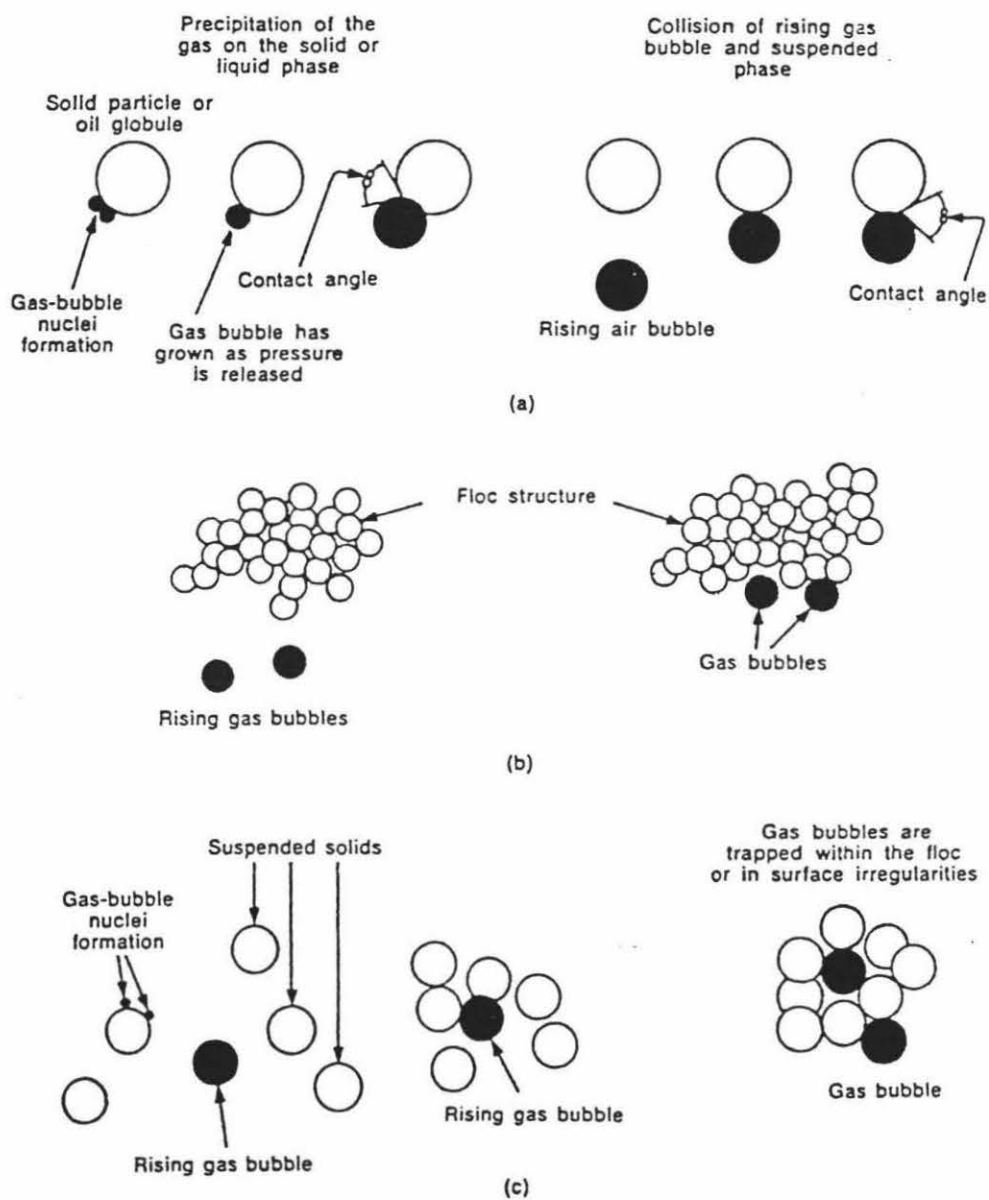
Figure 2.1 The mechanism of bubble-particle attachment (Bennett, 1988).
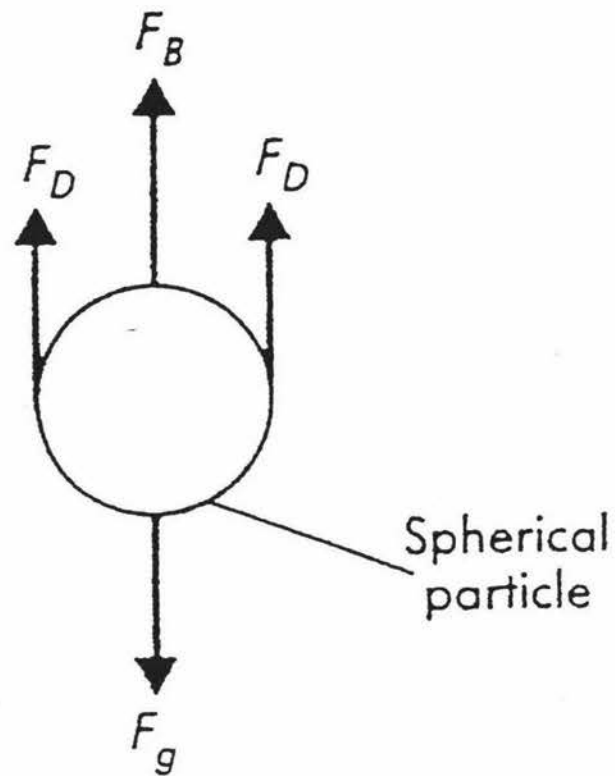
Figure 2.2 Forces acting on a spherical particle when in the state of suspension
F_B = Force of Buoyancy, F_D = Force of Drag, F_G = Force of Gravity

Gardner (1972) found that the air is released from solution as a stream of small bubbles within a relatively narrow size range of 30 to 120 microns with a rising velocity which follows Stokes' law. It is observed that the bubble diameters are smaller than the particles they are attached to in the liquid suspension (Bennett, 1988).

Vrablik (1959) formulated a relationship for the maximum bubble size for complete viscous flow upon the parameters Reynold's number N_{Re}, and coefficient of resistance f, and observed that for viscous flow the maximum diameter of the bubble is 130 microns.

2.4.1 Air saturation and precipitation

The solubility of air is also a function of temperature and solids concentration in the liquid. As the temperature of the liquid increases air dissolution decreases. The solubility of air in water at $0°$ C is twice that at $30°$ C, all else being equal (Eckenfelder, 1989). Air solubility values, which vary with change in temperature, are shown in Table 2.4.

Table 2.4 Showing variation of air solubility values with temperature

Temperature °C	Air Solubility (weight) mg/l
0	37.2
10	29.3
20	24.3
30	20.9
40	18.5
50	17.0
60	15.9
70	15.3
80	15.0

Air precipitation takes place in two stages. 1) The formation of nuclei, and 2) the growth of the nuclei. After pressurization and release of the water into the flotation chamber through a pressure reducing valve, the bubbles will nucleate on any low-energy sites on solid particles. If there are no energy sites available bubbles will nucleate homogeneously in the liquid phase (Vrablik, 1959; Roberts *et al.*, 1978).

The amount of air which will theoretically be released from solution when the pressure is reduced to one atmosphere is given by,

$$S = S_a \left(\frac{P}{14.7} + 1 \right) \qquad (2.3)$$

Where,

S is the amount of gas released at atmospheric pressure in mg/l,

S_a is the gas saturation at atmospheric pressure and

P the absolute pressure.

Bratby and Marais (1975) have shown that in dissolved air flotation not all of the air will precipitate out in the flotation tank, hence, a correction factor 'f' was applied to the above equation 2.3,

$$S = S_a \left(\frac{fP}{14.7} + 1 \right) \qquad (2.4)$$

The important parameter in the saturation process is the factor 'f', the efficiency of saturation. Gardner (1972) observed that the quantity of air released is dependent on the degree of mixing at the given point of pressure reduction and on the degree of saturation. To achieve 90% saturation, mechanical mixing or packing is frequently used, whereas with conventional designs of pressure vessels only 50% of air saturation was achieved.

Maddock (1979) observed that at low pressures air saturation is considerably less and consequently precipitation of air is difficult. On the other hand high pressures produce large bubbles and which tend to coalesce rapidly. Maddock (1979) conducted tests using a range of pressures and found the optimum efficiency to be in the range of 250-350 kPa for potable waters. He measured the saturation efficiency for precipitation of air by passing water from the saturator through a needle valve. Gehr and Henry (1978) measured the air saturation using a dissolved oxygen meter and found the air saturation to be around 90% for potable water.

Normally air has been the gas of choice in the flotation systems, but CO_2, N_2, and CH_4, and their combinations have been tested by Conway et al. (1981) and Travers and Lovett (1985). Conway et al.(1981) found that by using gases of higher aqueous solubility the operation of the DAF system improved and was able to produce thicker floats. They proposed the following equation for calculating the ratio of gas to suspended solids,

$$G/S = \frac{RC_s f(P/101.3)}{S_o Q + S_e R} \tag{2.5}$$

Where,

R = pressurised flow, l/d

C_s = gas saturation concentration at atmospheric pressure, mg/l-atm

f = saturator efficiency

P = gauge pressure, kPa

S_o = suspended solids in the sludge, mg/l

Q = sludge flow, l/d

S_e = suspended solids in pressurized liquid, mg/l

2.5 The parameters which influence the flotation process

There are number of parameters which influence the process of flotation. The important parameters are bubble size, rise rate, Air/Solids ratio and the mode of pressurization. They are discussed in detail in the following sections.

2.5.1 Bubble Size

The most important variable in air flotation systems is bubble size. Bubble size is dependent on,

1) physical parameters of the system,
2) suspended solids concentration, and
3) hydrophobicity.

Vrablik (1959) has done extensive research into bubble formation and their size distribution over a range of sizes. He developed a method to compute bubble sizes depending on the pressure, and this is shown in Figure 2.3. The bubble sizes reported by Vrablik (1959) ranged from approximately 30-120 microns with mean diameters of 75 to 85 microns at 20 and 50 lb/in^2 saturation pressures. Vrablik (1959) also noted that the largest bubble that will rise in viscous flow in water was 130 microns which is much smaller than the ones produced in induced air flotation which are in the range of 1000 microns.

The number and size of air bubbles formed in a given volume of water are dependant on the physical parameters and chemical content of the water. Van Vuuren *et al.* (1968) observed that for optimum flotation removal, existing small bubbles must be trapped or occluded in growing floc, rather than adhering to existing floc.

Surface tension and suspended solids concentration are important parameters in bubble formation (Ramirez, 1979). Katz (1960) reported that as surface tension decreases smaller bubbles in larger number are formed. Ramirez (1979) also found similar results.
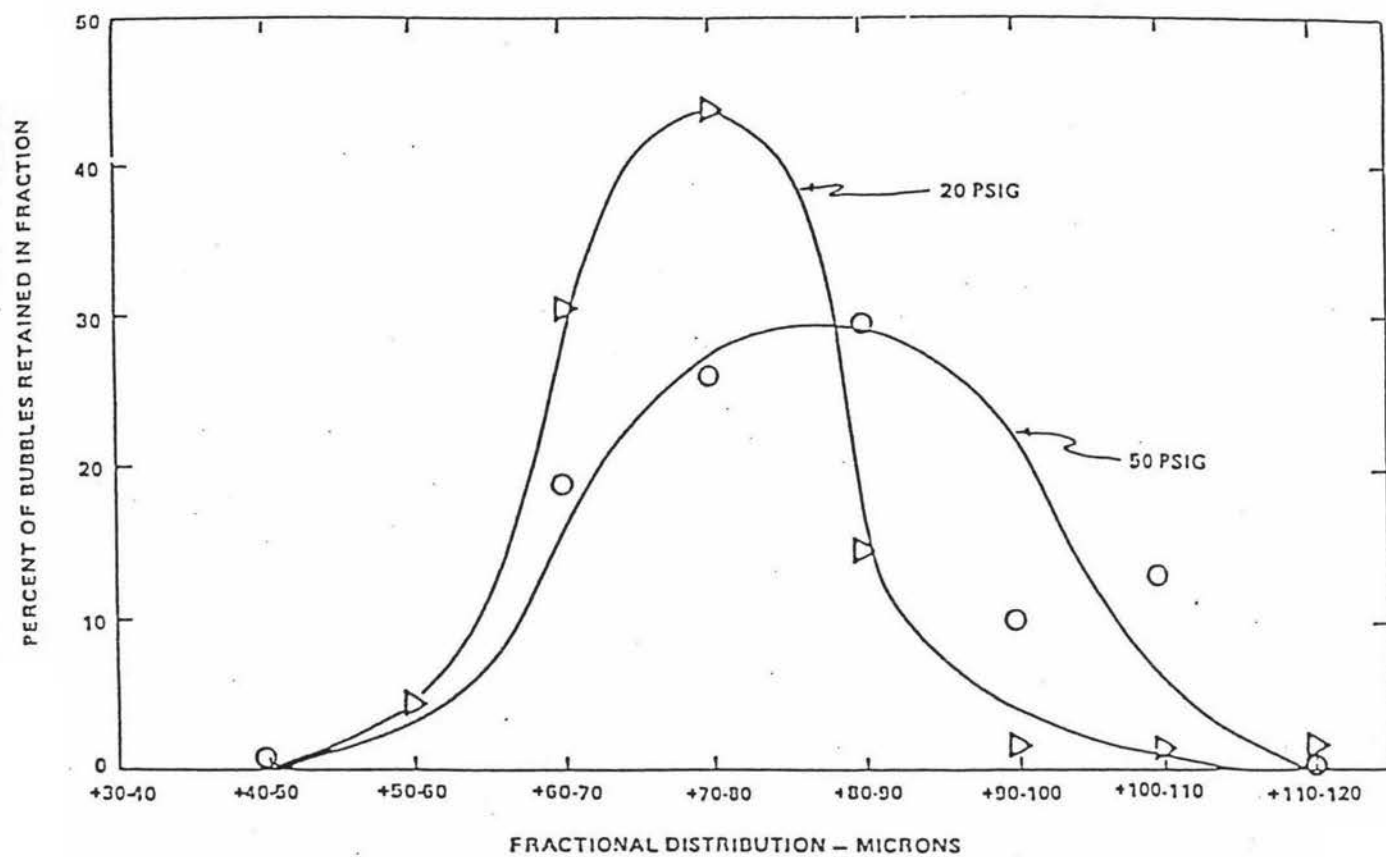
Figure 2.3 Bubble size distribution in dissolved air flotation (Vrablik, 1959).

He gives the ideal values of the surface tension of water to be below 72 dynes and preferably below 65 dynes per centimetre at 25° C. He observed that as the surface tension of the water decreased, the ability of the liquid to form stable air-liquid mixture significantly decreased.

Reay and Ratcliff (1973) noted that for bubble diameters upto 0.1 mm (i) flotation rate was proportional to the bubble frequency but independent of bubble diameter. At any given gas flow rate bubble frequency is maximized by producing very small bubbles, (ii) flotation of large particles was improved by coagulation and (iii) flotation of sub micron particles was enhanced by coagulation only if the size of the particle became sufficiently large.

The effect of bubble size on the separation efficiency of the flotation process is also strongly influenced by the size of the particle to be removed. High bubble density promotes good removal efficiency by increasing the probability of bubble particle encounter and by making more bubbles available for attachment to each particle (Cassell *et al.*, 1975; Malley and Edzwald, 1991).

Conway *et al.* (1981) studied the effect of high solubility gases on bubble size in flotation. They concluded that for efficient utilization of high solubility gases the bubble size should be controlled in the 50-100 micron diameter range as effervescent larger diameter bubbles interfere with solids capture. Travers and Lovett (1985) have measured bubble sizes in both CO_2 and air saturated dissolved air flotation systems at 200 kPa pressure. According to them, bubble sizes, 10 seconds after release were, five times larger when CO_2 was used compared to air and turbulent conditions were created in the flotation chamber due to much faster rise rate.

Gochin *et al.* (1983) observed that hydrophobicity plays an important role in the stability of the bubble particle attachment. They also observed that hydrophillic substances can be made hydrophobic by using surface active compounds, which help in the flotation process. The establishment of a contact angle between the solid phase and the air bubble appears to be the determinant factor in the attachment mechanism.

Malley and Edzwald (1991) reported that bubble sizes of 10-100 microns were produced in larger quantities for pressures greater than 344 kPa, when a recycle method of pressurization was used for treating drinking waters by dissolved air flotation.

2.5.2 Rise Rate

The rise rate in a flotation system is calculated using Stokes' law (equation 2.2) and gives the efficiency of the process. The units of rise rate are same as that of velocity but are expressed as $m^3/m^2/h$. The size of the flotation cell is calculated according to the rise rate of the agglomerate. A correction factor is often applied to scale up the height of the flotation unit depending on the laboratory and pilot plant tests (Vrablik, 1959).

Ramirez (1979) noted that the rise rate of bubbles greater than 150 microns was considerably faster than predicted by Stokes' law due to an elliptical shape, and also because the resistance to flow was less. He also found that when the pressure was higher, the micro bubbles were larger. Wood and Dick (1973) also observed that the rise rate was an important parameter.

Gulas *et al.* (1978) found that interfacial rise rates increased with increase in feed solids concentration up to 3000 mg/l, and then decreased for higher concentrations. Gehr and Henry (1978) failed to observe a correlation between the air/solids ratio and rise rate. Contrary to the observations of Gehr and Henry (1978), Maddock (1980) found that rise rate of the particles can be varied by changing the air/solids ratio, which in turn varies with the rate of recycling the effluent to the saturation unit. The rise rate of the bubble-particle agglomerate was observed to vary from 2.56 to 12.7 cm/min (Eckenfelder, 1989) and increases with an increasing air/solids ratio. The initial rise rate varies with the character of the solids present in the liquid.

2.5.3 Air/Solids (A/S) ratio

The air/solids ratio is the most important parameter in process performance of the flotation system. It governs the rise rate of bubble particle agglomerates in dissolved air flotation systems. It is defined as the mass of air precipitating per unit mass of waste water solids (Eckenfelder, 1989). If the A/S ratio is less the efficiency of the flotation system is reduced. The effect of A/S ratio on effluent quality as a function of process performance is shown in Figure 2.4.

Maddock (1979), in his experiments on pilot scale plant, observed that variations in the air/solids ratio can change the concentration of solids in the floated sludge by altering the compaction due to buoyant forces. He observed that the air/solids ratio can be varied by changing either the concentration of solids in the feed to the plant, or the recycle ratio, or by varying the pressure.

El-Gohary *et al.* (1980) observed that the optimum air/solids ratio is dependent on the suspended solids concentration in the feed. They observed that an initial increase in concentration of solids leads to a decrease in air/solids ratio but with higher concentrations of solids air/solids ratio did not vary much. They reasoned that this may be due to the fact that a higher suspended solids concentration in wastewater gives better adhesion between solid particles and the air surface. Hence the increased liquid-solid separation rates.

The range of air/solids ratio used in the flotation process depends on the amount of solids present, the pressure and recycle ratio. Air solids ratio is calculated by the following equation,

$$A/S = \frac{1.3 S_a Q}{RX} \left(\frac{fP}{p} - 1\right)$$

Where,
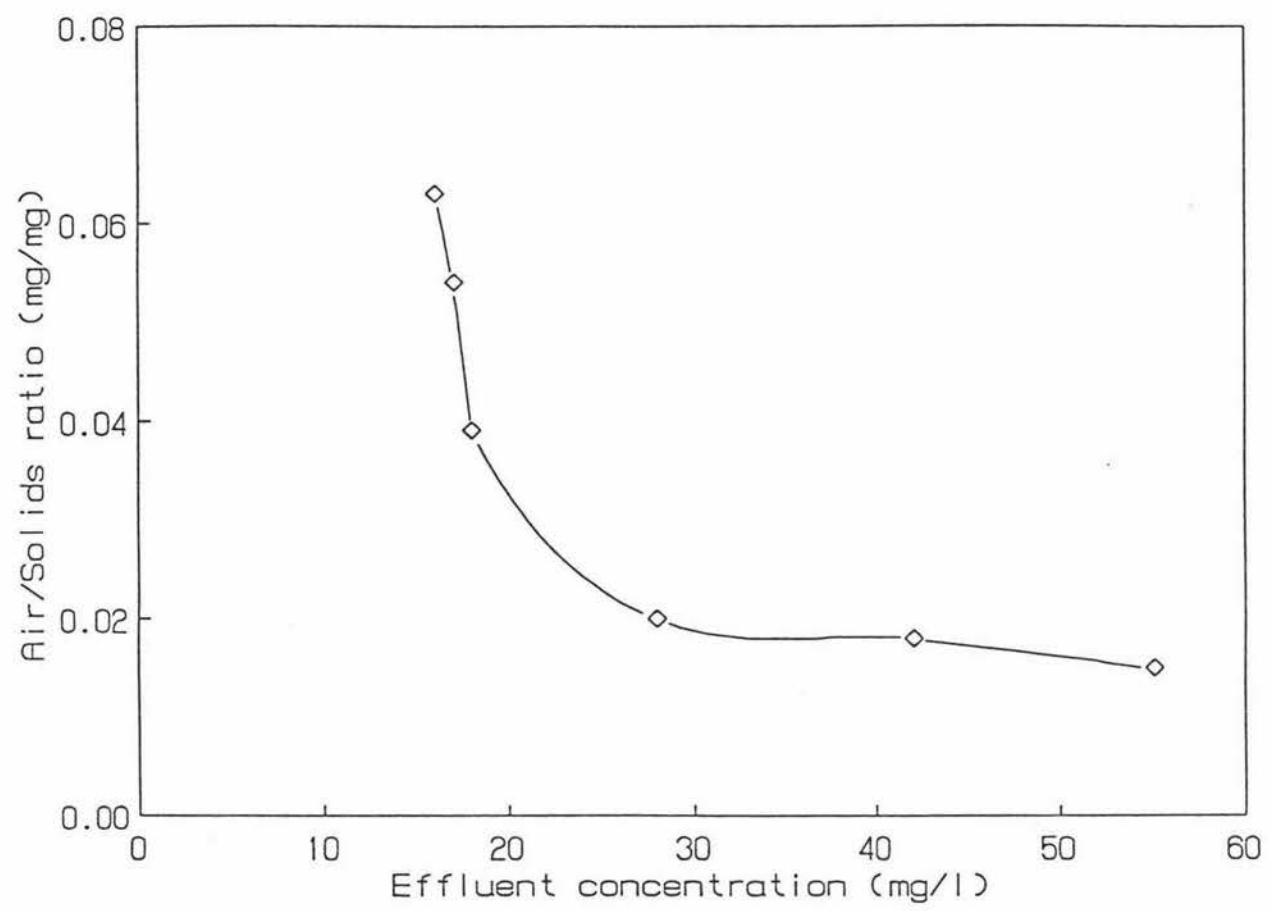
Figure 2.4 Effect of Air/Solids ratio on effluent quality (Eckenfelder, 1989)

Sa   = Air solubility in water at a given temperature, m/l

X   = Influent suspended solids, mg/l

P   = Pressure, for pressurising the wastewater, kPa

p   = Standard atmospheric pressure, kPa

R   = Recycle or partial pressurized effluent, ml

Q   = Amount of wastewater used, ml.

2.5.4 Pressurization of wastewater

There are three types of pressurization which are used in dissolved air flotation. They are 1) full flow, 2) partial flow, and 3) recycle

In full flow pressurisation all of the incoming wastewater is pressurized and saturated with air. Earlier flotation systems were based on this type of pressurisation. The disadvantage of the system is it requires a large saturation system and the flocs are sheared by direct exposure to the pressure.

In the partial flow pressurization system, part of the incoming water is pressurized and mixed with a known quantity of wastewater in the flotation unit. The advantage of this system is reduced pumping costs and reduced breakup of flocs. The main disadvantage is that the amount of air saturation is less due to a lower flow rate.

In the recycle method of pressurization a known percentage of the treated wastewater is returned to the pressurization system to reduce the shearing of flocs and emulsification of oil. The only disadvantage in this method is the requirement of a larger flotation unit due to the increase in the flow rate. However a better effluent quality nullifies this disadvantage. Pressurised recycle will usually yield a superior effluent quality when flocculated sludges are to be clarified since the flocs are not subject to direct shear through pressurization. The recycled flow, usually 5-50%, is mixed with the unpressurized water just before admission into the flotation unit.

Currently all the dissolved air flotation systems operate under the recycle pressurisation system (Eckenfelder, 1989; Bratby and Marais, 1977; Metcalf and Eddy Inc., 1989). Different types of pressurization systems are shown in Figure 2.5 (Eckenfelder, 1989). Maddock (1979), in his studies in sewage treatment works, applied comparatively low recycle ratios between 7-20%. Increased rates of recycle were found to be necessary if the feed solids concentration was increased. Gehr and Henry (1978), in their studies, used tap water for recycle. Based on the results, they concluded that recycle liquid should be as clear as possible.

2.6 Influence of pH, Temperature and Coagulants

The pH, temperature and coagulants play significant roles in the treatment of wastewaters by flotation. The effects are discussed in the following sections.

2.6.1 pH

There are not many studies reported on the effect of pH alone on the process of flotation. In general pH is adjusted in conjunction with the usage of coagulants. The only studies reported are for Ion Flotation. Ion Flotation is susceptible to variations in pH, because changes in pH have marked effects on the nature and charge of both collector and colligend (Pinfold, 1972). The effects to be expected are a) a change may occur in the charge of the agglomerate, due to hydrolysis or the formation of other complexes; b) Changes may occur in the ionization of the collector; acids and amines may lose their charges at low or high pH values which changes the coagulating ability of the collectors; c) Variation in pH can lead to a change in the nature of the process (Pinfold, 1972).

2.6.2 Temperature

In general, flotation experiments are carried out under normal temperature conditions. But temperature is an important parameter in the flotation systems where the
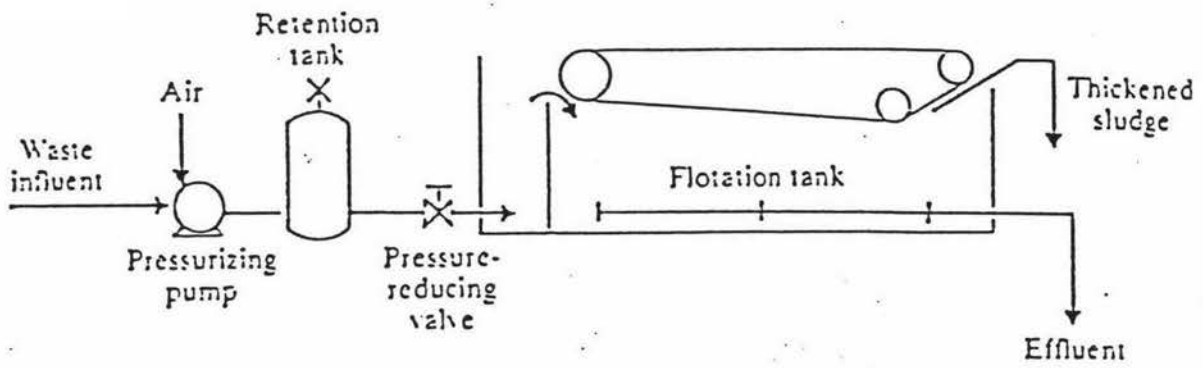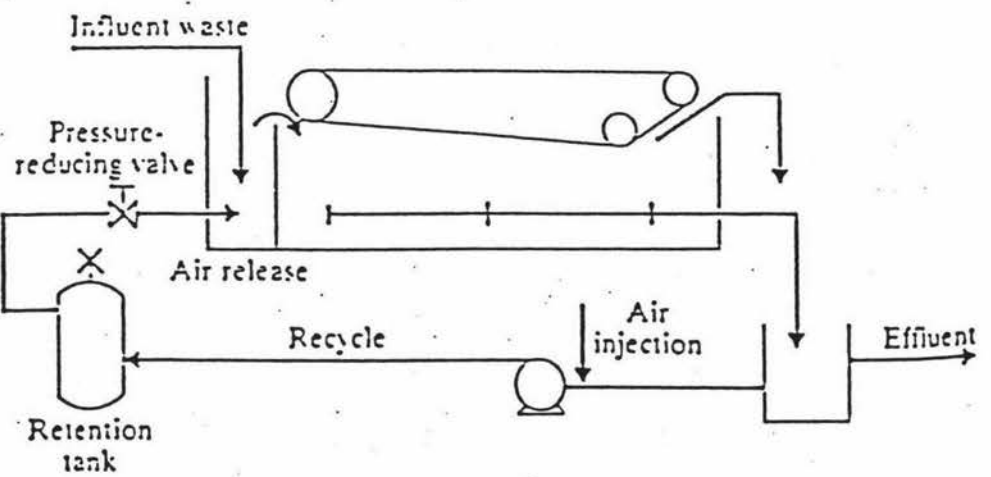
Figure 2.5 a) Full flow pressurization system b) Recycle flow pressurization system.

wastewater to be treated is discharged at high temperatures as air solubility depends on the temperature of the wastewater (Eckenfelder, 1989; Metcalf and Eddy Inc., 1989). As presented in section 2.4.1, the solubility of air is a function of temperature and decreases with an increase in temperature.

Shannon and Buisson (1980) carried out dissolved air flotation experiments to find the effect of temperature on bubble formation. Their experiments covered the temperatures 50 and 80° C. They found the bubble size to be changing considerably with pressure at these temperatures. The bubbles tend to take an elliptical shape with an increase in temperature and they coalesce rapidly at high temperatures. They obtained an average bubble size of 66 microns at 210 kPa and 42 microns at 350 kPa.

Malley and Edzwald (1991) observed that temperatures around 25° C are ideal for bubble formation and bubble-particle attachment. They also observed that flotation performance decreased at low temperatures.

2.6.3 Coagulants

In the treatment of waste waters using dissolved air flotation, coagulants are used for better effluent quality. Coagulants aid flotation by forming stable flocs with the suspended particles in the water. Alum is the general coagulant used with a combination of either cationic or anionic polyelectrolytes depending upon the charge characteristics of the suspended matter. In practice it is difficult to complete separation by using only coagulants (Barry, 1977). The flocculating agents also known as polyelectrolytes, on their own, will not coagulate dissolved solids. The availability of excellent flocculating chemicals gives a high stability of operation and a high degree of clarification in flotation (Krofta et al., 1987).

Three general groups of coagulating agents are used to enhance flocculation. They are, i) inorganic salts, ii) natural polymers and iii) synthetic polymers.

There are two types of colloids i) hydrophillic and ii) hydrophobic. The hydrophillic colloids are stabilised by water of hydration and it is very difficult to break down the forces which keep them in suspension. The hydrophobic colloids do not have a natural affinity for water and due to their surface charge they prevent the flocs from coming together. For most colloids the charge known as the Zeta potential is electronegative. Once the charge of the colloid is determined, a polymer of opposite charge is used. The polymers operate in two ways. One is charge neutralizing and the other is by bridging the flocs (Barry, 1977).

Eckenfelder (1989) observed that a certain level of alkalinity was required in the wastewater for the coagulant alum to act efficiently. The alkalinity in wastewater converts the charge on the surface of the colloids, proteins and fat particles to negative. As alum is added the cations are attracted by the opposing charges coating the material, microflocs are thus formed, which retain a positive charge in the acid range because of the absorption of hydrogen ions. Flocculation agglomerates the particles with a hydrous oxide floc. In this phase surface adsorption is also active. Colloids not readily adsorbed are removed by enmeshment in the floc. For protein wastes the optimum pH for floc formation was around 5.2 (Eckenfelder, 1989). The solubility of the proteins is dependent on the pH range.

A particle that exhibits hydrophillic nature cannot be floated unless it is made hydrophobic by use of some surface active agents (Gochin and Solari, 1983). Gochin and Solari (1983), in their studies on micro-flotation of silica, found that quartz particles which are hydrophillic are not floatable by dissolved air flotation unless they are made hydrophobic by the use of some surface active agent. They also confirmed that floc characteristics also play an important role in the flotation. In a way the application of coagulants reduces the A/S ratio and float single unflocculated fine particles by forming hydrophobic colloids.

For most of the coagulants the process of floc formation is pH dependant and the process is carried out at the isoelectric pH of the liquid to be treated (Maddock 1979). Maddock (1979) observed that after usage of alum as a coagulant the effluent quality

decreased for domestic wastewater because alum produced delicate floc which resulted in weaker bubble attachment. He observed that the characteristics of waste are important in the usage of coagulant. However, usage of polymer Zetag 94 produced a clear effluent but the suspended solids concentration remained the same. El-Gohary (1980) also used alum as a coagulant and achieved a high process efficiency in the range of 98%.

Anderson (1984) reported on experiments with dairy waste to find the feasibility of treatment by chemical precipitation, by using $Al_2(SO_4)_3$, $FeCl_3$ and $Ca(OH)_2$ at different concentrations as precipitants. The treatment was not as effective as biological treatment in the case of reduction of oxygen demand, but removal of phosphorous and nitrogen were better in comparison. He concluded that by using alum and ferric chloride at controlled pH, chemical treatment of dairy wastes can be carried out efficiently. If dissolved air flotation is used after chemical treatment the treatment could be more efficient.

Claggett (1972) used alum and sodium hydroxide to treat fish industry wastewaters. He found that the optimum dosage of alum was 375 mg/l, and of sodium hydroxide 75 mg/l to remove oil, protein and solids from the wastewater. He achieved 95% removal of solids, 78% of protein and nearly 90% of oil. The sludge was used as poultry feed. Alum, upto 1% level, in the diet had no significant effect on chicken.

Merrill and Jordan (1975) used lime precipitation to treat raw domestic wastewaters by dissolved air flotation. They used lime from 150 mg/l to 350 mg/l. They achieved suspended solids removals of 95%, 98.5% and 99% at lime dosages of 150, 250 and 350 mg/l respectively. Other pollutants were also similarly removed. They justified the usage of high concentrations of lime by emphasising the fact that wastewater type and composition play important role.

Wang and Guss (1988) used alum at the rate of 11.0mg/l and polymer 728 at the rate of 9.75 mg/l to treat wastewater from dairy industry. They obtained removals for

fat, oil and grease, and total suspended solids in the range of 50-62%. With chemical addition they obtained a floated sludge concentration of 5.4% to 29.4%.

Malley and Edzwald (1991) used alum and poly aluminium chloride as coagulants. The flocculation period for dissolved air flotation was 5 minutes whereas conventional gravity settlement required 20 minutes of flocculation. They found similar levels of dissolved aluminium in both types of tests.

2.7 General application of dissolved air flotation (DAF)

Dissolved air flotation is applied in the primary treatment of different types of wastewaters. The objective of using dissolved air flotation is to remove suspended solids, fat, oil and grease and BOD. The results reported in the literature for industrial wastes treated by dissolved air flotation show suspended solids and BOD reductions of 69 to 97.5% and 60 to 91.8% respectively (Quigley and Hoffman, 1966). The efficiencies obtained for different wastewaters are shown in Table 2.5.

Table 2.5 Application of DAF and efficiencies obtained for different wastes (Quigley and Hoffman, 1966).

Waste source	SS in influent ppm	Efficiency obtained %	BOD in influent ppm	Efficiency obtained %
Petroleum production	441	95.0		
Railroad maintenance	500	95.0		
Meat packing	1400	85.6	1225	67.3
Paper manufacturing	1180	97.5	210	62.6
Vegetable-oil processing	890	94.8	3048	91.6
Fruit and vegetable- - canning	1350	80.0	790	60.0
Soap manufacture	392	91.5	309	91.6

Cesspool pumpings	6448	96.2	3399	87.0
Primary sewage treatment	252	69.0	325	49.2
Glue manufacture	542	94.3	1822	91.8

Coertze (1978) described the application of dissolved air flotation to paper mill effluent treatment is South Africa. The treatment removed 98% of suspended cellulose fibre through partial pressurization of the effluent. As alum is already present in the effluent polyelectrolytes and lime are used for flocculation.

Krofta *et al.* (1987) reported about the development of a highrate dissolved air flotation unit known as Supra cell, for secondary clarification of activated sludge systems instead of conventional sedimentation. They also reported the use of the high rate supra cell clarifier to treat secondary effluent from biological treatment for a paper mill effluent, a petro chemical complex and a municipal waste treatment system. The process was found to be highly efficient for all three cases. They reported that for the municipal wastewater treatment system the efficiency of suspended solids removal ranged from 92 to 99%.

Malley and Edzwald (1991) compared laboratory dissolved air flotation with conventional gravity settling. They achieved good performance with dissolved air flotation, which required lower flocculation times.

DAF is applied for the treatment of abattoir wastes, fish wastes, dairy wastes, tanneries, mineral industry wastes, food processing wastes, refinery wastes and wastes which have high concentrations of suspended solids, proteins and BOD.

Dissolved air flotation is an effective method of primary treatment of meat wastes and its performance is directly related to the size of the particle to be floated (Lovett and Travers, 1986). The addition of chemicals to the waste in order to promote coagulation of individual particles into larger agglomerates and thereby improved

flotation has been studied by Denmead and Wilkinson (1972), Cooper and Denmead (1979), Hopwood (1980), and Travers and Lovett (1984).

Most methods of chemical treatment involve an initial pH change using acid or, to a lesser extent an alkali. The pH change causes the precipitation of some soluble organics and changes the surface charge on colloidal particles so that coagulation and flocculation can occur. It also breaks fat-water emulsions. By using dissolved air flotation in treating abattoir wastes a dual objective of purification and recovery of protein containing animal feeding material is achieved (Denmead and Cooper, 1975).

Lignosulphonic acid treatment for proteinaceous waste waters has the capacity to purify and allow the recovery of the protein to be used as animal feed. Tonseth and Berridge (1968) introduced the concept of treatment by acidification together with lignosulphonic acid to precipitate proteins and other materials from slaughter house wastes. Subsequently dissolved air flotation is applied to separate the precipitated solids.

Jorgenson (1971), in his studies on protein removals from wastewater, observed that lignosulphonic acid was more effective in protein removal than the other chemicals tested. He found aluminum sulphate to be effective in phosphate removal. He used the chemicals sulphuric acid, aluminum sulphate, glucose trisulphate and lignosulphonic acid.

Denmead and Cooper (1975) observed that acidification alone at a pH of 4.0 to 4.5 precipitated protein from meat wastes, a considerable amount of which settled only very slowly on standing. They achieved optimum removal of COD from the wastes in the laboratory at a pressure of 3 atmospheres with a recycle ratio of 25 percent. The optimum pH was found to be 4.5. They achieved a purification of 70% in COD, and a coliform reduction of 90% at pH 4.5. Further they found that with acid coagulation, 93% removal efficiency could be achieved compared to without acid which gave only 44% removal.

Travers and Lovett (1985) studied the effects of pH reduction and high gas/solids ratio, COD and fat, using flotation with carbon dioxide or a carbon dioxide/nitrogen mixture. They observed that fat removals were higher than those for suspended solids due to the natural tendency of the fat to float and because the hydrophobic nature of the fat particles increases the probability that a collision with a bubble would result in adhesion (Vrablik, 1959; Kitchener and Gochin, 1981). The COD removals were lower than suspended solids removals.

Travers and Lovett (1985) reported the maximum efficiencies for removal of suspended solids, COD and fat from non- coagulated abattoir wastes by using carbon dioxide or a 1:3 mixture of carbon dioxide and nitrogen to be similar to those obtained by using air.

From the literature survey it can be concluded that flotation is an effective method of preliminary treatment for treating any type of wastewater. The performance of flotation can be enhanced by chemical treatment of wastewater by coagulation before flotation. The process efficiency is high with flotation treatment and if further reduction in oxygen demand is required biological treatment may be carried out.

In this thesis, purification of dairy wastewaters is examined by using dissolved air flotation, in the laboratory on a bench scale. The efficiency of the flotation process is examined by changing the conditions of pH and temperature. Also the use of the coagulant alum is examined along with a cationic polymer.

CHAPTER III
EXPERIMENTAL METHODS

3.1 Introduction

This chapter presents the experimental methods carried out to determine the extent to which purification could be achieved by DAF. The wastewater was collected from a dairy factory engaged in the production of milk powder, butter and cheese. The effluent for the experiments was supplied by NZDRI. The effluent was supplied in batches of 100-120 l in plastic containers of 20 l each. Initially the experiments were carried out on the effluent from milk powder plant. Later effluent from butter plant was mixed and this effluent is a composite sample collected over 24 hr period.

The wastewater was frozen in a -11° C freezer. The samples were stored in a freezer, to ensure that the characteristics were not changed significantly. Before the experiments samples were kept in the cold room for defreezing. The effluent was taken out before the experiments and left to liquify. The temperature of the effluent was measured before the flotation experiments.

3.2 Analytical Methods
3.2.1 pH measurement

The pH was measured using a standard pH meter, a glass electrode (Watson Victor, NZ). The pH adjustments were done by using conc. H_2SO_4 (Analar grade, BDH, Poole) and 0.1 N NaOH (Analar grade, BDH, Poole).

3.2.2 Suspended Solids analysis

Principle of the method: A known volume of well mixed sample, is passed through tared glass fibre filter. The filter and entrained solids are dried at 103-105° C, cooled and reweighed. The difference in weight due to solids is defined as non-filtrable residue or suspended solids and is reported in mg/l.

cooled and reweighed. The difference in weight due to solids is defined as non-filtrable residue or suspended solids and is reported in mg/l.

Glass fibre filters (Whatman, GFC, 4.7 cm diameter) used for non-filtrable residue are prewashed with three successive 20 ml portions of distilled water. After washing, the filters are dried at 103-105° C (Watvic Oven, Watson Victor, NZ) cooled and weighed. All the weighings are done on a digital weighing machine (Mettler AE160, digital balance, Watson Victor, NZ). For Volatile solids determination the filter is pre-ignited at 550° C in a muffle furnace before cooling and weighing.

Filters were taken out before the experiments and are cooled in the daisycutter before using in filtering apparatus. The filter is wetted with distilled water and vacuum is applied. A sample of 40 ml was used every time for suspended solids determination. After all the water is drained, the filter with residue on it is placed in 103-105° C oven until constant weight is obtained. Once the sample is dry, it was placed again in the desiccator and cooled completely to room temperature. The filter was weighed. The difference between initial weight and final weight is the weight of the residue in mg/l.

3.2.3. Volatile Suspended Solids

The volatile fraction of the suspended solids, determined by the above method determined by igniting the sample with filter at 550-560° C. This gives the rough approximation of organic matter present in the solids fraction wastewater, activated sludge and industrial wastes.

The residue on the filter after suspended solids determination was ignited in the muffle furnace at a temperature of 550-560° C. The temperature of the furnace is reached before the sample is placed in it. The filter was ignited for 15-20 minutes. After that the crucible with the residue in it was placed in a daisycutter for cooling down. It was weighed immediately after cooling down to room temperature. The loss of weight on ignition was taken as the volatile fraction of the solids in the wastewater.

3.2.4 Fat Analysis:

For analysing the fat, Rose-Gottlieb method as given in IDF journal was followed. The method is as follows.

Principle of method : The fat content is gravimetrically determined by extraction of the fat from an ammonical alcoholic solution with diethyl ether and light petroleum ether, evaporation of the solvents and weighing of the residue, according to the principle of Rose Gottlieb.

All the reagents used are of AR (Analar grade, BDH, Poole) quality. The reagents used in the test are 1. Ammonia solution 35% m/v, 2. Ethanol 96%+2%, redistilled in a glass system, 3. Diethyl ether- re-distilled and peroxide free, 4. Light petroleum ether Bpt. 40-60°, 5. Mixed ethers- prepared before test by mixing equal volumes of diethyl ether and petrol ether.

Clean flasks were dried in the oven before the experiments. The flasks were taken out from the oven and cooled for one hour. The cooled flasks are weighed. The sample was pipetted into the mojonnier tubes. For dairy effluents it was recommended that 10 ml sample be used. Two extractions were carried out for effluents. 2 ml of ammonia was added in to the mojonnier tubes and the tube was shaken well for uniform mixing. 10 ml of ethanol was added in to the tubes and the liquids are mixed by shaking the tubes gently. 25 ml of diethyl ether was added to the tubes, and shaken vigorously and inverted repeatedly for one minute. Then 25 ml of petrol ether was added. The tube was shaken for 30 seconds, with inverting. After centrifuging for one minute, the supernatant is carefully transferred to the Erlenmeyer flask. At the end of the transfer the neck of the flask is washed with few mls of mixed ethers.

For second extraction 5 ml of ethanol was added to the mojonnier flasks and mixed gently. Then 50 ml of mixed ethers was added to the tubes. After shaking for 30 s, with inverting. The liquid was centrifuged as above. Generally two extractions are sufficient for fat extraction from effluent. The solvents are distilled off carefully using

Rotovapor. The samples are taken off rotovapor when no further solvent is coming off. The flask was put in the oven for one and half hours. After taking the flasks out from the oven they were cooled for one hr and weighed.

The difference between the final weight and initial weight gives the fat present in 10 ml of effluent in ppm. This measure is weight per volume. If the difference in weight is divided by the sample weight, the fat content will be given as a percentage (w/w).

3.2.5 COD

COD analysis was done by spectrophotometric determination by closed reflux colorimetric method as described in Standard methods (1985).

The chemical oxygen demand is a measure of the oxygen equivalent of the organic matter content of a sample that is susceptible to oxidation by a strong chemical oxidant. For samples from a specific source, COD can be related empirically to BOD, organic carbon, or organic matter content.

Principle of the method : A sample is refluxed in a strongly acid solution (a mixture of chromic and sulphuric acids) with a known excess of potassium dichromate, and read spectrophotometrically at 600 nm absorbance.

Reagents (all Analar grade, BDH, Poole) used in the method: 1. Potassium hydrogen phthalate was used as standard, 2. Sulphuric acid, 3. Silver sulphate, 4. Potassium Dichromate, 5. Mercuric Sulphate.

Reagents are prepared as follows.

Digestion Solution: In approximately 500ml distilled H_2O, 10.216 gm $K_2Cr_2O_7$, primary standard grade, previously dried at 103° C for two hours, was dissolved. To it 167 ml conc. H_2SO_4, and 33.3g $HgSO_4$ was added. After dissolving the solution is

allowed to cool down to room temperature and made up to 1000 ml with distilled H_2O.

Sulphuric acid reagent: $Ag_2 SO_4$ of technical grade in powder form was added to conc. $H_2 SO_4$ at the rate of 5.5 gm Ag_2SO_4/kg H_2SO_4. The solution was allowed to stand for two days in order to dissolve $Ag_2 SO_4$.

Potassium Hydrogen phthalate standard: Potassium hydrogen phthalate ($HOOCC_6H_4 COOK$) was lightly crushed and then dried to constant weight at 120° C. Then 1.062g was dissolved in distilled water and diluted to 250 ml. KHP has a theoretical COD of 1.176 mgO_2/mg and this solution has a theoretical COD of 5000 gO_2/m^3. This solution is stable for three months when refrigerated. Once in three months fresh standard solution was prepared. The standard was diluted 25 times to a concentration of 200 ppm.

Blanks, standards and samples are all analyzed in Hach screw-capped vials. Some times samples are diluted with distilled water. All blanks and standard are prepared is duplicate and samples are analyzed triplicate. The solutions are bottled and pippeters were fixed on the bottles.

3.5 mls of sulphuric acid reagent was run down the inside of the vial followed by 1.5 ml of digestion reagent. An acid layer is formed under the sample digestion solution layer. 2.5 mls of the standards was pippetted into the vials. Similarly 2.5 mls of the Sample was pippetted into other vials. Vials were tightly capped and inverted several times to mix completely. Adequate protection is taken when using the reactor. Blanks with distilled water are prepared.

The vials were placed in the reactor preheated to 150° C and refluxed for two hours. After two hours they are taken out and cooled to room temperature. Cooled vials are inverted and the solids were allowed to settle down before measuring the absorbance using spectrophotometer (Spectro PU 8625 UV/VIS, Phillips, NZ).

A calibration curve was prepared with the standards so as to measure the COD of the sample against the standard. The calibration curve is shown in appendix.

COD = {(Corrected sample absorbance) / (Corrected Standard absorbance)} S where, S = Standard concentration.

Every time glass vessels were cleaned and were free of organic matter. They were dried in the oven before use.

3.3 Dissolved air flotation

A laboratory bench scale test procedure given by Eckenfelder (1989) was followed throughout this study. The primary variables examined were recycle ratio, feed pressure, feed solids concentration, effluent solids concentration.

The principal components of the flotation system are a pressurizing cylinder, air injection facilities, pressure regulating device and a flotation unit (imhoff cone, made of pyrex glass) as shown in Figure 3.1.
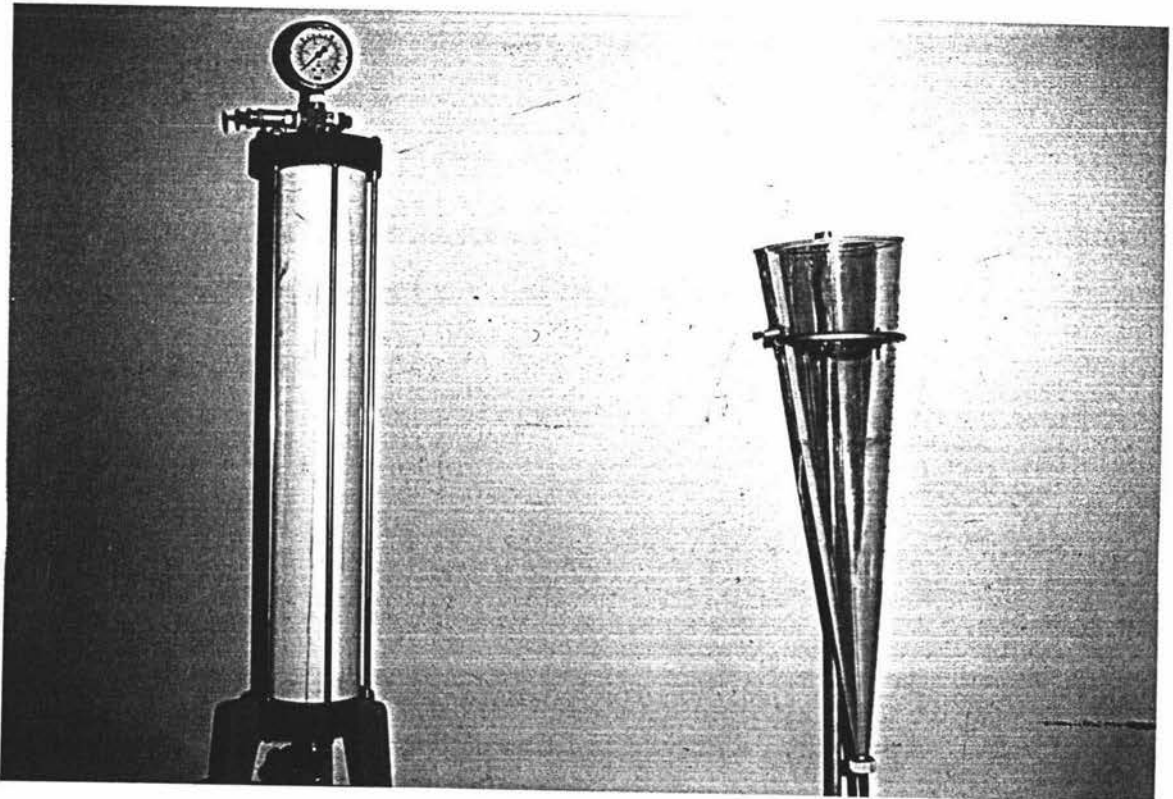

Figure 3.1 Flotation unit used for the experiments

The tests were done at five different pressures on type I effluent. Four pressures were used on type II effluent. Partial pressurization method was used to carry out the flotation studies. For each trial a quantity of 600 ml of the effluent was taken into the flotation cell pressurised liquid of quantity 400 ml was released into the flotation cell. The A/S ratio is dependent upon pressure and the quantity of liquid pressurized. In the experiments the quantity of effluent pressurized is kept constant and pressure was varied. The optimum A/S ratio in terms of process performance can be predicted by the relationship between A/S ratio and effluent suspended solids (Eckenfelder, 1989).

Procedure:

The following procedure was adopted to determine the flotation characteristics of the waste.

Initially some known quantity of wastewater was taken into the pressurising vessel and was pressurised for 7 minutes, including shaking the pressure vessel for one minute. A known volume of the wastewater i.e 600 ml was placed in the flotation unit, and the pressurised water, volume of 400ml was released into the flotation vessel. Due to reduction of pressure to atmospheric pressure air comes out in the form of minute bubbles, and form bubble-particle agglomerate and floats to the top. After the separation takes place, the float was taken from the top and the subnatant was drawn out through the bottom valve of the unit. The subnatant was analyzed for above mentioned parameters. Before pressurisation also the characteristics of the waste were determined. The efficiency was determined by calculating the difference between inlet and outlet concentrations as a percentage.

3.4 Temperature Studies

A water bath with a temperature control device was used to heat the liquid. The temperature effects studied in the range of 25 - 48° C. Temperature of the liquid was checked using a mercury thermometer. The temperature studies were done at pHs 7 and

8. The effects were studied at four pressures for temperatures 25 and 34 ° C. At 48° C, only one pressure, 500 kPa was used.

3.5 Coagulants

Aluminium sulphate, $Al_2 (SO_4)_3$, 18 H_2O (Analytical grade, allied colloids) in powdered form was used as coagulant. The wastewater was transferred in to 5 l jar and was mixed with a standard mixer (Watson Victor, NZ) at 250 rpm for two minutes and then mixed slowly for six minutes to facilitate floc formation. Alum was added without changing the pH of the wastewater. After thorough mixing as explained above pH was adjusted to 7.0 and the liquid was allowed to settle for half an hour before flotation. Before flotation the liquid was stirred.

3.5.1 Polyelectrolyte

Polyelectrolyte Zetag-92 (Allied Colloids, NZ) was used as 0.05% solution. It was used at concentrations of 5mg/l and 10 mg/l, along with aluminum sulphate. Polyelectrolyte solution was prepared according to the specification of the manufacture. Fresh solutions were prepared everyday.

Initially alum was added in powder form to the wastewater and mixed thoroughly and then polyelectrolyte solution in desired concentration was mixed. The wastewater was mixed as explained earlier (Section 3.4).

CHAPTER 4

ROLE OF pH, TEMPERATURE AND COAGULANTS ON DAF
PERFORMANCE

4.1 Introduction

In this chapter detailed results are presented on the experiments carried out by the methods described in chapter 3. Tests were carried out on two types of dairy wastewaters.

In the first type (Type-I) of dairy wastewater, discharges from butter plant were not mixed as the butter production plant did not operate at that time. With this wastewater flotation tests were carried out original pH of the wastewater, which is at pH 11.3 and at pHs 4 and 5. Flotation tests were carried out at five different pressures on this effluent as explained in Section 3.3.

After the seasonal closure of the plant, all the operations were started again in July 1992. A composite sample was collected from the disposal points, which represented the the characteristics of the wastewater over 24 hours period.

The initial pH varied from 10.6-12.3 for the second type (Type-II) of wastewater. Flotation tests were initially carried out at original pH of the wastewater and at pH 4, 5, 7 and 8. Also the effects of temperature and coagulant alum were carried out. The wastewater characteristics did not vary much during the experimental period. The temperature of the wastewater varied from 11° C to 17° C for the experiments done without changing temperature. The temperature of the wastewater was measured before the experiments as air solubility is dependant on the temperature.

4.2 Experiments on Type - I wastewater

Dissolved air flotation tests were carried out on this wastewater as explained in Section 3.5. Float separation took place in about 10-12 minutes. But a standing time of

20 minutes was observed for all the tests. Fat content in the effluent is less as butter plant waste is not mixed. The characteristics of the wastewater are shown in Table 4.1

Table 4.1 Characteristics of Type - I wastewater

Influent characteristic	Concentration (mg/l)
Suspended Solids	467-661
Volatile suspended solids	458-652
Fat	270-287
COD	1529-3742

4.2.1 Results at pH 11.3

Table 4.2 shows the results of the experiments with dissolved air flotation. As discussed in Chapter 2, Section 2.4., A/S ratio is a function of pressure and as expected the results indicated that increase in pressure increased A/S ratio. Figure 4.1 shows the effect of A/S ratio on the effluent characteristics after flotation.

From Figure 4.1, it can be seen that as A/S ratio increases the effluent suspended solids concentration is decreases. The A/S ratio varied from 0.075 to 0.141 with pressure in the range of 350 kPa to 550 kPa. Lowest effluent solids concentration was obtained at pressure 550 kPa. These results agree with findings of other researchers (Eckenfelder, 1966, Cooper and Denmead, 1979). The effluent volatile suspended solids concentration showed similar results with increase in A/S ratio. Concentration of volatile suspended solids in the wastewater is same as that of suspended solids and also effluent volatile solids concentration is similar. The effect is shown in Figure 4.1.

The effect of A/S ratio on effluent COD is also given in Figure 4.1. The COD decreased with increasing pressure and the results showed that difference in effluent concentration at pressures 500 and 550 kPa is marginal. The effect of A/S ratio on

Table : 4.2 Summary of results at pH 11.3.

| Parameter					
Pressure (kPa)	350	400	450	500	550
A/S Ratio	0.075	0.092	0.108	0.125	0.141
Influent SS (mg/l)	467	467	467	467	467
Effluent SS (mg/l)	388	336	330	287	249
Efficiency (%)	17	28	29	39	47
Influent VSS (mg/l)	458	458	458	458	458
Effluent VSS (mg/l)	378	332	322	282	246
Efficiency (%)	17	28	30	38	46
Influent Fat (mg/l)	270	270	270	270	270
Effluent Fat (mg/l)	205	180	155	140	125
Efficiency (%)	24	33	43	48	54
Influent COD (mg/l)	1529	1529	1529	1529	1529
Effluent COD (mg/l)	655	645	604	521	495
Efficiency (%)	57	58	61	66	68
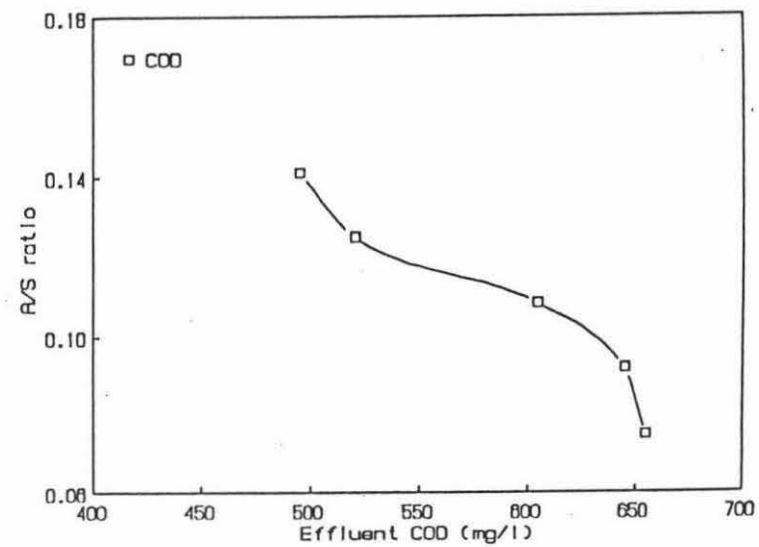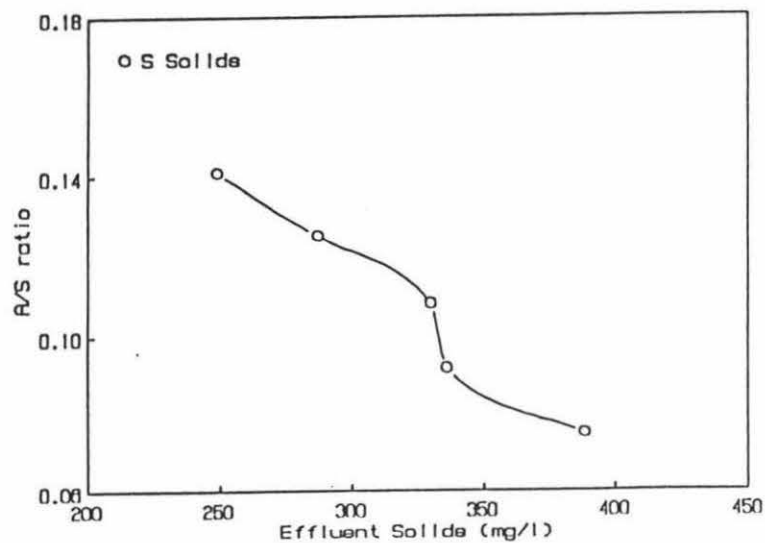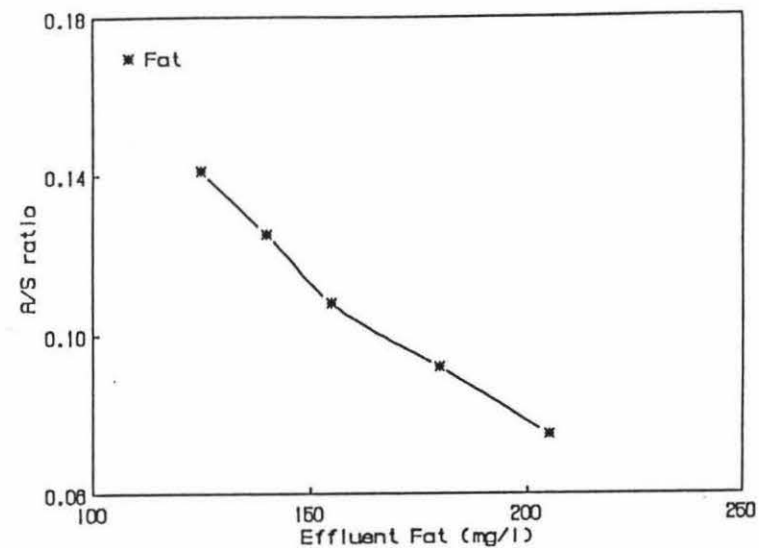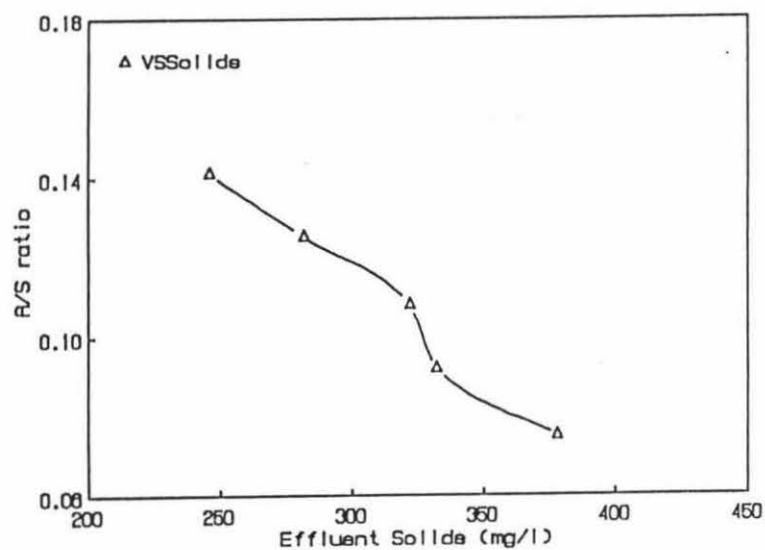
Figure 4.1 The effect of A/S ratio on effluent concentration at pH 11.3 for SS, VSS, Fat and COD

effluent fat concentration is also shown in Figure 4.1. The effluent fat concentration decreased with increasing A/S ratio. Lowest effluent fat concentration was achieved at a pressure 550 kPa.

Figure 4.2 shows the effect of pressure on removal efficiency. The figures show similar effect of pressure on removal efficiency as to that of Figure 4.1. The removal efficiency increased with increase in pressure, optimum efficiency being at A/S ratio of 0.141 at a pressure 550 kPa for all the parameters examined. The efficiency was calculated as the difference between the inlet and outlet concentration of the parameters determined before and after flotation studies and is presented as percentage (given in Appendix).

Maximum efficiency was obtained for COD. Maximum fat removal of 54% was achieved at pressure 550 kPa. Solids removals were comparatively low at this pH.

4.3 Effect of change in pH

The effect of pH on Type-I wastewater was carried out at pH 4 and 5. The pH was adjusted by using concentrated sulphuric acid and 0.1 N sodium hydroxide. Effluent characteristics for suspended solids, volatile solids, COD and fat were determined before and after flotation.

4.3.1 DAF performance at pH 4.0

Studies at pH 4.0 were carried out because the isoelectric point of protein is between 4.0 and 4.6 (Eckenfelder, 1989; Ecalard, 1984; Denmead and Cooper, 1975). As reported earlier fat and solids precipitated after adjusting the pH to 4.0. Similar phenomena was observed by Denmead and Cooper (1975) for meat wastewaters, which contained fat and solids identical to dairy wastewaters. The results of these experiments are presented in Table 4.3. Table shows the initial and final concentrations and removal efficiency for the parameters described above.
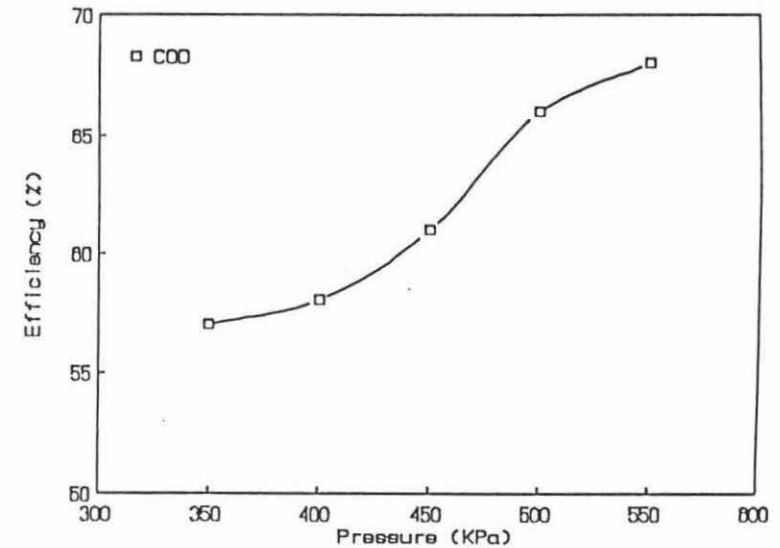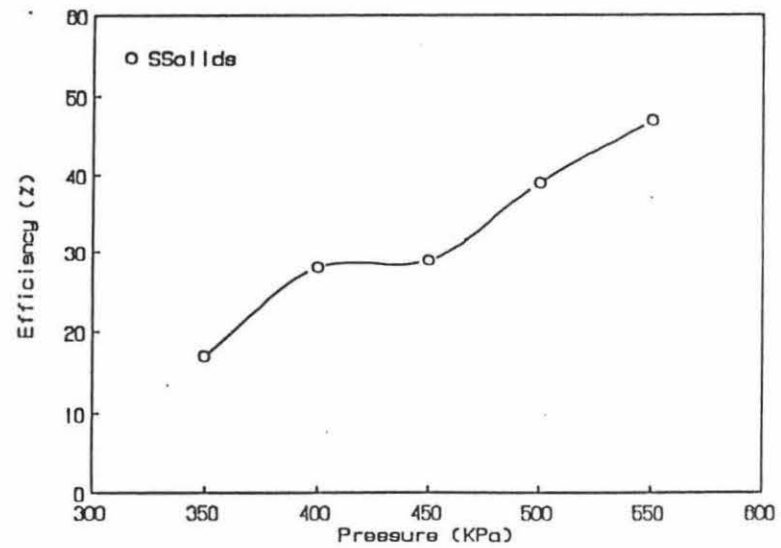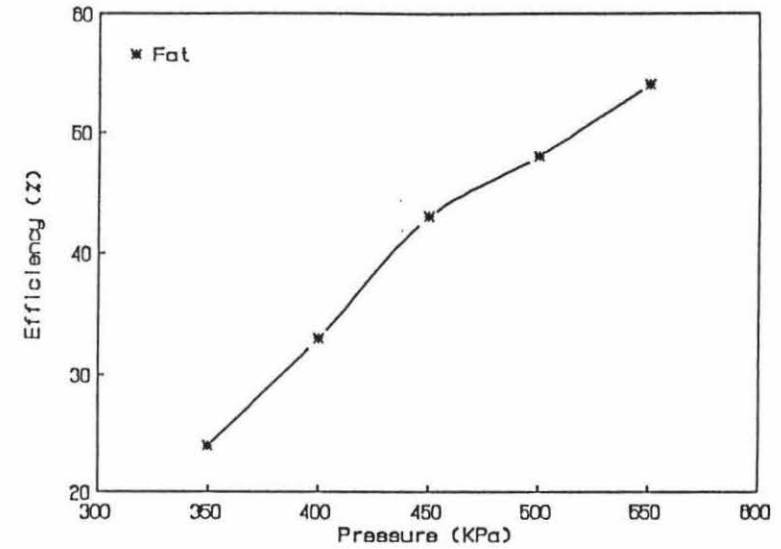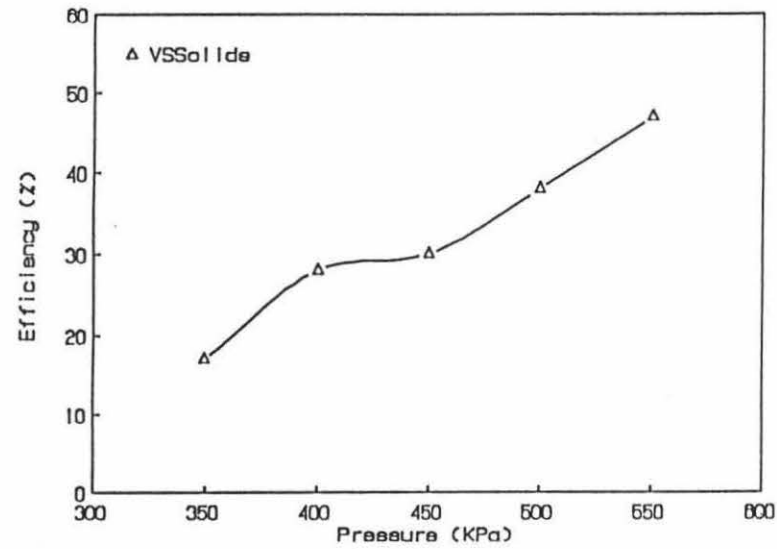
Figure 4.2 The effect of pressure on efficiency at pH 11.3, for SS, VSS, Fat and COD.

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Table : 4.3 Summary of results at pH 4.0.

Parameter					
Pressure (kPa)	350	400	450	500	550
A/S Ratio	0.054	0.066	0.078	0.090	0.102
Influent SS (mg/l)	661	661	661	661	661
Effluent SS (mg/l)	211	129	89	74	61
Efficiency (%)	68	80	87	89	91
Influent VSS (mg/l)	652	652	652	652	652
Effluent VSS (mg/l)	204	113	83	71	61
Efficiency (%)	69	83	87	89	91
Influent Fat (mg/l)	275	275	275	275	275
Effluent Fat (mg/l)	133	78	53	27	23
Efficiency (%)	52	72	81	90	92
Influent COD (mg/l)	1586	1586	1586	1586	1586
Effluent COD (mg/l)	1049	946	594	350	280
Efficiency (%)	34	40	63	78	82

Figure 4.3 shows the effect of A/S ratio on effluent concentration for the parameters determined. As shown in the figure, effluent solids concentration decreased with increase in A/S ratio. This is because at higher pressures the bubble particle attachment is better (Eckenfelder, 1989). Also in the present experiments pressurized effluent was released very slowly in to the flotation vessel reducing the turbulence (Maddock,1979). A/S ratio varied from 0.054 to 0.102. The low values of A/S ratio are due to increase in the solids concentration due to precipitation at pH 4.0. For Type-I wastewater volatile solids concentration is similar to the suspended solids concentration. Effect of A/S ration on effluent concentration was shown in Figure 4.3. Lowest effluent concentration was obtained at A/S ratio of 0.102 and pressure 550 kPa. From the figure it can be seen that the effluent COD concentration decreased with increasing A/S ratio. Effluent fat concentration also decreased remarkably with increase in A/S ratio as shown in Figure 4.3.

Compared with the effluent concentrations at pH 11.3, effluent concentrations at pH 4.0 were low. Also the inlet concentration of suspended solids was more at pH 4.0. This is due to precipitation of solids (Denmead and Cooper, 1975).

Removal efficiencies were found to be higher at pH 4.0. As explained above, this could be due to the precipitation of protein and better bubble-particle adhesion due to floc formation. A thick float was formed at the top of liquid surface in the flotation vessel. Denmead and Cooper (1975) reported similar results for meat waste, containing high concentration of protein and fat.

Figure 4.4 shows the effect of pressure on removal efficiency. The efficiencies varied between 68-91% for solids, 52-92 % for fat and 34-82 % for COD (Figure 4.4). With increase in pressure from 350 kPa to 550 kPa. It can be observed from the figures that efficiencies as high as 90% are achieved at pressure 550 kPa for all the parameters. Removal efficiency increased with pressure for all the above parameters determined. The summary of results at pH 4 are given in Table 4.3.
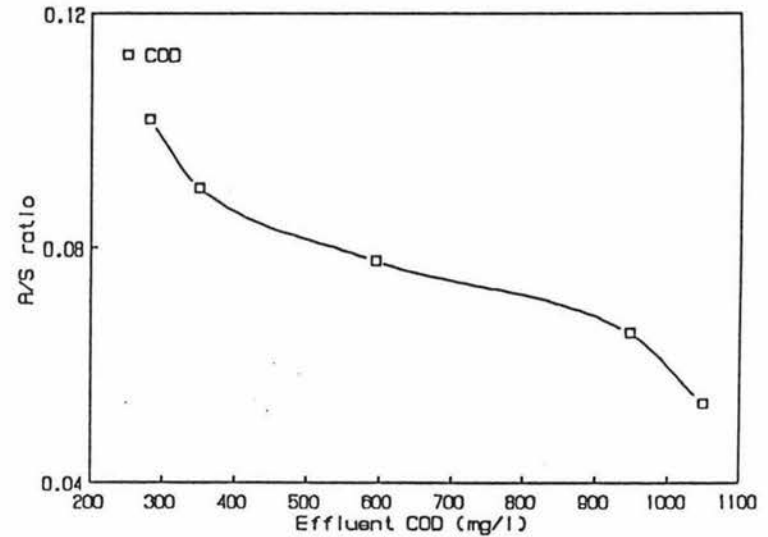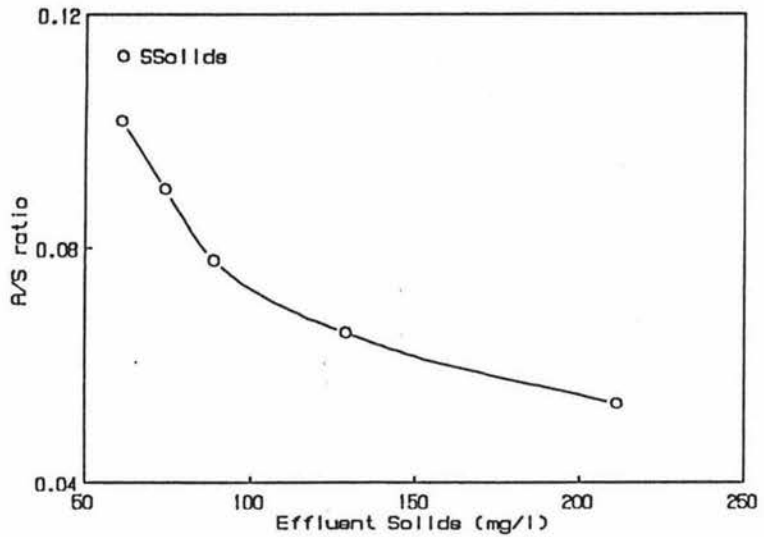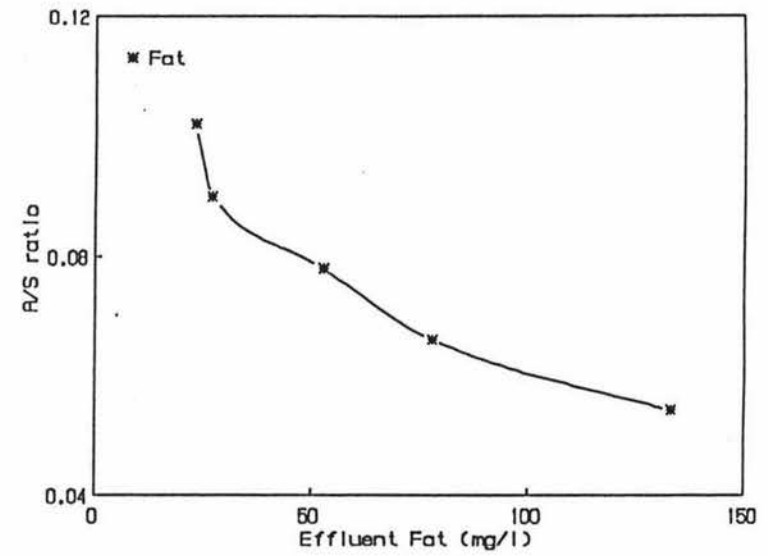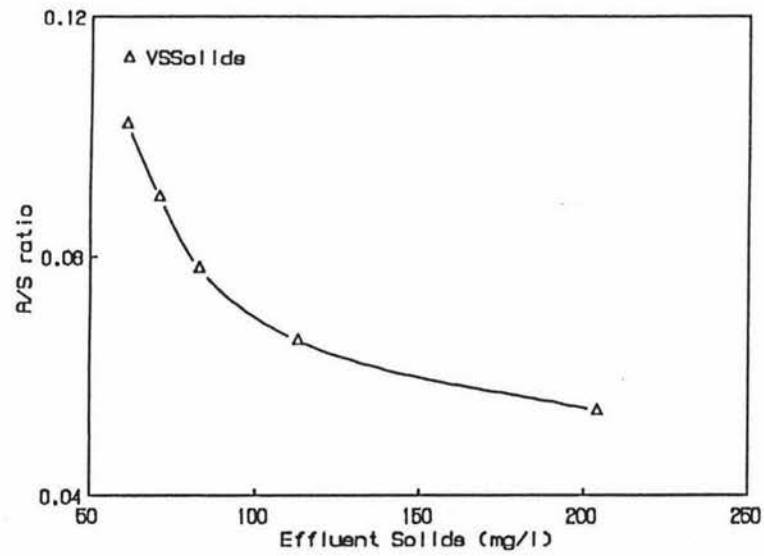
Figure 4.3 The effect of A/S ratio on effluent concentration at pH 4.0, for SS, VSS, Fat and COD
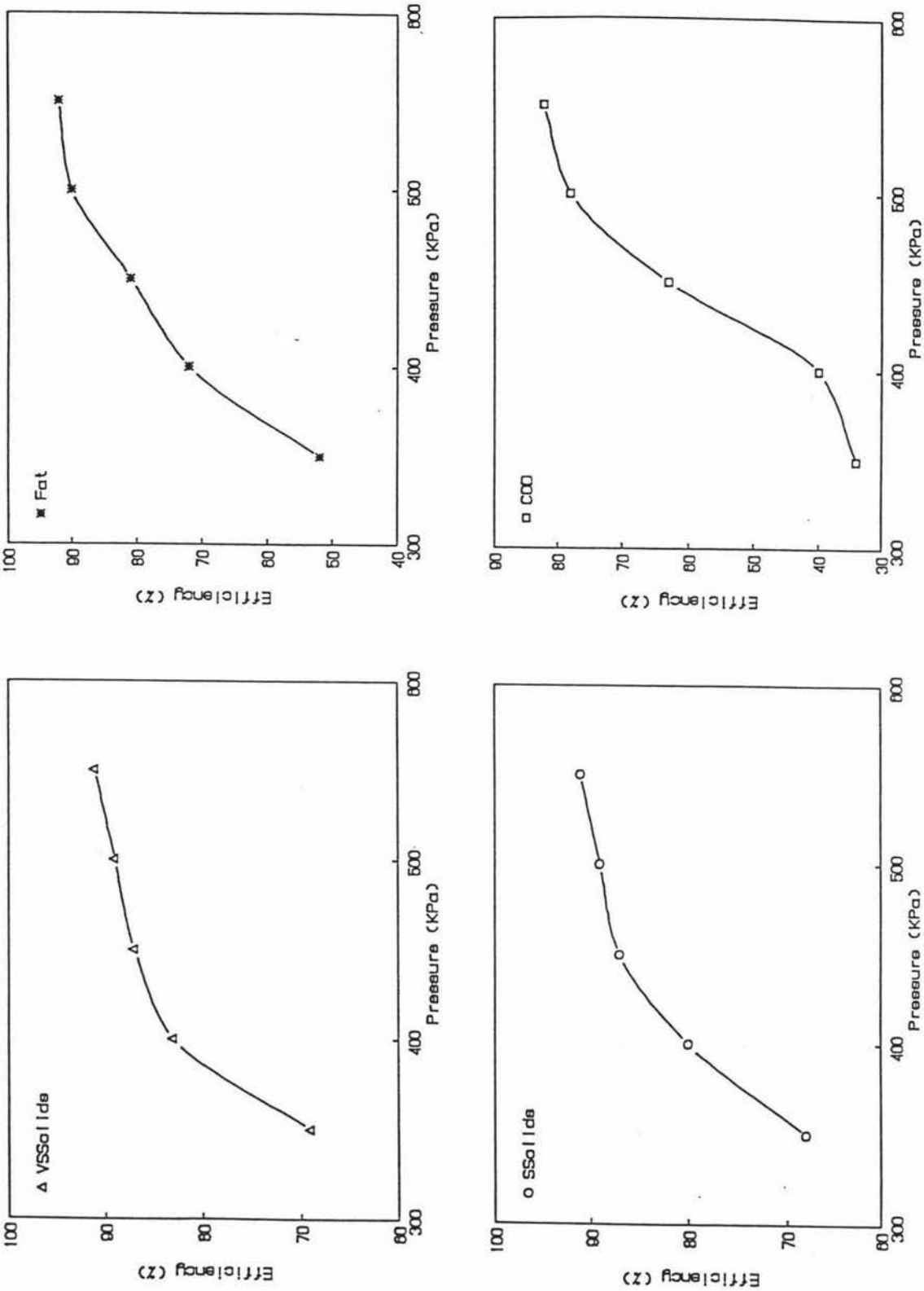
Figure 4.4 The effect of pressure on efficiency at pH 4.0, for SS, VSS, Fat and COD.

4.3.2 DAF performance at pH 5.0

This section discusses the results obtained for the experiments at pH 5. The summary of results obtained are given in Table 4.4.

Figure 4.5 shows the effect of A/S ratio on effluent suspended solids concentration. It can be seen from the figure that as the A/S ratio increases the effluent suspended solids concentration decreases. A/S ratio varied from 0.080 to 0.148. The optimum removal was obtained at a pressure 450 kPa and at an A/S ratio of 0.113. The removal of suspended solids decreased at pressures of 500 kPa. Figure 4.5 also shows the effect of A/S ratio on volatile suspended solids.

The effect of A/S ratio on effluent COD is given in Figure 4.5. COD decreased with increasing A/S ratio upto 0.113 and there is marginal increase at A/S ratio 0.137 and pressure 500 kPa and decreased again for higher pressure and A/S ratio. In general compared to other parameters COD removal was lesser. The effect of A/S ratio on effluent fat is also shown in Figure 4.5. The effluent fat decreased with increasing A/S ratio upto 0.113 at pressure of 450 kPa. Effluent fat concentration increased for higher A/S ratios obtained at pressures of 500 and 550 kPa. This could be due to the fact that at higher pressures more air is dissolved and when the pressurised liquid is released in to the flotation vessel, due to turbulence there may not be the necessary bubble-particle attachment (Ramirez, 1981). Also the change in pH could have played a role in not forming better bubble-particle agglomerate, as the solids and fat globules may not be in a state of adhesion. This pH could be a transition pH for th eisoelectric properties of the wastewater.

The effect of pressure on efficiency is given in Figure 4.6. The solids efficiency varied from 21% to 36%, maximum of 44% being at 450 kPa. Similar effects were observed for the other effluent parameters as shown in the figure.

There is remarkable change in the removal efficiency at this pH. In general removal of solids and fat is very low as is COD. This could be due to shearing effects

Table 4.4 Summary of results at pH 5.0.

| Parameter					
Pressure (kPa)	350	400	450	500	550
A/S Ratio	0.080	0.097	0.113	0.137	0.148
Influent SS (mg/l)	467	467	467	467	467
Effluent SS (mg/l)	369	365	263	330	299
Efficiency (%)	21	22	44	29	36
Influent VSS (mg/l)	463	463	463	463	463
Effluent VSS (mg/l)	366	363	260	320	298
Efficiency (%)	21	22	44	31	36
Influent Fat (mg/l)	287	287	287	287	287
Effluent Fat (mg/l)	220	193	123	174	153
Efficiency (%)	23	33	57	39	47
Influent COD (mg/l)	3742	3742	3742	3742	3742
Effluent COD (mg/l)	2696	2836	3186	2897	3120
Efficiency (%)	28	24	15	23	17
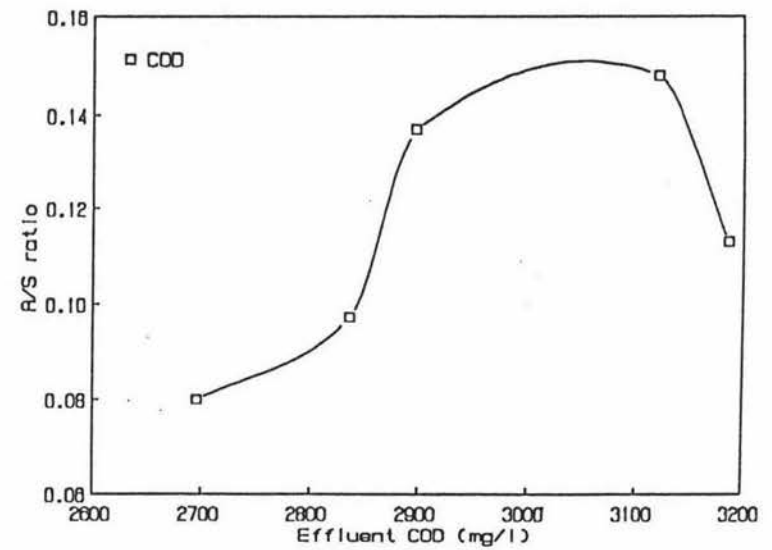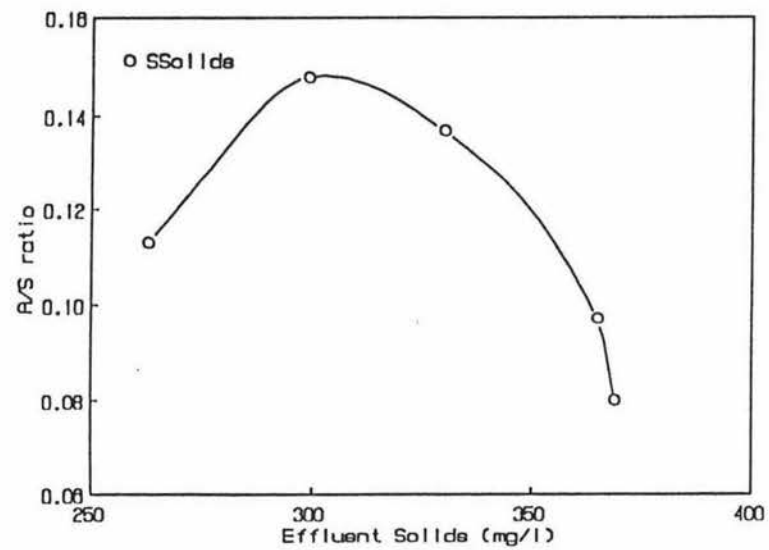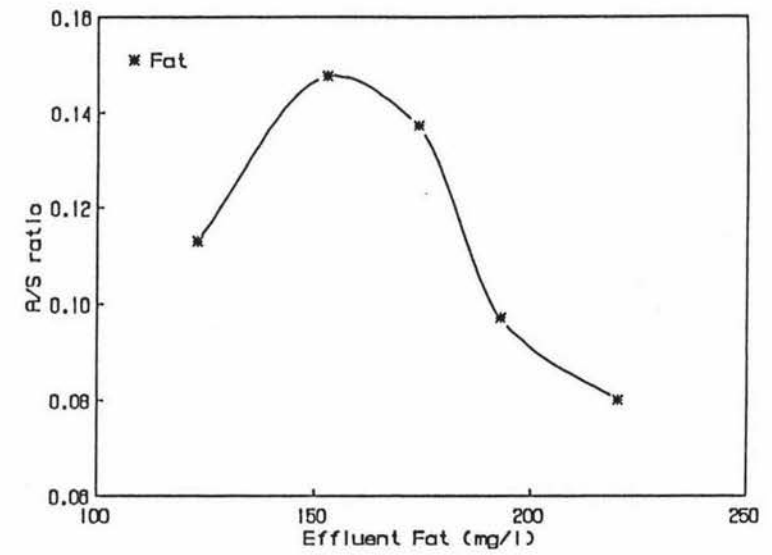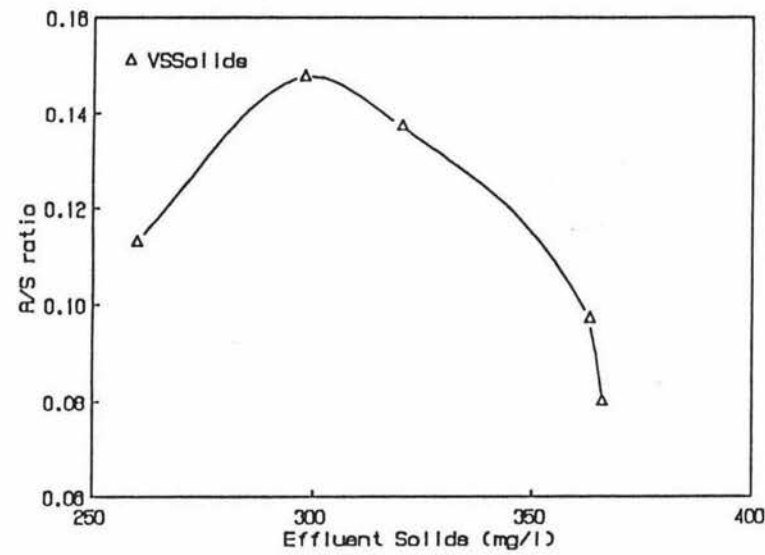
Figure 4.5 The effect of A/S ratio on effluent concentration at pH 5.0, for SS, VSS, Fat and COD
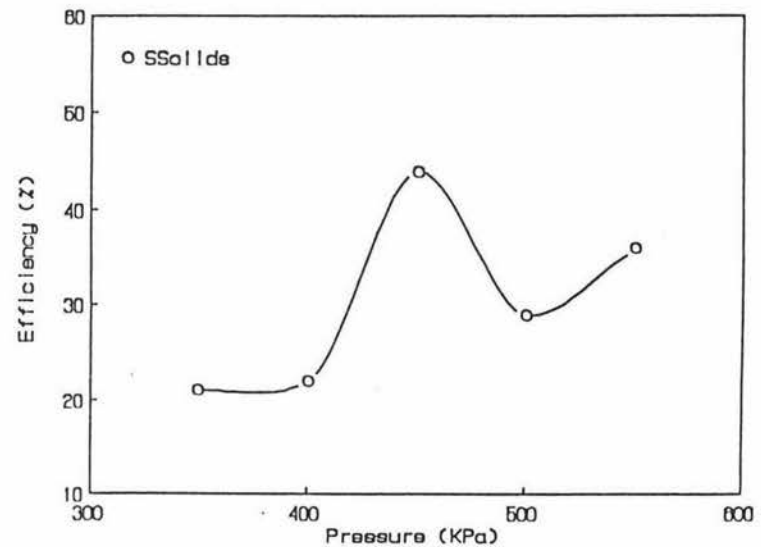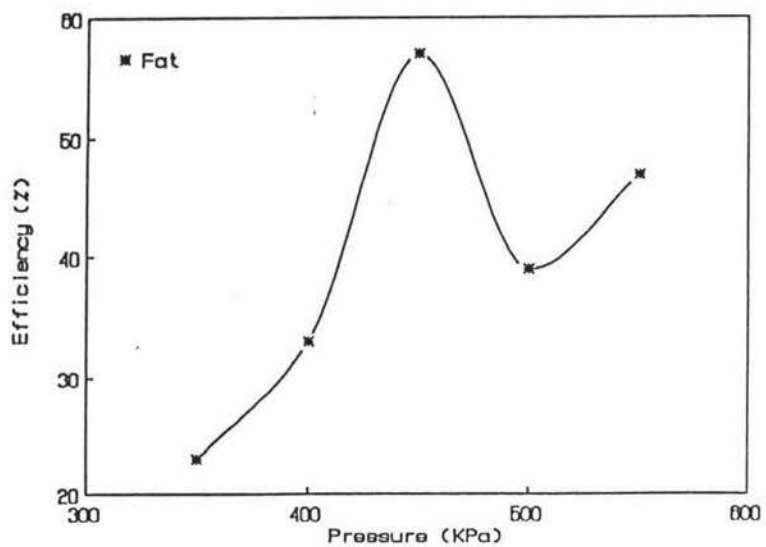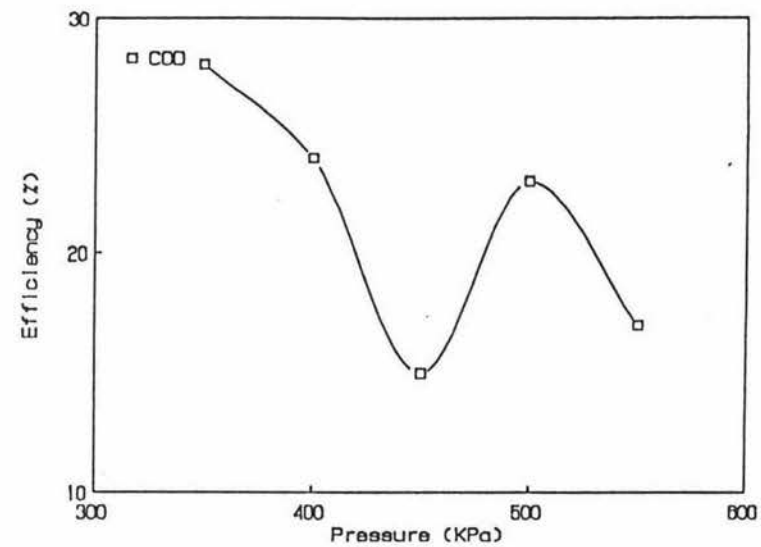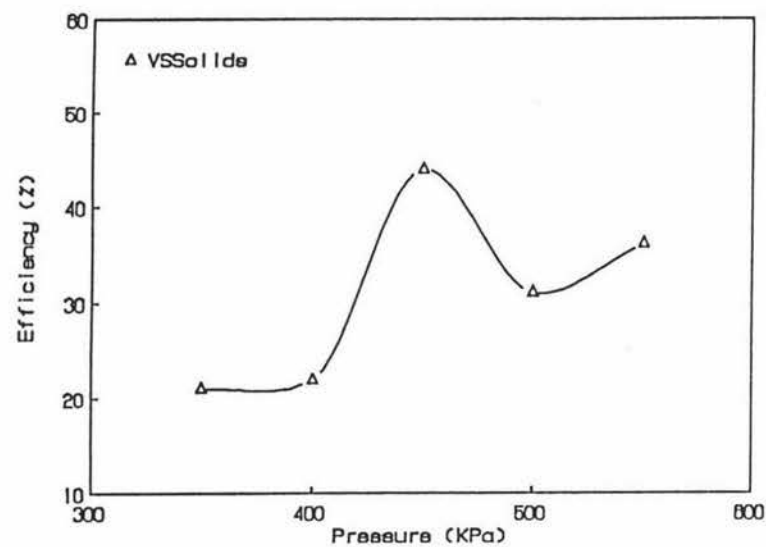
Figure 4.6 The effect of pressure on efficiency at pH 5.0, for SS, VSS, Fat and COD.

caused by turbulence as the particles did not precipitate as in the case of pH 4. This pH could be a transition pH, where by the effluent characteristics are not stable.

4.4 Studies on Type-II wastewater

The characteristics of Type-II wastewater are given in Table 4.5. This wastewater consisted discharges from all the plant operations. Fat concentration was more in this waste compared to Type-I wastewater. Solids concentration was less when compared to Type-I effluent.

Table 4.5 Characteristics of Type-II wastewater

Influent Characteristic	Concentration (mg/l)
Suspended Solids	190-307
Volatile Suspended Solids	189-306
Fat	305-585
COD	1066-1186

For Type-II wastewaters experiments were carried out at four different pressures ranging from 400 to 550 kPa. The results for Type - I effluent indicated that removal efficiency is lesser at lower pressures than 400 kPa, for all pHs. Based on these results it was decided to carry out further tests at pressure stating from 400 kPa.

The retention time in flotation chamber was maintained at 20 minutes for these experiments. In these experiments also float separation took place much earlier approximately in 12-14 minutes time.

4.4.1 Studies at pH 10.6 (actual pH of wastewater)

Initially experiments were carried out without altering the pH of the waste which was 10.6. The results obtained were summarized in Table 4.6. A/S ratio varied from 0.182 to 0.278 for pressures between 400 to 550 kPa. As shown in Figure 4.7, the effluent solids concentration decreased with increasing A/S ratio and varied between 189 mg/l and 94 mg/l. These results were similar to results obtained with Type-I wastewater in previous section. Similar behaviour was observed for volatile suspended solids, (Figure 4.7). Effluent COD concentration also decreased with increasing A/S ratio, but the effluent COD concentration is high. Effect of A/S ratio on effluent COD is shown in Figure 4.7, which also shows the effluent fat behaviour with increasing A/S ratio. At a pressure of 500 kPa and A/S ratio of 0.246, lowest effluent fat concentration of 70 mg/l was achieved.

Effect of pressure on removal efficiency is shown in Figure 4.8. For suspended solids and volatile solids efficiency increased with increase in pressure. The efficiency at pressures 450 kPa and 500 kPa is almost same, varying only by 1%. COD removal efficiencies were generally low varying from 8% to a maximum of 16 %. For fat optimum removal efficiency was 88% at pressure of 500 kPa. It decreased slightly at 550 kPa.

4.4.2 Flotation studies at pH 4

Initial pH of the waste was 12.3. pH was adjusted as explained earlier. Experiments were carried out at the indicated pH. Removal efficiencies are comparable to the results with Type-I effluent. Table 4.7 gives the summary of experimental results. The initial concentration of suspended solids was 307 mg/l.

The effect of A/S ratio on effluent parameters is shown in Figure 4.9. Lowest effluent concentration of 50 mg/l was obtained at an A/S ratio of 0.226. The effect of A/S ratio on volatile solids is similar to that of suspended solids. Effluent COD

Table 4.6 Summary of results at pH 10.6.

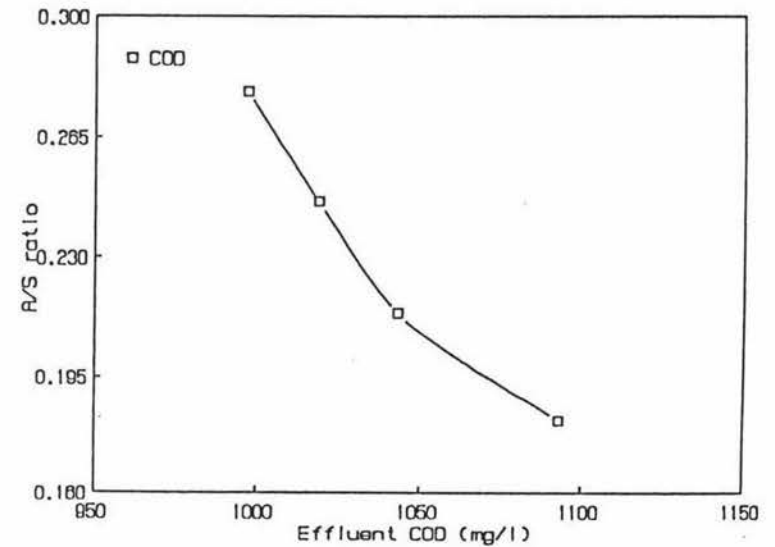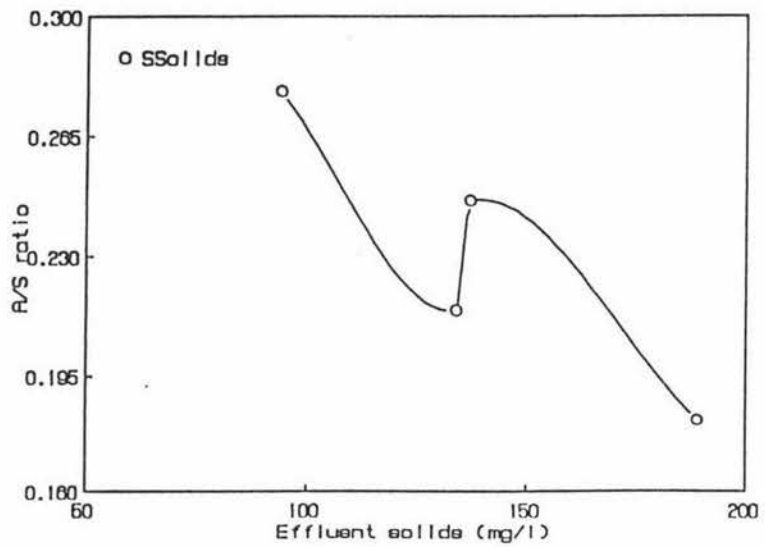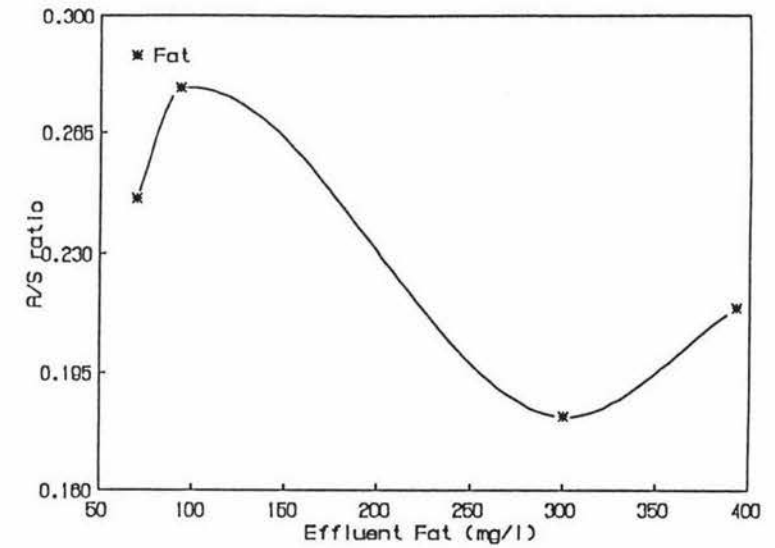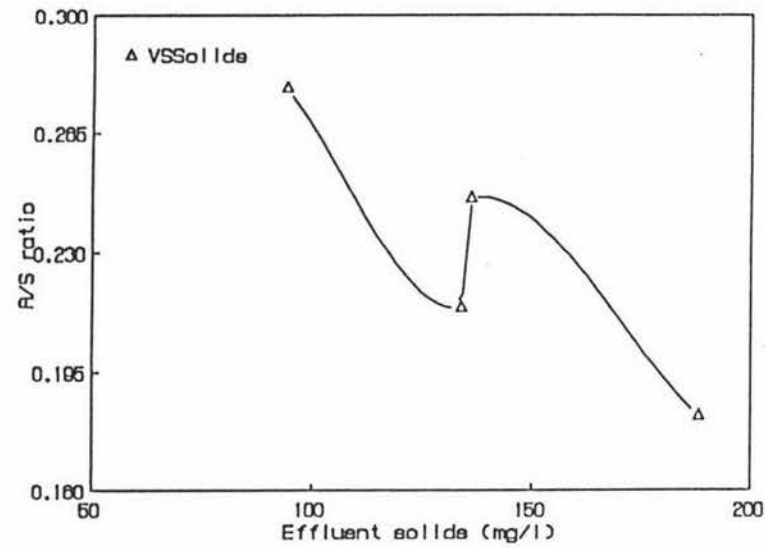| Parameter				
Pressure (kPa)	400	450	500	550
A/S Ratio	0.182	0.214	0.246	0.278
Influent SS (mg/l)	249	249	249	249
Effluent SS (mg/l)	189	134	137	94
Efficiency (%)	24	46	45	62
Influent VSS (mg/l)	248	248	248	248
Effluent VSS (mg/l)	188	134	136	94
Efficiency (%)	24	46	45	62
Influent Fat (mg/l)	585	585	585	585
Effluent Fat (mg/l)	300	393	70	93
Efficiency (%)	49	33	88	84
Influent COD (mg/l)	1186	1186	1186	1186
Effluent COD (mg/l)	1093	1043	1019	997
Efficiency (%)	8	12	14	16

Figure 4.7 The effect of A/S ratio on effluent concentration at pH 10.6, for SS, VSS, Fat and COD
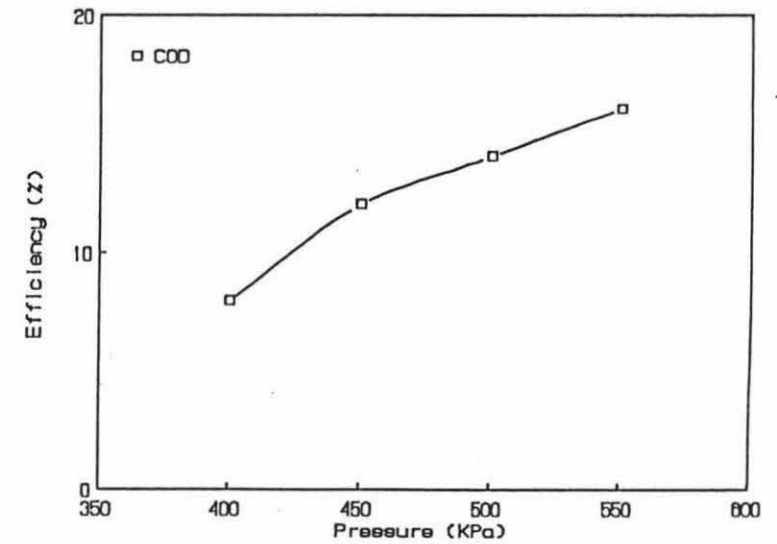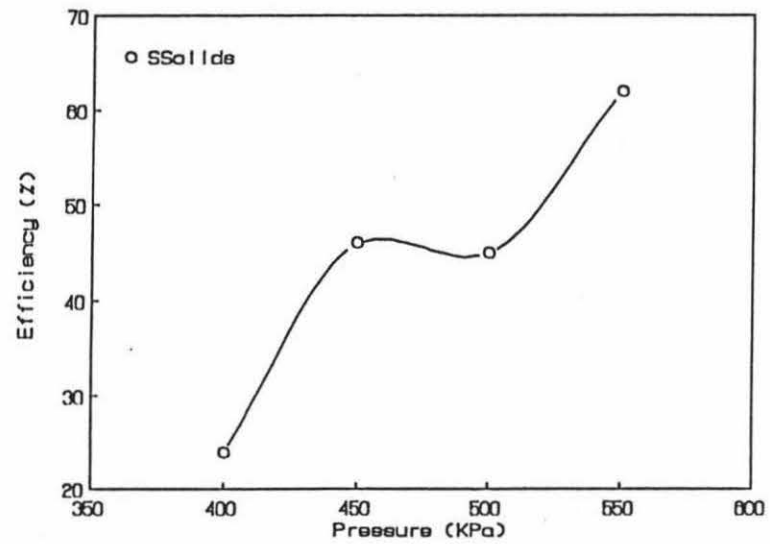
Figure 4.8 The effect of pressure on efficiency at pH 10.6, for SS, VSS, Fat and COD.

Table 4.7 Summary of results at pH 4.0.

Parameter				
Pressure (kPa)	400	450	500	550
A/S Ratio	0.148	0.174	0.200	0.226
Influent SS (mg/l)	307	307	307	307
Effluent SS (mg/l)	144	98	59	50
Efficiency (%)	53	64	81	84
Influent VSS (mg/l)	306	306	306	306
Effluent VSS (mg/l)	143	98	58	50
Efficiency (%)	53	68	81	84
Influent Fat (mg/l)	548	548	548	548
Effluent Fat (mg/l)	140	130	90	60
Efficiency (%)	74	76	84	89
Influent COD (mg/l)	1167	1167	1167	1167
Effluent COD (mg/l)	751	697	634	724
Efficiency (%)	36	40	46	38

decreased from 751 mg/l to 634 mg/l upto A/S ratio of 0.200 and a pressure of 500 kPa, but at A/S ratio 0.226 i.e with increase in pressure effluent COD increased to 724 mg/l (Figure 4.9). Effluent fat decreased from an initial concentration of 548 mg/l to 60 mg/l with increase in A/S ratio up to 0.226.

The effect of pressure on removal efficiency for all the parameters is shown in Figure 4.10. The figure shows that as the pressure is increased removal efficiency also increased, similar to that of earlier results. Maximum efficiency was observed at a pressure 550 kPa, for all the parameters.

4.4.3 Studies at pH 5

Initial pH of the wastewater was 12.3. The pH was adjusted to 5 and the performance of flotation was evaluated.

Summary of the results are given in Table 4.8. It can be seen from the table that A/S ratio is high. This could be due to low concentration of solids. As A/S ratio is dependent on solids concentration, more air is dissolved for the low concentration of solids present in the wastewater (Bratby and Marais, 1975).

Effect of A/S ratio on effluent parameters is shown in Figure 4.11. Effluent solids concentration was similar at A/S ratios 0.275 and 0.358 and pressures 450 and 550 kPa. Effluent solids concentration varied between these two values. Effluent solids concentration increased at pressure 500 kPa, volatile solids also showed similar behaviour. Effluent fat decreased with increase in A/S ratio. Lowest effluent fat concentration of 250 mg/l was obtained at an A/S ratio of 0.358. Effluent COD concentration is high showing that removal is low. Effluent solids and fat concentrations were also high compared to the results at pH 4.

Figure 4.12 shows the effect of pressure on efficiency. For solids maximum removal was obtained at a pressure of 450 KPa. Optimum efficiency for fat was 51% at a pressure of 550 KPa. COD removal efficiencies are rather low, varying between 9-

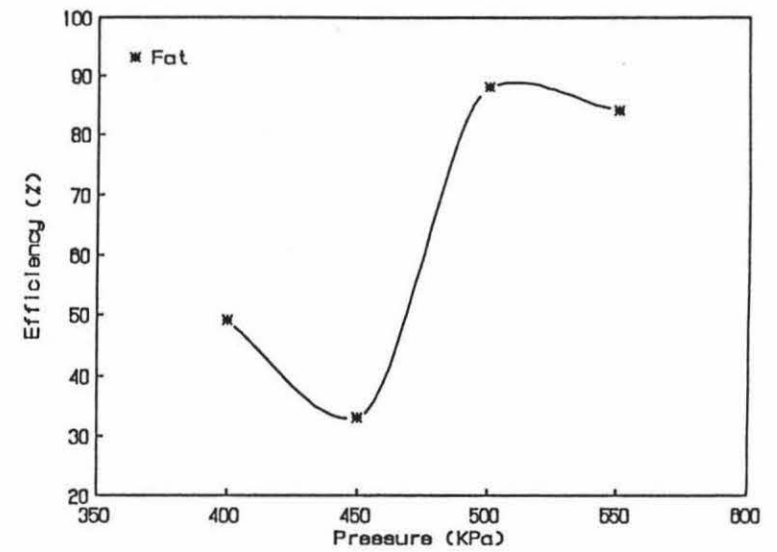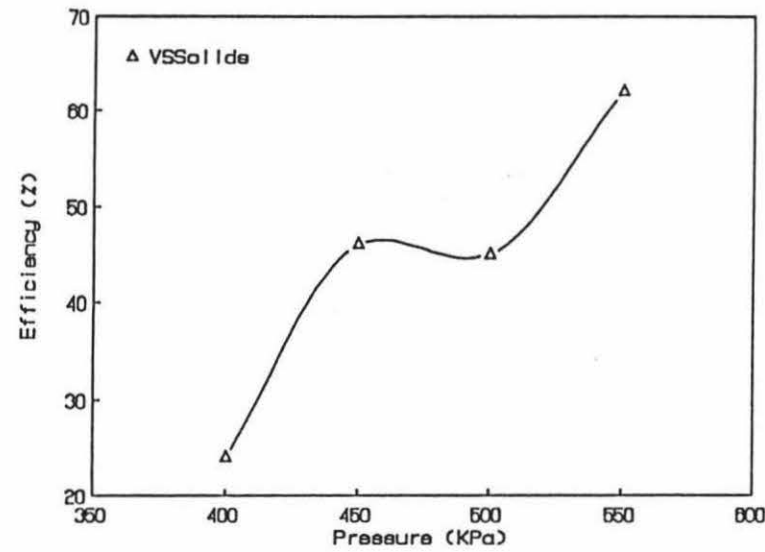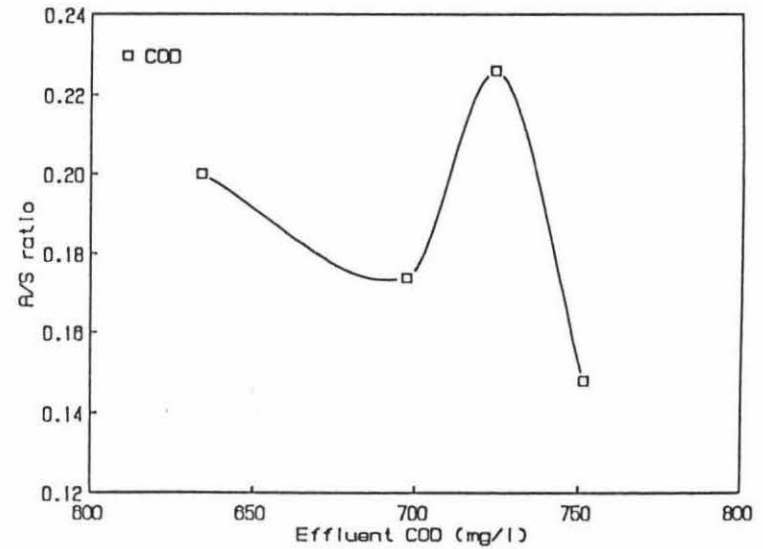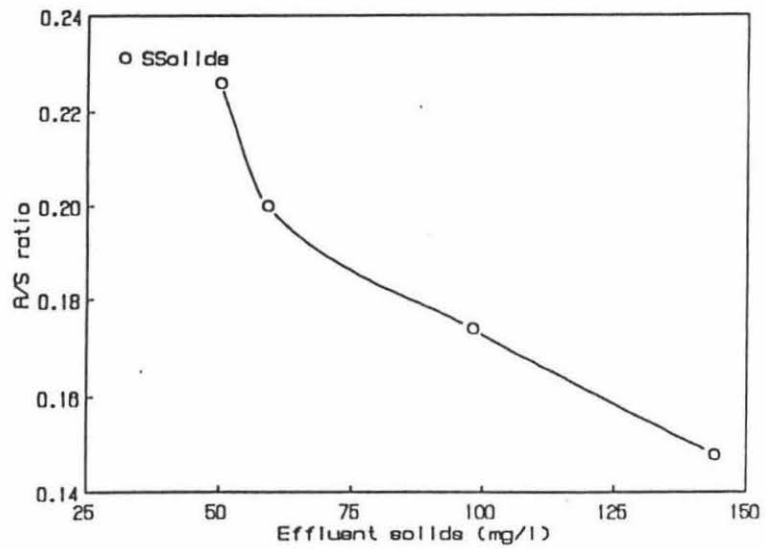Figure 4.9 The effect of A/S ratio on effluent concentration at pH 4.0, for SS, VSS, Fat and COD.

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Figure 4.10 The effect of pressure on efficiency at pH 4.0, for SS, VSS, Fat and COD.

Table 4.8 Summary of results at pH 5.0.

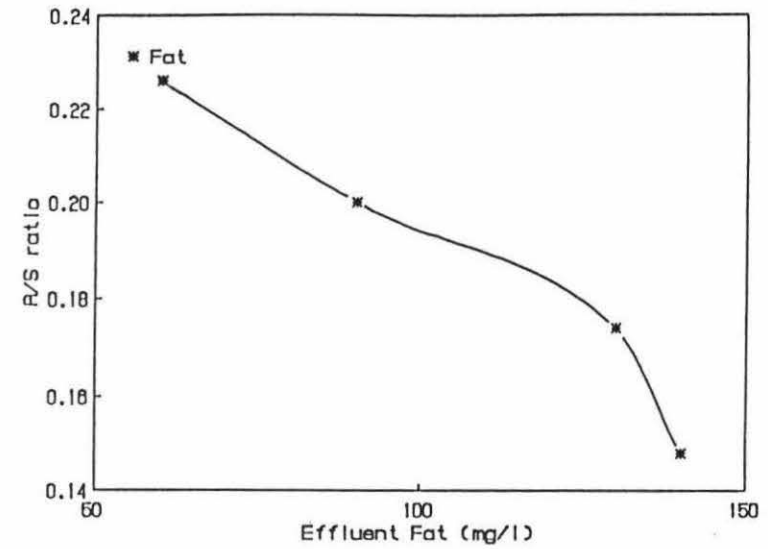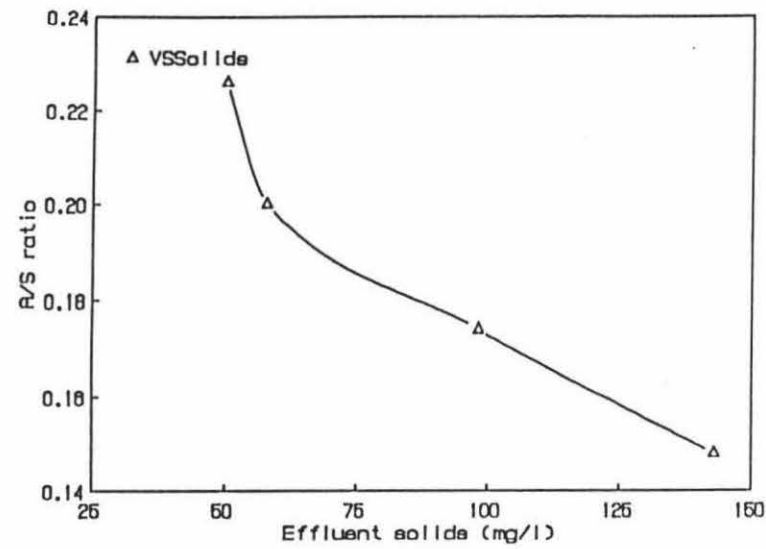| Parameter				
Pressure (kPa)	400	450	500	550
A/S Ratio	0.234	0.275	0.317	0.358
Influent SS (mg/l)	190	190	190	190
Effluent SS (mg/l)	147	99	128	101
Efficiency (%)	22	48	32	47
Influent VSS (mg/l)	189	189	189	189
Effluent VSS (mg/l)	147	99	128	100
Efficiency (%)	22	48	32	47
Influent Fat (mg/l)	510	510	510	510
Effluent Fat (mg/l)	450	300	270	250
Efficiency (%)	13	41	47	51
Influent COD (mg/l)	1155	1155	1155	1155
Effluent COD (mg/l)	1055	1014	938	978
Efficiency (%)	9	12	19	15

Figure 4.11 The effect of A/S ratio on effluent concentration at pH 5.0, for SS, VSS, Fat and COD.
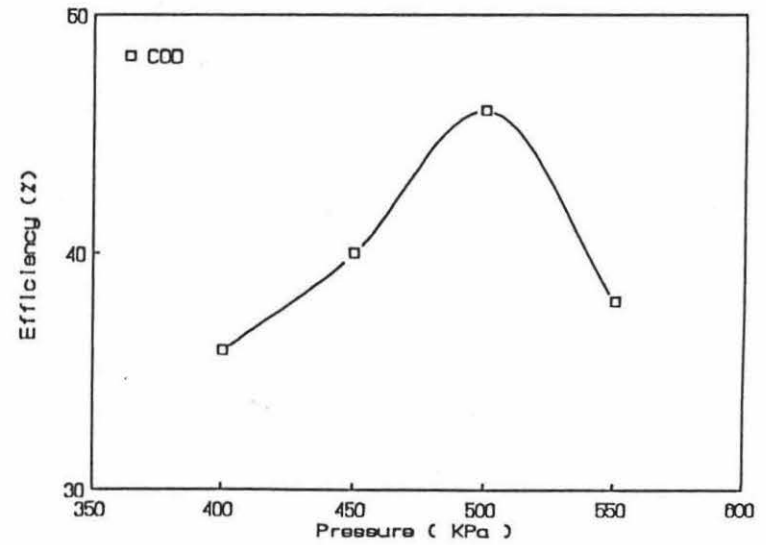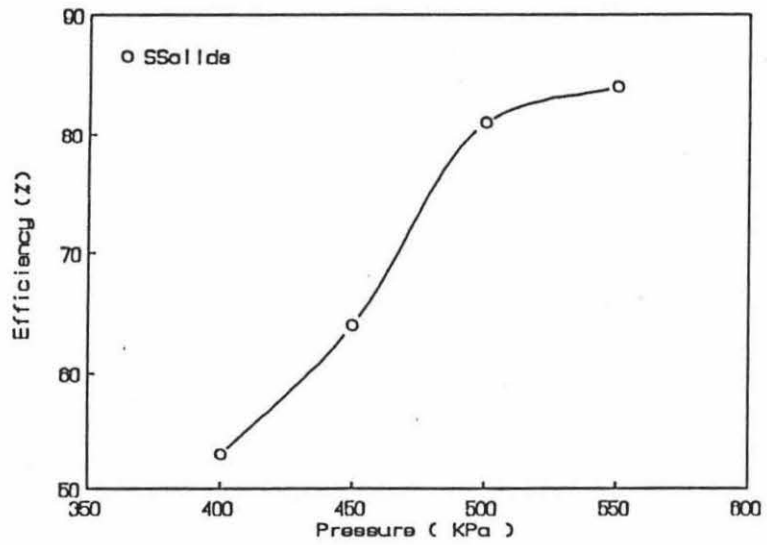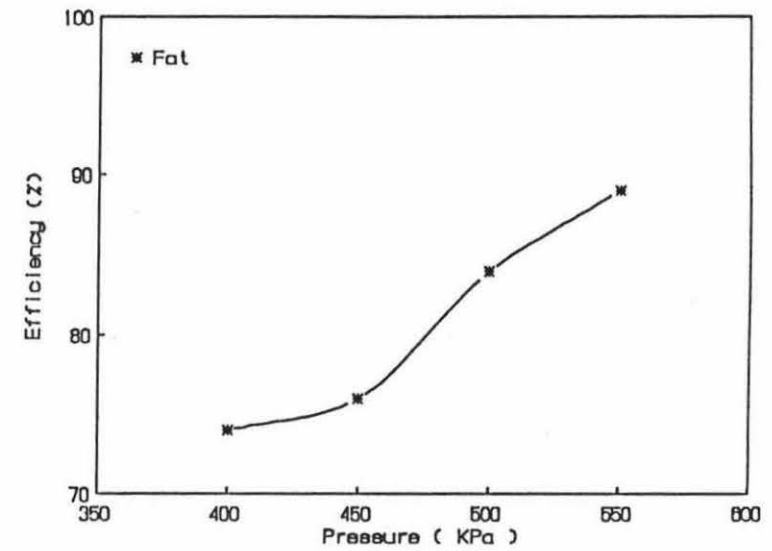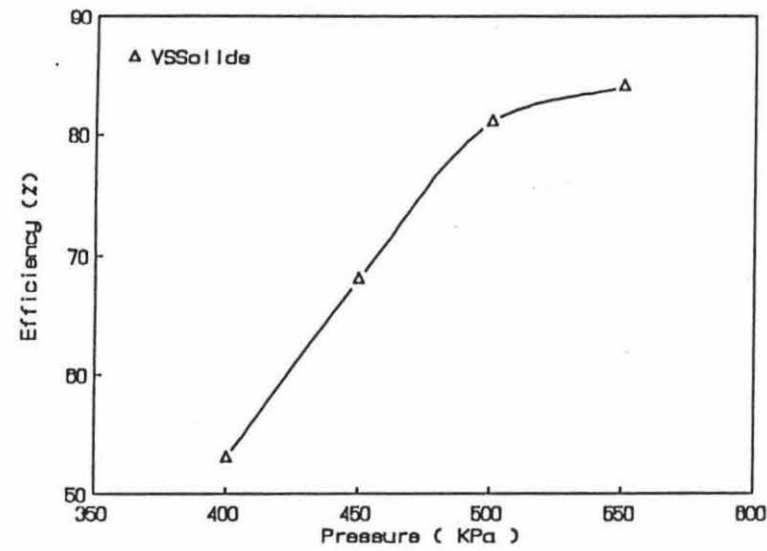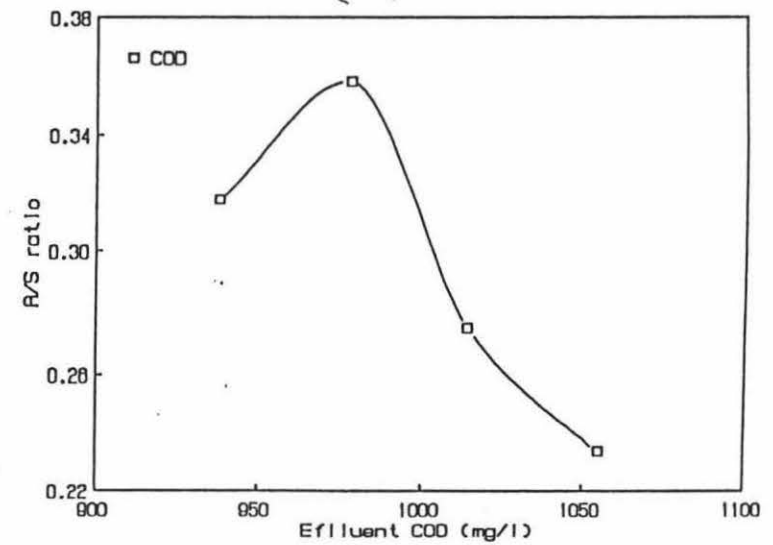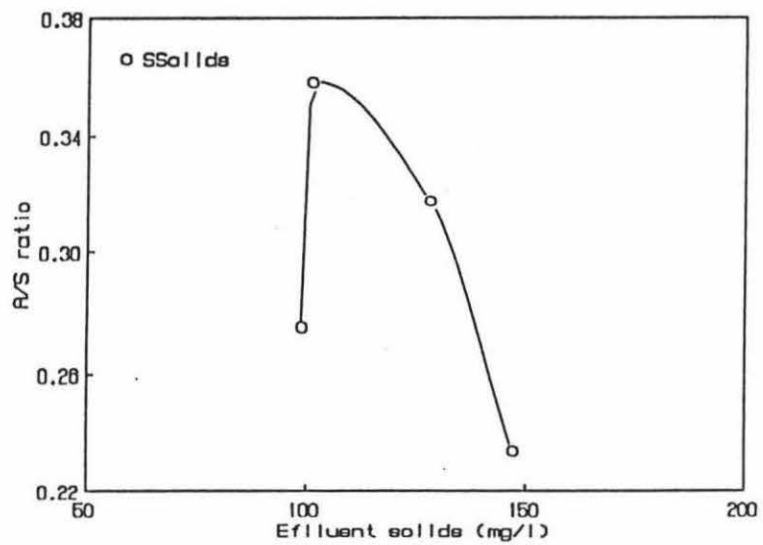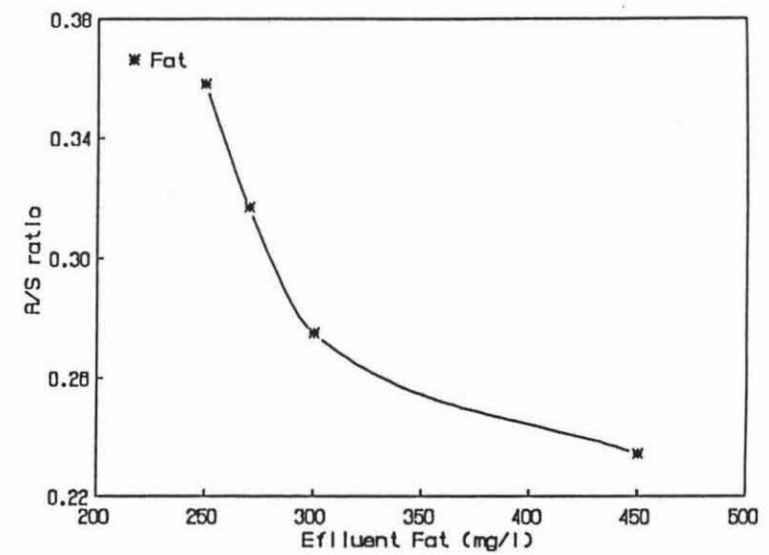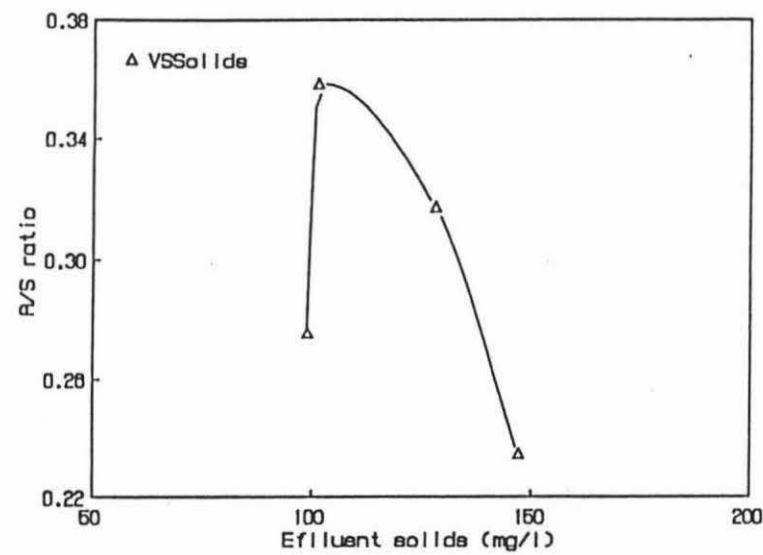
Figure 4.12 The effect of pressure on efficiency at pH 5.0, for SS, VSS, Fat and COD.

19%. Low COD removal could be due to the presence of butter component in the Type-II wastewater. This is evident as the COD removals in Type-I wastewater are comparatively higher. The results show similarity to the tests at same pH with Type-I wastewater.

4.4.4 DAF performance at pH 7

Results obtained from the experiments are presented in Table 4.9. As given in the table A/S ratio varied from 0.170 to 0.262. Inlet concentration of solids and fat was low compared to earlier tests. The effect of A/S ratio on effluent concentration is shown in Figure 4.13. From the figure it can be observed that effluent suspended solids and volatile solids is same at A/S ratio of 0.232 and 0.262. Effluent concentration decreased with increase in A/S ratio for both the parameters. Figure 4.13 also shows effluent COD concentration, but the removal is low i.e effluent concentration is high. It is similar to the results observed earlier with type II wastewater. Effluent fat concentration also decreased with increase in A/S ratio. Fat concentration reached a low of 55 mg/l at an A/S ratio of 0.232 and at pressure 500 kPa.

Figure 4.14 shows the effect of pressure on removal efficiency at pH 7.0. For suspended solids and volatile solids removal efficiency was same at pressures 500 and 550 kPa. Removal efficiency is low at 45 percent, this is shown in the figure. Comparatively COD removals are very low ranging from 15 to 24 percent, reaching a high of 24% at 500 kPa. Fat removal efficiencies were between 49 to 82 percent. But at pressure 500 kPa removal efficiency was optimum at 82%. This is lower than the efficiency achieved at pH 4.0 as shown in the figure.

4.4.5 Studies at pH 8

Studies at this pH were carried out to observe the changes in the characteristics of effluent because if further treatment like biological treatment is to be carried out, it would be useful to observe the changes after flotation. This is done keeping in view the

Table 4.9 Summary of results at pH 7.0.

Parameter				
Pressure (kPa)	400	450	500	550
A/S Ratio	0.170	0.202	0.232	0.262
Influent SS (mg/l)	260	260	260	260
Effluent SS (mg/l)	164	150	143	143
Efficiency (%)	37	42	45	45
Influent VSS (mg/l)	260	260	260	260
Effluent VSS (mg/l)	164	150	143	143
Efficiency (%)	37	42	45	45
Influent Fat (mg/l)	305	305	305	305
Effluent Fat (mg/l)	155	115	55	65
Efficiency (%)	49	62	82	79
Influent COD (mg/l)	1066	1066	1066	1066
Effluent COD (mg/l)	903	868	809	861
Efficiency (%)	15	19	24	19
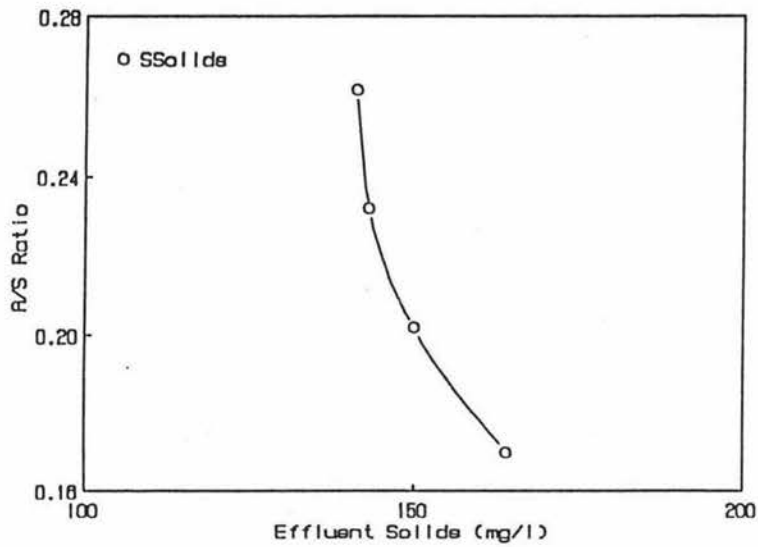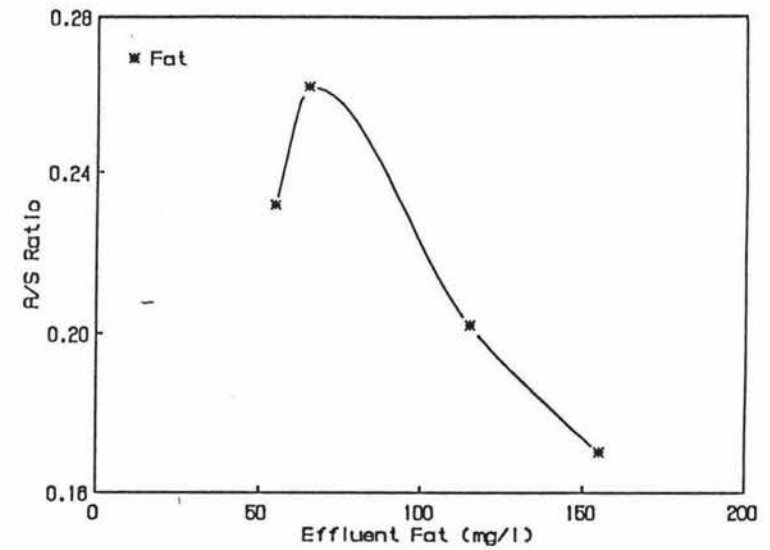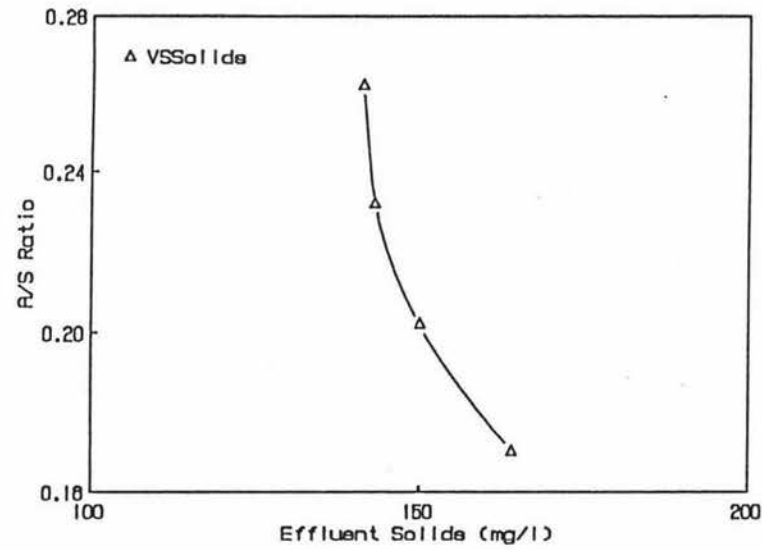
Figure 4.13 The effect of A/S ratio on effluent concentration at pH 7.0, for SS, VSS, Fat and COD.
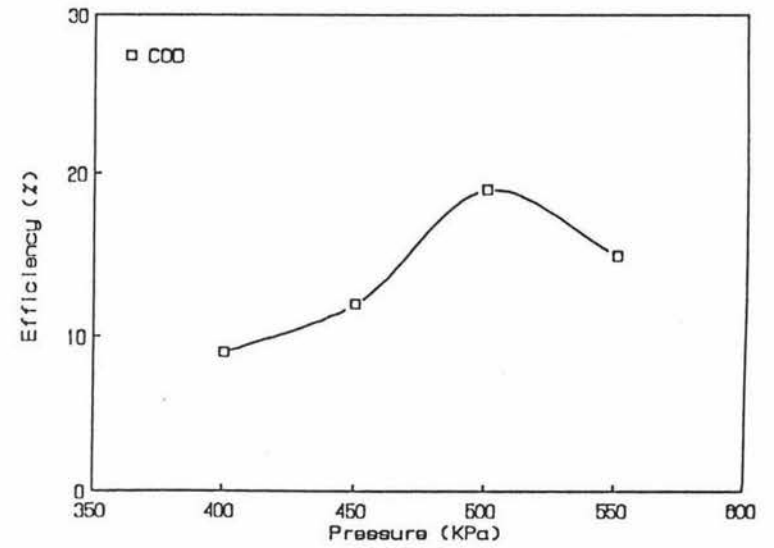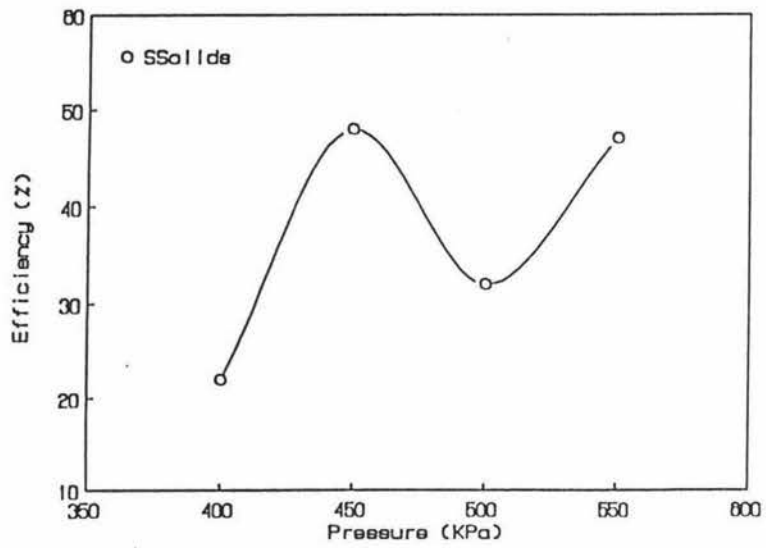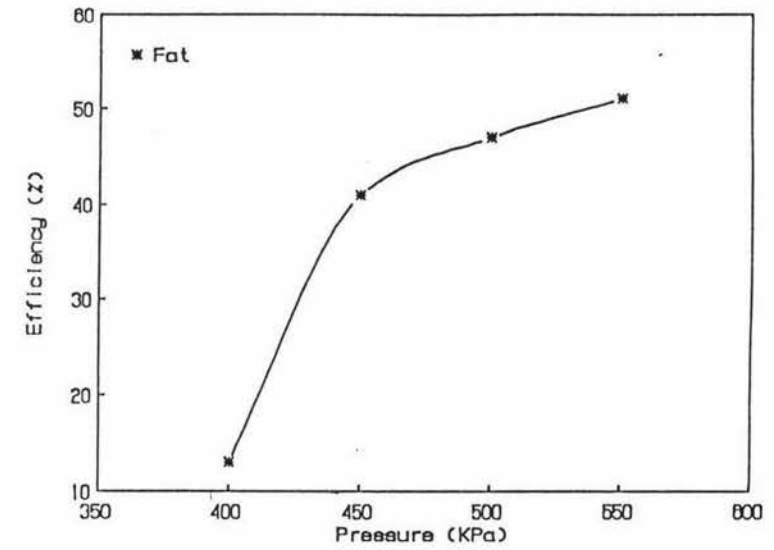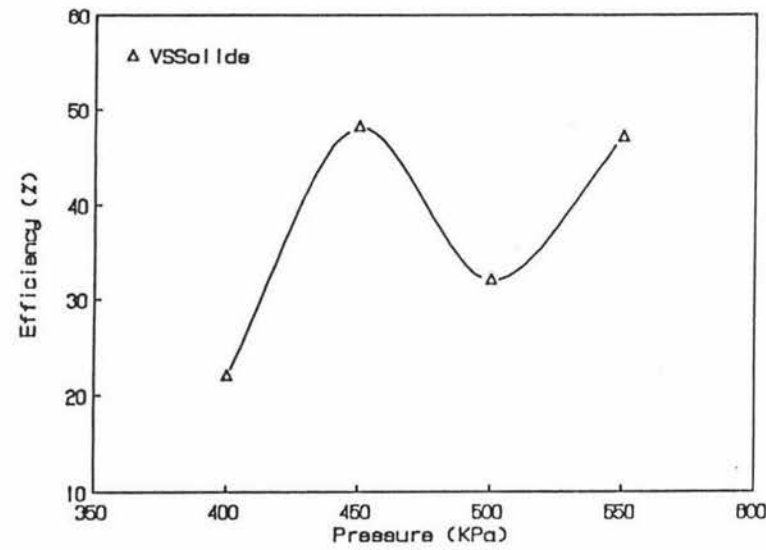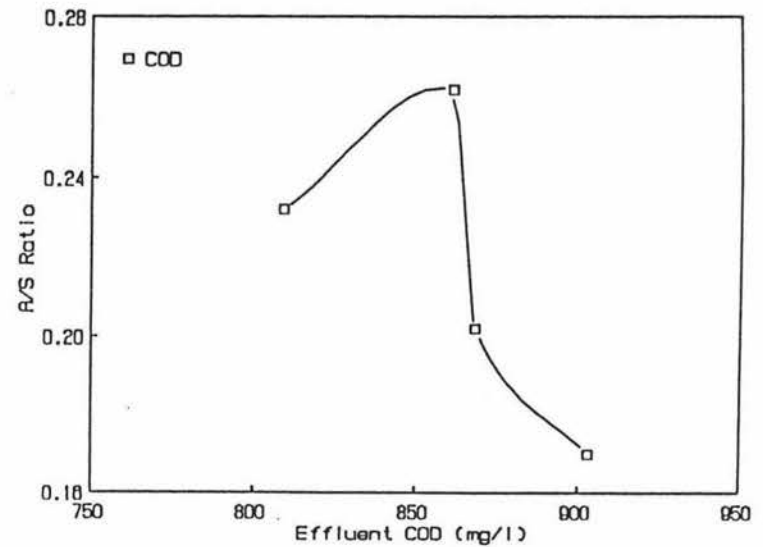
Figure 4.14 The effect of pressure on efficiency at pH 7.0, for SS, VSS, Fat and COD.

optimum pH for biological treatment which is between 6.5 and 8.5.

Results of the flotation experiments at pH 8 are presented in Table 4.10. The effect of A/S ratio on effluent concentration and the effect of pressure on efficiency are given in Figures 4.15 and 4.16 respectively. Suspended solids and volatile solids concentration decreased with increase in A/S ratio as before. Optimum removal was achieved at an A/S ratio of 0.250 and pressure 500 KPa. The removal efficiency was 71% at this pressure. COD removals are in general less but compared to the results at pH 7.0, they are more. Effluent COD concentration decreased with increase in A/S ratio, as shown in the figure. Fat removals were lower than at pH 7.0, and ranged from 38 to 57 percent between pressures 400 and 550 kPa. Optimum efficiency being at a pressure of 550 kPa and at an A/S ratio of 0.283. The removal efficiencies at pH 8.0, were lower compared to the efficiencies at pH 7.0, for all the parameters except COD.

After carrying out the pH studies and observing the trend, the effect of pH on efficiency at a pressure of 500 kPa is plotted and is shown in Figure 4.17 for all the parameters studied.

4.5 Conclusions from the pH effects

Changing the pH had remarkable influence on the flotation performance. The removal efficiency varied with change in pH. Higher removal efficiencies were obtained when the pH was changed to 4. This could be due to coagulation and precipitation of solids and fat as isoelectric point of fat and protein is around 4. This effect was observed for both types of wastewater.

Studies at pH 5 indicated that flotation is not effective at this pH as the observed removal efficiencies were low. This pH may be a transition pH as it nears the isoelectric pH of protein. The colloids (Bubble-particle agglomerates) may not be strongly adhered to each other thus causing the break down of bubble-particle attachment. The float formed at this pH for various pressures was not stable.

Table 4.10 Summary of results at pH 8.0.

| Parameter				
Pressure (kPa)	400	450	500	550
A/S Ratio	0.184	0.217	0.250	0.283
Influent SS (mg/l)	241	241	241	241
Effluent SS (mg/l)	111	90	69	77
Efficiency (%)	54	63	71	68
Influent VSS (mg/l)	240	240	240	240
Effluent VSS (mg/l)	111	90	69	77
Efficiency (%)	54	63	71	68
Influent Fat (mg/l)	513	513	513	513
Effluent Fat (mg/l)	317	263	253	223
Efficiency (%)	38	49	51	57
Influent COD (mg/l)	1150	1150	1150	1150
Effluent COD (mg/l)	942	885	768	737
Efficiency (%)	18	23	33	36
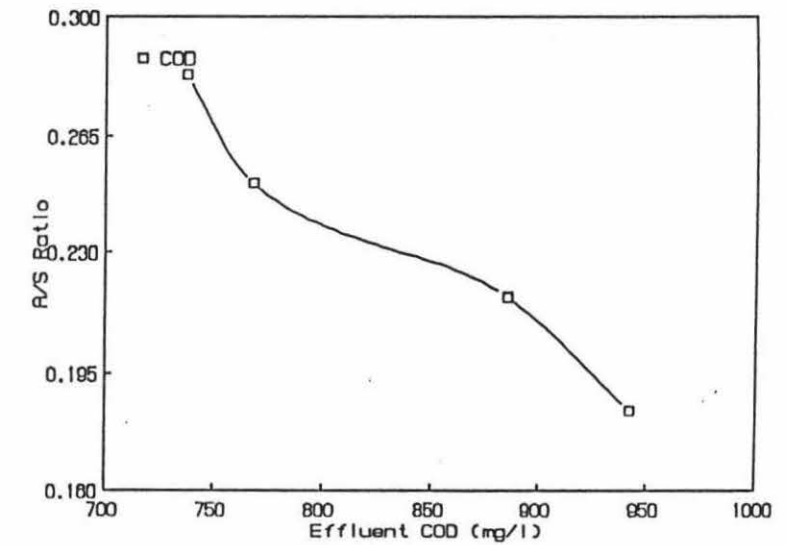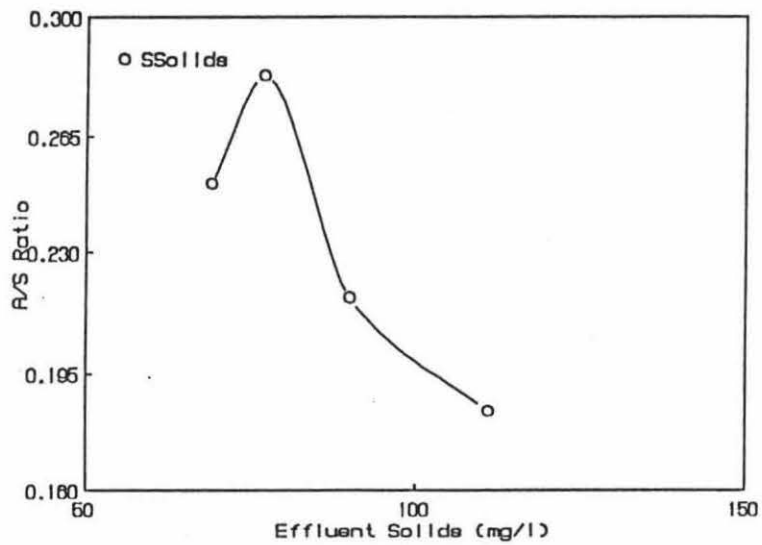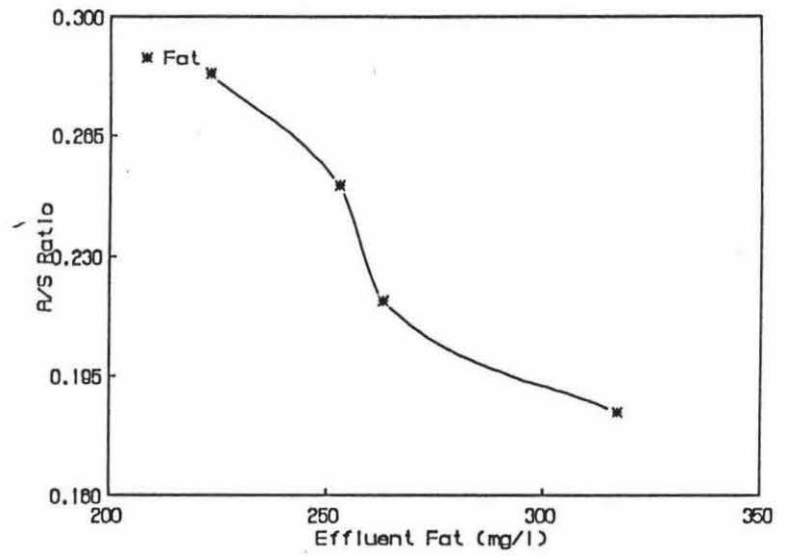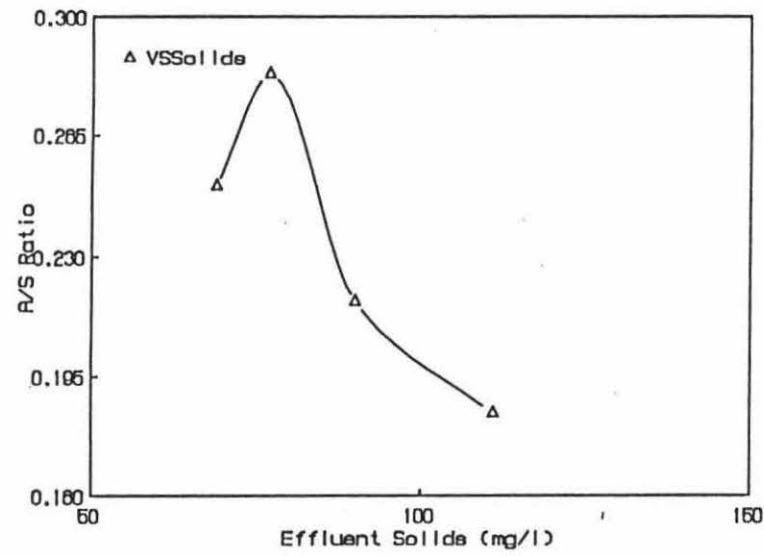
Figure 4.15 The effect of A/S ratio on effluent concentration at pH 8.0, for SS, VSS, Fat and COD.
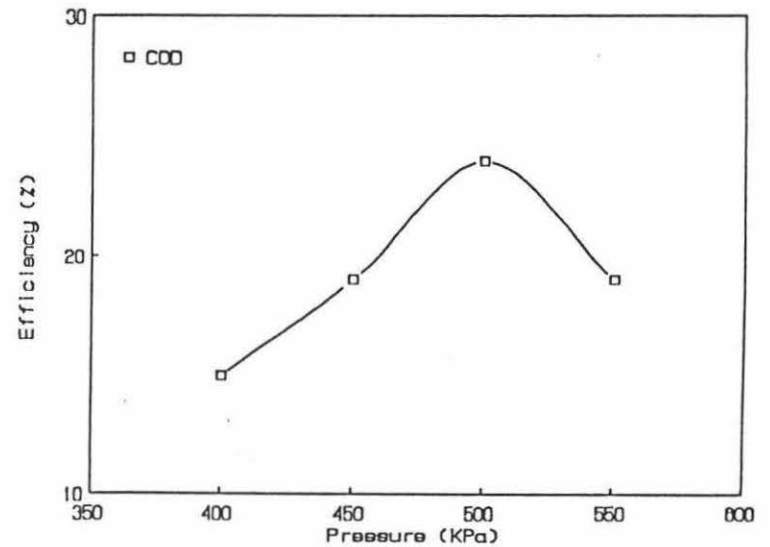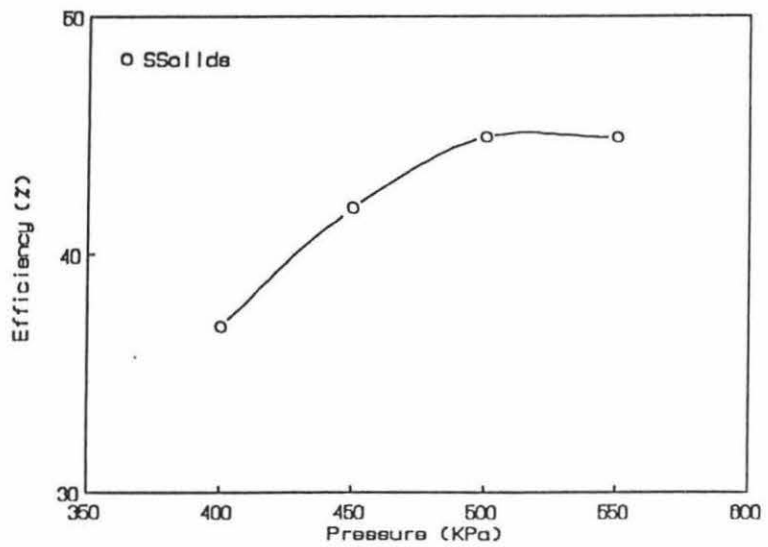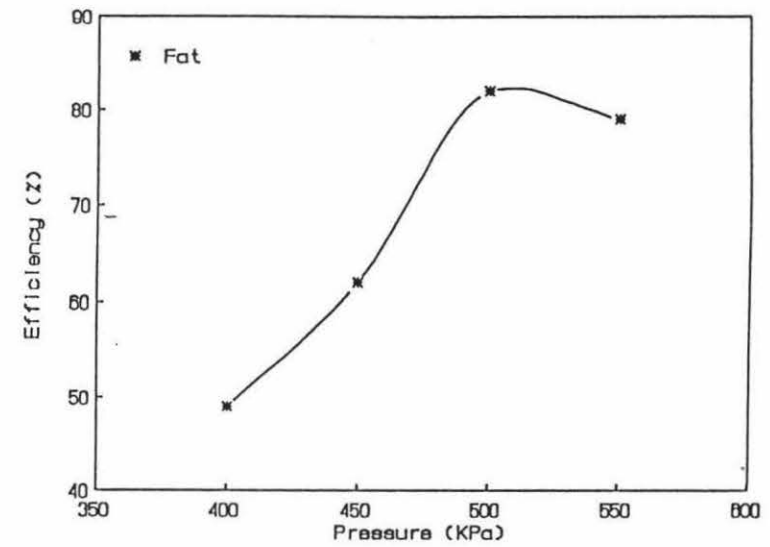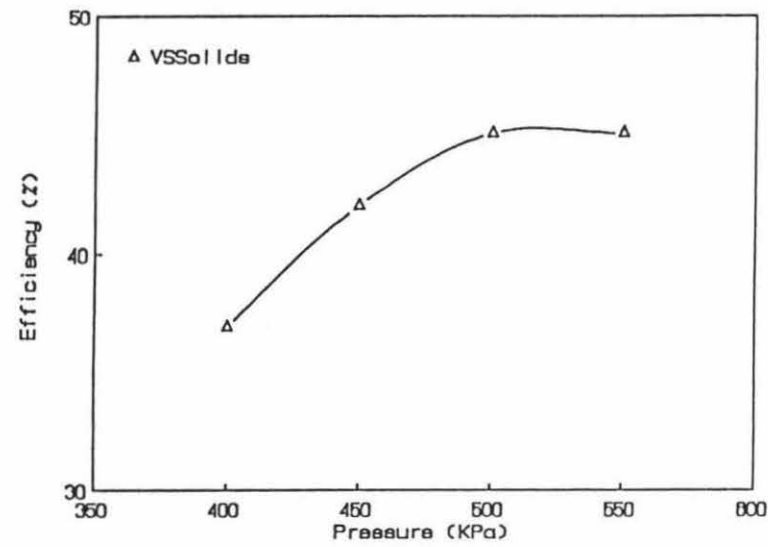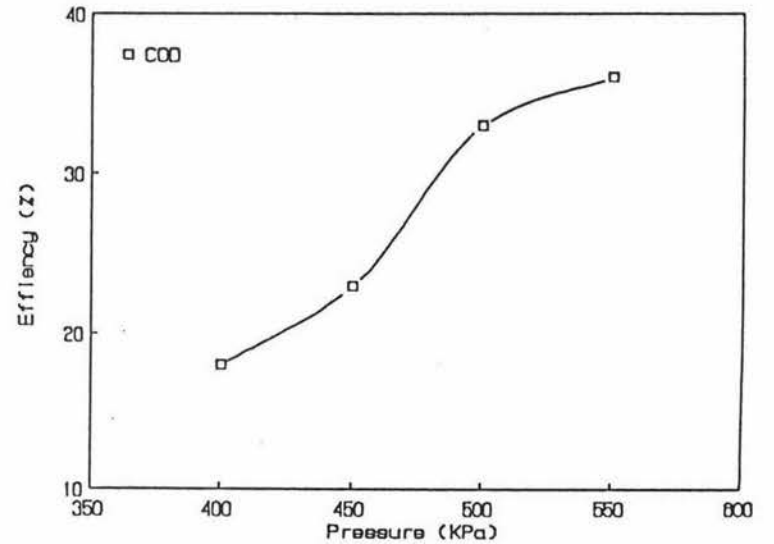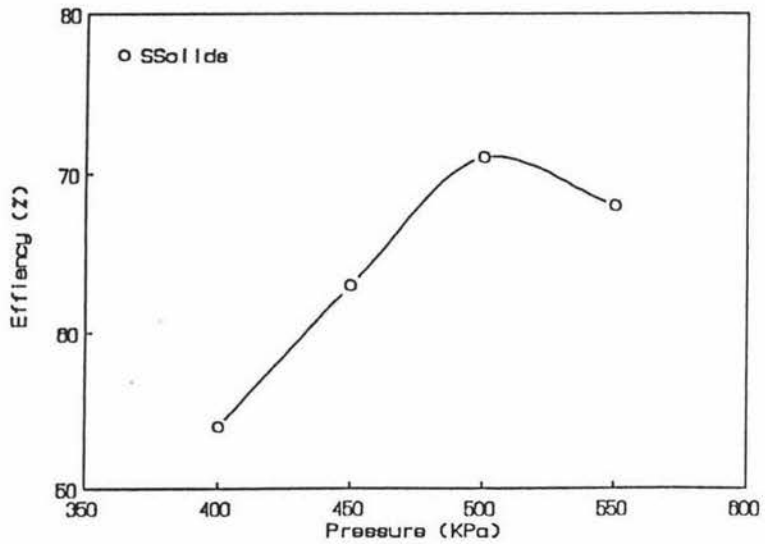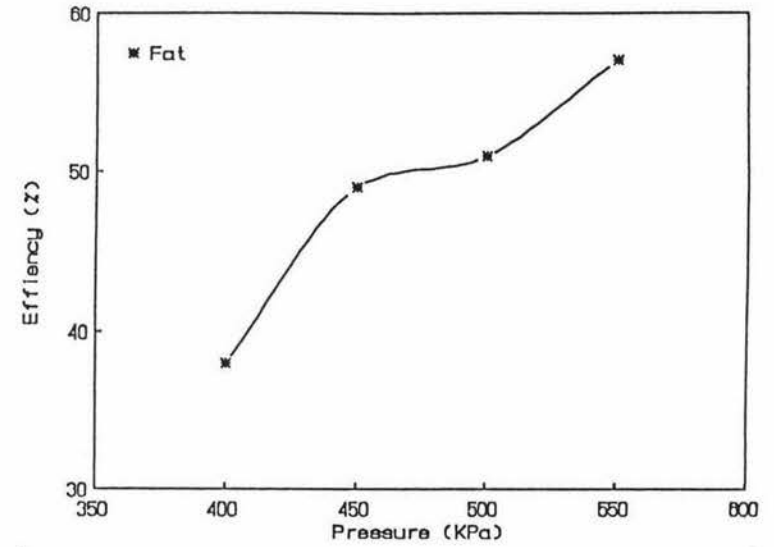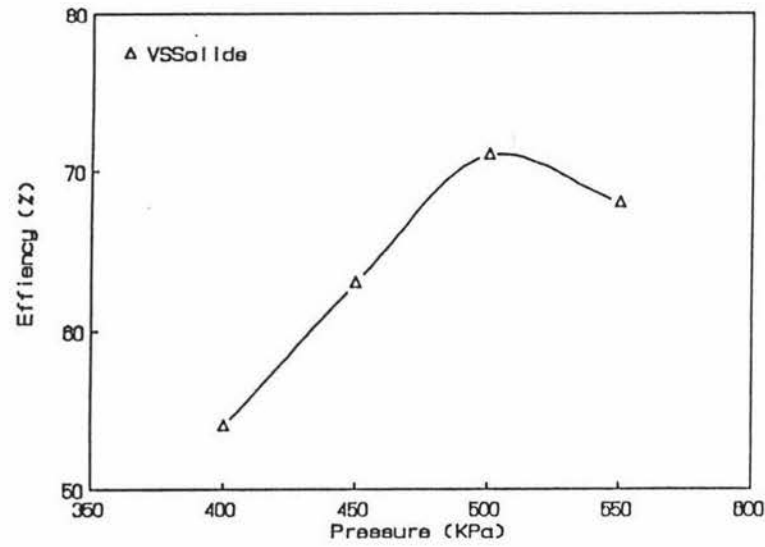
Figure 4.16 The effect of pressure on efficiency at pH 8.0, for SS, VSS, Fat and COD.
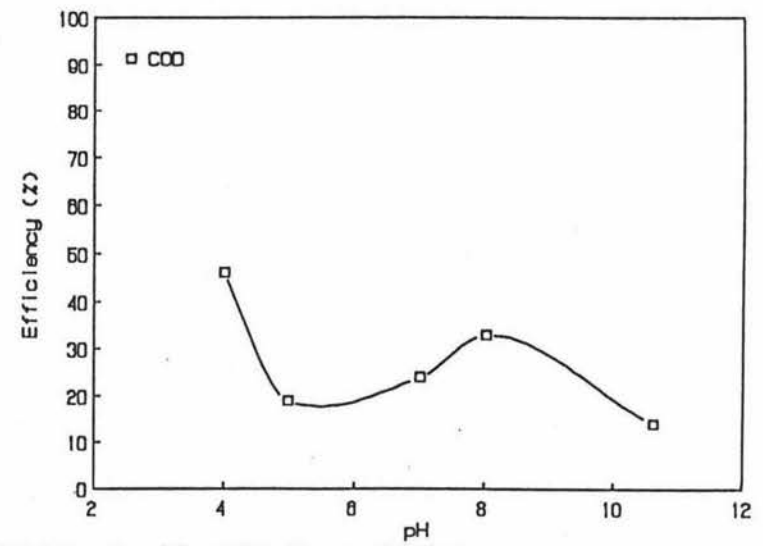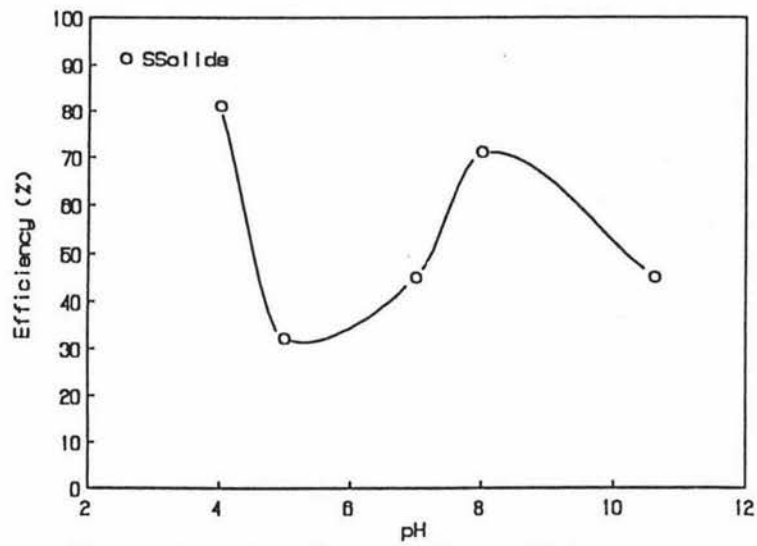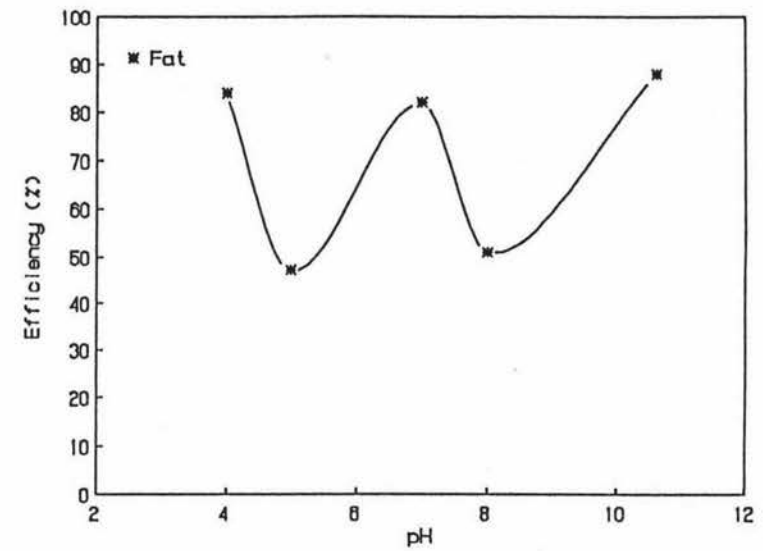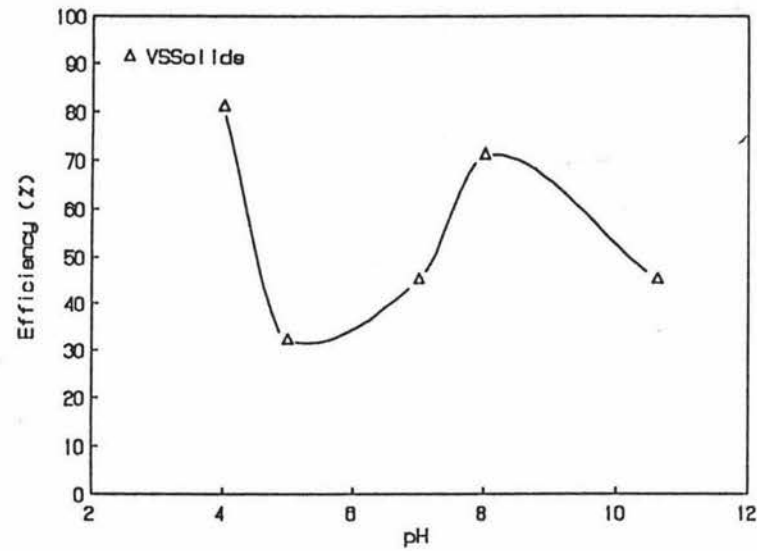
Figure 4.17 The effect of pH on efficiency at pressure 500 kPa, for SS, VSS, Fat and COD.

Flotation experiments at pH 7 and 8 indicated the process efficiency to be average. But the efficiencies were higher compared to that of pH 5. But neutral pH is suitable for further treatment with coagulant alum (Anderson, 1984). Of all the pHs studied flotation performance is superior at pH 4 but if further biological treatment is to be carried out this pH is not suitable. Again pH adjustment with lime is necessary, which is not economical.

4.6 Effect of changes in Temperature on Flotation
4.6.1 Introduction

Temperature is an important parameter which influences the process of flotation. Air solubility decreases with increase in temperature (Eckenfelder, 1989). At higher temperatures the bubbles are deformed and take an elliptical shape thus inhibiting the formation of bubble particle attachment (Shannon and Buisson, 1980). The temperature of the wastewater from the dairy industry is fairly high because of the process involved in the manufacture of milk and other products.

The present work was carried out to assess the effects of temperature on the performance of flotation. In all flotation performance was observed at three different temperatures. The temperatures at which flotation testes were carried out are 25° C and 34° C and 48° C. Performance of flotation was observed at these temperatures at two pHs namely 7 and 8. After observing the trends it is decided to carry out studies at a temperature of 48° C at a pressure of 500 kPa and pH of 7.0.

4.6.2 Effect of Temperature on flotation performance at 25° C

The wastewater was heated in a water bath till the desired temperature was attained. The liquid was constantly stirred in the water bath. pH of the liquid was adjusted before heating. During heating of the wastewater floatable fat was formed as globules in the water bath. For each trial, a quantity of 400 ml wastewater was pressurised in the pressure cylinder.

4.6.2.1 Flotation studies at pH 7

Results of the flotation experiments at pH 7 and temperature 25°C are presented in Table 4.11. Suspended solids concentration is higher in this wastewater as this waste was collected again when the earlier wastewater was over. The variation in concentrations could be due to changes in production in the plant.

Figure 4.18 shows the effect of A/S ratio on effluent concentration for the parameters suspended solids and fat. A/S ratio varied from 0.063 to 0.097 between pressures 400-550 kPa. Lowest effluent solids concentration was obtained at A/S ratio of 0.097 at pressure 550 kPa. Similar trend was observed for volatile solids. Effluent fat concentration also decreased with increase in A/S ratio, lowest being at 0.097. Fat removal was as expected but in comparison, suspended solids removal was almost same at pressures 400 and 500 kPa and increased again as the pressure is increased to 550 kPa. Effluent COD concentrations were high, indicating a similar trend observed earlier.

The influence of pressure on removal efficiency is shown in Figure 4.19 Optimum removal for solids and fat was 82% and 77% at a pressure of 550 kPa. The difference in removal efficiency at pressures 450 and 500 kPa is not significant. As observed earlier with experiments on effect of changes in pH, COD removal efficiencies are very low, ranging from 10-19%. The low COD removals could be due to the characteristics of wastewater. There could be some other factor contributing to the oxygen demand apart from solids and fat.

When the results are compared with the results of flotation studies at pH 7.0, it can be observed that solids removal efficiency is higher. Fat removal is similar at pH 7. Even though solids concentration is high when compared to solids concentration at pH 7, their removal is also high. This could be due to improved air solubility. This agrees with the findings of Malley and Edzwald (1991), who observed that process performance is better at temperature of 22° C when flotation was carried out on waters containing algae.

Table 4.11 Summary of results at pH 7.0 and Temparature 25° C

Parameter				
Pressure (kPa)	400	450	500	550
A/S Ratio	0.063	0.075	0.085	0.097
Influent SS (mg/l)	563	563	563	563
Effluent SS (mg/l)	199	130	134	100
Efficiency (%)	65	77	76	82
Influent VSS (mg/l)	561	561	561	561
Effluent VSS (mg/l)	199	130	134	100
Efficiency (%)	65	77	76	82
Influent Fat (mg/l)	405	405	405	405
Effluent Fat (mg/l)	185	135	110	95
Efficiency (%)	54	67	73	77
Influent COD (mg/l)	1225	1225	1225	1225
Effluent COD (mg/l)	1105	1044	998	995
Efficiency (%)	10	15	19	19
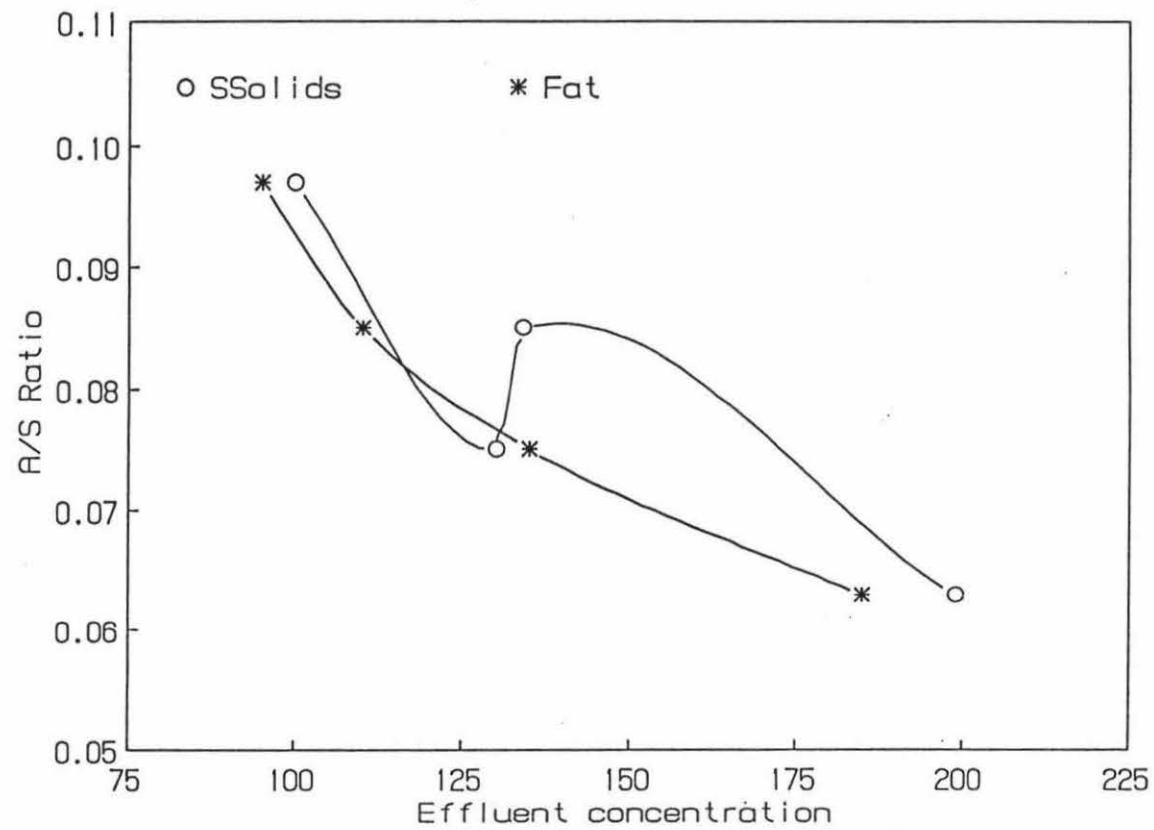
Figure 4.18 The effect of A/S ratio on effluent concentration at pH 7.0 and temperature 25 ° C, for SS, and Fat.

Figure 4.19 The effect of pressure on efficiency at pH 7.0 and temperature 25° C, for SS and Fat.

4.6.2.2 pH 8

The results of the experiments carried out at temperature at 25° C and pH 8.0 are presented in Table 4.12. The effect of A/S ratio on effluent suspended solids and fat and the effect of pressure on efficiency for solids and fat are shown in Figures 4.20 and 4.21 respectively.

From Figure 4.21 it can be observed that removal efficiency is same at pressures 500 and 550 kPa. A/S ratio was 0.088 and 0.099 for these two pressures. Effluent suspended solids concentration decreased with increase in A/S ratio. The difference in effluent concentration at pressures 500 and 550 kPa was negligible. Effluent fat concentration decreased with increase in pressure upto 500 kPa but increased when the pressure was raised to 550 kPa. This could be because of shearing effects at higher pressures inhibiting attachment between fat and solids particles. Maximum fat removal of 85% was achieved at pressure 500 kPa. COD removal efficiencies are low varying from 15 to 18 %, which are similar to the earlier observations.

When these results are compared with results at pH 8.0, the removal efficiencies are better for solids and fat. But COD removal efficiencies are less. A/S ratios are also low in comparison. This is due to the fact that inlet concentration of the solids is more in the present case.

4.6.3 Studies at Temperature 34° C

Experiments at this temperature were carried out to determine whether there is any change in the flotation characteristics of the waste. Wastewater was heated to the desired temperature before experiments. Experiments with two pHs were carried out at this temperature similar to earlier experiments (Section 4.6.2)

Table 4.12 Summary of results at pH 8.0 and Temparature 25° C

| Parameter				
Pressure (kPa)	400	450	500	550
A/S Ratio	0.065	0.076	0.088	0.099
Influent SS (mg/l)	548	548	548	548
Effluent SS (mg/l)	155	129	106	105
Efficiency (%)	72	76	81	81
Influent VSS (mg/l)	546	546	546	546
Effluent VSS (mg/l)	155	130	106	106
Efficiency (%)	72	76	81	81
Influent Fat (mg/l)	410	410	410	410
Effluent Fat (mg/l)	275	250	60	145
Efficiency (%)	33	39	85	65
Influent COD (mg/l)	1225	1225	1225	1225
Effluent COD (mg/l)	1041	1051	1006	1002
Efficiency (%)	15	14	18	18
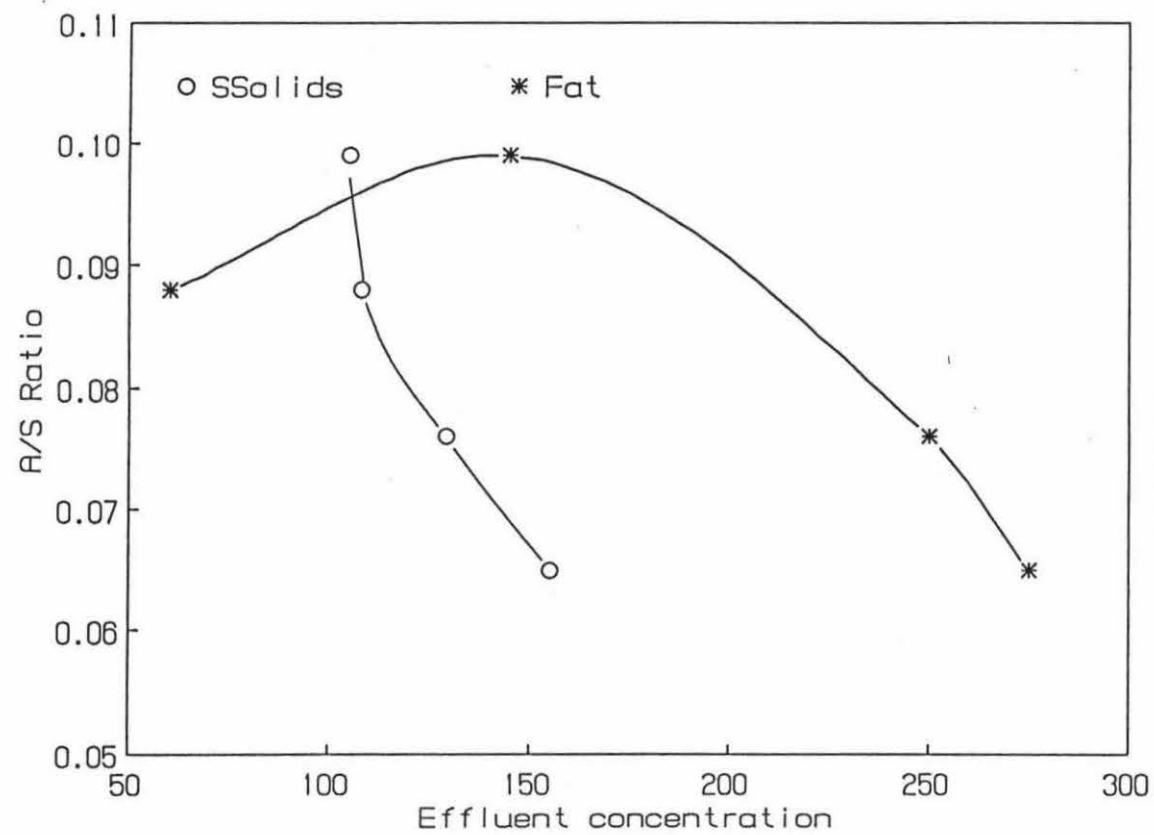
Figure 4.20 The effect of A/S ratio on effluent concentration at pH 8.0 and temperature 25° C, for SS and Fat.
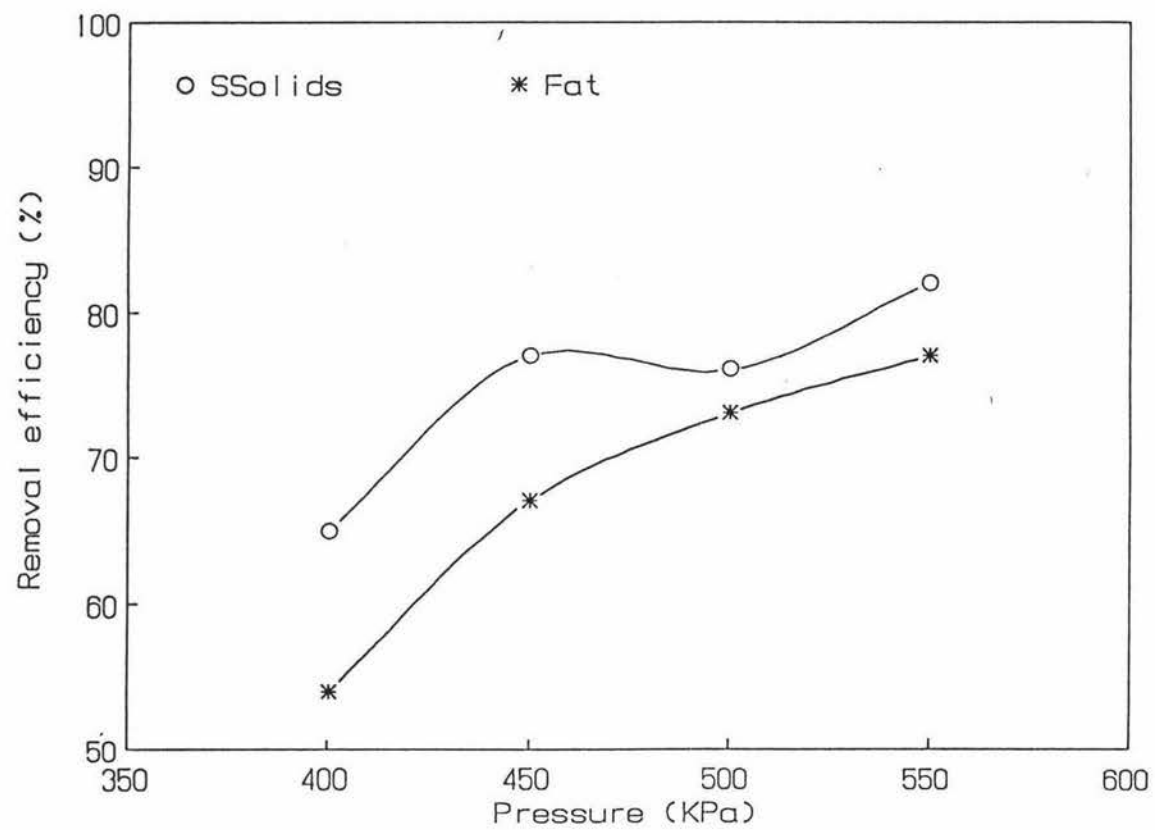
<u>Figure 4.21</u> The effect of pressure on efficiency at pH 8.0 and temperature 25° C, for SS and Fat.

4.6.3.1 pH 7

Results of the flotation experiments at pH 7.0 are shown in Table 4.13. A/S ratio varied from 0.070 to 0.106 between pressures 400 and 550 kPa. Figure 4.22 shows the effect of A/S ratio on effluent concentration for the parameters solids and fat. Effluent solids concentration decreased with increase in A/S ratio upto 0.095 at pressure 500 kPa and increased again at A/S ratio of 0.106 at pressure 550 kPa. Volatile suspended solids variation also showed similar trends. On the other hand effluent COD concentrations were high and change in A/S ratio has little effect. High effluent concentrations of COD may be the effect temperature. Effluent fat concentration varied between 160 and 105 mg/l between A/S ratios 0.070 and 0.106. Effluent fat concentration was similar at pressures 450 and 550 kPa. Lowest fat concentration was obtained at an A/S ratio of 0.106.

Figure 4.23 shows the effect of pressure on efficiency. Removal efficiency for solids increased with increase in pressure up to 500 kPa, where optimum of 85% was achieved. Effluent COD removals are quite low. Maximum removal is only 4%. The low COD removals could be due to increase in temperature or could be due to the contribution of some other characteristic of wastewater component other than solids and fat. The variation in COD removals is very little with increase in pressure. Fat removal varied between 60 to 74% with increase in pressure from 400 to 550 kPa. At pressure 450 kPa 73% fat was removed, which is same as the removal efficiency obtained at 550 kPa.

4.6.3.2 pH 8

Experiments were also carried out at pH 8.0 at this temperature as explained in the previous section. Results of the flotation studies are presented in table 4.14. A/S ratio for this experiments varied from 0.082 to 0.125. Effluent concentration of solids decreased with increase in A/S ratio upto 0.111 and increased again thereafter. This is similar to the results obtained at pH 7.0 and same temperature. At an A/S ratio of 0.111

Table 4.13 Summary of results at pH 7.0 and Temparature 34° C

| Parameter				
Pressure (kPa)	400	450	500	550
A/S Ratio	0.070	0.082	0.095	0.106
Influent SS (mg/l)	453	453	453	453
Effluent SS (mg/l)	170	154	70	86
Efficiency (%)	62	66	85	81
Influent VSS (mg/l)	451	451	451	451
Effluent VSS (mg/l)	170	156	70	85
Efficiency (%)	62	65	84	81
Influent Fat (mg/l)	400	400	400	400
Effluent Fat (mg/l)	160	110	145	105
Efficiency (%)	60	73	64	74
Influent COD (mg/l)	1205	1205	1205	1205
Effluent COD (mg/l)	1170	1162	1160	1147
Efficiency (%)	3	4	4	6

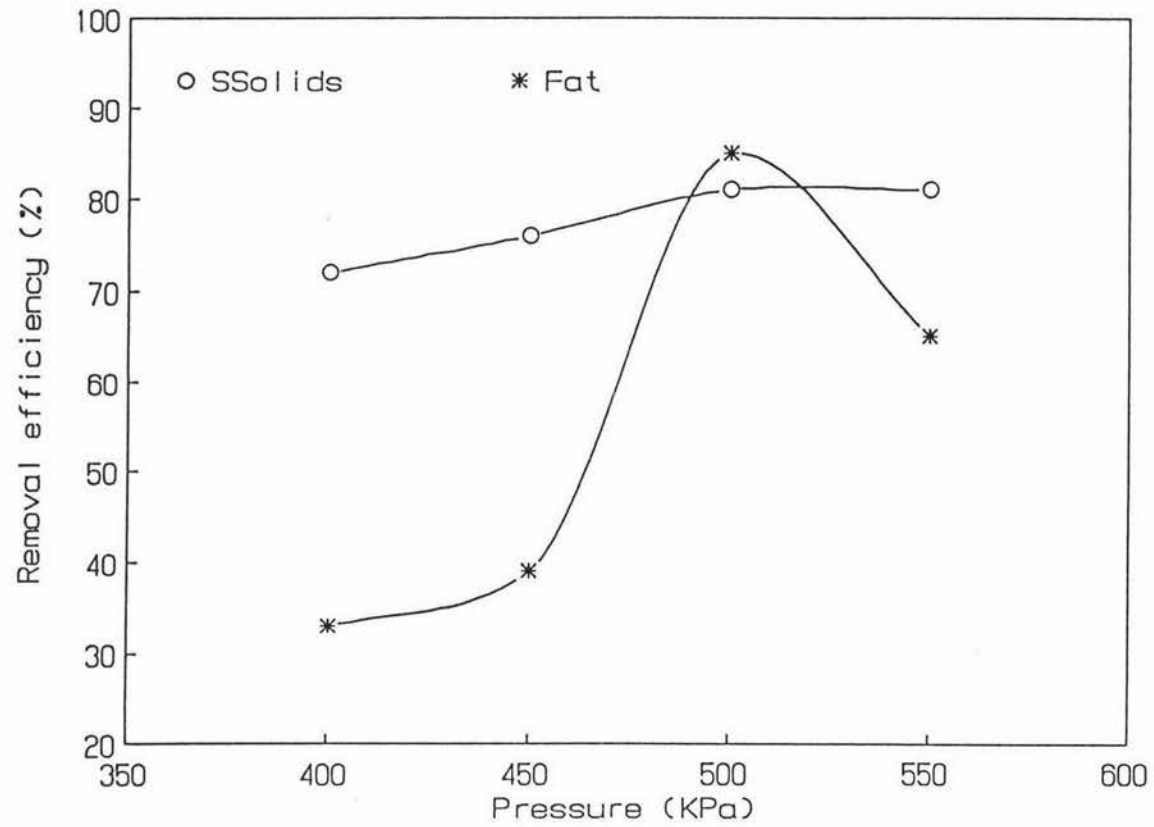Figure 4.22 The effect of A/S ratio on effluent concentration at pH 7.0 and temperature 34° C, for SS and Fat.

Figure 4.23 The effect of pressure on efficiency at pH 7.0 and temperature 34° C, for SS and Fat.

Table 4.14 Summary of results at pH 8.0 and Temparature 34° C

Parameter				
Pressure (kPa)	400	450	500	550
A/S Ratio	0.082	0.096	0.111	0.125
Influent SS (mg/l)	383	383	383	383
Effluent SS (mg/l)	174	114	55	69
Efficiency (%)	55	70	86	82
Influent VSS (mg/l)	379	379	379	379
Effluent VSS (mg/l)	174	117	54	68
Efficiency (%)	54	69	86	82
Influent Fat (mg/l)	405	405	405	405
Effluent Fat (mg/l)	135	90	65	70
Efficiency (%)	67	78	84	83
Influent COD (mg/l)	1177	1177	1177	1177
Effluent COD (mg/l)	1161	1125	1101	1095
Efficiency (%)	1	4	6	7

maximum removal efficiency of 86% was obtained for suspended solids. Similar trend was observed for the volatile solids. Effluent COD concentration is high therefore removal efficiencies are very low. Maximum of 7% being at pressure 550 kPa. Maximum fat removal of 84% was obtained at pressure 500 kPa. Similar removal was obtained at pressure 550 kPa. Effluent solids and fat concentrations showed similar trends with change in A/S ratio. The effect of A/S ratio on effluent concentration is shown in Figure 4.24 and the effect of pressure on efficiency is shown in Figure 4.25.

Flotation studies at this pH and temperature indicated that the removal efficiencies are better compared to the tests carried out at the same temperature and pH 7.

4.6.4 Studies at Temperature 48° C

After observing the trends in removal efficiency in flotation tests at temperatures 25° C and 34° C, it was decided to examine the flotation characteristics at a higher temperature and at pH 7. Wastewater from the plant is also discharged at similar temperature. As optimum removal efficiency was obtained at a pressure 500 kPa in earlier tests, present tests were carried out at this pressure.

Wastewater was heated in a water bath as explained in Section 4.6.2. It was observed that fat tended to solubilise when heated to this temperature. This was not the case when studies were carried out at lower temperatures. Results of the experiments are presented in Table 4.15.

From the table it can be seen that the efficiencies are rather low. For suspended solids and volatile solids the efficiency was 50% and for fat it was 42 %. Effluent COD concentration was also very low at 13 %. A/S ratio was 0.050. Low efficiencies could be due to less air dissolution as the temperature is high (Eckenfelder, 1989). Another reason could be, at higher temperatures bubbles tend to coalesce rapidly taking elliptical shape initially (Shannon and Buisson, 1980).
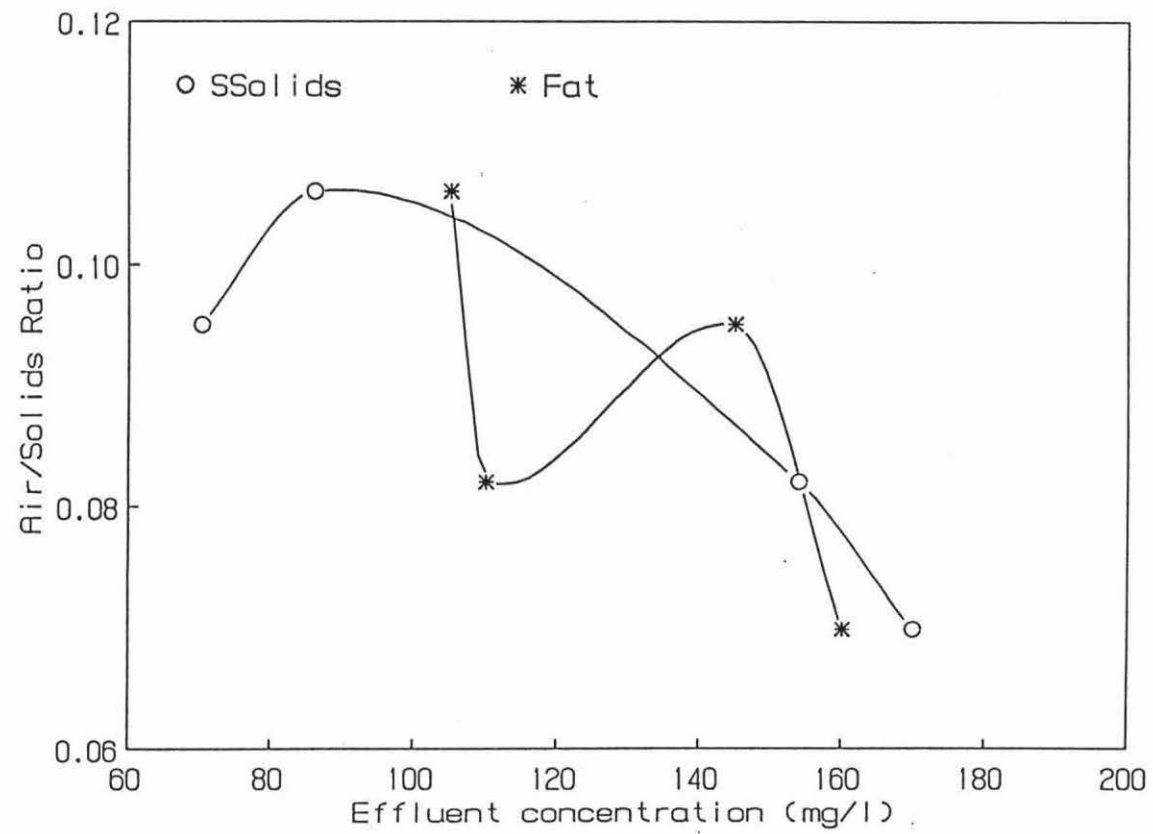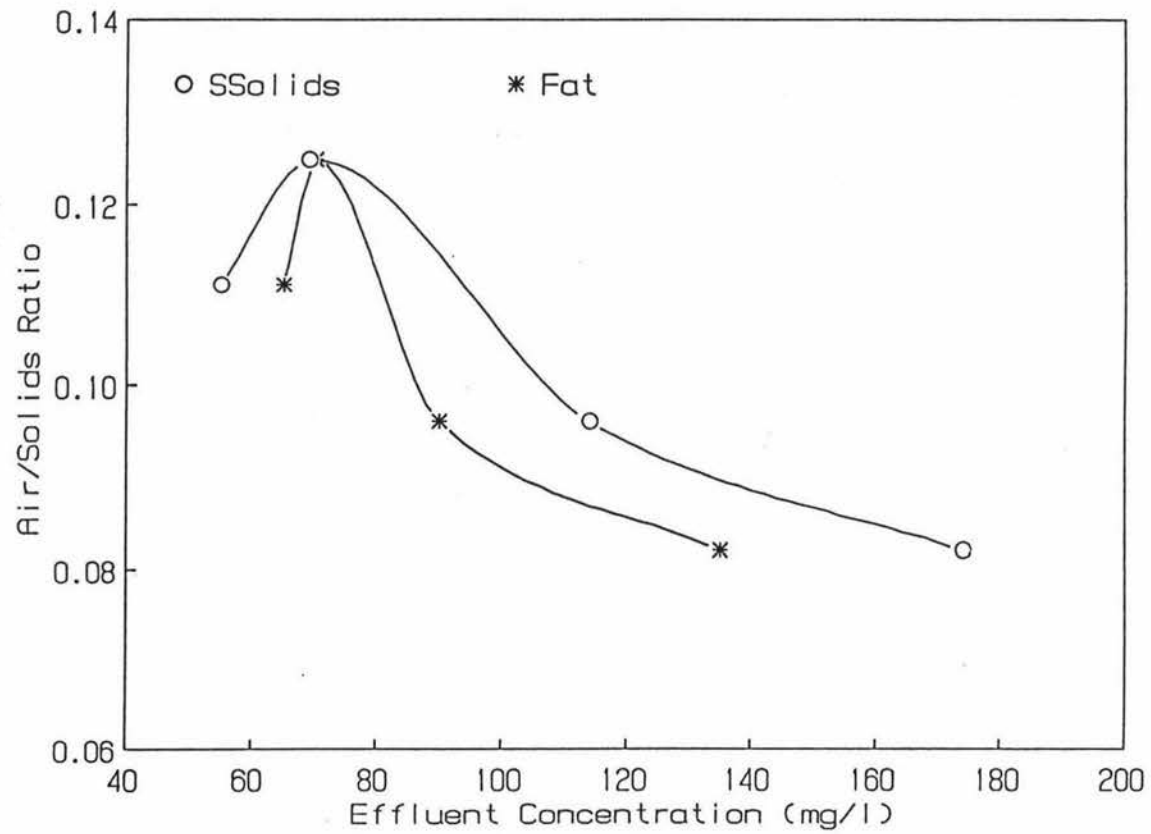
Figure 4.24 The effect of A/S ratio on effluent concentration at pH 8.0 and temperature 34° C, for SS and Fat.

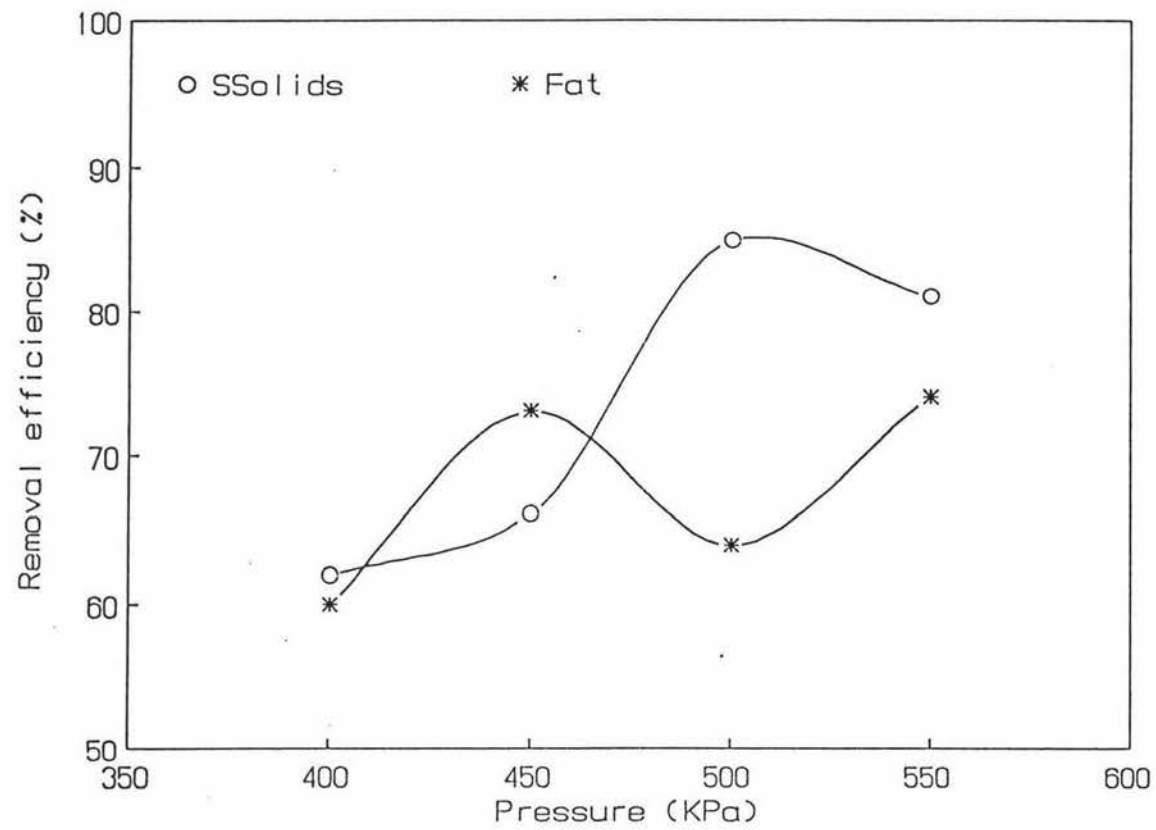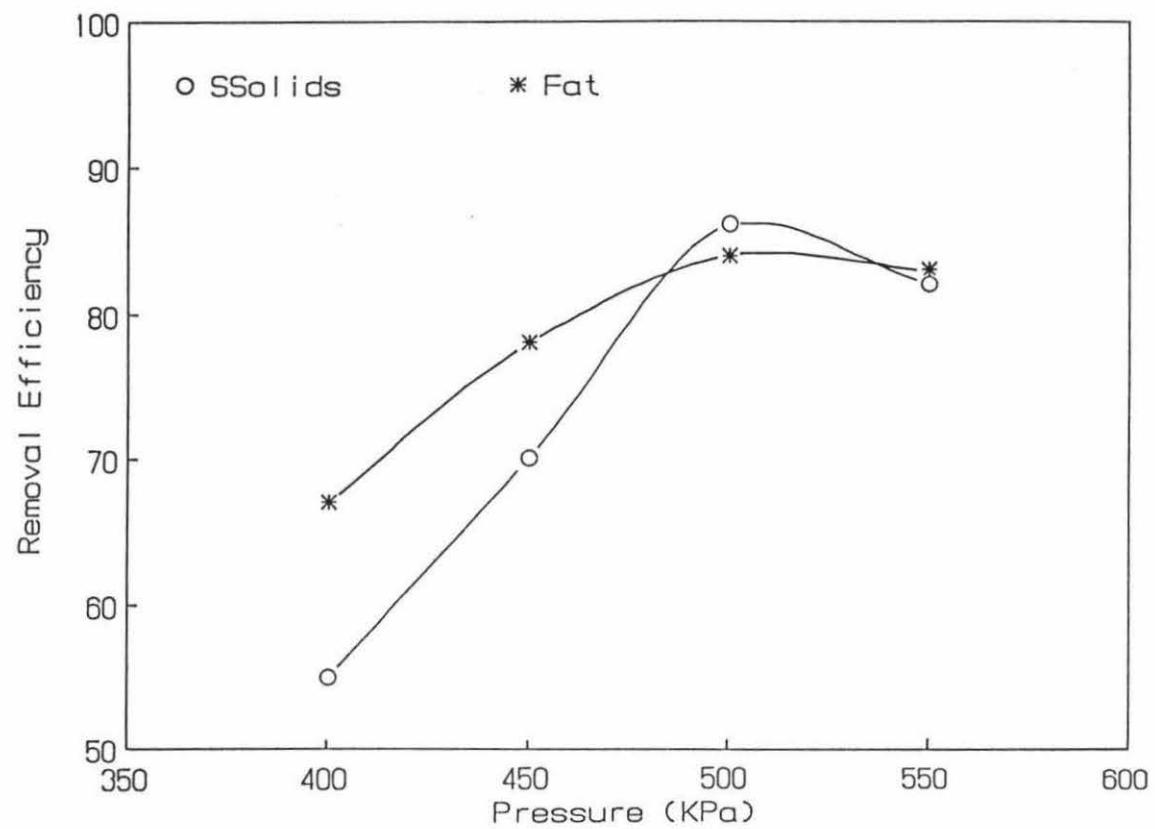Figure 4.25 The effect of pressure on efficiency at pH 8.0 and temperature 34° C, for SS and Fat.

Table 4.15 Summary of results at temperature 48° C and pH 7

Pressure (kPa)	500
A/S Ratio	0.050
Influent SS (mg/l)	564
Effluent SS (mg/l)	283
Efficiency (%)	50
Influent VSS (mg/l)	544
Effluent VSS (mg/l)	271
Efficiency (%)	50
Influent Fat (mg/l)	420
Effluent Fat (mg/l)	243
Efficiency (%)	42
Influent COD (mg/l)	1045
Effluent COD (mg/l)	915
Efficiency (%)	13

Figure (4.26) shows the effect of temperature on efficiency at pH 7 and pressure 500 kPa. For suspended solids the optimum removal was at temperature 34° C and the efficiency decreased with further increase in temperature. Fat removal efficiency deceased with increase in temperature, lowest efficiency being at 48° C. Optimum removal was obtained at 25° C. It can be concluded that the performance of flotation process is dependant on temperature and decreases at higher temperatures.

4.7 Influence of Coagulant alum on DAF

Coagulation is the process by which the performance of the treatment system can be enhanced. In the present studies coagulant alum was used to enhance the flotation characteristics of the wastewater. Alum acts as a good coagulant and precipitates the solids and fat. Alum was chosen because it acts as a efficient coagulant at pH 7.0 (Anderson, 1984) and also is a very suitable coagulant for dairy wastewater. Also alum is very economical to use compared to other coagulants like Iron salts, lime etc. (Coertze, 1978).

In the present studies alum was used in powdered form at pH 7. Judging by the previous experiments, the optimum pressure of 500 kPa was used in the tests. After alum was added to the wastewater, it is observed that the solids and fat precipitated. The floc tended to settle to the bottom, and supernatant is very clear. The inlet solids concentration increased with the dosage of alum in direct proportion.

During the jar tests (section 3.5), at low concentrations of alum flocs formation did not take place. Floc formation was good at higher concentrations of alum, which is around 300 mg/l and higher. Foltz *et al* (1973) used alum in similar concentration range to treat fish industry wastewater, which contains high protein, solids and oil. In dairy wastes also solids, protein and fat are present in high concentrations.

Alum was used in three concentrations in the present experiments at 300, 350, and 400 mg/l based on the observations with jar tests. The results of the flotation experiments are presented in Table 4.16. At the dosage of 300 mg/l the concentration
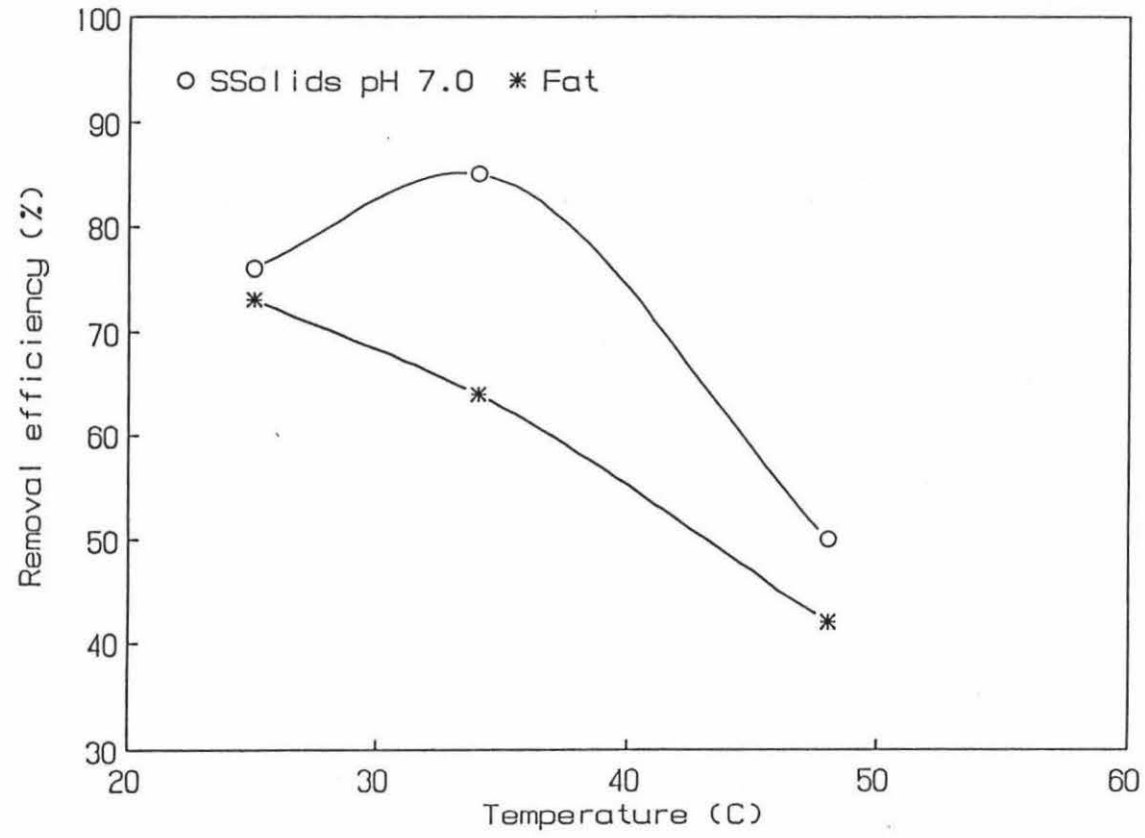
Figure 4.26 The effect of temperature on efficiency at pH 7 for SS and Fat

Table 4.16 Summary of results with coagulant alum at pH 7.0

Alum Dosage (mg/l)	300	350	400
Pressure (kPa)	500	500	500
A/S Ratio	0.050	0.046	0.033
Influent SS (mg/l)	1203	1320	1811
Effluent SS (mg/l)	221	146	133
Efficiency (%)	82	89	93
Influent VSS (mg/l)	1143	1118	1693
Effluent VSS (mg/l)	188	114	108
Efficiency (%)	84	90	94
Influent Fat (mg/l)	535	735	665
Effluent Fat (mg/l)	90	60	50
Efficiency (%)	83	92	92
Influent COD (mg/l)	1013	1034	975
Effluent COD (mg/l)	724	627	637
Efficiency (%)	29	39	35

of inlet solids is 1203 mg/l. This increase can be because of precipitation and alum concentration. Cooper and Denmead (1979) also observed that solids concentration increased when the waste is acidified to isoelectric pH or coagulated. A/S ratio is low at 0.050. The removal efficiency was 82% for solids, 84% for volatile solids, and 83 % for fat. COD removal was low at 29%.

When alum was used at 350 mg/l, inlet solids concentration increased to 1320 mg/l due to coagulation and precipitation of fat and solids. A/S ratio was 0.046. The removal efficiency for all the parameters was high except for COD. suspended solids removal was 89%, Fat removal was at 92% which is very high. COD removal efficiency was rather low at 39 %.

Experiments were carried out at higher dosage of 400 mg/l. A/S ratio is 0.033. Inlet solids concentration further increased to 1811 mg/l. Inlet fat concentration was 665 mg/l. High removal efficiencies were obtained for solids and fat at 93 and 94 percent. COD removal was again low at 35%. The subnatant was very clear. A thick float has formed in all the three cases.

When the results are compared it can be observed that efficiency increased with increase in alum dosage. Maximum removal efficiency being at an alum dosage of 400 mg/l. Figure 4.27 shows the effect of alum dosage on efficiency. The figure shows that the efficiency increases with increase in alum dosage.

Experiments with alum at 400mg/l and polyelectrolyte Zetag-92 at concentrations of 5 mg/l and 10 mg/l were carried out. Zetag-92 is a cationic polymer and is used in thickening of sludge. In the present studies it is used to enhance the floc stability and to improve the removal efficiency by flotation. Alum dosage of 400mg/l was chosen, after observing the experimental results using alum. Also alum dosage of 150 mg/l was tried in order to observe the process efficiency at low concentrations of alum and polyelectrolyte. Results of the experiments are presented in Table 4.17.
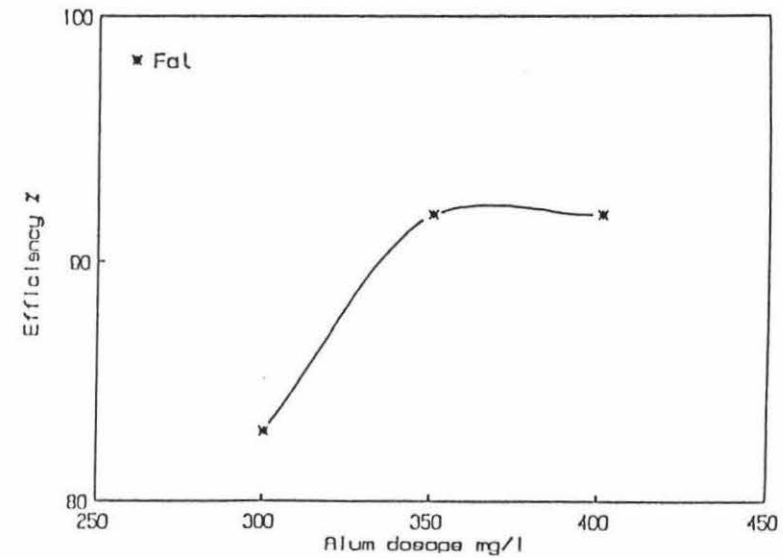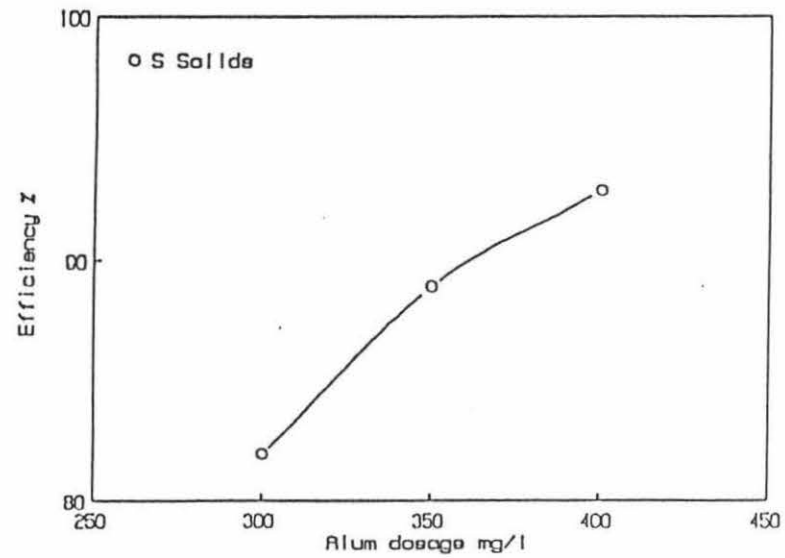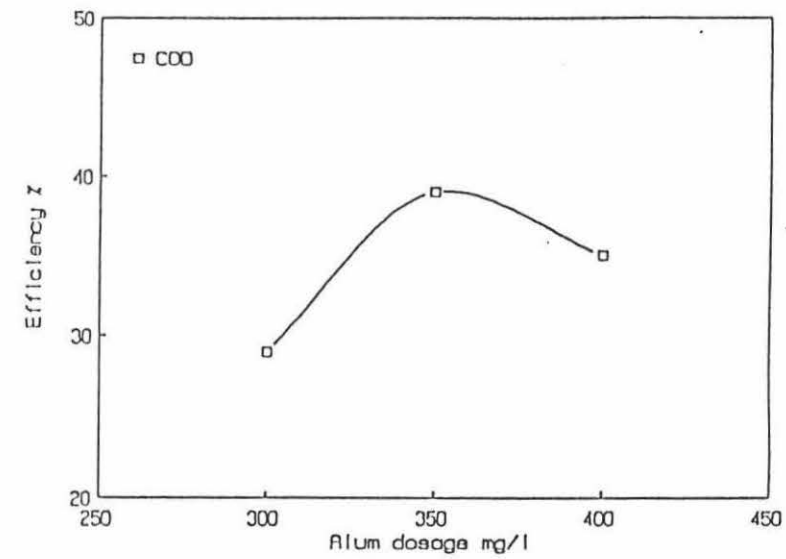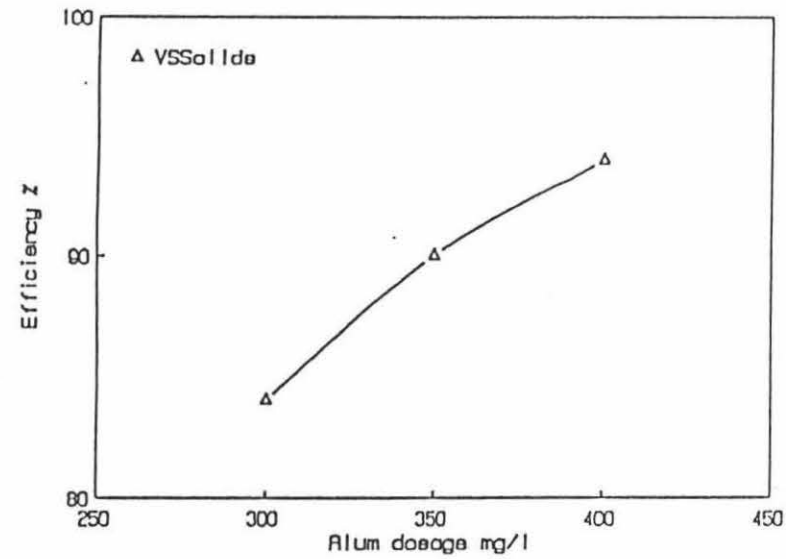
Figure 4.27 Effect of alum dosage on removal efficiency for SS, VSS, Fat and COD

Table 4.17 Summary of results with coagulant alum and ployelectrolyte Zetag-92 at pH 7.0

Alum + Polyelectrolyte (mg/l)	150+5	400+5	400+10
Pressure (kPa)	500	500	500
A/S Ratio	0.078	0.025	0.046
Influent SS (mg/l)	710	2193	1208
Effluent SS (mg/l)	439	166	127
Efficiency (%)	38	92	89
Influent VSS (mg/l)	693	2031	1171
Effluent VSS (mg/l)	433	111	89
Efficiency (%)	38	95	92
Influent Fat (mg/l)	640	955	815
Effluent Fat (mg/l)	297	93	120
Efficiency (%)	54	90	85
Influent COD (mg/l)	1030	1010	974
Effluent COD (mg/l)	788	790	717
Efficiency (%)	24	22	26

When alum was used at 150 mg/l with 5 mg/l Zetag - 92, the efficiency obtained was low for suspended solids. Only 38% of the suspended solids were removed while the fat removal was 54%. These efficiencies are lower than the efficiencies obtained at experiments on the wastewater without changing the pH.

Experiments were carried out with alum at 400 mg /l and polyelectrolyte at 5 mg/l concentration. Inlet solids concentration was very high at 2193 mg/l. The increase in solids concentration could be due to better floc formulation and adhesion between particles. High removal efficiencies were achieved. Suspended solids removal was 92%, volatile solids removal was 95% and fat removal was 90%. COD removals are again low at 22%.

When the polyelectrolyte concentration was increased to 10 mg/l, the inlet solids concentration decreased to 1208 mg/l. The decrease in solids concentration could be because of inferior conditions for flocculation and precipitation. A/S ratio was 0.046 similar to the value obtained with alum dosage of 350 mg/l. Increase in polyelectrolyte concentration did not help to increase efficiency further. Solids removal efficiency decreased to 89%. Fat removal efficiency is also decreased to 85%. COD removal is also low at 26%.

The removal efficiencies are higher at polyelectrolyte dosage of 5 mg/l than at 10 mg/l. Without polyelectrolyte dosage also the results are comparable, when alum only was used.

From the coagulant studies it can be concluded that even though alum is required in high concentrations, the performance is very effective. Even though the solids concentration was high removal is also high. Same is the case with fat.

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

In the treatment of dairy wastewaters primary treatment and secondary treatment are important for the removal of solids and fat and where possible the reduction in oxygen demand. The primary treatment could be sedimentation or filtration or flotation. Flotation is a fairly novel method of treatment for treating dairy wastewaters. It has been in use for treatment of other industrial wastes. Dissolved air flotation is suitable for removing fat and solids by physical and physico-chemical treatment. The treatment depends on the characteristics of the wastewater and the optimised conditions for suitability of treatment.

The investigations carried out have involved the studies on the dairy wastewater treatment by dissolved air flotation. The studies involved the determination of process performance of flotation. The studies included effect of change in pH of the wastewater, temperature effects and the use of coagulant alum and polyelectrlolyte zetag-92.

pH studies : pH studies on two types of wastewater have been carried out. Type-I waste water contains discharges from milk plant only. Type-II wastewater contains discharge from milk powder plant and butter plant. Effect of change in pH were carried out on Type-I wastewater at three pHs, namely pH 4, 5, and actual pH of the waste water. Rest of the experiments were carried out with Type-II wastewater. With Type-II wastewater pHs 4, 5, 7, 8, and actual pH of wastewater have been carried out.

The studies on effects of pH indicated that, pH plays significant role in the treatment. For Type-I wastewater the optimum removal of 91% for solids and 92% for fat was obtained at a pH of 4 and at a pressure of 550 KPa. Considerable removals were obtained at pressure 500 KPa too. A/S ratio varied from 0.090 and 0.102 for these two pressures. At the actual pH of wastewater the removals were average. With Type-I wastewater considerable removals in COD were obtained. Optimum COD removal was obtained at pH 4 for a pressure of 550 KPa. At pH 4 solids concentration increased due to precipitation upon adjustment of pH.

At pH 5 the removals were quite low for all the parameters. Only for fat highest removal of 57% was obtained at a pressure of 450 KPa and A/S ratio of 0.113. The removals varied very much with increase in pH.

With Type-II wastewater also the optimum efficiency was obtained at pH 4. Optimum fat removal of 89% was obtained at pressure 550 KPa. Results were similar to that obtained with Type-I wastewater. Solids concentration was less and A/S ratios were high. This could be due to lesser solids in the influent indicating that solids concentration plays major role in the supply of air and air saturation in the wastewater. At the actual pH of wastewater also the removals were considerable for fat at higher pressures. COD removals were very low. This could be due to the presence of butter component in the wastewater. Butter plant wastewater was not present in the Type-I wastewater. At pH 4 the COD removals were average. Studies at pH 5 with this wastewater indicated similar to that of studies with Type-I wastewater. Similar variations in efficiencies were observed.

Studies at pH 7 and 8 showed the performance of flotation to be average. Better removals were obtained at pH 7. At pH fat removals were lesser than solids removal. Optimum solids removal of 71% was obtained at pressure 500 KPa. Optimum fat removal of 57% was obtained at pressure 550 KPa.

The process will be highly efficient and uniform results can be obtained when applied at pH 4. But this requires lot of acid dosing to adjust the pH. The pH of the wastewater is around 10.6-12. Again if further treatment is contemplated the pH should be raised to around neutral value.

Temperature Studies : After pH studies, the effect of change in temperature of the wastewater on flotation was observed. As air solubility decreases with temperature, sometimes the saturation could be just sufficient at optimum temperature. At temperature 25° C and pH 8, the efficiency obtained was good. Optimum of 85% being for fat. Solids removals were at 81% at pressures 500 and 550 KPa. Again COD removals were low. At pH 7 also the removals are considerable but were slightly less than the values

at pH 8. Optimum solids removal at both the pHs was similar. At 34°C the removals were comparable to that of studies at temperature 25° C.

Temperature studies at 48° C indicated that flotation is not suitable at higher temperature. Removal efficiencies were low. Fat removal was only 43%. Studies at this temperature were done at pH 7 and pressure 500 KPa. As optimum removals were obtained at this pressure.

Coagulant studies : After temperature studies with alum indicated good performance of the system. Alum was used as a coagulant at pH 7 and pressure 500 KPa. Alum is effective when used at pH 7. Also from earlier studies at pH 7 it is observed that the removals were good.

Jar tests indicated that alum dosage is required in high concentrations for effective coagulation and floc formation. The process performance increased considerably with the dosage of alum. Thick float formed at the top of liquid layer in the flotation tank and subnatant was very clear. Optimum efficiency was obtained at alum dosage of 400 mg/l. Solids and fat removals were 93% and 92% at this concentration. Polyelectrolyte Zetag-92 was used at this concentration of alum to enhance the floc stability. But the removals were similar. Indicating that only alum dosage is sufficient.

From these studies it can be concluded that dissolved air flotation if an effective primary treatment to remove solids and fat under optimised conditions. The bench scale studies indicate the applicability of the flotation for wastewaters. Pilot scale studies can be carried out to optimise the process and design of large scale treatment plants.

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NOMENCLATURE

SS   Suspended solids

VSS   Volatile Suspended solids

COD   Chemical oxygen demand

A/S   Air/Solids Ratio

APPENDIX

1. Sample calculation of removal efficiency for all the parameters Suspended solids, Volatile suspended solids, Fat and COD.

Removal efficiency is determined as

Removal Efficiency (%) = {(Inlet conc - outlet conc)/(Inlet Conc)}*100

Sample calculation at pH 4 (Type-I) wastewater at pressure 500 kPa.

1.1 Suspended solids

Inlet concentration (mg/l)	=	661
Outlet Concentration (mg/l)	=	74
Removal Efficiency (%)	=	{(661-74)/661}*100 = 89

1.2 Volatile Suspended solids

Inlet Concentration (mg/l)	=	652
Outlet Concentration (mg/l)	=	71
Removal Efficiency (mg/l)	=	{(652-71)/652}*100 = 89

1.3 Fat

Inlet Concentration (mg/l)	=	275
Outlet Concentration (mg/l)	=	27
Removal Efficiency (mg/l)	=	{(275-27)/275}*100 = 90

1.4 COD

Inlet Concentration	(mg/l)	=	1586
Outlet Concentration	(mg/l)	=	350
Removal Efficiency	(mg/l)	=	{(1586-350)/1586}*100 = 78

2 Calculation of Air/Solids (A/S) ratio Sample calculation pH 4 and Pressure 500 kPa

A/S ratio is calculated by using the following equation,

$$A/S = \frac{1.3 S_a Q}{RX} \left(\frac{fP}{p} - 1 \right)$$

Where,

Sa	= Air solubility in water at a given temperature, m/l	=	26.3
X	= Influent suspended solids, mg/l	=	661
P	= Pressure, for pressurising the wastewater, kPa	=	500
p	= Standard atmospheric pressure, kPa	=	100.2
R	= Recycle or partial pressurized effluent, ml	=	400
Q	= Amount of wastewater used, ml.	=	600

by substituting the values A/S ratio is found as,

A/S ratio   =   0.090