

DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

**EFFICIENCY IMPROVEMENT OF OIL
SEPERATION BY FLOTATION**

by

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İZMİR

EFFICIENCY IMPROVEMENT OF OIL SEPERATION BY FLOTATION

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by

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Ph.D. THESIS EXAMINATION RESULT FORM

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EFFICIENCY IMPROVEMENT OF OIL SEPERATION BY FLOTATION

ABSTRACT

Dissolved Air Flotation (DAF), is a flotation technique and is classified as (traditional) Classical DAF (CP-DAF) and new generation - microbubble pump DAF (MB-DAF) systems considering the air bubble generation method. In the presented study, the performance of CP-DAF and MB-DAFs (i.e. MB-DAF-1 and MB-DAF-2) were compared and the effect of flow rate and pressure on the performance of oil/grease, organic matter, and suspended solids was investigated in wastewater. The results shown that CP-DAF System achieved lower removal efficiency than the MB-DAF systems. The optimal operational pressure was determined to be 4 bar in both systems with the highest performance obtaining at flowrate of $1\text{m}^3/\text{h}$. In optimal operating conditions, the MB-DAF system demonstrated a performance increase of approximately 10% in the removal of oil-grease, organic matter, and SS when compared to the CP-DAF system. The impact of impeller profile modifications on microbubble generation was investigated by increasing and decreasing the number of blades. The MOMB-DAF 1 and MOMB-DAF 2 were operated at the optimal pressure determined in the previous stage. The modified MB-DAF systems exhibited approximately 5% higher efficiency than the CP-DAF system. An artificial neural network was created using the data obtained from experimental studies for CP-DAF, MB-DAF-1 and MB-DAF-2. The neural network was trained using the Levenberg-Marquardt backpropagation algorithm. The model shown that an average margin of error of 7.33%, accompanied by a high correlation coefficient of $R = 0.98966$, indicating its strong predictive accuracy.

Keywords: Dissolved air flotation (DAF), microbubble generator pump, modification of the pump blade, artificial neural network, treatment efficiency

FLOTASYON İLE YAĞ GİDERİMİNDE VERİM ARTTIRIMI

ÖZ

Çözünmüş Hava Flotasyonu (DAF), bir flotasyon tekniği olup hava kabarcığı oluşturma yöntemi dikkate alındığında (geleneksel) Klasik DAF (KP-DAF) ve yeni nesil - mikro kabarcık pompalı DAF (MK-DAF) sistemler olarak sınıflandırılır. Sunulan çalışmada, KP-DAF ve MK-DAF'ların (yani MK-DAF-1 ve MK-DAF-2) performansı karşılaştırılmış ve giriş debisi ve basıncın yağ/gres, organik madde ve askıda katıların performansı üzerindeki etkisi gerçek atıksuda incelenmiştir. Sonuçlar KP-DAF Sisteminin MK-DAF sistemlerine göre daha düşük giderim verimi elde ettiğini göstermiştir. Her iki sistemde de optimum işletme basıncının 4 bar olduğu belirlenmiş olup, en yüksek performans $1\text{m}^3/\text{h}$ debide elde edilmiştir. MK-DAF sistemi, optimum çalışma koşullarında, KP-DAF sistemine kıyasla yağ-gres, organik madde ve AKM gideriminde yaklaşık %10 oranında performans artışı göstermiştir. Pervane profilindeki değişikliklerin mikro kabarcık oluşumuna etkisi, kanatçık sayısının artırılması ve azaltılması yoluyla araştırılmıştır. MOMB-DAF 1 ve MOMB-DAF 2, önceki aşamada belirlenen optimum basınçta çalıştırıldı. Modifiye edilmiş MB-DAF sistemleri, CP-DAF sistemine göre yaklaşık %5 daha yüksek verimlilik gösterdi CP-DAF, MB-DAF-1 ve MB-DAF-2 için deneysel çalışmalardan elde edilen veriler kullanılarak yapay sinir ağı oluşturulmuştur. Sinir ağı Levenberg-Marquardt geri yayılım algoritması kullanılarak eğitilmiştir. Model, %7,33'lük ortalama hata payına sahip olduğunu ve $R = 0,98966$ 'lık yüksek korelasyon katsayısının da güçlü tahmin doğruluğuna işaret ettiğini göstermiştir.

Anahtar kelimeler: Çözünmüş Hava Flotasyonu, mikro hava kabarcığı üreten pompa, pompa çarkının modifikasyonu, yapay sinir ağı, arıtma verimliliği

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LIST OF SYMBOLS

| | | |
|----------|---|--|
| V_t | : | the terminal rising velocity of the agglomerate |
| D | : | the effective diameter of the agglomerate |
| g | : | the gravitational constant |
| ρ_0 | : | the density of the aqueous phase |
| ρ_a | : | the density of the agglomerate |
| μ | : | the viscosity of the aqueous phase |
| p | : | the partial pressure of the gas |
| C | : | the concentration of the gas dissolved in the solution |
| k | : | the Henry's Law constant |
| S | : | the gas released at atmospheric pressure |
| S_g | : | the gas saturation at atmospheric pressure |
| P | : | the gauge pressure of pressurization |
| f | : | a fractional system dissolution efficiency factor |
| G | : | the gas concentration |
| S | : | the SS (oil) concentration |
| R | : | the pressurized liquid flow rate |
| C_s | : | the gas saturation concentration at atmospheric pressure |
| f | : | the saturation efficiency |
| P | : | the saturation pressure |

- S_o : the SS (or oil) in wastewater
- Q : the raw wastewater flow rate
- S_e : the SS (oil) in the pressurized liquid stream
- A/S : the air/solids plus oil
- C_s : the air solubility at 1.0 atm pressure and operating temperature
- X_f : the concentration of SS plus oil in the feed
- P_a : the absolute saturation pressure
- f : the fraction of air actually dissolved at the elevated pressure in the saturation chamber
- l : the air left in solution at atmospheric pressure.

ABBREVIATIONS

| | | |
|---|---|----------|
| Dissolved Air Flotation | : | DAF |
| Classical DAF | : | CP-DAF |
| Micro bubble pump | : | MBP |
| Micro bubble Pump DAF | : | MB-DAF |
| Modified Microbubble Generator Pump DAF System | : | MOMB-DAF |
| Surface Loading Rate | : | SLR |
| An artificial neural network model | : | ANN |
| Biological Oxygen Demand | : | BOD |
| Chemical Oxygen Demand | : | COD |
| Suspended Solids | : | SS |
| Induced Air Flotation | : | IAF |
| Nozzle Air Flotation | : | NAF |
| Recirculation Rate | : | % R |
| Hydraulic retention time | : | HRT |
| Nephelometric Turbidity Unit | : | NTU |
| Computational Fluid Dynamics | : | CFD |

CHAPTER ONE

INTRODUCTION

1.1 The Problem Definition

Due to the increasing agricultural and industrial production and population growth, the amount of wastewater has been increased gradually in the world. The discharge of wastewater into the natural environment without adequate treatment has a deleterious effect on water quality, resulting in significant environmental and health consequences. In addition, the discharge of untreated waste water into rivers, streams, etc. can lead to the contamination of fresh water sources and contribute to the depletion of fresh water resources. Since the availability of freshwater sources has adversely been affected from the wastewater discharges, implementation of efficient wastewater treatment plants has emerged as a critical concern, particularly in developing countries.

Effective wastewater management has also been identified as a key concern for industry, as contaminants such as heavy metals, dyes, oil, pathogens and organic compounds released from various processes can be toxic in high concentrations. There is a wide range of technological options available for the treatment of industrial wastewater. Physical, chemical and biological processes can be used to remove pollutants from industrial wastewater. Many factors, such as removal efficiency, flexibility, operation, land requirement, etc. are considered in the decision. In addition, cost, i.e. capital costs, operation and maintenance costs are involved in technology selection. From the perspective of employers, a wastewater treatment plant that exhibits low capital and operating costs (including minimal energy requirements and low chemical use) is a preferred option. In this regard, efforts are being made to find solutions that are both efficient and cost effective. In line with this perspective, the present thesis investigated the potential for enhancing the efficiency of the flotation process through the elimination of certain equipment (e.g., pressurized vessels, compressors, piping, etc.) and the reduction of energy consumption.

Flotation is a treatment method used for the removal of oil/ grease and suspended solids from wastewater. Among the various flotation techniques, dissolved air flotation (DAF) has emerged as an effective method for the removal of dissolved organic substances and oils and is widely used on a global scale. Therefore, it has been successfully implemented in a variety of industrial sectors, including milk and dairy plants, slaughterhouses, paper mills, metal processing and coating plants, food plants, and petrochemical industry, for the purpose of pre-treatment.

The principle of the DAF system, is based on the flotation of oil and grease, suspended solids and other floating matters in wastewater which have density less than water and removing these substances with surface scrapers. DAF systems have many design criteria, such as the ratio between width-length-height, geometry of the tank, retention time, hydraulic properties, recirculation ratio and micro bubble formation. Bubble size is an important parameter in the DAF system. It can improve process performance by increasing the gas-liquid interface area. Therefore, microbubble-generating systems have attracted considerable interest recently and are preferred to conventional classical pump DAF (CP-DAF) systems due to their superior properties, including high removal efficiency, low energy consumption, simplicity of operation, and a small area requirement.

The CP-DAF system which have been also widely utilized in Turkey comprises a circulation pump (conventional DAF pump), a pressure vessel, and compressors. However, in practice, it has been observed that the DAF system with conventional pumps exhibits certain drawbacks such as sensitivity to wastewater characteristics, macro size bubble generation, high maintenance requirements, etc. In a CP-DAF system, the recirculation pump that transfers the wastewater to the pressure tank is selected from the multistage pumps. Multistage pumps are typically used to transport clean water and are therefore well-suited for potable water applications; however, when utilized in the transfer of wastewater, internal/spoon-related issues may arise. In addition, the CP-DAF system is unable to produce micro size air bubbles which is

necessary for effective pollution removal. Furthermore, pump failures are a common problem in the CP-DAF system due to the incompatibility of the multistage pump with the wastewater. As the pump is not in operation during the period of failure and subsequent repair, the wastewater cannot be treated. This has an adverse impact on the overall performance of the system. Moreover, it is critical that the equipment utilized in the CP-DAF system be operated and maintained by qualified technical personnel.

An alternative option is the new generation DAF system, namely the MB-DAF system, which provides fine air bubbles using a micro bubble pump (MBP). The MB-DAF system offers less equipment and technical personnel. Furthermore, the system is capable of continuously producing microbubbles, enhancing its overall efficiency by reducing energy consumption.

On the other hand, a considerable volume of oily wastewater is produced on a daily basis from a variety of sources, including oil refineries, the petrochemical industry, metal processing, slaughterhouses, milk and dairy processing, and numerous other processes. The inadequate treatment and discharge of oily wastewater have a detrimental impact on the environment. Therefore, it is crucial to enforce stringent discharge regulations and implement effective wastewater treatment plants to mitigate the adverse effects. There is various oil–water separation technologies including floatation, adsorption, coagulation-flocculation, membrane processes biological treatment and combinations of the above. Air flotation technology presents a high potential due to its high removal efficiency, energy efficiency, operational simplicity, cost-effectiveness, and its applicability to a wide range of oily wastewater. Among the various floatation methods, MB-DAF technology is recommended as a feasible, promising, and effective method for oily wastewater treatment due to its high separation efficiency, cost-effectiveness, and simple operation. However, the number of studies evaluating the performance of the MB-DAF system and conventional DAF system are limited. To determine the efficacy of the floatation process and the impact of microbubble generation on removal efficiency, further research is necessary.

1.2 Objectives and Scope of the Study

As described in the previous section, flotation is an effective and reliable wastewater treatment process mainly used to treat oil/grease and suspended solids. Dissolved Air Flotation is widely used and recommended as an effective wastewater pretreatment alternative for treating oil containing wastewater from a variety of sources: petroleum refining, metal finishing and coating, bilge and ballast wastes, metal plating, meat processing - slaughterhouses, dairies, paper mills, etc.

Engineering handbooks or reference books given in the literature have been used by the engineers for designing of the DAF systems. Recycle rate and pressure, air to solids ratio, hydraulic loading, surface loading, ratio between the dimensions, geometry of the tank, retention time, and micro bubble formation have been used as design parameters for the DAF systems. However, the values provided for these parameters in existing references may be outdated or insufficient when compared to data from the actual systems in operation. Furthermore, the literature review conducted for this thesis indicates that notable discrepancies exist in the design values. For example, the retention time varies between 11-120 minutes, Air/Solids value varies between 0.5-0.01, and the Surface Loading Rate (SLR) value varies between 10-23m/h, also. In terms of design parameters, there are no values that are comparable in the existing literature. For this reason, in DAF designs, it is important in DAF designs to make a pilot scale and start the real application in accordance with the information obtained from pilot study.

Therefore, in this study a pilot scale DAF plant produced from PP (polypropylene) material is designed and operated with wastewater obtained from milk and dairy industry. The performance of conventional and new generation DAF systems was investigated and compared based on the oil, suspended solid and organic matter removals. Moreover, this study examined the impact of microbubble formation on oil/grease removal through the use of CP-DAF and MB-DAF systems. On the other hand, the shape and number of blades have been identified as crucial elements

influencing the performance of microbubble-generating pumps. Thus, several studies have been conducted with the objective of modifying the geometrical characteristics of the impeller. The presented study also aims to examine the impact of the blades on microbubble formation. To this end, the number of blades was increased and decreased in order to assess the effect of blade configuration on the generation of microbubbles.

The principal objectives of the presented study, as well as its original contributions to the existing literature, are outlined below:

Operation of the CP-DAF and MB-DAF systems with Dairy Wastewater: The presented study was conducted to investigate and compare the treatment performances of the CP-DAF and MB-DAF systems using a wastewater obtained from a dairy plant at same conditions. There is no study in literature that compares the CP-DAF and MB-DAF systems using non-synthetic wastewater. Therefore, use of real wastewater instead of synthetic wastewater is one of the distinctive features of this study.

Development of knowledge on MB-DAF equipment: In the environmental technologies market, brands such as NIKUNI, ACNITI (Japan), FLAGSHIPINDIA (India) and AKVOLA, EDUR (Germany) have distinguished themselves based on their performance, especially in MB-DAF systems. Within the scope of the study, NIKUNI and EDUR pumps were supplied as micro bubble pumps and their respective performances were evaluated.

MB-DAF system revision to Modified Microbubble Generator Pump DAF System (MOMB-DAF): Another distinct feature of the thesis is the investigations performed with a modified impeller system. Because, there is no study in the literature examine the impact of microbubble generating pump impeller system on the removal efficiency in DAF system. The most efficient MGP of the two MGPs to be tested was

selected and the number of blades of the impeller system was revised. The pollution removal efficiencies obtained by increasing and decreasing the number of blades were also examined.

Comparison of Systems: The prototype was operated in a variety of modes including CP-DAF, MB-DAF and MOMB-DAF systems. Comparative analyses of removal efficiencies were conducted to evaluate the effectiveness of these operational modes.

Creation of Artificial Neural Network: An artificial neural network model (ANN) was created using the results obtained from CP-DAF and MB-DAF systems. In the literature, there was no ANN study created with MB-DAF data. Since artificial neural networks could be used to generate new data, it had been observed that when the input parameters of the DAF system were changed, the outputs could be predicted without the need for experimental work to determine efficiency. Although there are some ANN studies on organic and/or inorganic contaminants in wastewater treatment, no ANN study was found to predict contaminants such as oil/fat, suspended solids and COD in conventional and new generation DAF systems. Therefore, use of ANN for CP-DAF and MB-DAF System is another distinctive feature of this study.

CHAPTER TWO

LITERATURE REVIEW

2.1 Oily Wastewater and Treatment

2.1.1 Generation and Characteristics of Oily Wastewater

Today, municipalities and industries have to treat their wastewater to government limits before it is discharged into a water resource. These limits protect public health, prevent the spread of waterborne diseases and maintain water quality in rivers and lakes. Industrial wastewater is a major environmental problem. It contains high levels of pollutants and can affect water quality and public health. There are a number of practices involved in effective industrial wastewater management. This includes the treatment, re-use and recycling of wastewater, the efficient use of water resources and the prevention of pollution. In addition, compliance with regulations is of utmost importance particularly for industries. The concentration of pollutants that can be discharged, such as oils and heavy metals, has been the subject of regulation for some time. Industries have to use various wastewater treatment technologies, including physical, chemical and biological treatment methods, to control wastewater discharges. (Singh, et al., 2023).

The volume of oily wastewater is increasing every year worldwide due to the wide and continuing use of oil and oil-related products in the industries (Affandi et al. 2014; Kuyukina et al. 2020). Oily wastewater consists mainly of heavy and light hydrocarbons, oils, greases, fats, lubricating oils, cutting oils, wax oils and a wide range of suspended organic and/or inorganic solids in high concentrations. (Adetunji & Olaniran, 2021; Srinivasan & Viraraghavan 2010). Disposal of oily wastewater without treatment may cause environmental disruptions and health threats. In addition, the discharge of oil-based wastewater into water bodies results in increased chemical and biological oxygen demand, which has various impacts on aquatic ecosystems (Medeiros et al. 2022). Therefore, it must be treated before discharge, considering its harmful effects on the environment.

Oily wastewater is generated by various industries including metalworking, restaurants, slaughterhouses, dairies, poultry processing, edible oil refineries, petrochemicals, tanneries, etc. (Adetunji & Olaniran, 2021; Ahmed et al., 2007; Chen & He, 2003; Machín-Ramírez et al., 2008). Depending on the source of the wastewater, the concentration of oil in the wastewater can vary considerably. The largest source of oil-contaminated effluent is from oil exploration and extraction operations, where effluent has very high levels (4000-6000mg/l) of oils and grease. The next largest source of oil-contaminated wastewater is the metalworking industry, which consists of grinding oils, cutting oils, lubricating fluids, and cooling oils in both soluble and emulsified oil forms with concentrations ranging from 100-5000 mg/L. Other major contributors to oily wastewater are the food processing industry; slaughterhouses, dairies, poultry. In addition, the fish and meat packing industries produce significant amounts of oil/grease during slaughtering, cleaning and processing the by-products. The oil/grease content of the wastewater from food packaging plants can be as high as 1000 mg/L (Yang, 2007).

Among the various food processing industries, the dairy industry has an important role in both the agricultural and food sectors in Turkey as well as in the world; therefore, the proper management of dairy effluents has attracted more attention. The dairy industry includes processing raw milk into pasteurized and sour milk, yoghurt, hard, soft and curd cheese, cream and butter products, ice cream, milk and whey powders, lactose, condensed milk and various desserts (Slavov, 2017). Wastewater generally results from cleaning and washing of tanks during the production of products such as sterilized and pasteurized milk, cheese, butter, ice cream and yoghurt. The wastewater contains high levels of Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), dissolved and suspended solids (SS) and oil/grease. (Castillo et al., 2017; Pereira et al., 2018; Rad et al., 2014; Sarkar et al., 2006; Özdemir, et al., 2024a, Özdemir, et al., 2024c; Tikariha & Sahu, 2014). Depending on the production process, BOD can vary between 40-48,000 mg/L, COD 80-95,000 mg/L, oil/grease 20-3,000 mg/L, SS 60-22,000 mg/L, pH 4-11(Slavov, 2017). The release of untreated dairy waste into surface water has negative impacts on ecosystems because of high

levels of TSS, oil/grease and turbidity (Pereira et al., 2018; Leite et al., 2019). These highly polluted wastewaters need to be treated with appropriate methods to reduce their negative effects.

2.1.2 Treatment of Oily Wastewater

Oily wastewater can be divided into four categories according to their physical and chemical properties: free oil, dispersed oil, emulsified oil and dissolved oil. (Cerff et al. 2021). Free floating oil has a droplet diameter greater than 150 μm and is relatively easy to separate from water. It floats to the surface in calm conditions due to its lower specific gravity compared to water. The oil droplets that are present in wastewater generally range in size from a few millimeters in size to large droplets. It is relatively easy for the oil droplets to coalesce and float to the top of the water. Dispersed oil has droplet sizes in the range of 20 to 150 μm and can be relatively easily removed by gravity and/or stabilizers. Oil emulsions can be classified as mechanically or chemically stabilized emulsions if the droplet size is less than 20 μm . The formation of mechanically stabilized emulsions is mainly due to the electrical charge on the surface of the oil droplet in the water. Similar to mechanical emulsions, chemically stabilized emulsions form. However, they have additional stability due to chemical interactions at the oil/water interface. Chemical emulsions may contain detergents, soaps, and other additives that prevent coalescence. Depending on the formation conditions and the relative amounts of oil and water components, oil-in-water, water-in-oil and complex oil-in-water-in-oil emulsions are possible. In petroleum, pharmaceutical and food production, simple O/W and W/O emulsions are generally more common than complex emulsions. Removal of emulsified oil requires sophisticated processes. These include using auxiliary techniques such as adding coagulants and surfactants. Dissolved oil has droplets smaller than 5 μm . It is extremely difficult to remove and requires the use of special chemical and physical processes. Dissolved oil occurs when the oil is dissolved in the water and there are no droplets of oil present. Aliphatic hydrocarbons are usually poorly soluble in water, however aromatic hydrocarbons such as single-ring compounds such as benzene,

toluene, ethylbenzene and xylenes, and double-ring naphthalene's, together with phenols and organic acids, are the major constituents of dissolved oil.

Simple physical processes can be used to separate the free or suspended oils in these wastes from the aqueous phase. However, chemically stabilization of oil/water solutions should be managed in an appropriate manner. The most commonly used process for the treatment of oily effluents consists of a series of physical and chemical steps, such as free oil separation, suspended solids separation, chemical emulsion breaking, dissolved air flotation, electrostatic precipitation and filtration (Stasinakis et al., 2022). Flotation technology has great potential due to less sludge production and high removal efficiency for both suspended solids and oil and grease removal. However, some soluble organic compounds (such as surfactants) discharge untreated in these treatment stages, resulting in increased BOD and COD levels in the plant's discharge. It is therefore very common for biological treatment, such as activated sludge, to follow the physical treatment stage.

Conventional wastewater treatment plants for milk and dairy wastewater that is one of the oily wastewater sources, include pre-treatment process for oil-grease, suspended solids removal, and biological treatment processes for organic pollutants and nutrients removal (Ahmad et al., 2019; Das et al., 2022; Joshibaa et al., 2019; Kaur 2021; Kuzin et al., 2020; Özcan & Harputlugil, 2021; Zhao et al., 2020). In some plants, between air floatation and biological treatment, there is a pre-treatment with chemical coagulation. (Pathe et al., 2011; Saha et al., 1998;). If necessary, the tertiary treatment stage is also taken into consideration (Andrade et al., 2013; Cruz et al., 2023). Using an efficient pre-treatment stage, especially before biological treatment, can provide advantages such as reducing the size of the aeration pool, reducing the blower capacity, energy saving and reducing initial investment and operating costs (Özdemir et al., 2024a). As the aim of this thesis is the evaluation of the performance of the conventional pump and microbubble pump DAF system, detailed information about DAF system is introduced in Chapter 2.2.

2.2 Treatment of oily wastewater by Flotation Methods

Flotation is a treatment process used to remove oil/grease and suspended solids from wastewater. (Özdemir, et al., 2024d) Flotation units aim to float oil, suspended solids and other floating materials whose density is less than water, and to remove surface scrapers (Alkhatib et al., 1991; Hami et al., 2007; Li et al., 2007; Peters, 1989).

Flotation is carried out in the form of fine bubbles in the water. The tiny air bubbles adhere to the oil particles suspended in the water because the floating density of oil is lower than that of water, forming a scum layer separated from the water. (Moosai & Dawe, 2003). Flotation is a very effective method of liquid-solid separation. It has the distinct advantage of removing low density particles. These particles tend to float.

There are a number of air flotation plant modifications available to achieve adequate effluent treatment, these include electrical flotation, Dissolved Air Flotation (DAF), Induced Air Flotation (IAF) and Nozzle Air Flotation (NAF). Air flotation has been used for many years. The flotation of suspended solids (SS), fibres and other low-density solids was its first application in wastewater treatment. (Wang et.al., 2005; Wang, 2006). According of practical, reliable and efficient treatment process of air flotation has also been used to remove oil and grease from wastewater (Alkhatib et.al., 1991 Alsulaili & Refaie, 2021; Peters, 1989). In addition, oily wastewater treatment has great potential due to flotation's lower sludge production and separation efficiency advantages (Rubio et al., 2002). Flotation is also used to thicken activated sludge (Wang et.al., 2007) and flocculated chemical sludges.

The process of flotation consists of four basic steps (Shammas et.al., 2010; Wang, 1985):

1. Bubble formation in wastewater.
2. Contact the gas bubble with the suspended particle or oil droplet.

3. Attachment of the particle or the drop of oil to the bubble of gas.
4. Rising air/solids combination to surface that floating material is skimmed off.

Flotation uses the difference in density between the bubbles, to which the small solid particles and oil droplets are attached, and the water to achieve the separation. Since agglomerates have a lower density than the medium, they are in, they will float to the surface for removal.

2.2.1 Theory of Flotation

The separation of particles by flotation is subject to the same laws as sedimentation, but in a "reverse field of force". Stoke's Law is the governing equation in air flotation separation (at least in laminar flow), as in all gravity-controlled processes. This is used to calculate the rate of rise of bubble flocs, agglomerates and bubble-oil aggregates. (Krofta & Wang, 2000; Wang et. al., 2005).

$$V_t = \frac{gD^2(\rho_a - \rho_0)}{18\mu} \quad (2.1)$$

Abbreviations used in the formula are explained below.

| Abbreviations | Description | Unit |
|----------------------|---|-----------------------|
| V_t | : the terminal rising velocity of the agglomerate | cm/s |
| D | : the effective diameter of the agglomerate | cm |
| G | : the gravitational constant | 980 cm/s ² |
| ρ_0 | : the density of the aqueous phase | g/cm ³ |
| ρ_a | : the density of the agglomerate | g/cm ³ |
| μ | : the viscosity of the aqueous phase | cp |

A reduction in the effective density of the oil (or solid) particle (or agglomerate), achieved by attaching or encapsulating a bubble onto or within flocs, bubbles or solid

particles, is the key to increasing the rate of bubble/solid or bubble/oil agglomerate rise over that of unaerated systems (Fig.2.1).

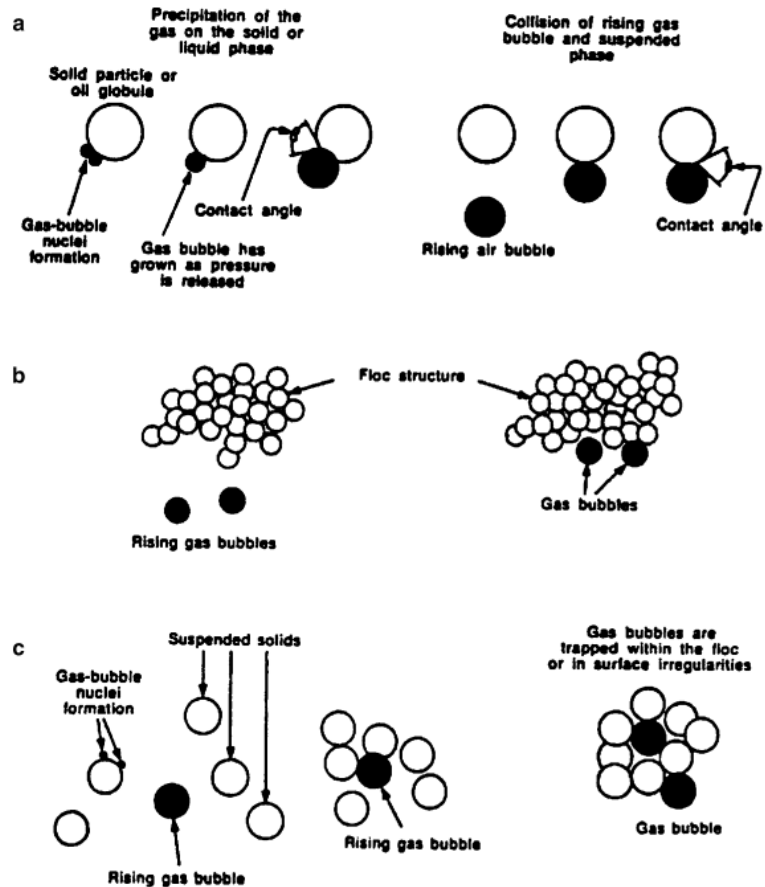


Figure 2.1 Bubble/droplet formation and adhesion mechanisms in dissolved air flotation (Shammas & Bennet, 2010)

The process follows these steps (Krofta & Wang, 2000).

- 1- Adding of gas bubbles into the wastewater
- 2- Collision between the gas bubble and the suspended matter (suspended particles as well as oil droplets)
- 3- The attachment of fine bubbles to the surface of the suspended matter
- 4- Collision between gas-attached suspended particles to form agglomerates

5- Inclusion of more gas bubbles in the agglomerates

6- Upward movement of floc structures in a sweeping action called "sweep flocculation".

2.2.2 Gas Solubility

The dissolution of air (or any other suitable gas) under pressure, and the reduction of that pressure to form bubbles, is the key to DAF. The amount of gas going into solution generally follows Henry's Law:

$$\rho = kC \quad (2.2)$$

Abbreviations used in the formula are explained below.

| Abbreviations | Description |
|----------------------|--|
| ρ | : the partial pressure of the gas |
| C | : the concentration of the gas dissolved in the solution |
| k | : the Henry's Law constant |

Thus, both dissolved gas volume and gas volume liberated during pressure reduction are direct functions of initial air pressure. The solubility of gases is also a function of the temperature and the concentration of the dissolved solids.

The amount of gas theoretically released from solution on reduction of pressure to 1 atm is given by the following equation:

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

Abbreviations used in the formula are explained below.

| <i>Abbreviations</i> | <i>Description</i> | <i>Unit</i> |
|----------------------|--|-------------|
| S | : the gas released at atmospheric pressure | mg/L |
| S_g | : the gas saturation at atmospheric pressure | mg/L |
| P | : the gauge pressure of pressurization | psig |

Bratby and Marais (1975) have shown that, in accordance with diffusion theory, most, but not all, of the dissolved air is precipitated out in the flotation tank. Since dissolution systems are not 100% efficient, the above equation must be modified by including f , a "fractional system dissolution efficiency factor".

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

Obviously " f ", the saturation efficiency, is one of the key parameters in the above equation. Useful methods for determining the mass of air dissolved under pressure have been developed by Bratby and Marais (1975). It volumetrically measures the amount of air released from the pressurized solution to atmospheric pressure.

The relevant design equation for calculating the ratio of gas to SS or oil is as follows (Conway et. al. 1981);

$$\frac{G}{S} = \frac{RC_{sf}(P/101.3)}{S_0Q - S_eR} \quad (2.5)$$

Abbreviations used in the formula are explained below.

| Abbreviations | Description | Unit |
|----------------------|--|---------------------------------|
| G | : the gas concentration | mg/L |
| S | : the SS (oil) concentration | mg/L |
| R | : the pressurized liquid flow rate | L/d; |
| Cs | : the gas saturation concentration at atmospheric pressure | mg/L |
| <i>f</i> | : the saturation efficiency | |
| P | : the saturation pressure | kN/m ² (psig x 6.89) |
| So | : the SS (or oil) in wastewater | mg/L |
| Q | : the raw wastewater flow rate | L/d |
| Se | : the SS (oil) in the pressurized liquid stream | mg/L |

2.2.3 Bubble Size

Bubble size is the most important dependent variable in air flotation. The operating principle of DAF systems is the flotation process, which essentially uses air MBs to trap microparticles and then separates the emulsions produced based on their physico-chemical properties (Matsui, 1998). A reduction in bubble size has been shown to increase the contact angle and bond strength between particles, which in turn increases the chances of floc formation. (Gulden et al., 2018; Vinnett, 2018; Lichti & Bart, 2018).

In fact, the study of microbubble characteristics in the flotation process helps to ensure microbubble stability and removal efficiency. (Prakash, 2020; Juwana et al., 2019; Wang et al., 2021). For this reason, that physical factors (i.e. pressure, dissolved air flow and temperature) are important in creating microbubbles. The flotation process involves a number of parameters such as depend on the optimum generation of microbubbles, the contact between the bubbles and the characteristics of the wastewater. (Fanaie et al., 2019; Kouhestani, 2020).

Vrablik (1959) produced the data on the bubble-size distribution shown in Fig. 2.2 Bubble sizes reported by Vrablik ranged from approximately 45-115 microns with average diameters of 75-85 microns at 20 and 50 psi saturation pressures. Vrablik also

noted that the largest bubble that rises in viscous (laminar) flow in water is 130 μm . This is much smaller than the approximately 1,000 mm diameter bubbles produced in induced air flotation.

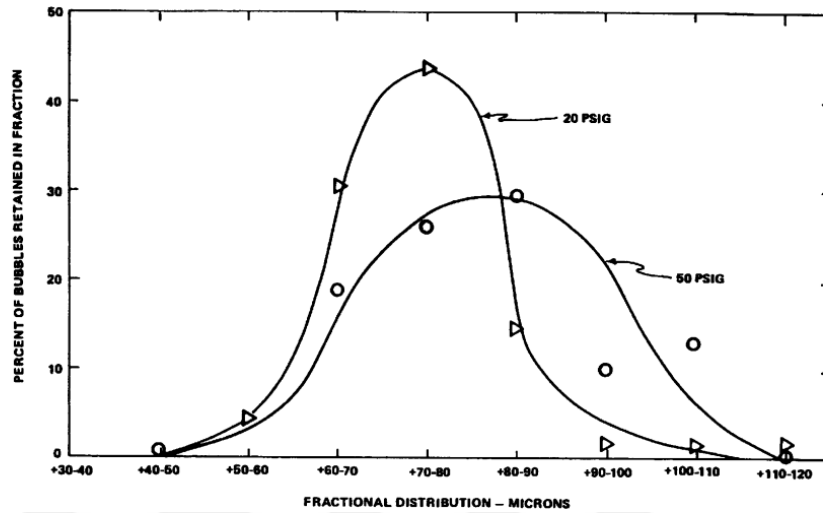


Figure 2.2 In a laboratory flotation test, the size distribution of air bubbles released into a flotation chamber. (Vrablik,1959)

A function of both the physical system and the chemical content of the wastewater determines the number and size of air bubbles formed in a given volume of water. For the latter, surface tension and dissolved solids concentration are extremely important parameters. Katz (1960) reported: "As the surface tension decreases, smaller bubbles are formed in greater numbers."

On the other hand, Shannon and Buisson (1980), who experimented with a DAF system at elevated temperatures (50 and 80 $^{\circ}\text{C}$), found that there was a considerable variation in the size of the bubbles with the pressure. They obtained an average bubble size of 66 μm at 30.5 psi and 42 μm at 40 psi.

Air is released from the solution with a rising velocity that obeys Stoke's law as a stream of small bubbles within a relatively narrow size range of 30-120 μm . The bubbles have a flotation effect only to the extent to which they adhere to the particles

and droplets. This condition generally means that bubble diameters are smaller than the material or floc diameters in suspension.

2.2.4 Rise Rate

Air flotation systems typically treat large volumes of water. The detention time in the air flotation chamber therefore becomes a very important process variable. The retention time, in turn, depends primarily on the rate of ascent of the air bubbles in the liquid; the rate of ascent, in turn, can be calculated using Stoke's law (the equation that governs bubble motion in flotation). The results of the calculation are shown graphically in Fig. 2.3.

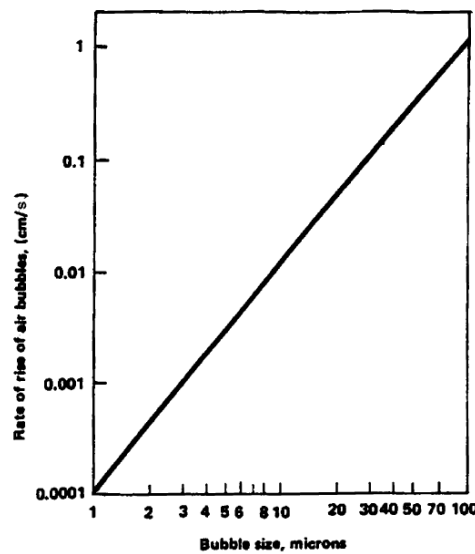


Figure 2.3 Rise rate of air bubbles in tap water (Shammas & Bennet, 2010)

The larger the diameter of the bubble, the higher the rate at which it rises and therefore the shorter the life of the bubble. (Mazahernasab, & Ahmadi, 2014; Tao et al., 2019). Thus, the contact time of the microbubble is reduced.

2.2.5 Air/Solids Ratio

A parameter governing the rise rate of bubble-particle agglomerates in solid-particle DAF systems is the air–solids ratio, which is defined as the mass of air precipitating (coming out of solution as the pressure on the aerated stream is reduced) per unit mass of wastewater solids. In systems containing oil, the term “solids” can be replaced by “oil and grease” or “suspended solids plus oil and grease,” a term defined by Steiner (1977). The most important parameter in designing air flotation systems according to Eckenfelder (1980), Krofta and Wang (2000) is the air/solids ratio. The efficiency of solids (or oil) removal is reduced if less than the optimum amount of air is used in the air flotation system. If the air supply is too high, power will be wasted in the compression of the excess air. The design of air flotation systems therefore seeks to optimize this important variable.

The result of this interaction is a net reduction in the specific gravity of the dispersed phase (air/particle agglomerate) and a corresponding increase in the rate of rise, regardless of how the gas bubbles and dispersed phase interact. Rise velocity (rate) is usually expressed in the form of Stoke’s Law, Eq. (2.1).

Equation (2.1) shows that as more air bubbles are incorporated into the aggregate, the net density of the aggregate will decrease and the rate of rise of the aggregate will increase.

The air/solids plus oil ratio are easily calculated for dissolved air systems using the following equation (2.5):

$$\frac{A}{S} = \frac{C_s}{X_f} (fP_a - 1) \quad (2.6)$$

Abbreviations used in the formula are explained below.

| Abbreviations | Description | Unit |
|----------------------|---|----------------------|
| A/S | : the air/solids plus oil | mg/mg |
| C_s | : the air solubility at 1.0 atm pressure and operating temperature | mg/L |
| X_f | : the concentration of SS plus oil in the feed | mg/L |
| P_a | : the absolute saturation pressure | atm |
| f | : the fraction of air actually dissolved at the elevated pressure in the saturation chamber | typically f is 0.8 |
| 1 | : the air left in solution at atmospheric pressure. | |

In pressurised recycle systems, all of the air is imparted to the recycle stream and the suspended contaminants are in the raw-waste stream; thus the equation must be modified as follows equation (2.6):

$$\frac{A}{S} = \frac{RC_s}{QX_f} (fP_a - 1) \quad (2.7)$$

2.3 Dissolved Air Flotation (DAF)

Among the different flotation technologies, Dissolved Air Flotation (DAF) is effective in removing dissolved organic substances and oils from wastewater and is frequently used in the world (Amin et al. 2017; Cagnetta, 2019; Villar-Navarro, 2018; Zabel & Melbourne, 1980). First introduced in 1924 by Peterson and Sveen for recovering fiber and white water in the paper industry, DAF became widely accepted in the 1960s for treating drinking water and sewage. The DAF process was also used in Finland, Sweden and South Africa for drinking water and wastewater treatment in the 1970s. (Edzwald, 2010). Since then, DAF has been used in many applications.

DAF systems are reported to be an effective method for pre-treatment of wastewater with high oil content from milk and dairy plants, slaughterhouses, paper mills, metal processing and coating plants, food plants, and petrochemical industries (Ansari et al., 2018; Amin et al., 2017; Falletti et al.2015; Han et al.; 2021; Kim et al. 2015; Liu et

al. 2010; Ng et al.; 2022; Thorat & Sonwani, 2022; Wang et.al. 2010). In addition, DAF has been applied in many industries such as in the preparation of raw water by water companies at wastewater treatment plants (Edzwald & Haarhoff, 2012; Hague, 2003), particle removal in the mining and mineral processing industries (Al-Thyabat & Al-Zoubi, 2012; Azevedo, 2018; Rodrigues et al., 2019, Rubio, 2002), for pre-treatment in the desalination process (Haarhoff & Edzwald, 2013; Shutova, et al., 2016), for cleaning up animal waste in the agricultural industry (Creamer et al., 2010), for waste treatment in food processing plants (Yoo & Hsieh, 2010), and in crude oil refineries (Moursy & El-Ela, 1982).

Due to the flotation device's treatment capacity, less sludge production and separation efficiency advantages, the oily wastewater treatment has great potential (Rubio et al., 2002).

The process involves three separate zones, each with different mechanisms. The contact zone allows bubbles and flocs to contact and adhere (aggregation), while the flotation-separation zone separates the resulting aggregates from the water phase. (Lundh et al.2001,) In the sedimentation zone, in materials heavier than water due to the density difference settling. In the DAF system, water is exposed to microbubbles created by supersaturating a stream of treated water - called DAF recycle - with air in a pressurised vessel (0.4-0.6 MPa), then suddenly releasing the pressure and injecting the DAF recycle stream into a contact zone upstream of the flotation zone. (Crossle & Valade 2006; Fanaie, et al. 2019). Microbubbles attach to flocs to form bubble-flocs aggregates in the contact zone. Then the bubble–floc aggregates are separated from water due to the density difference in the separation zone. The materials that are heavier than water according to the difference in density, settling in sedimentation zone.

Schematic process diagram for a conventional DAF plant is given in Figure 2.4.

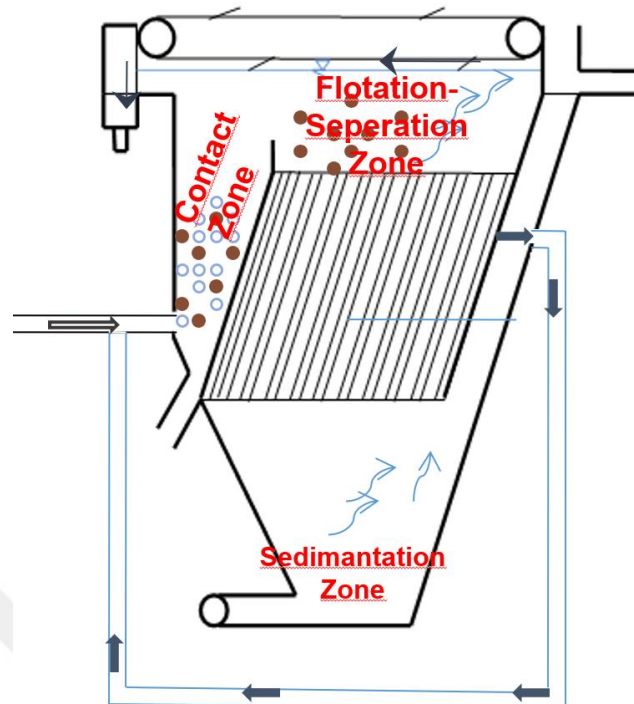


Figure 2.4 Schematic process diagram for a conventional DAF plant

There are some advantages of DAF such as;

- DAF system is very compact, low hydraulic retention time (HRT), high loading rates, small flocculation tanks, so that it is resulting in lower construction costs;
- DAF system has low detention time allows rapid startup of ,12 h;
- DAF system has high quality effluent generally ,0.5 Turbidity, NTU (Nephelometric Turbidity Unit), leading to longer filter runs;
- DAF system has low taste and odor (T&O) because of owing to short detention time of algae cells and aeration;
- If a skimmer used, in DAF system has solids already concentrated to 3% mass/volume that happened to less leading to less post-processing (Crossle & Valade, 2006; Muñoz-Alegría et al., 2021).

2.3.1 Design Parameters of Dissolved Air Flotation (DAF)

The parameters affecting the efficiency in the DAF system are the number and size of air bubbles, gas input rate, hydraulic design, concentration of dissolved materials, concentration and type of suspended solids and oils, chemical addition, temperature, hydraulic retention time, temperature, recycling rate, pH. (Krofta & Wang, 2000; Roberts et al., 1978; Sansalone & Srinivasan, 2001; Shammass, et al., 2010; Wang et al., 2005;).

In addition, DAF design parameters vary according to the hydrodynamics of the flotation tank, i.e., its geometry (Fanaie et al., 2019; Oh et al., 2019), baffle angle (Lee et al., 2020), flotation kinetics (Fanaie & Khiadani, 2020), water inflow rate (Rodrigues et al., 2019), the characteristics of the MB generating device (Kouhestani et al., 2020; Pourkarimi et al., 2016), surface tension, wastewater density, number of MBs, and MB rise velocity (Satpathy et al., 2020). Another design parameter of DAF is the air to solid ratio (A/S), which is directly related to the required removal efficiency and indicating the mass of air required in the pressure mechanism per unit mass of particulate (Ortiz-Oliveros & Flores-Espinosa, 2020, Sanchez et al., 2018). The concentration and size of the suspended particles determine the amount of air required in the DAF design (Fanaie & Khiadani, 2020). The concentration of particles carried by the bubbles depends on their size, while the loading capacity is controlled by the availability of the total surface area (Ansari et al., 2018; Lee et al., 2020; Maeng et al., 2017.)

Other parameters are hydraulic loading capacity, temperature, gas holdup (Edzwald, 2010), recirculation rate (% R), air pressure, surface loading rate (SLR) (Crossley & Valade, 2006), and hydraulic retention time (HRT) (Krofta & Wang, 2000; Leite et al., 2019; Ortiz-Oliveros & Flores-Espinosa, 2020, Pourkarimi et al., 2016; Sansalone & Srinivasan, 2001; Shammass, et al., 2010; Wang et al., 2005). The design parameters and values of Conventional DAF systems reported in various studies in the literature are presented in the following table (see Table 2.1).

Table 2.1 Main DAF design parameters

| N o. | Inlet flow rate (m ³ /h) | HRT (min) | SLR (m/h) | Air pressure (psi) | A/S (ml/m) | %R | Removal efficiency (%) | Ref. |
|------|-------------------------------------|-----------|-----------|--------------------|------------|-------|--|-----------------------|
| 1 | 0.5 | - | - | 43.51-72.52 | - | 10 | - | Wang et al., 2019 |
| 2 | - | 120 | - | 14.50-75.52 | - | - | 99 (NH ₄ ⁺ -N) | Zang et al., 2014 |
| 3 | 1.8-2.4 | 11-14 | 11.4-15 | 87.02 | - | 20-25 | 95 (Pb ²⁺ and Cu ²⁺) | Azevedo et al., 2018 |
| 4 | 1.6-4 | 25-60 | 10-22 | 43.51-87.02 | 0.5 | 12-40 | 94-96 (TSS) | Sanchez et al., 2018 |
| 5 | - | - | 11.8-23.4 | - | 0.01 | - | - | Lakghomi et al., 2015 |
| 6 | - | 10-20 | - | 89.92 | 0.35 | 40 | 99 (Ni, Cu, Cr, Pb liquid radioactive waste) | Ortiz et al., 2020 |

An important tool to design DAF systems is Computational Fluid Dynamics (CFD). In numerical simulations of DAF using CFD, the flow regime is an essential parameter for flotation tank design, analysis, and control because it helps to improve the performance by directing heat and mass transfer (Wang et al., 2019). The factors affecting the flow regime include the geometrical variables of the flotation tank (diameter, length, baffle angle, bubbler pore diameter, and cross-sectional area), particle size, dynamic variables (such as fluid flow velocity), and the physical properties of the wastewater (Prakash et al., 2018).

2.3.2 *Developments in Dissolved Air Flotation (DAF) Systems*

Parameters affecting efficiency in the DAF system has shown that the effect of bubble size and distribution is significant (Liu et al., 2010). For gas-liquid or gas-liquid-solid multiphase flow, bubble size is an important parameter. Microbubbles can improve the performance of process by increasing the surface area of the gas-liquid interface or by increasing the collision rate between bubbles and particles. The study of microbubbles in flotation processes, such as water treatment and mineral processing, has become a very attractive topic in recent years.

In the previous application, due to the low lifting force of the coarse or dense particles, microbubbles were not successful in recovering mineral particles. Recent studies have shown that the separation efficiency of microbubbles is improved compared to that of macrobubbles in the conventional condition. Thus, it has been seen that traditional DAF systems have begun to yield to a new generation of flotation systems that produce micro-bubbles primarily. Because the new generation DAF systems that produce a high quantity of smaller size bubbles are more efficient in the removal of oil/grease and use less energy and equipment, thus leading to decreased operating costs (Al-Dulaimi & Al-Yaqoobi 2021; Jia et al. 2023; Khuntia et al. 2012; Muñoz-Alegría et al. 2021; Rajapakse et al., 2022; Xiao et al. 2019; Özdemir & Alpaslan, 2021; Özdemir, et al., 2024a, Özdemir, et al., 2024c; Özdemir, et al., 2024d; Shammam & Bennett 2010).

2.3.2.1 DAF with Classical Pump System (CP-DAF)

Classic DAF system consists of pressure tank, compressor and recirculation pumps. (Eckenfelder, 1966). Approximately 30-40% treated wastewater from the system outlet is taken into the pressure tank. It is desired to create dissolved air in the pressure tank operating at 4-6 bar operating pressure. (Eckenfelder et al., 1989). These pumps are selected from multistage pumps, which are pumps with low flow rate and high pressure, in order to renew the pressure in the pressure tank, and are generally used for the transmission of clean water such as drinking water. Air is supplied into the pressure tank by a compressor. In the pressure tank, water is saturated with air under pressure. Water saturated with air is taken into the flotation unit and the pressure applied to the water in the flotation unit is removed. Air dissolved under pressure suddenly turns into a gas under atmospheric conditions and forms bubbles. If the process is carried out properly within the framework of this principle, a large amount of micro air bubbles will be produced. These produced micro air bubbles are 50 to 120 microns in diameter and rise at a very slow speed, while also carrying organic loads and dissolved oils in the water upwards. (Şengül & Küçükgül, 1990) Subsequently, the flocs to be formed are removed from the water surface by the scum scraper system and transferred to the sludge tank. The flow diagram of the CP-DAF system is given in Figure 2.5.

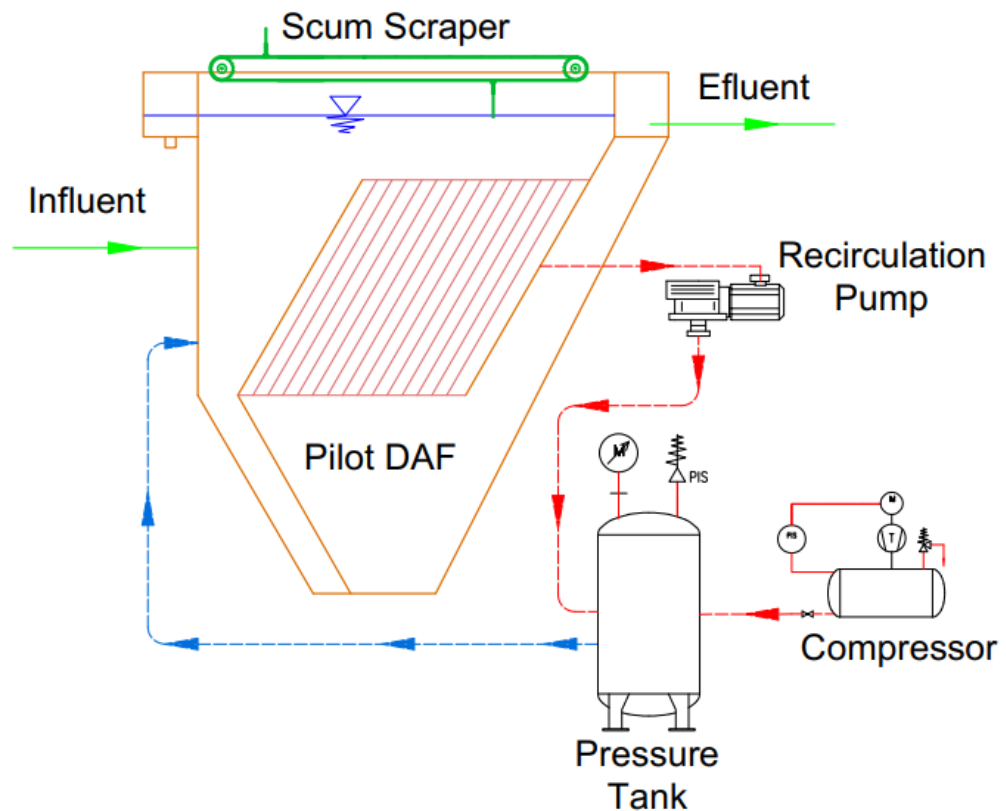


Figure 2.5 The flow diagram of the CP-DAF system

2.3.2.2 DAF with Microbubble Generator Pump (MB-DAF)

In MB-DAF systems, which are an alternative to this system, a separate pressure tank or compressor is not used, instead of them there is MBP. While this pump circulates 30-40% of the purified water into the system, it produces micro air bubbles by mixing the air taken from the atmosphere with the wastewater and gives it to the flotation system. These produced micro air bubbles are 20 to 50 microns in diameter in MB-DAF System. The flow diagram of the MB-DAF system is given in Figure 2.6. As can be seen from the figure, there is no separate pressure tank, compressor and recirculation pump in the system.

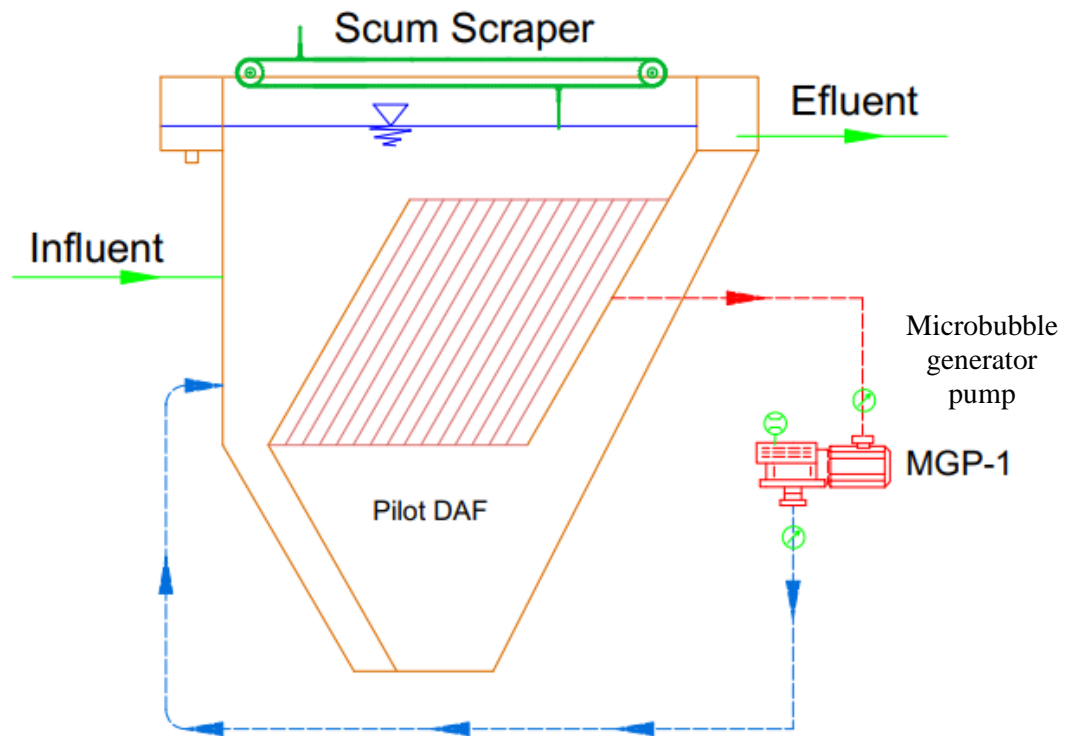


Figure 2.6 The flow diagram of the MB-DAF system

2.3.2.3 Comparison of CP-DAF System and MB-DAF Systems

The CP-DAF system has a more complex structure than the MB-DAF systems. In addition, because it consists of more equipment, the need for maintenance and repair is more and it breaks down more often. It should be work under the control of a technician person in order not to interrupt the operation. This situation requires constant effort and attention in terms of the enterprise. According to the specified features, it can be stated that the operation process of the CP-DAF system is more complex and the effluent quality is lower than the MB-DAF system. The main differences between the two systems are summarized in Table 2.2. (Özdemir & Alpaslan, 2021)

The biggest difference between the two systems is the microbubble size. Generally, the bubble size in CP-DAF systems is 50-120 microns in diameter, and in MB-DAF systems it is reduced to 20-50 microns. As the microbubble size decreases and the surface area increases, the removal efficiency of MB-DAF systems increases.

Table 2.2 Differences between CP-DAF System and MB-DAF System

| In CP-DAF System | In MB-DAF System |
|---|--|
| <ul style="list-style-type: none"> • Compressor is used for air requirement | <ul style="list-style-type: none"> • Compressor is not available |
| <ul style="list-style-type: none"> • There is a pressure tank for the mixture | <ul style="list-style-type: none"> • There is no pressure tank |
| <ul style="list-style-type: none"> • A pressure switch is used for level control in the pressure tank | <ul style="list-style-type: none"> • There is no pressure switch because it is not pressure tank |
| <ul style="list-style-type: none"> • Pneumatic valve is used | <ul style="list-style-type: none"> • Pneumatic valve is not used because it is not pressure tank |
| <ul style="list-style-type: none"> • Level float is used in the pressure tank | <ul style="list-style-type: none"> • Level float is not used because it is not pressure tank |
| <ul style="list-style-type: none"> • The number of materials and control mechanism in the electrical panel is high | <ul style="list-style-type: none"> • The number of materials and control mechanism in the electrical panel is few |
| <ul style="list-style-type: none"> • More automation steps | <ul style="list-style-type: none"> • Less automation steps |
| <ul style="list-style-type: none"> • It requires large area | <ul style="list-style-type: none"> • A compact design is available |

In the literature, there are studies related to the Classical DAF (CP-DAF) and the New-Generation DAF (MB-DAF) systems. The performance of CP-DAF and MB-DAF systems in treating restaurant wastewater has been investigated in a study carried out by Zheng. (Zheng et al. 2015). The study used a flotation tank with a volume of 14 L and a microbubble pump with 1.1 kW and 13-40 L / min capacity. The microbubble pump was operated at 35 MPa pressure and 25% return flow ratio, with a detention time of 15 min. In the MB-DAF system, the treatment efficiency for oil, COD and

turbidity was found to be 10.3%, 22.6% and 15% higher, respectively, compared to the CP-DAF system.

In a laboratory-scale (2 L volume) study by Pereira et al. (Pereira et al. 2018), the effect of factors such as pressure, recycling ratio, pH, and coagulant addition on the CP-DAF system has been investigated with synthetically prepared milk wastewater. COD, color and turbidity efficiencies were determined as 87.5%, 83.1% and 97.8%, respectively.

In a similar study (Couto et al. 2004), synthetically prepared milk wastewater was used. In the 5.5 L flotation tank, the microbubble size in different pressure applications was examined, and the efficiency with respect to the recycling ratio was determined. A treatment efficiency of 90% was obtained when the return and recirculation flow rates were the same, and the working pressure was 4 atm.

Studies in the literature demonstrate that the MB-DAF system is more efficient than the CP-DAF technology. However, these studies were carried out on a laboratory scale with small volumes and using synthetic wastewater. On the other hand, the treatment is a rather dynamic process due to the differences in the influent wastewater flow rate, pollutant concentration, operating characteristics, etc. Therefore, modelling studies are important for taking these variables into account during planning and operation. The complex processes can be modelled, and the effects of different variables can be estimated using historical data and/or pilot scale experimental setups.

CHAPTER THREE

EXPERIMENTAL STUDIES

3.1 Experimental Procedure

Experimental studies were carried out on a pilot-scale DAF system that can be operated as both a classical DAF (CP-DAF) and a new-generation DAF (MB-DAF) system by using appropriate piping and instrumentation. The effect of microbubble formation on treatment performance was evaluated using a conventional pump and a microbubble pumps. The set-up operated as a classical DAF (CP-DAF) first. The system was run with clean water, first to check the piping and instrumentation. the flow rate of each unit with a flow meter was measured and the pressure adjustments with a manometer was made. Once the system had been checked, the experimental studies started using dairy wastewater. The inlet flow rates were changed between 1 and 5m³/h (1-2-3-4-5 m³/h). The pressures were set at 3, 3.5, 4, 4.5 and 5 bar. After the CP-DAF operation, the setup was converted to the new generation microbubble DAF systems by changing the pipes and instruments. Experiments were then continued with microbubble-generating pumps. The set-up was operated by microbubble pumps, nominated as MB-DAF-1 and MB-DAF-2. Once each MB-DAF unit was installed, the system was run with clean water to check the piping and instrumentation. Once the system had been checked, the experimental studies started using dairy wastewater. The performance of each system was determined by analyzing of the oil and grease, suspended solids (SS), and chemical oxygen demand (COD) the inlet and outlet samples were collected from the M-01 and M-02 water taps Temperature and pH were measured for control purposes. The performance of each system was determined separately: CP-DAF, MB-DAF-1 and MB-DAF-2. The effects of operating parameters such as flow rate and pressure on the efficiency of the pilot-scale DAF systems were investigated, also.

In the second step, the impact of the impeller profile of the microbubble pump were evaluated by modifying the blades. The revision was carried out on MB-DAF-1 system which was the most efficient one. The both of an increase and a decrease in the number of blades on microbubble generation were examined. The pilot systems with increased numbers of blades were designated as MOMB-DAF 1, while the other was MOMB-

DAF 2. Both MOMB-DAF 1 and MOMB-DAF 2 were operated at the optimal pressure determined in the previous stage. These systems were run at different flow rates, namely 1, 2, 3, 4 and 5 m³/h at 4 bars. The treatment efficiency was calculated using COD, oil and grease and SS parameters. A schematic overview of the experimental procedure is provided in Figure 3.1, while Figure 3.2 list of the variables.

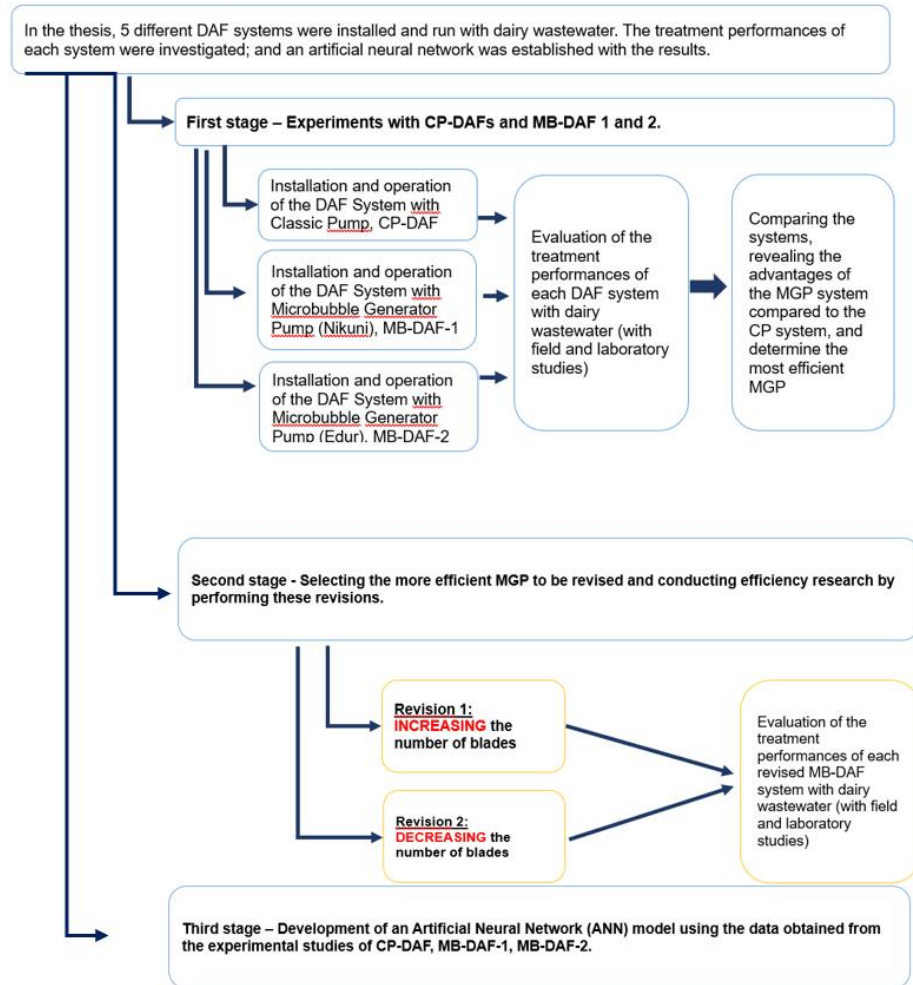


Figure 3.1 A schematic overview of the experimental procedure

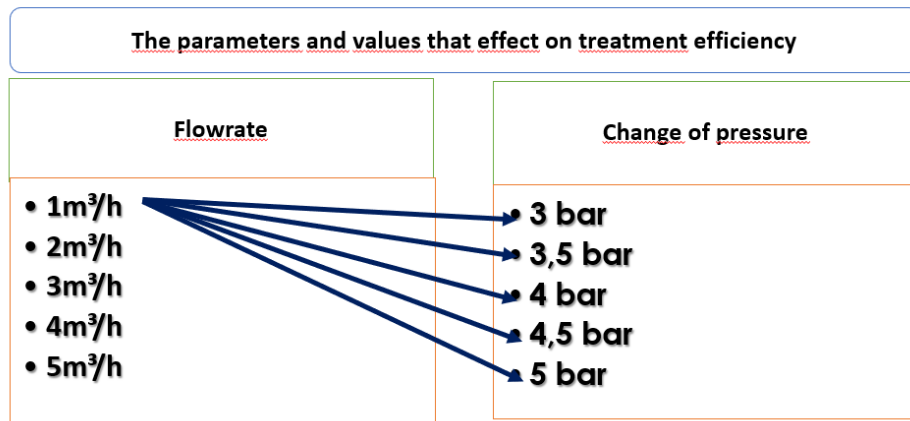


Figure 3.2 List of the variables

CP-DAF, MB-DAF-1 and MB-DAF-2; three different DAF setup each has physical and technological differences. In order to evaluate the treatment efficiency of each DAF system, experiments were carried out by gradually changing the parameters that affect the purification efficiency. In this way, it was seen whether each parameter had a positive or negative effect on the efficiency.

Finally, an Artificial Neural Network (ANN) using data obtained from experimental studies for CP-DAF, MB-DAF-1 and MB-DAF-2 were configured. ANN was designed to learn the operation and design parameters of the DAF system for use under different operating conditions that is given Figure 3.2. This allows us to determine the efficiency of the DAF system to be operated under different operating conditions without testing. ANN was used to train and apply the results obtained from the experimental sets with the program written in MATLAB using the Levenberg-Marquardt backpropagation algorithm.

3.2 Experimental Set-Up (Pilot Scale DAF Systems)

In the experimental studies, a pilot-scale DAF unit made of polypropylene was used. Prior to construction, a three-dimensional drawing of the DAF unit was produced

(see Figure 3.3). The pilot-scale DAF unit measures 100-150-155 cm (width-length-height) and has a volume of approximately 1.50 m³. The set-up was designed with a relatively high capacity compared to literature studies (laboratory scale DAF systems reported in the literature ranged from 2-14 L). Because, the capacity of the microbubble generating pump that could be obtain on the market was 1m³/hour. It was thought that using a high-capacity pump in a very small volume would make it difficult to eliminate the scale effect. Therefore, in order to obtain more realistic results, we preferred to use a larger capacity experimental set-up in our studies. The DAF pilot system was constructed with funding provided by KOSGEB (Project No. B.14.2.KGS.1.35.02.00-110.02.01.-844).

The pilot DAF unit was comprised of three distinct zones: contact, flotation, and sedimentation. For DAF systems to operate efficiently, their geometric design and the relationship between the zones within them are also important. A scraper was fitted on top to remove oils that will accumulate in the flotation section (see Figure 3.4). Sampling taps made of PVC material were located on the inlet and outlet for the collection of wastewater samples. A flow meter and a valve were placed on the inlet to regulate the flow. The settled materials in the sludge chamber, located at the bottom of the sedimentation section, were removed using a sludge removal valve. The schematic view of the pilot DAF systems is given Figure 3.4.

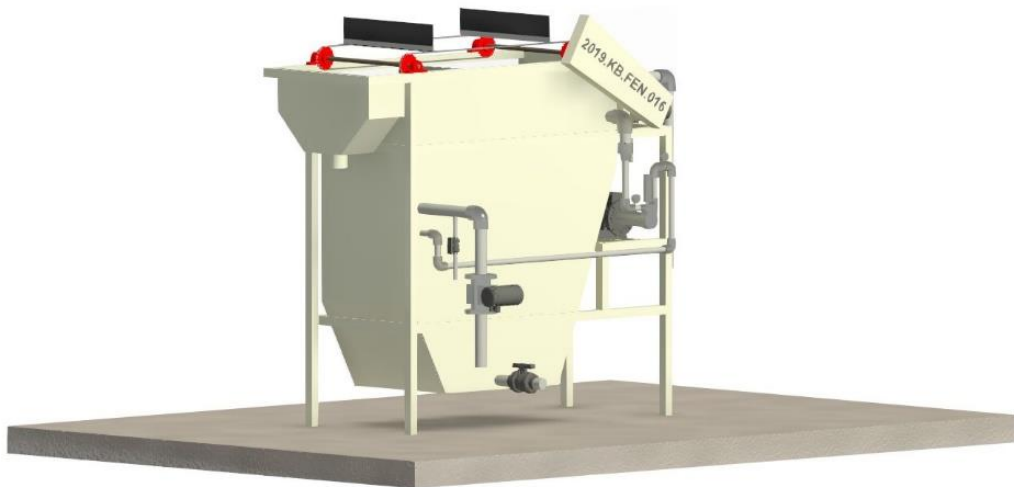


Figure 3.3 Three-dimensional drawing of the DAF pilot plant

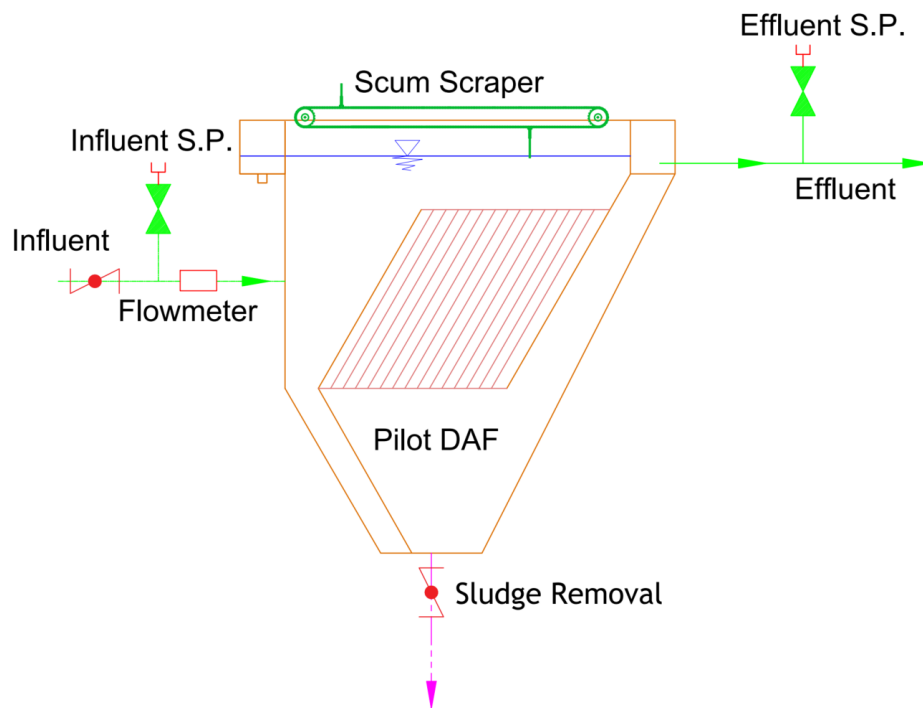


Figure 3.4 The schematic view of the pilot DAF systems

3.2.1 Classical DAF System (CP-DAF)

The CP-DAF system consisted of a pressure tank, compressor and recirculation pump. Approximately 30-40% of the effluent was recirculated to the pressure tank. The pressure tank was created dissolved air at 4-6 bar operating pressure. The pressure tank was made from galvanized steel and had a diameter of 40 cm and a height of 70 cm. It included a range of instruments, including a digital manometer (0-10 bar), digital vacuum meter (0-1 bar), air flow meter (6-60 L/min), pneumatic pressure switch (0.5-12 bar), level sensor, level float 1/2", pneumatic valve Ø40 1 1/4" actuated spherical valve + direction valve + switch box, DG25 40 bar digital manometer, semi-automatic 1/4" 5-2 Namur valve 24 V DC, and etc. The compressor used in the Pilot CP-DAF System had 1.1 kW power, 980 rpm speed, and dimensions (W x L x H) of 600 x 1150 x 1000 mm. A multistage horizontal shaft centrifugal pump was used for recirculation purposes. It was made from stainless steel and had a power of 1.1 kW, a flow of 2 m³/h (63 mSS).

The CP-DAF system was supplied with wastewater taken from the equalization tank by a submersible pump during the operation. 40% of the wastewater from the effluent was pumped to the pressure tank by means of a centrifugal pump. At the same time, the compressor was used to introduce air to the pressure tank. Pressurized air was dissolved in water and then fed into the system. The influent and pressurized effluent met in the contact chamber. The air bubbles attached to the oil droplets and brought them to the surface. Oil, grease and light particles were then removed by a surface scum scraper. The effluent samples were collected from effluent sampling valves. The flow diagram of the CP-DAF System is given in Figure 3.5, and the images of the CP-DAF System are given in Photos 3.1, 3.2 and 3.3.

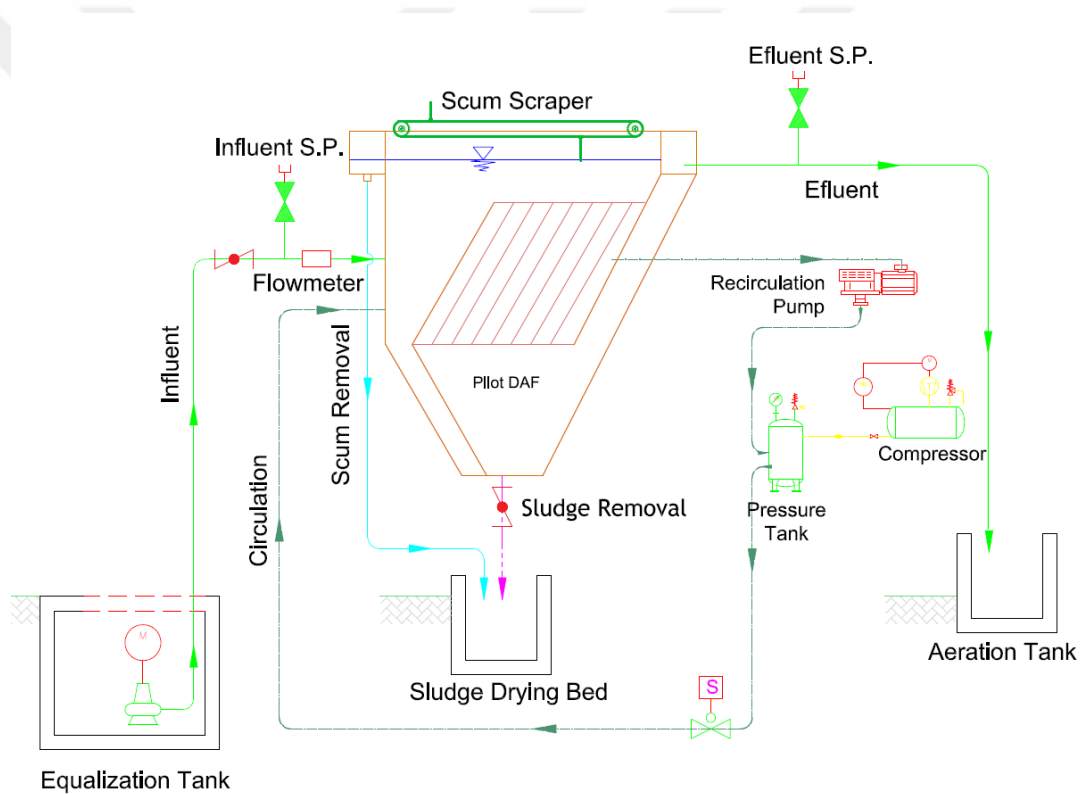


Figure 3.5 Flow Diagram of CP-DAF System used in the field studies



Photo 3.1 CP-DAF System used in the field studies



Photo 3.2 The pressure tank of CP-DAF System used in the field studies (Personal archive, 2022)



Photo 3.3 The pressure tank of CP-DAF System used in the field studies, (Personal archive, 2022)

3.2.2 Microbubble Generator Pump DAF-1 System (MB-DAF-1)

The MB-DAF-1 used a pump that absorbs both air and water at the same time, producing micro air bubbles by dissolving the air in the water in the pump. In the MB-DAF-1, the pressure tank and compressor were replaced with a microbubble generator pump (MBP). The MBP circulated 30-40% of the effluent, mixing it with the air was taken from the atmosphere and producing micro air bubbles. The Nikuni pump was used in the MB-DAF-1 System. It had 1.1 kW power and was operated at 3-5 bar. The pump had a speed of 1450 min^{-1} and a flow of $1 \text{ m}^3/\text{h}$.

The schematic diagram of the Microbubble Generating Pump-1 is given Figure 3.6, The images and the flow diagram of the MB-DAF-1 System is given in Figure 3.7, respectively. In addition, images of MB-DAF-1 System on Pilot DAF used in field studies and its' piping are given in Photos 3.4, and 3.5.

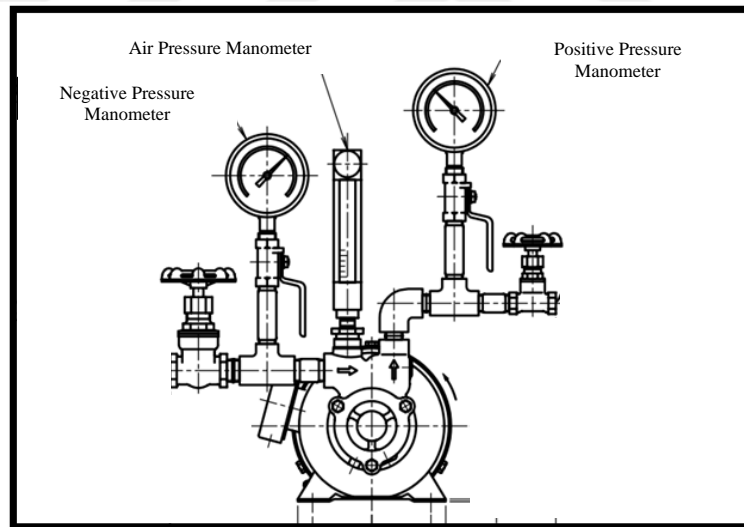


Figure 3.6 The schematic diagram of the Microbubble Generating Pump-1

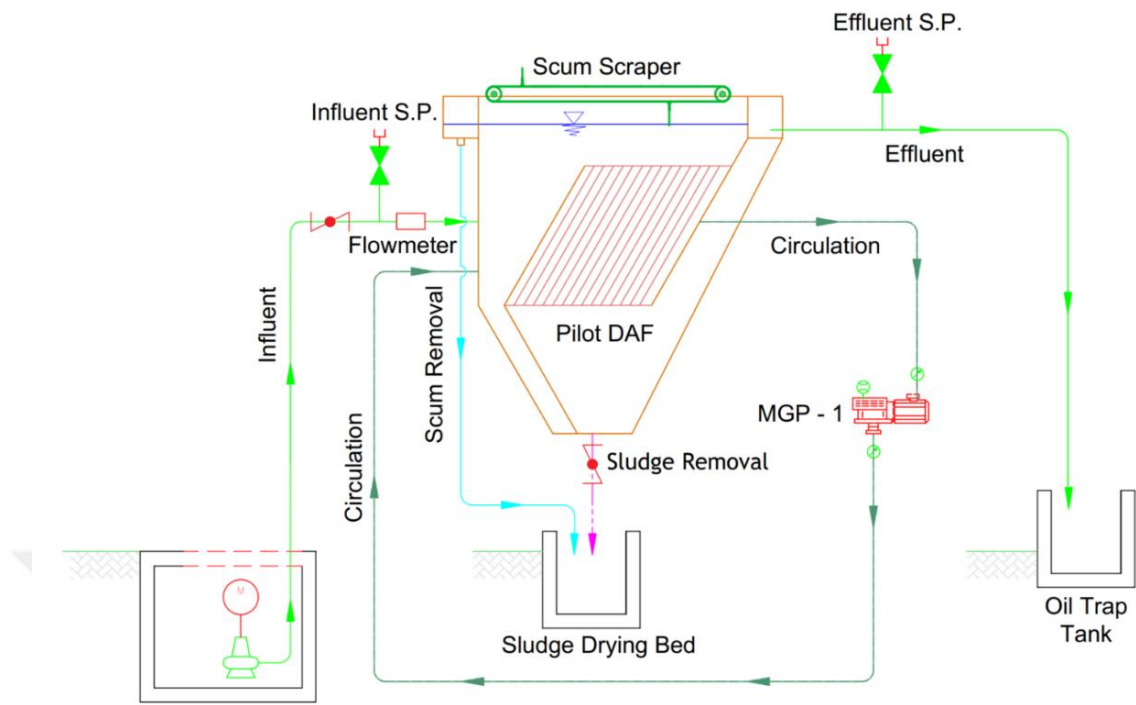


Figure 3.7 Flow Diagram of MB-DAF-1 System (Özdemir, et al., 2024c)



Photo 3.4 Images of MB-DAF-1 System on Pilot DAF used in Field Studies (Personal archive, 2022)



Photo 3.5 Piping of the MB-DAF-1 System (Personal archive, 2022)

3.2.3 Microbubble Generator Pump DAF-2 System (MB-DAF-2)

The MB-DAF-2 used a pump that absorbs both air and water at the same time, producing micro air bubbles by dissolving the air in the water in the pump. This pump was purchased as part of the research project (BAP). The MB-DAF-2 system used only the microbubble generator pump (MBP), not the pressure tank and compressor. The MBP circulated 30-40% of the effluent, mixing it with the air was taken from the atmosphere and producing micro air bubbles during operation. The MB-DAF-2 System used an Edur pump with 1.1 kW power and an operating pressure of 3-5 bar. The pump had a speed of 1450 min⁻¹ and a flow of 1 m³/h. In general, the technical specifications of the Edur microbubble pump were similar to Nikuni, but the impeller structure of the pump that produces microbubbles was different.

The schematic diagram and a flow diagram of the Microbubble Generating Pump-2 are shown in Figure 3.8 and Figure 3.9, respectively. In addition, images of MB-

DAF-2 System on Pilot DAF used in Field Studies and its' piping are given in Photo 3.6 and Photo 3.7.

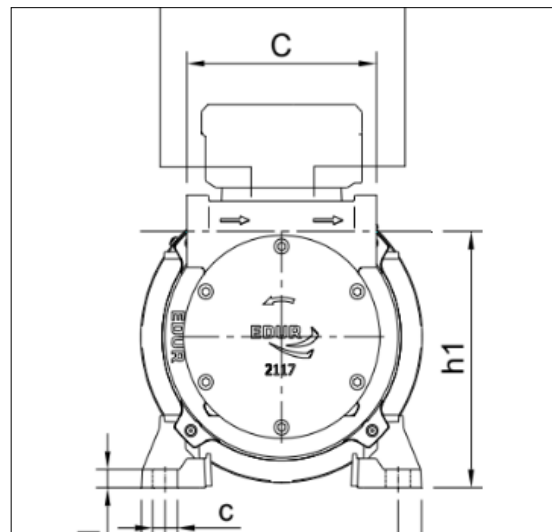


Figure 3.8 The schematic diagram of the Microbubble Generating Pump-2

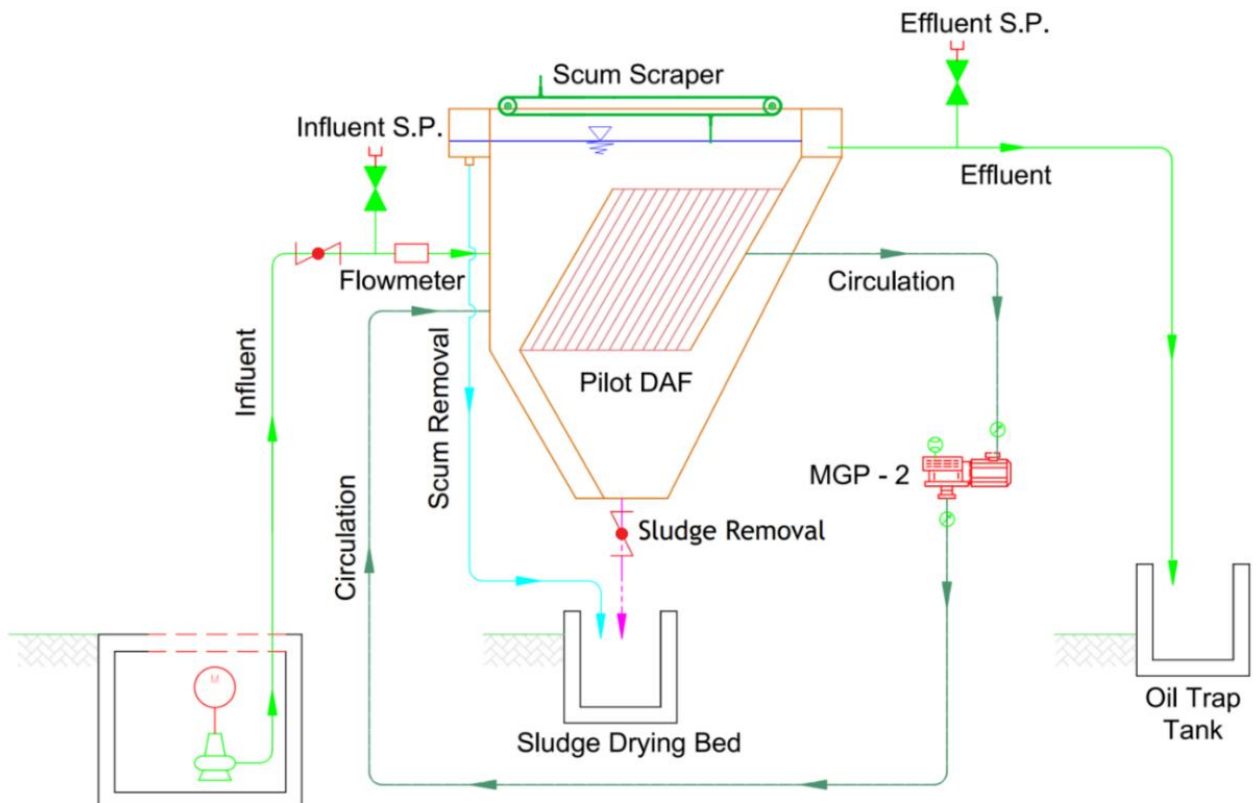


Figure 3.9 Flow Diagram of MB-DAF-2 (Özdemir, et al., 2024c)



Photo 3.6 Images of MB-DAF-2 System on Pilot DAF used in field studies (Personal archive, 2022)



Photo 3.7 Piping of the MB-DAF-2 System (Personal archive,2022)

3.2.4 Modified Microbubble Generator Pump DAF System (MOMB-DAF-1 and MOMB-DAF-2)

Microbubbles are produced by the high-pressure mixing of water and air supplied by the pump inlet due to the strong swirling flow due to the rotating of the impeller and the vanes of the impeller blade. The shape and number of the blades are crucial components of the microbubble-generating pumps. Therefore, various studies had been conducted changing the impeller's geometric parameters.

The microbubble pumps used in this study were conventional microbubble pumps (i.e. MB-DAF 1 and MB-DAF 2). They had an open channel impeller that have simple structure and lower manufacturing cost. The number of blades of the MB-DAF 1 and MB-DAF 2 pumps are 44 and 24 respectively.

The MB-DAF-1 impeller system is equipped with 44 blades. The impeller system of Microbubble Generator Pump (MBP) -1 is given Photo 3.8 and Photo 3.9.



Photo 3.8 The impeller system of MBP-1 (Personal archive,2022)



Photo 3.9 The impeller system of MBP-1 (Personal archive,2022)

The MB-DAF-2 impeller system is equipped with 24 blades. The impeller system of Microbubble Generator Pump (MBP) -2 is given Photo 3.10 and Photo 3.11.



Photo 3.10 The impeller system of MBP-2
(Personal archive,2022)



Photo 3.11 The impeller system of MBP-2
(Personal archive,2022)

The highest efficiency was obtained with the Nikuni pump in studies (44 blades). The main difference of between these two pumps was the number of blades. So that, to observe the effect of increasing and decreasing the number of blades on microbubble formation, a modification was made to the impeller of the pump.

Firstly, the number of blades had been increased to 52, which is the highest number of blades made on a turning lathe (Modified Microbubble Generator Pump DAF System (MOMB-DAF-1). Prior to manufacture, technical drawings and the three-dimensional model of impeller system- MOMB-DAF-1 were made (see Figure 3.10 and 3.11). A prototype was then produced on the 4-axis CNC machine. The photos of these works are presented at Photo 3.12. The photo that comparison of impeller system of MB-1 ad MB-2 with MOMB-1 is shown in Photo 3.13.

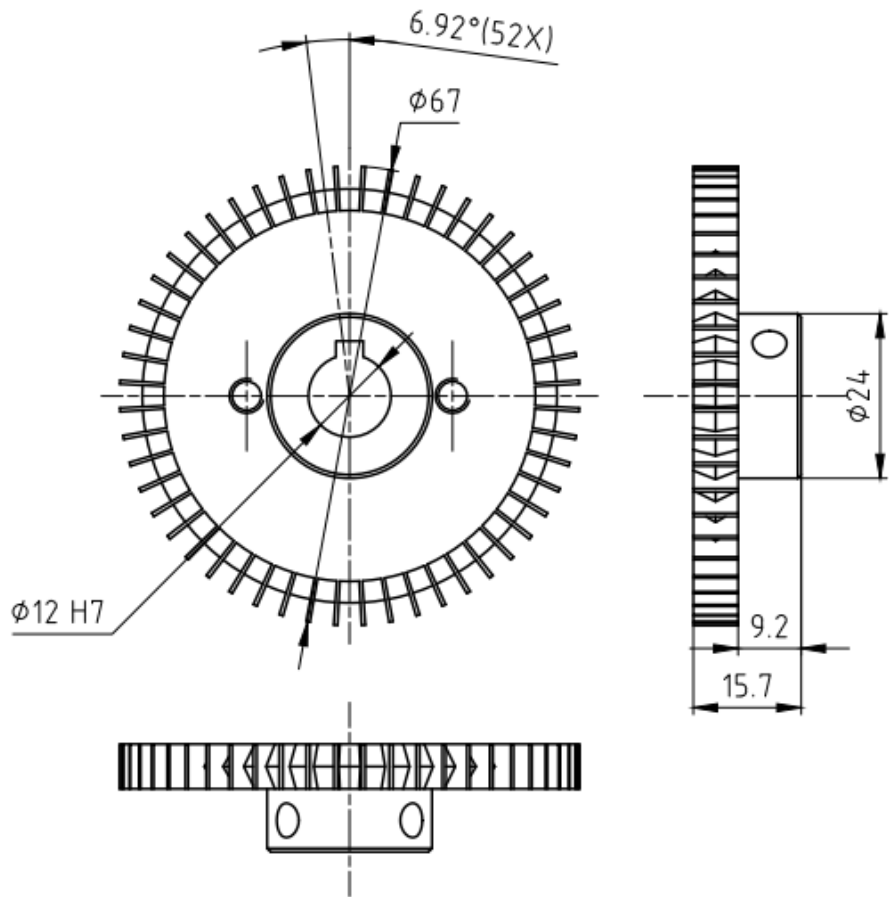


Figure 3.10 Technical drawing of impeller system- MOMB-DAF-1

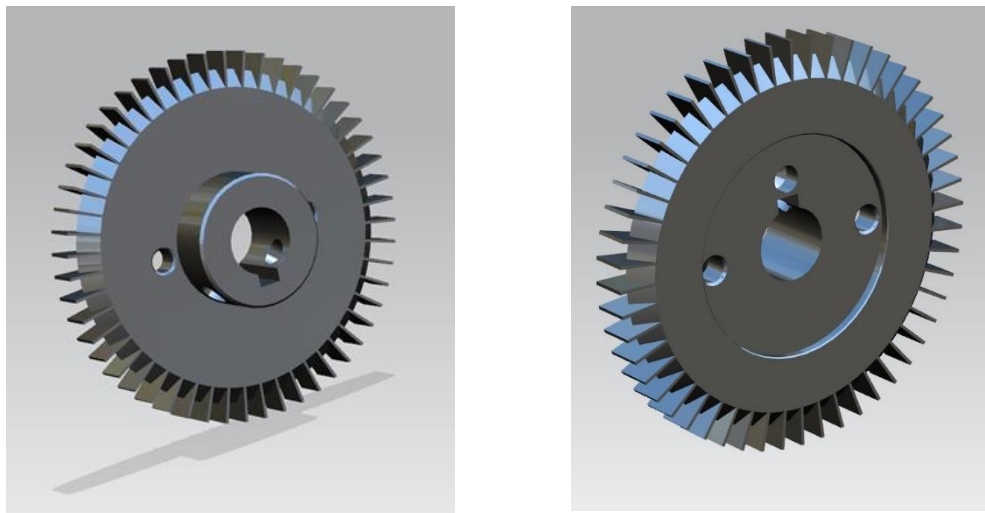


Figure 3.11 The three-dimensional model of impeller system - MOMB-DAF-1



Photo 3.12 Pictures of the production of the modified MB pump on a 4-axis CNC machine (Personal archive,2023)

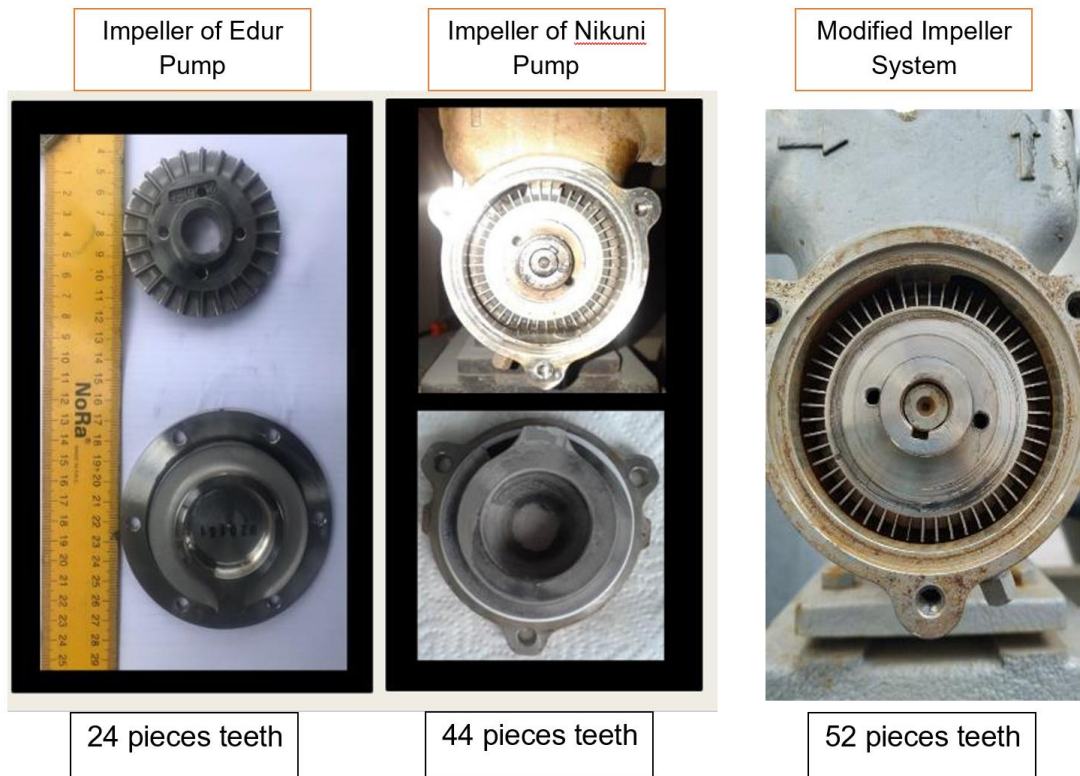


Photo 3.13 Comparison of impeller system of MB-1 ad MB-2 with MOMB-1 (Personal archive,2023)

In addition, to observe the effect of decreased number of blades on microbubble formation, a modification was made to the impeller of the pump. The number of blades

had been decreased to 36 (Modified Microbubble Generator Pump DAF System (MOMB-DAF-2)).

Technical drawing of impeller system- MOMB-DAF-2 is given in Figure 3.12 and the three-dimensional model of impeller system MOMB-DAF-1 Figure 3.13, respectively. In addition, Comparison of impeller system of MB-1 ad MB-2 with MOMB-2 is given in Photo 3.14.

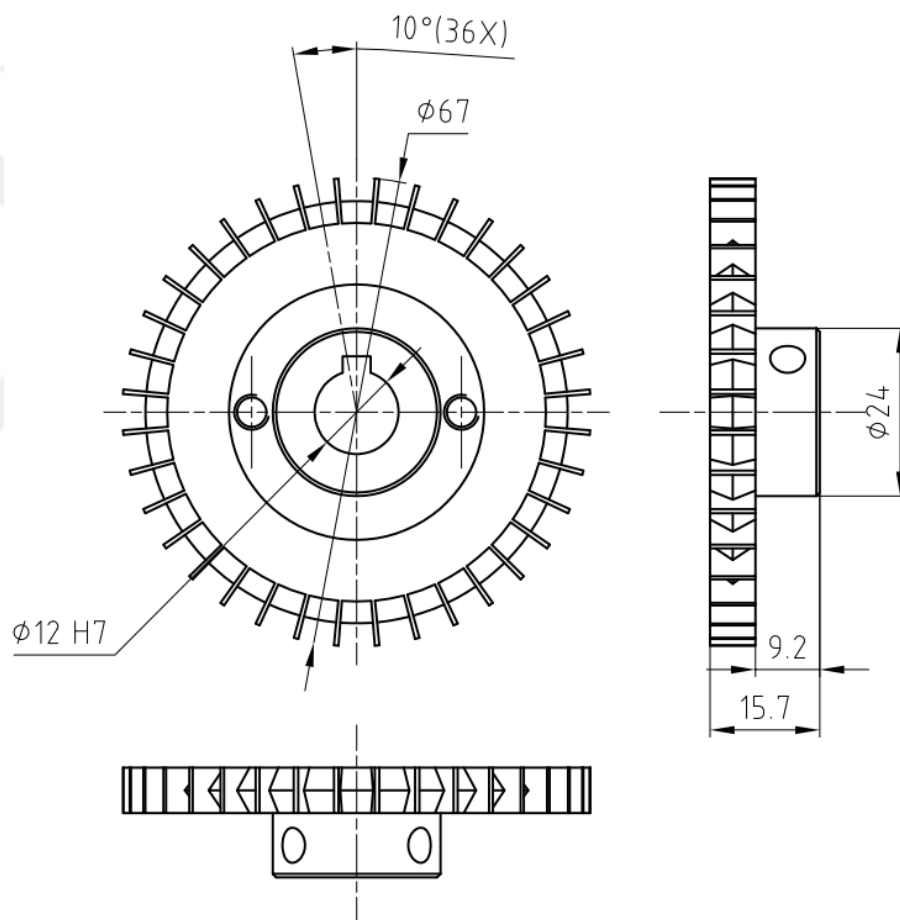


Figure 3.12 Technical drawing of impeller system- MOMB-DAF-2

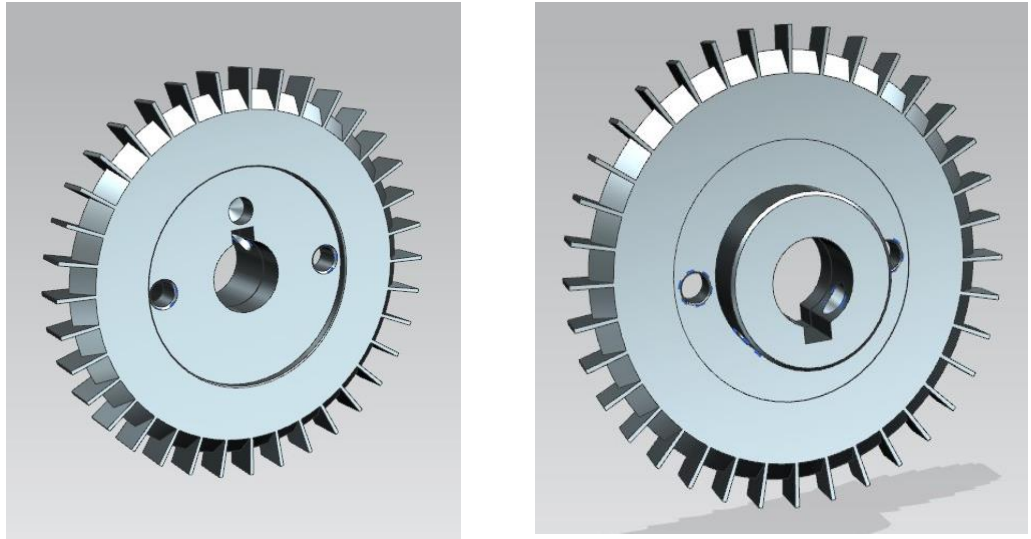


Figure 3.13 The three-dimensional model of impeller system - MOMB-DAF-2

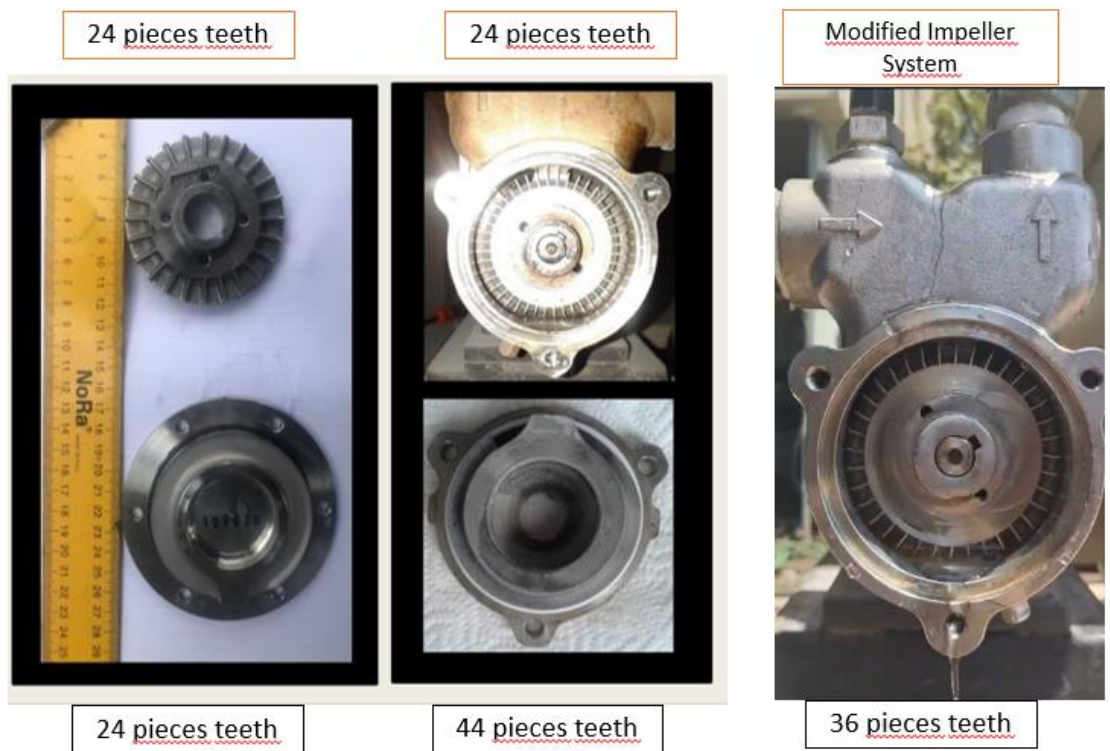


Photo 3.14 Comparison of impeller system of MB-1 ad MB-2 with MOMB-2 (Personal archive,2024)

3.3 Wastewater Characterization

Experimental studies carried out with wastewater from a milk and dairy products industry. The company is located in Izmir-Foça and produces yoghurt, butter, cheese, ayran and milk desserts. The whey is collected separately and sent to the recycling plant. It has a wastewater treatment plant with a capacity of 200 m³/day. The wastewater treatment plant consists of an equalization tank, an oil trap tank and a biological treatment system using the activated sludge process. Since the pilot plant's capacity was high, it was not feasible to obtain the wastewater from the factory to feed it on a daily basis. Therefore, the pilot plant was installed within the factory throughout the experimental period. The pilot plant was located between the V-01 equalization tank and the V-02 oil trap tank. The effluent from the equalization tank was fed to the pilot DAF and the effluent was diverted to the aeration tank. Figure 3.14 shows the location of the pilot DAF system in the existing effluent treatment plant.

The influent was collected from the equalization tank and analyzed regularly. The minimum, maximum and average values of COD, SS and oil/grease parameters are shown in Table 3.1.

Table 3.1 Characteristics of wastewater

| Parameter | COD (mg/l) | Oil/Grease (mg/l) | SS (mg/l) |
|---------------|---------------|----------------------|--------------|
| Minimum Value | 1.073 | 110 | 485 |
| Average Value | 1.968 | 194 | 842 |
| Maximum Value | 3.034 | 676 | 1.350 |

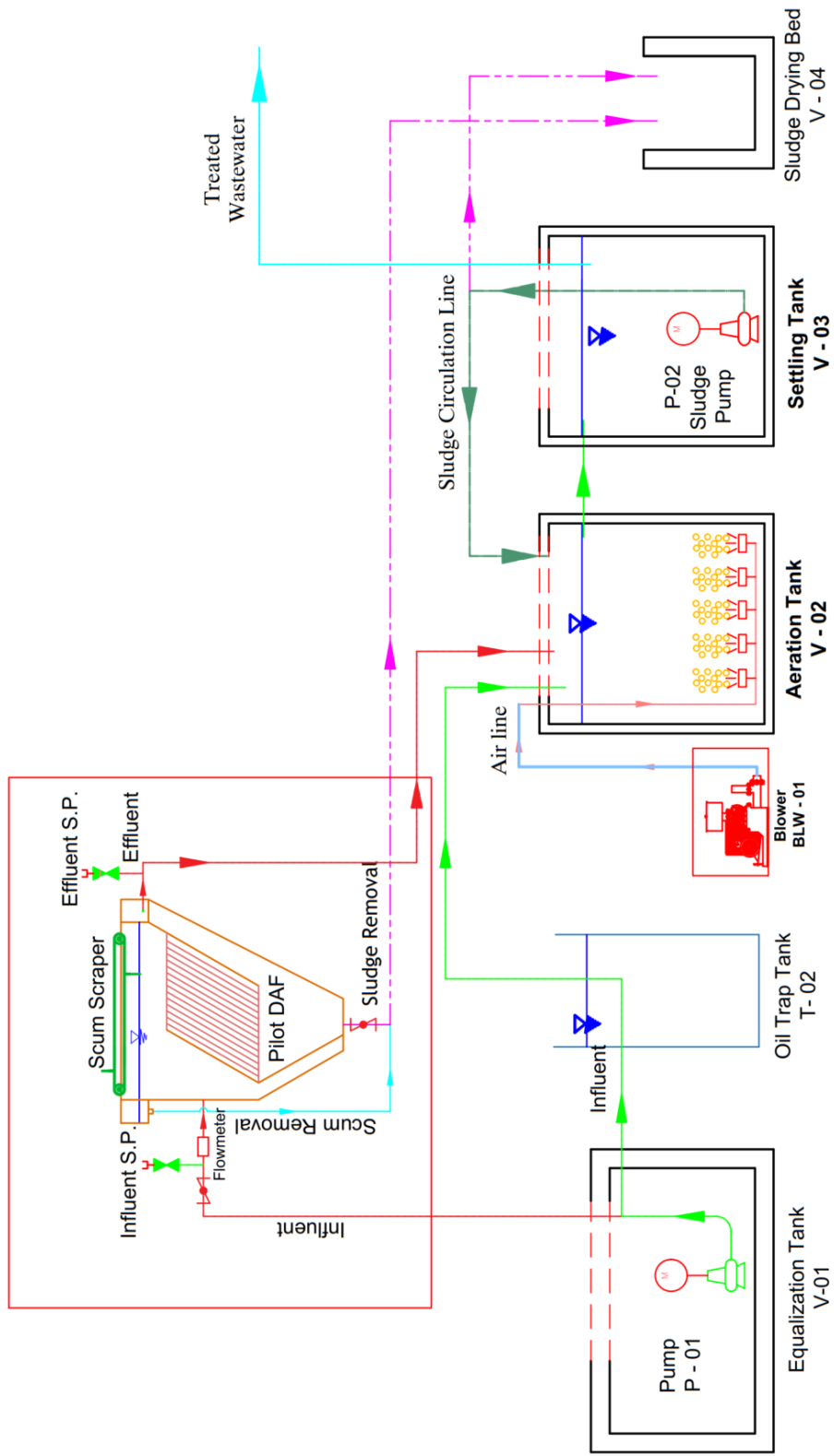


Figure 3.14 Location of Pilot DAF System in Existing Wastewater Treatment Plant

3.4 Sampling and Analyses

Once the DAF Systems had been installed, the piping and mechanical equipment was checked. Each DAF system was run on clean water to see the micro-bubbles that formed. The flowrate values were measured with a flow meter. the cloud (micro-bubble cloud) formed was observed at each pressure value. Once the system was confirmed to be functioning correctly, experimental studies were started with real wastewater. The samples for analysis of the DAF systems were taken manually from two different points:

- From the sampling tap on the influent wastewater line (M-01)
- From the sampling tap on the effluent wastewater line (M-02)

Sampling locations on Pilot DAF is given Figure 3.15.

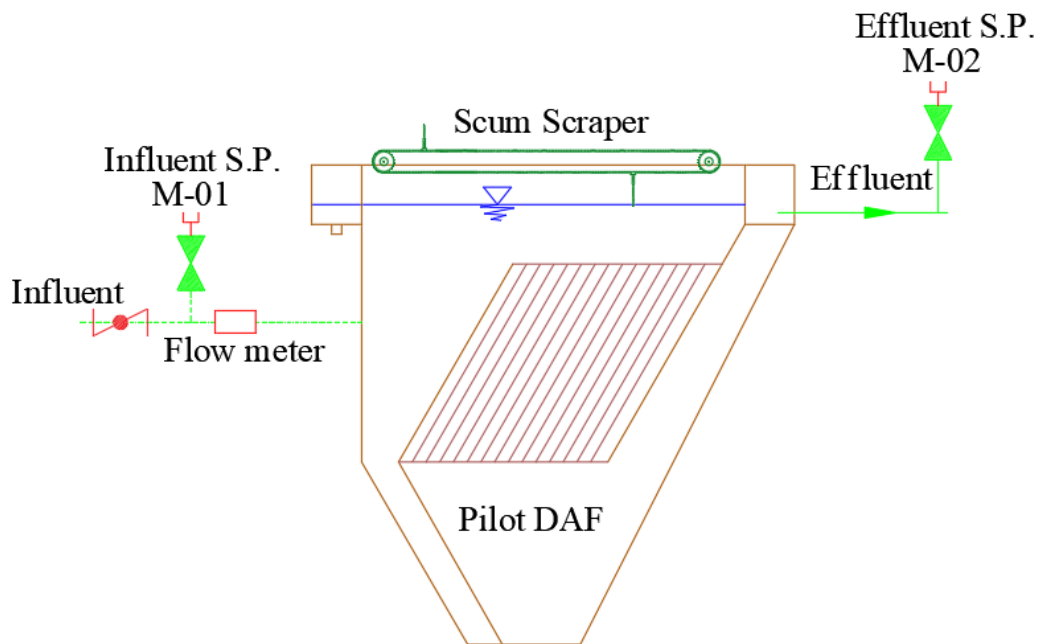


Figure 3.15 Sampling locations on Pilot DAF

The capacity of the pilot DAF unit was 1.54 m^3 . The retention times were calculated as 92, 46, 31, 23, and 18 minutes for flowrates 1, 2, 3, 4, and $5 \text{ m}^3/\text{h}$, respectively. During the experiments, the pilot unit was operated at the specified flow rates (i.e. 1-

5m³/h). Influent samples were taken from the inlet of the unit. At the end of the retention time calculated for each flow rates, effluent samples were taken. This was repeated 3 times and hence three samples were taken from the inlet and effluent; and the bottle was filled to the correct level. The samples were taken in one-liter plastic PET bottles. The samples were labelled with the date, inlet-outlet, flow rate and pressure information written on them. The sample of the chart used in the sampling is shown in Figure 3.16, also sample bottles are given Photo 3.15.

| SAMPLE NUMBER | DATE | VALUES | | | | INLET | | | | | OUTLET | | | | | EFFICIENCY | | | | |
|---------------|------------|-------------|-------|---------------|--------------------|-------------|------|------------|------|------|--------|-------------|------|------------|------|------------|------|-----|------|------|
| | | Hava Durumu | | Qinlet-outlet | Set Pressure Value | Sample Time | COD | Oil&Grease | SS | T °C | pH | Sample Time | COD | Oil&Grease | SS | T °C | pH | KOI | Yağ | Akm |
| | | Temp. | Rains | m3/h | Bar | saat | mg/l | mg/l | mg/l | °C | | saat | mg/l | mg/l | mg/l | °C | | % | mg/l | mg/l |
| 1 | 3.02.2022 | 14°C | NO | 1 | 3 | 12:00 | 2034 | 256 | 1000 | 30,1 | 8,45 | 13:40 | 1277 | 108 | 600 | 29,1 | 8,37 | 37% | 58% | 40% |
| | | | | | | 12:10 | | | | | | 13:50 | | | | | | | | |
| | | | | | | 12:30 | | | | | | 14:10 | | | | | | | | |
| 2 | 4.02.2022 | 17°C | NO | 1 | 3,5 | 10:30 | 1500 | 200 | 780 | 23,5 | 8,56 | 12:10 | 884 | 80 | 400 | 21,9 | 8,24 | 41% | 60% | 49% |
| | | | | | | 10:40 | | | | | | 12:20 | | | | | | | | |
| | | | | | | 10:50 | | | | | | 12:30 | | | | | | | | |
| 3 | 4.02.2022 | 11°C | NO | 1 | 4 | 12:30 | 1939 | 196 | 1200 | 26,7 | 8,6 | 14:10 | 942 | 59 | 450 | 20,7 | 7,94 | 51% | 70% | 63% |
| | | | | | | 12:40 | | | | | | 14:20 | | | | | | | | |
| | | | | | | 12:50 | | | | | | 14:30 | | | | | | | | |
| 4 | 12.02.2022 | 11°C | NO | 1 | 4,5 | 10:45 | 1908 | 236 | 850 | 30,7 | 8,54 | 12:25 | 966 | 82 | 340 | 26,4 | 7,64 | 49% | 65% | 60% |
| | | | | | | 10:55 | | | | | | 12:35 | | | | | | | | |
| | | | | | | 11:05 | | | | | | 12:45 | | | | | | | | |
| 5 | 17.02.2022 | 10°C | NO | 1 | 5 | 15:00 | 2300 | 330 | 710 | 28,2 | 8,69 | 16:40 | 1335 | 126 | 316 | 27,2 | 8,16 | 42% | 62% | 55% |
| | | | | | | 15:10 | | | | | | 16:50 | | | | | | | | |
| | | | | | | 15:20 | | | | | | 17:00 | | | | | | | | |

Figure 3.16 Sample chart of the analyses



Photo 3.15 The Sample Bottles

The performance of DAF Systems with conventional and microbubble pumps were determined with COD, oil/grease and SS parameters. The temperature and pH were measured as part of the control process. The chemical oxygen demand (COD)

experiment was carried out using a photometric system, a spectrophotometer (Hach Lange DR3900) and a COD kit (ready-to-use reagent) (Standard Methods: 5220D). The spectrophotometer and the Thermoreactor were purchased by the researcher with her own funds. These are shown in Photos 3.16 and 3.17. The kits were purchased under the BAP. Influent and effluent kits are given in Photo 3.18 and 3.19. The SS experimental was carried out using the gravimetric method (SS-2540). Used in suspended solids test, oven and filtration apparatus are shown in Photo 3.20 and 3.21. The gravimetric method was used for the oil/grease experiment, which was extracted using the Soxhlet method (SM-5520-D). Oil tests were carried out within the scope of BAP with the support of the DEÜ Environmental Engineering Wastewater Laboratory.



Photo 3.16 DR3900 The Spectrophotometer



Photo 3.17 The Thermoreactor



Photo 3.18 Influent COD Measurement Kit



Photo 3.19 Effluent COD Measurement Kit



Photo 3.20 Oven used in SS Experiment



Photo 3.21 Filtration apparatus



CHAPTER FOUR

EXPERIMENTAL RESULTS

4.1 Performance of the Classical DAF System (CP-DAF)

In order to determine the treatment performance of the classical system, the set-up was operated with classical pump DAF (CP-DAF) as first. The system was run at varied inlet flow rates between 1 and 5 m³/h (1-2-3-4-5 m³/h). The pressures were set at 3, 3.5, 4, 4.5 and 5 bar. The results of the CP-DAF system are given in Table 4.1.

In the case of a flow of 1m³/h, as shown in Table 4.1, the inlet COD concentration ranged from 1230 to 3034 mg/L. The COD removal ranged from 23-45%. Data obtained from the experiments indicated that COD removal was affected by pressure changes. At a flow rate of 1 m³/h, the increase in pressure caused an increase in COD removal. For example, COD removal increased from 25% to 45% at 3.5 and 4 bar pressure. However, after a certain point, i.e. 4 bar, the COD removal efficiencies were reduced to 32% and 27%. Thus, in the operation of the CP-DAF system, at 1m³/h flow rate, the highest COD removal efficiency (45%) was obtained at a pressure of 4bar. The concentration of oil /grease in the influent ranged from 120 to 262 mg/L. At 1m³/h flow conditions, Oil/Grease removal ranged between 45-61%. Similar to COD removal, increases in pressure resulted in a corresponding increase in the removal of oil/grease, up to a certain point. The highest oil removal was similarly obtained at 4bar pressure, with a removal efficiency of 61%. However, pressures exceeding 4 bar resulted in approximately 8% reduction in oil/grease removal efficiency. In DAF systems, as stated in the previous sections, suspended solids also cling to air bubbles and move upwards and are removed by scraping from the surface. The influent SS concentrations of the dairy wastewater exhibited considerable fluctuations, with values ranging between 510 and 1300 mg/L. The removal efficiency was determined to be between 29 and 54%. The highest removal was measured at 4bar. Similar to the COD and Oil/Grease parameters, increases in pressure resulted in a corresponding increase in the removal of suspended solids. Pressures above 4 bar resulted in approximately 12% reduction in solid removal.

In the case of a flow of 2m³/h, the inlet COD concentration ranged from 1277 to 2900 mg/L (see Table 4.1). COD removal was between 22-41%. The experimental data indicated that changes in pressure resulted in corresponding variations in COD removal. At a flow rate of 2 m³/h, 22% of the initial COD was removed in 3 bar. The COD removal was increased to 30% and 41% in 3.5 and 4 bar, respectively. However, after 4 bar, the COD removal efficiencies were reduced to 29% and 24%. Thus, maximum COD efficiency was obtained for 4bar, the efficiency decreased at higher or lower pressure conditions. The concentration of oil /grease in the influent ranged from 120 to 144 mg/L, at 2m³/h inflow rate. The Oil/Grease removal rate was determined to be 20-48%. The maximum Oil/Grease removal was achieved at a pressure of 4 bar with a removal efficiency of 48%. At 4bar pressure, concentration of oil/grease decreased from 144mg/l to 75mg/l. The oil/grease removal decreased under higher or lower pressure conditions, similar to organic matter. The pressures exceeding 4 bar resulted considerable reduction in oil/grease removal efficiency. Furthermore, the SS removal was achieved at a rate of 32-53%. The highest removal was measured at 4bar. Pressures above 4 bar resulted in approximately 20% reduction in solid removal.

For the 3m³/h flow rate, the inlet COD concentration ranged from 1260 to 2415 mg/L. At 3m³/h flow conditions, COD removal ranged from 11-39%. Similar results were obtained with regard to the changes in pressure. At a flow rate of 3 m³/h, the increase in pressure caused an increase in COD removal. For example, the COD removal rate was 11% at 3 bar, whereas it increased to 12% and 39% at 3.5 and 4 bar pressure, respectively. However, after 4 bar, the COD removal efficiencies were reduced to 24% and 22%, for the 4.5 and 5 bars, respectively. Thus, in the operation of the CP-DAF system, at 3m³/h flow rate, the highest COD removal efficiency (39%) was obtained at a pressure of 4bar. The concentration of oil /grease in the influent ranged from 115 to 155 mg/L, at 3m³/h inflow rate. The oil/grease removal rate was determined to be 31-45%. The maximum oil/grease removal was achieved at a pressure of 4 bar with a removal efficiency of 45%. At 4bar pressure, concentration of oil/grease decreased from 144mg/l to 79mg/l. The oil/grease removal decreased under higher or lower pressure conditions, similar to organic matter. The pressures exceeding

4 bar resulted considerable reduction in oil/grease removal efficiency. In addition, the SS removal was achieved at a rate of 39-57%. The highest removal was measured at 4bar. Pressures above 4 bar resulted in approximately 8% reduction in solid removal.

Data obtained from CP-DAF experiments have shown that increasing flow rates caused a decrease in efficiency, as well. The inlet COD concentration ranged from 1110 to 2450 mg/L (see Table 4.1) at 4m³/h inflow rate. COD removal was between 16-33%. Treatment performances were also influenced from the pressure changes. At a flow rate of 4 m³/h, 16% of the initial COD was removed in 3 bar pressure. The COD removal was increased to 30% and 33% in 3.5 and 4 bar, respectively. However, after 4 bar, the COD removal efficiencies were reduced to 31% and 23%. Thus, maximum COD efficiency was obtained for 4bar, the efficiency decreased at higher or lower pressure conditions. The concentration of oil /grease in the influent ranged from 124 to 184 mg/L, at 4m³/h inflow rate. The oil/grease removal rate was determined to be 25-43%. The maximum removal was achieved at a pressure of 4 bar with a removal efficiency of 43%. At 4bar pressure, concentration of oil/grease decreased from 124mg/l to 71mg/l. The pressures exceeding 4 bar resulted considerable reduction in oil/grease removal efficiency. Furthermore, the SS removal was achieved at a rate of 24-45%. The highest removal was measured at 4bar. Pressures above 4 bar resulted considerably reduction in solid removal.

The CP-DAF system exhibited the lowest removal efficiency at a flow rate of 5 m³/h. The inlet COD concentration ranged from 1290 to 2450 mg/L. At 5m³/h flow conditions, treatment performance of the CP-DAF unit was extremely reduced. The COD removal ranged from 7-19%. The increase in pressure caused an increase in COD removal up to 4bar. The COD removal rate was 7% at 3 bar, whereas it increased to 14% and 19% at 3.5 and 4 bar pressure, respectively. However, after 4 bar, the COD removal efficiencies were reduced to 13% and 8%, for the 4.5 and 5 bars, respectively. Thus, in the operation of the CP-DAF system, at 5m³/h flow rate, the highest COD removal efficiency (19%) was obtained at a pressure of 4bar which was considerable

lower than other treatments. The concentration of oil /grease in the influent ranged from 110 to 170 mg/L, at 5m³/h inflow rate. The oil/grease removal rate was determined to be 18-33%. The maximum oil/grease removal was achieved at a pressure of 4 bar with a removal efficiency of 33%. At 4bar pressure, concentration of oil/grease decreased from 138mg/l to 93mg/L. The oil/grease removal decreased under higher or lower pressure conditions, similar to organic matter. The pressures exceeding 4 bar resulted a reduction in oil/grease removal efficiency. In addition, the SS removal was achieved at a rate of 14-23%. The highest removal was measured at 4bar. Pressures above 4 bar resulted in approximately 5% reduction in solid removal.

The data presented in Table 4.1 is illustrated in Figures 4.1–4.3. The impact of the flow rate on COD removal is illustrated in Figure 4.1. As shown in Figure 4.1, the highest chemical oxygen demand (COD) removals were achieved at 4 bar for all flow rates. At 4 bar, the COD removals were found to be 45%, 41%, 39%, 33%, and 19% for flow rates of 1, 2, 3, 4, and 5 m³/h, respectively. The maximum chemical oxygen demand (COD) removal was achieved at a flow rate of 1 m³/h, with a reduction in COD from 3034 to 1659, resulting in an efficiency of 45%.

The impact of the flow rate on oil/grease removal is illustrated in Figure 4.2. As shown in Figure 4.2, the highest oil/grease removals were achieved at 4 bar for all flow rates. At 4 bar, the oil removals were 61%, 48%, 45%, 43%, and 33% for flow rates of 1, 2, 3, 4, and 5 m³/h, respectively. The maximum oil/grease removal was achieved at a flow rate of 1 m³/h, with a reduction in oil/grease from 262 to 102, resulting in an efficiency of 61%.

And, finally, the impact of the flow rate on suspended solid (SS) removal is shown in Figure 4.3. As can be seen in Figure 4.3, the highest SS removals were achieved at 4 bar for all flow rates. At 4 bar, the SS removals were 54%, 53%, 57%, 45%, and 23% for flow rates of 1, 2, 3, 4, and 5 m³/h, respectively. The maximum SS removal

was achieved at a flow rate of 1 m³/h, with a reduction in solids from 1300 to 600, resulting in an efficiency of 54%.

Consequently, the performance of the CP-DAF system was investigated based on oil/grease, suspended solid, and organic matter. The experimental results shown that approximately 61% of the oil/grease and 54% of suspended particles could be removed in the CP-DAF unit.



Table 4.1 Experimental Study Results of the CP-DAF System

| Values | | | Inlet | | | | | Outlet | | | | | The Efficiency | | |
|---|----------------|------------------------|----------|-----------------|---------|---------------------------|-----|----------|-----------------|---------|---------------------------|-----|----------------|--------------|------|
| Inlet Wastewater Flow m ³ /h | Temperature °C | Operating Pressure Bar | COD mg/l | Oil/Grease mg/l | SS mg/l | Wastewater Temperature °C | pH | COD mg/l | Oil/Grease mg/l | SS mg/l | Wastewater Temperature °C | pH | COD % | Oil/Grease % | SS % |
| | | | | | | | | | | | | | | | |
| 1 | 11 | 3 | 1516 | 155 | 700 | 31.8 | 8.3 | 1160 | 85 | 495 | 27.5 | 7.8 | 23 | 45 | 29 |
| 1 | 13 | 3.5 | 1958 | 175 | 860 | 30.3 | 8.4 | 1467 | 89 | 510 | 27.1 | 7.9 | 25 | 49 | 41 |
| 1 | 12 | 4 | 3034 | 262 | 1.300 | 32 | 8 | 1659 | 102 | 600 | 28.3 | 7.5 | 45 | 61 | 54 |
| 1 | 14 | 4.5 | 1672 | 160 | 800 | 26.9 | 7.9 | 1137 | 74 | 420 | 23 | 7.3 | 32 | 54 | 48 |
| 1 | 13 | 5 | 1230 | 120 | 510 | 27.5 | 8.2 | 900 | 57 | 297 | 24 | 7.8 | 27 | 53 | 42 |
| 2 | 14 | 3 | 1410 | 138 | 805 | 29.7 | 7.8 | 1100 | 110 | 550 | 27.1 | 7.3 | 22 | 20 | 32 |
| 2 | 13 | 3.5 | 1517 | 127 | 820 | 30 | 7.5 | 1060 | 94 | 420 | 28.2 | 7.1 | 30 | 26 | 49 |
| 2 | 15 | 4 | 2900 | 144 | 1350 | 27 | 7.7 | 1716 | 75 | 630 | 25.3 | 7.3 | 41 | 48 | 53 |
| 2 | 16 | 4.5 | 2338 | 120 | 960 | 28.9 | 7.5 | 1650 | 80 | 530 | 27.1 | 7.1 | 29 | 33 | 45 |
| 2 | 11 | 5 | 1277 | 138 | 750 | 26.8 | 7.3 | 970 | 99 | 500 | 24.6 | 7 | 24 | 28 | 33 |
| 3 | 12 | 3 | 1698 | 155 | 635 | 27.7 | 7.9 | 1510 | 102 | 390 | 25.4 | 7.5 | 11 | 34 | 39 |
| 3 | 14 | 3.5 | 1647 | 150 | 810 | 28.3 | 8.2 | 1447 | 93 | 410 | 26.9 | 7.9 | 12 | 38 | 49 |
| 3 | 15 | 4 | 2258 | 144 | 1100 | 26.6 | 7.8 | 1375 | 79 | 470 | 25.1 | 7.1 | 39 | 45 | 57 |
| 3 | 17 | 4.5 | 2415 | 115 | 950 | 27.5 | 8.1 | 1831 | 65 | 430 | 25.6 | 7.5 | 24 | 43 | 55 |
| 3 | 14 | 5 | 1260 | 155 | 880 | 28.2 | 7.7 | 985 | 107 | 445 | 27.1 | 7.1 | 22 | 31 | 49 |
| 4 | 15 | 3 | 1631 | 126 | 485 | 27.8 | 8.5 | 1370 | 95 | 370 | 26.1 | 7.9 | 16 | 25 | 24 |
| 4 | 15 | 3.5 | 1725 | 127 | 610 | 28.7 | 8.1 | 1200 | 89 | 440 | 26.3 | 7.6 | 30 | 30 | 28 |
| 4 | 12 | 4 | 2066 | 124 | 980 | 29.5 | 7.6 | 1380 | 71 | 540 | 27.1 | 7.1 | 33 | 43 | 45 |
| 4 | 13 | 4.5 | 2450 | 184 | 660 | 26.7 | 7.5 | 1700 | 112 | 450 | 24.6 | 7 | 31 | 39 | 32 |
| 4 | 13 | 5 | 1110 | 158 | 570 | 27.8 | 8.2 | 850 | 112 | 420 | 26.1 | 7.6 | 23 | 29 | 26 |
| 5 | 12 | 3 | 1430 | 110 | 510 | 27.2 | 8.3 | 1330 | 90 | 440 | 25.7 | 7.5 | 7 | 18 | 14 |
| 5 | 11 | 3.5 | 1504 | 137 | 650 | 28.1 | 7.9 | 1300 | 96 | 520 | 26.2 | 7.3 | 14 | 30 | 20 |
| 5 | 12 | 4 | 2450 | 138 | 750 | 28.3 | 7.7 | 1980 | 93 | 580 | 26.6 | 7.2 | 19 | 33 | 23 |
| 5 | 11 | 4.5 | 2356 | 169.6 | 595 | 26.9 | 7.9 | 2050 | 120 | 470 | 24.8 | 7.4 | 13 | 29 | 21 |
| 5 | 14 | 5 | 1290 | 150 | 570 | 27.7 | 8.2 | 1190 | 117 | 470 | 26.1 | 7.7 | 8 | 22 | 18 |

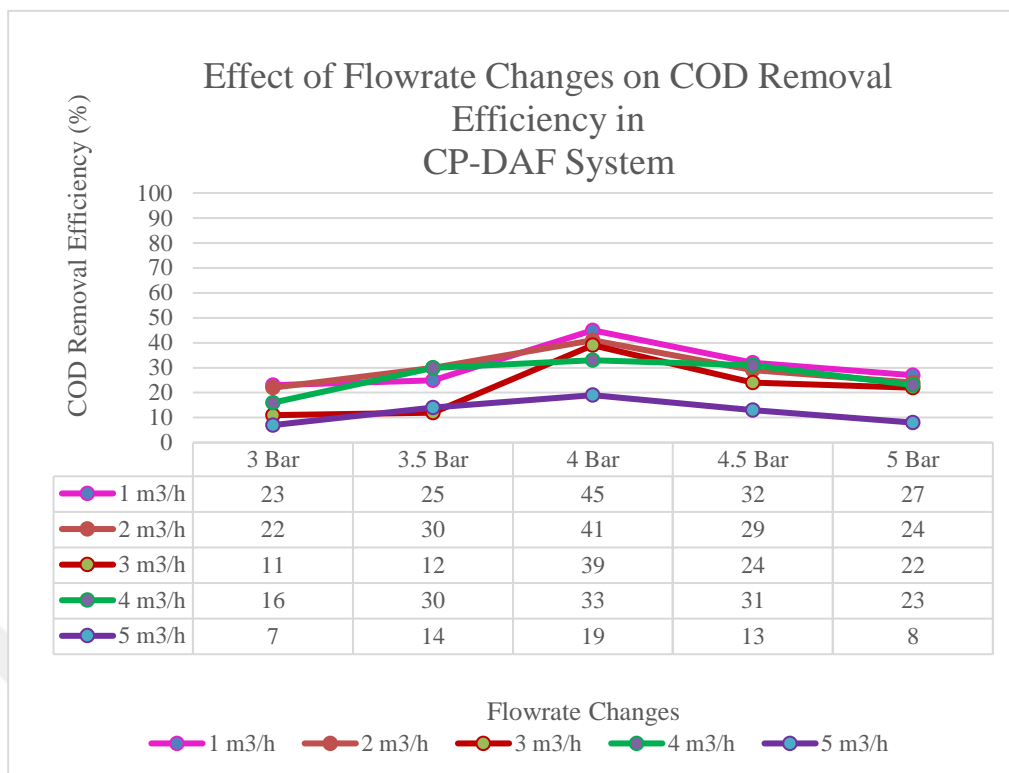


Figure 4.1 Effect of Flowrate Changes on COD Removal Efficiency in CP-DAF System

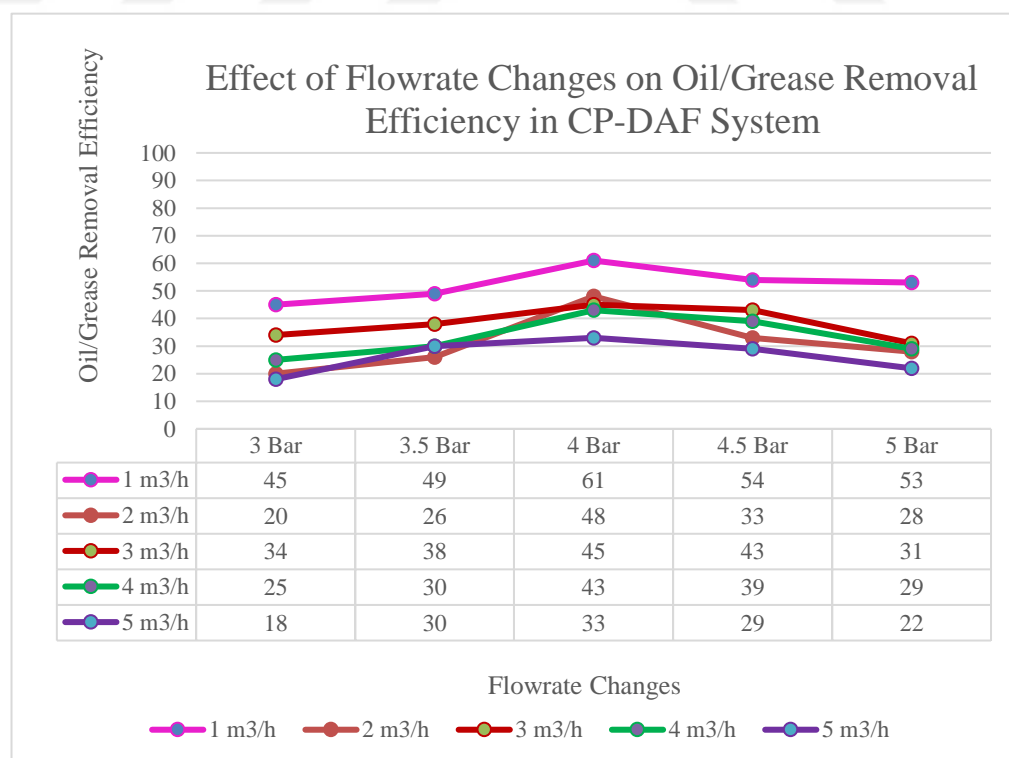


Figure 4.2 Effect of Flowrate Changes on Oil/Grease Removal Efficiency in CP-DAF System

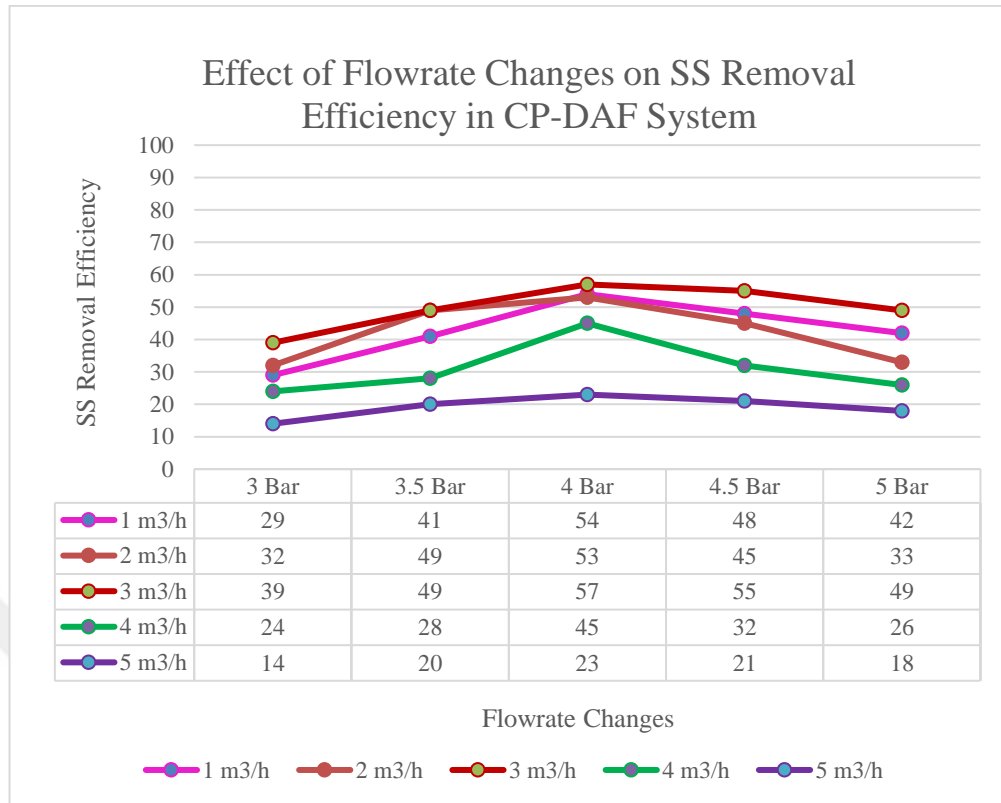


Figure 4.3 Effect of Flowrate Changes on SS Removal Efficiency in CP-DAF System

4.2 Performance of the Microbubble Generator Pump DAF-1 System (MB-DAF-1)

In order to determine the treatment performance of the MB-DAF-1 system, it was operated at different inlet flow rates between 1 and 5 m³/h (1-2-3-4-5 m³/h). The pressures were set at 3, 3.5, 4, 4.5 and 5 bar. The results of the MB-DAF-1 system are given in Table 4.2.

In the case of a flow of 1m³/h, as shown in Table 4.2, the inlet COD concentration ranged from 1500 to 2300 mg/L. At 1m³/h flow conditions, COD removal ranged from 37-51%. Data obtained from the experiments indicated that COD removal was affected by pressure changes. At a flow rate of 1 m³/h, the increase in pressure caused an increase in COD removal. For example, COD removal increased from 41% to 51% at 3.5 and 4 bar pressure. However, after a certain point, i.e. 4 bar, the COD removal

efficiencies were reduced to 49% and 42%. Thus, in the operation of the CP-DAF system, at 1m³/h flow rate, the highest COD removal efficiency (51%) was obtained at a pressure of 4bar. The concentration of oil /grease in the influent ranged from 196 to 330 mg/L. At 1m³/h flow conditions, Oil/Grease removal ranged between 58-70%. Similar to COD removal, increases in pressure resulted in a corresponding increase in the removal of oil/grease, up to a certain point. The highest oil removal was similarly obtained at 4bar pressure, with a removal efficiency of 70%. However, pressures exceeding 4 bar resulted in approximately 10% reduction in oil/grease removal efficiency. In DAF systems, as stated in the previous sections, suspended solids also cling to air bubbles and move upwards and are removed by scraping from the surface. The influent SS concentrations of the dairy wastewater exhibited considerable fluctuations, with values ranging between 710 and 1200 mg/L. The removal efficiency was determined to be between 40 and 63%. The highest removal was measured at 4bar. Similar to the COD and Oil/Grease parameters, increases in pressure resulted in a corresponding increase in the removal of suspended solids. Pressures above 4 bar resulted in approximately 8% reduction in solid removal.

In the case of a flow of 2m³/h, the inlet COD concentration ranged from 1073 to 1900 mg/L (see Table 4.2). COD removal was between 38-55%. The experimental data indicated that changes in pressure resulted in corresponding variations in COD removal. At a flow rate of 2 m³/h, 38% of the initial COD was removed in 3 bar. The COD removal was increased to 55% in 4 bar. At 4 bar, COD decreased from 1900mg/l to 861mg/l. However, after 4 bar, the COD removal efficiencies were reduced to 47% and 38%. Thus, maximum COD efficiency was obtained for 4bar, the efficiency decreased at higher or lower pressure conditions. The concentration of oil /grease in the influent ranged from 128 to 168 mg/L, at 2m³/h inflow rate. The Oil/Grease removal rate was determined to be 53-65%. The maximum Oil/Grease removal was achieved at a pressure of 4 bar with a removal efficiency of 65%. At 4 bar pressure, concentration of oil/grease decreased from 128mg/l to 45mg/l. The oil/grease removal decreased under higher or lower pressure conditions, similar to organic matter. The pressures exceeding 4 bar resulted considerable reduction in oil/grease removal

efficiency. Furthermore, the SS removal was achieved at a rate of 38-63%. The concentration of SS in the influent ranged from 540 to 720 mg/L, at 2m³/h inflow rate. The highest removal was measured at 4bar. The SS removal was 50% and 38% in 4.5 and 5 bar, respectively.

For the 3m³/h flow rate, the inlet COD concentration ranged from 1926 to 2150 mg/L. At 3m³/h flow conditions, COD removal ranged from 28-50%. Similar results were obtained with regard to the changes in pressure. At a flow rate of 3 m³/h, the increase in pressure caused an increase in COD removal. For example, the COD removal rate was 28% at 3 bar, whereas it increased to 30% and 50% at 3.5 and 4 bar pressure, respectively. However, after 4 bar, the COD removal efficiencies were reduced to 41% and 40%, for the 4.5 and 5 bars, respectively. Thus, in the operation of the CP-DAF system, at 3m³/h flow rate, the highest COD removal efficiency (50%) was obtained at a pressure of 4bar. The concentration of oil /grease in the influent ranged from 110 to 190 mg/L, at 3m³/h inflow rate. The oil/grease removal rate was determined to be 22-63%. The maximum oil/grease removal was achieved at a pressure of 4 bar with a removal efficiency of 63%. At 4bar pressure, concentration of oil/grease decreased from 176mg/l to 66mg/l. The oil/grease removal decreased under higher or lower pressure conditions, similar to organic matter. The pressures exceeding 4 bar resulted considerable reduction in oil/grease removal efficiency. In addition, the SS removal was achieved at a rate of 50-70%. The highest removal was measured at 4.5bar. At 4.5bar pressure, concentration of SS decreased from 1000mg/l to 300mg/l. The SS removal decreased under higher or lower pressure conditions from 4.5bar, at 3m³/h inflow rate.

Data obtained from MB-DAF-1 experiments have shown that increasing flow rates caused a decrease in efficiency, as well. The inlet COD concentration ranged from 1663 to 2449 mg/L (see Table 4.2) at 4m³/h inflow rate. COD removal was between 26-49%. Treatment performances were also influenced from the pressure changes. At a flow rate of 4 m³/h, 26% of the initial COD was removed in 3 bar pressure. The COD

removal was increased to 49% in 3,5 bar, however was decreased to 44%, 36%, 30% in 4 bar, 4,5, 5,0 bar, respectively. Thus, maximum COD efficiency was obtained for 3,5bar, the efficiency decreased at higher or lower pressure conditions. The concentration of oil /grease in the influent ranged from 230 to 390 mg/L, at 4m³/h inflow rate. The oil/grease removal rate was determined to be 40-60%. The maximum removal was achieved at a pressure of 4 bar with a removal efficiency of 60%. At 4bar pressure, concentration of oil/grease decreased from 295mg/l to 118mg/l. The pressures exceeding 4 bar resulted considerable reduction in oil/grease removal efficiency. Furthermore, the SS removal was achieved at a rate of 28-55%. The highest removal was measured at 4bar. Pressures above 4 bar resulted considerably reduction in solid removal.

The CP-DAF system exhibited the lowest removal efficiency at a flow rate of 5 m³/h. The inlet COD concentration ranged from 1765 to 2628 mg/L. At 5m³/h flow conditions, treatment performance of the MB-DAF-1 unit was extremely reduced. The COD removal ranged from 9-28%. The increase in pressure caused an increase in COD removal up to 4bar. The COD removal rate was 9% at 3 bar, whereas it increased to 21% and 28% at 3.5 and 4 bar pressure, respectively. However, after 4 bar, the COD removal efficiencies were reduced to 20% and 13%, for the 4.5 and 5 bars, respectively. Thus, in the operation of the MB-DAF-1 system, at 5m³/h flow rate, the highest COD removal efficiency (28%) was obtained at a pressure of 4bar which was considerable lower than other treatments. The concentration of oil /grease in the influent ranged from 310 to 676 mg/L, at 5m³/h inflow rate. The oil/grease removal rate was determined to be 20-44%. The maximum oil/grease removal was achieved at a pressure of 4 bar with a removal efficiency of 44%. At 4bar pressure, concentration of oil/grease decreased from 676mg/l to 376mg/L. The oil/grease removal decreased under higher or lower pressure conditions, similar to organic matter. The pressures exceeding 4 bar resulted a reduction in oil/grease removal efficiency. In addition, the SS removal was achieved at a rate of 4-26%. The highest removal was measured at 4.5bar. Pressures above 4.5 bar resulted a considerably reduction in solid removal.

The data presented in Table 4.2 is illustrated in Figures 4.4–4.6. The impact of the flow rate on COD removal is illustrated in Figure 4.4. As shown in Figure 4.4, the highest chemical oxygen demand (COD) removals were achieved at 4 bar for all flow rates excluding 4 m³/h. The maximum chemical oxygen demand (COD) removal was achieved at a flow rate of 1 m³/h, with a reduction in COD from 1939 to 942, resulting in an efficiency of 51%.

The impact of the flow rate on oil/grease removal is illustrated in Figure 4.5. As shown in Figure 4.5, the highest oil/grease removals were achieved at 4 bar for all flow rates. At 4 bar, the oil removals were 70%, 65%, 63%, 60%, and 44% for flow rates of 1, 2, 3, 4, and 5 m³/h, respectively. The maximum oil/grease removal was achieved at a flow rate of 1 m³/h, with a reduction in oil/grease from 196 to 59, resulting in an efficiency of 70%.

And, finally, the impact of the flow rate on suspended solid (SS) removal is shown in Figure 4.6. As can be seen in Figure 4.6, the highest SS removals were achieved at 4 bar for all flow rates, except of 3 and 5 m³/h. At 4 bar, the SS removals were 63%, 63% and 55% for flow rates of 1, 2, and 4 m³/h, respectively. The maximum SS removal was achieved at a flow rate of 3 m³/h, with a reduction in solids from 1000 to 300, resulting in an efficiency of 70%.

Consequently, the performance of the MB-DAF-1 system was investigated based on oil/grease, suspended solid, and organic matter. The experimental results shown that approximately 70% of the oil/grease and 70% of suspended particles and 55% or COD could be removed in the MB-DAF-1 unit.

Table 4.2 Experimental Study Results of the MB-DAF-1 System

| Values | | | Inlet | | | | | Outlet | | | | | The Efficiency | | |
|---|----------------|------------------------|----------|-----------------|---------|---------------------------|------|----------|-----------------|---------|---------------------------|------|----------------|--------------|------|
| Inlet Wastewater Flow m ³ /h | Temperature °C | Operating Pressure Bar | COD mg/l | Oil/Grease mg/l | SS mg/l | Wastewater Temperature °C | pH | COD mg/l | Oil/Grease mg/l | SS mg/l | Wastewater Temperature °C | pH | COD % | Oil/Grease % | SS % |
| | | | | | | | | | | | | | | | |
| 1 | 14 | 3 | 2034 | 256 | 1000 | 30.1 | 8.45 | 1277 | 108 | 600 | 29.1 | 8.37 | 37 | 58 | 40 |
| 1 | 17 | 3.5 | 1500 | 200 | 780 | 23.5 | 8.56 | 884 | 80 | 400 | 21.9 | 8.24 | 41 | 60 | 49 |
| 1 | 11 | 4 | 1939 | 196 | 1200 | 26.7 | 8.6 | 942 | 59 | 450 | 20.7 | 7.94 | 51 | 70 | 63 |
| 1 | 11 | 4.5 | 1908 | 236 | 850 | 30.7 | 8.54 | 966 | 82 | 340 | 26.4 | 7.64 | 49 | 65 | 60 |
| 1 | 10 | 5 | 2300 | 330 | 710 | 28.2 | 8.69 | 1335 | 126 | 316 | 27.2 | 8.16 | 42 | 62 | 55 |
| 2 | 13 | 3 | 1073 | 143 | 590 | 26.5 | 8.5 | 668 | 67 | 325 | 23 | 7.9 | 38 | 53 | 45 |
| 2 | 13 | 3.5 | 1178 | 168 | 540 | 27.7 | 8.2 | 729 | 72 | 245 | 24.9 | 7.8 | 38 | 57 | 55 |
| 2 | 13 | 4 | 1900 | 128 | 720 | 26.8 | 8.7 | 861 | 45 | 265 | 24.2 | 8 | 55 | 65 | 63 |
| 2 | 13 | 4.5 | 1655 | 146 | 700 | 27.3 | 7.9 | 880 | 63 | 350 | 25.1 | 7.5 | 47 | 57 | 50 |
| 2 | 13 | 5 | 1523 | 144 | 580 | 27 | 8 | 947 | 65 | 360 | 24.9 | 7.4 | 38 | 55 | 38 |
| 3 | 10 | 3 | 2075 | 173 | 600 | 29.1 | 8.22 | 1484 | 96 | 300 | 29.1 | 7.32 | 28 | 45 | 50 |
| 3 | 11 | 3.5 | 1955 | 190 | 1100 | 30 | 7.11 | 1359 | 98 | 400 | 28.5 | 7.07 | 30 | 48 | 64 |
| 3 | 11 | 4 | 2150 | 176 | 900 | 29 | 7.48 | 1080 | 66 | 300 | 29.4 | 7.44 | 50 | 63 | 67 |
| 3 | 10 | 4.5 | 1934 | 110 | 1000 | 27.4 | 8.16 | 1148 | 52 | 300 | 29 | 7.43 | 41 | 53 | 70 |
| 3 | 11 | 5 | 1926 | 148 | 750 | 26.5 | 8.37 | 1150 | 116 | 300 | 24 | 7.79 | 40 | 22 | 60 |
| 4 | 15 | 3 | 1663 | 230 | 710 | 29.3 | 8.29 | 1226 | 137 | 490 | 28.4 | 7.27 | 26 | 40 | 31 |
| 4 | 15 | 3.5 | 2449 | 334 | 890 | 28 | 8.11 | 1255 | 195 | 610 | 26 | 7.25 | 49 | 42 | 31 |
| 4 | 15 | 4 | 1738 | 295 | 985 | 27 | 8.45 | 969 | 118 | 440 | 25 | 7.36 | 44 | 60 | 55 |
| 4 | 15 | 4.5 | 2250 | 308 | 950 | 27.2 | 7.76 | 1441 | 155 | 620 | 26.3 | 7.45 | 36 | 50 | 35 |
| 4 | 15 | 5 | 2200 | 390 | 960 | 26.5 | 8.31 | 1550 | 210 | 690 | 24.7 | 7.26 | 30 | 46 | 28 |
| 5 | 11 | 3 | 1765 | 310 | 500 | 30 | 8.56 | 1608 | 248 | 480 | 27.7 | 7.16 | 9 | 20 | 4 |
| 5 | 11 | 3.5 | 2319 | 394 | 660 | 29.5 | 8.75 | 1829 | 236 | 500 | 25 | 7.35 | 21 | 40 | 24 |
| 5 | 11 | 4 | 2459 | 676 | 790 | 28.7 | 8.32 | 1772 | 376 | 590 | 27.2 | 7.17 | 28 | 44 | 25 |
| 5 | 11 | 4.5 | 2628 | 330 | 920 | 29.4 | 8.21 | 2092 | 218 | 680 | 26.4 | 7.46 | 20 | 34 | 26 |
| 5 | 11 | 5 | 2382 | 380 | 780 | 28.4 | 8.45 | 2066 | 285 | 740 | 25.9 | 7.37 | 13 | 25 | 5 |

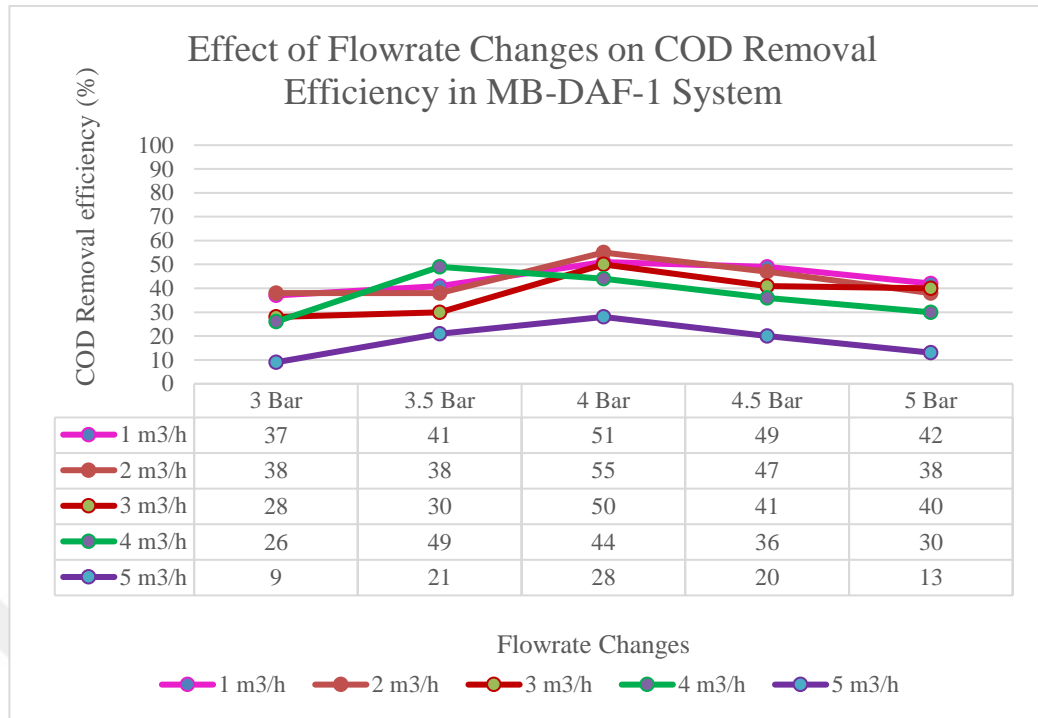


Figure 4.4 Effect of Flowrate Changes on COD Removal Efficiency in MB-DAF-1 System

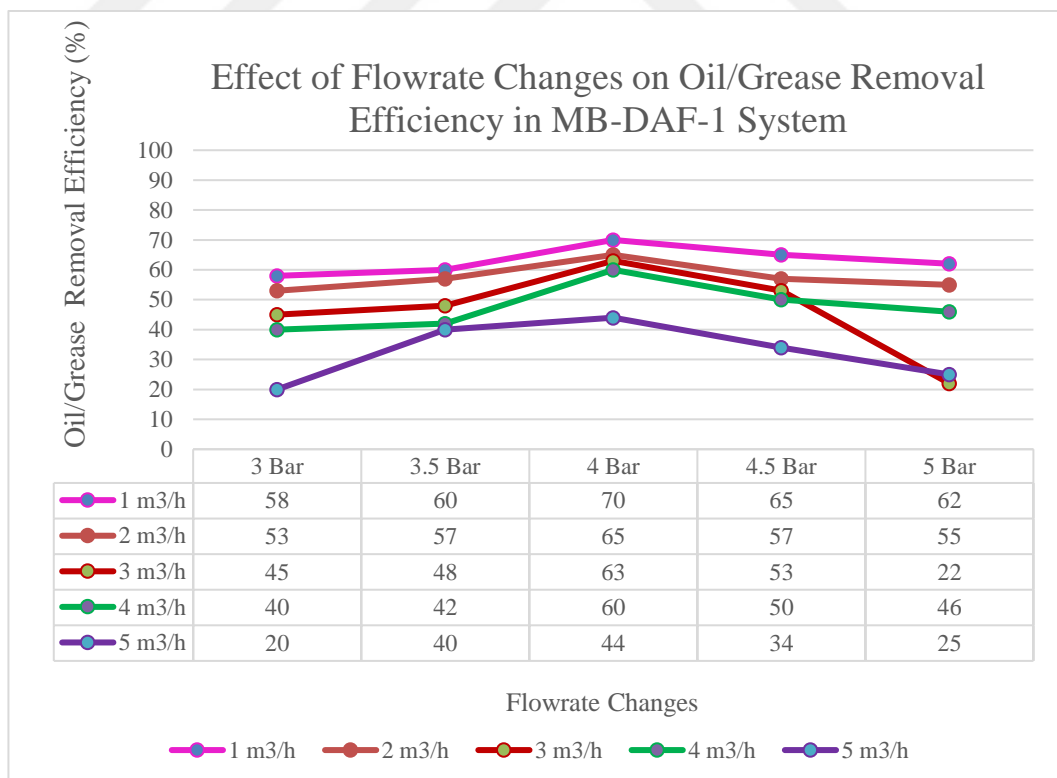


Figure 4.5 Effect of Flowrate Changes on Oil/Grease Removal Efficiency in MB-DAF-1 System

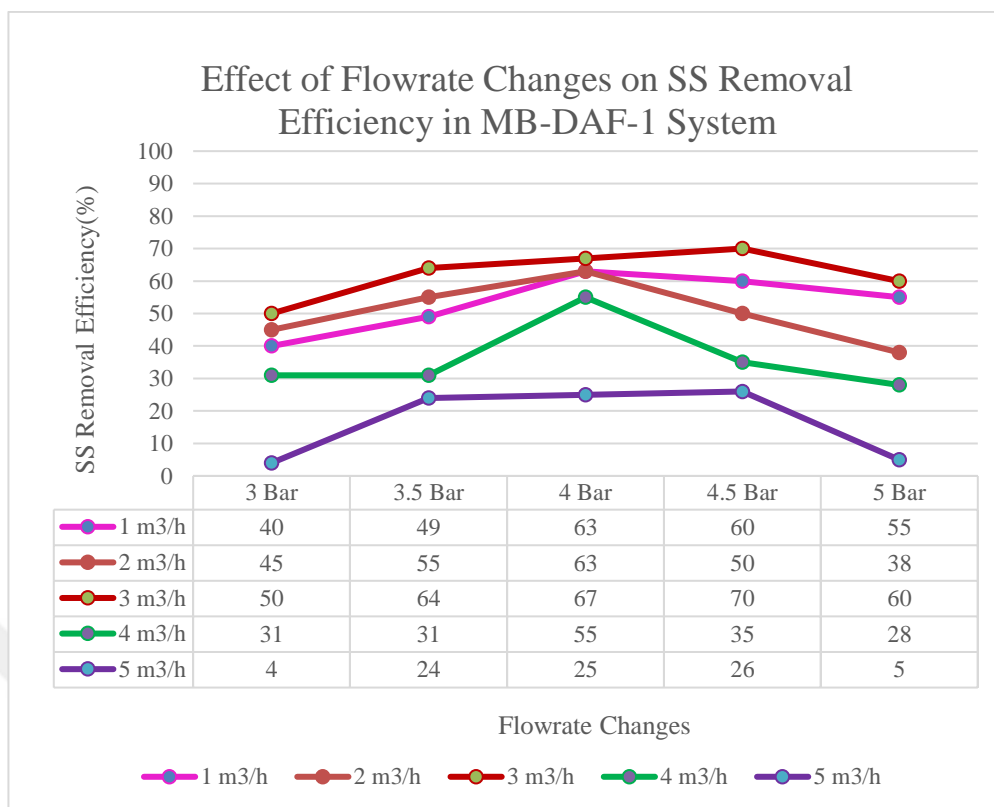


Figure 4.6 Effect of Flowrate Changes on SS Removal Efficiency in MB-DAF-1 System

4.3 Performance of the Microbubble Generator Pump DAF-2 System (MB-DAF-2)

In order to determine the treatment performance of the MB-DAF-2 system, it was operated at different inlet flow rates between 1 and 5 m³/h (1-2-3-4-5 m³/h). The pressures were set at 3, 3.5, 4, 4.5 and 5 bar. The results of the MB-DAF-2 system are given in Table 4.3.

In the case of a flow of 1m³/h, as shown in Table 4.3, the inlet COD concentration ranged from 2150 to 2370 mg/L. At 1m³/h flow conditions, COD removal ranged from 35-50%. Data obtained from the experiments indicated that COD removal was affected by pressure changes. At a flow rate of 1 m³/h, the increase in pressure caused an increase in COD removal. For example, COD removal increased from 37% to 50% at 3.5 and 4 bar pressure. However, after a certain point, i.e. 4bar, the COD removal

efficiencies were reduced to 47% and 35%. Thus, in the operation of the CP-DAF system, at 1m³/h flow rate, the highest COD removal efficiency (50%) was obtained at a pressure of 4bar. The concentration of oil /grease in the influent ranged from 145 to 198 mg/L. At 1m³/h flow conditions, Oil/Grease removal ranged between 51-75%. Similar to COD removal, increases in pressure resulted in a corresponding increase in the removal of oil/grease, up to a certain point. The highest oil removal was similarly obtained at 4bar pressure, with a removal efficiency of 75%. However, pressures exceeding 4 bar resulted in approximately 17% reduction in oil/grease removal efficiency. The influent SS concentrations of the dairy wastewater exhibited considerable fluctuations, with values ranging between 850 and 1032 mg/L. The highest removal was measured at 4 and 4.5 bar, this value was 56%, it was also similar.

In the case of a flow of 2m³/h, the inlet COD concentration ranged from 1856 to 2105 mg/L, as shown in Table 4.3. COD removal was between 34-50%. The experimental data indicated that changes in pressure resulted in corresponding variations in COD removal. At a flow rate of 2 m³/h, 35% of the initial COD was removed in 3 bar. The COD removal was 40% and 50% in 3.5 and 4 bar, respectively. However, after 4 bar, the COD removal efficiencies were reduced to 45% and 34%. Thus, maximum COD efficiency was obtained for 4bar, the efficiency decreased at higher or lower pressure conditions. At 2m³/h flow rate, the highest COD removal efficiency (50%) was obtained at a pressure of 4bar. This value was also the same at 1m³/h at 4bar (50%). The concentration of oil /grease in the influent ranged from 182 to 198 mg/L, at 2m³/h inflow rate. The Oil/Grease removal rate was determined to be 27-51%. The maximum Oil/Grease removal was achieved at a pressure of 4bar with a removal efficiency of 51%. At 4bar pressure, concentration of oil/grease decreased from 192mg/l to 94mg/l. The oil/grease removal decreased under higher or lower pressure conditions, similar to organic matter. The pressures exceeding 4 bar resulted considerable reduction in oil/grease removal efficiency. Furthermore, the SS removal was achieved at a rate of 35-56%. The concentration of SS in the influent ranged from 950 to 1203mg/L, at 2m³/h inflow rate. The maximum SS removal was achieved at a

pressure of 4 bar with a removal efficiency of 56%. At 4bar pressure, concentration of SS decreased from 1203mg/l to 530mg/l.

For the 3m³/h flow rate, the inlet COD concentration ranged from 1940 to 2320 mg/L. At 3m³/h flow conditions, COD removal ranged from 27-43%. Similar results were obtained with regard to the changes in pressure. At a flow rate of 3m³/h, the increase in pressure caused an increase in COD removal. The COD removal rate was 27% at 3 bar, whereas it increased to 29% and 43% at 3.5 and 4 bar pressure, respectively. However, after 4 bar, the COD removal efficiencies were reduced to 42% and 37%, for the 4.5 and 5 bars, respectively. Thus, in the operation of the MB-DAF-2 system, at 3m³/h flow rate, the highest COD removal efficiency (43%) was obtained at a pressure of 4bar. The concentration of oil /grease in the influent ranged from 142 to 212 mg/L, at 3m³/h inflow rate. The oil/grease removal rate was determined to be 43-54%. The maximum oil/grease removal was achieved at a pressure of 4 bar with a removal efficiency of 54%. At 4bar pressure, concentration of oil/grease decreased from 182mg/l to 83mg/l. The oil/grease removal decreased under higher or lower pressure conditions, similar to organic matter. The pressures exceeding 4 bar resulted considerable reduction in oil/grease removal efficiency. In addition, the SS removal was achieved at a rate of 50-70%. The concentration of SS in the influent ranged from 895 to 1032 mg/L, at 3m³/h inflow rate. The highest removal was measured at 4bar. At 4bar pressure, concentration of SS decreased from 970mg/l to 398mg/l, with removal efficiency of 54%.

For the 4m³/h flow rate, the inlet COD concentration ranged from 1970 to 2045 mg/L (see Table 4.3) at 4m³/h inflow rate. COD removal was between 20-38%. Treatment performances were also influenced from the pressure changes. At a flow rate of 4 m³/h, 20% of the initial COD was removed in 3 bar pressure. The COD removal was increased to 32% and 38% in 3.5 and 4 bar, respectively. However, after 4bar, the COD removal efficiencies were reduced to 20% and 38%. Thus, maximum COD efficiency was obtained for 4bar, the efficiency decreased at higher or lower

pressure conditions. The highest COD removal efficiency was 38%. The concentration of oil /grease in the influent ranged from 154 to 76 mg/L, at 4m³/h inflow rate. The oil/grease removal rate was determined to be 32-51%. The maximum removal was achieved at a pressure of 4 bar with a removal efficiency of 51%. At 4bar pressure, concentration of oil/grease decreased from 154mg/l to 76mg/l. The pressures exceeding 4 bar resulted considerable reduction in oil/grease removal efficiency. Furthermore, the SS removal was achieved at a rate of 29-51%. The highest removal was measured at 4bar. Pressures above 4 bar resulted considerably reduction in solid removal. At 4bar pressure, concentration of SS decreased from 966mg/l to 488mg/l, with removal efficiency of 51%.

The MB-DAF-2 system exhibited the lowest removal efficiency at a flow rate of 5 m³/h. Data obtained from MB-DAF-2 experiments have shown that increasing flow rates caused a decrease in efficiency, also. The inlet COD concentration ranged from 1625 to 2161 mg/L. At 5m³/h flow conditions, treatment performance of the MB-DAF-2 unit was extremely reduced. The COD removal ranged from 8-27%. The increase in pressure caused an increase in COD removal up to 4bar. The COD removal rate was 8% at 3 bar, whereas it increased to 17% and 27% at 3.5 and 4 bar pressure, respectively. However, after 4 bar, the COD removal efficiencies were reduced to 17% and 13%, for the 4.5 and 5 bars, respectively. Thus, in the operation of the MB-DAF-2 system, at 5m³/h flow rate, the highest COD removal efficiency (27%) was obtained at a pressure of 4bar which was considerable lower than other treatments. The concentration of oil /grease in the influent ranged from 165 to 191 mg/L, at 5m³/h inflow rate. The oil/grease removal rate was determined to be 22-42%. The maximum oil/grease removal was achieved at a pressure of 4 bar with a removal efficiency of 42%. At 4bar pressure, concentration of oil/grease decreased from 165mg/l to 96mg/L. The oil/grease removal decreased under higher or lower pressure conditions, similar to organic matter. The pressures exceeding 4 bar resulted a reduction in oil/grease removal efficiency. In addition, the SS removal was achieved at a rate of 20-27%. The highest removal was measured at 4bar. At 4bar pressure, concentration of SS decreased

from 790mg/l to 580mg/l, with removal efficiency of 27%. Pressures above 4 bar resulted in approximately 5% reduction in solid removal.

The data presented in Table 4.3 is illustrated in Figures 4.7–4.9. The impact of the flow rate on COD removal is illustrated in Figure 4.7. As shown in Figure 4.7, the highest chemical oxygen demand (COD) removals were achieved at 4 bar for all flow rates. At 4 bar, the COD removals were found to be 50%, 50%, 43%, 38%, and 27% for flow rates of 1, 2, 3, 4, and 5 m³/h, respectively. The maximum chemical oxygen demand (COD) removal was achieved at a flow rate of 1 m³/h and 2 m³/h, resulting in an efficiency of 50%.

The impact of the flow rate on oil/grease removal is illustrated in Figure 4.8. As shown in Figure 4.8, the highest oil/grease removals were achieved at 4 bar for all flow rates. At 4 bar, the oil removals were 75%, 51%, 54%, 51%, and 42% for flow rates of 1, 2, 3, 4, and 5 m³/h, respectively. The maximum oil/grease removal was achieved at a flow rate of 1 m³/h, with a reduction in oil/grease from 152 to 38, resulting in an efficiency of 75%.

And, finally, the impact of the flow rate on suspended solid (SS) removal is shown in Figure 4.9. As can be seen in Figure 4.9, the highest SS removals were achieved at 4 bar for all flow rates. At 4 bar, the SS removals were 56%, 56%, 59%, 51%, and 27% for flow rates of 1, 2, 3, 4, and 5 m³/h, respectively. The maximum SS removal was achieved at a flow rate of 3 m³/h, resulting in an efficiency of 59%.

Consequently, the performance of the MB-DAF-2 system was investigated based on oil/grease, suspended solid, and organic matter. The experimental results shown that approximately 44% of the oil/grease, 42% of suspended particles and 33% of COD could be removed in the MB-DAF-2 unit.

Table 4.3 Experimental Study Results of the MB-DAF-2 System

| Values | | | Inlet | | | | | Outlet | | | | | The Efficiency | | |
|-----------------------|-------------|--------------------|-------|------------|-------|------------------------|-----|--------|------------|------|------------------------|-----|----------------|------------|----|
| Inlet Wastewater Flow | Temperature | Operating Pressure | COD | Oil&Grease | SS | Wastewater Temperature | pH | COD | Oil&Grease | SS | Wastewater Temperature | pH | COD | Oil&Grease | SS |
| m ³ /h | °C | Bar | mg/l | mg/l | mg/l | °C | | mg/l | mg/l | mg/l | °C | | % | % | % |
| 1 | 29 | 3 | 2150 | 195 | 850 | 26.7 | 7.5 | 1370 | 95 | 561 | 25 | 7.3 | 36 | 51 | 34 |
| 1 | 29 | 3.5 | 2260 | 198 | 902 | 27 | 7.6 | 1420 | 89 | 497 | 26.4 | 7.5 | 37 | 55 | 45 |
| 1 | 29 | 4 | 2310 | 152 | 921 | 28 | 7.4 | 1155 | 38 | 405 | 26.9 | 7.2 | 50 | 75 | 56 |
| 1 | 29 | 4.5 | 2370 | 145 | 912 | 29.2 | 7.5 | 1256 | 51 | 400 | 28.1 | 7.1 | 47 | 65 | 56 |
| 1 | 29 | 5 | 2280 | 196 | 1.032 | 29.5 | 7.7 | 1482 | 82 | 552 | 28.7 | 7.5 | 35 | 58 | 47 |
| 2 | 34 | 3 | 1920 | 184 | 950 | 28 | 7.0 | 1248 | 117 | 541 | 26 | 7.3 | 35 | 36 | 43 |
| 2 | 34 | 3.5 | 2010 | 198 | 1.100 | 29 | 7.0 | 1206 | 144 | 517 | 27 | 7.1 | 40 | 27 | 53 |
| 2 | 34 | 4 | 1856 | 192 | 1.203 | 25 | 7.0 | 928 | 94 | 530 | 23 | 7.3 | 50 | 51 | 56 |
| 2 | 34 | 4.5 | 2105 | 190 | 1.198 | 26.7 | 6.9 | 1157 | 100 | 623 | 24.7 | 7.1 | 45 | 47 | 48 |
| 2 | 34 | 5 | 1945 | 182.4 | 1.063 | 26.5 | 7.3 | 1283 | 121 | 690 | 24.5 | 7 | 34 | 34 | 35 |
| 3 | 6 | 3 | 2162 | 162 | 895 | 26.7 | 7.5 | 1578 | 93 | 439 | 25.2 | 7.5 | 27 | 43 | 51 |
| 3 | 6 | 3.5 | 2320 | 142 | 1.032 | 28 | 7.9 | 1647 | 77 | 465 | 26.5 | 7.9 | 29 | 46 | 55 |
| 3 | 6 | 4 | 1940 | 182 | 970 | 29 | 7.8 | 1105 | 83 | 398 | 27.5 | 7.1 | 43 | 54 | 59 |
| 3 | 6 | 4.5 | 2048 | 212 | 995 | 29.2 | 8.0 | 1187 | 106 | 423 | 27.7 | 7.5 | 42 | 50 | 57 |
| 3 | 6 | 5 | 2179 | 195 | 988 | 29.5 | 7.7 | 1372 | 105 | 494 | 28 | 7.1 | 37 | 46 | 50 |
| 4 | 29 | 3 | 2405 | 179 | 1.125 | 27.8 | 8.0 | 1924 | 121 | 796 | 26.8 | 7.9 | 20 | 32 | 29 |
| 4 | 29 | 3.5 | 2250 | 183 | 1.300 | 28.7 | 7.8 | 1530 | 113 | 800 | 27.7 | 7.6 | 32 | 38 | 38 |
| 4 | 29 | 4 | 2310 | 154 | 996 | 29.5 | 7.5 | 1432 | 76 | 488 | 28.5 | 7.1 | 38 | 51 | 51 |
| 4 | 29 | 4.5 | 2015 | 170 | 800 | 26.7 | 7.9 | 1350 | 95 | 532 | 25.7 | 7 | 33 | 44 | 34 |
| 4 | 29 | 5 | 1970 | 178 | 752 | 27.8 | 8.1 | 1478 | 110 | 532 | 26.8 | 7.6 | 25 | 38 | 29 |
| 5 | 29 | 3 | 1860 | 191 | 510 | 27.5 | 7.9 | 1711 | 149 | 406 | 27 | 7.5 | 8 | 22 | 20 |
| 5 | 29 | 3.5 | 1625 | 183 | 530 | 27.3 | 7.6 | 1348 | 113 | 410 | 26.8 | 7.3 | 17 | 38 | 23 |
| 5 | 29 | 4 | 1973 | 165 | 790 | 27.6 | 7.8 | 1440 | 96 | 580 | 27.3 | 7.2 | 27 | 42 | 27 |
| 5 | 29 | 4.5 | 2153 | 172 | 750 | 27.4 | 7.9 | 1788 | 115 | 562 | 27.2 | 7.4 | 17 | 33 | 25 |
| 5 | 29 | 5 | 2161 | 184 | 780 | 27.6 | 7.5 | 1880 | 141 | 610 | 28.9 | 7.7 | 13 | 23 | 22 |

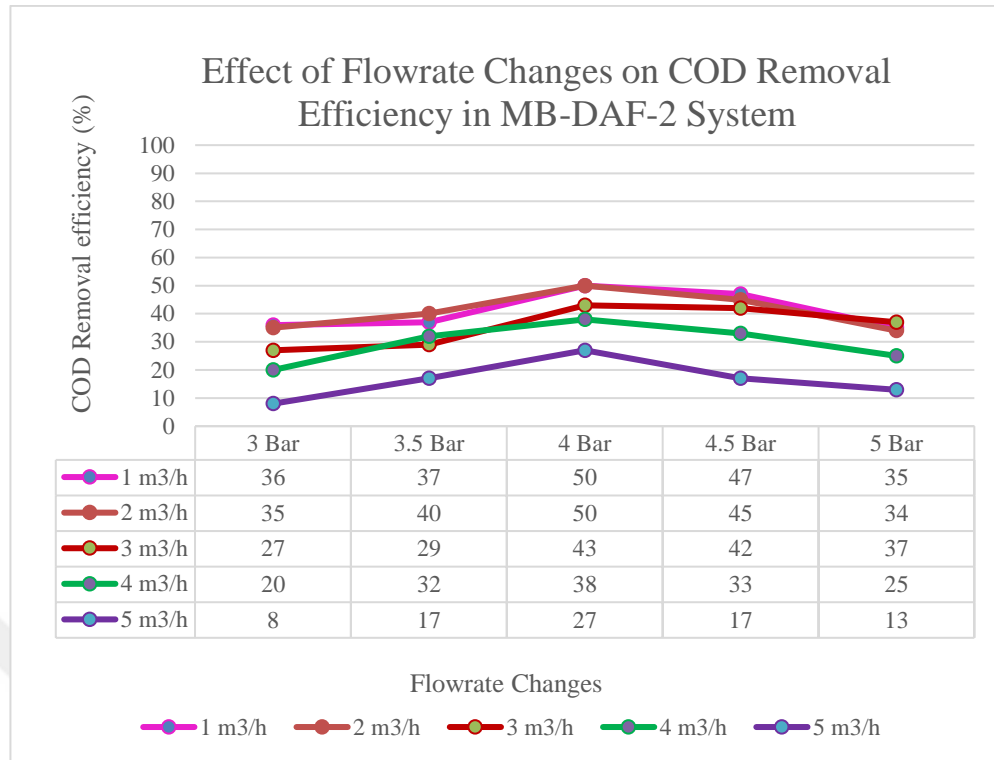


Figure 4.7 Effect of Flowrate Changes on COD Removal Efficiency in MB-DAF-2 System

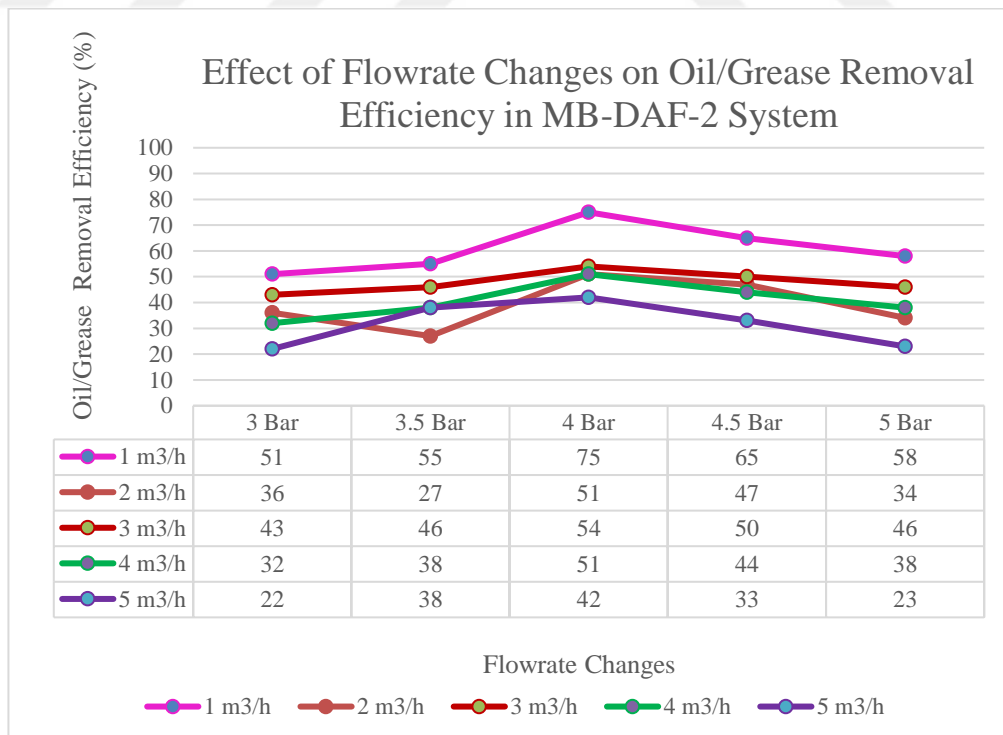


Figure 4.8 Effect of Flowrate Changes on Oil/Grease Removal Efficiency in MB-DAF-2 System

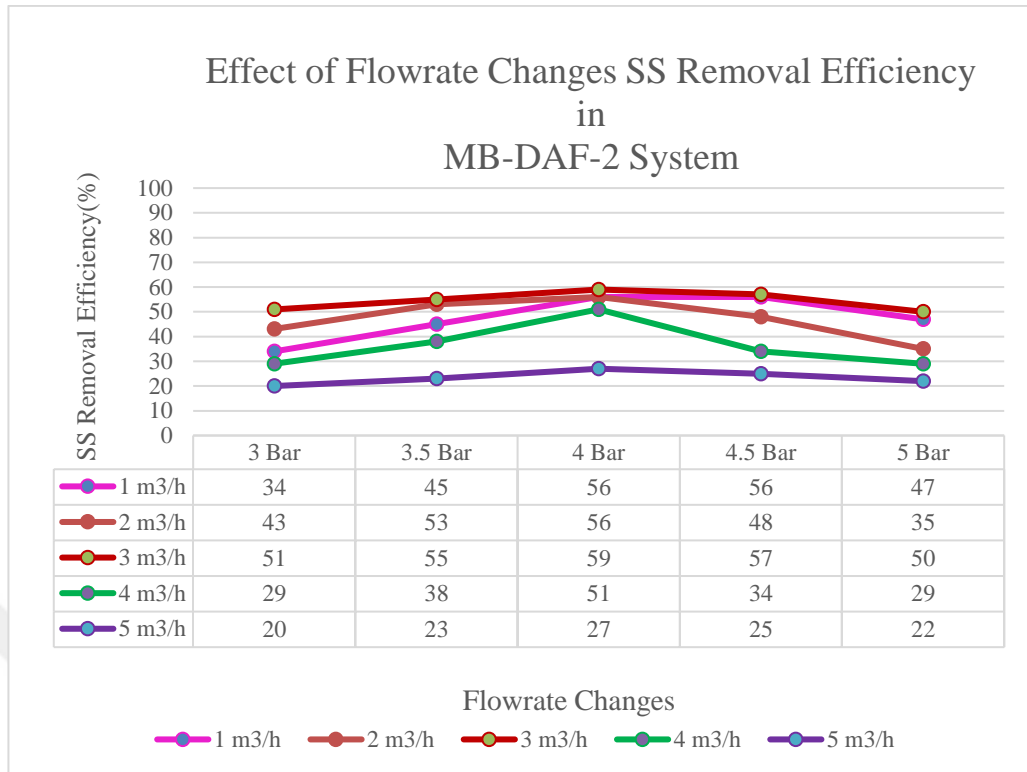


Figure 4.9 Effect of Flowrate Changes SS Removal Efficiency in MB-DAF-2 System

4.4 Performance of the Modified Microbubble Generator Pump MOMB-DAF-1 System

The number of blades of the MGP-1 impeller system modified by increasing (MOMB-DAF-1). The efficiency of the revised pumps impeller system was determined. The MB-DAF-1 System was reviewed. It was determined at which pressure value the best efficiency was obtained for COD, SS and Oil/Grease. In the operation of the MB-DAF-1 system at 1m³/h, 2m³/h, 3m³/h, 4m³/h and 5m³/h flow conditions. the highest COD removal efficiency was obtained at a pressure of 4bar. On the other hand, at 4m³/h flow conditions, the highest COD removal efficiency was obtained at a pressure of 3.5bar. Under the same conditions in the MB-DAF-1 system, the highest Oil/Grease removal efficiency was obtained at a pressure of 4bar, the highest SS removal efficiency was obtained at a pressure of 4bar. On the other hand, at 3m³/h flow conditions, the highest SS removal efficiency was obtained at a pressure of 4.5bar. Generally, maximum removal efficiency was obtained at 4bar for all parameters and efficiency decreased for increasing and decreasing pressures at MB-

DAF-1 System. So that, each different flow rates value MOMB-DAF System was operated only 4bar and its purification efficiency was checked. The results of the studies performed with the MOMB-DAF-1 system is given in Table 4.5.

In the operation of the MOMB-DAF-1 system at 4bar condition, the highest COD removal efficiency was obtained at a $1\text{m}^3/\text{h}$. The highest COD removal was obtained at $1\text{m}^3/\text{h}$, with a removal efficiency of 51%. The COD value decreased 1739 mg/l to 850 mg/l. The COD removal efficiency was 51% at $1\text{m}^3/\text{h}$, 45% at $2\text{m}^3/\text{h}$, 46% at $3\text{m}^3/\text{h}$, 33% at $4\text{m}^3/\text{h}$ and 21% at $5\text{m}^3/\text{h}$. The COD removal decreased under higher flow rates conditions. Data obtained from the experiments indicated that COD removal was affected by flow rates changes. The effect of flow rates changes on COD removal efficiency is presented in Figure 4.10.

When the Oil/Grease results were examined, the maximum Oil/Grease efficiency was obtained at a $1\text{m}^3/\text{h}$ and it is 74%. The Oil/Grease value decreased 176 mg/l to 45 mg/l. The Oil/Grease removal efficiency was 74% at $1\text{m}^3/\text{h}$, 64% at $2\text{m}^3/\text{h}$, 52% at $3\text{m}^3/\text{h}$, 50% at $4\text{m}^3/\text{h}$ and 40% at $5\text{m}^3/\text{h}$. The Oil/Grease removal decreased under higher flow rates conditions. Data obtained from the experiments indicated that Oil/Grease removal was affected by flow rates changes. The effect of flow rates changes on Oil/Grease removal efficiency are presented in Figure 4.11.

The SS results were examined, the maximum SS efficiency was obtained at a $1\text{m}^3/\text{h}$ and it is 55%. The SS value decreased 748 mg/l to 336 mg/l. The SS removal efficiency was 52% at $2\text{m}^3/\text{h}$, the SS value decreased 724 mg/l to 344 mg/l, also. The SS removal efficiency was 50% at $3\text{m}^3/\text{h}$, 40% at $4\text{m}^3/\text{h}$ and 37% at $5\text{m}^3/\text{h}$. The SS removal decreased under higher flow rates conditions. Data obtained from the experiments indicated that SS removal was affected by flow rates changes. The effect of pressure changes on SS removal efficiency at different flow rates is presented in Figure 4.12 respectively.

Table 4.4 Experimental Study Results of the MOMB-DAF-1 System

| Values | | | Inlet | | | | Outlet | | | | The Efficiency | | | | |
|-----------------------|-------------|--------------------|-------|------------|------|------------------------|--------|------|------------|------|------------------------|-----|-----|------------|-----|
| Inlet Wastewater Flow | Temperature | Operating Pressure | COD | Oil/Grease | SS | Wastewater Temperature | pH | COD | Oil/Grease | SS | Wastewater Temperature | pH | COD | Oil/Grease | SS |
| m ³ /h | °C | Bar | mg/l | mg/l | mg/l | °C | | mg/l | mg/l | mg/l | °C | | % | % | % |
| 1 | 11 | 4 | 1739 | 176 | 748 | 19.2 | 8.2 | 850 | 45 | 336 | 19.3 | 8.1 | 51% | 74% | 55% |
| 2 | 13 | 4 | 1669 | 168 | 724 | 19.5 | 7.8 | 916 | 60 | 344 | 19.4 | 7.8 | 45% | 64% | 52% |
| 3 | 11 | 4 | 2475 | 575 | 1100 | 18.2 | 7.6 | 1334 | 276 | 550 | 18.3 | 7.5 | 46% | 52% | 50% |
| 4 | 15 | 4 | 2350 | 569 | 975 | 18.9 | 8.1 | 1575 | 284 | 586 | 18.7 | 8.2 | 33% | 50% | 40% |
| 5 | 11 | 4 | 2405 | 584 | 1035 | 18.7 | 7.9 | 1899 | 350 | 652 | 18.8 | 7.8 | 21% | 40% | 37% |

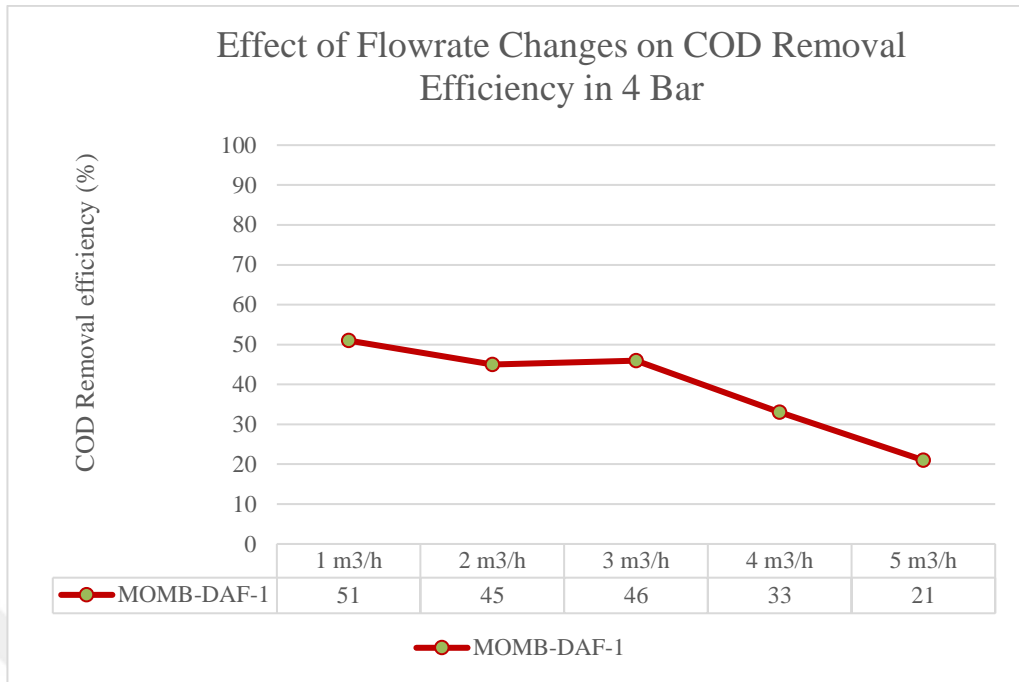


Figure 4.10 Effect of Flowrate Changes COD Removal Efficiency in MOMB-DAF-1 System

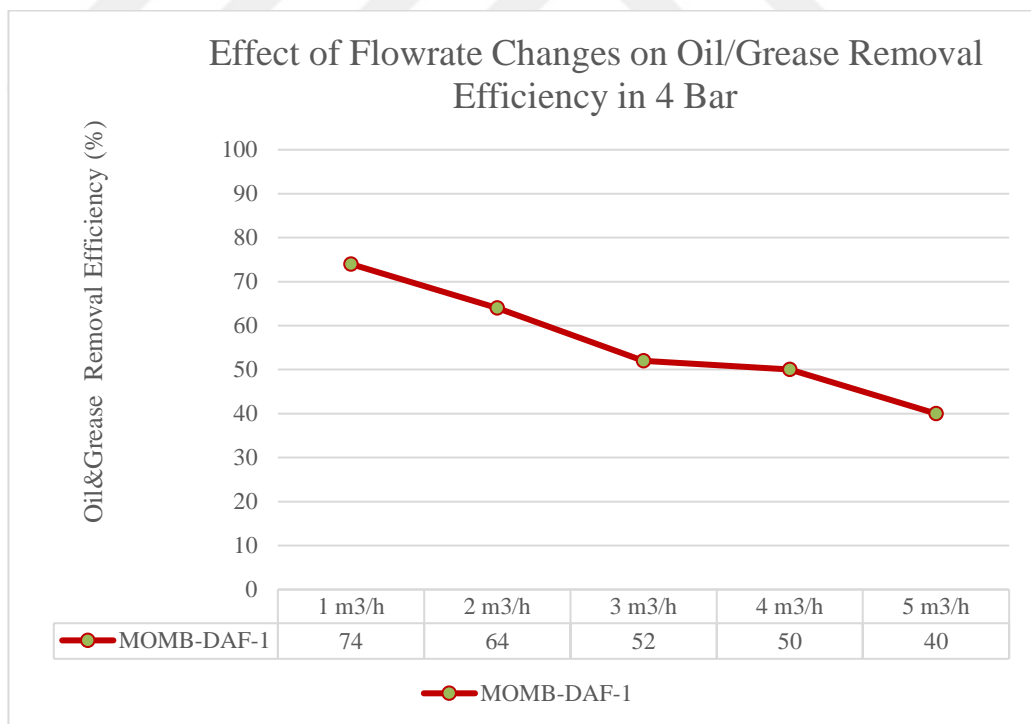


Figure 4.11 Effect of Flowrate Changes Oil/Grease Removal Efficiency in MOMB-DAF-1 System

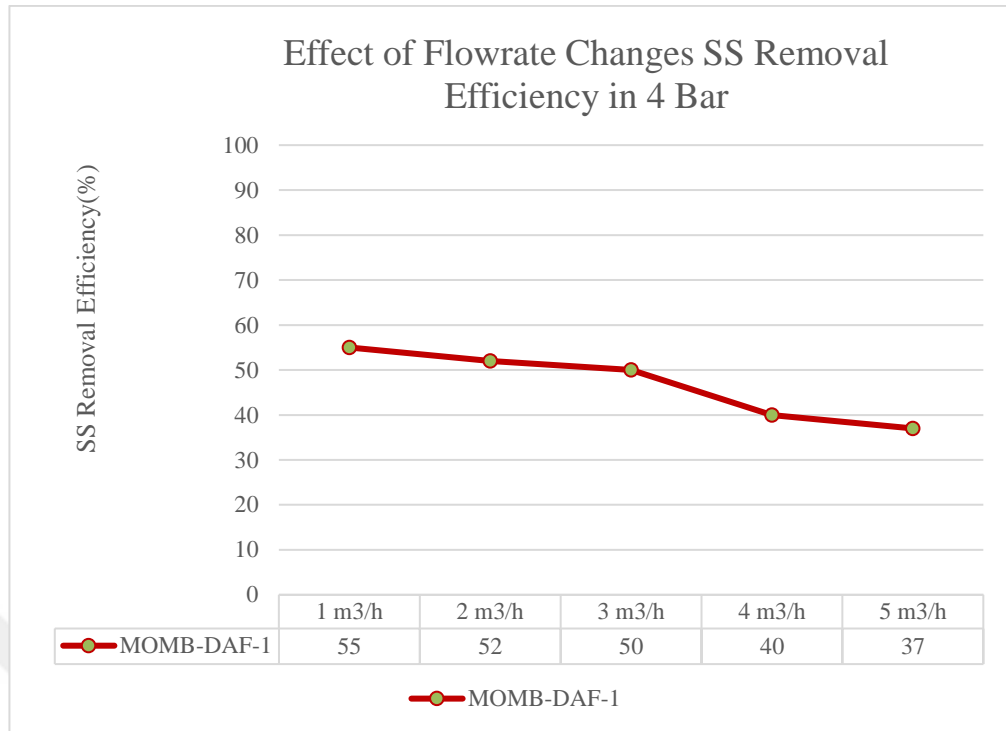


Figure 4.12 Effect of Flowrate Changes SS Removal Efficiency in MOMB-DAF-1 System

4.5 Performance of the Modified Microbubble Generator Pump MOMB-DAF-2 System

The number of blades of the MGP-1 impeller system modified by decreasing (MOMB-DAF-2). The efficiency of the revised pumps impeller system was determined. The modified DAF system was operated at 4bar and its purification efficiency was checked.

In the operation of the MOMB-DAF-2 system at 4bar condition, the highest COD removal efficiency was obtained at a 1m³/h. The COD value decreased 1421 mg/l to 785 mg/l. At 2m³/h condition, COD concentration decreased from 1523mg/l to 879mg/l and the COD removal efficiency was 42%. At 3m³/h condition, COD concentration decreased from 1356mg/l to 845mg/l and the COD removal efficiency was 38%. At 4m³/h condition, COD concentration decreased from 1689mg/l to 1012mg/l and the COD removal efficiency was 40%. At 5m³/h condition, COD

concentration decreased from 1925mg/l to 1540mg/l and the COD removal efficiency was 20%. Summarily, the COD removal efficiency was 45% at 1m³/h, %42 at 2m³/h, 38% at 3m³/h, 40% at 4m³/h and %18 at 5m³/h. The effect of pressure changes on COD removal efficiency at different flow rates are presented in Figure 4.13.

When the Oil/Grease results were examined, the maximum Oil/Grease efficiency was obtained at a 1m³/h and it is 64%, Oil/Grease concentration decreased from 156mg/l to 56mg/l. At 2m³/h condition, Oil/Grease concentration decreased from 178mg/l to 84mg/l and the COD removal efficiency was 53%. At 3m³/h condition, Oil/Grease concentration decreased from 165mg/l to 91mg/l and the Oil/Grease removal efficiency was 45%. At 4m³/h condition, Oil/Grease concentration decreased from 184mg/l to 108mg/l and the Oil/Grease removal efficiency was 41%. At 5m³/h condition, Oil/Grease concentration decreased from 195mg/l to 123mg/l and the Oil/Grease removal efficiency was %37. Summarily, the Oil/Grease removal efficiency was 64% at 1m³/h, 53% at 2m³/h, 45% at 3m³/h, 41% at 4m³/h and 37% at 5m³/h. The Oil/Grease removal decreased under higher flow rates conditions. Data obtained from the experiments indicated that Oil/Grease removal was affected by flow rates changes. The effect of pressure changes on COD removal efficiency at different flow rates are presented in Figure 4.14.

The SS results were examined, the maximum SS efficiency was obtained at a 1m³/h and it is 50%, SS concentration decreased from 156mg/l to 56mg/l. At 2m³/h condition, SS concentration decreased from 178mg/l to 84mg/l and the SS removal efficiency was 53%. At 3m³/h condition, SS concentration decreased from 165mg/l to 91mg/l and the SS removal efficiency was 45%. At 4m³/h condition, SS concentration decreased from 184mg/l to 108mg/l and the SS removal efficiency was %41. At 5m³/h condition, SS concentration decreased from 195mg/l to 123mg/l and the SS removal efficiency was 37%. Summarily, the SS removal efficiency was 50% at 1m³/h, 47% at 2m³/h, 42% at 3m³/h, 40% at 4m³/h and 25% at 5m³/h. The SS removal decreased under higher flow rates conditions. Data obtained from the experiments indicated that

SS removal was affected by flow rates changes. The effect of pressure changes on SS removal efficiency at different flow rates are presented in Figure 4.15.

In MOMB-DAF-2 System, the Oil/Grease efficiency values were higher than SS than COD.

The results of the studies performed with the MOMB-DAF-2 system are given in Table 4.6. The effect of pressure changes on COD, Oil/grease and SS removal efficiency at different flow rates are presented in Figure 4.13, 4.14 and 4.15 respectively.

Table 4.5 Experimental Study Results of the MOMB-DAF-2 System

| Inlet Wastewater Flow m ³ /h | Values | | | Inlet | | | | Outlet | | | | The Efficiency | | | |
|--|-------------------|---------------------------|-------------|--------------------|------------|------------------------------|-----|-------------|--------------------|------------|------------------------------|----------------|----------|-----------------|---------|
| | Temperature °C | Operating Pressure Bar | COD mg/l | Oil/Grease mg/l | SS mg/l | Wastewater Temperature °C | pH | COD mg/l | Oil/Grease mg/l | SS mg/l | Wastewater Temperature °C | pH | COD % | Oil/Grease % | SS % |
| 1 | 31 | 4 | 1421 | 156 | 630 | 29 | 8 | 785 | 56 | 315 | 28,9 | 7,9 | 45% | 64% | 50% |
| 2 | 32 | 4 | 1523 | 178 | 600 | 29,2 | 8,2 | 879 | 84 | 318 | 29,1 | 8,1 | 42% | 53% | 47% |
| 3 | 31 | 4 | 1356 | 165 | 576 | 29,4 | 7,3 | 845 | 91 | 334 | 29,5 | 7,4 | 38% | 45% | 42% |
| 4 | 30 | 4 | 1689 | 184 | 720 | 29,6 | 7,4 | 1012 | 108 | 432 | 29,4 | 7,6 | 40% | 41% | 40% |
| 5 | 31 | 4 | 1925 | 195,2 | 910 | 29,4 | 7,9 | 1579 | 123 | 680 | 29,2 | 7,8 | 18% | 37% | 25% |

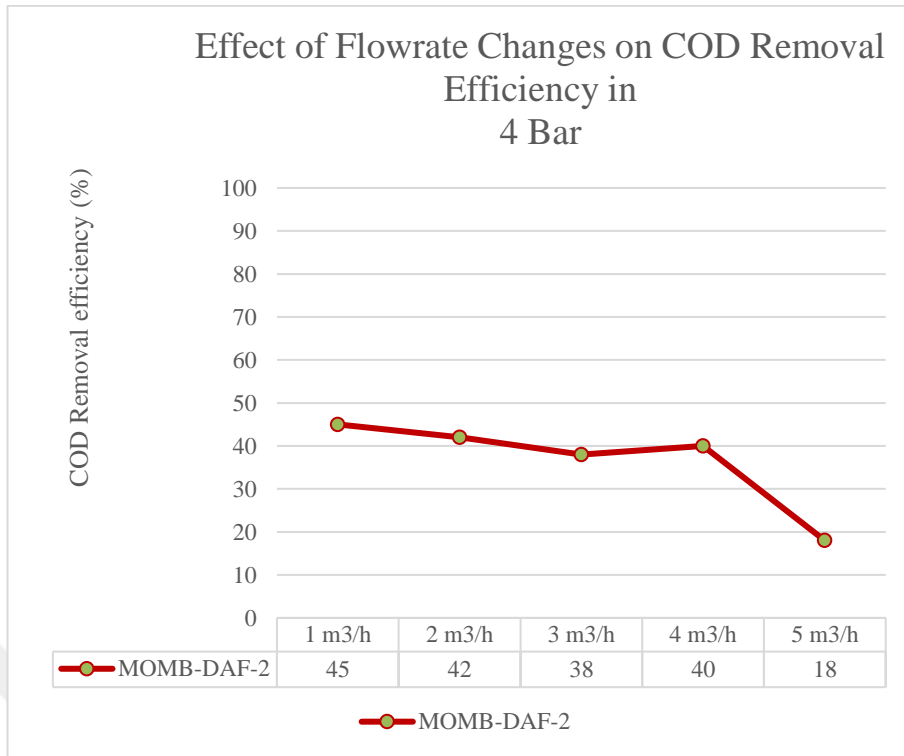


Figure 4.13 Effect of Flowrate Changes COD Removal Efficiency in MOMB-DAF-2 System

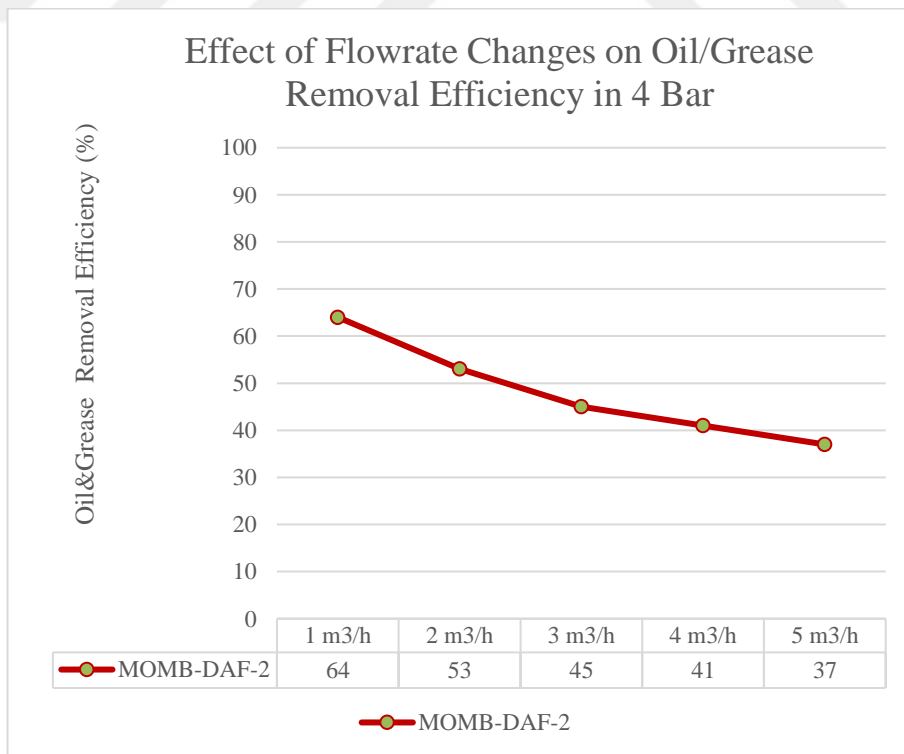


Figure 4.14 Effect of Flowrate Changes Oil/Grease Removal Efficiency in MOMB-DAF-2 System

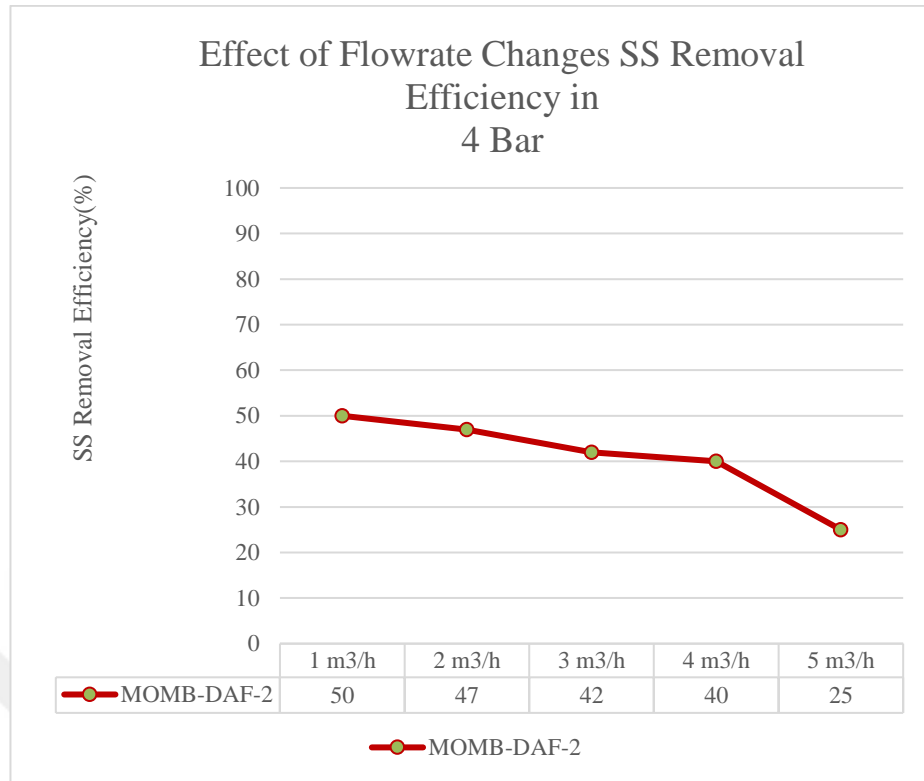


Figure 4.15 Effect of Flowrate Changes SS Removal Efficiency in MOMB-DAF-2 System

4.6 Comparison of the Results of Classical and Microbubble Generator Pump DAF System (MB-DAF-1, MB-DAF-2)

The graphs of the values obtained from the Classic DAF and Microbubble pump DAF systems are presented below. When the graphs are examined, it is seen that all flow rates were generally most efficient at 4bar.

All results shown in Figure 4.16, at 4bar condition, the COD efficiency values of CP-DAF was lower than MB-DAF-1 and MB-DAF-2 in every inflow rate. At 1m³/h, the COD concentration decreased from 3034mg/l to 1659mg/l, the COD removal efficiency was 45% in CP-DAF system. At 1m³/h, the COD removal efficiency was 51% at MB-DAF-1, the COD concentration decreased from 1939mg/l to 942mg/l. At 1m³/h, the COD removal efficiency was 50% in MB-DAF-2, the concentration decreased from 2310mg/l to 1155mg/l. At a flow rate of 1 m³/h, the maximum COD

removal efficiency was achieved in the MB-DAF-1 was 60%. At 2m³/h, the COD removal efficiency was 41% at CP-DAF, 55% at MB-DAF-1, 50% at MB-DAF-2. At 2m³/h, the COD concentration decreased from 1900mg/l to 861mg/l, with MB-DAF-1 system. At a flow rate of 2 m³/h, the maximum COD removal efficiency was achieved in the MB-DAF-1 was 55%. At 3m³/h, the COD removal efficiency was 39% at CP-DAF, 50% at MB-DAF-1, 43% at MB-DAF-2. At a flow rate of 3 m³/h, the maximum COD removal efficiency was achieved in the MB-DAF-1 was 50%. At 4m³/h, the COD removal efficiency was 33% at CP-DAF, 44% at MB-DAF-1, 38% at MB-DAF-2. At a flow rate of 4 m³/h, the maximum COD removal efficiency was achieved in the MB-DAF-1 was 44%. At 5m³/h, the COD removal efficiency was 19% at CP-DAF, 28% at MB-DAF-1, 27% at MB-DAF-2. At a flow rate of 5 m³/h, the maximum COD removal efficiency was achieved in the MB-DAF-1 was 28%. In generally, all of the systems, as the flow rate increased, the COD efficiency decreased, except at MK-DAF-1 system with 2m³/h. In MK-DAF-1 system, at 2m³/h, the COD removal efficiency was higher than at 1m³/h condition. Comparison of COD Efficiency values in the Classical and Microbubble Generator Pump DAF Systems are given in Figure 4.16.

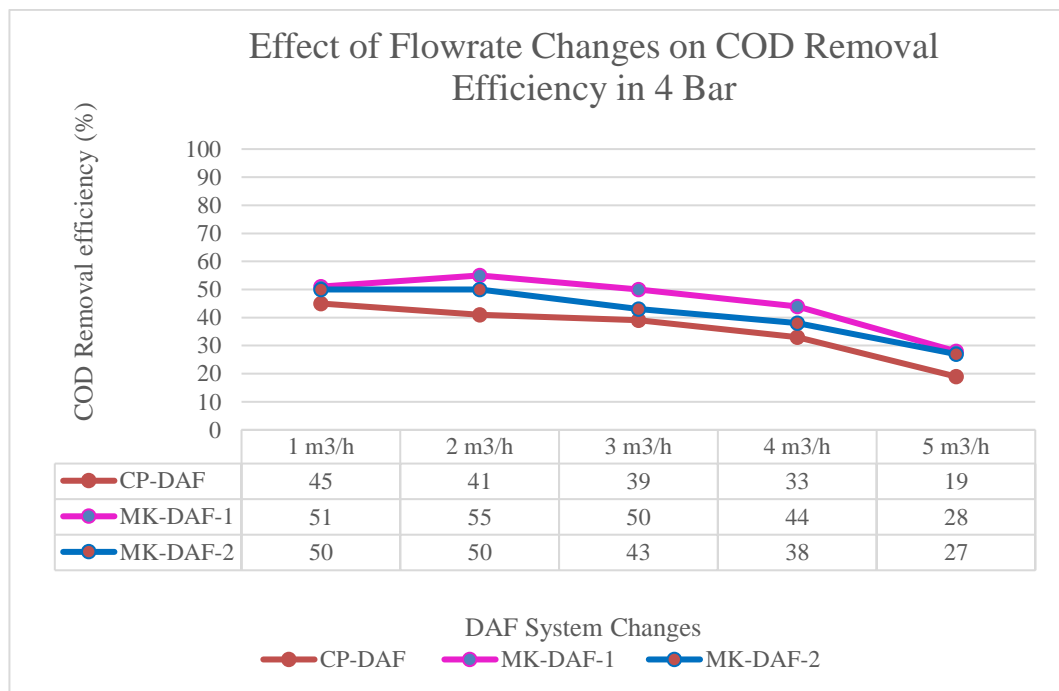


Figure 4.16 Comparison of COD Efficiency in the Classical and Microbubble Generator Pump DAF Systems

When the Oil/Grease results were examined, the oil/grease efficiency values of CP-DAF were lower than MB-DAF-1 and MB-DAF-2. This was illustrated as follows in Figure 4.17. At 1 m³/h, the oil/grease removal efficiency was 61% at CP-DAF, 70% at MB-DAF-1, 75% at MB-DAF-2. At 1 m³/h, the Oil/Grease concentration decreased from 262mg/l to 102mg/l, in CP-DAF system. At 1 m³/h, the Oil/Grease concentration decreased from 196mg/l to 59mg/l, in MB-DAF-1 system. At 1 m³/h, the Oil/Grease concentration decreased from 152mg/l to 38mg/l, in MB-DAF-2 system. At a flow rate of 1 m³/h, the maximum Oil/Grease removal efficiency was achieved in the MB-DAF-2 was 75%. At 2 m³/h, the oil/grease removal efficiency was 48% at CP-DAF, 65% at MB-DAF-1, 51% at MB-DAF-2. At 2 m³/h, the Oil/Grease concentration decreased from 128mg/l to 45mg/l, in MB-DAF-1 system. At 2 m³/h, the Oil/Grease concentration decreased from 144mg/l to 75mg/l, in MB-DAF-2 system. At a flow rate of 2 m³/h, the maximum Oil/Grease removal efficiency was achieved in the MB-DAF-1 was 65%. At 3 m³/h, the oil/grease removal efficiency was 45% at CP-DAF, 63% at MB-DAF-1, 54% at MB-DAF-2. At 3 m³/h, the Oil/Grease concentration decreased from 176mg/l to 66mg/l, in MB-DAF-1 system. At a flow rate of 3 m³/h, the maximum Oil/Grease removal efficiency was achieved in the MB-DAF-1 was 63%. At 4 m³/h, the oil/grease removal efficiency was %43 at CP-DAF, 60% at MB-DAF-1, 51% at MB-DAF-2. At 4 m³/h, the Oil/Grease concentration decreased from 124mg/l to 71mg/l, in CP-DAF system. At a flow rate of 4 m³/h, the maximum Oil/Grease removal efficiency was achieved in the MB-DAF-1 was 60%. At 5 m³/h, the oil/grease removal efficiency was %33 at CP-DAF, %44 at MB-DAF-1, %42 at MB-DAF-2. At a flow rate of 5 m³/h, the maximum Oil/Grease removal efficiency was achieved in the MB-DAF-1 was 44%. In generally, all of the systems, as the flow rate increased, the Oil/Grease efficiency decreased, except at MK-DAF-2 system with 3 m³/h. In MK-DAF-2 system, at 3 m³/h, the COD removal efficiency was higher than at 2 m³/h condition, it was 54%, and 51%, for 3 m³/h and 2 m³/h, respectively. Comparison of oil/grease Efficiency values in the Classical and Microbubble Generator Pump DAF Systems are given in Figure 4.17.

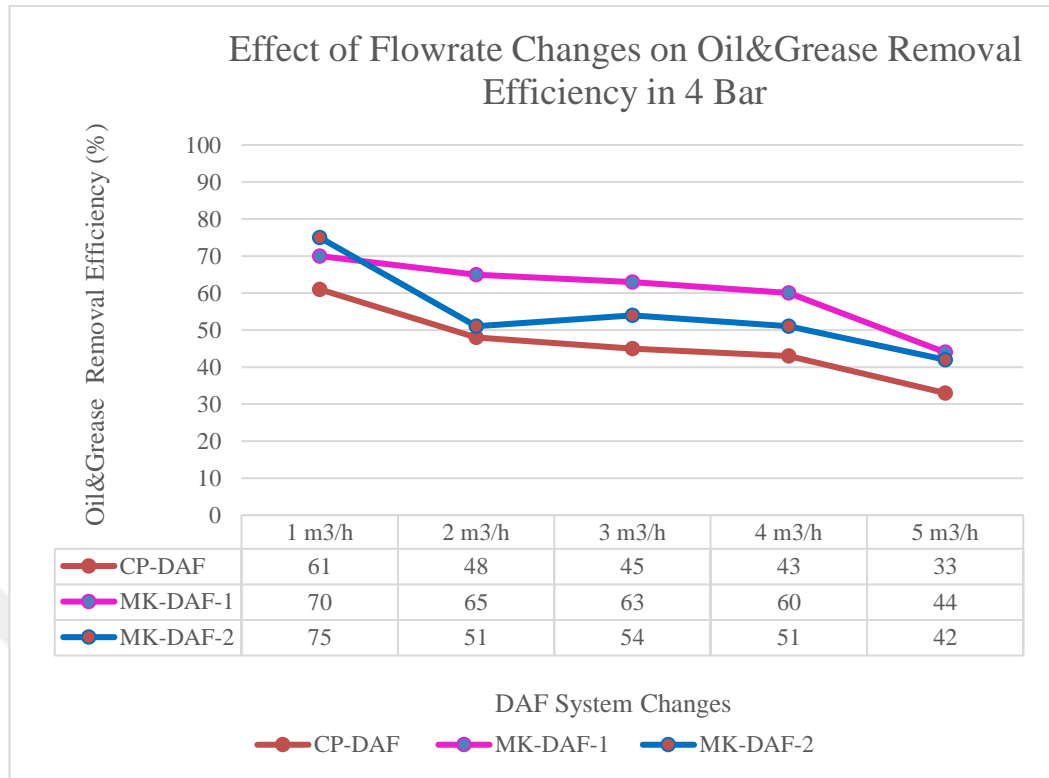


Figure 4.17 Comparison of Oil/Grease Efficiency in the Classical and Microbubble Generator Pump DAF Systems

All results showed that, the SS efficiency values of CP-DAF were lower than MB-DAF-1 and MB-DAF-2. At 1 m³/h, the SS removal efficiency was 54% at CP-DAF, 63% at MB-DAF-1, 56% at MB-DAF-2. At 1 m³/h, the SS concentration decreased from 1300mg/l to 600mg/l, in CP-DAF system. At 1 m³/h, the SS concentration decreased from 1200mg/l to 450mg/l, in MB-DAF-1 system. At 1 m³/h, the SS concentration decreased from 921mg/l to 405mg/l, in MB-DAF-2 system. At a flow rate of 1 m³/h, the maximum SS removal efficiency was achieved in the MB-DAF-1 was 63%. At 2 m³/h, the SS removal efficiency was 53% at CP-DAF, 63% at MB-DAF-1, 56% at MB-DAF-2. At 2 m³/h, the SS concentration decreased from 1350mg/l to 630mg/l, in CP-DAF system. At 2 m³/h, the SS concentration decreased from 720mg/l to 265mg/l, in MB-DAF-1 system. At 2 m³/h, the SS concentration decreased from 1203mg/l to 530mg/l, in MB-DAF-2 system. At a flow rate of 2 m³/h, the maximum SS removal efficiency was achieved in the MB-DAF-1 was 63%, the same value was achieved at 1 m³/h. At 3 m³/h, the SS removal efficiency was 57% at CP-DAF, 67% at MB-DAF-1, 59% at MB-DAF-2. At 3 m³/h, the SS concentration

decreased from 1100mg/l to 470mg/l, in CP-DAF system. At 3m³/h, the SS concentration decreased from 900mg/l to 300mg/l, in MB-DAF-1 system. At 3m³/h, the SS concentration decreased from 970mg/l to 398mg/l, in MB-DAF-2 system. At a flow rate of 3 m³/h, the maximum SS removal efficiency was achieved in the MB-DAF-1 was 67%. At 4m³/h, the SS removal efficiency was 45% at CP-DAF, 55% at MB-DAF-1, 51% at MB-DAF-2. At 4m³/h, the SS concentration decreased from 980mg/l to 540mg/l, in CP-DAF system. At 4m³/h, the SS concentration decreased from 985mg/l to 440mg/l, in MB-DAF-1 system. At 4m³/h, the SS concentration decreased from 996mg/l to 488mg/l, in MB-DAF-2 system. At a flow rate of 4m³/h, the maximum SS removal efficiency was achieved in the MB-DAF-1 was 55%. At 5m³/h, the SS removal efficiency was 23% at CP-DAF, %25 at MB-DAF-1, 27% at MB-DAF-2. At 5m³/h, the SS concentration decreased from 750mg/l to 580mg/l, in CP-DAF system. At 5m³/h, the SS concentration decreased from 790mg/l to 590mg/l, in MB-DAF-1 system. At 5m³/h, the SS concentration decreased from 750mg/l to 580mg/l, in MB-DAF-2 system. At a flow rate of 5m³/h, the maximum SS removal efficiency was achieved in the MB-DAF-2 was 27%. Comparison of SS Efficiency values in the Classical and Microbubble Generator Pump DAF Systems are given in Figure 4.18.

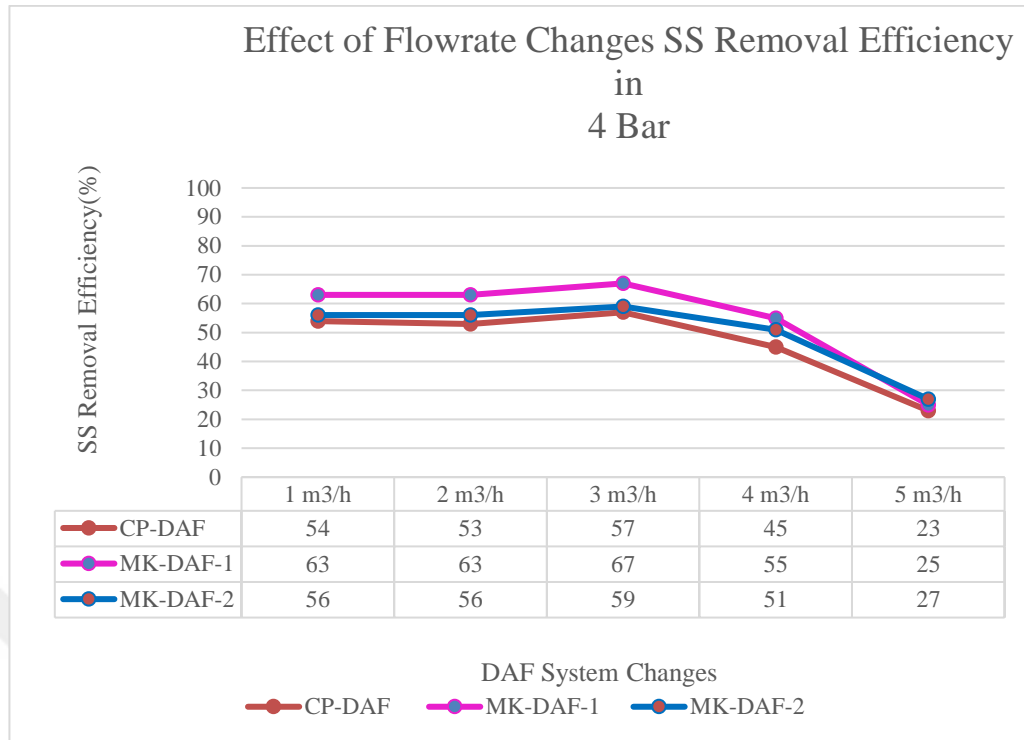


Figure 4.18 Comparison of SS Efficiency in the Classical and Microbubble Generator Pump DAF Systems

When comparison of the results, the COD, oil/grease, SS efficiency values of CP-DAF were lower than MB-DAF-1 and MB-DAF-2, each flowrate and pressure changes condition.

In this situation, it had been proven that DAF systems with microbubble pumps were more efficient than classical DAF systems.

4.7 Comparison of the Results of Classical, Microbubble Generator Pumps and Modified Microbubble Generator Pumps System

In the operation of the MOMB-DAF-1 system at 4bar conditions, the highest COD removal efficiency was obtained at a 1m³/h. The COD value decreased 1739 mg/l to 850mg/l. The COD removal efficiency was 51% at 1m³/h, 45% at 2m³/h, 46% at 3m³/h, 33% at 4m³/h and 21% at 5m³/h.

In the operation of the MOMB-DAF-2 system at 4bar conditions, the highest COD removal efficiency was obtained at a 1m³/h. The COD value decreased 1421 mg/l to 785mg/l. The COD removal efficiency was 45% at 1m³/h, 42% at 2m³/h, 38% at 3m³/h, 40% at 4m³/h and 18% at 5m³/h.

All results show that, the COD efficiency values of MOMB-DAF-1 and MOMB-DAF-2 were lower than MB-DAF-1 and MB-DAF-2, except at 3m²/h's value in MB-DAF-2 for MOMB-DAF-1. At 3m²/h, MOMB-DAF-1's COD efficiency is higher MK-DAF-2. But, all of the values of MOMB-DAF system were higher or similar value than CP-DAF. At 1m³/h, the COD removal efficiency was 45% at CP-DAF, %51 at MB-DAF-1, 50% at MB-DAF-2, 51% at MOMB-DAF-1, 45% at MOMB-DAF-2. At 2m³/h, the COD removal efficiency was %41 at CP-DAF, 55% at MB-DAF-1, 50% at MB-DAF-2, 45% at MOMB-DAF-1, 42% at MOMB-DAF-2. At 3m³/h, the COD removal efficiency was 39% at CP-DAF, 50% at MB-DAF-1, 43% at MB-DAF-2, 46% at MOMB-DAF-1, 38% at MOMB-DAF-2. At 4m³/h, the COD removal efficiency was 33% at CP-DAF, 44% at MB-DAF-1, 38% at MB-DAF-2, 33% at MOMB-DAF-1, 40% at MOMB-DAF-2. At 5m³/h, the COD removal efficiency was 19% at CP-DAF, 28% at MB-DAF-1, %27 at MB-DAF-2, 21% at MOMB-DAF-1, 18% at MOMB-DAF-2.

Comparison of COD removal efficiency are given in Figure 4.19 for all the system.

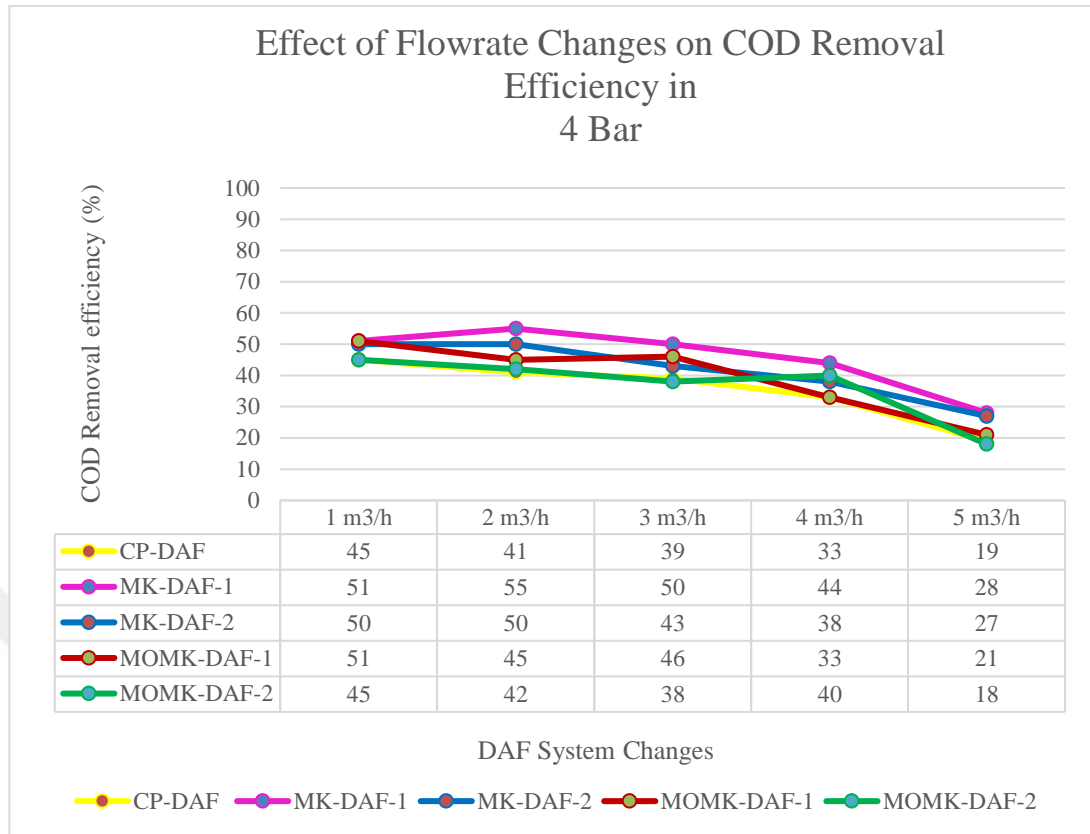


Figure 4.19 Comparison of COD Efficiency in all the Systems

For MOMB-DAF-1, when the Oil/Grease results were examined, the maximum Oil/Grease efficiency was obtained at a 1m³/h. It is 74%, for MOMB-DAF-2 was 64%, also. For MOMB-DAF-1, the Oil/Grease removal efficiency was 74% at 1m³/h, %64 at 2m³/h, 52% at 3m³/h, 50% at 4m³/h and 40% at 5m³/h. For MOMB-DAF-2, the Oil/Grease removal efficiency was 64% at 1m³/h, 53% at 2m³/h, 45% at 3m³/h, 41% at 4m³/h and 37% at 5m³/h. All results show that, generally the Oil/Grease efficiency values of MOMB-DAF-1 and MOMB-DAF-2 were lower than MB-DAF 1 and MB-DAF-2, except at 1m²/h's value in MB-DAF-1 for MOMB-DAF-1 and at 2m²/h's value in MB-DAF-2 for MOMB-DAF-2. At 1m²/h, the Oil/Grease removal efficiency was 61% at CP-DAF, 70% at MB-DAF-1, 75% at MB-DAF-2, 74% at MOMB-DAF-1, 64% at MOMB-DAF-2. At 2m²/h, the Oil/Grease removal efficiency was 48% at CP-DAF, 65% at MB-DAF-1, 51% at MB-DAF-2, 64% at MOMB-DAF-1, 53% at MOMB-DAF-2. At 3m²/h, the Oil/Grease removal efficiency was 45% at CP-DAF, 63% at MB-DAF-1, 54% at MB-DAF-2, 52% at MOMB-DAF-1, 45% at MOMB-

DAF-2. At 4m²/h, the Oil/Grease removal efficiency was 43% at CP-DAF, 60% at MB-DAF-1, 51% at MB-DAF-2, 50% at MOMB-DAF-1, 41% at MOMB-DAF-2. At 5m²/h, the Oil/Grease removal efficiency was 33% at CP-DAF, 44% at MB-DAF-1, 42% at MB-DAF-2, 40% at MOMB-DAF-1, 37% at MOMB-DAF-2.

Comparison of oil/grease removal efficiency are given in Figure 4.20 for all the system.

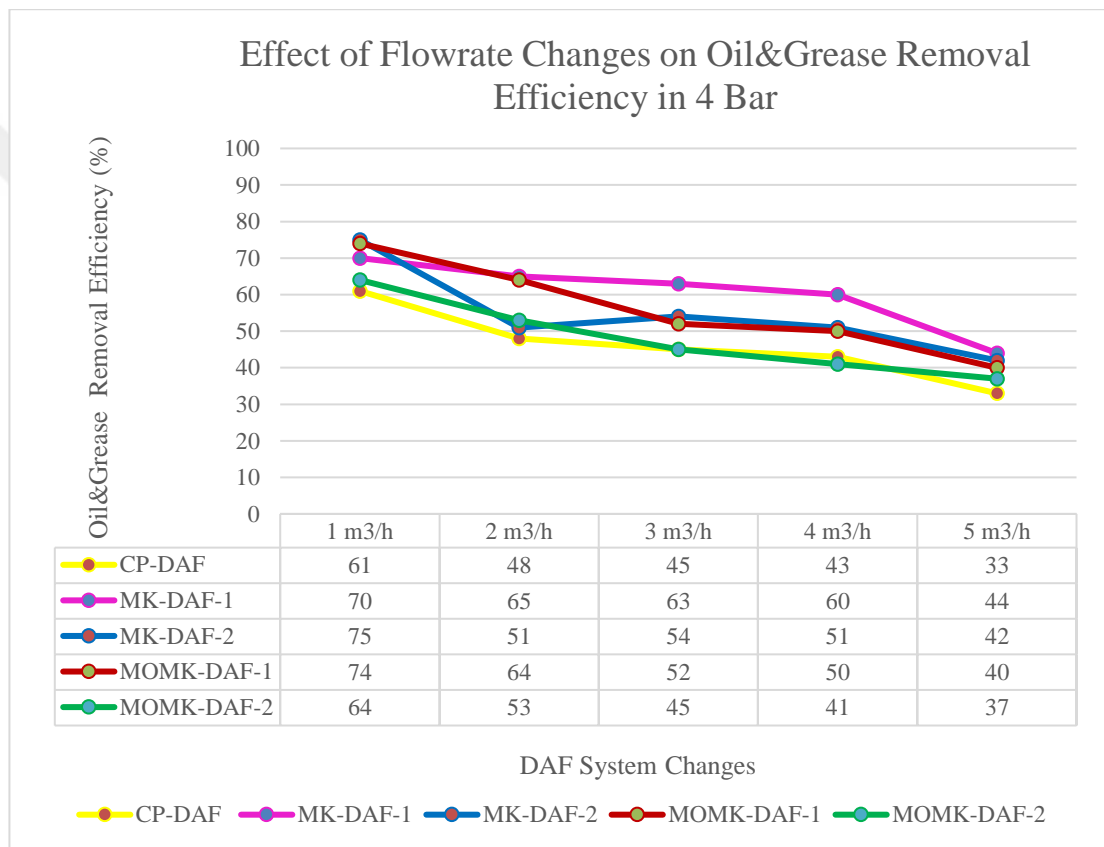


Figure 4.20 Comparison of Oil/Grease Efficiency in all the Systems

The SS results of MOMB-DAF System were examined, the maximum SS efficiency was obtained at a 1m³/h. It is %55. The SS removal efficiency was 55% at 1m³/h, 52% at 2m³/h, 50% at 3m³/h, 40% at 4m³/h and 37% at 5m³/h. All results show that, generally the SS efficiency values of MOMB-DAF-1 and MOMB-DAF-2 were

lower than CP-DAF, MB-DAF-1 and MB-DAF-2, except at 5m²/h for MOMB-DAF-1 value.

Comparison of SS removal efficiency are given in Figure 4.21 for all the system.

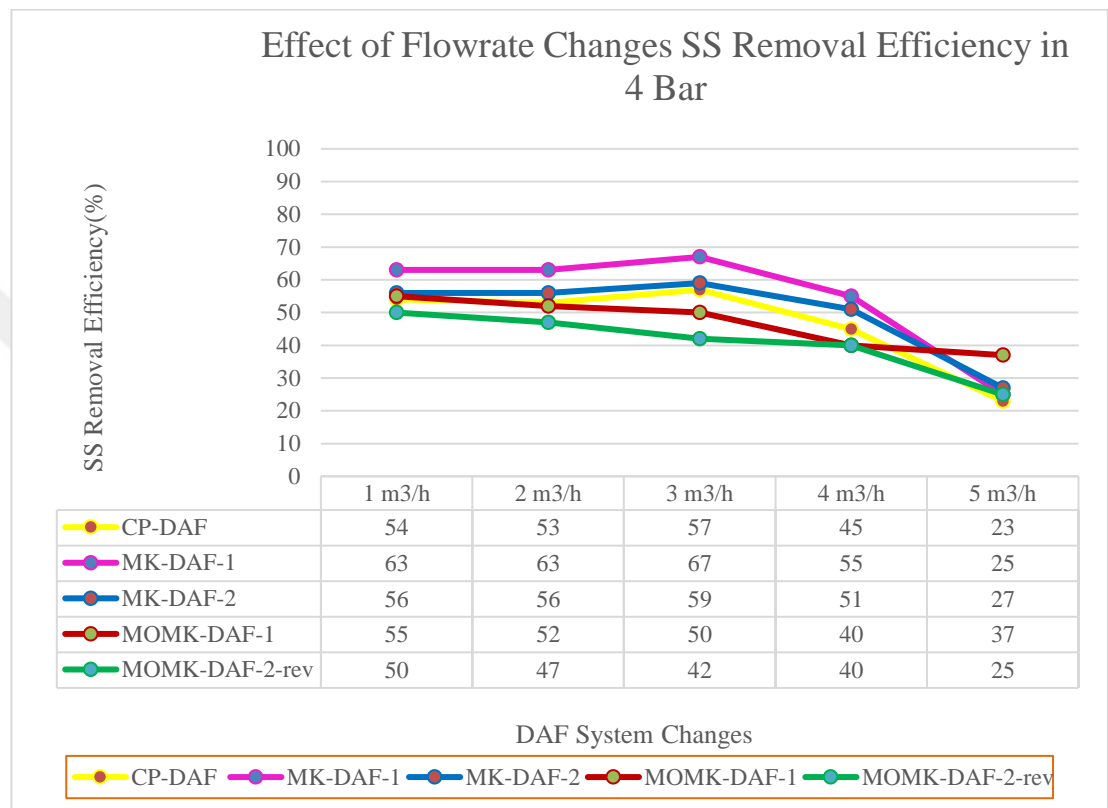


Figure 4.21 Comparison of SS Efficiency in all the Systems

The COD and Oil/Grease removal efficiency of MB-DAF-1, MB-DAF-2, MOMB-DAF-1 and MOMB-DAF-2 were higher or similar value than CP-DAF, but SS removal efficiency values of MOMB-DAF-1 and MOMB-DAF-2 were lower than CP-DAF.

CHAPTER FIVE

ARTIFICIAL NEURAL NETWORK MODELLING

5.1 Artificial Neural Network Method and Applications in Environmental Engineering

Artificial neural networks (ANNs) are a prominent approach in modeling studies. They are designed to address problems with unknown required outputs (unsupervised learning algorithms), and known outputs (supervised learning algorithms) (Matheri et al. 2021; Ansari et al. 2021) The process entails the acquisition of knowledge through the act of learning, memorizing, and generalizing the learned information. The objective is to generate new knowledge and demonstrate the relationships between the variables. Consequently, it is possible to analyse the factors that affect the treatment processes and evaluate the results.

There are numerous applications in the literature of ANNs in the environmental engineering. In the context of air pollution, ANNs have been successfully implemented in many short- and long-term forecasting applications (Cabaneros & Hughes, 2022). Nagendra and Khare (2005) stated that the ANN approaches can improve prediction accuracy compared to previously used statistical methods. The earliest applications of ANN for air pollution were the prediction of SO₂, NO, CO levels in various regions of the world. More recent attempts have included the combination of remotely sensed aerosol optical depth (AOD) and meteorological data to estimate surface concentrations of PM_{2.5} and PM₁₀ (Maleki et. al., 2019; Alimissis et. al. 2018).

Artificial intelligence models have also been extensively utilized to address many water and wastewater treatment problems like processing, forecasting and controlling the results (Al Saleh, 2021). Conducted studies show that the model results are consistent with wastewater quality parameters and can be applied to other sources such as industrial wastewater and leachate. Therefore, a number of studies have recently been carried out to develop models for predicting water quality. For instance, Singh et al. (2009) applied the ANN methodology for computing the dissolved oxygen (DO)

and biochemical oxygen demand (BOD) levels in the Gomti river (India). The results of the heavy metal analyses of Bartın River were modelled by artificial neural networks (ANN) by Ozel et al., 2020. Another study using ANNs to model the values of selected seawater quality variables was conducted by Palani et. al (2008). The authors stated that the model may be employed as a predictive tool in the ongoing field monitoring program in the East Johor Strait region. Chen et al. (2020) investigated the ANN models used in water quality estimation. They conducted extensive research and analysis on ANN-based water quality prediction from three aspects, namely feedforward, recurrent and hybrid architectures. Based on 151 papers published from 2008 to 2019, 23 types of water quality variables were highlighted. They concluded that ANN models are capable of dealing with different modeling problems in rivers, lakes, reservoirs, wastewater treatment plants (WWTPs), groundwater, ponds, and streams. Sakiewicz et al. (2020) applied the ANN model to predict the biogas generation from anaerobic fermentation process. The model was trained, validated, and tested using real industrial data collected over 3 years. The results indicate that the ANN model can be used as a predictive tool, an important element in such complex processes as control strategies or for their optimization, as well as for testing other promising process intensification and optimization scenarios.

In addition, there are various applications to predict the removal of parameters such as COD, color, and heavy metals in wastewater treatment (Bekkari & Zeddouri 2019; Alsulaili & Refaie 2021; Asgari et al. 2020; Bhagat et al. 2020; Buaisha et al. 2019). Tümer and Edebalı (2015) used a number of variables, including chemical and biological oxygen demand and total suspended solids, to evaluate the effectiveness of a wastewater treatment plant using ANN modeling. Aghdam et al. (2023) used artificial intelligence methods to predict BOD and COD, using monthly data collected over a three-year period in Hong Kong from the influent of 7 WWTPs. The ANN has been employed for optimization and prediction of TDS, COD, and BOD removals in leachate by Nabavi (2023). Hassen and Asmare (2019) studied the application of ANN to predict the effluent quality of the Habesha Brewery WWTP. The influent and effluent water quality data quality were used to develop, calibrate and validate the

models. The model results proved that ANN can predict the effluent water quality parameters with a correlation coefficient (R) between the observed and predicted output values of up to 0.969. Artificial neural network (ANN) models have been designed to predict faecal coliform and total coliform removal for an intermittent cycle extended aeration-sequential batch reactor (Khatri et al. 2020). The potential for Pb(II) adsorption from an aqueous solution using rice husk carbon (RHC) was investigated by Khan et al. (2017) using artificial neural networks (ANN). The results of the ANN analysis demonstrated that the efficient simulation and prediction of Pb (II) adsorption from an aqueous solution can be achieved through the use of neural network modeling.

The ANN model has also been used by several researchers for the optimization of membrane filtration processes (Muhammad et al. 2022;). Jawad et al. (2020) modeled forward osmosis process using ANNs to predict permeate flux. The developed model is tested for its generalization capability by including lab-scale experimental data from several published studies. The study shows that enough number of input parameters can define the system for generalized predictions. Li et al. (2021) investigated the application of artificial intelligence in process control for drinking water treatment, reporting applications such as the determination of coagulant dosage in chemical treatment processes and the control of by-products in disinfection processes.

There are a limited number of ANN models in the literature on floatation. Artificial neural network (ANN) modeling techniques were applied to evaluate the performance of full-scale, pilot-scale, and bench-scale dissolved air flotation (DAF) treatment of low turbidity, low alkalinity, and color water at Port Hardy, BC by Hossain (2003) The developed ANN models were able to predict DAF effluent color and DAF effluent turbidity with a high degree of accuracy and hold promise for successful process control applications. Wei and friends (2023) compared the response surface methodology (RSM), artificial neural network (ANN), and adsorption kinetic model (AKM) in DAF treatment process. The results showed that ANN exhibited superior fitting ability compared to RSM and AKM. Esmaeili et al. (2014) used ANN to predict

the combination of coagulation and DAF processes for Cr(VI) removal from aqueous solution. The study investigated the individual and interactive effects of coagulation and flotation factors, i.e., pressure, coagulant dose, and bubble injection time, on the removal of Cr(VI).

A three-layer ANN with a tangent sigmoid transfer function in the hidden layer and a linear transfer function in the output layer was proposed to predict the efficiency of Cr(VI) ion removal. Although there are some ANN studies on organic and/or inorganic contaminants in wastewater treatment, no ANN study was found to predict contaminants such as oil/fat, suspended solids and COD in conventional and new generation DAF systems. Therefore, the ANN modeling has been carried out to predict the quality of the effluent from conventional pump and microbubble pump DAF systems operated at different flow rates and pressures, in the thesis.

5.2 Application of The Artificial Neural Network Method to Experimental Data

The Artificial Neural Network (ANN) method was used to predict the treatment performance and pollution levels in the effluent of DAF systems operated under different working conditions. Data used for training to ANN were obtained from three different DAF systems under different operating conditions.

Chemical Oxygen Demand (COD), oil/grease, Suspended Solids (SS) value, wastewater temperature and pH value were measured in the inlet and outlet wastewater. We used these data to estimate different input and output values with the help of the artificial neural network method (ANN). The neural network is comprised of three layers: an input layer, two hidden layers, and an output layer.

The input layer consists of 9 values and the output layer consists of 5 values. The input layer includes the DAF type, influent flow rate (m^3/h), air temperature ($^{\circ}\text{C}$),

operating pressure (bar), COD (mg/L), Oil/Grease (mg/L), TSS (mg/L), influent temperature (°C), and pH parameters. The output layer consists of COD (mg/L), Oil/Grease (mg/L), TSS (mg/L), effluent temperature (°C), and pH parameters. The three different DAF setup has been classified as CP-DAF System 1, MB-DAF-1 System 2, and MB-DAF-2 System 3. Input and output layer details are given below. In addition, neural network architecture is shown in Figure 5.1.

Input Layer;

1- Type of DAF: The DAF System is classified into three distinct operating modes. There is the Classic Pump DAF, the microbubble-generating DAF with Nikuni pump, and the microbubble-generating DAF with Edur pump. These are designated in ANN as CP-DAF, MB-DAF-1, and DAF MB-DAF-2, respectively.

2- Inlet wastewater flowrate (m³/h): Five different flow rates are used in DAF Systems. The inlet wastewater flowrate is set as 1 m³/h, 2 m³/h, 3 m³/h, 4 m³/h 5 m³/h.

3- Air Temperature (°C): Air temperatures were measured during the operation of the DAF systems

4- Operating Pressure (Bar): DAF Systems were operated with different pressure values. The working pressures are set at 3 bar, 3.5 bar, 4 bar, 4.5 bar and 5 bar.

5- COD (mg/l) : Chemical Oxygen Demand (COD) values were measured by taking samples from the influent.

6- Oil&Grease (mg/l) : The oil & grease values were measured by taking samples from the influent.

7- SS (mg/l) : The Suspended Solids (SS) values were measured by taking samples from the influent.

8- Wastewater Temperature (°C) : Temperature values were measured by taking samples from the influent.

9- pH :The pH values were measured by taking samples from the influent.

Output Layer;

1- COD (mg/l) : Chemical Oxygen Demand (COD) values were measured by taking samples from the effluent.

2- Oil&Grease (mg/l) : The oil & grease values were measured by taking samples from effluent.

3- SS (mg/l) : The Suspended Solids (SS) values were measured by taking samples from the effluent.

4- Wastewater Temperature (°C) : The temperature values were measured by taking samples from the effluent.

5- pH : The pH values were measured by taking samples from the effluent.

Figure 6.1 shows the artificial neural network, which consists of an input layer, two hidden layers and an output layer.

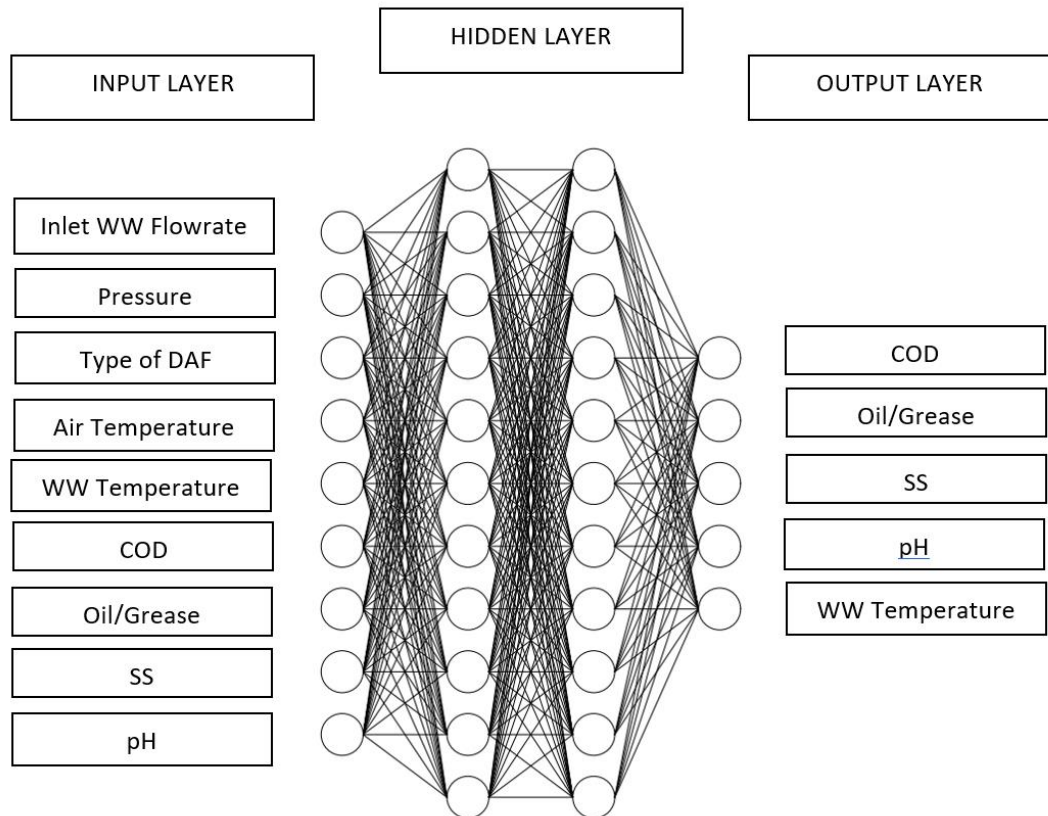


Figure 5.1 Neural network architecture

During the training of the neural networks, the input and output values are scaled in the range of 0 to 1. This is often called the normalization process. This process has been completed for all network input and output values. First, each value has been divided by the maximum value. The ANN was then performed and implemented using the Levenberg-Marquardt backpropagation algorithm with a program written in MATLAB.

The hidden and output layers of the ANN were modelled using a positive linear transfer function. Trials were conducted to determine the best artificial neural network model. The optimal model has two hidden layers, each with 11 neurons. The network completed its learning process in 402 iterations using the mean squared error method. The network's learning process was completed in 402 iterations using the mean squared error method.

The experimental results consisting of 72 datasets (Table 5.1) were used to train and test the ANN model. To evaluate the performance of the trained network model, three datasets were selected, one from each DAF type (CP-DAF, MB-DAF-1, MB-DAF-2). These three datasets were strictly not used for training the ANN model. (Özdemir, et al., 2024b) The datasets which were not used in the ANN model are shown in Table 5.2.

Table 5.1 ANN Dataset

| ANN DATASET | | | | | | | | | | | | | | |
|-------------|-------------------|-----------------|----------|------|------------|------|----------------|------|--------------|------------|------|----------------|------|-----|
| INPUT LAYER | | | | | | | | | OUTPUT LAYER | | | | | |
| TYPE of DAF | Inlet WW Flowrate | Air Temperature | Pressure | COD | Oil&Grease | SS | WW Temperature | pH | COD | Oil&Grease | SS | WW Temperature | pH | |
| | m ³ /h | °C | Bar | mg/l | mg/l | mg/l | °C | | mg/l | mg/l | mg/l | °C | | |
| CP-DAF | 1 | 1 | 11 | 3 | 1516 | 155 | 700 | 31,8 | 8,3 | 1160 | 85 | 495 | 27,5 | 7,8 |
| | 1 | 1 | 13 | 3,5 | 1958 | 175 | 860 | 30,3 | 8,4 | 1467 | 89 | 510 | 27,1 | 7,9 |
| | 1 | 1 | 12 | 4 | 3034 | 262 | 1300 | 32 | 8 | 1659 | 102 | 600 | 28,3 | 7,5 |
| | 1 | 1 | 14 | 4,5 | 1672 | 160 | 800 | 26,9 | 7,9 | 1137 | 74 | 420 | 23 | 7,3 |
| | 1 | 1 | 13 | 5 | 1230 | 120 | 510 | 27,5 | 8,2 | 900 | 57 | 297 | 24 | 7,8 |
| | 1 | 2 | 14 | 3 | 1410 | 138 | 805 | 29,7 | 7,8 | 1100 | 110 | 550 | 27,1 | 7,3 |
| | 1 | 2 | 13 | 3,5 | 1517 | 127 | 820 | 30 | 7,5 | 1060 | 94 | 420 | 28,2 | 7,1 |
| | 1 | 2 | 15 | 4 | 2900 | 144 | 1350 | 27 | 7,7 | 1716 | 75 | 630 | 25,3 | 7,3 |
| | 1 | 2 | 16 | 4,5 | 2338 | 120 | 960 | 28,9 | 7,5 | 1650 | 80 | 530 | 27,1 | 7,1 |
| | 1 | 2 | 11 | 5 | 1277 | 138 | 750 | 26,8 | 7,3 | 970 | 99 | 500 | 24,6 | 7 |
| | 1 | 3 | 14 | 3,5 | 1647 | 150 | 810 | 28,3 | 8,2 | 1447 | 93 | 410 | 26,9 | 7,9 |
| | 1 | 3 | 15 | 4 | 2258 | 144 | 1100 | 26,6 | 7,8 | 1375 | 79 | 470 | 25,1 | 7,1 |
| | 1 | 3 | 17 | 4,5 | 2415 | 115 | 950 | 27,5 | 8,1 | 1831 | 65 | 430 | 25,6 | 7,5 |
| | 1 | 3 | 14 | 5 | 1260 | 155 | 880 | 28,2 | 7,7 | 985 | 107 | 445 | 27,1 | 7,1 |
| | 1 | 4 | 15 | 3 | 1631 | 126 | 485 | 27,8 | 8,5 | 1370 | 95 | 370 | 26,1 | 7,9 |
| | 1 | 4 | 15 | 3,5 | 1725 | 127 | 610 | 28,7 | 8,1 | 1200 | 89 | 440 | 26,3 | 7,6 |
| | 1 | 4 | 12 | 4 | 2066 | 124 | 980 | 29,5 | 7,6 | 1380 | 71 | 540 | 27,1 | 7,1 |
| | 1 | 4 | 13 | 4,5 | 2450 | 184 | 660 | 26,7 | 7,5 | 1700 | 112 | 450 | 24,6 | 7 |
| | 1 | 4 | 13 | 5 | 1110 | 158 | 570 | 27,8 | 8,2 | 850 | 112 | 420 | 26,1 | 7,6 |
| | 1 | 5 | 12 | 3 | 1430 | 110 | 510 | 27,2 | 8,3 | 1330 | 90 | 440 | 25,7 | 7,5 |
| 1 | 5 | 11 | 3,5 | 1504 | 137 | 650 | 28,1 | 7,9 | 1300 | 96 | 520 | 26,2 | 7,3 | |
| 1 | 5 | 12 | 4 | 2450 | 138 | 750 | 28,3 | 7,7 | 1980 | 93 | 580 | 26,6 | 7,2 | |
| 1 | 5 | 11 | 4,5 | 2356 | 169,6 | 595 | 26,9 | 7,9 | 2050 | 120 | 470 | 24,8 | 7,4 | |
| 1 | 5 | 14 | 5 | 1290 | 150 | 570 | 27,7 | 8,2 | 1190 | 117 | 470 | 26,1 | 7,7 | |
| 2 | 1 | 14 | 3 | 2034 | 256 | 1000 | 30,1 | 8,45 | 1277 | 108 | 600 | 29,1 | 8,37 | |
| 2 | 1 | 17 | 3,5 | 1500 | 200 | 780 | 23,5 | 8,56 | 884 | 80 | 400 | 21,9 | 8,24 | |
| 2 | 1 | 11 | 4 | 1939 | 196 | 1200 | 26,7 | 8,6 | 942 | 59 | 450 | 20,7 | 7,94 | |
| 2 | 1 | 11 | 4,5 | 1908 | 236 | 850 | 30,7 | 8,54 | 966 | 82 | 340 | 26,4 | 7,64 | |
| 2 | 1 | 10 | 5 | 2300 | 330 | 710 | 28,2 | 8,69 | 1335 | 126 | 316 | 27,2 | 8,16 | |
| 2 | 2 | 13 | 3 | 1073 | 143 | 590 | 26,5 | 8,5 | 668 | 67 | 325 | 23 | 7,9 | |
| 2 | 2 | 13 | 3,5 | 1178 | 168 | 540 | 27,7 | 8,2 | 729 | 72 | 245 | 24,9 | 7,8 | |
| 2 | 2 | 13 | 4 | 1900 | 128 | 720 | 26,8 | 8,7 | 861 | 45 | 265 | 24,2 | 8 | |
| 2 | 2 | 13 | 5 | 1523 | 144 | 580 | 27 | 8 | 947 | 65 | 360 | 24,9 | 7,4 | |
| 2 | 3 | 10 | 3 | 2075 | 173 | 600 | 29,1 | 8,22 | 1484 | 96 | 300 | 29,1 | 7,32 | |
| 2 | 3 | 11 | 3,5 | 1955 | 190 | 1100 | 30 | 7,11 | 1359 | 98 | 400 | 28,5 | 7,07 | |
| 2 | 3 | 11 | 4 | 2150 | 176 | 900 | 29 | 7,48 | 1080 | 66 | 300 | 29,4 | 7,44 | |
| 2 | 3 | 10 | 4,5 | 1934 | 110 | 1000 | 27,4 | 8,16 | 1148 | 52 | 300 | 29 | 7,43 | |
| 2 | 3 | 11 | 5 | 1926 | 148 | 750 | 26,5 | 8,37 | 1150 | 116 | 300 | 24 | 7,79 | |
| 2 | 4 | 15 | 3 | 1663 | 230 | 710 | 29,3 | 8,29 | 1226 | 137 | 490 | 28,4 | 7,27 | |
| 2 | 4 | 15 | 3,5 | 2449 | 334 | 890 | 28 | 8,11 | 1255 | 195 | 610 | 26 | 7,25 | |
| 2 | 4 | 15 | 4 | 1738 | 295 | 985 | 27 | 8,45 | 969 | 118 | 440 | 25 | 7,36 | |
| 2 | 4 | 15 | 4,5 | 2250 | 308 | 950 | 27,2 | 7,76 | 1441 | 155 | 620 | 26,3 | 7,45 | |
| 2 | 4 | 15 | 5 | 2200 | 390 | 960 | 26,5 | 8,31 | 1550 | 210 | 690 | 24,7 | 7,26 | |
| 2 | 5 | 11 | 3 | 1765 | 310 | 500 | 30 | 8,56 | 1608 | 248 | 480 | 27,7 | 7,16 | |
| 2 | 5 | 11 | 3,5 | 2319 | 394 | 660 | 29,5 | 8,75 | 1829 | 236 | 500 | 25 | 7,35 | |
| 2 | 5 | 11 | 4 | 2459 | 676 | 790 | 28,7 | 8,32 | 1772 | 376 | 590 | 27,2 | 7,17 | |
| 2 | 5 | 11 | 4,5 | 2628 | 330 | 920 | 29,4 | 8,21 | 2092 | 218 | 680 | 26,4 | 7,46 | |
| 2 | 5 | 11 | 5 | 2382 | 380 | 780 | 28,4 | 8,45 | 2066 | 285 | 740 | 25,9 | 7,37 | |
| 3 | 1 | 29 | 3 | 2150 | 195 | 850 | 26,7 | 7,5 | 1370 | 95 | 561 | 25 | 7,3 | |
| 3 | 1 | 29 | 3,5 | 2260 | 198 | 902 | 27 | 7,6 | 1420 | 89 | 497 | 26,4 | 7,5 | |
| 3 | 1 | 29 | 4 | 2310 | 152 | 921 | 28 | 7,4 | 1155 | 38 | 405 | 26,9 | 7,2 | |
| 3 | 1 | 29 | 4,5 | 2370 | 145 | 912 | 29,2 | 7,5 | 1256 | 51 | 400 | 28,1 | 7,1 | |
| 3 | 1 | 29 | 5 | 2280 | 196 | 1032 | 29,5 | 7,7 | 1482 | 82 | 552 | 28,7 | 7,5 | |
| 3 | 2 | 34 | 3 | 1920 | 184 | 950 | 28 | 7 | 1248 | 117 | 541 | 26 | 7,3 | |
| 3 | 2 | 34 | 3,5 | 2010 | 198 | 1100 | 29 | 7 | 1206 | 144 | 517 | 27 | 7,1 | |
| 3 | 2 | 34 | 4 | 1856 | 192 | 1203 | 25 | 7 | 928 | 94 | 530 | 23 | 7,3 | |
| 3 | 2 | 34 | 4,5 | 2105 | 190 | 1198 | 26,7 | 6,9 | 1157 | 100 | 623 | 24,7 | 7,1 | |
| 3 | 2 | 34 | 5 | 1945 | 182,4 | 1063 | 26,5 | 7,3 | 1283 | 121 | 690 | 24,5 | 7 | |
| 3 | 3 | 6 | 3 | 2162 | 162 | 895 | 26,7 | 7,5 | 1578 | 93 | 439 | 25,2 | 7,5 | |
| 3 | 3 | 6 | 3,5 | 2320 | 142 | 1032 | 28 | 7,9 | 1647 | 77 | 465 | 26,5 | 7,9 | |
| 3 | 3 | 6 | 4 | 1940 | 182 | 970 | 29 | 7,8 | 1105 | 83 | 398 | 27,5 | 7,5 | |
| 3 | 3 | 6 | 4,5 | 2048 | 212 | 995 | 29,2 | 8 | 1187 | 106 | 423 | 27,7 | 7,5 | |
| 3 | 3 | 6 | 5 | 2179 | 195 | 988 | 29,5 | 7,7 | 1372 | 105 | 494 | 28 | 7,1 | |
| 3 | 4 | 29 | 3 | 2405 | 179 | 1125 | 27,8 | 8 | 1924 | 121 | 796 | 26,8 | 7,9 | |
| 3 | 4 | 29 | 3,5 | 2250 | 183 | 1300 | 28,7 | 7,8 | 1530 | 113 | 800 | 27,7 | 7,6 | |
| 3 | 4 | 29 | 4 | 2310 | 154 | 996 | 29,5 | 7,5 | 1432 | 76 | 488 | 28,5 | 7,1 | |
| 3 | 4 | 29 | 4,5 | 2015 | 170 | 800 | 26,7 | 7,9 | 1350 | 95 | 532 | 25,7 | 7 | |
| 3 | 4 | 29 | 5 | 1970 | 178 | 752 | 27,8 | 8,1 | 1478 | 110 | 532 | 26,8 | 7,6 | |
| 3 | 5 | 29 | 3 | 1860 | 191 | 510 | 27,5 | 7,9 | 1711 | 149 | 406 | 27 | 7,5 | |
| 3 | 5 | 29 | 4 | 1973 | 165 | 790 | 27,6 | 7,8 | 1440 | 96 | 580 | 27,3 | 7,2 | |
| 3 | 5 | 29 | 4,5 | 2153 | 172 | 750 | 27,4 | 7,9 | 1788 | 115 | 562 | 27,2 | 7,4 | |
| 3 | 5 | 29 | 5 | 2161 | 184 | 780 | 27,6 | 7,5 | 1880 | 141 | 610 | 28,9 | 7,7 | |

Table 5.2 The dataset unused in the training of ANN

| ANN DATASET | | | | | | | | | | | | | | |
|-------------|-------------------|-----------------|----------|------|------------|------|----------------|------|--------------|------------|------|----------------|------|-----|
| INPUT LAYER | | | | | | | | | OUTPUT LAYER | | | | | |
| TYPE of DAF | Inlet WW Flowrate | Air Temperature | Pressure | COD | Oil&Grease | SS | WW Temperature | pH | COD | Oil&Grease | SS | WW Temperature | pH | |
| | m ³ /h | °C | Bar | mg/l | mg/l | mg/l | °C | | mg/l | mg/l | mg/l | °C | | |
| CP-DAF | 1 | 3 | 12 | 3 | 1698 | 155 | 635 | 27,7 | 7,9 | 1510 | 102 | 390 | 25,4 | 7,5 |
| MB-DAF-1 | 2 | 2 | 13 | 4,5 | 1655 | 146 | 700 | 27,3 | 7,9 | 880 | 63 | 350 | 25,1 | 7,5 |
| MB-DAF-2 | 3 | 5 | 29 | 3,5 | 1625 | 183 | 530 | 27,3 | 7,6 | 1348 | 113 | 410 | 26,8 | 7,3 |

5.3 Results of Artificial Neutral Network

The learning performance of the system is given in Figure 5.2, and the network correlation coefficient is shown in Figure 5.3. In Figure 5.3, it is clear that the trained network model is the best network model, as it has the highest correlation coefficient. ($R = 0.98966$, see Figure 4) after 402 iterations. (Özdemir, et al., 2024b) In addition, the minimum mean squared error of the model was 0.00063414 during the training process of the network.

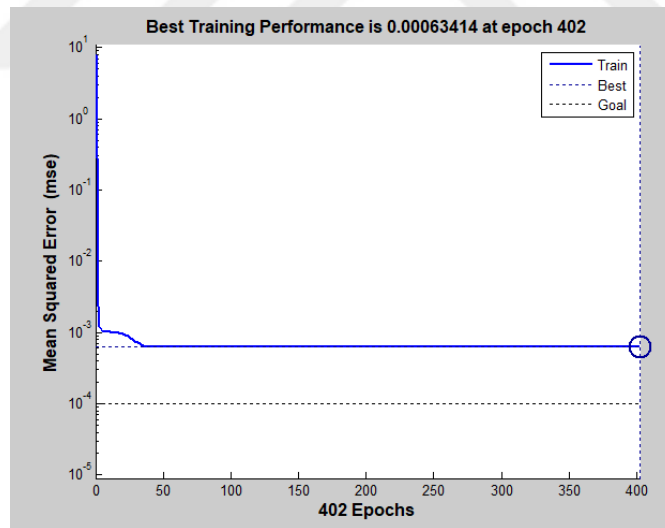


Figure 5.2 Learning performance

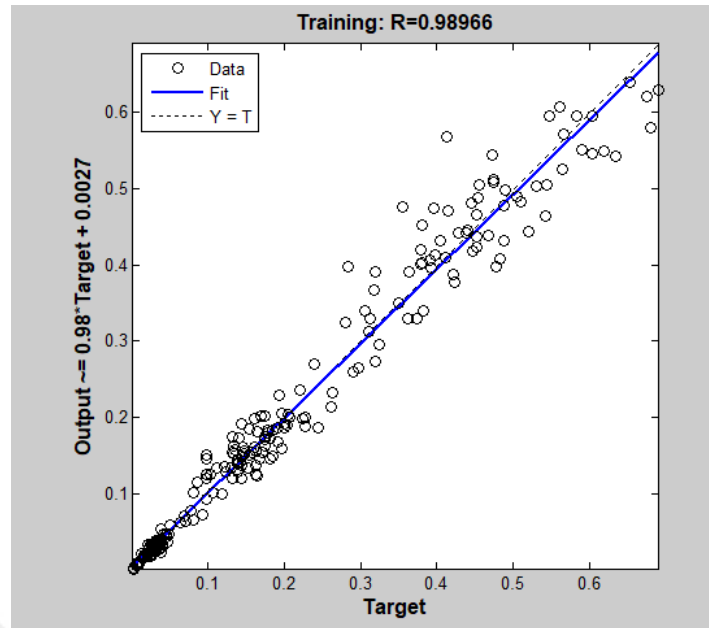


Figure 5.3 Network correlation coefficient

As can be seen from Figure 5.4, the difference between the tested values and the predicted values are so close to each other when the values before and after the learning were compared.

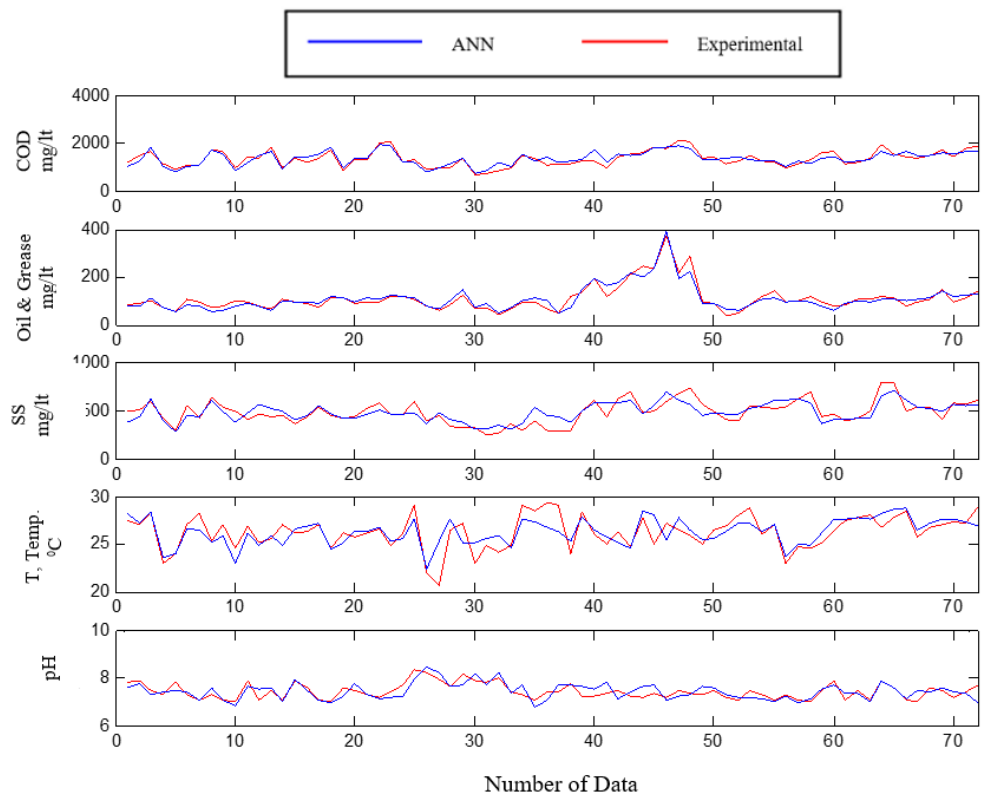


Figure 5.4 Comparison of experimental study and ANN results

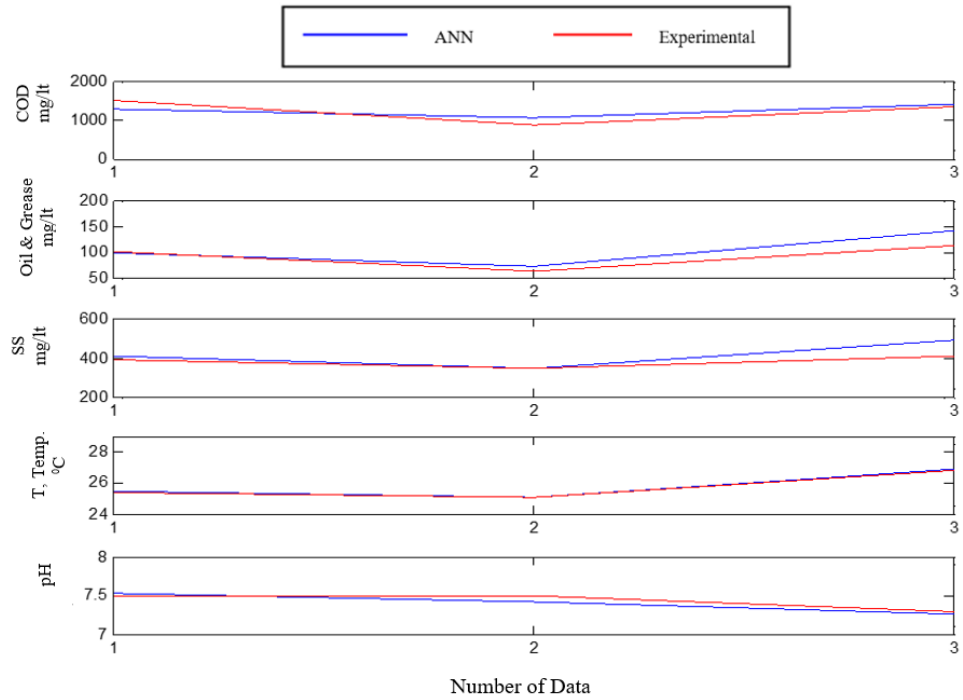


Figure 5.5 Comparison of unused experimental data in the training and ANN results

The unused data in the training of the ANN has been tested, and the results are shown in Figure 5.5. As can be seen in the figure, the predicted values are very close to the actual (original) values. The average error values for the COD, oil and grease, SS, temperature and pH parameters are calculated as 13.3167%, 14.0213%, 8.3811%, 0.2581%, 0.6733%, respectively. Furthermore, the calculated average error given in Figure 5.5 for each variable are shown in Figure 5.3.

Table 5.3 In ANN used to parameters and to the system belonging average mistake value

| Parameter | Average Error Value (%) |
|--------------------------|--------------------------------|
| COD | 13.3167 |
| Oil/Grease | 14.0213 |
| SS | 8.3811 |
| Temperature | 0.2581 |
| pH | 0.6733 |
| ANN Average Error | 7.330 |

The results show that the training of the ANN model have been successful and the average error value is acceptable.

Consequently, when evaluating all outputs related to the prediction performance of the designed neural network, there is a strong correlation between the predicted and actual values. The model shows an average margin of error of 7.33%, complemented by a high correlation coefficient of $R = 0.98966$, indicating its strong predictive accuracy (Özdemir, et al., 2024b)

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The main objective of the thesis was to provide a solution for the treatment of wastewater containing high organic pollution and oil originating by a compact MB-DAF system, which was more efficient and requires less maintenance-repair and operator compared to CP-DAF systems. With this understanding, removal of oil, organic matter and suspended solids from wastewater was investigated using CP-DAF, MB-DAF-1 and MB-DAF-2 systems, and the effects of operating parameters such as flow rate and pressure on efficiency were investigated. There was no study in the literature comparing the performances of the CP-DAF and MB-DAF systems under the same real wastewater conditions. Within the scope of the project, the prototype CP-DAF and MB-DAF systems were used to investigate and compare treatment efficiencies using wastewater obtained from a dairy factory. In the market of environmental technologies brands such as NIKUNI, ACNITI (Japan), FLAGSHIPINDIA (India) and AKVOLA, EDUR (Germany) deserve special attention among the MB-DAF systems. Thus, NIKUNI and EDUR pumps were used within the scope of the thesis to improve the existing knowledge of new generation solutions. In addition to the achievements of the new generation DAF systems, the results obtained from experimental studies are summarized below.

The experimental results have shown that the DAF systems are particularly effective in the removal of oil and grease. In the experiment, the highest removal efficiency was achieved for oil/grease. Oil/grease removal was followed by suspended solids and organic matter removal.

The MB-DAF systems have shown better performance than the CP-DAF systems. Results from field studies using wastewater obtained from the dairy industry have shown that under optimal conditions (1 m³/h flow and 4 bar pressure), the MB-DAF systems showed an approximately 15% higher performance in removing oil,

approximately 10% higher performance in removing suspended solids, and approximately 5% higher performance in COD removal compared to the CP-DAF systems.

The modifications carried out impeller systems (i.e. MOMB-DAF-1 and MOMB-DAF-2) have resulted relatively higher efficiency than the CP-DAF system in terms of oil/grease and organic matter removals. On the other hand, SS removal efficiencies were negatively affected from the modifications. However, for particularly oil/grease parameter, it had been proven that DAF systems with microbubble pumps were more efficient than classical DAF systems.

The appropriate operating pressure was determined to be 4 bar, and it was found that the treatment efficiency decreased at pressures above 4 bar. Theoretically, air bubble size and contact time are important parameter in oil/grease removal. Smaller micro-bubble generation at high pressures yields high surface area and resulted an increase in the removal efficiency. However, the experimental results showed that the pressure increase did not have a positive effect beyond a certain point. This was explained that reducing the amount of micro-bubble air-water mixture supplied to the system by tightening the valve at suction and discharge line.

The increase in the inlet flow rate at a fixed volume has negatively affected the treatment efficiency. This situation was explained by the decrease in the detention time and the contact time in the tank depending on the inlet flow rate, when the return cycle rate and pressure value do not change.

Regarding the economics of the DAF units both capital and operating costs are evaluated in the thesis. The main component that increases the investment cost is the microbubble generating pump. According the economic analyses, investment cost of

the MB-DAF system is 60% higher than CP-DAF system. In addition, although the investment cost of the new generation DAF system is higher than traditional DAF systems, its operating costs are lower due to lower energy consumption. On the other hand, in traditional DAF systems, especially the electricity consumption of the pump and compressor is high. Therefore, when the new generation DAF Systems are used, the total electrical energy consumption per unit volume of treated wastewater is lower which is resulted a decrease in operating costs. Although a comprehensive cost analysis was not carried out within the scope of the study, the CP-DAF and MB-DAF systems were compared based on the power values of the mechanical equipment used. The CP-DAF unit is equipped with a 1.1 kW compressor and a 1.1 kW recirculation pump. Also, there is an electrical connection (0.09 kW) to the control equipment (pressure switch and level sensor) on the pressure tank. In the MB-DAF system, only one pump with a power of 1.1 kW pump is used. Based on these data, it is estimated that MB-DAF systems are approximately 50% more advantageous in terms of operating costs. The total electrical energy consumption per unit m³ wastewater is lower in the MB-DAF system. In addition, conventional systems can be upgraded to the new generation of DAF systems with simple modifications. This is another important advantage for the MB-DAF systems. Considering these advantages, MB-DAF had been suggested to use widely as an effective pre-treatment alternative before the biological treatment stage especially for industrial wastewater containing oil-grease, SS and COD parameters.

As stated in the thesis, there are many parameters that affect the design of the DAF system. Among the various design parameters, the hydraulic retention time, which is defined as the time the wastewater remains in the DAF unit, is of particular importance. Our experience has shown that it is important to allow sufficient time for both bubble-flock contact and floc separation. Therefore, it is recommended to calculate the HRT separately for the contact zone and the flotation/separation zone of the DAF system. There is no reference in the literature to HRTs for the contact and flotation zones. In the thesis, the HRT for dairy effluent is calculated to be 5-7 minutes and 30-45 minutes for contact and floating zones respectively.

Finally, Artificial Neural Network (ANN) modeling techniques are an important tool to evaluate the performance of full-scale, pilot-scale, and bench-scale treatment systems, as mentioned in the previous section. In this study, an artificial neural network (ANN) was created using the obtained data and variables to predict the output pollutant values of DAF systems operated under different conditions. Considering all the output of the ANN regarding prediction performance, a high correlation coefficient of $R = 0.98966$ indicated a match with an average error of 7.330% between the predicted and actual values. Considering the effect of variables such as wastewater flow rate, pressure, pollutant concentration, operational characteristics, etc., the effluent water values of the examined DAF systems could be predicted by modelling the data obtained from pilot-scale studies using an ANN. It has been observed that the model has an excellent prediction ability with a high correlation coefficient. Therefore, it has been demonstrated that different DAF systems could be designed for different conditions, and optimal operating conditions could be determined by using ANN.

6.2 Recommendations

In the thesis, the data obtained from the experiments are modelled using ANN. In addition to ANN, the use of Artificial Intelligence (AI) technology to predict the performance of DAF systems can bring a new approach to science. Therefore, implementation of AI is recommended for further researches.

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