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Dissolved Air Flotation (DAF) Operational Parameters and Limitations for Wastewaters Treatment with Cost Study

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A R T I C L E I N F O

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A B S T R A C T

Dissolved air flotation (DAF) technology is one of the efficient techniques for purification of many types of wastewaters which contain pollutants less dense than water. Nowadays, due to high quality standards, wastewaters should be treated with high quality wastewater treatment techniques which meet the appropriate standards. DAF can remove suspended materials and oily particles contained in raw wastewaters. The study aims to review DAF system with its operation and limitations of the system. Additionally, the cost of system is discussed. Pre-treatments of primary sedimentation and post treatments such as filtration, biological, and chemical treatments can enhance the removal of pollutants and efficiency of the system.

1. Introduction

Increasing industrialization and urbanization have great impact on consuming large quantities of water resulting in generating excess wastewaters in domestic and industrial sectors (Varjani et al., 2019). Disposing and directly discharging wastewaters into the water bodies without proper treatment is alarming and has great effect to natural water and environment. This work aims to investigate the use of Dissolved Air Flotation (DAF) technology for treatment of wastewaters. Moreover, the operation parameters and performance of DAF, as well as pre and post treatment of DAF process are explained and reviewed. Nowadays, DAF technology has been widely used in many industries to treat various types of wastewaters, such as oil refineries, paper making, laundries, car washings, metal processing, and many other industries. The DAF process consists of four basic steps including:

- Generating bubbles in the wastewater;
- Contact between the gas bubble and the suspended particles in wastewater;
- Attachment of the suspended particles to the gas bubbles;
- Rising of the air/solids combination to the surface where the floated material is skimmed off (Shammas et al., 2010).

2. DAF and functions for wastewaters treatment

The main objective of air flotation process, is an efficient way to separate light particulates and oils from wastewater. Particles that adhere to air bubbles can float from the liquid phase. DAF is also separation process between oil and water droplets. Removals is accomplished by dissolving the air in water or wastewater under pressure of 40 psi to 80 psi and then releasing the air under atmospheric pressure in the

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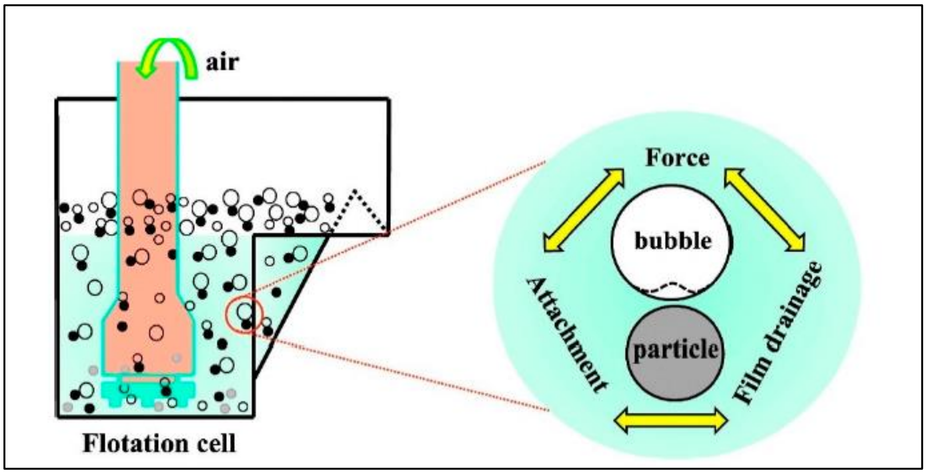

Figure 1. Principle and concept of DAF (Abuhasel et al., 2021)

flotation tank. When the pressure is reduced in DAF tank, the result is the formation of micro bubbles ranging in size between 20-100 μm. Small bubbles move upward to the surface and become entrapped by oil particles and organic matters, and are consequently removed with the froth (Al-Shamrani et al., 2002; Shammas et al., 2010), Figure 1.

Many methods and techniques used for water and wastewater treatment, among them DAF, have become the more advanced efficient techniques for reducing impurities and suspended particles inside the wastewater.

Jung et al. (2016) used the DAF technique for drinking water applications and reported that DAF had a sufficient impact on reducing algal load since algae were characterized by the tendency to float, low cell density, its small size, and negative surface charges. According to Teixeira and Rosa (2006), comparison was made between DAF and conventional sedimentation technique for the treatment of algae rich water. It was recorded that generally DAF technique could be considered more effective than sedimentation. However, the dose and type of coagulant, as well as the coagulation, flocculation and DAF operating conditions were key parameters for removing bacteria cells. Yu et al. (2017) recorded that DAF could remove 90 % of oil and 92.5 % of chemical oxygen demand (COD) in the treatment of oily wastewaters.

3. Performance of DAF and influencing factors

The effectiveness of the process mainly depends on how well the particles can be agglomerated with air bubbles in order to achieve maximum collision and attachment between air bubbles and the suspended particles. In addition, bubbles must rise under laminar flow conditions. This avoids shredding of flocs, which can occur in a turbulent regime. The maximum bubble size for laminar flow is 130 μm (AWWA, 1999). The main factors involved in the DAF process are air pressure, recycle ratio, and air to solid ratio. The size of the bubbles is an important factor to achieve an efficient solid-liquid separation during their float to the surface (Torrealba, 2007).

3.1. Air pressure

Bubble generation and size of bubbles in wastewater depends on the air pressure which has been pressurized into the DAF tank. Typical value of operational parameter for air pressure ranges between 40-80 psi (Torrealba, 2007). In DAF system, there are two methods for generating bubbles in DAF unit. Wastewater is pressurized through air diffuser or air nozzle discharged from the bottom of flotation tank. Or the wastewater is aerated with air until it is saturated at atmospheric pressure (Tang and Liu, 2006).

3.2. Recycle ratio

The recycle ratio is the fraction or part of treated wastewater when the final effluent is returned to the pressurization DAF tank. The recycle ratio helps the DAF unit to avoid flocs and agglomerated particles to disruption with generated bubbles. The portion can vary typically between 15-50 % or 20-100 % for water and wastewater applications, respectively (Tang and Liu, 2006; Srinivasan, 2009). Rattanapan et al. (2011) used 20-40 % recycle ratio for the treatment of biodiesel wastewater by DAF with alum and acidification. Recorded removal efficiency of COD was 85-95 %.

3.3. Air to solid ratio (A:S)

This parameter refers to the amount of air needed to float solid particles to the surface of floatation tank. The higher air/solid ratio causes higher turbulence of water and results in breaking the bond between solid particles and bubbles. Typically for low influent concentration, the system starts with low A:S ratio, between 0.005 and 0.010 (Ross et al., 2000).

4. Operational parameters of DAF unit

4.1. Hydraulic Retention time (HRT)

One of the most important parameter in designing DAF system is the time of remaining wastewater in the tank, i.e. flotation time that has impact on the performance and optimization of the operation parameters of the DAF system.

Typically, HRT for DAF ranges from 20-60 minutes. However, when treating high flow and high flow effluents, the longer flotation time will be used.

HRT decreases by increasing flow rate, which results in decreasing bubble production and longer time needed for air to dissolve totally inside the reactor (Dassey and Theegala, 2012).

Alshahri et al. (2021) evaluated three flotation times 5, 10, and 15 min. Thereby, it was found that 10 min of flotation time was effective at improving the raw water quality. Results indicate there is an optimum flotation time which is a function of the feed water quality, type and dose of coagulant, where further studies are required to identify this value. Table 1 shows different HRT with operating conditions for DAF system.

Table 1
HRT with operating conditions for DAF system

No.	Wastewater type	Treatment technique	Operation conditions	HRT	Removal (%)	Reference
1	Urban wastewater	Chemical coagulant + DAF	FOG: 57 mg/l	4 months	FOG: 74	Collin et al. (2020)
2	Biodiesel wastewater	DAF by acidification and coagulation	pH:3 , 1 g/l alum, chloride and ferric chloride recycle rate: 20-30 %	1 d	Oil and grease 85-95	Rattanapan et al. (2011)
3	Raw water	DAF and GAC	Loading rate: 20-40 $m^3/m^2.h$ Q: 500 m^3/d	-	Turbidity: 98	Jung et al. (2016)
4	Raw water	High rate DAF and filtration	Cold water 3-5 ºC Loading rate 30-40 m/h Flocculation time: 5min	-	Good turbidity removal	Edzwald et al. (1999)
5	Car wash wastewater	Hybrid process; coagulation-flocculation and DAF	Ferric chloride, Alum and quick lime coagulants, Pressure:1,3 and 5 bar	1-5 h	COD: 92 Turbidity: 98	Golestani and Fathali (2015)
6	Municipal wastewater	DAF	10mg/l Poly aluminum chloride, 22 % Recycle ratio, Flocculation time G-value 55 S^{-1}	8 min	Total phosphorus:90 COD:47 TSS:77	Koivunen and Heinonen (2008)
7	Coal mining wastewater	Coagulation, flocculation and DAF	Coagulant 50mg/l Flocculants: 0.5 mg/l Air pressure 4.5 bar Recycle ratio 30 %	5 min	Turbidity: up to 98 %	Couto et al. (2011)

5. Improvements for DAF

Industries that discharges their effluents into rivers, lakes, and environment have used DAF for many years. DAF system was the first generation used for the treatment in industry where the oil and grease were extracted in the tanks under flotation phenomenon. The second generation of DAF was discovered in 1960s, since then the units are used widely same way they are as used today. The typical design values for these unit plants are with surface loading rate below 5-7 m/h and flocculation time 45 min. In late 1960s a filter DAF process was introduced, where the flotation takes place above the filter. This process is called DAF/filtration (DAFF).

Moreover, at the end of the 1990s, the third generation of DAF was developed based on the idea of DAFF such as counter current DAF filtration (CoCoDAFF). In this process, recycle flow occurs above the filter media through special flow rate nozzles that are designed to disperse the bubbles widely inside the reactor (Wang et al., 2010). Rapid DAF and Aqua DAF are other recent technologies that are used with high flotation loading rate and high rate of DAF. Moreover, dissolved ozone flotation (DOF) is recently used as an alternative to DAF to decrease the cost of treatment and provide better results (Naumczyk and Marcinowski, 2012). For the past 20 years DAF has been developed widely in many designs and configurations and has led to the increase of the efficiency for industrial application (Karhu et al., 2014).

6. Pre and post treatment techniques for DAF

In order to reach a specified effluent quality, many treatment processes should be done to enhance the process. According to Liu and Nie (2016), flotation agents should be added to improve flotation, since they adhere adsorption and colloidal particles together while bubbles float. Pre-treatment of DAF for oily wastewater treatment could be done by using primary settling, coagulation or adsorption prior to flotation in order to optimize the performance of DAF. Koivunen, and Heinonen (2008) supplied DAF pilot-plant with the effluent of wastewater treatment from plant secondary or primary settling tanks. DAF performance achieved approximately 46-99 % reductions of enteric microbial numbers and 30-80 % reductions of total phosphorus, COD, and other measured water quality parameters. In addition, the efficiency of DAF process in treatment of primary effluents improved when the coagulant/ flocculant was added. Wang (2007) applied a settling tank simulation and carried out procedure involving sedimentation tank, combined with the flotation process in a small pilot study, when the influent concentration of oil was 3,000-14,000 mg/L, the effluent quality of the oil average concentration was of 300 mg/L or less, and the minimum had reached 97 mg/L, the flotation process improving the degreasing effect (Wang, 2007; Yu et al., 2017).

6.1. Coagulation/flocculation

Coagulation and flocculation are widely used in water and wastewater treatment. By adding coagulants with the help of mixing the impurities are mixed with the chemical aids and they aggregate to form stable flocs. Then by flotation the flocs can be removed by sedimentation, air flotation, or rapid filtration, Figure 2 (Jaji, 2012).

A coagulation-flocculation process is often used before the flotation tank, depending on the wastewater to be treated, in order to ensure better adhesion between the micro particles and the bubbles (Muñoz-Alegría et al., 2021).

Alshahri et al. (2021) used two coagulation modes with the combination of DAF system, such as liquid ferrate (high and low yield) and ferric chloride for the treatment of sea water. The assessment and performance of the process was conducted by measuring the removal efficiency for turbidity and other pollutants. It was concluded that the process was an efficient and cost-effective pretreatment method during algal bloom events.

Teixeira and Rosa (2006) compared coagulation/flocculation/dissolved air flotation (C/F/DAF) and coagulation/flocculation/sedimentation (C/F/S) for removing cyanobacterial cells. The result showed C/F/DAF was the best process to remove single cells of M. aeruginosa, yielding very high chlorophyll removal ranging between 93-98 %, with no toxin release to water (8-15 %), using a low recycle ratio (8 %), lower coagulant doses, and shorter flocculation time.

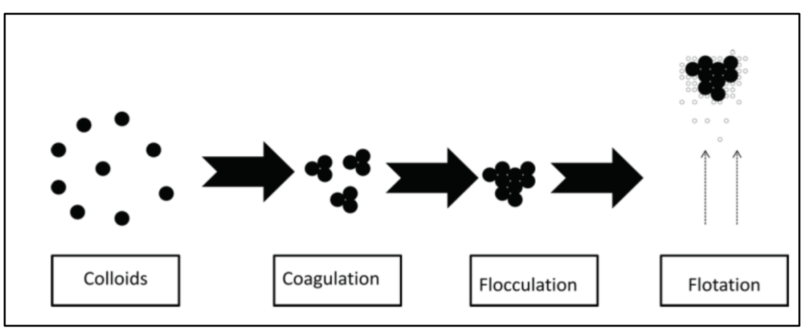

Figure 2. Coagulation/DAF system

6.2. Adsorption

Adsorption is another technique used in wastewater treatment processes. It is recognized as an efficient chemical/physical approach. The most commonly used adsorbent is activated carbon (AC), powdered AC (PAC), and granular AC (GAC) (Aziz et al., 2012). In adsorption, molecules distribute themselves between two phases, one of which is a solid, whilst the other may be a liquid or a gas. Several investigations of DAF with PAC are evaluated by Jung et al. (2016) for the treatment of several water samples, such as raw water, coagulated water, and lake water. The preliminary experiments were done by Jar test in the laboratory for the removal of turbidity and Chlorophyll-a. The results showed that at 12 mg/l PAC concentration, the removal efficiency of turbidity and Chlorophyll-a were 96.8 % and 98 %, respectively.

6.3. Treatment by chemicals

Electrochemical oxidation is the most effective treatment for various types of wastewaters, such as oil refinery, paper mill, and textile wastewater. In this process a medium that provides the ion transport mechanism between the anode and the cathode is necessary to maintain the process (Bashir et al., 2014).

Chemical treatment is an important requirement as a pre-treatment process for DAF for effective flotation. To obtain good attachment between particles and air bubbles, a relatively high surface area and destabilized flocs, as well as a hydrophobic nature, are required. The addition of the coagulant allows the oil impurities to aggregate to form larger droplet flocs (Coca et al., 2011).

Table 2 illustrates the performance of different chemicals (coagulants) which have been used for different water chemistry.

Table 2
Different coagulants usage with removal efficiencies (Saththasivam et al., 2016)

Coagulant type	Optimal dosage (ml/L)	pH	Influent (SOG mg/L)	Removal efficiency (%)
Aluminium sulphate	100	8	1,630	99.3
	50	4	500	93
	800-1,400	8	-	99 COD
	50	5	1,218	94
Ferric sulphate	120	7	1,630	99,9
	700-1,000	8	170	73
	50	5	1,218	91
Ferric chloride	500-700	8	170	73
	100	6	500	95
	50	5	1,218	92
Alumminium Chloride	50	5	1,218	93
Poly-aluminium chloride	30	6	100.9	90
Polyacrylamide	15	6	100.9	90

Treatment by chemicals is an easy and effective first treatment step to provide aggregated oil drops and larger flocs from wastewater but cost of chemicals and high volume of sludge generation are contributing problems in this treatment (Saththasivam et al., 2016).

7. Cost Study

Thompson et al. (1972) recorded costs for the three basic flotation systems which were rectangular DAF, circular (cylindrical) DAF and rectangular induced air flotation (IAF). The most economical system was the cylindrical DAF as it required less space and steel in installation and construction.

Using chemicals in the treatment process would not only improve the efficiency of the process, but would influence the running cost. El-Gohary et al. (2010) studied the comparative cost evaluation for wastewater treatment techniques, such as coagulation/precipitation (C/P) versus coagulation/DAF (C/DAF) for pre-treatment of personal care products (PCPs). The results showed initial and running costs for C/P was higher by 27.3 % and 23.7 %, respectively.

Therefore, chemical coagulation with DAF was more economical for the treatment of the wastewater. As noted by Edzwald (2011), the comparison of costs between sedimentation and DAF processes should include both capital and operation and maintenance (O&M) costs.

Floc tanks in sedimentation process required a relatively high capital cost but low operating cost. In contrast, DAF process required low initial costs but high operating cost because of its energy consumption associated with the saturator and diffusers.

8. Conclusions

After conducting the present research the following conclusions were outlined:

- The main important function of DAF is to remove suspended and colloidal solids from influent raw wastewater via flotation (rising) or by decreasing their apparent density.
- DAF technology is an efficient pre-treatment technique before biological treatment, since it removes high concentration of COD and oil and grease which can be 92.5 % and 90 %, respectively.
- Three factors: air pressure, recycle ratio and air to solid ratio affect the performance of DAF and effectiveness this process.
- Pre and post treatment of DAF lead to a better removal efficiency; however, the cost and operation of the system are high.
- The focus of future work should be on developing DAF technologies that utilize renewable energy, as well as ways to reduce the energy consumption of various elements (such as pressure pumps, motors, air compressors, and mechanical systems).

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Operativni parametri i ograničenja postupka flotacije sa rastvorenim vazduhom (DAF) za tretman otpadnih voda sa studijom troškova

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INFORMACIJE O RADU

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I Z V O D

Tehnologija rastvorenog vazdušnog taloženja (DAF) je jedna od efikasnih tehnika za pročišćavanje različitih vrsta otpadnih voda koje sadrže zagađivače manje gustine od vode. Danas, zbog visokih standarda kvaliteta, otpadne vode treba tretirati visokokvalitetnim tehnikama za tretman otpadnih voda koje ispunjavaju odgovarajuće standarde. DAF može ukloniti suspendovane materijale i uljaste čestice prisutne u sirovim otpadnim vodama. Studija ima za cilj pregled sistema DAF sa njegovim operativnim parametrima i ograničenjima. Takođe, razmatra se i cena sistema. Prethodni tretmani, poput primarne sedimentacije, i naknadni tretmani poput filtracije, biološkog i hemijskog tretmana, mogu poboljšati uklanjanje zagađivača i efikasnost sistema.