XVI International Mineral Processing and Recycling Conference
28-30 May 2025, Belgrade, Serbia

DOI: 10.5937/IMPRC25469K Research article

DISSOLVED AIR FLOTATION: IS IT REALLY A SUITABLE SOLUTION FOR INDUSTRIAL PURIFICATION PROCESSES?

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ABSTRACT – There is no doubt that one of the most important problems we face today is water scarcity as a result of increasing urbanization and climate changes. This situation necessitates sustainable water management. Although many methods have been implemented to control water pollution from past to present, the interest to usage of flotation (dissolved air flotation) as physical treatment method, has been gradually increasing its application areas in recent years. In this review, the recent developments in the application of dissolved air flotation in waste/recirculating water treatment processes was examined to provide a comprehensive understanding of the current status.

Keywords: Water Treatment, Dissolved Air Flotation, Sustainable Water Management.

INTRODUCTION

Sustainable water management and reliable access to water resources are undoubtedly one of the most important complexities of recent years. Pollution resulting from increasing world population, climate change, and increased consumption coupled with increased agricultural/industrial practices pose serious challenges in water management. As a result, sustainable water management and control of water pollution are becoming increasingly vital importance. Although many water treatment methods, including sedimentation, adsorption, advanced biological treatment, nano-based technologies and membrane technology have been developed and successfully applied to reduce environmental impacts and water consumption, the current use of these methods is still far from the desired results depending on the pollution sources, energy dependencies and socio-economic characteristics of the countries.

The methods used for water and wastewater treatment according to applied techniques are given in Fig.2. In applications, treatment methods are used alone or in combination with each other, in the early stages of the process or at the end, in a series of separation stages such as second and third stage separators. The choice of treatment processes for any particular application depends on the quality of received effluent, type of pollutant, required quality of the treated water and the economic resources available to pay both capital and operating cost [1,2].

Flotation actually is a widely used method in mineral processing and beneficiation to effectively separate mineral particles. The method based on the attachment of

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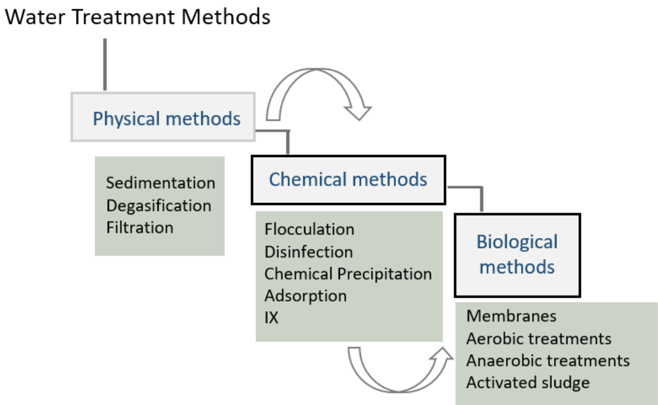

Figure 1 The methods used for water and wastewater treatment [1]

hydrophobic or conditioned particulate matter to gas bubbles and the introduction of gas bubbles as a transport medium. It was first developed for the separation of minerals in the mining industry and later was adapted for fiber separation in the 1930s by the paper industry [3]. Since then, the process has been continuously improved and in the early 1960s, it was first used in the purification of water for drinking water.

Flotation can be classified depending on the method used to generate the bubbles follows; dispersed, dissolved air and electroflotation. Among these, DAF is a continuously growing option in the treatment of paper mill and refinery wastewater, tertiary treatment of municipal water, recycled paper deinking, wastewater recovery and drinking water treatment. Recently Kyzas et al. [4] stated that in 2021, there are over 90 water treatment installations operating in the U.K. utilizing the DAF process and around the world it has been reported that there were 37 works in Finland, 26 in Australia, 26 in South Africa, 20 in the United States, etc.

DISSOLVED AIR FLOTATION (DAF)

Principle of DAF

DAF is a solid-liquid separation process based on the production of microbubbles as a result of the pressure effect and the transfer of solids to the liquid surface by binding of solid particles to fine air bubbles. As can be seen at Fig.2, in this sequential operation series, water is first saturated with high-pressure air, usually between 3 and 6 atm. The saturated water is then forced to flow through needle valves, and bubbles (10–100 µm in diameter) are produced immediately downstream of the constriction, and finally, solids are separated by bubble-particle binding [5]. Although DAF can be applied alone, it is mostly used in conjunction with coagulation/flocculation. Such usage coagulation and flocculation pretreatment steps ensure improvement in the efficiency of the bubble-particle capture during flotation.

The mechanism of application of dissolved air flotation is based on the theory of reversible chemical reactors and Henry's law, which governs the dissolution of gases in aqueous solutions as a function of pressure [6]. In principle, two factors, bubble formation and bubble-particle interaction, have a direct effect on the working

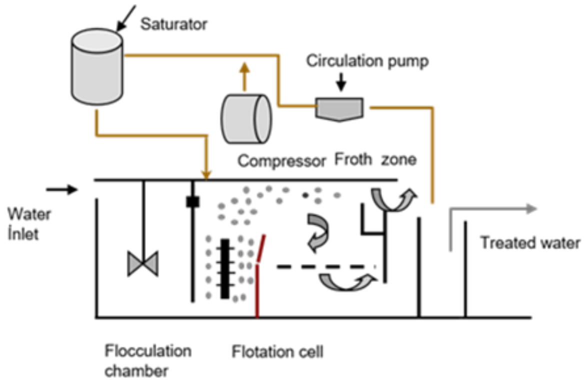

Figure 2 Rectangular flotation tank with recycle flow system

mechanism of DAF. For bubble formation, the first process is the nucleation process that begins when pressurized water and air are released from the nozzle, while the second step is the transfer of excess air in the saturated water to the flotation tank in gas form. Bubble-Particle attachment performed by collision or precipitation of air on the solid surface, bubble entrapment in a floc structure, and bubbles being absorbed in a floc structure while the floc is forming. Adhesion or collision, entrapment, and absorption are the sequential mechanisms in bubble-particle bonding.

APPLICATIONS

In most cases, DAF is an alternative process to sedimentation for the removing of suspended solid particles, metallic ions, microorganism, and macro-molecules. The technique offers several advantages, including better final water quality, rapid startup, higher rates of operation, and thicker sludge. Additionally, DAF systems need less space compared with normal clarifiers, and due to their modular components, they allow easy installation and setup. Rather than the unit operation, an application of DAF as an integrated with sorption or membrane processes has also recognized as an efficient and quite promising method especially for the removal of metal ions from waste/surface water. Heavy metal removal based on precipitation of metal hydroxides and subsequent thickening or filtration of the sludge is one of the traditional methods used for many years. However, this method has some limitations, such as incomplete precipitation, chemical instability of the precipitates and formation of large volumes of sludge difficult to filter. As an overcome these limitations it was reported that DAF method can be considered as a primary alternative separation technique for the treatment of heavy metals (Ni, Cr, and Cu) from metal finishing process water by SEPA [7]. The results confirmed that DAF is more effective than sedimentation. Another study on the use of DAF for the removal of metal ions from solutions was reported by Rubio and Tessele, 1997 [8]. In this study, Zn, Cu and Ni were successfully removed from the solution by carrier flotation where the small-sized zeolite particles and $Fe(OH)_3$ precipitates were used as

Not only an alternative to sedimentation, several lab. and pilot scale applications confirmed that DAF can be considered as an ideal alternative treatment options for the clarification of paper mill and refinery wastewaters, treatment of municipal waters, recycled paper de-inking, wastewater reclamation and recently in drinking water clarification to improve filtration as secondary or tertiary stages. A research study conducted by Bourgeois et al., [9] on the treatment of drinking water residuals showed that DAF can be used effectively for the separation of solids of lower density. Pennsylvania-US, city of Waco and Atkins-North Saluda water treatment plants are the examples of a system that installed as pilot scale; which confirmed that it could efficiently remove algae, Giardia/Cryptospordium and iron /manganese ions provided with low turbidity, exceeded filter run times and high sludge solids for dewatering. The South San Joaquin Irrigation District, CA-US can also be given as an example for the treatment of raw water having high TOC, color and algae by DAF. The pilot study verified that a combination of DAF and membrane technologies without employing polymer was a winning solution for the treatment plant [10]. A recent study published by Kurama et al. [11] showed that DAF can be evaluated as an alternative method for the removal of ammonium (NH_4) ions from surface water. Natural zeolite, clinoptilolite samples with fine particle size (<10 µm) were used as carrier material during flotation tests. The tests results revealed that test loaded with 5 mg/L ammonium resulted in a residual ammonium concentration of <0.5 mg/L with corresponding turbidity values of treated water (<10 NTU).

A number of studies in the literature have shown that coagulation with ferric and an aluminum metal salt combined with DAF is an effective method for the treatment of oily wastewater with a removal performance of over 90%. Apart from these known salts, there are many studies in the literature focused on the use of more environmentally friendly and low-cost adsorbents. Among the alternative adsorbents, one of the most interesting materials is organoclay. The usability of organoclay integrated with DAF was investigated in a relatively recent study by Younker and Walsh [12]. In this study, the treatment capacity of the integrated process was compared with the individual unit processes of $FeCl_3$ coagulation and organoclay adsorption followed by DAF. It was reported that coagulation performed with organoclay is very effective for dispersed oil removal even at relatively low $FeCl_3$ doses but its efficiency is highly dependent on the OC dose and mixing time. The results of the OC-$FeCl_3$-DAF integrated treatment showed that the reduction of oil and grease concentration to below 30 mg/L is possible. A study on reducing algae load for drinking water applications was conducted by Jung et al [13] using the DAF technique and reported that DAF had a sufficient effect because algae were characterized by their buoyancy, low cell density, small size and negative surface charge. Another study supporting the potential of DAF in the treatment of oily wastewater was reported by Yu et al. [14]. The results noted that DAF could remove 90% of oil and 92.5% of chemical oxygen demand (COD) in the treatment of oily wastewater.

Another interesting research result on the application of DAF was reported by Ortiz-Oliveros et al. [15] for the treatment of radioactive liquid wastes originating from the nuclear industry. In this study, it was emphasized that the DAF process supported by a coagulant/flocculent system consisting of a modified cationic polyamine and a light cationic polyacrylamide is a viable alternative for the treatment of oily wastewater contaminated with radionuclides produced in nuclear power plants.

An example of the possible contributions of DAF use in production processes can be given for the paper industry. The increasing concentration of suspended, colloidal and dissolved substances with different properties in the reused water during production processes, causing unwanted blockages in purification and circulation systems, and the negative effects of impurities included in the production process and incompletely purified water on product quality is important problems that need to be eliminated. In this context, the study conducted by Miranda et al. [16] investigating the charge density of cationic (C-PAM)/anionic polyacrylamide (A-PAM) with a coagulant in single and double treatments and the removal of dissolved and colloidal material with DAF is important in terms of its contribution to practical use. The results showed that for single systems, good results can be achieved with both low and high charge C-PAMs (1.0 and 3.0–3.5 meq/g), while for double systems, high charge C-PAMs (3.0–3.5 meq/g) and A-PAMs (1.5 meq/g) are the most efficient options.

Another application area for the use of DAF is the treatment of process water in the metalworking industry prior to reuse. A study focusing on the usability of DAF as an alternative to conventional treatment methods was recently proposed by Amin et al. [17]. In this study, the final treatment of industrial wastewater contaminated with metalworking fluids was carried out using a chemically added dissolved air flotation (CA-DAF) unit followed by a photo-Fenton process. The authors noted that this hybrid approach revealed removal efficiencies of 99.85% and 98.9% for COD and TPH in the optimized photo-Fenton process as pH 3, $FeSO_4$: 100 mg/l, and H_2O_2: 17.8 g/l. In addition, the cost analysis for energy (6 kWh) and chemicals (0.01818 kg $FeSO_4$ and 17.15 kg H_2O_2) consumed for the proposed process was calculated as approximately \$26 per m^3 DAF waste. An example of possible proposal for the use of DAF integrated with biological treatment systems was presented by Özgün et al. [18] for a multistage sewage treatment scheme coming from different production lines in the confectionery industry, producing approximately 170,000 m^3 of wastewater per year. The wastewater treatment system consisted of a conventional activated sludge system with screens, equalization tanks, dissolved air flotation, anaerobic expanded granular sludge bed reactor (EGSB) and sludge treatment line. The research results proved that COD in an anaerobic reactor reached 88%, while the use of an anaerobic reactor led to a 95% reduction in COD. These results are encouraging for the use of anaerobic technology as a pretreatment before conventional oxygen treatment. The wastewater applications of the flotation method and the effect of changing bubble size from nano to micro on the flotation process in these applications were discussed in detail in a recent review by Kyzas et al. [4].

Apart from the water industry mentioned above, an interesting application for DAF usage in mining industry has recently been released by Santos et al. [19]. In this work, a wastewater treatment using DAF, associated with coagulation and flocculation, has been investigated to develop an alternative process for the reuse of the water from tailings dams of an industrial apatite flotation unit. The recycling water had the following characteristics: 288 NTU for turbidity, 2.25 mg/L for fluoride, 35 mg/L for calcium, 15 mg/L for magnesium, and 33 mg/L for phosphate. Results have shown that the use of recycling water after the wastewater treatment resultant a good performance of apatite flotation, leading to recovery (80.5%) and grade (31.2%) of P_2O_5 highest than minimum acceptable in this industry. More recently the DAF process was evaluating to test its efficiency for the treatment of coal industry wastewater in order to reuse water in the beneficiation plant by Hudson et al. [20], It was proposed that possible to obtain good turbidity removal efficiencies (up to 98%) using low concentrations of coagulant (50 mg/L) and flocculant (0.5 mg/L). In experiments air saturation pressure in the saturator vessel was 4.5 bar (450 kPa). The flow of air-saturated liquid was controlled according to the recycle ratio of 30%. The results emphasized that the possibility of using the DAF as an alternative technique for treating wastewater from coal mining, allowing the reuse of water in the plant. It was noted that the iron chloride coagulant was more effective in conjunction with the previous addition of the flocculating agent into the air saturation tank, making it possible to obtain high removal efficiencies of corrected turbidity (above 98%) with small coagulant dosages (50 mg / L) and Nalco flocculent (0.5 mg/ L).

CONCLUSION

The high efficiency of modern equipment, new designs, low sludge formation, high productivity and low application costs are main drivers of the DAF to extent its usage in the field of applicability of green technology areas. However, although the process has some challenge such not suitable for raw waters with high concentrations of suspended solids, limitations for flotation freezing, which leads to sedimentation of previously floated solids due to weather conditions, and relatively high cost compared to simple sedimentation, it is expected to become more widespread with increasing optimization using artificial intelligence to closely monitor the flotation process and predict characteristic bubble parameters such as shape, size and rise speed.

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