

Review on Oil Separator for Industrial Waste

Samir Shaikh¹, Sameer D. Katekar²

Department of Mechanical Engineering, SKN Sinhgad College of Engg, Pandharpur, India.

Corresponding Author: ¹sameer.katekar@sknscoe.ac.in

Abstract

Industrial processes such as petroleum refining, metal fabrication, food processing and chemical manufacturing produce waste water containing free, dispersed and emulsified oil fractions. Removal of oil from waste water is essential to meet environmental discharge standards, reduce environmental impact and reuse of oil or water. Oil separators such as API (American Petroleum Institute) gravity separators, coalescing plate separators, hydro-cyclones and dissolved air floatation (DAF) units are widely use in the industries. This review study provides a comprehensive analysis of the mentioned separation technologies considering their working principles, performance characteristics, efficiency and application. The recent advancements in separation technologies, challenges, high load waste streams and compact system design are also discussed in the study. Comparative analysis has been made to highlight the differences in separation efficiency with respect to oil droplet size and waste water concentration. The review concluded by finding the operational gaps in the current separation technics and recommended the future directions for hybrid separators, smart automation and membrane integrated systems. The findings help the researchers, engineers and industry professionals in selecting appropriate separation systems for industrial waste water treatment.

1. INTRODUCTION

Industrial growth worldwide has resulted in significantly increase in oily wastewater mainly coming from petrochemicals, automotive services, metallurgy, textiles, food manufacturing and pharmaceutical sectors. Wastewater generating from these industries mainly contain a mixture of hydrocarbons, lubricants, surfactants, heavy metals, and suspended solids. Oily wastewater led to severe effects on environment including soil contamination, groundwater pollution and aquatic ecosystems. Therefore, water treatment becomes essential to separate the contaminations and oil from the water before it comes into the environment.

Presence of oil in the waste water categorized as free oil, dispersed oil and dissolved hydrocarbons. Free oil droplets greater than 150 μm float easily and can be removed by the effect of gravity. Dispersed oil can be separated by coalescence mechanism where the oil droplet size is between 20-150 μm . But the emulsified oil which has the oil droplet size less than 20 μm requires special method of separation. Hence, the selection of oil separator mainly depends on the oil droplet size.

API gravity separators were widely used in the industries which depends on density difference and Stoke's law to separator the floating oil. Limitation of API separators to remove small oil droplets leads to the development of coalescing plate separators. Compared with API separators coalescing plate separators showed improved separation efficiency by enhance droplet collision and merging. Further development in the oil separators led to hydrocyclones which work on the principle of centrifugal force to accelerate separation. Hydrocyclones are compact in design and high-performance separators and also suitable for high pressure industrial systems.

Dissolved air flotation (DAF) systems are superior due it's capability to remove fine oil droplets and suspended solids simultaneously. Modern DAF systems include micro-bubble generation,

optimized coagulant dosing and programmable automation. More stringent regulations on industrial discharge leads to move the researchers to invent highly efficient separation systems. The current technological improvement in waste water separators found in hybrid systems, membrane integrated separators, advanced materials for coalescing media and real time monitoring systems. Selection of existing technologies is crucial for industries which strongly depends upon efficient, Fcost-effective solutions considering environmental standards.

2. LITERATURE REVIEW

Need of efficient waste water treatment technologies for multiple industries resulted in rigorous research in oil water separation methods. The American Petroleum Institute (API) suggested the standard for API separators designs based on fundamental Stoke's law for determining oil droplet velocity rise [1]. Although these API separators are widely used in the petroleum refineries where large volume of oil waste water is produced, their limited efficiency for small oil droplet size less than 150 μm restrict their use [2].

To overcome this difficulty, researchers presented coalescing plate separation method which involved plate packs or corrugated media to increase the droplet collisions. Hazen et. al., used lamella plates for 30 to 100 μm oil droplet which significantly improves separation efficiency by increasing area to volume ratio [3]. In another research, coalescing media as polypropylene and stainless steel were responsible for droplet attachment and its growth. This was possible due to it's hydrophobicity which results in higher separation efficiency from emulsified oils [4].

Bradley and Svarovsky studied hydrocyclones as the emerged technology for separation process. Hydrocyclones generates strong centrifugal force up to 1000 times gravity which resulted in high oil water separation. Apart from this higher efficient method, it was a compact system and also suitable for high pressure industrial streams [5]. Hydrocyclone was experimented for small oil droplet size in the range of 10 to 20 μm which was dependent on inlet pressure and vortex design [6]. Due to the advantage of compact size, low operational cost and continuous operation capability makes it suitable for petroleum and chemical plants. [7].

Yoon and Luttrell demonstrated dissolved air flotation (DAF) system and observed significant removal of fine droplets and suspended solids simultaneously. DAF system generates micro air bubbles in the range of 20-50 μm size which attached to the oil droplets and plays an important role in oil separation process. The fundamental of increase in buoyancy and accelerating rise velocity is the main key in oil separation [8]. Some studies reported 95% oil removal efficiency for DAF system. This was made possible by optimizing with chemical coagulants such as alum or polyacrylamide [9]. Further improvement in separation efficiency was observed by using high-rate DAF (H-DAF). It used pressurized recycle streams and enhanced saturation tanks [10].

Emulsified oils with droplet size less than 10 μm requires advanced separation technology. Emulsified oils generally produced from industries using surfactants, coolants or detergents requires development in treating stable oil emulsions. Researchers have explored polymeric coalescers, fibrous media and ceramic membrane assisted separators. Karhu et. al., studied ceramic microfiltration system which showed effective removal of emulsions. It was suggested for hybrid pretreatment systems to overcome the fouling issue from ceramic microfiltration unit [11].

Researchers also tested new materials and nanostructured media for improved coalescence. Superhydrophobic oleophilic meshes, graphene coated sponges and metal organic frameworks (MOFs) were found to be suitable for oil absorption from wastewater [12]. Due to cost and durability challenges, these materials are found limited for experimental and small-scale applications. Hybrid systems were observed to be most suitable for efficient, lifespan and cost-

effective solution for oil separation. Commonly used hybrid systems are gravity separation, hydrocyclones and floatation. Lee et. al., tested hybrid system and found reduction in energy consumption by 20 to 35% and improvement in overall removal efficiency in complex waste streams [13]. Whereas membrane-DAF hybrid systems showed superior performance in removal of both oil and fine particulates from the waste water and improvement in membrane lifespan. [14].

Another emerging research direction includes automation and digital monitoring of oil separators. These systems incorporated with turbidity sensors, oil in water analysers and IoT based monitoring for optimal performance. DAF efficiency was observed to be improved by 15% with use of real time control strategies to control coagulant dosing and air saturation pressure [15].

Even though, significant researches have been done on oil separation technology, still some challenges are needed to be address. These challenges include handling fluctuating influent loads, surfactant stabilized emulsions and compact system design for space restricted industries. Advancement in research also observed in computational fluid dynamics to optimize separator geometry, droplet breakup modelling and advanced materials for coalescing [16].

3. RESULTS AND DISCUSSION

From the critical literature review, a comparative analysis between API gravity separator, coalescing separator, hydrocyclones and dissolved air flotation (DAF) system. It is clearly observed has been studied and presented.

3.1 Separation Efficiency vs Oil Droplet Size

Figure 1 shows the rise of efficiency with droplet diameter for API gravity separator, coalescing separator, hydrocyclones and dissolved air flotation (DAF) system. It is clearly observed that API separator shows steep improvement in efficiency after 50 μm . It is limited for the fine droplet size. Coalescers and hydrocyclones shows strong results for mid-size range droplets while DAF shows highest efficiency for all droplet sizes.

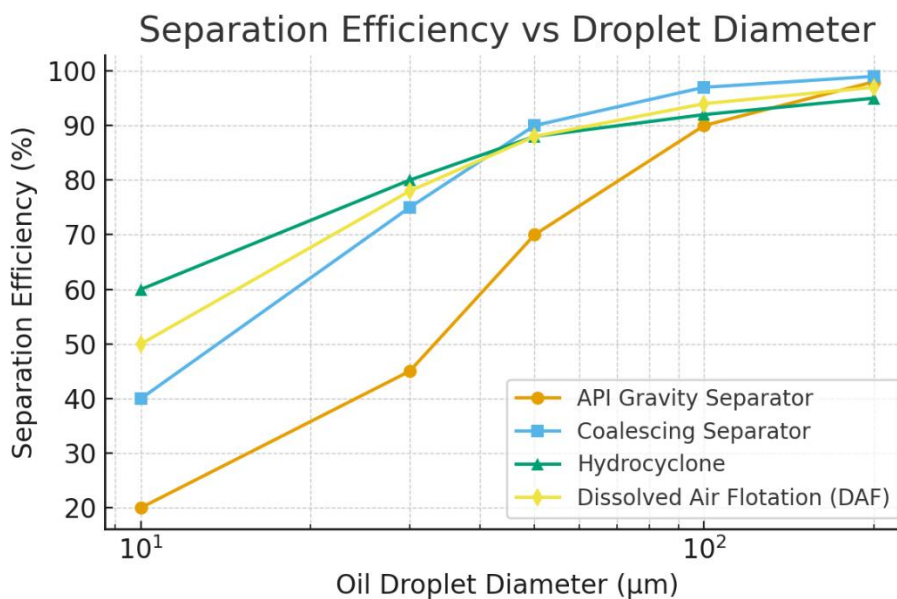


Figure 1: Separation Efficiency vs Droplet Diameter

3.2 Separation Efficiency vs Influent Oil Concentration

Figure 2 shows the variation of separation efficiency with influent oil concentration all separators. API failed to maintain the performance with increase in influent loads. Hydrocyclones and coalescers maintains stable efficiency up to moderate concentrations. DAF was observed to be superior compared to other separators in maintain efficiency with increase in influent loads. The bubble assisted flotation mechanism in DAF plays a vital role to sustain the influent loads.

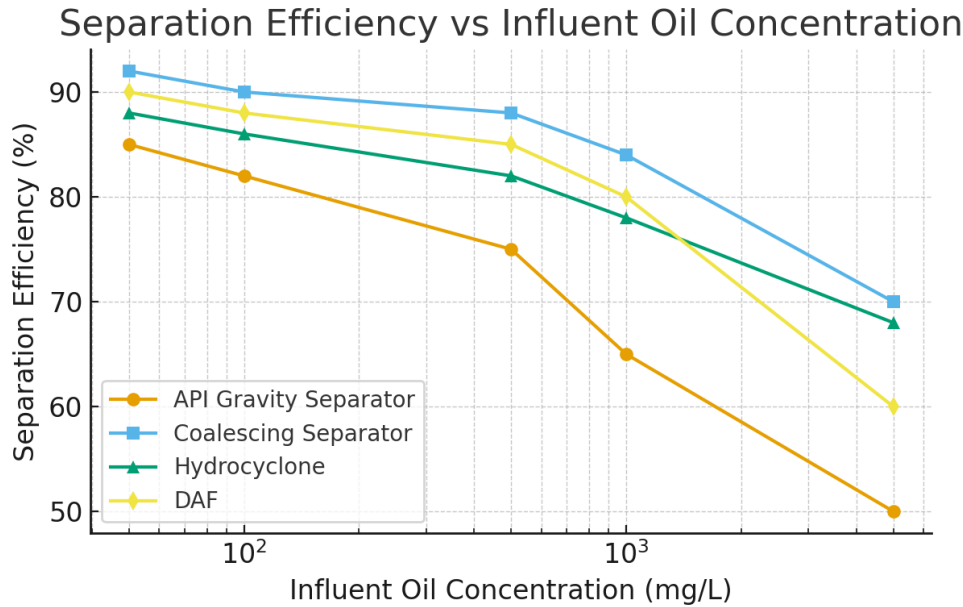


Figure 2: Separation Efficiency vs Influent Oil Concentration

Table 1: Comparative Literature Summary of Oil Separation Technologies

Technology	Effective Droplet Size Range (µm)	Removal Efficiency (%)	Strengths	Limitations
API Separator	>150	50-80	Simple, low cost	Large footprint, poor for small droplets
Coalescing Plate Separator	>60	80-95	Improved efficiency, compact	Fouling of plates, maintenance needs
Hydrocyclone	10-40	90+	Compact, high throughput	Sensitive to flow variations
DAF	>20	95+	Excellent for fine droplets	Requires chemicals, high energy

Table 2: Comparative Separation Efficiency vs Droplet Size

Droplet Size (µm)	API Separator (%)	Coalescing Plate (%)	Hydrocyclone (%)	DAF (%)
30	10	40	85	95

Droplet Size (μm)	API Separator (%)	Coalescing Plate (%)	Hydrocyclone (%)	DAF (%)
60	25	80	92	97
150	70	93	98	99

Table 1 represents the comparison between all separation techniques considering effective droplet size range, removal efficiency, strengths and limitations. Table 2 represents the comparative efficiencies for all separators with droplet size of 30, 60 and 150 micrometers. Gravity assisted API separators are found to be suitable for large droplet sizes but inefficient for small size droplets. Coalescing plate separators shows promising results for 60 to 150 micrometer droplets size with improved separation efficiency. Hydrocyclones found to superior in performance compared with API. It is capable of removing small droplets with relatively high efficiency. It is the compact design and suitable for the industries with space limitation to maintain optimal performance. DAF systems are found to be most effective separator technology with consistency in separation efficiency for all range of droplet sizes. These systems are suitable for the industries where fine dispersed oils and emulsified waste generated. The limitation of DAF system is more energy consumption and use of chemicals.

4. CONCLUSION

Even though the several separation technologies are available it is critical to process industrial waste water with different types of oil contamination. Although API separators are widely used in the industries but has limitations of small size droplet removal and requires large space. Coalescing and hydrocyclones offered compact design, improved operational efficiency and dispersed oil droplet separation. DAF system is most superior and has highest efficiency for fine droplets also. Bubble assisted flotation mechanism improves its ability for varying influent loads. Promising current and future research includes advancements in materials, hybrid technologies and digital automation for further improvement in separation efficiency, reliability and system compactness. DAF systems show superior performance in terms of separation efficiency and different wastewater conditions. Selection of suitable separation technology strongly depends upon waste water characteristics, operational constraints and regulations. Future development should focus on use of advanced materials, hybrid integration, smart monitoring to fulfil the stringent environmental standards.

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