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The Influence of Surface Modification of Porous Materials to Improve the Efficiency of Separation of Water-Oil Emulsions: A Review

Olga Soloveva[1*], Sergei Solovev[2], Rozalina Shakurova[1]

[1]Institute of Heat Power Engineering, Kazan State Power Engineering University, 420066 Kazan, Russia
[2]Institute of Digital Technologies and Economics, Kazan State Power Engineering University, 420066 Kazan, Russia

Abstract. Water/oil (W/O) emulsions are formed during oil fields and production development, thereby reducing the oil quality. In order to separate the emulsions, specialists use various methods, equipment, and materials. Most emulsions formed during oil production are stable and persistent, and traditional methods such as sedimentation and centrifugation are ineffective in the separation process. Addressing this challenge, porous materials characterized by selective super-wetting properties are used for the high-quality separation of stable W/O emulsions. Therefore, this review presents recent advancements in highly porous cellular materials that separate W/O emulsions. It further discusses the features, limitations, and advantages of using superhydrophobic/superleophilic and superhydrophilic/superleophobic porous materials such as metallic and polymeric foams. The influence of the structure and nature of porous materials on the efficiency of the separation of W/O emulsions is analyzed. Additionally, this review also explores methods for modifying highly porous materials to improve selective wettability.

Keywords: Absorption capacity; Contact angle; Emulsion separation efficiency; Porous material; Separation of emulsions

1. Introduction

Water/oil (W/O) emulsions are a common problem during oil production, formed when water is injected into an oil reservoir to increase pressure and displace oil. Although this method is widely adopted for its high efficiency and ease of implementation, it results in the mixing of W/O leading to the formation of undesired W/O emulsions. These emulsions have an effect on the oil quality, corrode equipment, and pollute water and soil. Subsequently, water, acting as a ballast, introduces specific complications in the transportation and processing of oil, making oil dehydration a mandatory stage in the production process. Therefore, there is a pressing need to study effective methods and materials for separating W/O emulsions (Zeng and Taylor, 2020; Poerwadi *et al.*, 2020). These emulsions are characterized by a two-component system of liquids insoluble in each other, while one phase is continuous, and the second is in a dispersed state. There are three types of emulsions, which include direct type (oil in water), reverse type (water in oil), and complex emulsions (water-oil-water or oil-water-oil) (Camelo-Silva *et al.*, 2022; Jhawat Gulia, and Sharma, 2021). Figure 1 shows the classification and types of emulsions.

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[*] Corresponding author's email: solovyeva.ov@kgeu.ru Tel.: +7-927-4010999

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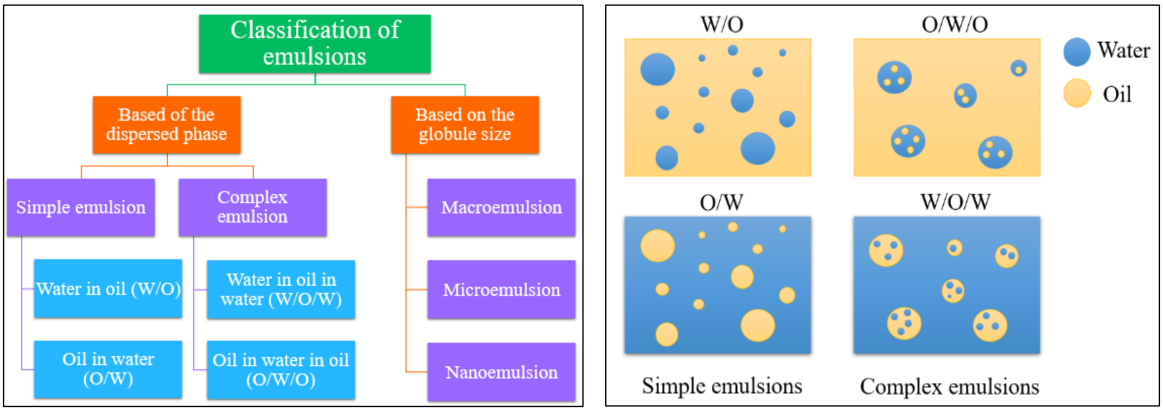


Figure 1 Classification and types of emulsions

The main properties of W/O and oil/water (O/W) emulsions are stability, viscosity, water content, and density (Sapei *et al.*, 2022). In the various industries, petroleum/water emulsions exhibit specific characteristics, including oil density of 0.86–1 (mg/L), emulsions viscosity from $1.40 \cdot 10^3$ to $9.28 \cdot 10^4$ (mPa·s), emulsion stability from 0 to $3.36 \cdot 10^4$ (s), and water content varying between 30–90%. Industrial processes also yield emulsions based on petroleum products which include diesel O/W (density 0.83–0.85 mg/L, viscosity $8.04 \cdot 10^5$ mPa·s); fuel O/W (density 0.98–1.00 mg/L, stability from $5.9 \cdot 10^2$ to $1.3 \cdot 10^3$ s, water content 76–77%); gasoline/oil (density 0.71–0.76 mg/L, viscosity $1.5 \cdot 10^5$ mPa·s) etc. (Fingas and Fieldhouse, 2004). Some of the published studies predominantly focus on the separation of the processes of various emulsions such as n-hexane/water (95%, 0.6–0.7 g/cm^3, 0.3–0.4 mPa·s) (Qiang *et al.*, 2018), ethanol/water (10–40%, 0.6–0.7 g/cm^3, 0.9–2 mPa·s) (Cho *et al.*, 2016), pump O/W (40–80%, 0.85–0.95 g/cm^3, 60–80 mPa·s) (Liu *et al.*, 2020), toluene/water (0.85–0.9 g/cm^3, 0.5–0.6 mPa·s) (Xu *et al.*, 2021), soybean O/W, etc.

The separation of emulsions includes dividing crude oil into oil and aqueous phases, and this demulsification process is carried out in refineries (Acharya and Potter, 2021). Various methods contribute to emulsions separation, including mechanical (Semenov, Slavyanskiy, and Mitroshina, 2021; Portnov *et al.*, 2021; Solovyev *et al.*, 2021), thermal (Santos *et al.*, 2017; Fortuny *et al.*, 2007), chemical (Wang *et al.*, 2021a; Sun *et al.*, 2020; Kang *et al.*, 2006), biological (Zahari, Yan, and Rahim, 2022; Esmaeili *et al.*, 2021; Fajun *et al.*, 2020; Sachdev and Cameotra, 2013), and electrical (Moldes *et al.*, 2007; Mostefa and Tir, 2004). Methods such as ultrasound and magnetic fields are recognized for separating or improving the separation of emulsions methods. These methods can be effectively combined with highly porous cellular materials for the separation of W/O emulsions.

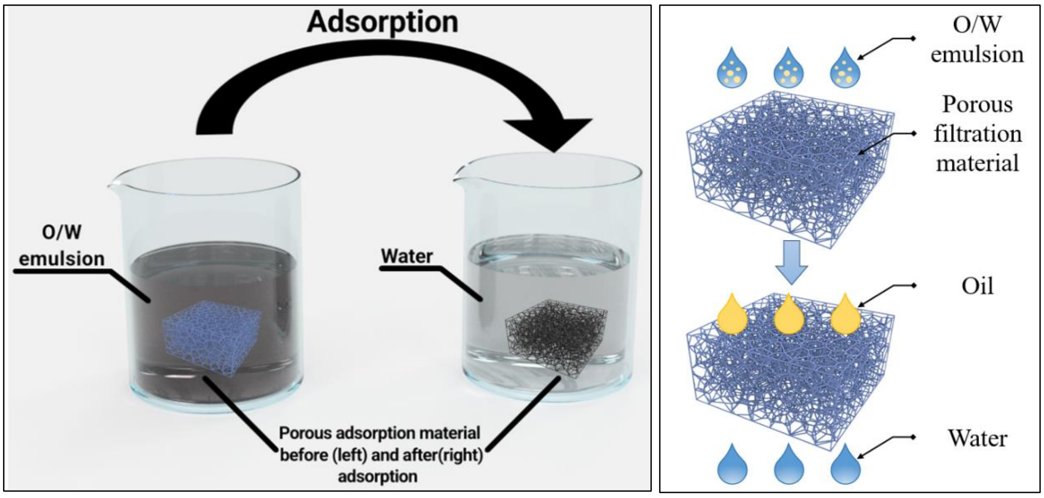
Porous materials play an active role in separating W/O emulsions, characterized by high permeability, low density, hydrophobicity, and lightweight (Satria and Saleh, 2022; Yang *et al.*, 2021a; Qin *et al.*, 2016). These materials, depending on the types, serve as an effective absorbent or filter material, intensifying the separation of emulsions in the implementation of thermal separation methods (Wu *et al.*, 2020a; Yan *et al.*, 2020; Yang *et al.*, 2019). Figure 2 shows diagrams of the process of separating O/W emulsions using porous material, which is used as an absorbent (Figure 2a) or as a filter material (Figure 2b).

Numerous publications focus on the use of porous materials for the separation of W/O emulsions. Many investigations have solved problems such as the separation of W/O emulsions using metal (Solov'eva *et al.*, 2021) and polymer (Qiang *et al.*, 2018) foams, studied the adsorption capacity and efficiency of emulsions separation by hydrophobic (Xue *et al.*, 2021a) and hydrophilic materials, examined the methods for applying a hydrophobic coating to the surface of porous material (Álvarez-Gil, Ramirez, and

Fernandez-Morales, 2021), synthesized the composite porous materials by surface modification (Cho *et al.*, 2016), assessing the influence of the type of modifier and the concentration on water contact angle (WCA), adsorption capacity, and emulsions separation efficiency (Ahmed, Anis, and Khalil, 2021; Zhang, Liu, and Qiao, 2020). Investigations also examine factors such as the influence of liquid pH on adsorption capacity (Alazab and Saleh, 2022). Researchers have studied the features of emulsion separation using materials such as polyurethane foam, melamine foam, polydimethylsiloxane foam, nanocellulose sponge, iron foam, nickel foam, and copper foam. Various surface modifiers (metal nanoparticles, polymer compounds, carbon nanotubes) and methods of their application (immersion in solution, polymerization, freeze-drying, sol-gel process, etc.) have been studied. In addressing these aspects, scientists have solved many problems related to the separation of W/O emulsions by porous media.

The purpose of this study is to systematize and classify research results, as well as to identify unsolved problems in this area. The relevance and novelty of this review lie in providing comprehensive systematic data on research related to the separation of emulsions. This information assists specialists by helping in the identification of (i) the effective use of porous materials to separate certain types of emulsions, and (ii) synthesizing composite porous materials with the necessary properties to solve specific engineering problems. In this review, articles focusing on emulsion separation using metal and polymer porous materials were selected. The data were classified according to the material of the porous medium (metal, polymer); wettability of the material (hydrophobic, oleophobic); type of modifier; method of applying the modifier to the surface of the porous medium; the influence of the modifier on the properties of porous medium (contact angle, adsorption capacity).

This systematic review specifically focuses on metal and polymer porous materials used for separating emulsions, namely foams made from nickel, iron, polyurethane, melamine, polydimethylsiloxane, etc. This review discusses two methods for separating emulsions: filtration and adsorption, which are implemented using porous materials. Furthermore, the distinctive feature and advantage is the analysis of the influence of various surface modifiers (metal nanoparticles, polymer compounds, graphene, etc.) on surface wettability and emulsion separation characteristics (separation efficiency and adsorption capacity).



(a) (b)

Figure 2 Separation of O/W emulsions using porous materials by adsorption (a) and filtration (b)

2. Methodology

Surface wettability is the fundamental characteristic of materials for emulsion separation (Wang and Deng, 2019). It is assessed by measuring WCA.

2.1. *Water contact angle (WCA) in air*

Theoretically, WCA depends on the interaction between the solid, liquid, and gaseous phases for a perfectly smooth surface. WCA can be obtained from Young's Equation (1) (Jiang, Müller-Plathe, and Panagiotopoulos, 2017):

$$\cos\theta = \left(\gamma_{GS} - \gamma_{SL}\right) / \gamma_{GL} \tag{1}$$

where θ – contact angle on a perfectly smooth surface, $(\gamma_{GS}-\gamma_{SL})/\gamma_{GL}$ – surface tension between a solid and a liquid (γ_{SL}), solid and gas (γ_{GS}), and liquid and gas (γ_{GL}). At $\theta<90°$ surface is considered hydrophilic, at $\theta>90°$ hydrophobic, and a surface with contact angle $\theta>150°$ is called superhydrophobic (Yang *et al.*, 2021b) (Figure 3).

Young's equation describes the wettability of a perfectly smooth surface, however, the real surface is rough. According to the study by Robert Wenzel, it was reported that water droplets fill the rough structure, thereby increasing the contact area and surface wettability, in which case Equation (2) applies (Sarkar and Kietzig, 2013):

$$\cos\theta_W = r \cdot \cos\theta = r \cdot \left(\gamma_{GS} - \gamma_{SL}\right) / \gamma_{GL} \tag{2}$$

where θ_W – apparent contact angle, r – the ratio of the contact area of the interface between a solid and a liquid in the case of a rough surface to the contact area in the case of a perfectly smooth surface. Applying equation (2) to surfaces with high roughness or to porous structures, the value of $\cos\theta_W$ will be greater or less than one, which is unacceptable from a mathematical point of view. In the Cassie-Baxter theory, air pockets under a layer of water are considered a superhydrophobic environment, which prevents water penetration (Chu, Feng, and Seeger, 2015). The Cassie-Baxter regime is described by the following contact angle Equation (3) (Feng and Jiang, 2006):

$$\cos\theta_{CB} = -1 + \Phi_s \cdot \left(1 + \left(\gamma_{GS} - \gamma_{SL}\right) / \gamma_{GL}\right) \tag{3}$$

where Φ_s – is the proportion of the surface in contact with the liquid.

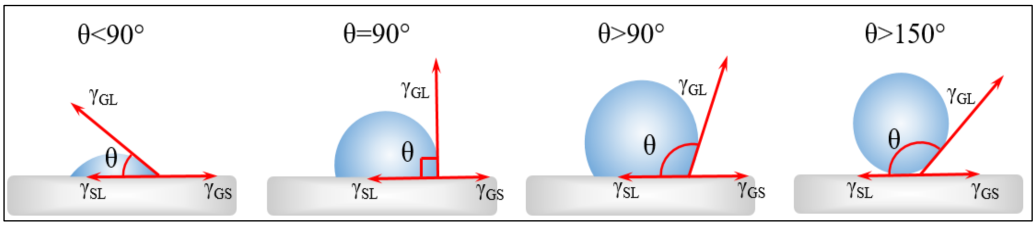


Figure 3 WCA formed by liquid droplets on a smooth, solid surface, in the air.

2.2. *Contact angle under water or oil*

The above wetting regimes are valid for the case of liquid contact with a solid (smooth or rough) surface in the air. However, to calculate the contact angle of liquid drop A (L_A) under liquid B (L_B) the following Equation (4) is derived (Liu *et al.*, 2009):

$$\cos\theta_{Liq.A} = (\gamma_{LAG} \cdot \cos\theta_A - \gamma_{LBG} \cdot \cos\theta_B) / (\gamma_{LA} - \gamma_{LB}) \tag{4}$$

where γ_{LAG}, γ_{LBG}, and $(\gamma_{LA}-\gamma_{LB})$ – surface tensions at the interfaces, respectively: liquid A-gas, liquid B-gas, and liquid A-liquid B. The angles θ_A and θ_B are the contact angles of fluids A and B with air. Figure 4 shows the modes of surface wetting with liquid A under liquid B.

Depending on the contact angle, the wettability regime, and the environment (air, water, oil), there are several possible extreme wettability states (Wang *et al.*, 2015; Chen and Xu, 2013), namely: superhydrophilic, superhydrophobic, superolephilic, and superoleophobic wettability in the air; underwater superoleophobicity and underwater superoleophilicity in water; underoil superhydrophilicity and underoil superhydrophobicity (Li *et al.*, 2016a; Wang *et al.*, 2015).

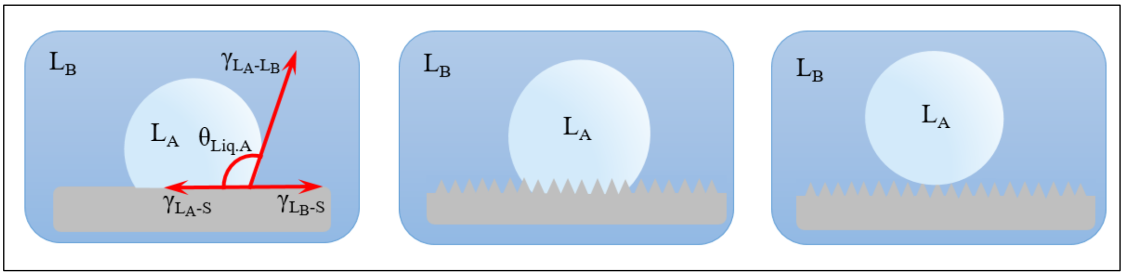


Figure 4 Regimes of wetting a solid surface with liquid A (L_A) in liquid B (L_B)

To describe the properties of porous materials used for emulsion separation and evaluate their effectiveness, the comparison includes characteristics such as contact angle, absorption capacity, and emulsion separation efficiency. We consider surfaces with WCA of 0°, <90°, >90° and >150° to be superhydrophilic, hydrophilic, hydrophobic, and superhydrophobic, respectively. Surfaces with oil contact angles (OCA) of 0°, <90°, >90° and >150° we consider to be superoleophilic, oleophilic, oleophobic and superoleophobic, respectively.

Absorption capacity is determined by immersing the test material in W/O until the material is saturated with liquid. The test sample is then removed from the liquid, and the mass is measured. Absorption capacity (Q) is calculated by Equation (5) (Meng *et al.*, 2017):

$$Q=\left(m_{s,o}-m_s\right)/m_s \tag{5}$$

where m_s and $m_{s,o}$ – the mass of the test material before and after liquid absorption, respectively. Absorption capacity is measured in g/g, and the process is influenced by factors such as porosity and pore size of the adsorbent; pH, density, and viscosity of a liquid; size of liquid molecules; concentration of dispersed phase particles (Sobolčiak *et al.*, 2021). The wetting regime is influenced by the porosity and pore size of the adsorbent. As these increase, the liquid penetration into the porous structure also increases. Porous materials absorb high-viscosity liquids, such as oil or diesel, better than low-viscosity liquids, such as hexane, that is, the adsorption capacity is proportional to the density of the oil (Wang *et al.*, 2020; Li *et al.*, 2019a). The adsorption capacity of porous material to droplets of oil in the emulsion varies depending on the pH of the water. According to a study by (Alazab and Saleh, 2022), the highest adsorption capacity was achieved in neutral water (31 g/g at pH = 7); in an acidic environment, the adsorption capacity decreased slightly (30 g/g at pH = 2), in an alkaline environment, porous material absorbs oil even worse (26 g/g at pH=12). According to (Ahmed, Anis, and Khalil, 2021), the smaller the size of oil droplets, the lower the adsorption capacity.

The emulsion separation efficiency is calculated by Equation (6) (Li *et al.*, 2019b):

$$\eta=\left(C_{feed}-C_{filtrate}\right)\cdot 100\%/C_{feed} \tag{6}$$

where C_{feed} – oil concentration in the initial emulsion, $C_{filtrate}$ – oil concentration in the filtrate.

3. Results and Discussion

3.1. Metal Foams Used for Emulsion Separation

Porous metals are actively used in industry to solve various problems related to filtration and heat transfer (Solovev *et al.*, 2022; Soloveva *et al.*, 2022; Soloveva, Solovev, and Yafizov, 2021; Solovev *et al.*, 2019). These metal foams exhibit effective absorption of both water and oil well. Therefore, to separate W/O emulsions, hydrophobic coating, for example, HDTMS, hydrophobic silica, carbon nanoparticles, etc., is applied to the surface of the metal foam. For instance, the study by (Zhang *et al.*, 2019a) developed nickel foam by synthesizing the ZnO@Co_3O_4 hierarchical structure using hydrothermal method followed by calcination and hydrophobic modification with HDTMS. The modified foam showed a high WCA of 158°, separation efficiency varied from 97 to 99%. The following methods are used for coating the surface of metal foam: electrochemical deposition method (Zhang *et al.*, 2023), immersion deposition method (Eum *et al.*, 2019), simple dipping method followed by drying in an oven (Wang *et al.*, 2021b), acid dipping and etching method (Álvarez-Gil, Ramirez, and Fernandez-Morales, 2021), etc. In the study by (Zhang *et al.*, 2019b) hydrophobic-oleophilic iron foam was developed by immersion in n-dodecyl mercaptan (NDM). The Fe-NDM foam showed high hydrophobicity (WCA=145°) and a separation efficiency of O/W emulsions of 98%. Subsequently, coating a metal foam results in a reduction in cell size and a decrease in the permeability of the foam. The coating should be as thin as possible while providing high hydrophobic or oleophobic properties. In the study, (Chen *et al.*, 2020) proposed a method for applying a superoleophobic coating, in which a metal felt was immersed in a colloidal suspension of silicon dioxide, washed, dried, and then annealed at 550°C. The thickness of the coating layer was about a hundred nanometers, thereby the pore sizes remained practically unchanged. The resulting material showed high efficiency in absorbing water from W/O emulsions, maintaining excellent performance after 30 use cycles.

Metal foams have been extensively examined as an absorbent material for separating W/O and O/W emulsions. However, using porous metals as coalescing baffles in gravity-dynamic separators is also known from the literature. A comparison between plate and highly porous partitions serves to intensify the process of separation of the emulsion. In a study by (Solov'eva *et al.*, 2021), the influence of the baffle design on the emulsion separation process was investigated. A comparison between the plate and highly porous baffles showed that porous baffles provide more effective separation at low emulsion flow rates, and plate baffles are more effective at high emulsion flow rates.

Metal foams are characterized by the following advantages, which include high mechanical strength and lightweight, high porosity, and large surface area. However, the widespread application is affected by susceptibility to contamination and corrosion. In emulsion separation, the foam becomes clogged with oil droplets and organic substances, which leads to a decrease in the wettability of the surface and a decrease in separation efficiency. The foam must be washed periodically, for example, with ethanol, to restore the performance. To solve the problem of pollution, scientists are developing foams capable of self-cleaning (Li *et al.*, 2022; Wu *et al.*, 2020b; Kang *et al.*, 2018). Self-cleaning surfaces are characterized by a high static WCA and a small sliding angle, which leads to the so-called self-cleaning effect (Zhang *et al.*, 2013). Another disadvantage of metal foams is corrosion, and hydrophobic and anticorrosive coating is often applied to the surface of the foam to solve this problem (Li *et al.*, 2022).

3.2. Polymer foams used for emulsion separation

In addition to metal foams, polymeric foams are used to separate emulsions. The most widely used polyurethane (PUF) and melamine foams (MF) are due to their cost-effectiveness, ease of production, and high wettability. Polymeric foams are characterized by high hydrophilicity and oleophilicity (Krishnamoorthi *et al.*, 2021; Wang *et al.*, 2014). Foams are often coated with hydrophobic/oleophilic, less often with hydrophilic/oleophobic coating to separate emulsions (Jin *et al.*, 2022; Li *et al.*, 2018; Li *et al.*, 2016b). Hydrophobic coatings increase surface roughness (Hou *et al.*, 2019), thereby ensuring hydrophobicity of the material (Ejeta *et al.*, 2021). Table 1 shows the characteristics of polymeric foams modified with various hydrophobic coatings.

Surface modifier affects the adsorption capacity of porous material. In a study by (Qiang *et al.*, 2018), they synthesized composite sponges based on polyurethane foam and graphene oxide nanoribbons (GONR) and modified them with two different silanol groups: trimethoxyoctadecylsilane (TMOS) and trimethoxysilane (FAS). TMOS-modified foam became superhydrophobic (WCA=153°) and superoleophilic (OCA = 0°). The foam treated with FAS achieved superhydrophobicity using WCA of 165 contact angle with superoleophobic behavior towards specific oils such as diesel, toluene, and n-hexane. Surface modification influenced the foam adsorption capacity, with FAS-modified samples showing significantly lower absorption rates for n-hexane, toluene, gasoline, and diesel compared to samples treated with GONR and TMOS. The study reported that the surface properties of composites could be adapted to water or oil by adjusting the end groups of silane molecules. Hydrophobic coating changes the surface roughness of the foam, forms a hierarchical structure, and leads to an increase in capillary forces, which affects the rate of oil adsorption. In a study by (Xue *et al.*, 2021b) PU foam was modified with polydimethylsiloxane (PDMS/PU) and copper terephthalate (CuT-PA/PDMS/PU). CuTPA/PDMS/PU foam had higher roughness than PDMS/PU foam, and the presence of a hierarchical structure resulted in increased capillary forces and an 8-fold increase in motor oil adsorption rate compared with PDMS/PU foam. In another study by (Xu *et al.*, 2021) MF was modified with microporous polymers using carboxyl (CMP-COOH) and hydroxyl (CMP-OH) groups. Modification with carboxyl groups provides a higher adsorption capacity of the composite foam, for comparison: the adsorption capacity of CMP-COOH and CMP-OH foams for toluene was 75 g/g and 56 g/g, respectively. The modifier concentration also affects the adsorption capacity. According to the study by (Xue *et al.*, 2021a) melamine sponge was modified with MXene and tetradecylamine (TDA) in different concentrations. Increasing the concentration of both MXene and TDA increased WCA. The addition of MXene increased oil adsorption capacity compared to pure melamine sponge.

However, MXene@MS foam continued to absorb water due to its hydrophilic nature. The addition of TDA reduced the surface energy of the melamine sponge, increasing hydrophobicity. As a result, TDA@MS and TDA-MXene@MS composite foams did not absorb water at all and displayed higher oil adsorption capacity. This indicates that the choice of modifier and its concentration influence surface roughness, form a microporous hierarchical structure, bolster capillary forces, and consequently impact oil adsorption capacity and rate.

In addition to the above modifiers, polymer foams are modified with reduced graphene oxide (Jamsaz and Goharshadi, 2020; Zhang, Liu, and Qiao, 2020; Zhou *et al.*, 2019; Cao *et al.*, 2019; Zhang *et al.*, 2017), carbon nanotubes (Visco *et al.*, 2021), carbon nanofibers (Guo *et al.*, 2021; Baig, Alghunaimi, and Saleh, 2019), carbon black (Chen *et al.*, 2023; Yang *et al.*, 2023), etc. Carbon modifiers contributed to a significant increase in the hydrophobicity of foams (WCA > 150°), and also improved the mechanical properties.

In addition to polyurethane foam and melamine foam, less common polymeric foams are known to be synthesized from polystyrene-divinylbenzene (Zhang *et al.*, 2016), polylactic acid (Wang *et al.*, 2019), and polypropylene (Mi *et al.*, 2019).

Traditionally, emulsion separation materials have been characterized by either hydrophobic or oleophobic properties. However, contemporary investigation is focusing on developing materials with opposite wettability, capable of displaying both hydrophobic and oleophobic properties, depending on the conditions. For example, when the material is pre-wetted with oil, it exhibits superoleophilic and superhydrophobic properties. Conversely, when the material is initially wetted with water, it shows superhydrophilic and superleophobic properties. This behavior is explained by the presence of hierarchical voids in the material. If the material has micro- and nano-sized pores, the first infusion liquid, for example, water, penetrates through the micropores. Laplace forces retain the second (oil), and the material exhibits superleophobic properties.

Despite the extensive investigations in using porous materials for separating emulsions, critical challenges persist including (i) protecting metal porous adsorbers from corrosion and (ii) cleaning adsorbers from oil contaminants to extend the service life remain unresolved.

Table 1 Characteristics of polymeric foams modified with hydrophobic coatings

Base material	Coating material	WCA	Oil	Oil absorption capacity, g/g	Ref.
PUF	Graphene oxide nanoribbons	153°	n-hexane	34	(Qiang *et al.*, 2018)
	Stearic acid	140°	n-hexane	23	(Wang and Zheng, 2017)
	Octadecyl Trichlorosilane	156°	n-hexane	21	(Liang *et al.*, 2019)
	Fe_3O_4 nanoparticles,	145°	n-hexane	10	(Alazab and Saleh, 2022)
	Titanate nanotubes	128°	n-hexane	20	(Pan *et al.*, 2015)
	Polydimethylsiloxane	157°	n-hexane	12.5	(Xue *et al.*, 2021b)
MF	Microcrystals MgAl-LDH	163.2°	n-hexane	70.5	(He *et al.*, 2022)
	TiO_2 nanoparticles	161.1°	ethanol	46	(Cho *et al.*, 2016)
	Polydimethylsiloxane	157°	ethanol	58	(Wang *et al.*, 2020)
	Copper nanoparticle	148.5°	pump oil	90	(Li *et al.*, 2019c)
	Waste epoxy resins	146.5°	pump oil	80	(Liu *et al.*, 2020)
	Conjugated microporous polymers	153.92°	toluene	73	(Xu *et al.*, 2021)
	Acrylic copolymer/silica	153.5°	n-hexane	78	(Li *et al.*, 2019b)
	Tetradecylamine-MXene	152°	toluene	60	(Xue *et al.*, 2021a)
	Halloysite NP and SiO_2	158°	toluene	110	(Song *et al.*, 2022)
PDMS foam	Graphene	130.8°	n-hexane	10.2	(Pan *et al.*, 2021)
	Multiwalled carbon nanotubes	157°	–	–	(Zhou *et al.*, 2023)

4. Conclusions

In conclusion, porous materials with selective wettability were actively used to separate O/W and W/O emulsions formed during oil production or as a result of oil spillage. At industrial enterprises, various emulsions were formed, the properties of which depend on the density (0.71 – 1.07 g/mL) and viscosity (from 1 to $3.04\cdot10^5$ mPa·s) of petroleum and oil, as well as water content (10 – 90%). To improve the oil quality and purify wastewater, O/W, and W/O emulsions were separated by adsorption or filtration with porous materials. This review systematically presented the results of the separation of emulsions by porous media, emphasizing the influence of surface modifiers on the separation characteristics. The analysis showed that the type and concentration of the modifier significantly influenced WCA, adsorption capacity, and separation efficiency. The water contact angle (WCA) of PU foam, treated with different hydrophobic coatings, ranged between 128° and 157°, showcasing hydrophobicity or superhydrophobicity. Additionally, the adsorption capacity for n-hexane fluctuated from 10 to 34 g/g. The viscosity and density of emulsions also affected adsorption capacity. Porous materials absorb high-viscosity liquids ($2 \cdot 10^3$ – $2 \cdot 10^5$ mPa·s) better than low-viscosity liquids (0.5 – 120 mPa·s). Hydrophobic and oleophilic composites were used for the adsorption of oil from emulsions. Accordingly, these composites are advisable to use for eliminating oil and oil products that spill water. Hydrophobic composites were not suitable for gravitational separation of emulsions, because water naturally settles under oil on the surface of the composite, forming a barrier layer and preventing oil droplets from penetrating the pores. In addition, hydrophobic composites quickly become contaminated with oil during gravitational separation. In this scenario, it was advisable to use hydrophilic and oleophobic porous composites.

Acknowledgments

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