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Review Research

ENVIRONMENTAL SIGNIFICANCE OF FOULING ON THE CRUDE OIL FLOW. A COMPREHENSIVE REVIEW

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Abstract: Investigating important challenges to eliminate crude oil fouling in pipelines needs to be studied thoroughly. According to environmental and economic issues, fouling in pipelines increases the price of crude oil. According to chemical and environmental experts, the loss in heat required additional energy to compensate which meant higher fuel consumption and more carbon emissions into the atmosphere. The increase in fluid flow rate combined with a constant drop in pressure is dangerous for pipelines. In addition, the Iraqi crude oils block refinery preheat trains because they contain very little asphaltene. The fouling of a variety of these crude oils and their blends is examined in this paper. Fouling may be caused by four major processes: solid particles, corrosion, sedimentation, and chemical reaction.

Keywords: *Fluid flow; environmental pollution; pipeline; sustainability.*

1. Introduction

Petroleum processors predict unit shutdowns for cleaning because of widespread fouling from well to refinery. Refining has several incentives to reduce fouling, including cleaning expenses, energy replacement costs, and production losses. Cleaning units may cost the greatest amount of lost production. When the economy recovers, demand for refinery products will exceed capacities, raising the cost of lost output. Consequently, reduced crudes are often not acquired because it might cause higher fouling. The asphaltenic components of crude oil are the biggest components that settle in refinery preheat trains, although little is understood regarding their structure and behavior [1-13].

Authors recently focused on fouling studies and they demonstrate that environmental initiatives focused on minimizing chemical fouling inhibitors [1]. The demand for petroleum products has caused a significant growth in the world's capacity to refine crude oil [2-3]. The industry should maintain strict environmental regulations to reduce carbon emissions caused by rising oil consumption, which represents a new concern [4].

Several chemical and physical processes cause crude oil fouling including Wax, salt, catalyst particles, corrosion products, chemical reaction fouling, sedimentation, and bio-fouling. Refineries worldwide spend millions on fouling maintenance. Crude oil preheat exchangers damage most. Fouling increases fuel consumption, reduces heat recovery, shuts down manufacturing lines, and poses safety risks [5]. Wax components in crude oil are likely to produce contamination in the refinery units [6, 7]. Recently, there has been a considerable demand

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for liquids and natural gas. However, major challenges still need to be investigated in reducing crude oil pollution in pipelines [8]. There are few studies on oil flow and improving crude oil properties through pipelines, it is an essential area of study [9]. As described by Myers et al., a portion of the crude oil is upgraded before it enters the pipeline. Their work aims to improve oil flow through the pipeline [10].

Fouling is a significant phenomenon in the functioning of machinery, particularly machinery used for heat transmission. The accumulation of solid material on the equipment surfaces is a sign of fouling. This deposit can be caused by a variety of factors, including the deposition of particulates on the surfaces (particulate fouling), phase changes brought on by temperature differences between the fluid and the surface (such as crystallization fouling), chemical reactions close to the surface, and biofouling. The two methods that corrosion fouling can happen are as follows. First, corrosion byproducts build up and stick to the surface, preventing heat transmission. Second, corrosion products may be moved from the corrosion site as particulate material. The deposited solid material may block flow passageways, resulting in a decrease in flow or an increase in pressure drop. This is why fouling is crucial. As a result of the deposited material's potential resistance to heat transmission, heat exchanger heat recovery may be limited, raising energy and cleaning expenses [11-12].

This research aims to investigate the environmental impact of fouling. In addition, summaries the most important methods and procedures that reduce oil pollution.

1.1 Fouling Problems

Crude oil fouling challenges have affected the oil industry for years [14]. Since this particular configuration of heat exchangers recovers 60–70% of distillation duty as shown in Fig. 1 [15-17].

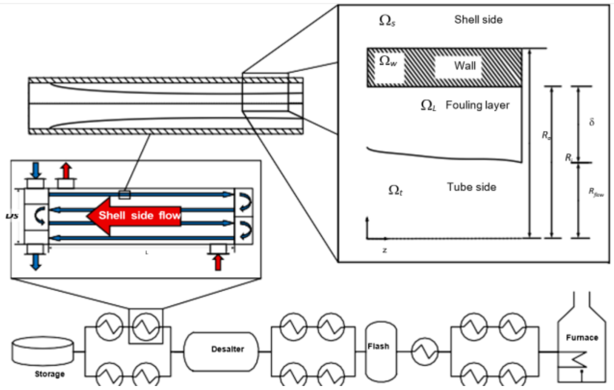

Figure 1. Crude oil fouling in the preheat train [18]

Technologies that just evaluate heat integration, underestimate the cumulative performance loss caused by fouling [19]. Despite fouling costing over $1 billion in the US alone at a time when oil seems to be much affordable [20], recent trends are commonly used to make accurate predictions regarding fouling in refineries [21-28]. Researchers have recently investigated the fouling in a shell-and-tube heat exchanger [29-32].

The heat exchanger's surface precipitates calcium and magnesium ions from the liquid. Aqueous solutions like untreated water, saltwater, geothermal water, or caustic soda and other salts may damage heat exchanger tubes. Flushing hot water into exchangers with refractory and malleable salt deposits is necessary [33]. Brushes, abrasives, and contemporary electrical cleaning equipment with a flexible spinning shaft remove the fouling. Then a brush head is significantly smaller than the inner tube's diameter for straightforward entrance. Furthermore, chemicals dissolve and eliminate salt accumulation. To reduce the concentration of salts in the liquid, special filters should be used to treat and analyze the water before it enters the heat exchanger tubes or other equipment [34].

The formation of molecular and biological deposits consisting of solid materials, cuttings, waste, dead parts, microbial deposits, algae, fungi, yeasts and bacteria that stick to the liquid used for cooling and adhere to the surface of the heat exchanger tubes and are difficult to remove by some commercial cleanings compounds such as Oket or Duel and may be effective. In removing more difficult deposits, they are used according to product requests. To reduce these deposits, filter filters are used for the water entering the heat exchanger [35].

To clean these deposits, hot water passed through pipes, air or steam at high pressure is used, or brushes and scrapers suitable for this type of deposit are used, formed as a result of chemical reactions between the liquid and the surface of the heat exchanger [36-37].

1.2 Fouling in Heat Exchangers

Fouling is undesirable sedimentation on heat transfer surfaces, which may reduce equipment efficiency. Thus, operational capabilities may degrade [38]. Calcium carbonate, sulfate, and silicate deposits are common on heat exchanger surfaces. These depositions generate a layer with poor thermal conductivity that slows heat transmission in heat exchangers (i.e. 2.9 Wm-1 K-1) of the mineral salts [39]. As a consequence, efficiency falls, pressure drops, and maintenance costs increase. When developing new systems, engineers are need to take into account the influence that fouling has on heat exchangers. This is due to the aforementioned considerations [38-39] as shown in Fig. 2 in al-Dora Refinery.

Figure 2. Fouling of heat exchangers (AL-Daura Refinery).

1.3 Cost Imposed Due to Fouling

Fouling is normally costs the oil industry disproportionately as boiler and turbine fouling cost Chinese utilities $4.68 billion in 2006 is 0.169% of GDP. Inefficient heat transfer, malfunctioning equipment, blocked flow, increased pressure drop, redirected flow within components, flow instabilities, and early electrical heating element failure may cause the loss. Losses of 5 MW or more from the steam turbine output are possible due to the fouling at a conventionally burned 500 MW power plant unit [40Heat exchanger fouling costs: Capital expenditures include transportation and installation costs, foundation costs, space and device costs, and high fouling surface area costs. Energy costs for utilizing more fuel in heat-exchanging equipment to battle fouling, maintenance costs for removing fouling deposits, chemical costs, or other antifouling device operating costs. Heat exchanger fouling may cause planned or unplanned plant shutdowns and large production losses. The principal expense of fouling is disposing of large amounts of chemicals and additives required to reduce it, which is difficult to evaluate [41–43].

2. Process Parameter Affecting Fouling

2.1 Fluid Flow Velocity

Fluid flow velocity in the process plant is one of the most important factors that influence fouling. In other work, the effect of speed on the rate of deposition over time has been studied [44]. They found, the rate at which calcium carbonate forms would go up as the speed of the fluid flow goes up. Furthermore, they demonstrate that faster speeds lower the resistance to diffusion, which increases the rate of deposition. In contrast, researchers observed that in a fully formed turbulent flow, the thickness of the deposit gets thinner as the flow speed rises. The possible explanation for this is because the removal rate increases near the boundary surface, which produces the shear force near the solid-liquid interface greater. Several studies have also shown that the speed affects the thickness of the deposit and the rate at which it is eliminated by attempting to make the shear stress greater [45].

2.2 Surface Temperature

Temperature greatly affects fouling, and researchers are interested [46, 47]. Some believe that higher temperatures decrease fouling [47, 48], while others suggest that fouling develops up more slowly at normal temperatures and is easier to remove. As temperature increases, scaling, accelerated reactions, crystal formation, the "baking-on" effect, and corrosion increase fouling [49].

2.2 Surface Roughness

The surface roughness is supposed to have high impact on fouling formation as it increases the settling of the initial deposits [50]. In addition, it creates turbulence fluid flow with more likely viscous sub-layer [51]. It was recommended to use smooth pipelines to enhance the oil flow and reduce fouling [52]. Rough surfaces allow particle deposition and deposit adhering, according to authors. After fouling, the roughness effects will depend more on the deposit [53]. Although, in some cases due to the scale formation and other affecting parameters such as corrosion, smooth surfaces become rough and led to the fouling formation [54].

2.3 Surface Materials

To reduce fouling, different surface material was selected and examined [55]. According to reports, calcium carbonate deposition that has collected on the surfaces of the materials has been connected to various surface materials [56]. Carbon steel is one of the materials that is often utilized in industry. Despite the fact that its intrinsic property is to be more corrosive than copper and brass [57]. Therefore, it would be beneficial to examine how fouling affects carbon steel. Copper has the highest thermal conductivity of all materials for heat transfer applications [58].

2.4 Impurities and Suspended Solids

Small gaps of pollutants could develop or substantially enhance fouling. They could either function as catalysts for the fouling processes or deposition as a fouling layer. Tiny pollutant particles may act as spores to start the deposition process in crystallization fouling. Through sedimentation or gravitational settling onto the heat transfer surfaces, suspended materials encourage particle fouling [59-60].

2.5 The pH values

The pH values are essential in calculating fouling rate, focusing mostly on crystallization fouling. At a neutral state the pH value is 7 and low fouling was found in this case. However, these were changed when it is either acidic or alkaline.

The X-ray powder diffraction (XRD) method could only locate calcium sulfate below a pH of

6. At higher pH levels, calcium carbonate and calcium sulfate smell in different amounts at each pH level. But crystals that form in the middle and upper layers are strongest at pH 7, followed by pH 6. Even though scaling is less likely to happen at these two pH values, crystallization will happen with very strong molecular bonds [61].

3. Fouling Mitigation and Control

Numerous studies have shown the challenges and costs associated with heat exchanger fouling [62]. The quality standards for designing heat exchangers for industrial applications have also been highlighted, including selecting a suitable heat exchanger type, optimizing industrial operating circumstances, such as higher flow velocities, and improving heat exchanger design.

Different approaches for reducing fouling have been developed in recent years. These techniques to water purification may be categorized as chemical, mechanical, and physical approaches [62].

3.1 Chemical Methods

Four methods regulate $CaCO_3$ scale: (a) low pH facilitation (b) sequestrates (c) low focus cycles, (d) scale inhibitors [63]. By sustaining a low pH, employing corrosive acid is an effective way to prevent the formation of calcium carbonate fouling. However, it creates problems due to its hazardous nature and ability to accelerate metal erosive processes. Additionally, the utilization of sequestering professionals is too significant for applications using open recycling water. Use of scale inhibitors is a commonly recognized approach that entails increasing the concentration of corrosion inhibitors in treated water [64]. Phosphonate and carboxylate agglomerates are monomeric or polymeric additives. They act at threshold levels because to the huge inhibitor concentration ratio [65]. Nanoparticles may achieve maximum inhibition by Langmuir adsorption. Adsorption onto the CaCO3 crystal surface limits crystal development (s). Liu et al. identify three scale inhibition mechanisms [66].

Scaling can be controlled using many chemical additions, although current ones present environmental consequences [67-68]. Thus, researchers have investigated ecologically friendly [69]. Hoang et al. generated calcium sulphate utilizing nine organic additives in a pipe system with a multiple flow system Little additions inhibited pipe wall calcium sulphate scaling [70].

3.2 Mechanical Methods

Reactions divided mechanical approaches into two classes, the use of brute forces including drills, lances, and high-pressure jets; and soft techniques including sponge balls and brushes [71–73]. A recent study suggests adding moderate quantities of fiber to a calcium sulphate solution to slow fouling deposition. Fibers restrict reactants' access to the surface and continuously crash on the heat transfer surface, slowing deposition. Others used a bigger pipe diameter, heated portion, and pipe material to simulate industrial circumstances and found similar results. They also found that fiber concentrations reduce fouling for longer [74-76].

3.3 Physical Water Treatment

In recent years, with all the climate change circumstances, authors aimed to find new sustainable methods that are environmentally friendly. [77] Physical water treatment (PWT) technologies for fouling include permanent magnets [78-86], catalytic material alloys, solenoid coil devices, and natural fibers [78]. The control of scale formation from the dissolved impurities have been studied [79-89] and they found that Zinc inhibits fouling 35% at 5 mgL^{-1}

[81]. Others showed that adding magnesium ions to the fouling solution may increase the induction period [84–85] and that adding 2mgL-1 of zinc significantly slows the deposition of calcium carbonate fouling in the system. [85].

4. The Environmental Impact of Fouling

Industrial sector heat exchanger fouling affects energy recovery and environmental satisfaction [90]. A lack of knowledge of fouling mechanisms and its transient impact on heat exchanger performance inhibits fouling management. Fouling in tubes, flow channels, or other processing equipment may lead to decreased heat transfer, under-deposit corrosion, pressure loss, and flow maldistribution (as shown in Figure 3 in Iraq). Lower efficiency, throughput, and output during scheduled or unplanned shutdowns will negatively impact costs, safety, health, and the environment [90]. Recent work indicates that increased water, electricity, fossil fuel, and other resource usage, chemical and/or mechanical antifouling device use, replacement of corroded or blocked equipment, and other variables raise maintenance costs. Heat exchangers require a large heat transfer surface. Despite growing environmental impacts and emissions of these toxic chemicals, heat exchanger fouling's environmental impacts have probably received the least attention. Nevertheless, CO_2 emissions and water/land pollution have raised this problem recently. in addition to NOx, SOx, and carcinogenic effluents. Chemical fouling inhibitors, cooling water, and temperature rises are also restricted, in addition to chemical waste disposal. Recent studies examined cleaning, mitigation, and fouling [91-92]. Heat exchanger fouling impacts the environment, briefly. The cumulative impact of heat exchanger fouling is difficult to assess since it depends on fouling intensity and exchanger operation. However, essential aspects may be recognized [92].

5. Economic and Environmental Significance of Fouling

Fouling in crude preheat exchangers has high costs, including the following.

- ***Energy costs and environmental impact.***

Exchanger fouling lowers the preheat train's heat recovery, consuming extra furnace fuel. Pressure drop-related pump power losses may potentially be significant. Increasing fuel produces more CO_2, which impacts the environment [93].

Figure 3. Environmental pollution in Iraq.

expense of performing a shutdown due to fouling, At a factory producing 100,000 US barrels per day, a 10% output loss brought on by the removal of a heat exchanger would cost $20,000 per day (assuming $2 per US barrel of lost productive capacity) if the preheat train throughput is furnace-limited.

Since the product was made outside specification, resuming manufacturing costs more [93].

- *Capital expenditure*. Extra surface area, higher shipping and installation expenses, provisions for greater space, anti-fouling equipment costs, installation costs for online cleaning equipment and treatment facilities, higher disposal costs for the (greater) replacement bundles, and higher heat exchanger prices are all included [93].

- *Maintenance costs*. This comprises staffing expenses, additional expenses for removing fouling deposits, and chemical or additional running costs for anti-fouling technologies. Disposal of cleaning supplies after cleaning has financial and environmental costs as well. [93].

6. Previous studies

Many authors investigate the environmental impact of fouling on the crude oil flow [94-118], which significantly impacts climate change. Environmental impact increased as a result of pollution levels. Oil exploration and water treatment, paints, acids, and different chemicals are the sources of the most impacted pollutants, which also affects climate change [97].

In recent years, more than 886 published manuscripts indexed in Scopus about the impact of oil fouling, as shown in Fig. 4.

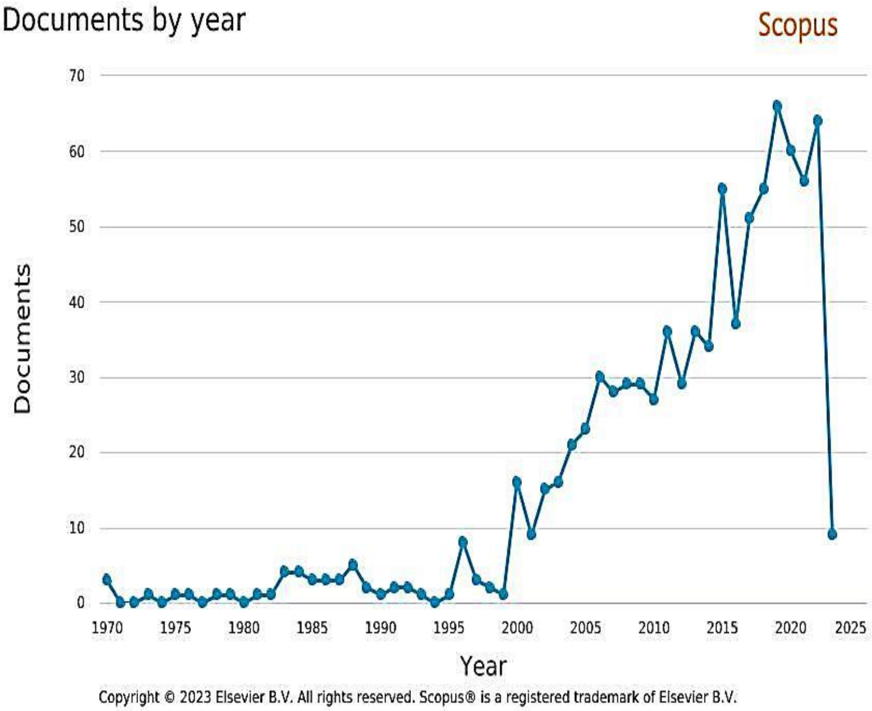

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Figure 4. Number of published documents per year on fouling of crude oil.

Important bibliographic records for literature evaluations frequently draw on these excellent sources of systematic and scientific data. This study used 886 published works from Scopus and Web of Science to look for the term "fouling of the crude oil" in publications all over the world from 1970 to 2023. Table 1 shows the number of publications in different countries indexed in Scopus on crude oil fouling, showing that the highest number of publications is from the United States, United Kingdom, and China.

Table1. Number of publications in different countries indexed in Scopus on fouling of crude oil

Country	No.	Country	No.
United States	214	Ukraine	5
United Kingdom	158	Algeria	4
China	139	Denmark	4
Canada	74	Finland	4
Malaysia	34	South Africa	4
India	30	Egypt	3
Iran	30	Ghana	3
Brazil	28	Pakistan	3
Saudi Arabia	25	Venezuela	3
Mexico	24	Bulgaria	2
France	18	Cuba	2
Germany	18	Czech Republic	2
Poland	14	Hungary	2
Italy	13	Iraq	2
Norway	13	Lithuania	2
Spain	12	Luxembourg	2
Kuwait	11	Morocco	2
Netherlands	11	Nigeria	2
Singapore	11	Qatar	2
Australia	10	Trinidad and Tobago	2
Indonesia	10	Austria	1
Japan	10	Bangladesh	1
South Korea	10	Brunei Darussalam	1
Russian Federation	8	Greece	1
United Arab Emirates	8	Hong Kong	1
Taiwan	6	Israel	1
Argentina	5	Jamaica	1
Belgium	5	Lebanon	1
Colombia	5	Libyan Arab Jamahiriya	1
Oman	5	Slovakia	1
Switzerland	5	Viet Nam	1
Thailand	5		

Dave et al. [94] reported that Oil production and flames in Iraqi oil refineries contaminated domestically because of insufficient government and regulatory procedures. Owing to the war, oil, and gas infrastructure present health hazards. Paramilitary groups and locals have utilized refineries, tanks, pipelines, and oil fields. The US-led coalition's attacks are designed the oil industry to restrict ISIS's revenue. Oil spills, fires, and smoke have impacted the ecosystem. Petroleum flames emit sulphur dioxide, nitrogen dioxide, carbon monoxide, PAHs, particulate matter, and metals. These strategies affect Al-Qayyarah, the Hamrin Mountains, the Baiji oil plant, and Kirkuk's oil infrastructure.

Jawda and Jaafar [95] studied heavy crude oil's rheological properties. Rheological features are demonstrated by steady flow, yield stress, transient flow, thixotropy, and viscoelastic behavior. Heavy crude oil does not exhibit Newtonian shear thinning in the shear rate range investigated (0.1-750 s1). Heavy crude oil hardens approximately 25°C and 65°C. The viscosity of heavy crude oil lowers from 10 Pa. s to 1.2 Pa. s at 25 °C if mixed with 10% light crude oil to produce a 10% HLCO combination. Heavy crude oil has 321.65 kPa/s thixotropic areas at 25 °C. 118.62 kPa/s at 65 °C, were mixing decreases thickening.

Kondyli and Schrader [96] examined crude oil fouling's environmental effects. Beginning in 2004, Iraq's significant oil operations and quick growth in crude oil output produced massive quantities of associated gas, most of which was consumed by these processes, resulting in substantial gas and oil losses. Pollution causes environmental damage. Thus, Iraq's lack of environmental pollution regulations affects its inhabitants' quality of life. Fig. 3 illustrates how the oil and gas sector polluted Iraq's water, air, and land. In addition, the oil industry and its water, paints, acids, and other chemicals contribute to global warming [97].

Land runoff, vessel crashes, repeated tanker discharges, and bilge discharges pollute the waters. In addition, oil spills damage humans, fish, birds, and animals. This study examined the International Guidelines for Preventing Oil Spills and Responding to Disasters and oil spill characteristics. The comparative research found that mechanical oil recovery, dispersants, and bioremediation were the most effective marine oil spill responses [108].

Coletti et al., in 2015, [98] studied "Fouling" in Highly Complex Petroleum Mixtures. "Fouling," the unwanted deposition of particles, is a $1 billion problem in petroleum production and processing. Low-solubility substance precipitate or chemically foul petroleum (insoluble material is produced during a chemical reaction and often accumulates on heat exchanger surfaces).

According to Asomaning and Watkinson et al. [99], the classification of organic fluid fouling into autoxidation, polymerization, and thermal breakdown is essential. It does not address asphaltene fouling. Autoxidation fouling research has advanced thanks to fuel stability and jet fuel consumption studies. However, styrene reactions have received little study, thus polymerization fouling trends must be validated in other systems.

Crittenden and Khater [100] examined fouling science; they reported the mechanisms of crystallization, particle and biological fouling were reviewed with a focus on chemical reaction and corrosion fouling in crude oil. Asphaltene precipitation, autoxidation, corrosion, polymerization, and thermal cracking. Fouling-related topics include start, transit, attachment, removal, and aging. Their work concludes by examining how crude oil content, operating environment, and surface conditions impact these phenomena.

Samimi et al., 2013 [101] evaluated heat exchanger fouling in blends of heavy oil with asphaltenes and carrier fluids consisting of fuel oil cut with various amounts of aliphatic or aromatic fluid. In a recirculation loop, an annular, electrically heated probe detected fouling. Heteroatomic species additions, dissolved oxygen, and carrier fluid composition were examined. Hot filtration quantified insolubles in the mixtures, and the probe deposits were asphaltene-like. Fouling rates were connected to suspended asphaltene concentrations and instability indices.

Li et al., 2019 [103], evaluated fouling rates kerosene rapidly through a miniature horizontal tube furnace. During vaporization, the tube's base had the lowest surface temperature and the greatest fouling rate. By decreasing feedstock oxygen or boosting wall superheat, fouling rates were greatly lowered between 1 and 2.5 bars of pressure.

Essien and John, in 2010 [104], discussed fouling factor, which addresses oil exchanger fouling and wax fouling in oil mixtures. They discussed fouling most critical consideration when designing heat exchangers and how disregarding it affects the oil sector and other businesses. If this factor is underestimated, heat exchanger issues may prevent process fluids from reaching the desired temperature.

Mir, 2022 [105], studied Iranian oil refineries' preheat trains for crude oil fouling avoidance. Crude oil fouling machine surfaces causes operational issues, financial fines, environmental damage, and health and safety hazards. To increase capacity, Iran's Preheat Trains' crude oil fouling costs $4 million every year. Crude oil fouling costs $200,000,000 per year, assuming $50 per barrel. Gasoline burning increases CO_2 emissions, harming the environment and economy. Thus, surface modification, additives, and operating conditions have been used to reduce crude oil fouling. To reduce fouling, modify the surface's structure, roughness, or surface energy.

Li, 2022 [106] studied the semi-axisymmetric excitation mode's leakage guided wave's green pipeline blockage elimination potential. They suggested an innovative, ecologically friendly pipeline fouling prevention method using defective ultrasonic guided waves (LUGWs) generated by a quasi-axisymmetric excitation mode. Cavitation from LUGWs in liquid mediums eliminates pipe fouling. Cavitation corrosion and the high-speed jet from cavitation bubble collapse dissolve the fouling layer, making this fouling removal method environmentally safe. Observational and finite element modeling determines the operating frequency. Energy-dispersive spectroscopy, scanning electron microscopy, and mass analysis assess removal and its uniformity on macroscopic to microscopic scales. Descaling tests reveal that the suggested approach can clean pipes thoroughly.

Mir et al. [110], 2022, studied oil/water separation in crude oil processing, using nanomaterial-based filtering methods. They replace demulsifiers with a better separation method. This technique eliminates oil from water and changes its wettability. Industrial oil-water separation requires a flexible filtration system. Sousa et al., [112] 2023 published a study on the economic and environmental implications of waxy crude oils characterized oil production by temperature, accessibility, and paraffinic composition, which affect wax deposition. The authors examined the Deepwater Horizon incident was the most detailed case study, allowing for financial and environmental impacts to be examined. The study's main contribution was impact layers to optimize the fouling effect. Authors illustrated that ecosystems are affected by species biological alterations beyond acute loss. This approach lacks relevant economic and environmental impact data.

Yang et al. 2023, [113] tested hydrated manganese hydrogen phosphate ($MnHPO_43H_2O$, MHP) as an anti-crude oil-fouling coating. MHP prevents crude oil fouling due to its numerous hydrogen phosphate groups. Even after crude oil pollution, the coating adheres to water effectively. The anti-oil-fouling characteristics of the MHP coating enable copper mesh to separate highly viscous crude oil/water combinations and crude oil-in-water emulsions without prewetting, in addition to eliminating floating crude oil from oily wastewater. These features are encouraging for elementary oil treatment.

Wang et al. 2023, [118] concluded that global disasters released millions of metric tons of crude oil. Oily wastewater disrupts marine life and ecosystems. Therefore, they stressed wastewater crude oil removal. Traditional separation equipment cannot classify oily contribute to water pollution crude oil because crude oil commonly conforms to separation materials. Wang et al. produced super-hydrophilic chitosan hydrogel-coated metal mesh with excellent anti-high viscosity crude oil-fouling performance utilizing a simple coating approach and the cross-linking reaction of chitosan and glutaraldehyde (CS-SSM). The super-hydrophilic CS-outstanding SSM's 99.99% separation efficiency for very viscous crude oil/water shows its versatility. As proven by molecular dynamics modeling, the chitosan hydrogel on the metal mesh's surface may considerably minimize crude oil molecules' interaction with the mesh, enabling CS-SSM excellent anti-high viscosity crude oil-fouling. Unfortunately, the super-hydrophilic CS-SSM oil skimmer also contained significant crude oil spills. Table 2 shows previous studies for local Iraqi researchers.

Table 2. Local Iraqi researches related**.**

Process	Reference
Theoretical Study on Heat Transfer in the Presence of Fouling	Hallaf.,2013[119]
The Effect of Circulating Glass Beads on Crystallization Fouling and Fouling Resistance in Double-Pipe Heat Exchanger	Hameed et al.,2016[120]
Corrosion Protect of Brass Tubes Heat Exchanger by using CuO Nanocoating with Thermal Pyrolysis Techniques	Mahmood et al.,2019[121]
Effect of Tube Material on the Fouling Resistance in the Heat Exchanger	Abbas et al.,2018[122]
Review on Recent Techniques for Improving the Energy Efficiency in Industrial Steam Boilers Through Boiler Tubes Corrosion Protection and Fouling Mitigation	Ibrahimet al.,2018[123]

7. Conclusions and Further work

Technically and economically, transporting crude oil from the well site to the refinery can be difficult. Because of the low API density and high viscosity, larger pipelines, better insulation, and more pumping stations are required. As a result of these considerations, it is potential that the construction of a pipeline may be impossible. Oil refineries preheat crude oil to high temperatures in preheat trains (PHT) of distillation units. after distillation, Crude-heavy components separate and deposit on heat exchanger walls in the form of sediment affecting heat exchanger thermodynamic, posing a significant obstacle not solved yet . It has been concluded that extensive quantitive studies are required to determine the environmental impact of fouling and its characteristics. Hence, the effort is needed to reduce fouling in heat exchangers; it encounters several challenges. These include mechanical challenges and economic advantages. Thus, prospective chemical, biomedical and biological research will require in the future. This review paper highlights the challenging topics related to the flow of crude oil through pipelines and its impact on the environment. The outcomes of recent investigations into oil fouling are presented in this paper to identify the origin of fouling. Fouling in crude oil systems may greatly influence how much fuel a refinery requires. Hence, more research is necessary to determine how that affects carbon dioxide emissions and sustainability. This research concluded that it is critical to determine the most practical, economical, and long-lasting way to reduce fouling, which is a complicated function of oil composition, temperature, velocity, and particle concentration.

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Conflict of interest

The authors confirm that there is no conflict of interest.

Author contributions

Z.T and M.A conceived of the presented idea and supervised the work. Z.T, and Z.A design and carried out the work. Z.A, Z.T and M.A worked on the paper methodology and developing the theory and result analysis. Z.A., Z.T., M. A., H.O verified the data anlysis of the manuscript. All authors contributed to the final version of the manuscript.

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