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Comparative Evaluation of API Separation and Chemical Coagulation Methods for Oil and Grease Removal from Industrial Wastewater in a Middle Eastern Gas Refinery

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Abstract

Industrial wastewater generated by oil and gas refineries often contains significant amounts of oil and grease. These contaminants must be effectively removed to meet environmental discharge standards and prevent ecological harm. This study evaluated and compared the efficiency of chemical coagulation using ferric chloride ($FeCl_3$) and polyaluminum chloride (PACl) with the conventional American Petroleum Institute (API) separator in removing oil and grease from industrial wastewater at a major gas refinery in the Middle East. A descriptive-analytical methodology was applied. A series of controlled jar test experiments was conducted to assess the impact of varying coagulant dosages (10–100 mg/L) and pH levels (5, 7, 9, and 11) on treatment performance. These tests aimed to determine the optimal conditions for oil and grease removal using $FeCl_3$ and PACl. In parallel, the existing API separator system was evaluated by collecting samples at its inlet and outlet during both wet and dry seasons to examine seasonal effects on performance. Standard gravimetric analysis, following EPA protocols, was employed to quantify oil and grease concentrations in all samples. The results showed that both coagulants achieved high removal efficiencies, with $FeCl_3$ performing slightly better. Optimal removal (above 98%) occurred at pH 11 and 50–100 mg/L dosage. By comparison, the API separator maintained a consistent removal rate of ~92.5%, particularly during wet seasons with higher influent loads. Overall, chemical coagulation outperformed the API method under all tested conditions. It offers a more reliable approach for achieving environmental compliance and managing variable contaminant loads.

Keywords: Industrial Wastewater, Oil-Water Separation, Ferric Chloride, Polyaluminum Chloride, Coagulation

Introduction

Several methods are available for removing oil and grease from wastewater generated by activities in the oil and gas industry (1-3). Among them, gravity separators are commonly used to eliminate free and non-emulsified petroleum-based substances (4). These separators are a standard component in refinery wastewater treatment systems, where they are applied to remove oil, grease, and floating hydrocarbons. Additional treatment techniques—such as aeration, flocculation, advanced chemical agents use, flow through absorber plates, bed filtration, and microbial degradation—are often employed to enhance hydrocarbon removal efficiency (5-7). In theory, gravity separation operates based on Stokes' law, assuming an ideal environment without turbulence or circulation. In practice, however, the performance of a gravity separator depends on several design and operational factors, including hydraulic configuration, separator geometry, overall efficiency, and wastewater retention time (8, 9).

Gravity separators are generally categorized into two main types: American Petroleum Institute (API) and Corrugated Plate Interceptor (CPI) systems. The API separator is specifically designed to separate oil from water according to established API standards (10, 11). These systems are typically constructed in either circular or rectangular configurations, with standardized designs that are widely used in industrial practice (12). In addition to removing oil and grease, these units can also eliminate large solid debris—such as nuts, bolts, plastic sheets, and metal fragments—that are commonly found in industrial wastewater. Magnetic separators are sometimes integrated to enhance the removal of such solid contaminants. Furthermore, sludge removal mechanisms are often required to handle the accumulated waste materials (11). Oil-water separation systems, including gravity-based filters, are typically designed based on differences in fluid density (13, 14). The effectiveness of these separators depends on multiple factors, such as the type and physical state of the oil and grease in the wastewater, flow dynamics, separator design and dimensions, and hydraulic retention time (6, 15).

Industrial wastewater generated at the studied gas refinery originates from multiple processing units, including gas treatment, dew point adjustment, and liquid stabilization (16). As the refinery expanded its capacity, the existing API separator—designed to remove oil from wastewater—proved insufficient for handling the increased volume and pollutant load. This limitation has led to a significant portion of oil and grease escaping treatment and entering the effluent stream. Consequently, the current system not only falls short of Environmental Protection Agency (EPA) environmental compliance standards but also contributes to potential environmental pollution.

However, the use of chemical coagulants such as $FeCl_3$ and PACl also raises environmental concerns. These concerns include the generation of chemical sludge that requires safe disposal, potential residual metal ions in treated water, and the need for pH adjustment, which may increase chemical consumption. Therefore, while chemical coagulation improves treatment efficiency, it must be integrated with appropriate post-treatment and sludge management strategies to ensure overall environmental sustainability.

Given these challenges, this study aimed to evaluate and compare the efficiency of chemical coagulation methods using advanced flocculants ($FeCl_3$ and PACl) against the traditional API separator. The objective was to identify an optimized treatment approach that could enhance oil and grease removal efficiency. The study also considered the applicability of treated water for secondary uses, such as green space irrigation and reinjection into subsurface water systems, aligning with sustainable water management practices within the refinery.

Materials and Methods

Study Area

This descriptive-analytical study was conducted at a gas refinery company that has been operational since 1988, specializing in the purification of gas extracted from nearby gas fields. The facility manages an estimated recoverable gas reserve of approximately 720 billion cubic meters (m3).

Wastewater Treatment Process

Different methods, such as aeration and flocculation, advanced chemical compounds, pass through the absorber plates, crossing the bedding, and using micro-organisms to separate hydrocarbon materials. This study evaluates the effectiveness of advanced flocculation chemicals in reducing impurities, comparing their performance with the existing treatment system. The evaluation is conducted in accordance with EPA standards, considering multiple reuse applications such as irrigation, landscaping, and reinjection into underground water resources to optimize water utilization (12).

Optimization of Coagulant Dose

To determine the optimal dosage and pH conditions for $FeCl_3$ and PACl coagulants, a series of jar tests was conducted on refinery wastewater samples. Each test involved six 1-liter beakers, each containing 500 mL of wastewater. The pH of the samples was adjusted to four levels (5, 7, 9, and 11) using 0.02 N KOH or 0.01 N H_2SO_4. Coagulant stock solutions (1%) were prepared and added in varying doses of 10, 15, 20, 30, 50, and 100 mg/L.

The jar test procedure included three mixing stages. First, a rapid mixing phase at 120 rpm for 3 minutes was performed to disperse the coagulant uniformly. This was followed by a slow mixing phase at 30 rpm for 45 minutes to promote flocculation. Finally, a 30-minute settling phase allowed the flocs to sediment. After settling, the supernatant was carefully extracted and analyzed for oil and grease concentration using the standard gravimetric method according to EPA Method 1664. The conditions that achieved the highest removal efficiency were identified as the optimal parameters for each coagulant (12).

API Separator operation in two seasons

To evaluate the performance of the API separator during wet and dry seasons, samples were collected from both the influent and effluent of the system. After allowing phase separation, 250 ml of the water phase was decanted, and the organic phase was collected in beakers. The water phase was subjected to a second separation step using a separation funnel to isolate residual organics. The organic phases from both steps were combined and placed in beakers, then evaporated in a hot water bath at 70 °C. Following complete solvent evaporation, the beakers were dried in an oven for 2–3 minutes and subsequently cooled in a desiccator. The results from the following formula, according to mg/L, were obtained. The equation to calculate these was the following:

Oil & Grease (mg/L) = ((Beaker final weight (g) − Beaker initial weight (g)) × 10000) / Sample volume (mL))

Results

The analysis conducted throughout this study revealed the comparative performance of API separators and chemical coagulants ($FeCl_3$ and PACl) in removing oil and grease from industrial wastewater. Results consistently showed that chemical coagulation, particularly with $FeCl_3$ and PACl at optimal pH and dosing conditions, outperformed the API method in terms of removal efficiency. While the API system demonstrated stable baseline performance, especially during high inflow in the wet season, the chemical methods achieved significantly higher removal percentages. It highlights suitability for more demanding conditions or where regulatory compliance is critical. Figures 1 and 2 show the optimal conditions for $FeCl_3$ and PACl, demonstrating that both coagulants effectively remove oil and grease from wastewater. The efficiency of both coagulants increases with higher pH levels and greater coagulant concentrations, reaching removal rates above 98% at optimal conditions (pH 11, 100 mg/L). Monthly analysis of influent and effluent oil concentrations also confirmed the system's consistent ability to reduce oil content, though fluctuations suggest possible environmental or operational influences.

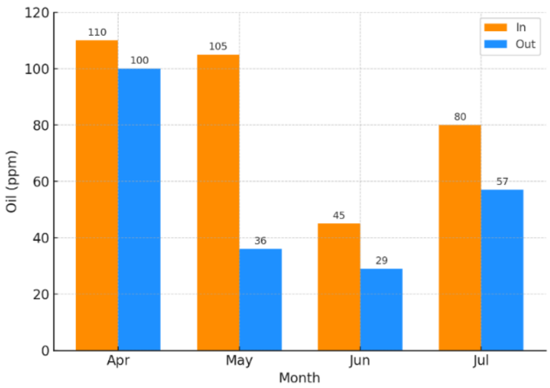

Figure 1. Comparison of the percentage removed oil and grease of two coagulants, FeCl3 and PACL

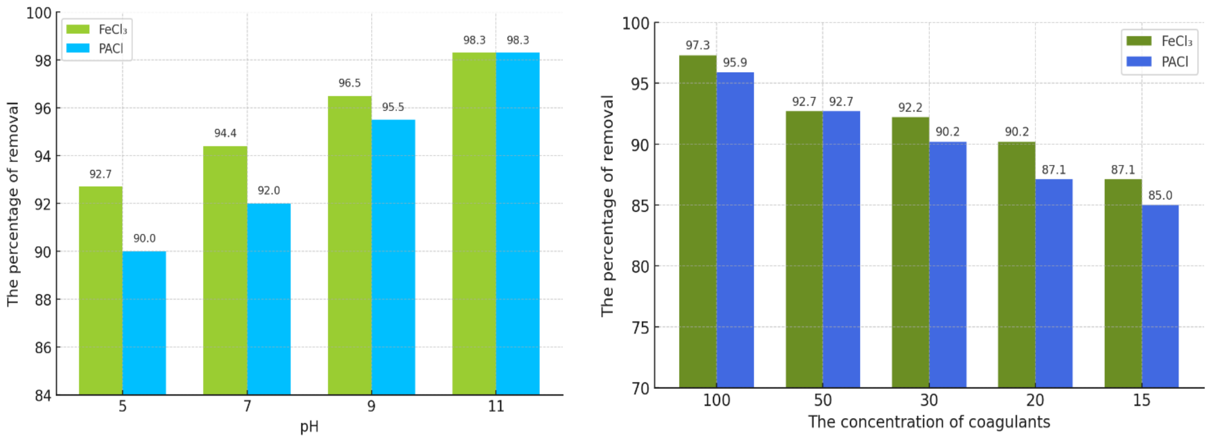

Figure 2. The percentage of removal of grease at different pH levels for two coagulants, $FeCl_3$ and PACL, of 50 milligrams per liter.

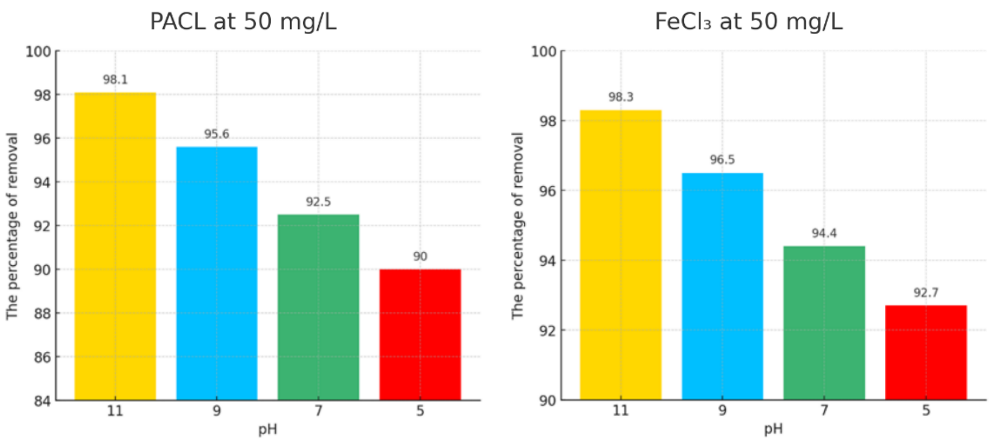

Figure 3. Percentage of oil and grease removed by coagulants PACL and $FeCl_3$ (50 mg/L) at different pH levels

The efficiency of coagulants at varying doses is presented in Figure 3. Results show that both PACl and $FeCl_3$ effectively remove oil and grease from water, with enhanced performance observed at higher pH levels. The removal efficiency for both coagulants peaks at pH 11, with $FeCl_3$ reaching 98.3% and PACL achieving 98.1%. As the pH decreases, the removal efficiency gradually drops for both, reaching the lowest values at pH 5. However, $FeCl_3$ consistently performs slightly better than PACL across all pH levels.

Figure 4 illustrates the monthly comparison of influent and effluent concentrations from September to December, highlighting the system's treatment efficiency over time. In all months, influent values (In) are significantly higher than effluent values (Out), confirming effective pollutant removal. The highest influent value is observed in November (1806), while the lowest effluent value is seen in December (55). Although influent concentrations vary greatly month to month—possibly due to seasonal or operational changes—the effluent values remain consistently low, emphasizing the system's stable and efficient performance in reducing contaminants.

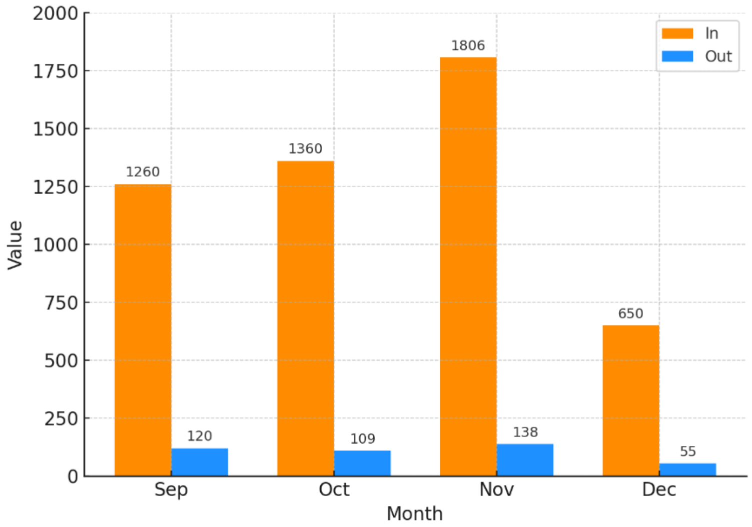

Figure 4. Amount of grease and oil-consuming industrial waste fat in the dry season in the entrance and exit system

The combined results presented in Figure 5 highlight the seasonal variations in the performance of the API treatment system for industrial wastewater. During the wet season, both the influent concentrations of oil and grease and their removal efficiency were notably higher compared to the dry season. This suggests that while the system handles a greater pollutant load in the wet season, it also operates more effectively under those conditions. The comparison of average influent and effluent values confirms that the API unit consistently reduces grease and oil levels more significant removal observed during periods of higher flow and contamination. Figure 6 presents a comparison of the mean oil and grease removal efficiencies using three different treatment methods: $FeCl_3$, PACl, and the API system, based on accumulated data from both wet and dry seasons. The results show that $FeCl_3$ achieved the highest average removal rate at 98.3%, closely followed by PACl with 98.1%, indicating excellent performance of both chemical coagulants. In contrast, the API system exhibited a lower removal efficiency of 92.5%, suggesting that while it provides a baseline level of treatment, chemical coagulation is significantly more effective for removing oil and grease under varying seasonal conditions.

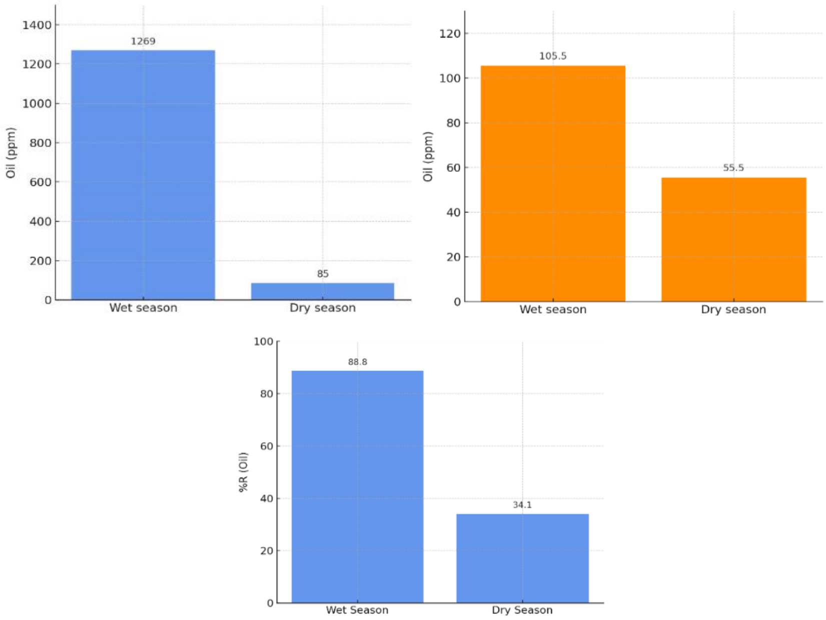

Figure 5. The amount of grease and oil in industrial wastewater at the inlet and outlet of the treatment system during wet and dry seasons, along with a comparison of the average grease and oil values entering and exiting the API system.

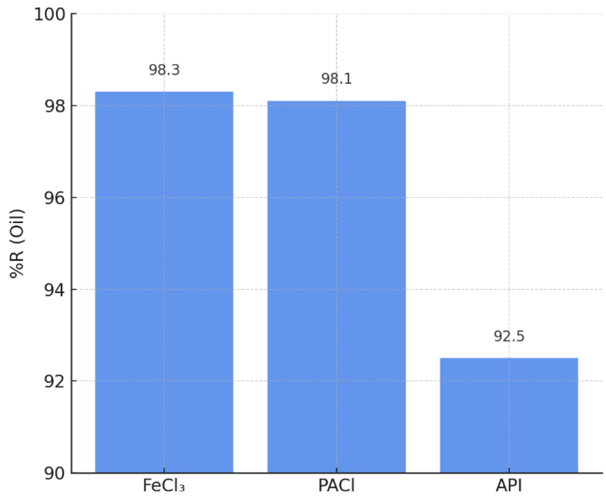

Figure 6. Comparison of means to remove oil and grease through the wet and dry seasons

Discussion

API separators are widely used in water treatment plants and many industrial units (17, 18). This study compared the chemical coagulation, flocculation, and removal of oil and grease from wastewater API Separator in one of the largest gas refineries in the Middle East. After performing various tests on the influent and effluent, the jar test was performed for the gas refinery the company's industrial degreasers wastewater, which uses PACL and $FeCl_3$ coagulants to remove oil and grease from wastewater. The first two coagulants in the sample, pH 6.7, are in good condition to reduce oil and grease. Optimal removal was achieved at a coagulant dose of 50 mg/L; increasing the dose to 100 mg/L resulted in only a marginal improvement of approximately 1%. Further jar tests across pH values of 5, 7, 9, and 11 confirmed that $FeCl_3$ performed best at 50 mg/L and pH 11. The results showed that the optimum conditions for using $FeCl_3$ at doses of 50 mg/l and pH 11 are equal. The tests related to the type of system API Separator are fat.

One study showed that the system CPI's ability to remove oil-free up to a diameter of 60 µm with efficiencies of about 100%.Compared to other separators, this performance makes the CPI preferable over the gravity-based API separator. Corrugated plates of this system cause the oil droplets to collide with each other. These droplets accumulate in the ridges of the corrugated sheets, forming a rise upward. Meanwhile, sinking particles settle on the aggregated pages and eventually move to the bottom of the tank (19).

Pyrsahb and colleagues evaluated the use of alum and FeCl3 coagulants to determine the most effective option under optimal conditions for treating textile wastewater at the Cute Karaps treatment plant. Parameters, color, COD, and BOD5 were evaluated in this study. The pH of the test for selecting the optimum pH, 4, 5, 6, 7, 8, and 9, the optimum, and were obtained the amount of coagulants, alum and $FeCl_3$, respectively, 5-5.8 and 6-7.7 mg/L. The color removal by alum and $FeCl_3$ to 72 and 95 percent, respectively. The results showed that coagulation could result in a lot of colors, BOD5, and COD in wastewater in the textile industry. $FeCl_3$ in this study is higher than the alum removed (20). Arami et al., in their study on textile industry wastewater treatment, reported that coagulants used for treating textile colorants often contain primarily organic and toxic elements, including chromium. In this article, effluent from a factory, several times during the sampling and mixing to reduce COD, and color removal chemical methods have been refined. The results show that the alum's chemical treatment can reduce COD by up to 65% of COD and paint waste by about 60% (21).

Although this study focused primarily on removal efficiency. However, a brief cost comparison suggests that chemical coagulants such as $FeCl_3$ and PACl, while effective, may incur higher operational costs compared to the API system. These costs arise from reagent consumption, sludge disposal, and pH adjustment. However, their higher treatment performance and potential compliance with stricter environmental regulations could offset these costs in the long term, particularly in high-load scenarios. A more detailed cost-benefit analysis is recommended in future studies to support large-scale implementation.

The results of this study are consistent with recent findings in the field. For example, Panhwar and Bhutto (2021) reported effective removal of oil and grease from sugar industry effluent using $FeCl_3$ and PACl, with $FeCl_3$ showing slightly superior performance at higher pH levels, similar to our results (7). Farajnezhad and Gharbani (2012) also demonstrated that both coagulants performed well for petroleum wastewater, but PACL showed better results at lower turbidity levels (22). In contrast, Solmaz et al. (2024) produced $FeCl_3$ from steel industry waste and reported over 95% oil removal efficiency, supporting the viability of $FeCl_3$ as a cost-effective solution in industrial settings (14). Collectively, these studies reinforce the applicability of chemical coagulation, particularly $FeCl_3$ and PACl, across diverse wastewater types and operational conditions.

This study was conducted under controlled conditions using jar tests and seasonal sampling within a single refinery site. It may limit the generalizability of the results to other facilities with different wastewater characteristics. Additionally, factors such as temperature fluctuations, coagulant cost-effectiveness, and long-term sludge management were not fully addressed and should be considered in future research to support large-scale implementation. Despite these limitations, the study offers valuable insights. It directly compares the performance of both traditional (API) and advanced (chemical coagulation) treatment methods under real operational conditions. The inclusion of seasonal data enhances the relevance of findings by capturing system behavior across varying inflow loads. Moreover, the use of two widely available and cost-effective coagulants ($FeCl_3$ and PACl) provides practical guidance for industrial application and optimization of treatment systems in similar contexts. Future studies are recommended to explore the integration of chemical coagulation with other advanced treatment technologies, assess long-term operational costs, and evaluate sludge management strategies. Additionally, pilot-scale or full-scale implementations in different industrial settings would help validate and expand the applicability of the findings.

Conclusion

The findings of this study clearly show that the API separator provides a baseline level of treatment. Its efficiency is highly influenced by seasonal variations. The separators perform notably better during the wet season when production and influent load are higher. However, the use of chemical coagulants, specifically $FeCl_3$ and PACl, significantly enhances the removal efficiency of oil and grease from industrial wastewater. Under optimal conditions (50 mg/L dose, pH 11), $FeCl_3$ achieved up to 98.3% removal, outperforming both PACl and the API system. This indicates that chemical coagulation methods are more reliable and effective, particularly when higher effluent quality standards are required. Therefore, incorporating chemical treatment—either as a standalone or integrated with existing physical systems like API—can substantially improve the overall performance of refinery wastewater treatment, ensuring better compliance with environmental regulations and more sustainable reuse of water resources.

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Authors' Contributions

Morteza Arabzadeh contributed to the conceptualization, supervision, methodology, and investigation of the study. Samaneh Dehghani contributed to data curation, methodology, writing—review and editing. Azam Mahrodi was involved in data curation, investigation, and formal analysis. Moslem Tazik was involved in data curation, investigation, and formal analysis. Amir Heasam Hasani supported data curation, visualization, and formal analysis. Alireza Pendashteh provided supervision, resources, and writing—review and editing. Zahra Eslamidoost was responsible for conceptualization, methodology, validation, and writing the original draft. Hamed Soleimani contributed to supervision, project administration, and writing—review and editing.

Zahra Eslamidoost and Hamed Soleimani contributed equally as corresponding authors.

Consent for publication

This manuscript does not contain any person's data.

Availability of data and material

The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request.

Competing interests

The authors have no competing interests to declare relevant to this article's content.

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