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Experimental Investigation and Optimization for Desulfurization of Diesel Fuel Using Microwave Irradiation and Activated Carbon

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Abstract: Due to increased emissions of sulfur compounds, the extensive use of diesel fuel in industry, transportation, and power generation causes a number of environmental issues. Because sulfur-containing chemicals have a tendency to cause a number of environmental problems, diesel fuel must be free of them. One of the best techniques for this is the use of microwave irradiation technology to remove oxidative sulfur in diesel fuel. quick and affordable processes use microwave heating in conjunction with peroxide oxidation, 7.5 ml of acetic acid, and 1 g of activated carbon to treat sulfur-containing diesel fuel. The purpose of the study was to assess efficiency hydrogen peroxide as oxidizing agent and the acid as activator. This technique uses microwave radiation to create electromagnetic waves. Software was used to optimize operations for optimal conditions, and the experiments made use of a rotatable central composite design with three variables. The findings showed that 500 watts produced the best sulfur extraction efficiency from diesel fuel, with a peroxide-to-diesel volume ratio of 0.7 and an optimal treatment duration of 150 to 160 seconds. With a maximum sulfur removal efficiency of 85%, the diesel fuel's initial sulfur concentration is 2865 ppm. The ability of microwave technology to extract sulfur from diesel fuel is proof that it is a practical and environmentally beneficial technique.

Keywords: Microwave irradiation, Desulfurization, Oxidative sulfur

Introduction

The energy and transportation sectors still rely heavily on liquid transportation fuels, despite advancements in environmentally friendly practices (Mohankumar & Senthilkumar, 2017). Desulfurization procedures are necessary due to strict limitations on the amount of sulfur in transportation fuel and growing concerns about air quality (Song, 2003; Zongxuan et al., 2011). Reducing the levels of sulfur compounds in transportation fuels and petroleum fractions is a continuous necessity for protecting the environment. The sulfur problem is increasingly severe, especially with diesel fuels. Diesel fuel is rigorously desulfurized in highly industrialized nations, with the goal of achieving ultra-clean diesel (<10 ppm) by reducing the sulfur content to insignificant level (Naviri et al., 2015; Dasgupta et al., 2013). Deep self-sufficient machines are now essential in oil refineries due to recent advancements. Numerous projects have looked into efficient and cost-effective desulfurization techniques. Conventional HDS faces many industrial problems, including high hydrogen gas consumption, harsh operating conditions (temperatures between 300 and or 400 °C and pressures between 10 and 140 bar), and significant fluctuations in thiophenic sulfur compound reactivity (Hernandez et al.,2010; Tian et al., 2014). More work is needed to address the problems associated with current hydrodesulfurization (HDS) practices because the current methods are not enough to produce ultra-clean fuels (Rodríguez-Cabo et al., 2014; Li et al., 2016). The deep desulfurization of fuels has been made possible by recent developments in a variety of non-

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hydrodesulfurization techniques, including adsorptive, oxidative, extractive, alkylation, with biological desulfurization (Liu et al., 2018; Rudreshwar et al., 2016). These techniques are among the most promising non-HDS methods. As a result, it has attracted a lot of scholarly interest because of its exceptional selectivity and the need for mild operating conditions. Sulfur compounds converted into corresponding sulfones by the oxidative process, which then uses polarity difference and other chemicals in a subsequent treatment. Organic acids, polyoxometalate acids, ionic liquids, and Fenton reagents are among the many catalytic systems that have recently been used of catalytic oxidation desulfurization process for removes Sulphur compounds (Xiong et al., 2014; Ressler et al., 2010).

Polyoxometalates have attracted significant attention homogeneous catalysts for desulfurization owing to unique properties, such strong reversibility, multi-electron redox conversions with mild circumstances, and exceptional stability. Various heteropolyacids (HPAs) with Keggin-type structures, including phosphomolybdates and oxovanadium phosphomolybdates, employed as homogeneous catalysts of microwave-assisted oxidative desulfurization process (Shang et al., 2013). Multiple studies in literature employed hydrogen peroxide a homogeneous catalyst for promote oxidation sulfur compound under microwave irradiation, Previous research employed La phosphomolybdate and Ce phosphomolybdate homogeneous heteropolyacid catalyst to microwave-assisted oxidative desulfurization straight-run diesel with model fuels including BT with DBT, using H2O2 as the oxidizing agent. An ODS efficiency 80% to actual diesel fuel, 94% to DBT, with 91% to BT was attained using La-phosphomolybdate, whereas Ce-phosphomolybdate produced 96% for DBT and 75% for BT (Qiu et al., 2009). Nevertheless, these catalysts exhibit solubility of polar solvents, hindering extraction with reutilization from reaction mixture, hence presenting significant challenge to the application of HPAs as homogeneous catalysts in many contexts, including catalysis ODS (Qin et al., 2016). Consequently, multiple studies have shown that the incorporation of HPAs onto various porous solid substrates effectively mitigates this issue (Ye et al., 2016; Chamack et al., 2014; Hajjar et al., 2016).

Wang et al. (2010) synthesized multi-walled carbon nanotubes impregnated with Cs2.5H0.5PW12O40, resulting in a novel support heterogeneous catalyst for oxidative elimination DBT for liquid model fuels. Zhang et al. (2013) Phosphotungstic acid (PWA) support ceria was produced heterogeneous catalyst for the extraction of dibenzothiophene (DBT) from simulated oil using hydrogen peroxide (H2O2) under moderate condition, achieving a sulfur remove efficiency of 99.4%. Qin fixed phosphotungstic acids on amino-functionalized γ-alumina supported the catalysis oxidative desulfurization of model fuels including dibenzothiophene of n-octane. Abd Al-Khodor et al. (2020) the research examines the effective extraction sulfur for crude oil with 2.5 wt.% sulfur sourced from Halfaya Oils Field in southern Iraq by adsorption desulfurization utilizing activated carbon. The ideal operating parameters were determined to be 0.8 grams of activated carbon, 90 minutes, and 50 degrees Celsius. The adsorption process was determined to be spontaneous, endothermic, with to enhance randomization for sulfur compounds on adsorbent surface desulfurization efficiency was 28%, decreasing sulfur content from 2.5% to 1.8%.Ibrahim et al. (2015) the research looks at batch adsorption desulfurization processes to diesel fuels with 580 ppm sulfur, revealing effects of duration, temperature, diesel to activated carbon ratio, activated carbon particles size, mix velocity initial sulfur concentration of desulfurization effectiveness. results indicate a 57% efficiency under ideal conditions. The research use various kinetic models to predict equilibrium sorption capacity and adsorption isotherms. Ammar et al. (2017) The research examines the application of metal-impregnated activated carbon adsorbents to Sulphur removal from Iraqi gasoil fuel. The adsorbents were impregnated with copper, zinc, nickel oxides, yielding Cu2O, ZnO, and NiO. desulfurization process was improved by deposition of this metal onto activated carbon's surfaces. optimum desulfurization rates were achieved in continuous mode for Cu2O, ZnO, and NiO. The peak desulfurization rate was attained within 15 minutes. Ammar et al. (2017) and Yang et al. (2017) presented immobilization polyoxometallates (POMs) on polymeric (poly ionic liquids) substrate to the catalytic oxidation tobenzothiophene (BT) and dibenzothiophene (DBT) models fuel, deploying 30% hydrogen peroxide the oxidizing agent. proposed catalyst system can be reused eight time without substantial decrease in functionality.

Recently et al. (2019) examined immobilization phosphotungstic acid (PWA) in graphene oxide (GO) a heterogeneous catalyze to the extraction dibenzothiophene (DBT) from simulated oils, employ hydrogen peroxide (H2O2) oxidant with acetonitrile extracting solvent through an extractive catalytic oxidation desulfurization approach. Nonetheless, is a deficiency of prior research concerning heterogeneous catalytic oxidation desulfurization liquid fuels under microwave irradiation. A preliminary study by Mesdour et al. (2017) examined the influence microwave irradiation on extractive catalysts oxidative desulfurization (ECODS) liquid model fuel, employing vanadylacetylacetonate (VO(acac)2) as heterogeneous catalyst, an ionic liquid (N-carboxymethylpyridine hydrosulphate) a solvent,with a mixture of H2O2 and H2SO4 as an oxidant. They accomplished a minimum of 86% sulfur removal using microwave (500 W) ECODS on a brief reaction duration (90 s) under moderate circumstances, demonstrating substantial catalysts stability. Microwave radiation is seen as a more efficient method for transferring energy to molecules, allowing faster reactions than traditional heating methods. Bartoli (2021) illustrates the application of biosolids in lipid pyrolysis to diminish sulfur levels in crude pyrolysis oils. Elevating reaction temperature and extending processing duration may reduce sulfur content. Pretreatments and direct integration with adsorption agents may prove beneficial. The Soxleth method is the most efficient technique for recovering adsorbers. liquid extraction method for aerobic desulfurization can retrieve unreacted fatty acid, which may be transformed into hydrocarbon fuels. The liquid-liquid extraction method is most efficient, yielding fuel with minimal sulfur concentrations (Bartoli et al., 2021). Kareem (2021) the research examined the oxidative degradation of partially hydrotreated diesel utilizing a tripartite system comprising hydrogen peroxide, ferric chloride, and carboxylic acids (formic acid, acetic acid, with propanoic acid). It emerged that formic acid, acetic acid, and PA were completely soluble on diesel, rendering them unfit for aqueous extractants. AA revealed superior extraction efficacy compared to FA owing to its greater void radius. A molar ratio of nH_2O_2/nS of 36 facilitated the optimal elimination of sulfur compounds at 55°C. highest reduction of sulfur-based compounds was 65.1% (Kareem, 2021).

Solouki and Jaffer (2022) suggested an innovative microwave assisted method for demetallization and desulfurization crude petroleum oils, employing aqueous sodium hydroxide solutions and sulfuric acid. The method displayed a regeneration effectiveness of 99%. A techno-economic analysis revealed that it is more financially beneficial than hydro-desulfurization, with forecast CAPEX between 16 and 21 million USD and operational expenditures varying from 1.27 to 9.1 dollars per barrel. Supplementary advantages include catalyst-free operation, processing at ambient temperatures, and energy efficiency by selective microwave heating (Solouki et al., 2022). Bai and Risheng (2023) documented efficient with straightforward synthesis of nano-sized Ti-rich TS-1 (MFI) zeolites with substituting tetrabutyl orthotitanate (TBOT) and tetrabutyl orthotitanate tetramer (TBOT-tetramer). titanium precursor. reintroduced TBOT-tetramer impeded zeolite crystallization processes, hence controlling incorporation rate of Ti and crystal formation while preventing the excessive synthesis anatase radicals. synthesized Ti-rich TS- one zeolite exhibited a Si/Ti ratio of 27.6, in contrast to the standard sample, which had molar ratio of 40. The TBOT-tetramer boosted titanosilicate zeolites by increasing the concentration of active titanium species with expanding exterior surface area. The manufacturing anatase species was impeded, resulting in decreased catalytic efficiency for oxidative desulfurization dibenzothiophene in comparison to the conventional TS-1 zeolite formed and TBOT (Bai et al., 2023).

Mostafa (2024) examines a microwave assisted methods to desulfurization of commercial diesel fuel, noting reactivity of organic solvents with effects of solvent/feed ratio, microwave intensity, with irradiation duration. The findings demonstrate that ethyl acetoacetate is best suitable solvent due to its polarity. The optimal conditions for desulfurization include 7 minutes of irradiation, a solvent feeds ratio of 3:1, with a microwave intensity of 180 W (Mostafa et al., 2024). Nguyen (2024) proposed research introduces an innovative technology for synthesizing Z-scheme photocatalysts by sol-gel process integrated with microwave techniques. Technology lessens crystallization duration to 30 minutes and prevents the necessity for hazardous solvents. Under ideal conditions, the 20%$ZnO-TiO_2$/OCN photographic catalyst can convert 99.19% of dibenzothiophene (DBT) to DBT-O_2, hence eliminating 92.13% DBT from fuel oil samples. The results present a novel approach in next-generation Z-scheme composite materials, highlighting the sol gel technology for improved oxidative desulfurization (Nguyen et al., 2024). This study aims to investigate and enhance the desulfurization of diesel fuels use microwave treatment with hydrogen peroxide, acetic acid, with activated carbon. The principal variables analyzed are microwave power, treatment period, and the volume ratio of peroxide to fuel. A rotatable central composite design (RCCD) had been used to statistically optimize the process parameters. This study employs activated carbon for post-oxidation sulfur elimination and utilizes microwave radiation for efficient heating, differentiating it from previous research.

Materials and Methods

This study uses high-sulfur diesel fuel obtained from the Dora refinery near Baghdad, characterized by initial sulfur value of 2865 mg/L. The research employed liquid hydrogen peroxide (30%, GR Merck, Darmstadt, Germany), activated carbon, and acetic acid as the primary reagents in oxidative desulfurization methodology.

Experimental Setup

This procedure was conducted utilizing a microwave reaction device, with regulated radiation intensity and duration of reaction. A 100 cc quantity of diesel fuel was evenly employed in all trials. The sample was mixed with varying volumes of hydrogen peroxide (10 ml, 15 ml, 25 ml, 35 ml, 45 ml) with different amounts of acetic acid (5.5 ml, 7.5 ml, 9.5 ml, 11.5 ml, 13.5 ml). A same quantity of activated carbon (1 g) was included in all tests mixes were combined with an electric mixer at 1500 RPM for 10 minutes, followed by exposure to microwave radiation at power levels of 200, 300, 400, 500, and 600 watts for 50, 100, 150, 200, and 250 seconds. Subsequent to irradiation, the mixtures were magnetically agitated at 1100 RPM and 50°C for roughly one hour. Thereafter, the mixture was permitted to settle in a separating funnel for approximately 15 minutes until it stratified into two layers, with the lower layer being the treated diesel fuel. Samples were subsequently collected for analysis of sulfur contents. Sulfur removal rate was determined using the equation presented in Table 1 and Figure 1.

Removal rate = $\frac{x-y}{x}$ *100%

Where: x = sulfur concentration in initial diesel
y = sulfur concentration in the refined diesel

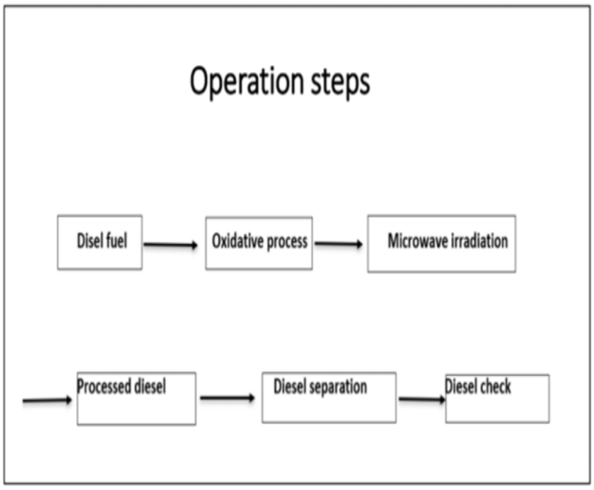

Figure 1. Operation step

Table 1. Three-factors five-level central composite design

Run no	Coding value			True value			Removal rate
	X1	X2	X3	Power emitted[W]	Treatment time [sec]	Volume of H2O2 to the volume of diesel [ml]	Y[%]
1	1-	1-	1-	300	100	0.3	71
2	1	1-	1-	500	100	0.3	69
3	1-	1	1-	300	200	0.3	76
4	1-	1-	1	300	100	0.7	66
5	1	1-	1	500	100	0.7	70
6	1-	1	1	300	200	0.7	68
7	1	1	1-	500	200	0.3	66
8	1	1	1	500	200	0.7	65
9	2-	0	0	200	150	0.5	65
10	2	0	0	600	150	0.5	60
11	0	2-	0	400	50	0.5	64
12	0	2	0	400	250	0.5	67
13	0	0	2-	400	150	0.1	79
14	0	0	2	400	150	0.9	72
15	0	0	0	400	150	0.5	75
16	0	0	0	400	150	0.5	75
17	0	0	0	400	150	0.5	75
18	0	0	0	400	150	0.5	75
19	0	0	0	400	150	0.5	75
20	0	0	0	400	150	0.5	75

Sulfur concentrations in model diesel, actual diesel fuel, and treated products were examined at the Refining and Gas Research Department of Petroleum Research and Development Center inside the Ministry Oil. Sulfur concentration was quantified by the XOS Sindie OTG sulfur analyzer (USA), employing monochromatic wavelength dispersive X_ ray fluorescences in compliance with ASTM D7039.

Design, Result and Discussion

Findings are illustrated Table 2-5 and Figure 2-3. This is effective technique to eliminating oxidized sulfur for diesel fuel. Microwave radiation serves as efficient and swift method for removal sulphur from diesel fuel by oxidation, owing to the volumetric and selective heating of fuel method to removal of sulfur for diesel fuels by oxidation, owing for volumetric and selective heating of the fuel. The microwave operates by producing high thermal energy that facilitates the acceleration of chemical processes. This can facilitate desulfurization reactions from diesel, expediting the process relative to conventional approaches such as hydrogen treatment or filtering.

Table 2. Sequence experiments with seration result according responses surface methodology (RSM)

Factors	Symbols	Level				
		-2	-1	0	+1	+2
Power emitted, W	X1	200	300	400	500	600
Treatment time, s	X2	50	100	150	200	250
Volume of H2O2 to the volume of diesel fuel, ml	X3	0.1	0.3	0.5	0.7	0.9

Table 3. Summary coefficient of polynomials results

Coefficients of a polynomial	Assess	Normal error	Minimum confidence threshold	Upper confidence threshold
a0	-0.2671	5.726815	-13.0273	12.4930
a1	0.2684	0.016134	0.2220	0.2939
a2	0.5643	0.031404	0.4107	0.5507
a3	31.237	7.764388	-50.2831	-15.6828
a4	-0.0003	0.0000054	-0.0005	-0.0003
a5	0.09172	0.013424	0.0513	0.1112
a6	-0.0725	0.026849	-0.1223	-0.0027
a7	-0.0004	0.000015	-0.0004	-0.0003
a8	-0.0067	0.000061	-0.0011	-0.0008
a9	1.4543	3.786174	-7.0157	9.8566

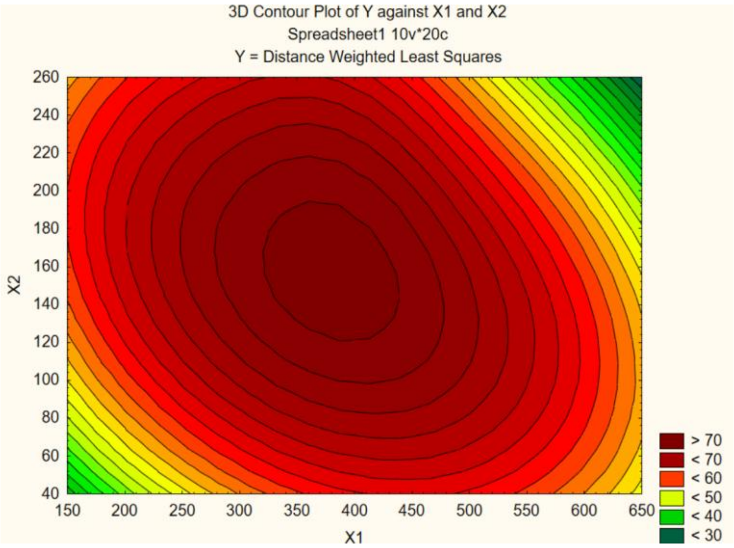

Figure 2. Three-dimensional representation of power output (W) vs time (s)

Model is:
y=a0+a1*x1+a2*x2+a3*x3+a4*x1*x2+a5*x1*x3+a6*x2*x3+a7*x1^2+a8*x2^2+a9*x3^2
Dep.Var: y.
Level of confidence: 95.0% (α = 0.050)

The microwave irradiation method has been effectively detailed here for removal of oxidized sulfur for diesel fuels at varying powers and durations. The findings recorded at 400 watts and 150 to 160 seconds shown in Fig 2 achieved highest efficiency of 70%. Figure 3 illustrates that the maximum separation efficiency roughly 85% was attained at 500 watts of power and volume ratio of 0.7.

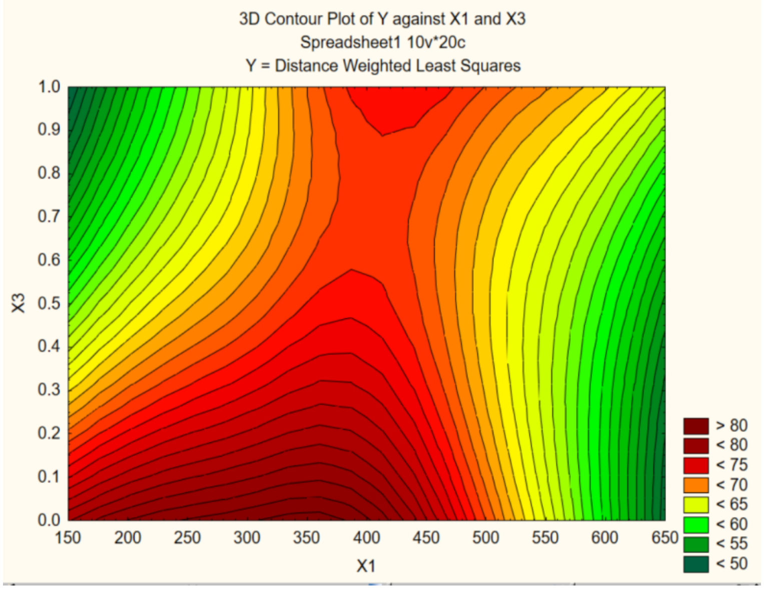

Figure 3. Three-dimensional representation of power (W) and volume rate (ml)

Table 4. p-level value

Factor	p-level
Constant	0.963717
X1	0.000000
X2	0.000000
X3	0.001695
X1 X2	0.000038
X1X3	0.000123
X2X3	0.042205
X1X1	0.000000
X2X2	0.000000
X3X3	0.715369

Model is:
y=a0+a1*x1+a2*x2+a3*x3+a4*x1*x2+a5*x1*x3+a6*x2*x3+a7*x1^2+a8*x2^2+a9*x3^2
Dep.Var: y.
Level of confidence: 95.0% (α = 0.050)

Table 5. The ANOVA analysis value.

Parameter	Value
Mixture squares to regression analysis	99618.23
Squared summary of the remaining	5.77
Degree the freedom for regression	10.00000
Degree the freedom for residual	10.00000
Degree the flexibility to regression versus corrected	10.00000
Total	9961.823

Parameter	Value
Mean squares to regression	0.577
Mean square to residual	9961.823
Mean square to regression vs. corrected total	17237.70
f-Rate for regression	377.94
f-Rate of regression vs- correct total	0.00
p-Rate of regression	0.00
p-Rate of regression vs- correct total	

Impact Power on Separation Efficiency

Radiated power (W) a critical factor affecting separation efficiency, demonstrated in Fig. 4. The figure demonstrates the separation efficiency represented by blue curve at 50 seconds and a volume ratio of 0.1. At 200 watts, the efficiency was 57.3%; With increasing the power to 300 watts, the efficiency rose to 59.2%. Raising the power to 400 watts yielded an efficiency of 61%, due to accelerated and more uniform heating, which facilitates the oxidation reaction by producing a greater quantity of reactive radicals from hydrogen peroxide.Upon increasing the power to 500 watts, efficiency declined for 58%, and at 600 watts, it further decreased to 48.3%. The reduced effectiveness of desulfurization beyond the appropriate threshold is due to the disproportionate breakdown of hydrogen peroxide, the creation of stable oxidized sulfuric acids, the rapid saturation of activated carbon, and high temperatures that may impede the chemical reaction. A specific red curve represents a duration of 100 seconds with a volume ratio of 0.3.

The efficiency rose to 200 watts, achieving 66.3%. Upon increasing the wage to 300 watts, efficiency reached 70%. Upon reaching 400 watts, the efficiency rose to 71.7%. At 500 watts, it diminished to 66.5%, and at 600 watts, it fell to 56.2%. At 150 seconds and a volume ratio of 0.5, the green curve indicated that the efficiency at 200 watts was 66.9%, increasing to around 73% at 300 watts. Efficiency rose to 74.2% to 400 watts but began to diminish at 500 watts, ultimately reaching 69.1%. It further diminished to 600 watts, attaining 59%. A secondary sky curve was seen at 200 seconds with a volume ratio of 0.7. The efficiency at 200 watts was 73%, and at 300 watts, it jumped to 77.1%. The efficiency rose to 78% at 400 watts, but when the power increased to 500 watts, it decreased to 73% and further declined to 64.3% at 600 watts. A separate curve in purple indicated that the efficiency at 200 watts decreased to 55.7% at 250 seconds, with a volume ratio of 0.9. Upon increasing the power to 300 watts, the value reached 60.1%, and upon further raising it to 400 watts, the value rose to 61.5%. Subsequently, it began to diminish, attaining 56% at 500 watts and decreasing to 46.6% at 600 watts.

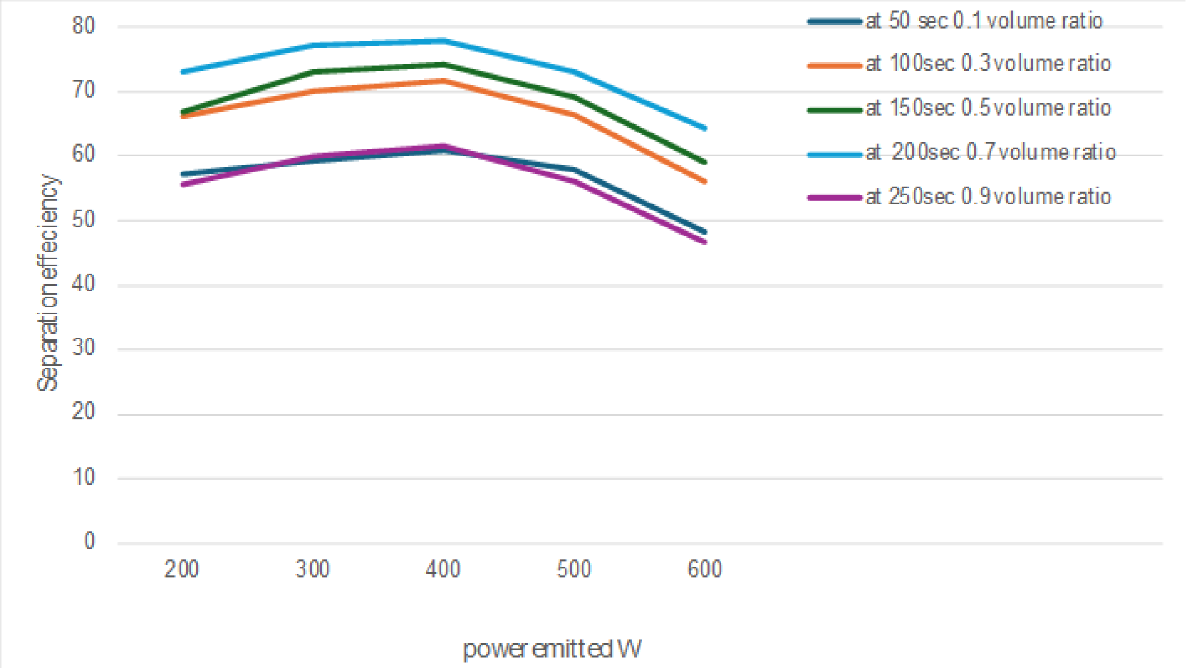

Figure 4. The impact power emitted on separation efficiency

Impact Time on Separation Efficiency

Figure 5 illustrates the impact of time on efficiency. The blue curve at 200 watts and a 0.1 volume ratio indicates that efficiency attained 55% at 50 seconds. Upon extending the duration to 100 seconds, efficiency reached 59%. At 150 seconds, the efficiency rose to 62% Efficiency improves when enhanced microwave heating facilitates the generation of reactive radicals that oxidize sulfur compounds, while activated carbon adsorbs these oxidized compounds, hence enhancing total removal. but when the duration was prolonged to 200 seconds, it declined to 58% Efficiency decreases due to excessive heat causing hydrogen peroxide to decompose without reacting, formation of stable sulfur compounds that are harder to remove, and saturation of activated carbon which reduces its adsorption capacity. It subsequently rose to 63% at 250 seconds. A red curve at 300 watts and a volume ratio of 0.3 exhibited an efficiency of 65% at 50 seconds. When the duration extended to 100 seconds, the efficiency reached 69%. At 150 seconds, it rose to 71%. At 200 seconds, it began to decline to 67%, and at 250 seconds, it increased to 71%. A green curve at 400 watts and 0.5 exhibited an efficiency of 72% at 50 seconds, then escalated to 76% at 100 seconds, further grew to 80% at 150 seconds, declined to 77% at 200 seconds, and ultimately reached 81% at 250 seconds. The curve in sky blue at 500 watts and 0.7 had an efficiency of 75% at 50 seconds, which ascended to 81% at 100 seconds and further improved to 85% at 150 seconds. Subsequently, it diminished to 82% in 200 seconds and increased to 85% in 250 seconds. The purple curve at a power of 600 watts and a volume ratio of 0.9 exhibited an efficiency of roughly 77% at 50 seconds, which improved to 80% by 100 seconds. The value rose to 84% in 150 seconds and thereafter declined to 80% at 200 seconds. At 250 seconds, it reached 83%.

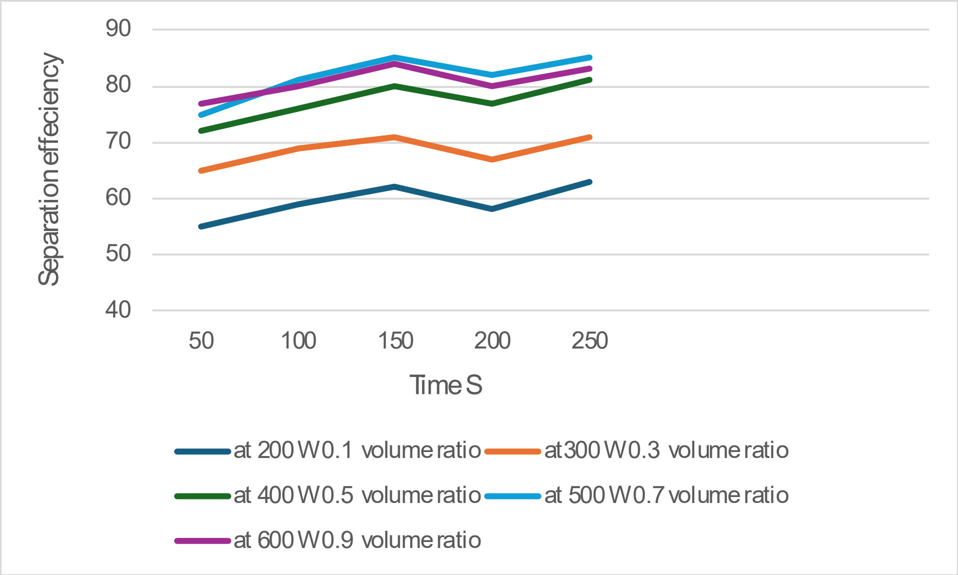

Figure 5. The impact of time on separation efficiency

Impact of Volume Ratio on Separation Efficiency

In Figure 6 The blue curve at 200 watts and 50 seconds demonstrated a separation efficiency of 57% at 0.1, whereas raising the ratio to 0.3 elevated the efficiency to 77%. The percentage rose to 81% at 0.5, subsequently decreased to 70% at 0.7, and further declined with higher quantities, reaching 44.5% at 0.9. At 300 watts and 50 seconds, the red curve exhibited an efficiency of 54.4% at 0.1, which increased to 74.1% when the ratio was elevated to 0.3. The percentage rose to 77% at 0.5, thereafter, declined to 66% at 0.7, and further decreased to 44.6% at 0.9. The green curve at 400 watts and 150 seconds had an efficiency of 51.2% at 0.1, which escalated to 71.3% at 0.3 and further rose to 75% at 0.5. Subsequently, it diminished to 65% at 0.7 and further fell to 44.8% at 0.9. The curve is azure at 500 watts and 200 seconds. The efficiency at 0.1 was 49.5%, increasing to 69.7% at 0.3 and further rising to 72% at 0.5. Subsequently, it diminished to 61% at 0.7 and further fell to 45% at 0.9. The purple curve recorded at 600 watts and 250 seconds had an efficiency of 45.7% at 0.1, which escalated to 65% at 0.3 and further rose to 69% at 0.5. Subsequently, it diminished to 59.9% at 0.7 and reverted to 45.4% at 0.9.

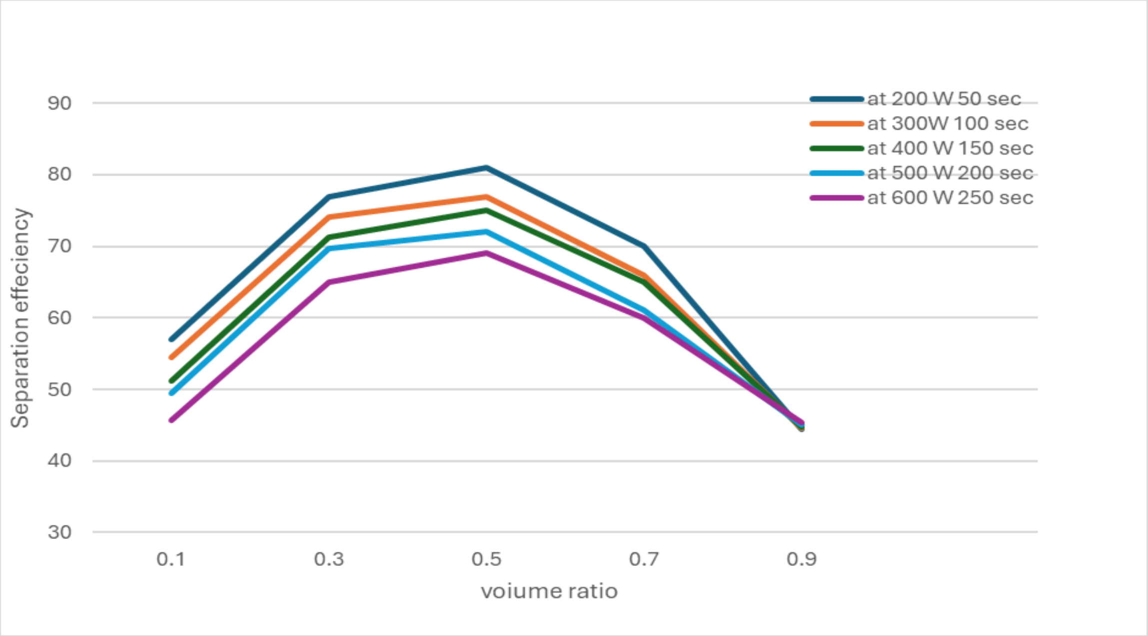

Figure 6. The impact of volume rate on separation efficiency

Conclusion

Studies show that microwave irradiation can effectively remove oxidative sulfur from fuel. Exposure to high-frequency electromagnetic waves may induce oxidation reactions and significantly reduce sulfur concentration. Various energy levels, durations, and volume ratios were employed using microwave irradiation, hydrogen peroxide in addition to acetic acid, activated carbon, and diesel fuel. The maximum efficiency was recorded at 400 watts and 150-160 seconds, with a volume ratio of 0.7 ml. The implementation of the CCR Design program (Composite Response Surface Design) proved highly effective in determining the best possible values for the three variables analyzed. Through extensive trials with five levels for each variable, we obtained accurate data on the impact of each parameter on the outcome, thereby improving efficiency in determining the optimal conditions. The peak efficiency achieved was roughly 85%.

Recommendations

Optimize microwave irradiation parameters to enhance productivity. Investigate the influence of scavenger and catalyst concentrations. Develop solutions for the reusability of activated carbon. Evaluate the impact of the process for diesel quality. Expand applicability to involve various sulfur compounds. Perform economic and environmental feasibility analyses.

Scientific Ethics Declaration

* The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Conflict of Interest

* The authors declare that they have no conflicts of interest

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