Original Article: An Overview of the Use of Photo Catalysts for Desulfurization

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ABSTRACT

According to international standards, sulfur in fuels used in the transportation industry, as one of the most important polluting industries, should be reduced to around 10 ppmw, while many refineries around the world produce sulfur fuels with more than 1000 ppmw. One of the new and cost-effective methods of reducing sulfur among all existing methods is photocatalytic oxidation methods. Another advantage of designed catalysts is that while they are used in the desulfurization process, the oxidation and adsorption processes take place rather than in separate steps (which in turn increases cost and time), due to the structural properties of this. The catalyst of both phases takes place simultaneously and simultaneously during one phase. In reactor experiments, the oxidative desulfurization (ODS) process of model diesel fuel, including the resistant compound of d-benzothiophene in n-shop solvent with 100 ppmw sulfur, was performed under mild operating conditions such as ambient temperature and pressure without hydrogen and the effect of operating parameters such as catalyst mass. Amount and concentration of H_2O_2 oxidant, type and amount of light radiation, amount of dopant and type of catalyst on the percentage of conversion of sulfur compounds and in other words on the efficiency of the study process and showed that increasing the amount of catalyst, amount and concentration of auxiliary oxidant and the amount of dopant to Certain will increase the efficiency and more than that will reduce the efficiency of the desulfurization process.

Introduction

Strict environmental laws around the world to reduce environmental pollution have drawn researchers' attention to the deep desulfurization of fuels used in transportation. The American Environmental Protection Agency enacted laws that forced the refining industry to reduce the sulfur content of gasoline and diesel fuel to about 30 ppmw and 15 ppmw in 2006 [1-3].

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Standards set by the European Union have also limited the maximum permissible sulfur content in petrol and diesel to 10 ppmw for 2009 [4-6]. Production of fuels with very low sulfur levels has been considered in order to use advanced pollution control systems with new technology that are sensitive to sulfur [7]. On the other hand, liquid hydrocarbon fuels such as gasoline, jet and diesel fuels are considered as ideal fuels in fuel cells used in motor vehicles and military equipment due to their high energy density, ease of access, storage and transportation. Due to the toxicity of catalysts used in fuel cells with sulfur compounds, the use of fuels with very low amounts of sulfur (less than 0.1 ppmw) is recommended for this purpose. Although reducing sulfur levels to very small amounts is environmentally beneficial, achieving very small amounts of sulfur from current levels is economically, operationally and technologically very difficult and complex, and factors such as catalysts, operating conditions, feed type and quality. The reactivity of sulfur compounds as well as the presence of inhibitors such as nitrogenous compounds, aromatics and hydrogen sulfide gas produced can have important effects on the desulfurization rate of fuels [8-10]. As a result, the use of new catalysts with higher activity or new processes to reduce sulfur to world standard values is required in the refining industry.

Sulfur in fuel consumption on the formation of pollutants

Combustion engine exhaust gases include sulfur and nitrogen oxides, carbon monoxide, carbon dioxide, particulate matter, and unburned hydrocarbons. Numerous studies have shown that the amount of sulfur oxides in the exhaust gases of the engine is directly related to the amount of sulfur in the fuel. In addition, the production of particulate matter is proportional to the amount of sulfur in diesel [12]. The direct effect of diesel fuel sulfur content on particulate matter in the output of diesel engines is shown in figure (1).
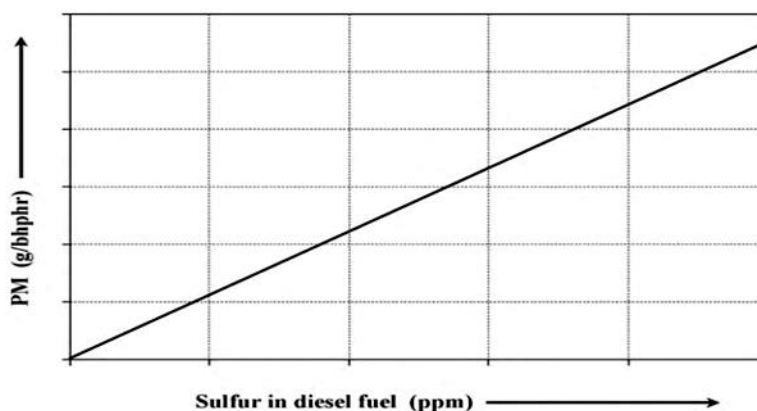

Figure 1: The direct effect of the amount of sulfur in diesel fuel on particulate matter in the output of diesel engines

About 2% of the sulfur in diesel fuel is converted to particulate matter, according to the American Environmental Protection Agency [13].

The particulate matter in the exhaust gases of diesel engines consists of three main components: the carbon core, the water-soluble organic part, and a mixture of sulfur oxides and water, which are major causes of cancer in humans. Pollution control equipment such as oxidation catalysts and nitrogen oxide adsorbents and particulate filters and selective reduction catalytic systems are commonly used at the exhaust of diesel engines to control pollution. Oxidation catalysts oxidize carbon monoxide, non-combustible hydrocarbons, particulate matter, and SOF into carbon dioxide and water in the exhaust gases of diesel engines [14].

Sulfur Oxidation Rate Sulfur dioxide is increased by oxidation catalysts and more sulfates are produced at the engine output. In

addition, sulfur poisons oxidation catalysts and reduces their activity for the oxidation of carbon monoxide, hydrocarbons and SOF in engine exhaust gases.

The activity of particulate filters and nitrogen oxide adsorbents is also affected in the presence of sulfur [15-16]. Since sulfates are more stable than nitrates, competition for oxidation at active sites creates competition between the two compounds, and active sites are significantly inactivated by sulfates. Reducing the amount of sulfur in the fuel in three ways leads to reducing pollutants in the exhaust gases of the engine, which are:

1) Direct reduction of sulfur dioxide and fine sulfate particles.

2) Better activity of oxidation catalysts in the absence of sulfur.

3) Ability to use new technologies to control pollutants such as new filters and nitrogen oxide adsorbents.

Studies by the US department of energy show that particulate matter emitted from diesel engines is reduced in fuels that contain lower amounts of sulfur [17-19]. By reducing the sulfur content of diesel fuel from 350 ppmw to 3 ppmw, the amount of particulate matter has been reduced by 29%.

Another study by MECA in 1999 reported a 14% reduction in particulate matter when diesel with 54 ppmw sulfur was used instead of 368 ppmw sulfur. Alexander Samokhvalov studied the process of desulfurization of liquids by photochemical methods in a review article [20]. Ultra-severe desulfurization of liquid fuels is very important for the environment; It also increases the service life of combustion engines and provides "green", tolerable, and carbon-neutral fuels for sol (fuel) applications. In this study, the author's attention is focused on photo catalysts and photochemistry for the preparation of clean fuels and valuable chemical products. This important review article organizes and analyzes studies on photocatalytic, light-sensitizing, and photochemical desulfurization of liquid fuels over the past 20 years [21-23].

An experimental study to obtain the reactivity of various sulfurous organic compounds and to test the effect of various parameters such as temperature, solvent and the amount of oxidizing agent in the oxidative desulfurization reaction (ODS) has been done by Luis Ceden˜o Caero *et al* [24]. This oxidation was performed using a vanadium-based catalyst in the presence of hydrogen peroxide and under mild reaction conditions, including ambient pressure and a temperature range of 303 to 343 Kelvin. The sulfur compounds studied are: 2-methylthiophene (2-MT), 2,5-dimethylthiophene (2,5-DMT), benzothiophene (BT), dibenzothiophene (DBT), 4-methyldiobenzothiophene (4-MDBT), and 4 -6-dithium (4,6-DMDBT) [25-27]. All of these sulfur compounds are a type of thiophene found in diesel fuels. A synthetic diesel with these compounds was prepared in hexadecane. The experimental results showed that the oxidative reactions are as follows:

DBT> BT> 4-MDBT> 2-MT> 2,5-DMT> 4,6-DMDBT

Some of the sulfur compounds removed from the diesel phase were not converted to their corresponding sulfonates under these operating conditions; But were removed only in the form of sulfur compounds by extraction and without reaction of ODS. Excess amounts of oxidant improved the equilibrium reaction, but thermal decomposition of the oxidant and oxidation reactions produced water, which was a barrier to ODS reactions [28-30].

Hence, a controlled increase in H_2O_2 improves the reactivity of ODS in sulfur compounds. In addition, the study of oxidative desulfurization of synthetic diesel under mild conditions (ambient pressure and temperature of 60°C) and in the presence of V_2O_5 / Al_2O_3 and V_2O_5 / TiO_2 catalysts was performed by the same research group [31]. Two main aspects were studied: 1) the effect of oxidizing agent and 2) the presence of nitrogen-containing compounds on ODS Common benzothiophene compounds in diesel such as benzothiophene and alkyl-substituted dibenzothiophene in positions 4 and 6. The results showed that the activity was improved by using hydrogen peroxide as the

oxidizing agent and V_2O_5 / Al_2O_3 as the catalyst. These results are attributed to the high decomposition of peroxide due to the presence of a catalyst. In the presence of nitrogenous compounds, ODS activity is reduced as follows:

Quinoline > Indole> Carbazole

To explain this effect, the successful chemical adsorption of DBT and quinoline on the V_2O_5 / Al_2O_3 catalyst was evaluated by FT-IR and the results showed that quinoline replaced DBT by occupying the catalyst adsorption centers. The effect of nitrogenous compounds can also be explained by the strong adsorption of nitrogenous compounds on catalytic centers. The team also studied titanium oxide (TiN) nanotubes and an SBA-15 molecular sieve made of titanium oxide-extruded porosity, fabricated and oxidized desulfurization of common dibenzothiophene compounds in diesel fuel. Two types of commercial titania were used as reference. The structural and textural properties of titanium-based catalysts were investigated by X-ray diffraction (XRD), scanning electron microscopy (SEM-EDXA), transmission electron microscopy (TEM), and nitrogen uptake and desorption assays. ODS tests were performed in a three-phase system (L – L – S); But to evaluate the occurrence of oxidation in the liquid phase, these tests were also performed in a two-phase system (L – S).

The results of the reactions showed that the best catalytic performance is obtained with TiN; And for most active catalysts, desulfurization may be limited to mass transfer between two liquid phases (extraction solvent and oil). To achieve the oxidative desulfurization of combustible oils, Jiang Zongxuan and colleagues review several attractive pathways, including the use of H_2O_2 / organic acids, H_2O_2 / heteropolyacid, H_2O_2 / titanium-containing zeolites, and other systems. Performed non-peroxidation (such as t-butyl hydroperoxide, etc.).

The following is a new intermittent oxidation desulfurization process using emulsion catalysts, specifying the components. Restrictions on mass transfer between the two phases are significantly reduced in the emulsion reaction. These emulsion catalysts are able to selectively oxidize the sulfur molecules in diesel to their corresponding sulfones when H_2O_2 is used as an oxidizer under mild conditions. Sulphones in oxidized fuel oils can be extracted with a polar extractant. The sulfur level in hydrogenated diesel can be reduced from a few hundred micrograms per gram to 0.1 micrograms per gram after oxidation and subsequent extraction; While the sulfur level in diesel decreases directly from 6000 to 30 micrograms per gram after oxidation and extraction [31-33].

Dishun Zhao and colleagues developed a technique for combining photochemical oxidation and ionic liquid extraction ([Bmim] PF6) in deep desulfurization of light oil with the presence of H_2O_2 optical oxidizer. In the process of [Bmim] PF6 being extracted; And mediated the photochemical reaction and was used to promote the oxidation of dibenzothiophene. In this deep oxidation desulfurization, 99.5% DBT depletion of n-octane and 90.6% deletion of real light oil were achieved under mild room temperature and ambient pressure conditions. The ionic liquid [Bmim] PF6 was recovered eight times, with a slight reduction in desulfurization efficiency. The oxidation desulfurization process of theophany in a synthetic mixture of theophany and isooctane, with copper-loaded titanium silicate 1 (TS-1) catalyst, has been studied in the presence of hydrogen peroxide as an oxidizing agent by N [34-36]. Jose et al. The conversion percentage increased to 240% in 240 minutes by adding 1.05% by weight of copper in TS-1. In these experiments, the optimal Box-Benken scheme was used to evaluate the effect of independent process variables, such as reaction temperature, amount of catalyst and moles of hydrogen peroxide per mole of thiophene, and their optimal values to achieve the conversion percentage. 93% were obtained at 70°C, 0.45 g (22.5 mol / l isoctane) and 19.9 mol (per 20 mL isoctane), respectively. The effect of mass transfer on the desulfurization reaction was minimized by selecting the appropriate agitation degree and catalyst size. An experimental kinetic model was used to interpret the velocity data. The apparent activation energy was calculated to be 28.67 kJ / mol. An experimental study on the oxidative

desulfurization of model sulfur compounds, such as dibenzothiophene and benzothiophene in toluene, which is simulated as a light furnace oil, with a mixture of hydrogen peroxide as the oxidant and various acids as catalysts. Performed by Asghar Molaei Dehkordi and colleagues [37-39].

Influence of various parameters including reaction temperature (T), molar ratio of acid to sulfur (Acid / S), molar ratio of oxidant to sulfur (O/S), type of acid and the presence of sodium tungstate and commercial activated carbon as a cocatalyst (associated catalyst). The percentage of conversion of sulfur compounds in the model was investigated. The obtained experimental data were used to determine the reaction rate constant of the model sulfur compounds and their corresponding activation energy. In addition, the adsorption of model sulfur compounds on commercial activated carbon supplied by Jacobi (Sweden, AquaSorb 101) was studied and the effects of various parameters such as temperature and various chemical modifications on the adsorption of sulfur compounds were investigated.

In addition, the oxidized desulfurization of unmodified kerosene with a total sulfur content of 1700 ppmw produced in an Iranian refining company (Isfahan Refinery) was successfully investigated.

These experiments were performed using formic acid as a catalyst and hydrogen peroxide as an oxidant and in mild operating conditions T = 50°C, O/S = 5 and Acid/S = 10. It was concluded that about 87% of the total sulfur content of unmodified kerosene can be eliminated after 30 minutes of oxidation with liquid-liquid extraction. Photocatalytic decomposition of 3-nitrobenzene sulfonic acid in the presence of solar and UV radiation, suspended with titanium dioxide, in batch and continuous reactors by Satyen Gautam, respectively. And his colleagues have been examined. The effect of catalyst loading, PH, presence of anions, cations and initial concentration on the rate of photocatalytic decomposition was investigated. Concentration-time data with velocity equation:

$$d[C_{t=0}] / dt = k_r K [C_{t=0}] / (1 + K[C_{t=0}])$$

Studies were performed on the comparison of photolysis, photochemical and photocatalytic methods. A. Abdel-Wahab et al. studied anomalous polyhydric sulfides (I-IV) in aerated acetonitrile and successfully oxidized to their corresponding sulfoxides and sulfonates by photocatalytic oxidation with TiO_2 [40-42].

A possible electron transfer mechanism, in which an empty orbital is formed by radiation on the TiO_2 surface, is also proposed for how it is catalyzed by a semiconductor. The desulfurization process of kerosene through optical oxidation and selective adsorption for fuel cell applications was studied by Hiroaki Tao et al. Optical oxidation was performed using a 5-watt low-pressure mercury lamp at 25 ° C in the presence of O_2. It was first observed that the optical oxidation rates of the predominant residual sulfur compounds in commercial kerosene were at least 100 times faster than those for benzothiophenes (BTs) and dibenzothiophenes (DBTs); However, their molecular states were not refined. The oxidation of these highly reactive sulfur compounds was completed within 30 minutes, and this process made them deflectable by adsorbents such as molecular sieves. On the other hand, unreactive sulfur compounds such as DBT were removed by adsorbents such as activated carbon. Using this proposed method, which combines the optical oxidation of highly active sulfur compounds with the absorption desulfurization of active and inactive sulfur compounds, the total sulfur content of kerosene can be effectively reduced to less than 0.1 μg / g (ppm) and decrease under mild conditions. Sadao Matsuzawa et al. studied the photocatalytic oxidation of dibenzothiophene (DBT) and 4,6-dimethyl dibenzothiophene (4,6 DM DBT) in acetonitrile using titanium dioxide (TiO_2 (P25)) [43-45].

The results obtained here can be used as a reference for sensing reactions in hydrocarbons; Reactions whose main purpose is to develop an oxidative desulfurization process for petroleum products. A 200-watt Hg – Xe lamp was used as a light source, and the catalytic performance of the four photocatalysts on the market (PC-1, PC-2, PC-3 and P25) were compared. Under light irradiation and in the presence of photocatalyst in acetonitrile, DBT was more stable than

4,6DMDBT. Among the photocatalysts used, TiO$_2$ (P25) showed the highest optical oxidation rate. However, if TiO$_2$ (P25) was used, the reduction in initial DBT or 4,6DMDBT was less than 40% after 10 h of irradiation. To accelerate the reaction, the effect of adding hydrogen peroxide (H$_2$O$_2$) and ultrasound to the TiO$_2$-containing system was studied. Although add [46-49].

Hydrogen peroxide (3%) and ultrasound more than doubled the speed of light oxidation, but this efficiency can only be achieved with H$_2$O$_2$. Detected reaction products from DBT and 4,6 DMDBT included: sulfoxide and sulfone, respectively. Methyl group oxidation occurs mainly when 4,6DMDBT reacts in the presence of TiO$_2$. This conclusion led to the discovery of the fact that oxidation of the methyl group occurs in nonpolar hydrocarbons. Optical decomposition (TiO$_2$ / UV Light) hydrocarbons: para-nitrophenol (PNP), naphthalene (NP) and dibenzothiophene (DBT) in three different reactors: discontinuous reactor (BBR), tubular reactor (TBR) and tubular pilot (TPP). pHs 3, 6 and 10 were analyzed and presented by Ronald Vargas et al. and the results were compared according to the duration of UV exposure. The results were consistent with the Langmuir-Hinswood (LH) model; Hence, the LH (K) absorption equilibrium constants and the apparent velocity constants (k) are reported to be the same as the quasi-first-degree velocity constants. The discontinuous reactor is the most selective reactor against changes in composition and PH in which the reaction order is: NP> DBT> PNP, although the catalyst adsorption order (K) used at all three PHs is: DBT> NP > PNP, of course, NP has the highest k values. Tube

Reactor (TBR) The most efficient reactor among the three reactors tested. D.Huang et al. A process for the synthesis of porous titanium dioxide with tetra butyl titanium.

Prefabricated, and presented in environmental conditions. For the synthesis of these substances from phospho-tungstenic acid as catalyst, type 4 ammonium bromide including: Octacyl trimethylammonium bromide (STAB), acetyl trimethyl ammonium bromide (CTAB), 1-tetracyl trimethylammonium bromide (TTA) Trimethyl ammonium bromide (DTAB) was used as a structural agent. STAB has been the best structural engineer. Porous TiO$_2$ calcined with STAB was studied by Xray fluorescence spectroscopy (XRF), X-ray diffraction (XRD), nasal spectroscopy (FTIR), transmission electron microscopy (TEM) and nitrogen adsorption / desorption measurements. Nitrogen adsorption / desorption isotherms provide porous structure properties. TEM results showed that irregular internal structures were formed through the accumulation of TiO2 nanoparticles. TiO$_2$ material showed good performance in DBT oxidation.

The effect of reaction temperature, catalyst concentration, H$_2$O$_2$ concentration and initial DBT concentrations on DBT oxidation was tested in detail. DBT removal from a 300 ppm mixture of dibenzothiophene was 98% in 2 minutes.

A) Synthesis method of two-component loading photo catalysts TiO2 (P25) and NaX nano-seolite:

Table (2) shows the results of XRF analysis for group (a) photo catalysts.

Table 2: Results of XRF analysis for the synthesized photo catalysts of group (a)

sample	Pcat(1)	Pcat(2)	Pcat(3)	Pcat(4)	Pcat(5)
% Zeolite NaX	44.54	56.63	68.32	77.38	**85**
% TiO$_2$ (P25)	55.46	43.37	31.68	22.62	**15**

Process isothermal study

In order to investigate the effect of different parameters on process efficiency, the basis of these experiments is that by keeping all the

parameters constant in an optimal constant value, and changing the parameter under study, the effect of changes in that factor on the reaction efficiency is measured. (Due to the high volume of experiments performed and the large

number of chromatograms related to GC-MS analysis in each section, only the results of the optimized laboratory conditions analysis for each parameter have been reported for brevity.)

Synthesis and characterization of Foxacite NaX nanozeolite

As described in the previous chapter, in this study, the base used to make desulfurizing photocatalysts is a zeolite base of the Naox Fujasite zeolite type. NaX nanoseolite was synthesized by hydrothermal method and evaluated using instrumental identification techniques such as XRD, SEM and TEM. XRD results showed that NaX nanoseolite crystals were formed, in other words, XRD results of synthesized zeolite crystals and SEM and TEM results confirm the nanoparticles of these particles. Thus, according to the synthesis results of the synthesized nanoseolite, it is Fujasite X and the particle size of zeolite is between 17 and 40 nm with an average particle size of 19 nm.

Effect of different parameters on the synthesis of NaX zeolite

The size of NaX zeolite crystals changes with change in different synthesis conditions, including different temperatures, mixing conditions and crystallization time. The results of this study are as follows:

Table 3: Synthesis conditions for different samples of NaX nanoseolite

Synthesis conditions	Time (h)	Temperature (°C)	Sample
Magnetic stirrer	48	60	a
Magnetic stirrer	48	45	b
	16	90	
Synthesis conditions	48	90	c

In this study, NaX nanoseolite was synthesized without the use of molding materials and the effect of various parameters such as temperature, biting intensity and time on the crystallization of nanoseolite was investigated. One of the effective ways to increase the efficiency of nanostructured catalysts is to increase the surface area of a material by reducing the particle size as well as creating pores and voids in the material. In this regard, eating is an effective factor in reducing the particle size. In addition, the crystallization temperature has a definite effect on the final size of the zeolite crystals, and increasing the temperature and synthesis time increases the particle size. However, the reaction temperature has a more significant effect on the average particle size of the synthesized zeolite grains compared to the reaction time; lower temperatures lead to the formation of smaller particle sizes.

Interpretation of scanning electron microscope (SEM) images

In order to identify and study the surface morphology of synthesized NaX zeolite nanoparticles and to study its shape and surface as well as to observe the sample with high magnification and resolution, SEM analysis was used. SEM is a method that is suitable for showing the surface and physical characteristics of the catalyst such as the shape of cavities and pores. The operation of this microscope is based on the interaction of the electron beam with matter, and the rays emitted from this interaction can be used for studies.

Transmission electron microscopy (TEM) images: TEM is a special tool in determining the structure and morphology of materials, so for direct studies and observations of microstructures of materials with high resolution and very large magnification of atomic size of synthesized NaX nanoseolite particles, TEM was used. In this study, TEM images taken from NaX nanoseolite. As can be seen in the image, the synthetic nanoseolite particles are largely crystallized as three-

dimensional cubic particles, and the particle size is measured at about 100 nm.

Conversion percentage: The conversion percentage in the desulfurization process is calculated according to the following equation:

$$Conversion\ \% = \frac{C_0 - C_f}{C_0} \times 100$$

In this regard, C_0 is the initial concentration of sulfur and C_f is its final concentration in the reaction. In all experiments, the conversion percentage of the sample increased over time, and the PH was constant before and after the reaction in the photo reactor. Since the surface area in Nano has increased compared to larger scales, this means that the nanoscale of photo catalysts used in the desulfurization process is very effective on the conversion efficiency. In general, for high photocatalytic activity, having a high surface area is required. The Nano photo catalysts synthesized in this study have an advantage in this field with their high specific surface area.

In order to optimize the test conditions to obtain the desired result of photochemical degradation in a discontinuous system, it is necessary to consider parameters.

Investigation of the effect of effective parameters on the efficiency of photocatalytic oxidation desulfurization process

Catalyst mass

The mass of the catalyst is directly related to the conversion percentage, i.e. the efficiency also increases with increasing the amount of catalyst, but this increase has some good performance and more than this amount will have the opposite effect on the efficiency. The reason for this is that by increasing the amount of catalyst, the number of active sites increases, which increases the degradation efficiency. On the other hand, increasing the amount of catalyst reduces the penetration of UV light into the solution due to the increased turbidity of the solution due to the presence of catalyst particles and prevents light from reaching the catalyst surface and its excitation, as well as excitation of H_2O_2 and its conversion to H_2O_2. The result is degradation at the catalyst level, which will reduce the efficiency. In addition, overuse of the catalyst will not be cost effective. For this purpose, to optimize the catalyst mass.

Table 4: Comparison of the results of catalyst mass change in efficiency

Efficiency	Radiation time	Type of radiation	Amount and concentration of H_2O_2	Mass (gr)	Catalyst type
2.01%				-	
54.74%	4hours	UV-C	-35% ml 0.2	0.3	**TiO₂(P25)**
97.96%				0.5	
99.69%				0.7	

According to table (4), the process efficiency is only 2.01%, which indicates that the low efficiency in this experiment, which lacks photo catalyst, does not improve the desulfurization process without photo catalyst, in other words, the need for a photo catalyst in this process is constant.

Conclusion

In the photocatalytic process, it is necessary to first activate the photocatalyst due to effective radiation. The need for a light path in the photocatalytic reactor controls the geometry and shape of the reactor. Because the maximum amount of effective radiation must be absorbed by the photocatalyst. Second, the maximum contact between the activated catalyst and the organic matter should be made, and the resulting products should be removed from the photocatalyst surface in the best way. These are just some of the goal-setting sharewares that you can use to get the most out of your reactor. Nanoparticles are incredibly effective in

increasing the effective surface area relative to the reactor volume and reducing the internal resistance. In addition, in these photo actors, a stirrer is used to create a homogeneous environment, and aeration is performed due to the need for oxygen. One of the applications of this technology that has attracted many researchers today is the creation of self-cleaning surfaces and hydrogen sensors. Finally, related practical examples that can be mentioned are solar units with a capacity of 300 liters per hour in Almeria (Spain), which are operated by sunlight, and units of 60 to 6000 liters per hour, which purify commercializes

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