Available online at https://ap.ardabil.iau.ir/
Islamic Azad University, Ardabil Branch
Anthropogenic Pollution Journal, Vol 7 (1), 2023: 97-103
ISSN: 2783-1736- E-ISSN: 2588-4646

ORIGINAL RESEARCH PAPER

Removal Study of Hazardous Thiols Pollution by Tributylammonium Halochromates(VI) / Silica , $(C_4H_9)_3NH^+[CrO_3X]^-$, (X=F, Cl): as an Oxidizing Agent

Mohammad Kazem Mohammadi

Department of Chemistry, Ahvaz Branch, Islamic Azad University, Ahvaz, Iran

ARTICLE INFORMATION

Received: 2023.07.29
Revised: 2023.08.06
Accepted: 2023.08.16
Published online: 2023.08.16

DOI: 10.22034/AP.2023.1992295.1163

KEYWORDS

Halochromates
Heterogeneous oxidants
Silica gel
Thiol
Disulfide

ABSTRACT

Oxidative coupling of thiols to the corresponding symmetrical disulfides were performed in the presence of silica gel supported tributylammonium fluorochromate(VI), (TriBAFC), and tributylammonium chlorochromate(VI), (TriBACC). Silica gel supported TriBAFC and TriBACC are versatile reagents for the effective and selective oxidation of organic substrates, in particular of thiol, under mild conditions. Disulfides are also key intermediates in a wide variety of organic synthetic routes. Considerable improvements are observed in the presence of the absorbent and making the work-up much more convenient. The nature of the solvent does not appear to be particularly critical. Hydrocarbons, benzene, ethers and chlorinated hydrocarbons are equally effective, the practical choice being oriented by the solubility of the products and the desired reaction temperature. The IR spectra of TriBAFC and TriBACC are similar to that of other fluoro and chlorochromates, TriBAFC and TriBACC are soluble in water, dimethylformamide, acetonitrile, acetone and dichloromethane; they are only sparingly soluble in benzene, carbon tetrachloride, chloroform and hexane.

How to Site: Mohammadi MK, Removal Study of Hazardous Thiols Pollution by Tributylammonium Halochromates(VI) / Silica , $(C_4H_9)_3NH[CrO_3X]$, (X=F, Cl): as an Oxidizing Agent, Anthropogenic Pollution Journal, Vol 7 (1), 2023: 97-103, DOI: 10.22034/AP.2023.1992295.1163.

Corresponding author: mkmohamadi@gmail.com

1. Background

Today, the human living environment is facing serious environmental hazards due to pollutants present in water, soil and air (Fekri et al., 2021; Tabari et al., 2021; Jalalzadeh et al., 2022; Khajeh Hoseini et al., 2022).

These compounds are toxic compounds resulting from industrial and laboratory activities, such as heavy metals (Sekhavati and jalilzadeh, 2021; Masoumi et al., 2022; Heidari Farsani et al., 2021), chemicals(Elmi et al., 2021; Farsani et al., 2022), pesticides (Orooji et al., 2022), drugs(Gashtasbi et al., 2017), industrial dyes(Farjam et al., 2014; Karbul et al., 2021)., petroleum derivatives (Alishiri et al., 2020;). and other synthetic compounds(Jalilzadeh et al., 2014).

Disulfides are one of the most important organic sulfur compounds possessing an exclusive chemistry both in biochemistry and in synthetic area (Fieser et al., 1967-84; Jocelyn, 1992; Capozzi et al., 1974). Disulfides are also key intermediates in a wide variety of organic synthetic routes (Lam et al., 1989 ; Attri et al. 2012; Oka et al., 2021) . Sweetening of catalyst poisons thiols to low volatile disulfides in oil industries (Holbrook, 1996; Leitao et al., 1987) and also industrial applications of disulfides in vulcanization of rubbers and elastomers led us to investigate the introduction and applications of new member of this category of reagents in oxidation of thiols to the corresponding disulfides.

Many stoichiometric reagents like Iodine (Zeinizadeh, 2002; Olivier et al., 2023) , potassium phosphate (Ashutosh, 2005) , Ti(IV) (Zeinizadeh et al., 2003) , TEMPO-Catalyzed Aerobic Oxidation(Liting et al., 2017), tripropylammonium chlorochromate (Ghammami et al., 2005) , N-tert-Butyl-N-chlorocyanamide (Kumar et al., 2008) [14], Dithiooxamide (Firouzabadi et al.,2015), photocatalytic aerobic oxidation (Talla et al., 2015) , Alkanes (Yu-Jian et al. 2023) , ethyl potassium xanthogenate (Soleiman-Beigi et al.,2018) and urea–hydrogen peroxide catalyzed by a Mn(III)–salen complex (Hosseinpoor et al .,2006) have been developed for this transformation. In constitution of our work on organic synthesis methodology, (Ghammamy et al.,2007; Ghammamy et al., 2008).

Physical & chemical (Karimipour et al., 2021; Babaei et al., 2017; Khayatnezhad and Nasehi, 2021, Wang et al., 2022) and biological methods (Abbaspour et al., 2013; Jalilzadeh Yengejeh et al., 2017; Beidaghdar et al., 2022) and many integrated methods are common to reduce or remove these compounds (pollutants). However, considering the variety of pollutants and in order to increase efficiency, it is necessary to use new technologies such as nano technology (Mehrdoost et al., 2022; Bayati et al., 2021), advanced oxidation processes (Yousefi et al., 2021; Shokri et al., 2019; Sadeghi et al., 2022; Talaei et al., 2022), ultrasonic (Sun et al., 2023), cold plasma process (Pillai and Thomas, 2023) along with existing methods to control and reduce and their removal should be considered before the evacuation of the receiving environment (Nouri Dodaran et al., 2019; Ahari et al., 2020; Nikpour et al., 2020; Kordestani et al., 2020).

We wish to report silica gel supported tributhylammonium fluorochromate (TriBAFC) and tributhylammonium chlorochromate (TriBACC) able to oxidize thiols to their disulfides efficiently under different reaction conditions.

2. Experimental

2.1. Materials and instruments

CrO_3 (Merck, p. a) was used without further purification. Solvents were purified by standard methods. Infrared spectra were recorded as KBr disks on a Shimadzu model 420 spectrophotometer. The UV/Vis measurements were made on an Uvicon model 922 spectrometer. Proton, ^{13}C, ^{19}F-NMR were carried out on a Bruker AVANCE DRX 500 spectrometer at 500, 125, 470.66 MHz, respectively. All the chemical shifts are quoted in ppm using the high-frequency positive convention; the ^1H and ^{13}C-NMR spectra were referenced to external $SiMe_4$ and the ^{19}F-NMR spectra to external $CFCl_3$. Chromium was estimated iodometrically. In the case of the reduced product of the oxidant, chromium was determined after oxidizing with acidic peroxodisulfate ($K_2S_2O_8$) solution. The percent composition of carbon, hydrogen and nitrogen were obtained from the Microanalytical Laboratories of the Department of Chemistry, OIRC, Tehran.

Experiments were carried out in multi mode Microsynth Milstone laboratory microwave oven using a 900 Watts Westpointe microwave operating at 2.45 GHz with an internal volume of 0.9 m^2

2.2. Tributylammonium Fluorochromate (TriBAFC), $(C_4H_9)_3NH\ [CrO_3F]$

1g (10 mmol) sample of chromium (VI) oxide, CrO_3, and 0.9 ml (20 mmol) of 40% hydrofluoric acid were added to 20 ml of water in a 100 ml polyethylene beaker with stirring. After 5-7 min the homogeneous solution was cooled to ca. 0-2 °C. To the resultant clear orange solution, tributylamine (2.35ml, 10 mmol) was added dropwise with stirring over a period of 0.5 h and stirring was continued for 0.5 h at -4 °C. The precipitated yellowish-orange solid was isolated by filtration on a polyethylene funnel, washed with petroleum ether (3 × 60 ml) and dried in vacuum for 2 h at room temperature Yield: (84%); mp 134 °C, $C_{12}H_{28}CrFNO_3$: Calc. C, 47.20; H, 9.24; N, 4.58 Found: C, 46.92; H, 9.64; N, 5.20. I.R. (KBr): 914 cm^{-1} $\nu_1(A_1)$ or $\nu(CrO_3)$, 634 cm^{-1} $\boldsymbol{\nu_2}(A_1)$ or ν(Cr-F), 950 cm^{-1} $\nu_4(E)$ or $\nu(CrO_3)$, Electronic absorption at 22321 cm^{-1}, corresponded to $^1A_2 \rightarrow {}^1E$ ($\boldsymbol{\varepsilon}$ = 177 $M^{-1}cm^{-1}$); 28735 m^{-1} to $^1E \rightarrow {}^1E$ ($\boldsymbol{\varepsilon}$ = 701 $M^{-1}cm^{-1}$) and 35971 cm^{-1} to $^1A_1 \rightarrow {}^1E$($\boldsymbol{\varepsilon}$ = 1314 $M^{-1}cm^{-1}$). UV/Visible, ^{13}C NMR, ^1H NMR and ^{19}F NMR were all consistent with the TriBAFC structure. The above procedure can be scaled up to larger quantities, if desired. The pH of 0.01 M solution of TriBAFC in water was 3.15.

2.3. *Tributylammonium chlorochromate (TriBACC), $(C_4H_9)_3NH^+ [CrO_3Cl]^-$*

Chromium(VI) oxide (1.0 g. 0.01 mol) was dissolved in water in a beaker and 6M hydrochloric acid (0.251 cm^3, 0.015 mol) was added under stirring at 0 °C. To the resultant clear orange solution, tributylamine (0.185 cm^3, 0.01 mol) was added dropwise under stirring over a period of 0.5 h and the stirring was continued for 0.5 h at 0 °C. The precipitated orange solid was isolated by filtration, washed with petroleum ether (3 x 60 cm^3) and dried under vacuum for 2 h at room temperature. Yield: (71 %); mp126 °C. Calcd. for $C_{12}H_{28}ClCrNO_3$: C, 44.79; H, 8.70; N, 4.35. Found: C, 44.59; H, 8.81; N, 4.38. IR (KBr): 898 cm^{-1} ν_1(A$_1$) or ν(CrO$_3$), 436 cm^{-1} ν_2 (A$_1$) or ν(Cr-Cl), 940 cm^{-1} ν_4(E) or ν(CrO$_3$) cm^{-1}. UV/Visible and ^{1}H-NMR were all consistent with the TriBACC structure. Electronic absorption at 21881 cm^{-1}, corresponding to $^1A_2 \rightarrow {}^1E$ (ε =336 dm^{3}mol^{-1} cm^{-1}); 28089 cm^{-1} to $^1E \rightarrow {}^1E$ (ε = 891 dm^3 mol^{-1} cm^{-1}) and 34965 cm^{-1} to $^1A_2 \rightarrow {}^1A_1$ (ε = 1178 dm^3 mol^{-1} cm^{-1}). The pH of 0.01 M solution of TriBACC in water was 2.9.

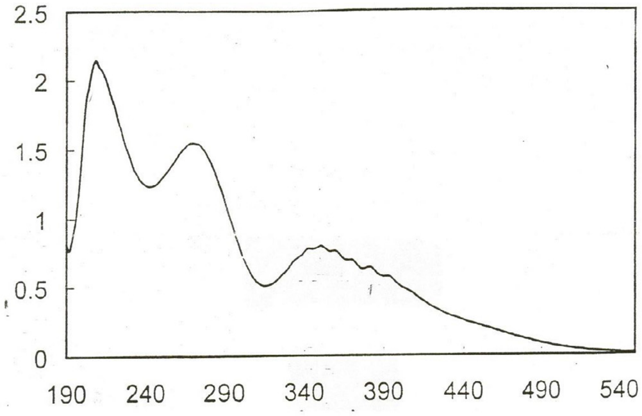


Figure 1. UV-Vis spectrum of Tributylammonium Fluorochromate (TriBAFC)

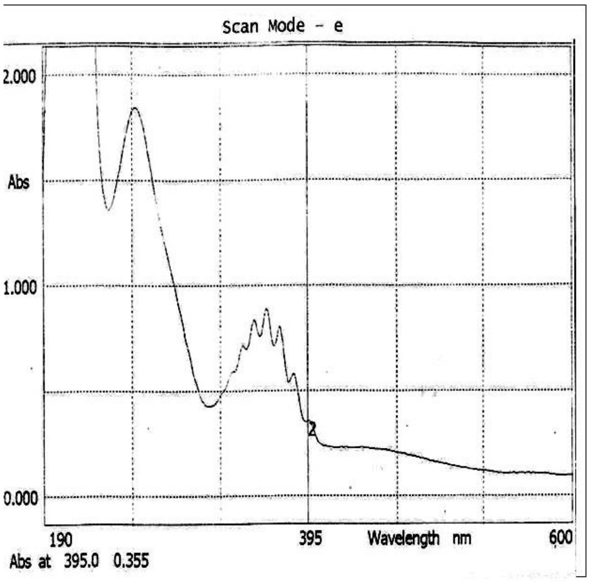


Figure 2. UV-Vis spectrum of Tributylammonium chloroochromate (TriBACC)

2.4. *General procedure for Preparation of silica gel supported reagents*

Neutral silica gel (Aldrich, - 150 mesh) added to the cold solution of TriBAFC or TriBACC. 30 min evaporation of the solvent under vacuum affords orange – red slurry, which is completely dried on the surface of highly dried day plate in the air.

2.5. *General procedure for oxidation of Thiols with TriBAFC and TriBACC*

To a stirred suspension of Tributylammonium halochromate absorbed on silica gel in dichloromethane (generally 5 cm^3), a solution of the substrate in the minimum amount of dichloromethane were added dropwise (Table 1).

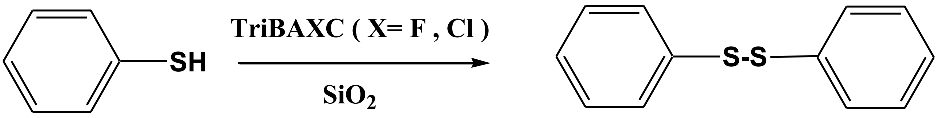
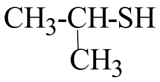
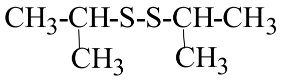
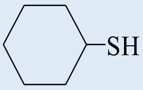
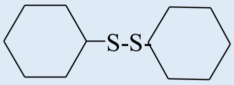
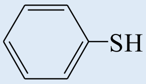
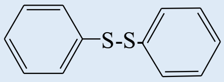
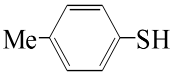
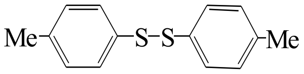
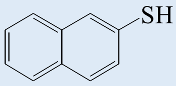
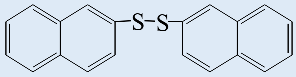


Figure 3. Synthesis of symmetrical disulfide with TriBAXC (X=F,Cl)

Table 1. Oxidation via TriBAFC and TriBACC / silica gel

	Substrate	Product	TriBAFC		TriBACC	
			Time (min)	Yield (%)	Time (min)	Yield (%)
1	 $CH_3\text{-}\underset{CH_3}{CH}\text{-}SH$ 1a	 $CH_3\text{-}\underset{CH_3}{CH}\text{-}S\text{-}S\text{-}\underset{CH_3}{CH}\text{-}CH_3$ 2a	115	78	150	91
2	n-C_5H_{11}-SH 1b	C_5H_{11}-S-S-C_5H_{11} 2b	105	86	120	87
3	n-C_8H_{17}-SH 1c	C_8H_{17}-S-S-C_8H_{17} 2c	108	90	80	91
4	 1d	 2d	95	82	152	89
5	HOOC-CH_2-SH 1e	HOOC-CH_2-S-S-CH_2-COOH 2e	109	80	212	85
6	 1f	 2f	123	87	38	92
7	 1g	 **2g**	128	84	34	89
8	 1h	 2h	138	81	50	92

The completion of the reaction was followed by TLC using ether/petroleum ether (60/40) as eluant. The mixture is diluted with ether (1:1 v/v) and filtered through a short column of silica gel to give a clear solution. The solution was evaporated and the residual product purified by distillation, recrystallization or column chromatography. (Figure 1)

3. Results

The known and existing reagents suffer from either one or more of the following disadvantages such as availability of the reagent, cumbersome work-up procedure, high cost of the reagent, over oxidation or oxidation of other functional groups in the presence of thiol group. As a result, there is still a need for the development of general, efficient, and new reagents to synthesize disulfides from the corresponding thiols under mild reaction conditions. These reactions are not only interest from ecological viewpoint, but also in many cases offer considerable synthetic advantages in terms of the yield, selectivity and simplicity of the reaction procedure. The results obtained with supported tributylammonium fluorochromate and tributylammonium chlorochromate are very satisfactory and show the new reagents to be valuable addition to the existing oxidizing agents. (Table 1) summarizes the products, yields and reaction times of silica gel supported TriBAFC and TriBACC with various substrates.

The spectral data for all disulfides are followed:

2- isopropyldisulfanyl-propane (2a). IR (KBr) Cm $^{-1}$ 3000-2900 C-H(aliph . strech), 1400-1350 C-H (aliph .bend) , 1200- 1100 C-S (strech) . ^{1}H NMR (300 MHz , CDCl$_3$) δ 2.7 (m, 2H) ,1.5 (d, 12H) . ^{13}C NMR (300 MHz , CDCl$_3$) δ 38.5 (d) , 24(q) . HRMS Calcd for $C_6H_{14}S_2$: M$^+$, 150.4125 . Found : *m/z* 150.4117(average).

1-pentyldisulfanyl – pentane (2b). IR (KBr) Cm $^{-1}$ 3000-2900 C-H(aliph . strech) 1200- 1100 C-S (strech) . ^{1}H NMR (500 MHz , CDCl$_3$) δ 2.5 (t , 4 H) ,1.6 (m, 4H) , 1.25(m, 4H) 1.3 (m , 4H) , .85 (t , 6H) . ^{13}C NMR (125 MHz , CDCl$_3$) δ 36, 33, 31, 23.5, 14.5. HRMS Calcd for $C_{10}H_{22}S_2$: M$^+$, 206.8542 . Found: *m/z* 206.1654(average).

1-octyldisulfanyl-octane (2c). IR (KBr) Cm $^{-1}$ 3000-2900 C-H(aliph . strech) 1200- 1100 C-S (strech) . ^{1}H NMR (500 MHz , CDCl$_3$) δ 2.6 (t , 4 H) ,1.5 (m, 4H) , 1.2(m, 18H) .9 (t, 6H) . ^{13}C NMR (125 MHz , CDCl$_3$) δ 33.66, 32.5, 31.43, 31.35, 31.22, 27.03, 23.5, 15.02. HRMS Calcd for $C_{16}H_{34}S_2$: M $^+$, 290.1213. Found : *m/z* 290.3564(average).

disulfanyl-cyclohexane (2d) . IR (KBr) Cm $^{-1}$ 3000-2900 C-H(aliph . strech) , 1200- 1100 C-S (strech) . ^{1}H NMR (500 MHz , CDCl$_3$) δ 2.5 (m , 2 H) ,1.65 (dt, 8H) , 1.4 (m, 12H) . ^{13}C NMR (125 MHz, CDCl$_3$) δ 52.56, 34.52, 26.59, 25.38. HRMS Calcd for $C_{12}H_{22}S_2$: M$^+$, 230.2135 . Found: *m/z* 230.2120 (average).

disulfanyl –acetic acid (2e) . IR (KBr) Cm $^{-1}$ 3500-3200 COOH(strech) , 3000-2900 C-H(aliph . strech) ,1200- 1100 C-S (strech) . ^{1}H NMR (500 MHz , CDCl$_3$) δ 2.27 (s , 4H) ,11.5 (s, 2H) . ^{13}C NMR (125 MHz , CDCl$_3$) δ 35 (t) , 179 (s) . HRMS Calcd for $C_4H_6O_4S_2$: M$^+$, 182.1478, Found: *m/z* 182.342(1average).

disulfanyl-benzene (2f) . IR (KBr) Cm $^{-1}$ 3200-3100 C-H(Ar . strech) , 1200- 1150 C-S (strech) . ^{1}H NMR (500 MHz , CDCl$_3$) δ 7.65 (d , 4 H) ,7.25 (m, 6H). ^{13}C NMR (125MHz , CDCl$_3$) δ 133, 131.4, 130.2, 129.53. $C_{12}H_{10}S_2$: : Calc. C, 66.1; H, 4.71; S, 29.37. Found: C, 66.22; H, 4.65; S, 29.2 .

4,4- di –methyl disulfanyl- benzene(2g) or bis(4-methylphenyl)disulfide: IR (KBr) Cm $^{-1}$ 3200-2100 C-H(Ar . strech) , 3000-2900 C-H(aliph . strech) 1480-1400 C-H (Ar.bend) ,1200- 1100 C-S (strech) .

. ^{1}H NMR (500 MHz , CDCl$_3$) δ 7.5 (d , 4 H) , 7.2(d, 4H) , 2.5(s, 6H) . ^{13}C NMR (125 MHz , CDCl$_3$) δ 126 (S) , 130 (d) , 127 (d) , 124 (s) , 21 (q) .$C_{14}H_{14}S_2$: Calc. C,68.29;

H, 5.70; S, 26.1. Found: C, 68.46; H, 5.60; S, 26.23 .

β-disulfanyl – naphthalene (2h) . IR (KBr) Cm $^{-1}$ 3200-3100 C-H(Ar . strech) , 1200- 1150 C-S (strech) . ^{1}H NMR (300 MHz , CDCl$_3$) δ 8.1 (s , 2 H) ,7.7 (d, 2H), 7.5 (d,6H) 7.32(d,4H) . ^{13}C NMR (300 MHz, CDCl$_3$) δ 137.76, 137.11, 135.26, 134.52, 131.57, 128.92, 127.08, 126.16, 125.02, 124.87. $C_{20}H_{14}S_2$: Calc. C,75.47; H, 4.40; S, 20.12. Found: C, 75.36; H, 4.32; S, 20.89.

4. Discussion

Oxidations may also occur using only TriBAFC and TriBACC, in the absence of SiO_2, but considerable improvements are observed in the presence of the absorbent. This implies that the SiO_2 may act as a reaction medium, providing an effective heterogeneous surface area for the oxidation and at the same time making the work-up much more convenient.

The nature of the solvent does not critical. Hydrocarbons, benzene, ethers and chlorinated hydrocarbons are equally effective, the practical choice being oriented by the solubility of the products and the desired reaction temperature. The chromium (VI) contents easily determined iodometrically.

The IR spectra of TriBAFC and TriBACC are similar to that of other fluoro and chlorochromates, TriBAFC and TriBACC are soluble in water, dimethylformamide, acetonitrile, acetone and dichloromethane; they are only sparingly soluble in benzene, carbon tetrachloride, chloroform and hexane.

5. Conclusion

In conclusion, it has been found that TriBAFC and TriBACC acts as a simple, efficient, and fast oxidizing reagent in the oxidative coupling of thiols. The easy procedure, simple work-up, the easy preparation of the reagent, short reaction times, and excellent yields of the products would make this reagent a useful addition to available oxidants. Also, it should be emphasized that the reactions can be performed cleanly and can be controlled to stop at the disulfide stage. Overoxidation has not been observed, even when the reactions were carried out under different conditions.

6. Acknowledgments

The author thanks Islamic Azad University, Ahvaz Branch for valuable helps.

References

Abbaspour, M., Javid, A. H., Jalilzadeh Yengjeh, R., Hassani, A. H., & Mostafavi, P. G. (2013). The biodegradation of methyl tert-butyl ether (MTBE) by indigenous Bacillus cereus strain RJ1 isolated from soil. Petroleum Science and Technology, 31(18), 1835-1841.

Ahari, S. M., Yangejeh, R. J., Mahvic, A. H., Shahamat, Y. D., & Takdastan, A. (2019). A new method for the removal of ammonium from drinking water using hybrid method of modified zeolites/ catalytic ozonation. Desalin Water Treat, 170, 148-57.

Alishiri, A., Fataei, E., & Ranjbar Baranloo, H. (2020). The effects of nutrients and folic acid on the biological treatment of petrochemical wastewater. Journal of Advances in Environmental health research, 8(3), 201-209.

Ashutosh V J , Bhusare S , Baidossi M, Qafisheh N , Sasson Y, (2005) Oxidative coupling of thiols to disulfides using a solid anhydrous potassium phosphate catalyst. Tetrahedron Lett, 46(20): 3583-3585

Attri P, Gupta S, Kumar R,(2012) Green methodology for the preparation of disulfide. Green Chem Lett and Rev, 5(1): 33-42.

Babaei, A. A., Ghanbari, F., & Yengejeh, R. J. (2017). Simultaneous use of iron and copper anodes in photoelectro-Fenton process: concurrent removals of dye and cadmium. Water science and technology, 75(7), 1732-1742.

Bayati, F., Mohammadi, M. K., Yengejeh, R. J., & Babaei, A. A. (2021). Ag 2 O/GO/TiO 2 composite nanoparticles: synthesis, characterization, and optical studies. Journal of the Australian Ceramic Society, 57, 287-293.

Beidaghdar, M., Fataei, E., Khanizadeh, B., & Imani, A. A. (2022). Feasibility study of using UV/H2O2/O3 advanced oxidation in phenol removal from petrochemical wastewater. Journal of Applied Research in Water and Wastewater, 9(1), 40-45.

Capozzi G, Modena S,(1974) *The Chemistry of the thiol Group*, Wiley, New York, . p.785.

Elmi, R., Farshi, A., Nejaei, A., Ramazani, M. E., & Alaie, E. (2021). Treatment of spent caustic effluent of oil refinery with catalytic oxidation and optimization of relevant parameters using response surface methodology. Anthropogenic Pollution, 5(1), 112-127.

Farjam, M. H., Mohammadi, M. K., & Mehraki, A. (2014). Adsorption evaluation of food and industrial dyes on nano copper oxide. Journal of Chemical Reactivity and Synthesis, 4(1), 31-44.

Farsani, M. H., Yengejeh, R. J., Mirzahosseini, A. H., Monavari, M., Hassani, A. H., & Mengelizadeh, N. (2022). Effective leachate treatment by a pilot-scale submerged electro-membrane bioreactor. Environmental science and pollution research, 1-14.

Fekri, R., Mirbagheri, S. A., Fataei, E., Ebrahimzadeh-Rajaei, G., & Taghavi, L. (2021). Organic compound removal from textile wastewater by photocatalytic and sonocatalytic processes in the presence of copper oxide nanoparticles. Anthropogenic Pollution, 5(2), 93-103.

Fieser LF, Fieser M ,(1967-84) Reagents for Organic Synthesis, 1-11,Wiley, New York.

Firouzabadi H, Iranpoor N, Gorginpour F, Samadi A. (2015) Dithiooxamide as an effective sulfur surrogate for odorless high-yielding carbon-sulfur bond formation in Wet PEG200 as an eco-friendly, safe, and recoverable solvent. Eur. J. Org. Chem, 13: 2914-2920

Gashtasbi, F., Yengejeh, R. J., & Babaei, A. A. (2017). Adsorption of vancomycin antibiotic from aqueous solution using an activated carbon impregnated magnetite composite. Desalination and water treatment, 88, 286-297.

Ghammami S, Tajbakhsh M. (2005) Oxidative coupling of thiols to disulfides in solution and under microwave radiation with tripropylammonium chlorochromate. J Sulf Chem , 26 (2): 145-153.

Ghammamy Sh, Eimanieh H, Mohammady M K. (2007) Cetyltrimethylammonium Bromochromate: A New and Efficient Oxidant for Organic Substrates . Synth Commun, 37: 601–607.

Ghammamy Sh, Mohammadi M K, Hassani Joshaghani A. (2008) Triethylamonium Halochromates /Silica gel: An Efficient Reagent For Oxidative Coupling of Thiols to Disulfides . Maced J Chem Chemi Eng, 27(2) 117–122 .

Heidari Farsani, M., Jalilzadeh Yengejeh, R., Hajiseyed Mirzahosseini, A., Monavari, M., Hassani, A. H., & Mengelizadeh, N. (2021). Study of the performance of bench-scale electro-membranes bioreactor in leachate treatment. Advances in Environmental Technology, 7(3), 209-220.

Holbrook DL, (1996) Handbook of Petroleum Refining Processes, Chap. 11.3, R.A. Meyers (Ed.), McGraw Hill.

Hosseinpoor F, Golchoubian H.(2006) Mild and highly efficient transformation of thiols to symmetrical disulfides using urea–hydrogen peroxide catalyzed by a Mn(III)–salen complex. Catalysis Lett, 111(3–4) :235-247.

Jalalzadeh, A., Rabieifar, H. R., Vosoughifar, H., Razmkhah, A., & Fataei, E. (2022). Investigation of daily waste load allocation in Zarrineh-rud river for environmental management of cold-water fish species. Anthropogenic Pollution, 6(1), 36-46.

Jalilzadeh Yengejeh, R., Pourjafarian, V., Afrous, A., Gholami, A., Maktabi, P., & Sharifi, R. (2017). Studying Bacillus cereus's ability to biodegrade crude oil in hot areas. Petroleum Science and Technology, 35(3), 287-291.

Jalilzadeh, Y. R., Sekhavatjou, M. S., Maktabi, P., ARBAB, S. N., Khadivi, S., & Pourjafarian, V. (2014). The biodegradation of crude oil by Bacillus subtilis isolated from contaminated soil in hot weather areas.

Jocelyn DC, (1992), Biochemistry of the Thiol Group. p. 1, Academic Press, New York.

Karbul, A., Mohammadi, M. K., Yengejeh, R. J., & Farrokhian, F. (2021). Synthesis and characterization of trimetallic Fe-Co-V/zeolite and Fe-Co-Mo/zeolite composite nanostructures. Materials Research, 24.

Karimipour, Z., Jalilzadeh Yengejeh, R., Haghighatzadeh, A., Mohammadi, M. K., & Mohammadi Rouzbehani, M. (2021). UV-Induced Photodegradation of 2, 4, 6-Trichlorophenol Using Ag–Fe 2 O 3–CeO 2 Photocatalysts. Journal of Inorganic and Organometallic Polymers and Materials, 31, 1143-1152.

Khajeh Hoseini, L., Jalilzadeh Yengejeh, R., Mohammadi Rouzbehani, M., & Sabzalipour, S. (2022). Health risk assessment of volatile organic compounds (VOCs) in a refinery in the southwest of Iran using SQRA method. Frontiers in Public Health, 10, 978354.

Khayatnezhad, M. & nasehi, F. (2021). Industrial pesticides and a methods assessment for the reduction of associated risks: a Review. Advancements in Life Sciences, 8, 202-210.

Kordestani, B., Takdastan, A., Jalilzadeh Yengejeh, R., & Neisi, A. K. (2020). Photo-Fenton oxidative of pharmaceutical wastewater containing meropenem and ceftriaxone antibiotics: influential factors, feasibility, and biodegradability studies. Toxin reviews, 39(3), 292-302.

Kumar V, Kaushik M P. (2008) Efficient Oxidative Coupling of Thiols into Disulfides Using N-tert-Butyl-N-chlorocyanamide. Bull. Chem. Soc. Jpn,81(1)160–162.

Lam J, Bildose H, ChristenseLP n, Thomsen T, (1989) Chemical Constituents of Santolina chamaecyparissus. Acta Chem Scand Ser B, 43: 799-802 .

Leitao A, Costa C, Rodrigues A, (1987) Studies on the impregnation step of the Merox process. Chem. Eng. Sci , 42,1987 (2291-2299).

Liting Y, Shuding Li, Yingchao D, Shan Z, Heng L, Panke Z, Bingxin Y, (2017) Pr TEMPO-Catalyzed Aerobic Oxidative Coupling of Thiols for Metal-Free Formation of S−N/S−S Bonds. Asian j of org chem, 6(3): 265-268.

Masoumi, A., & Yengejeh, R. J. (2020). Study of chemical wastes in the Iranian petroleum industry and feasibility of hazardous waste disposal. Journal of Environmental Health Science and Engineering, 18(2), 1037-1044.

Mehrdoost, A., Yengejeh, R. J., Mohammadi, M. K., Haghighatzadeh, A., & Babaei, A. A. (2022). Adsorption removal and photocatalytic degradation of azithromycin from aqueous solution using PAC/Fe/Ag/Zn nanocomposite. Environmental Science and Pollution Research, 29(22), 33514-33527.

Nikpour, B., Jalilzadeh Yengejeh, R., Takdastan, A., Hassani, A. H., & Zazouli, M. A. (2020). The investigation of biological removal of nitrogen and phosphorous from domestic wastewater by inserting anaerobic/anoxic holding tank in the return sludge line of MLE-OSA modified system. Journal of environmental health science and engineering, 18, 1-10.

Nouri Dodaran, P., Fataei, E., & Khanizadeh, B. (2019). Study on photocatalytic and sonocatalytic activity of Bi2O3 synthesized by Sol-gel method in removing organic compounds of ardabil textile factory effluents. Journal of Water and Wastewater; Ab va Fazilab (in persian), 30(4), 67-77.

Oka M, Kozako R, Iida H,(2021) combination of a riboflavin-derived organocatalyst and molecular iodine successfully promoted the aerobic oxidation of thiols to disulfides under metal-free mild conditions at room temperature. The the biomimetic flavin catalyst enables the transfer of electrons from the iodine forming the basis for a green oxidative synthesis of disulfides from thiols. Synlett, *32*: 1227-1230.

Olivier, H. ., Emmanuel, U. ., & Gloria, H. . (2023). Weather influence on the performance of solar collector . International Journal of Sustainable Energy and Environmental Research, 12(1), 10–16. https://doi.org/10.18488/13.v12i1.3379

Orooji, N., Takdastan, A., Jalilzadeh Yengejeh, R., Jorfi, S., & Davami, A. H. (2022). Monitoring of 2, 4-dichlorophenoxyacetic acid concentration in Karun River and effluents of water treatment plants. Toxin Reviews, 41(3), 785-794.

Pillai, R. R., & Thomas, V. (2023). Plasma Surface Engineering of

Natural and Sustainable Polymeric Derivatives and Their Potential Applications. Polymers, 15(2), 400.

Sadeghi, B., Shafaghatian, N., Alayi, R., El Haj Assad, M., Zishan, F., & Hosseinzadeh, H. (2022). Optimization of synchronized frequency and voltage control for a distributed generation system using the Black Widow Optimization algorithm. Clean Energy, 6(1), 105-118.

Sekhavati, E., & Yengejeh, R. J. (2021). Assessment optimization of safety and health risks using fuzzy TOPSIS technique (case study: construction sites in the South of Iran). Journal of Environmental Health and Sustainable Development.

Shokri, R., Yengejeh, R. J., Babaei, A. A., Derikvand, E., & Almasi, A. (2019). UV activation of hydrogen peroxide for removal of azithromycin antibiotic from aqueous solution: determination of optimum conditions by response surface methodology. Toxin Reviews.

Soleiman-Beigi M, Arzehgar Z. (2018) The reaction of aryl halides with ethyl potassium xanthogenate in the presence of MOF-199 provides *O*-Ethyl-*S*-aryl carbonodithioates as intermediates, that can be converted into symmetrical diaryl disulfides, unsymmetrical aryl alkyl(aryl′) disulfides by the reaction with *S*-alkyl(aryl) sulfurothioates (Bunte salts) as well as unsymmetrical aryl alkyl(aryl′) sulfides. Synlett, *29*: 986-992.

Sun, Q., Wang, L., Li, Y., Li, L., Li, S., & Zhu, G. (2023). Highly Efficient Removal of Mercury Ions from Aqueous Solutions by Thiol-Functionalized Graphene Oxide. Water, 15(14), 2529.

Tabari, M. R. R., Sabzalipour, S., Peyghambarzadeh, S. M., & Jalilzadeh, R. (2021). Dispersion of Volatile Organic Compounds in the Vicinity of Petroleum Products Storage Tanks. Environmental Engineering & Management Journal (EEMJ), 20(7).

Talaei, Y., Micula, S., Hosseinzadeh, H., & Noeiaghdam, S. (2022). A novel algorithm to solve nonlinear fractional quadratic integral equations. AIMS Mathematics, 7(7), 13237-13257. doi:10.3934/math.2022730

Talla A, Driessen B, Straathof N J W, Milroy L G, Brunsveld L, Hessel V, Noël T. (2015) Metal-free photocatalytic aerobic oxidation of thiols to disulfides in batch and continuous-flow. Adv. Synth. Catal, 357: 2180- 2186.

Wang, S., Ma, J., Li, W., Khayatnezhad, M. & Rouyendegh, B. D. (2022). An optimal configuration for hybrid SOFC, gas turbine, and Proton Exchange Membrane Electrolyzer using a developed Aquila Optimizer. International Journal of Hydrogen Energy, 47, 8943-8955.

Yousefi, M., Rahmani, K., Jalilzadeh Yengejeh, R., & Goudarzi, G. (2021). Green synthesis of zero iron nanoparticles and its application in the degradation of Sulphacetamide by using of PS/nZVI process. International Journal of Environmental Analytical Chemistry, 1-14.

Yu-Jian H, Li Y, Zhao Z W, Fan T G, Sun B X, Wang X N , Li Y M. (2023) Oxidative Dehydrogenative Coupling of Thiols with Alkanes for the Synthesis of Sulfoxides, Org Lett, 25(3): 517-521

Zeinizadeh B,(2002) Oxidative Coupling of Thiols to Disulfides with Iodine in Wet Acetonitrile. J chem res: 564-566

Zeinizadeh B,Iranpoor N (2003) Oxidative Coupling of Thiols to Disulfides with Ti(IV) in the Presence of NaI under Air Atmosphere. J Chin chem soc, 50(4): 849-852.