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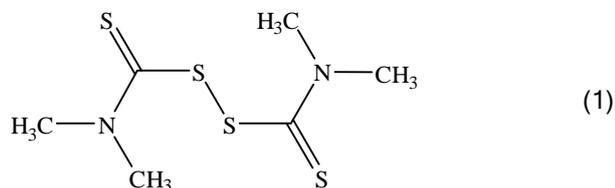
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SYNTHESIS OF TETRAALKYLTHIURAM DISULFIDES USING DIFFERENT OXIDANTS IN RECYCLING SOLVENT MIXTURE

A new optimized laboratory synthesis of tetraalkylthiuram disulfides, starting from dialkyl amines and carbon disulfide in presence of three oxidants (hydrogen peroxide, potassium peroxydisulfate and sodium hypochlorite) and appropriate reaction media (two mixtures of isopropyl alcohol-water used in two consecutive syntheses) was presented in this work. The first synthesis was performed in a recycled azeotropic mixture of isopropyl alcohol-water 87.7%-12.3%, and second in a filtrate obtained after first synthesis, which was a mixture of isopropyl alcohol-water 70.4%-29.6%. After the second synthesis and filtration, recycled azeotropic mixture isopropyl alcohol-water 87.7%-12.3% was regenerated from the filtrate by rectification. Considering this, the technology for beneficial use of recycling isopropyl alcohol-water mixture as a reaction medium for tetraalkylthiuram disulfides synthesis was developed. This concept could contribute to extraordinary economical benefit of implemented optimal laboratory synthesis at semi-industrial level. High yields of tetraalkylthiuram disulfides were obtained at both laboratory and semi-industrial level. Structure and purity of synthesized compounds were confirmed by elemental analysis, as well as FTIR, ¹H- and ¹³C-NMR, and MS spectral data.

Keywords: tetraalkylthiuram disulfide; optimization; reaction medium, oxidants.

Studies of the syntheses and properties of tetraalkylthiuram disulfides have been attractive to the scientists in the past and also nowadays due to the broad area of their application: vulcanization accelerator of natural rubber [1], fungicides [2] and additives [3]. The simplest compound in this series tetramethylthiuram disulfide (TMTD) has the following formula:

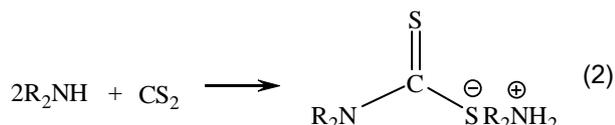


TMTD is widely used as a vulcanization accelerator of natural and styrene-butadiene caoutchouc, a

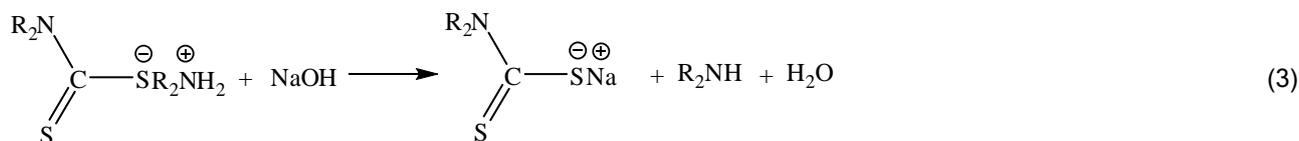
fungicide active compound for corn and wheat treatment [4]. Synthesis of higher alkyl analogues of tetraalkylthiuram disulfide is described in this work, which also could be used for rubber production and plant treatment, as well as protection of the seed during storage in a warehouse [4].

Synthesis of tetraalkylthiuram disulfide can be performed in a two-stage processes. In the first phase, reaction between carbon disulfide and corresponding secondary amine takes place. In the second step, oxidation of the obtained dialkyl ammonium salt of dithiocarbamic acid by the use of an oxidative agent produces tetraalkylthiuram disulfide. Many of thiuram disulfides were synthesized starting from secondary alkyl- and arylamines, carbon disulfide and sodium hydroxide [5], or ammonium hydroxide [6] using different oxidative agents in the presence of catalyst and different organic solvents. The synthesis of the dialkyl ammonium salt of dithiocarbamic acid takes place according to reaction (2) [6]:

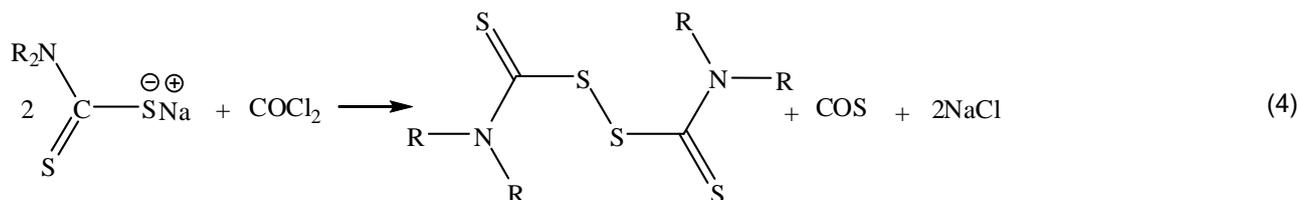
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In the presence of an oxidative agent, the dialkyl ammonium salt of dithiocarbamic acid has been transformed to thiuram [7]. Diethyl dithiocarbamic acid sodium salt (DEDTC) is a well known immunopotentiator and it was found to be potential medicament for clinical treatment of HIV infections [8]. On the other hand, sodium hydroxide produces the sodium salt of dialkyl dithiocarbamic acid presented by reaction (3) [9]:



The sodium salt of dialkyl dithiocarbamic acid can be transformed to tetraalkylthiuram disulfide by introducing phosgene to the reaction mixture [10,11]:



Moreover, synthesis of tetraalkylthiuram disulfide starting from dimethylamine and carbon disulfide in water in the presence of sodium hydroxide was described. In the first step, a sodium salt of dimethyl dithiocarbamic acid was obtained, and in the subsequent oxidation step of the obtained salt by the use of hydrogen peroxide in presence of sulfuric acid or gaseous chlorine produced TMTD [12]. Also, a well-known method for TMTD synthesis is starting with dimethylamine, carbon disulfide and hydrogen peroxide in presence of sulfur at room temperature [13]. Laboratory methods for syntheses of tetraalkylthiuram disulfides by reaction between secondary amines, carbon disulfide and oxidative agents (chlorine, ozone, hydrogen peroxide, bromine, iodine, sodium hypochlorite, carbon sulfochloride, potassium perborate) in presence of manganese(II) acetate and cesium(III) nitrate, were also published [14,15]. Alternatively, sulfur could be used in reaction with a secondary amine and carbon disulfide in appropriate solvent at temperature 0-150 °C, and in presence of a tertiary amine, metal catalyst and oxygen or gaseous mixture containing oxygen [16]. A method for synthesis of tetraalkyl or tetraarylthiuram disulfides, starting from secondary alkyl and

aryl amine, carbon disulfide in presence of triethylamine or ammonia, and oxidation performed by oxygen in presence of metal catalyst at temperature 0-200 °C, is presented. Optimal synthesis conditions were defined at 1.7 bar and at temperature of 50 °C. Metal catalyst based on copper, molybdenum, manganese, cesium and cobalt at ratio of 0.01 to 5.00 mmol of catalyst per mol of secondary amine could be a potential deleterious agent during vulcanization (retardation caused by metal contamination) [17,18]. Among other methods, it is worth mentioning tetraalkylthiuram disulfide synthesis in presence of ammonium lignosulfonate catalyst [19], reaction of metal

chloride with sodium salt of dithiocarbamic acid [20], and from the salt of dithiocarbamic acid [2,21].

The above-mentioned methods do not describe tetraalkylthiuram disulfides synthesis by reaction between secondary alkyl amine, carbon disulfide and oxidative agent (hydrogen peroxide - H₂O₂, potassium peroxydisulfate - K₂S₂O₈ and sodium hypochlorite - NaOCl) in a reaction medium recycled azeotropic mixture of isopropyl alcohol-water 87.7%-12.3%. Also, there are no literature data dealing about prolonged uses of such reaction medium after first synthesis, and recycling of depleted solvent mixture by rectification after second synthesis. By doing this, extraordinary economical benefit of overall cycles of tetraalkylthiuram disulfides synthesis was achieved at semi-industrial level of their production. The structure and purity of the synthesized compounds (tetramethylthiuram disulfide (TMTD), tetraethylthiuram disulfide (TETD), tetrapropylthiuram disulfide (TPTD), tetraisopropylthiuram disulfide (TiPTD), tetrabutylthiuram disulfide (TBTD) and tetraisobutylthiuram disulfide (TiBTDD)) were confirmed by results of elemental analysis, FTIR, ¹H- and ¹³C-NMR, as well as MS spectral data.

EXPERIMENTAL

Synthesis of TMTD by using hydrogen peroxide oxidant (method A)

1540 cm³ of azeotropic mixture of isopropyl alcohol-water 87.7%-12.3% and 437.4 cm³ (4.16 mol) of 50.0 % dimethyl amine solution, which increases the solution pH to 9.5, was added into a three-necked flask of 5000 cm³ equipped with a reflux condenser, dropping funnel, thermometer, cooling jacket and mechanical stirrer. After starting the stirrer, 256.4 cm³ (4.16 mol) of 98.0% carbon disulfide was added from the dropping funnel for 0.5 h while maintaining the temperature in the range 28-35 °C, provided by circulating cooling water. Upon completion of the reaction the pH of the reaction mixture was 6.5. At this point, 536.2 cm³ of 13.2% hydrogen peroxide solution, prepared by dilution of 178.6 cm³ (2.08 mol) 35.0% hydrogen peroxide with 406.5 cm³ of azeotropic mixture isopropyl alcohol-water 87.7%-12.3%, was added from the dropping funnel for 0.5 h at 35-40 °C. As soon as reaction took place, the reaction mixture became yellowish because of suspended TMTD particles. The end of the reaction was tested by sampling the reaction mixture, filtration and by adding a few drops of copper(II) sulfate solution into the filtrate. Appearance of black precipitate indicated that some unreacted dithiocarbamate was still present and the reaction was continued [22,23]. Suspension of TMTD (21%) obtained by cooling of the reaction mixture was filtered using a Büchner funnel and washed with distilled water. The combined filtrate and washing water contained a mixture of isopropyl alcohol-water 70.4%-29.6%, and it was used in subsequent synthesis.

The filtration cake was dried in a vacuum oven at 60-70 °C and 660 Pa, thereby reducing water content to less than 0.5%, and 494.8 g of TMTD (yield: 99.0%; purity: 99.2 %) was obtained. Purity was determined according to the literature method used for determination of dithio compounds residue based on sulfuric acid destruction and absorption of produced

carbon disulfide in potassium hydroxide - alcohol solution [24].

Synthesis of TMTD at different reactant molar ratio

Influences of reactant molar ratio of dimethyl amine:carbon disulfide:hydrogen peroxide on yield and purity of TMTD were studied by performing described experiments, and results of syntheses are given in Table 1.

Synthesis of TMTD at different concentration of suspension

Analogously to given example, a synthesis of TMTD at different quantity of initial recycled azeotropic mixture of isopropyl alcohol-water 87.7%-12.3% was performed to study the effects of dilution or concentration of reaction mixture. Concentration of suspension was calculated on the basis of obtained product and total reaction volume: 1690 cm³ - 18% suspension, example 8; 1771 cm³ - 17% suspension, example 9; 1840 cm³ - 16% suspension, example 10; 1920 cm³ - 15% suspension, example 11, 1380 cm³ - 22% suspension, example 12; 1309 cm³ - 23 % suspension, example 13; 1230 cm³ - 24% suspension, example 14; 1150 cm³ - 25% suspension, example 15. Yield, purity and melting point of the product synthesized according to examples 8-15 are given in Table 2.

Synthesis of TMTD in a mixture of isopropyl alcohol-water 70.4%-29.6% (method B)

Analogously to given example, a synthesis of TMTD was performed using 1540 cm³ of a filtrate from the first synthesis (example 2.1) containing mixture of isopropyl alcohol-water 70.4%-29.6% (20% suspension). 496.3 g of TMTD (yield: 98.7 %; purity: 99.1 %) was obtained.

Synthesis of tetraalkylthiuram disulfides according to Method A

Analogously to synthesis of TMTD (method A), syntheses of TETD, TPTD, TiPTD, TBTD and TiBTD were performed. The results are given in Table 3.

Table 1. Influences of reactant molar ratio on yield and purity of TMTD for amine amount of 1.00 mol; physico-chemical characteristics of TMTD: melting point 156.0 °C, ash residue at 550 °C 0.02 %; ash not soluble in conc. HCl - 0.0112 %, weight loss at 65 °C: 0.0390 %, Cu content: 8.49 ppm, Mn content: 10.00 ppm, no residue on a sieve 150 µm after grinding was obtained

Example	CS ₂ , mol	H ₂ O ₂ , mol	Yield, %	Purity, %
1	1.02	0.50	99.0	99.6
2	1.03	0.50	99.2	98.8
3	1.05	0.50	99.2	99.1
4	1.03	0.52	99.2	99.4
5	1.03	0.54	99.3	99.2
6	1.03	0.55	99.3	99.1
7	1.03	0.60	97.2	98.5

Table 2. Dependence of obtained yield of TMTD with respect to the concentration of suspension

Example ^a	Suspension, %	Yield, %	Melting point, °C	Purity, %
8	18.0	99.2	156.0	99.3
9	17.0	99.3	156.0	99.2
10	16.0	99.3	154.1	99.3
11	15.0	99.4	154.6	99.3
12	22.0	99.0	153.8	99.2
13	23.0	98.8	152.6	98.1
14	24.0	98.7	148.3	98.2
15	25.0	95.0	148.8	98.6

^aExperiment 2.1 - concentration of suspension was 21%

Table 3. Reaction conditions, yield and purity of tetraalkylthiuram disulfides obtained by methods A and B

Compound	Method	Amine, cm ³ ; mol; purity, %	Addition time, min		Lit. m.p., °C	M.p., °C	Yield, g; %; purity, %
			Amine	Oxidant			
TETD	A	389.4; 4.16; 98.0	35	65	70-72 [26]	72	603.4; 98.0; 99.3
	B						601.1; 97.6; 99.2
TPTD	A	532.0; 4.16; 97.0	35	40	47.5-48.5 [27]	60	724.2; 98.9; 99.2
	B						714.2; 97.8; 99.0
TiPTD	A	530.0; 4.16; 98.0	60	45	115-117 [27]	111	645.9; 88.5; 97.0
	B						943.7; 88.2; 97.1
TBTD	A	660.0; 4.16; 98.0	45	60	95 [26]	95	832.0; 98.0; 99.0
	B						828.0; 97.6; 99.0
TiBTD	A	661.0; 4.16; 98.0	30	40	73.5-74.5 [28]	72	820.0; 96.7; 99.3
	B						819.0; 96.5; 99.3

Synthesis of tetraalkylthiuram disulfides according to method B

Analogously to previous example, syntheses of TETD, TPTD, TiPTD, TBTD and TiBTD were performed. The results are given in Table 3.

Synthesis of tetraalkylthiuram disulfides by using potassium peroxodisulfate oxidant (method C)

Synthesis of tetraalkylthiuram disulfides was performed analogously to method C, following procedure to the point of oxidant addition. The oxidant, a solution of potassium peroxodisulfate solution prepared by dissolving 480 g (2.08 mol) 98% K₂S₂O₈ in

1134 cm³ of isopropyl alcohol-water 87.7%-12.3%, was added to the reaction mixture from the dropping funnel for 0.5 h at 35 to 40 °C. The end of the reaction was tested according to the method described in example 2.1, and suspension of TMTD (21%), obtained by cooling of reaction mixture, was filtered using a Büchner funnel and washed with distilled water. The filtration cake was dried in a vacuum oven at 60-70 °C and 660 Pa, reducing the water content to less than 0.5%. The product yields and purities are given in Table 4.

Table 4. Yield, melting point and purity of tetraalkylthiuram disulfides obtained by using different oxidants (methods A, C and D)

Compound	Yield, %			Melting point, °C			Purity, %		
	A	C	D	A	C	D	A	C	D
	H ₂ O ₂	K ₂ S ₂ O ₈	NaOCl	H ₂ O ₂	K ₂ S ₂ O ₈	NaOCl	H ₂ O ₂	K ₂ S ₂ O ₈	NaOCl
TMTD	99.3	97.3	90.2	156	149	146	99.1	98.9	97.7
TETD	98.0	97.0	88.1	72	71	71	99.3	98.2	96.8
TPTD	98.9	96.5	88.0	60	59	58	99.2	98.4	96.6
TiPTD	88.5	82.3	72.1	111	109	108	97.0	97.3	96.7
TBTD	98.0	95.2	87.3	95	94	93	99.0	98.0	97.7
TiBTD	96.7	84.8	74.2	72	70	69	99.3	98.4	97.8

Synthesis of tetraalkylthiuram disulfides by using sodium hypochlorite oxidant (method D)

Synthesis of tetraalkylthiuram disulfides was performed analogously to method A, following procedure to the point of oxidant addition. The oxidant, a 1134 cm³ solution of sodium hypochlorite (162 g active Cl₂ (2.08 mol/1000 cm³), was added for 0.5 h at 35 to 40 °C. The end of the reaction was tested according to the method described in example 2.1. Suspension of TMTD (21%) obtained by cooling of reaction mixture was filtrated using a Büchner funnel and washed with distilled water. The filtration cake was dried in a vacuum oven at 60–70 °C and 660 Pa, reducing the water content to less than 0.5%. The product yields and purities are given in Table 4.

Structure of synthesized tetraalkylthiuram disulfides was confirmed by results of elemental analysis, and FTIR, ¹H- and ¹³C-NMR, and MS spectral data (Tables 5 and 6).

Instrumental techniques used for structure determination of synthesized compounds

¹H- and ¹³C-NMR spectra were obtained on a Varian Gemini apparatus 2000, at 250 MHz for ¹H-NMR and 62.89 MHz for ¹³C-NMR spectra. Spectra were recorded at room temperature in deuterated dimethyl sulfoxide (DMSO-*d*₆). Chemical shifts were expressed in ppm relative to TMS reference signal ($\delta_{\text{H}} = 0$ ppm) for ¹H-NMR spectra, and compared to the solvent signal ($\delta_{\text{C}} = 39.5$ ppm) for ¹³C-NMR spectra. Fourier-transform infrared (FTIR) spectra were recorded in transmission mode using a BOMEM (Hartmann & Braun) spectrometer. Elemental analysis was performed using a Vario EL III elemental analyzer, and results were found to be in good agreement ($\pm 0.2\%$) with the calculated values.

All mass spectra were recorded on a Thermo Finnigan Polaris Q ion trap mass spectrometer, including TraceGC 2000 (ThermoFinnigan, Austin, TX, USA), integrated GC-MS/MS system. Direct insertion probe (DIP) mode has been used to introduce the sample and EI/MS/MS technique to acquire the

Table 5. ¹H- and ¹³C-NMR data and the results of elemental analysis of tetraalkylthiuram disulfides

Compound	¹ H-NMR (δ / ppm)	¹³ C-NMR (δ / ppm)	Elemental analysis, determined/calculated
TMTD	3.61 (12H, <i>d</i> , CH ₃)	41.2; 46.5; 193.6	%C 29.84; %H 5.12; %N 11.52; %S 53.54 %C 29.97; %H 5.03; %N 11.65; %S 53.35
TETD	1.35 (12H, <i>t</i> , CH ₃); 4.04 (8H, <i>q</i> , CH ₂)	10.8; 11.7; 46.8; 51.2; 192.9	%C 40.60; %H 6.72; %N 9.55; %S 43.13 %C 40.50; %H 6.80; %N 9.45; %S 43.25
TPTD	1.12 (12H, <i>t</i> , CH ₃); 1.76 (8H, <i>q</i> , CH ₂ CH ₃); 2.82 (8H, <i>t</i> , CH ₂ CH ₂)	11.3; 11.8; 13.2; 19.8; 22.4; 58.9; 193.4	%C 47.66; %H 8.09; %N 7.92; %S 36.33 %C 47.68; %H 8.00; %N 7.94; %S 36.37
TiPTD	1.12 (24H, <i>d</i> , CH ₃), 3.08 (4H, <i>m</i> , CH(CH ₃) ₂)	20.5; 21.1; 53.5; 58.6; 187.3	%C 47.64; %H 8.06; %N 7.98; %S 36.32 %C 47.68; %H 8.00; %N 7.92; %S 36.33
TBTD	1.08 (12H, <i>t</i> , CH ₃); 1.46 (16H, <i>m</i> , CH ₂ CH ₂ CH ₃); 2.88 (8H, <i>t</i> , NCH ₂)	12.3; 13.8; 19.8; 21.6; 22.6; 29.6; 30.8; 51.9; 52.8; 192.8	%C 52.88; %H 8.88; %N 6.85; %S 31.38 %C 52.86; %H 8.75; %N 6.94; %S 31.45
TiBTD	1.10 (24H, <i>t</i> , CH ₃); 1.76 (4H, <i>m</i> , CH(CH ₃) ₂); 2.80 (8H, <i>t</i> , NCH ₂)	20.6; 21.4; 25.3; 27.6; 56.2; 57.4; 189.2	%C 52.88; %H 8.88; %N 6.85; %S 31.38 %C 52.82; %H 8.78; %N 6.98; %S 31.42

Table 6. FTIR and mass spectrometry data of tetraalkylthiuram disulfides

Compound	FTIR (wave number, cm ⁻¹)	MS (<i>m/z</i>)
TMTD	2932 ($\nu_{\text{as}}\text{CH}_3$), 2876 ($\nu_{\text{s}}\text{CH}_3$), 1506 ($\delta_{\text{as}}\text{CH}_3$), 1402 ($\delta_{\text{s}}\text{CH}_3$), 1378, 1237, 1152 ($\nu\text{C}=\text{S}$), 1040 ($\nu\text{C}-\text{N}$), 978 ($\nu\text{C}-\text{H}$), 535 ($\nu\text{S}-\text{S}$)	240.20
TETD	2964 ($\nu_{\text{as}}\text{CH}_3$), 2912 ($\nu_{\text{as}}\text{CH}_2$), 2843 ($\nu_{\text{s}}\text{CH}_3$ and $\nu_{\text{s}}\text{CH}_2$), 1498 ($\delta_{\text{as}}\text{CH}_2$), 1456 ($\delta_{\text{s}}\text{CH}_2$), 1408 ($\delta_{\text{as}}\text{CH}_3$), 1335, 1256, 1188, 1121 ($\nu\text{C}=\text{S}$), 1056 ($\nu\text{C}-\text{N}$), 1042, 986 ($\nu\text{C}-\text{H}$), 910 ($\nu\text{C}-\text{H}$)	296.06
TPTD	2936 ($\nu_{\text{as}}\text{CH}_3$ and $\nu_{\text{as}}\text{CH}_2$), 2875 ($\nu_{\text{s}}\text{CH}_3$ and $\nu_{\text{s}}\text{CH}_2$), 1502 ($\delta_{\text{as}}\text{CH}_3$), 1465 ($\delta_{\text{as}}\text{CH}_2$), 1401 ($\delta_{\text{as}}\text{CH}_3$), 1371 ($\delta_{\text{s}}\text{CH}_3$), 1238, 1161 ($\nu\text{C}=\text{S}$), 1020 ($\nu\text{C}-\text{N}$), 965 ($\nu\text{C}-\text{H}$), 943 ($\nu\text{C}-\text{H}$), 776 ($\nu\text{C}-\text{H}$), 572 ($\nu\text{S}-\text{S}$)	352.10
TiPTD	2972 ($\nu_{\text{as}}\text{CH}_3$), 2924 ($\nu_{\text{as}}\text{CH}_2$), 2831 ($\nu_{\text{s}}\text{CH}_3$ and $\nu_{\text{s}}\text{CH}_2$), 1486 ($\delta_{\text{as}}\text{CH}_3$), 1432 ($\delta_{\text{as}}\text{CH}_2$), 1364 ($\delta_{\text{s}}\text{CH}_3$), 1308, 1165 ($\nu\text{C}=\text{S}$), 1124, 1102, 1046 ($\nu\text{C}-\text{N}$), 964 ($\nu\text{C}-\text{H}$), 889 ($\nu\text{C}-\text{H}$), 785 ($\nu\text{C}-\text{H}$), 535 ($\nu\text{S}-\text{S}$)	352.10
TBTD	2954 ($\nu_{\text{as}}\text{CH}_3$), 2914 ($\nu_{\text{as}}\text{CH}_2$), 2886 ($\nu_{\text{s}}\text{CH}_3$ and $\nu_{\text{s}}\text{CH}_2$), 1494 ($\delta_{\text{as}}\text{CH}_2$), 1410 ($\delta_{\text{as}}\text{CH}_3$), 1372, 1286, 1212, 1186 ($\nu\text{C}=\text{S}$), 1102, 1021 ($\nu\text{C}-\text{N}$), 945 ($\nu\text{C}-\text{H}$),	408.18
TiBTD	2920 ($\nu_{\text{as}}\text{CH}_3$ and $\nu_{\text{as}}\text{CH}_2$), 2833 ($\nu_{\text{as}}\text{CH}_3$ and $\nu_{\text{s}}\text{CH}_3$), 1496 ($\delta_{\text{as}}\text{CH}_2$), 1489, 1342, 1251, 1246, 1176 ($\nu\text{C}=\text{S}$), 970 ($\nu\text{C}-\text{H}$), 746 ($\nu\text{C}-\text{H}$), 511 ($\nu\text{S}-\text{S}$)	408.18

spectra. Ionization conditions were: ion source temperature 200 °C, maximum energy of electron excitation 70 eV, corona current 150 μ A. Gas chromatographic analysis (GC) has been performed on a Perkin-Elmer 8700 equipped with FID detector and filled column with 5% OV-210 on a Gas-Chrom Q (length 2 m, diameter 0.3175 cm (1/8")). Injector temperature 250 °C; detector temperature 270 °C; Column programmed mode: 50 °C (5 min) \rightarrow 10 °C /min \rightarrow 130 °C (15 min); carrier gas nitrogen (purity 99.99%) flow 1 cm³/min; air flow 250 cm³/min (purity 99.99%); hydrogen flow 25 cm³/min (purity 99.99%). Atomic absorption spectroscopy was used for determination of the metal content in synthesized tetraalkylthiuram disulfides using an AAS-306 Perkin Elmer spectrometer.

RESULTS AND DISCUSSION

In the experimental part of this work, optimal reaction conditions for the synthesis of tetraalkylthiuram disulfides, starting from carbon disulfide and corresponding dialkylamines in presence of different oxidative agents (hydrogen peroxide, potassium peroxodisulfate and sodium hypochlorite) in appropriate reaction media recycling mixture of isopropyl alcohol-water was described. The optimal reaction conditions were defined with respect to reactant molar ratio and concentration of suspension to obtain maximum of tetraalkylthiuram disulfides yield and purity. The tetraalkylthiuram disulfides syntheses were performed in two successive steps: in the first step (method A) recycled azeotropic mixture of isopropyl alcohol-water 87.7%-12.3% was used as the reaction medium, and in the second step (method B) the filtrate from the first step, isopropyl alcohol-water 70.4%-29.6% mixture, was used with similar success. After the second synthesis, the obtained filtrate, a mixture of isopropyl alcohol-water 57.0%-43.0%, was concentrated by rectification, producing the starting mixture isopropyl alcohol-water 87.7%-12.3%. Such concept of tetraalkylthiuram disulfides syntheses, by using recycled solvent mixture, offered an extraordinary techno-economical benefit for scale-up on semi-industrial level of production.

In the first part of the optimization procedure influences of the reactant molar ratio on yield and purity of TMTD was investigated, and obtained results are given in Table 1.

Based on the results presented in Table 1 it could be noticed that the molar excess of CS₂ and H₂O₂ with respect to amine do not have pronounced influences on TMTD yield. At 10% molar excess of H₂O₂ yield of TMTD start to drop steeply. Optimal molar reactant ratio dimethylamine:carbon disulfide:hyd-

rogen peroxide was established at 1.00:1.03:0.55, for which 99.3% yield of TMTD was obtained (purity 99.1%). At a higher molar ratio of oxidant with respect to amine, yield of TMTD decreases, which indicates that side reactions take place at a higher extent [25].

Due to heterogeneity of the reaction mixture, it was of interest to study the effect of dilution or concentration of the suspension on the product yield. The results of TMTD syntheses at different concentration of suspension (15-25%) are presented in Table 2.

The maximum of obtained yield of TMTD was 99.4% (Table 2) at 15% concentration of the suspension. However, in terms of productivity of the reactor, quite satisfactory yield (98.7%) was achieved in the reaction with 24% suspension. The optimal reaction condition of TMTD synthesis at semi-industrial level was established at 20% concentration of suspension, which offered satisfactory productivity of the reactor, and was governed by technical characteristics of the semi-industrial facility.

Summary of synthesized tetraalkylthiuram disulfides obtained according to methods A and B are presented in Table 3.

Based on the results presented in Table 3, it could be observed that similar yields of all synthesized compounds with respect to the reaction medium used were obtained. Furthermore, highest yield of TMTD (99.3%; Table 1) and lowest yield of TIPTD (88.2%) were obtained. These results indicate that the both isopropyl alcohol-water mixtures could be successfully used for tetraalkylthiuram disulfides syntheses. The determined melting points are in agreement with literature data indicating high purity of synthesized compounds.

The results of comparative synthesis of tetraalkylthiuram disulfides using different oxidants: hydrogen-peroxide (method A), potassium peroxodisulfate (method C) and sodium hypochlorite (method D) are presented in Table 4.

Based on the yields, obtained according to methods A, C and D (Table 4), it could be observed that the most effective oxidizing agent was hydrogen peroxide, less effective was potassium peroxodisulfate, and the lowest yields were obtained by the use of sodium hypochlorite. The lowest yield obtained by the use of sodium hypochlorite could be a consequence of the higher contribution of side reactions which cause increases of chloramine derivatives side products. Structure of synthesized tetraalkylthiuram disulfides were confirmed by results of elemental analysis, FTIR, ¹H- and ¹³C-NMR, and MS spectral data (Tables 5 and 6).

Results of TMTD syntheses, obtained at laboratory level, according to method A (Table 3), showed

that high yields of the product were obtained according to method A (88.5-99.0%), and somewhat lower yields were obtained according to method B (88.2-97.8%). Moreover, successful laboratory syntheses, conducted in both reaction medium isopropyl alcohol-water mixtures, indicated that implementation of both laboratory syntheses on semi-industrial level is feasible. Technological scheme of TMTD production is presented on Figure 1, and the results of semi-industrial synthesis of TMTD, by using hydrogen peroxide oxidant, are presented in Table 7.

Semi-industrial synthesis of TMTD (methods A and B)

Method A. 2454 kg of recycled azeotropic mixture of isopropyl alcohol-water 87.7%-12.3 % and 752 kg 60.0% of dimethylamine, which increases the solution pH to 9.5, was added into a reactor (1) of 5 m³, equipped with a reflux condenser (2), dropping funnel with alcohol (3), amine (4), carbon disulfide (5) and hydrogen peroxide (6), thermometer, cooling jacket and mechanical stirrer (Figure 1). After starting the stirrer, 780 kg 98.0% of carbon disulfide was added from the dropping funnel for 1.5 h while maintaining temperature in the range 28-35 °C provided by cir-

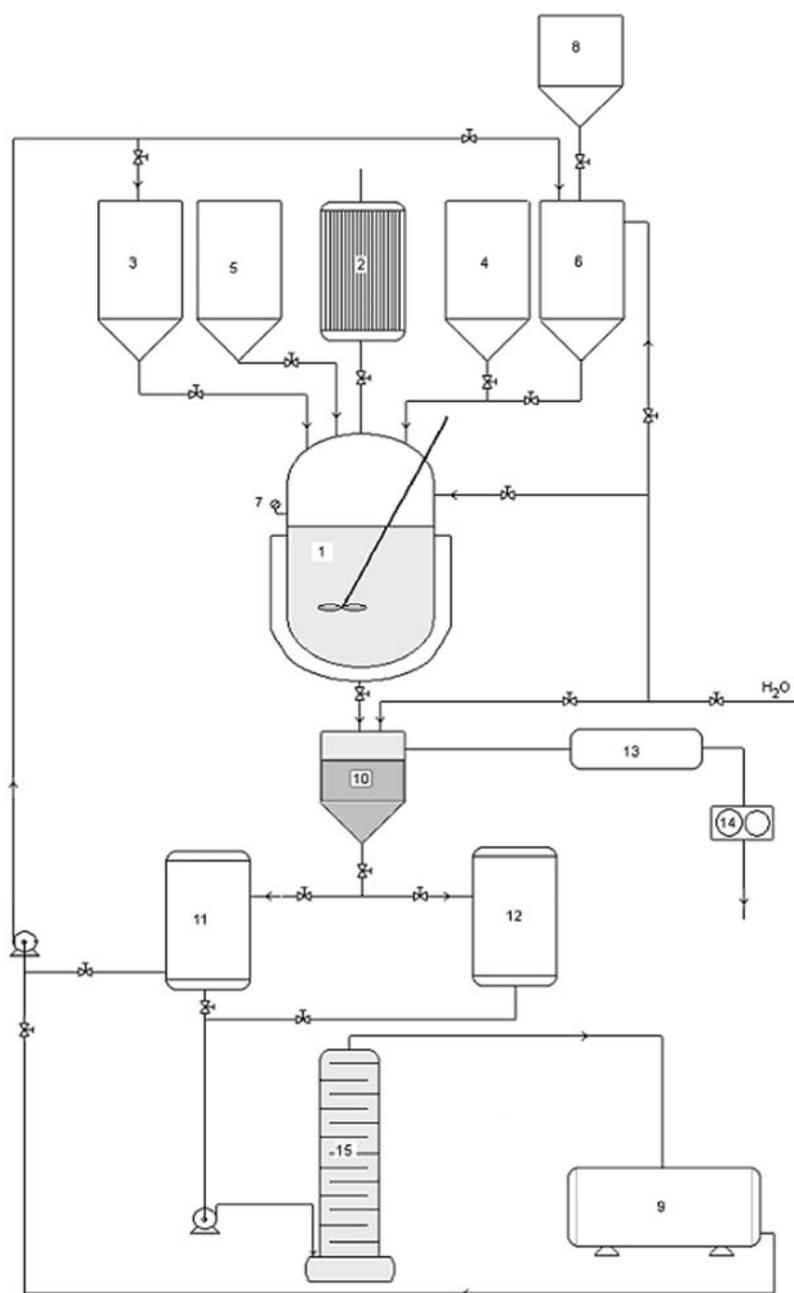


Figure 1. Technological scheme of TMTD production at semi-industrial level.

Table 7. Results of semi-industrial synthesis of TMTD by using hydrogen peroxide oxidant

Batch number	Isopropyl alcohol-water 87.7%-12.3%, kg	Isopropyl alcohol-water 70.4%-29.6%, kg	Reactants						Reaction conditions		Filtration	Product		
			(CH ₃) ₂ NH		CS ₂		H ₂ O ₂		Time	Temp.	cake	Yield	Purity	
			kg	kmol	kg	kmol	kg	kmol	h	°C	kg	kg	%	%
1 ^a	2454	-	752	10	780	10	1313	5.0	3.0	35	1614.5	1120	99.0	99.3
2 ^a	-	2580	752	10	780	10	1355	5.2	3.0	38	1617.0	1119	99.0	98.7
3 ^b	2134	-	654	8.7	678	8.7	1142	4.5	3.0	35	1404.6	993	99.3	99.2

^aBatch calculation is based on 1130 kg of TMTD (20% suspension); ^bbatch calculation is based on 1000 kg of TMTD (20% suspension)

culating cooling water. After completion of reaction the pH of the reaction mixture was 6.5, and at this point 1313 kg 13.2% of hydrogen peroxide was added from the dropping funnel for 1.5 h while maintaining temperature in the range from 35 to 40 °C. The solution was prepared by mixing 496 kg 35.0% hydrogen peroxide from receiver (8) and 817 kg of azeotropic mixture isopropyl alcohol-water 87.7%-12.3%, which was added from a collective reservoir for alcohol (9). As soon as the reaction took place, the reaction mixture became yellowish because of suspended TMTD particles. The end of the reaction was tested by sampling of reaction mixture, filtration and by adding of few drops of copper(II) sulfate solution - appearance of black precipitate meant that some unreacted dithiocarbamate was present and the reaction was continued until its disappearance.

After cooling, the reaction mixture was practically 20% TMTD suspension and after filtration on a continuous filtering apparatus, Oliver's filter (10), the filtration cake was washed twice with 480 kg of water. Filtration cake was dried in a vacuum oven with fountain fluidized packing layers (13) at 60-70 °C at 660 Pa, reducing water content to less than 0.5%. Dried TMTD was transferred to a grinding mill (14) giving 1120 kg of product (yield 99.0%) (Table 7). Purity, 99.3%, was determined applying analytical method for determination of dithio compounds residue by sulfuric acid destruction and by absorption of carbon disulfide in potassium hydroxide-alcohol solution [24]. Physico-chemical characteristics of synthesized TMTD: melting point 151.0 °C, ash residue at 550 °C was 0.0211%, ash not soluble material in conc. HCl, 0.0102%, weight loss at 65 °C: 0.0300 %, Cu content: 8.41 ppm, Mn content: 10.03 ppm, and no residue on a 150 µm sieve, after grinding, was obtained. Structure of TMTD was confirmed by FTIR, ¹H- and ¹³C-NMR, and MS spectral data, and by result of elemental analysis.

Method B. Combined filtrate and washing water from first synthesis, containing isopropyl alcohol-water 70.4 %-29.6 %, were collected in collecting reservoirs (11 and 12) and used as a reaction medium for next synthesis. The second semi-industrial synthesis

of TMTD, performed according to method B, also gave satisfactory yield and purity, given in Table 7. Filtrate from the second synthesis (containing of isopropyl alcohol mixture-water 57.0%-43.0%) from collecting reservoir (11) was mixed with the collecting reservoir solution of alcohol-water (12), and transferred to a rectification column (15), and after concentration it was used again as a reaction medium.

CONCLUSIONS

According to the results presented in this study, the optimal laboratory procedure for tetraalkylthiuram disulfides synthesis using dialkyl amine and carbon disulfide in presence of different oxidants (hydrogen peroxide, potassium peroxodisulfate, sodium hypochlorite), and appropriate reaction medium (two mixtures of isopropyl alcohol-water generated through the recycling process) was presented. Based on the yields obtained in the reactions, the most effective oxidizing agent is hydrogen peroxide, less effective is potassium peroxodisulfate, and the lowest yields were achieved by using sodium hypochlorite.

Based on the reproducible results and high conversion of tetraalkylthiuram disulfides synthesis, the feasible semi-industrial implementation of such concept of developed laboratory synthesis is presented in this study. Considering the importance of the synthesized compounds as fungicides and rubber vulcanization accelerator implementation of the optimal synthesis methods at semi-industrial level provides a powerful and versatile method for the production of tetraalkylthiuram disulfides. This method has several unique merits, namely, simple operation, mild reaction conditions, avoids hazardous organic solvents, uses moderately toxic and inexpensive reagents, also has short reaction times, and high product yields. This new environmentally benign process represents a suitable option to existing methods, and significant contribution to protection of human environment.

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REFERENCES

- [1] R. Hermanus, J. Bloemenkamp, A. Johannes, US 6465691 (2002)
- [2] H.S. Rathore, G. Varshney, S.C. Mojumdar, M.T. Saleh, J. Therm. Anal. Calorim. **90** (2007) 681-686
- [3] S.C. Abrahams, Quart. Rev. **10** (1956) 424
- [4] M. Milosavljević, M.Sc.Thesis, Faculty of Technology and Metallurgy, Belgrade, 1991 (in Serbian)
- [5] A.R. Parkinson, US 3992448 (1976)
- [6] JP patent 54/61123 (1979)
- [7] R. Trunta, Chem. Abstr. **61** (1964) 9408
- [8] V.K. Tiwari, A. Singh, H.A. Hussain, B.B. Mishra, V. Tripathi, Monats. Chem. **138** (2007) 653-658
- [9] J.P. Lawrence, DE patent 2725165 A1 (1977)
- [10] J. Braun, F. Stechele, Ber. **35** (1903) 2275
- [11] CSSR patent kl.451, 9/20, (A 01 n) N₀134154, (1969)
- [12] M.L. Nadler, W.E. Meece, US 2751416 (1953)
- [13] J.P. Lawrence, US 4066697 (1978)
- [14] L. Eisenhuth, H. G. Zengel, M. Bergfeld, US 4459424 (1984)
- [15] R. Hermanus, J. Bloemenkamp, A. Johannes, US 6465691 (2002)
- [16] M. Bergfeld, L. Erienbach, H.G. Zengel, US 5015752 (1991)
- [17] L. Eisenbuth, H. G. Zengel, M. Bergfeld, US 4468526 (1984)
- [18] M. Bergfeld, L. Eisenhuth, H. G. Zengel, US 5021603 (1991)
- [19] G. Matthijs, P. Christiaens, A. Van Gysel, US 6420602 (2002)
- [20] A.V. Ivanov, E.V. Korneeva, A.V. Gerasimenko, W. Forsling, Russ. J. Coord. Chem. **31**(10) (2005) 695-707
- [21] A.D. Marinković, M. Milosavljević, D. Milenković, G. Ivanović, Chem. Ind. Chem. Eng. Q. **14**(4) (2008) 251-255
- [22] M.C. Silva, M.M. Conceicao, M.F. Trindade, G. Souza, C.D. Pinheiro, J.C. Machado, P.F.A. Filho, J. Therm. Anal. Calorim. **75** (2004) 583-590
- [23] H.S. Rathore, K. Ishratullah, C. Varshney, G. Varshney, S.C. Mojumdar, J. Therm. Anal. Calorim. **94** (2008) 75-81
- [24] D. Clarke, H. Baum, E. Stanley, W. Hester, Anal. Chem. **23** (2002) 1842-1846
- [25] M. Milosavljević, M. Sovrlić, A. D. Marinkovic, D. D. Milenković, Monats. Chem. **141** (2010) 749-755.
- [26] F. Liang, Synthesis **22** (2008) 3579-3584
- [27] K. Adeppa, Synth. Commun. **41** (2011) 285-290
- [28] B.L. Richards Jr., BE 648878 (1964).

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NAUČNI RAD

SINTEZA TETRAALKILTURAM-DISULFIDA PRIMENOM RAZLIČITIH OKSIDACIONIH SREDSTAVA U RECIKLOVANOJ SMEŠI RASTVARAČA

U ovom radu je prikazan nov optimizovani laboratorijski postupak sinteza tetraalkiltiuram-disulfida, polazeći od dialkilamina i ugljendisulfida u prisustvu oksidacionih sredstava (vodonič-peroksid, kalijum-peroksodisulfat i natrijum-hipohlorit), u odgovarajućem reakcionom medijumu: dve smeše izopropil alkohol-voda korišćene u dve uzastopne sinteze. Prva sinteza se izvodi u reciklovanoj azeotropnoj smeši izopropil-alkohola-voda sastava 87,7%-12,3%. Izvršena je optimizacija postupka u odnosu na molarni odnos reaktanata i koncentraciju proizvoda u suspenziji. Filtrat, dobijen nakon filtriranja suspenzije tetraalkiltiuram-disulfida iz prve sinteze, koji sadrži smešu izopropil alkohol-voda 70,4%-29,6%, uspešno je korišćen za naredne sinteze tetraalkiltiuram-disulfida. Nakon druge sinteze, filtracijom suspenzije, dobija se filtrat kao smeša izopropil-alkohol-voda 57,0%-43,0%, koji se regeneriše rektifikacijom pri čemu se dobija azeotropna smeša sastava izopropil alkohol-voda 87,7%-12,3%. Primenom navedenog postupka osvojena je tehnologija koja uključuje proces reciklovanja smeše reakcionog medijuma izopropil alkohol-voda za sintezu tetraalkiltiuram-disulfida. Takav koncept doprinosi izvanrednoj ekonomičnosti implementiranog optimalnog laboratorijskog postupka sinteze na poluindustrijski nivo. Visoki prinosi tetraalkiltiuram-disulfida su dobijeni sintezama na laboratorijskom nivou, kao i primenom na poluindustrijskom nivou proizvodnje. Struktura i čistoća sintetisanih jedinjenja: tetrametiltiuram-disulfid (TMTD), tetraetiltiuram-disulfid (TETD), tetrapropiltiuram-disulfid (TPTD), tetraizopropiltiuram-disulfid (TiPTD), tetrabutiltiuram-disulfid (TBTD), tetraizobutiltiuram-disulfid (TiBTd), su potvrđene FTIR, ¹H- i ¹³C-NMR spektroskopijom, MS spektrometrijom i elementarnom analizom.

Ključne reči: tetraalkiltiuram disulfid; optimizacija; reakciona sredina, oksidanti.