ISSN 0965-5441, Petroleum Chemistry, 2019, Vol. 59, No. 1, pp. 99–105. © Pleiades Publishing, Ltd., 2019.
Russian Text © I.A. Aliev, L.A. Belovezhets, L.A. Oparina, 2019, published in Neftekhimiya, 2019, Vol. 59, No. 1, pp. 91–97.

# Fungicidal Activity of *S*-Esters of Thiocarboxylic Acids as Antimicrobial Additives to Petroleum Products

**I. A. Aliev[a], L. A. Belovezhets[b, *], and L. A. Oparina[b]**

[a] *Baku State University, Baku, AZ 1148 Republic of Azerbaijan*

[b] *Favorsky Institute of Chemistry, Irkutsk, Siberian Branch, Russian Academy of Sciences, Irkutsk, 664033 Russia*

**e-mail: lyu-sya@yandex.ru*

Received January 11, 2018; Revised March 15, 2018; Accepted July 26, 2018

**Abstract**—A variety of aliphatic and aromatic *S*-esters of thiocarboxylic acids have been tested for antimicrobial activity. The relationship between the chemical structure of the compounds $R^1SC(O)R^2$ and their toxicity for microorganisms has been revealed, and the effect of various functional groups on the antimicrobial properties has been shown. The cooling lubricant IKhP-45E with *S*-aryl thioacetate additives has been tested. It has been shown that the additives used (0.25–0.5 wt %) inhibit the growth of all the studied microorganisms; however, their activity with respect to fungi is higher. The introduction of *S*-aryl thioacetates provides the resistance of these oils to microbiological deterioration to retain the physicochemical properties for a long period of time.

**Keywords:** *S*-alkyl and *S*-aryl thiocarboxylates, petroleum products, biocide additives, antimicrobial activity

**DOI:** 10.1134/S096554411901002X

Like other types of petroleum-derived fuels, aviation fuel is readily deteriorated by microorganisms during storage, transportation, and operation. As a result of biodeterioration, its physicochemical and operational properties substantially worsen, which can be a reason for the faulty operation of aircraft equipment [1]. The synthesis of aggressive metabolites, first of all, organic acids, leads to the intensification of the metal corrosion and depressurization of fuel tanks. The accumulation of fungi biomass leads to the failure of instruments and equipment because pipelines, nozzles, clack valves, pipe bends for fuel level sensing, as well as fuel system filters of airplanes become clogged in this case. In addition, all the microbiological processes which occur with aviation fuel intensify multifold in warm and humid climate (subtropical and tropical zones) [2, 3]. In such cases, crash situations can occur, which happened to TU-204 airplanes which operated under tropical conditions [4]. The main microorganisms which cause the biodeterioration of fuels are bacteria of *Pseudomonas, Micrococcus,* and *Mycobacterium* genera as well as fungi *C1adosporium*, *Aspergillus, Penicillium, A1ternaria*, etc. Here, *Pseudomonas aeruginosa* bacteria and *Cladosporium resinae* fungi ("kerosene fungus") are detected in petroleum products more often than other microorganisms [5]. Full extermination of microorganisms developing in aviation fuels by any physical or physicochemical methods is impossible, because of which the problem of protecting aviation fuels from biodeterioration would attract constant attention and would require massive expenditures [6]. The main method of protection from the microbiological deterioration of petroleum products is the use of special antimicrobial additives, biocides. The search for organic compounds, the introduction of which to petroleum products can protect them from the harmful effects of microorganisms, as well as the studies on the investigation of the mechanism of action of antimicrobial substances are currently relevant.

*S*-esters of thiocarboxylic acids $R^1SC(O)R^2$ play an important role in bioorganic synthesis [7]. Thiocarboxylate groups are present in the structure of compounds possessing a wide range of biological activity [8, 9]. It is recognized that the bactericidal action of garlic and ramson is due to the derivatives of structurally similar allyl sulfides and sulfoxides [10]. However, before the beginning of our works, there was no information about the bactericidal and fungicidal activity of the compounds of this class. In order to expand the range of biocide additives and find the relationship between their structure and antimicrobial properties, the influence of *S*-esters of thiocarboxylic acids with various structures on the sources of microbiological deterioration of petroleum products was studied.

## EXPERIMENTAL

$^1H$ and $^{13}C$ NMR spectra were obtained on a Jeol FX-90Q spectrometer in a $CDCl_3$ solution using

$Me_4Si$ as the internal standard. IR spectra were recorded on a JFS-25 spectrometer (thin film, KBr). The *S*-esters of thiocarboxylic acids were synthesized according to a known procedure [11, 12]. Phenylacetone, 4-fluorophenyl acetate, and 8-hydroxyquinoline were commercial products.

*Synthesis of S-Esters of Thiocarboxylic Acids*

A mixture of an aliphatic or aromatic thiol (0.1 mol) and a carboxylic acid chloride (0.2 mol) was heated for 4 h at 60°C; after cooling, it was diluted with 60 mL of benzene, washed with a saturated solution of $NaHCO_3$ (4 × 30 mL), and dried over $MgSO_4$. The desired products were isolated by the fractionation of the residue under atmospheric pressure (compounds **1** and **2**) or in a vacuum (compounds **3**–**19**).

***S*-*n*-propyl thioacetate (1):** yield 9.7 g (82%), bp 136°C, $n_D^{20}$ 1.4556, $d_4^{20}$ 0.9793. IR spectrum (thin film, ν, $cm^{-1}$): 1695 (C=O). $^1H$ NMR spectrum ($CDCl_3$, δ, ppm): 0.92 (t, $^3J$ 6.9 Hz, 3H, Me), 1.52 (m, 2H, $CH_2$), 2.30 (s, 3H, Me), 2.87 (t, $^3J$ 6.9 Hz, $CH_2S$). $^{13}C$ NMR spectrum ($CDCl_3$, δ, ppm): 13.3 (Me), 22.7 ($CH_2$), 30.5 (Me), 30.6 ($CH_2S$), 194.0 (C=O).

***S*-isopropyl thioacetate (2):** yield 9.5 g (81%), bp 127°C, $n_D^{20}$ 1.4548, $d_4^{20}$ 0.9755. IR spectrum (thin film, ν, $cm^{-1}$): 1696 (C=O). $^1H$ NMR spectrum ($CDCl_3$, δ, ppm): 1.09 (d, $^3J$ 7.0 Hz, 6H, Me), 2.33 (s, 3H, Me), 2.93 (q, $^3J$ 7.0 Hz, CHS). $^{13}C$ NMR spectrum ($CDCl_3$, δ, ppm): 22.7 (Me), 30.6 (Me), 34.4 (CHS), 195.0 (C=O).

***S*-benzyl thioacetate (3):** yield 15.4 g (93%), bp 84°C (2 mmHg), $n_D^{20}$ 1.5409, $d_4^{20}$ 1.1843. IR spectrum (thin film, ν, $cm^{-1}$): 1696 (C=O). $^{13}C$ NMR spectrum ($CDCl_3$, δ, ppm): 30.2 (Me), 33.3 ($CH_2$), 127.8 ($C^4$), 129.2 ($C^{2,6}$), 129.5 ($C^{3,5}$), 138.9 ($C^1$), 198.1 (C=O).

***S*-phenyl thioacetate (4):** yield 12.0 g (79%), bp 85°C (3.5 mmHg), $n_D^{20}$ 1.5706, $d_4^{20}$ 1.1218. IR spectrum (thin film, ν, $cm^{-1}$): 1717 (C=O). $^1H$ NMR spectrum ($CDCl_3$, δ, ppm): 2.30 (s, 3H, Me), 7.40 (s, 5H, Ph). $^{13}C$ NMR spectrum ($CDCl_3$, δ, ppm): 29.7 (Me), 128.2 ($C^4$), 129.0 ($C^1$), 128.9 ($C^{3,5}$), 134.2 ($C^{2,6}$), 192.0 (C=O).

***S*-(2-methylphenyl) thioacetate (5):** yield 14.0 g (84%), bp 90–92°C (3 mmHg), $n_D^{20}$ 1.5610, $d_4^{20}$ 1.0518. IR spectrum (thin film, ν, $cm^{-1}$): 1716 (C=O). $^1H$ NMR spectrum ($CDCl_3$, δ, ppm): 2.34 (s, 3H, Me), 2.43 (s, 3H, Me), 7.21 (m, 1H, Ar), 7.30 (m, 2H, Ar), 7.39 (d, $^3J$ 7.4 Hz, 1H, Ar). $^{13}C$ NMR spectrum ($CDCl_3$, δ, ppm): 20.6 (Me), 30.1 (Me), 126.5, 127.4, 130.0, 130.7, 135.8 ($C^{1,3-6}$), 141.9 ($C^2$), 193.6 (C=O).

***S*-(3-methylphenyl) thioacetate (6):** yield 14.9 g (90%), bp 96°C (3 mmHg), $n_D^{20}$ 1.5572, $d_4^{20}$ 1.0886. IR spectrum (thin film, ν, $cm^{-1}$): 1715 (C=O). $^1H$ NMR spectrum ($CDCl_3$, δ, ppm): 2.35 (s, 3H, Me), 2.42 (s, 3H, Me), 7.11 (m, 1H, $H^5$), 7.26 (m, 2H, $H^{4,6}$), 7.35 (m, 1H, $H^2$).

***S*-(4-methylphenyl) thioacetate (7):** yield 15.0 g (90%), bp 76°C (0.5 mmHg), $n_D^{20}$ 1.5635, $d_4^{20}$ 1.0871. IR spectrum (thin film, ν, $cm^{-1}$): 1712 (C=O). $^1H$ NMR spectrum ($CDCl_3$, δ, ppm): 2.37 (s, 3H, Me), 2.41 (s, 3H, Me), 7.25 (m, 4H, Ar).

***S*-(3-methoxyphenyl) thioacetate (8):** yield 12.0 g (66%), bp 105°C (1 mmHg), $n_D^{20}$ 1.5606, $d_4^{20}$ 1.1596. IR spectrum (thin film, ν, $cm^{-1}$): 1718 (C=O). $^1H$ NMR spectrum ($CDCl_3$, δ, ppm): 2.40 (s, 3H, Me), 3.63 (s, 3H, MeO), 6.71 (m, 1H, $H^2$), 7.11 (m, 1H, $H^{4,6}$), 7.28 (d, $^3J$ 8.4 Hz, 1H, $H^5$).

***S*-(4-methoxyphenyl) thioacetate (9):** yield 14.1 g (77%), bp 98°C (0.5 mmHg), $n_D^{20}$ 1.5721, $d_4^{20}$ 1.1586. IR spectrum (thin film, ν, $cm^{-1}$): 1713 (C=O). $^1H$ NMR spectrum ($CDCl_3$, δ, ppm): 2.38 (s, 3H, Me), 3.81 (s, 3H, MeO), 6.93 (d, $^3J$ 8.8 Hz, 2H, $H^{3,5}$), 7.31 (d, $^3J$ 8.8 Hz, 2H, $H^{2,6}$).

***S*-(4-fluorophenyl) thioacetate (10):** yield 15.3 g (90%), bp 84–85°C (4 mmHg), $n_D^{20}$ 1.5452, $d_4^{20}$ 1.2100. IR spectrum (thin film, ν, $cm^{-1}$): 1721 (C=O). $^1H$ NMR spectrum ($CDCl_3$, δ, ppm): 2.28 (s, 3H, Me), 6.67 (m, 2H, $H^{3,5}$), 7.20 (m, 2H, $H^{2,6}$). $^{13}C$ NMR spectrum ($CDCl_3$, δ, ppm): 29.8 (Me), 116.7 (d, $^3J_{CF}$ 8.6 Hz, $C^{3,5}$), 124.5 (d, $^4J_{CF}$ 3.5 Hz, $C^1$), 137.1 (d, $^2J_{CF}$ 22.2 Hz, $C^{2,6}$), 163.2 (d, $^1J_{CF}$ 249.2 Hz, $C^4$), 193.2 (C=O).

***S*-(4-chlorophenyl) thioacetate (11):** yield 16.8 g (90%), bp 108°C (3 mmHg), mp 36°C. IR spectrum (KBr, ν, $cm^{-1}$): 1721 (C=O). $^1H$ NMR spectrum ($CDCl_3$, δ, ppm): 2.42 (s, 3H, Me), 7.28–7.33 (m, 4H, Ar).

***S*-(4-bromophenyl) thioacetate (12):** yield 20.3 g (88%), bp 96°C (1 mmHg), mp 53°C. IR spectrum (KBr, ν, $cm^{-1}$): 1722 (C=O). $^1H$ NMR spectrum ($CDCl_3$, δ, ppm): 2.42 (s, 3H, Me), 7.27 (d, $^3J$ 8.5 Hz, 2H, $H^{2,6}$), 7.54 (d, $^3J$ 8.5 Hz, 2H, $H^{3,5}$).

***S*-(4-iodophenyl) thioacetate (13):** yield 23.3 g (78%), mp 56°C. IR spectrum (KBr, ν, $cm^{-1}$): 1722 (C=O). $^1H$ NMR spectrum ($CDCl_3$, δ, ppm): 2.42 (s, 3H, Me), 7.13 (d, $^3J$ 6.7 Hz, 2H, $H^{3,5}$), 7.74 (d, $^3J$ 8.5 Hz, 2H, $H^{2,6}$).

***S*-phenyl thiotrichloroacetate (14):** yield 24.0 g (94%), bp 118°C (2 mmHg), mp 55°C. IR spectrum (KBr, ν, $cm^{-1}$): 1717 (C=O). $^1H$ NMR spectrum ($CDCl_3$, δ, ppm): 7.40 (s, 5H, Ph). $^{13}C$ NMR spec-

trum ($CDCl_3$, δ, ppm): 94.7 (C), 125.5 ($C^4$), 129.0 ($C^{3,5}$), 129.8 ($C^1$), 134.0 ($C^{2,6}$), 185.9 (C=O).

***S*-(4-fluorophenyl) thiochloroacetate (15):** yield 18.8 g (92%), bp 108°C (2 mmHg), $n_D^{20}$ 1.5660, $d_4^{20}$ 1.3626. IR spectrum (thin film, ν, $cm^{-1}$): 1721 (C=O). $^1H$ NMR spectrum ($CDCl_3$, δ, ppm): 4.17 (s, 2H, $CH_2Cl$), 7.02 (m, 2H, $H^{3,5}$), 7.30 (m, 2H, $H^{2,6}$). $^{13}C$ NMR spectrum ($CDCl_3$, δ, ppm): 48.5 ($CH_2Cl$), 117.2 (d, $^3J_{CF}$ 8.0 Hz, $C^{3,5}$), 123.0 (d, $^4J_{CF}$ 2.2 Hz, $C^1$), 137.7 (d, $^2J_{CF}$ 22.0 Hz, $C^{2,6}$), 164.3 (d, $^1J_{CF}$ 248.2 Hz, $C^4$), 192.3 (C=O).

***S*-phenyl thiobutyrate (16):** yield 14.6 g (81%), bp 120–121°C (9 mmHg). IR spectrum (thin film, ν, $cm^{-1}$): 1709 (C=O). $^1H$ NMR spectrum ($CDCl_3$, δ, ppm): 0.99 (t, $^3J$ 7.2 Hz, 3H, Me), 1.76 (m, 2H, $CH_2$), 2.64 (t, $^3J$ 7.2 Hz, 2H, $CH_2S$), 7.41 (s, 5H, Ph).

***S*-phenyl thioisobutyrate (17):** yield 15.7 g (88%), bp 92°C (2 mmHg), $n_D^{20}$ 1.5300, $d_4^{20}$ 1.1246. IR spectrum (thin film, ν, $cm^{-1}$): 1721 (C=O). $^1H$ NMR spectrum ($CDCl_3$, δ, ppm): 1.26 (d, $^3J$ 6.9 Hz, 6H, Me), 2.83 (t, $^3J$ 6.9 Hz, H, CH), 7.40 (s, 5H, Ph).

***S*-(4-fluorophenyl) thiopivalate (18):** yield 15.4 g (68%), bp 89°C (1 mmHg), $n_D^{20}$ 1.5176, $d_4^{20}$ 1.0851. IR spectrum (thin film, ν, $cm^{-1}$): 1154 (C–F), 1709 (C=O). $^1H$ NMR spectrum ($CDCl_3$, δ, ppm): 1.25 (s, 9H, Me), 6.60 (m, 2H, $H^{3,5}$), 7.13 (m, 2H, $H^{2,6}$). $^{13}C$ NMR spectrum ($CDCl_3$, δ, ppm): 27.5 (Me), 47.3 (C), 116.7 (d, $^3J_{CF}$ 8.6 Hz, $C^{3,5}$), 124.5 (d, $^4J_{CF}$ 2.5 Hz, $C^1$), 137.7 (d, $^2J_{CF}$ 21.2 Hz, $C^{2,6}$), 163.9 (d, $^1J_{CF}$ 244.2 Hz, $C^4$), 203.4 (C=O).

***S*-(4-fluorophenyl) thiobenzoate (19):** yield 19.7 g (85%), bp 162°C (3 mmHg), mp 50–51°C. IR spectrum (KBr, ν, $cm^{-1}$): 1153 (C–F), 1721 (C=O). $^1H$ NMR spectrum ($CDCl_3$, δ, ppm): 7.02 (m, 2H, $H^{3,5}$, Ar), 7.35 (s, 5H, Ph), 7.37 (m, 2H, $H^{2,6}$). $^{13}C$ NMR spectrum ($CDCl_3$, δ, ppm): 116.3 (d, $^3J_{CF}$ 8.6 Hz, $C^{3,5}$, Ar), 123.2 (d, $^4J_{CF}$ 3.5 Hz, $C^1$, Ar), 127.5 ($C^{3,5}$, Ph), 128.6 ($C^{2,6}$, Ph), 133.5 ($C^4$, Ph), 136.8 ($C^1$, Ph), 137.2 (d, $^2J_{CF}$ 22.0 Hz, $C^{2,6}$, Ar), 163.2 (d, $^1J_{CF}$ 249.0 Hz, $C^4$, Ar), 189.9 (C=O).

The synthesized organic compounds were introduced into the samples of fuel blends at a concentration of 0.01–1.0 wt %.

*Strains of Microorganisms and Cultivation Conditions*

A mixture of *Pseudomonas aeruginosa* BKM B-588 and *Mycobacterium lacticolium* BKM B-355 pure bacterial cultures was used for the tests because they are the most powerful destroyers of petroleum products. Pure cultures of the following fungal species were used in the test for fungicidal activity: *Aspergillus niger* BKM F-1119, *Hormoconis resinae* BKM F-1701, *Penicillium chrysegenum* Thom BKM F-245, *Chaciomium globosum* BKM D-109, and *Trichoderma viride* BKM F-1127. In addition, yeasts *Candida tropicalis* Y-2771 were used as well. Meat peptone agar (MPA) was used as the culture medium for the cultivation of bacterial cultures, while wort agar (WA) was used for fungi and yeasts.

*Investigation of Antimicrobial Properties*

The antimicrobial properties of the synthesized compounds were investigated by the agar well diffusion method using suspensions of various cultures of microorganisms according to GOST 9.052-88 "Unified System of Corrosion and Ageing Protection: Oils and Greases: Laboratory Test Methods for Mould Resistance", GOST 9.082-77 "Unified System of Corrosion and Ageing Protection: Oils and Lubricants: Methods of Laboratory Tests for Resistance to Bacteria Action", GOST 9.023-74 "Unified System of Corrosion and Ageing Protection: Oil Fuels: Method of Laboratory Testing Biostability of Fuels Protected by Antimicrobial Additives", and GOST 9.085-78 "Unified System of Corrosion and Ageing Protection: Cooling Lubricants: Bioresistance Test Methods."

The prepared inoculating suspensions of two individual bacterial cultures were mixed together in equal volumes and used for infecting the samples. The shelf life of the bacterial suspensions for inoculation should be no more than four to six hours from the moment of their preparation. A mixture of fungi was prepared in a similar manner. When conducting the study, a culture medium was poured into a Petri dish in the amount of 20–30 mL and allowed to solidify. To identify the zone of growth inhibition of microorganisms and for the arrangement of the samples of oils without a biocide and with organic compounds, four to six wells were prepared, which were "opened" on the surface of the solidified culture medium by a sterile drill with a diameter of 10 mm to the depth of 4–6 mm.

The samples which were unaffected by microorganisms are considered as almost not susceptible to microbiological deterioration. The growth of the test cultures and suppression zones were assessed in millimeters. The efficiency of the antimicrobial action of the additives being used was assessed by the value of the diameter of the zone of growth suppression of bacteria and fungi around the well with an additive.

The tests were performed on jet fuels of the T-1 and TS-1 brands, a cooling lubricant (CL) of the IKhP-45E brand, and a diesel oil of the D-11 brand (in a pure state and in a blend with additives 10% IKhP-101 + 2% SB-3 + 0.5% AzNII depressant + 0.003% PMS-200A) under the conditions mimicking tropical conditions (at 28–32°C and a relative air humidity of 90–100%) with an exposure of 30 days per experimental run; the growth of the test cultures was recorded every

ten days. The experiments were conducted in triplicates. The biocidal properties of the thioesters in aviation gasoline were compared with those of the known antimicrobial additive 8-hydroxyquinoline, which is generally used in fuel and lubricating oil formulations. Hexachlorophene was used as the reference material in the IKhP-45E cooling lubricant.

## RESULTS AND DISCUSSION

To perform the tests, *S*-esters of thiocarboxylic acids **1**–**19** with substituents of different natures in the thiol and carboxylate moieties have been synthesized. The reactions were carried out in the absence of catalysts and condensing agents according to a procedure described in [11, 12].

$$R^1SH + R^2-C(=O)Cl \xrightarrow[-HCl]{60^\circ C,\ 4\ h} R^1SC(O)R^2 \quad 65\text{–}93\%$$

The structure of synthesized compounds **1**–**19** has been confirmed by spectral data which are in agreement with the published data [11, 12]. There are intense bands at 1580, 1480, and 3040–3100 $cm^{-1}$ in the IR spectra of *S*-organyl thiocarboxylates which are due to stretching vibrations of the C=C and =C–H bonds in the benzene ring. The band at 820 $cm^{-1}$ characterize out-of-plane vibrations of CH in the 1,4-substituted benzene ring. The stable wavenumber band at 1153 $cm^{-1}$ in the spectra of 4-fluorophenyl thiocarboxylates is due to C–F stretching. The stretching vibrations of the C=O bond manifest themselves as an asymmetric band with a maximum at 1696 $cm^{-1}$ (in the case of alkyl thioacetates **1**–**3**) and 1709–1722 $cm^{-1}$ (in the case of aryl thiocarboxylates **4**–**19**).

The performed tests give evidence for the fact that all the studied *S*-esters of thiocarboxylic acids inhibit the growth of fungi and bacteria in the T-1 and TS-1 fuels (Table 1).

In antimicrobial activity, *S*-alkyl thioacetates (**1**–**3**) are noticeably inferior to *S*-aryl thioacetates (**4**–**13**). The latter exhibit pronounced bactericidal and fungicidal properties. Here, it has been found that the antimicrobial activity of the studied compounds is due to the presence of the ArSC(O) group because their carbon-containing $PhCH_2C(O)Me$ (**20**) and oxygen-containing $4\text{-}FC_6H_4OC(O)Me$ (**21**) analogues have low activity against the microorganisms under study. A significant decrease in antimicrobial activity has also been noted in the case of the replacement of the aryl radical $MeC_6H_4$ (in compounds **6** and **7**) by the arylalkyl radical $C_6H_5CH_2$ (in compound **3**), with of the total number of carbon atoms being the same. The antimicrobial properties of thioesters ArSC(O)R substantially depend on the nature of the thiocarboxylic acid. Introducing electron-withdrawing substituents into the carbonyl group (compounds **14** and **15**) leads to a 1.5–2.0-fold increase in the fungicidal activity; the antimicrobial activity of these compounds against *Cladosporium resinae* is higher than that of 8-hydroxyquinoline. Electron-donating substituents have the opposite effect. In passing from thioacetic to thiopivalic acid (R = *t*-Bu), the degree of bactericidal and fungicidal action sharply decreases (compare compounds **10** and **18**). It follows from the comparison of the antimicrobial activity of the thioesters of butyric and isobutyric acids (compounds **16** and **17**) that compounds containing unbranched radicals exhibit stronger fungicidal activity than their structural isomers.

The bactericidal and fungicidal activities of *S*-aryl thiobenzoates are very weak, being approximately the same as those of phenylacetone (compare **19** and **20**).

It has been found during the study that the general toxicity and selectivity of the action of aryl thioesters ArSC(O)Me depends on the character and position of the substituent in the arylthio group. Thus, the F, Cl, Me, and MeO substituents on the benzene ring increase the fungicidal activity of *S*-aryl thioacetates. Isomeric *S*-fluorophenyl and *S*-methylphenyl thioacetates are arranged in the following order of antimicrobial activity: *para*- > *meta*- > *ortho*-. *para*-Methyl-, methoxy-, and chloro-substituted aryl thioesters are comparable with the reference 8-hydroxyquinoline (antimicrobial agent Oxine), in fungicidal activity (Table 1).

Table 2 presents the results of testing the most active *S*-aryl thioacetates for antimicrobial activity in the IKhP-45E cooling lubricant. It was preliminarily found that introducing *S*-esters of thiocarboxylic acids into IKhP-45E does not alter its physicochemical properties and performance characteristics. It has been shown that all the studied compounds inhibit both bacterial and fungal cultures. Compound **9** turned out to be the most active; its microbial growth inhibition zone is substantially larger than that of the reference material.

Also, experiments (in a preliminary version) on the investigation of the antimicrobial activity of four esters of thioacetic **3**, **6**, and **7** and thiotrichloroacetic **14** acids in a D-11 diesel oil were conducted (Table 3).

Compounds **3**, **6**, **7**, and **14** at a concentration of 1 wt % exhibit high fungicidal activity.

A similar result was obtained when introducing additives to the diesel oil formulation with antioxidant, sulfonate, and silicon additives with the following composition: D-11 oil + 10% IKhP-101 + 2% SB-3 + 0.5% AzNII depressant + 0.003% PMS-200A.

Introducing thioesters to the formulation render it resistant to microbiological deterioration with preserving their physicochemical properties for a long period of time (Table 3).

There are no published data on the mechanism of antimicrobial action of aryl esters of thioacetic acid or compounds that are structurally similar to them.

**Table 1.** Antimicrobial activity of *S*-aryl esters of thiocarboxylic acids[1]

| Compound no. | Structural formula | Diameter of growth inhibition zone for test cultures, mm | |
|---|---|---|---|
| | | bacterial mixture (MPA) | fungal mixture (WA) |
| **1** | *n*-PrSC(O)Me | 12 | 13 |
| **2** | *i*-PrSC(O)Me | 11 | 11 |
| **3** | $PhCH_2SC(O)Me$ | 13 | 15 |
| **4** | PhSC(O)Me | 16 | 25 |
| **5** | $2\text{-}MeC_6H_4SC(O)Me$ | 16 | 24 |
| **6** | $3\text{-}MeC_6H_4SC(O)Me$ | 19 | 28 |
| **7** | $4\text{-}MeC_6H_4SC(O)Me$ | 21 | 35 |
| **8** | $3\text{-}MeOC_6H_4SC(O)Me$ | 18 | 25 |
| **9** | $4\text{-}MeOC_6H_4SC(O)Me$ | 20 | 32 |
| **10** | $4\text{-}FC_6H_4SC(O)Me$ | 20 | 27 |
| **11** | $4\text{-}ClC_6H_4SC(O)Me$ | 26 | 31 |
| **12** | $4\text{-}BrC_6H_4SC(O)Me$ | 11 | 17 |
| **13** | $4\text{-}IC_6H_4SC(O)Me$ | 15 | 19 |
| **14** | $PhSC(O)CCl_3$ | 26 | 35 |
| **15** | $4\text{-}FC_6H_4SC(O)CH_2Cl$ | 19 | 40 |
| **16** | PhSC(O)Pr-*n* | 11 | 20 |
| **17** | PhSC(O)Pr-*i* | 8 | 6 |
| **18** | $4\text{-}FC_6H_4SC(O)Bu\text{-}t$ | 7 | 4 |
| **19** | $4\text{-}FC_6H_4SC(O)Ph$ | 6 | 5 |
| **20** | $PhCH_2C(O)Me$ | 8 | 6 |
| **21** | $4\text{-}FC_6H_4OC(O)Me$ | 14 | 13 |
| | 8-Hydroxyquinoline (reference) | 29 | 24 |
| | TS-1 fuel (without additives) | +[2] | + |

[1] The additive concentration in T-1 is 0.25 wt %. [2] + means the absence of inhibition zone.

**Table 2.** Antimicrobial activity of *S*-aryl thioacetates in the IKhP-45E cooling lubricant[1]

| Biocide | | Diameter of growth inhibition zone for microorganisms, mm | |
|---|---|---|---|
| compound no. | structure | bacteria | fungi |
| **4** | PhSC(O)Me | 32 | 26 |
| **7** | $4\text{-}MeC_6H_4SC(O)Me$ | 40 | 24 |
| **9** | $4\text{-}MeOC_6H_4SC(O)Me$ | 46 | 50 |
| **10** | $4\text{-}FC_6H_4SC(O)Me$ | 24 | 48 |
| **11** | $4\text{-}ClC_6H_4SC(O)Me$ | 40 | 28 |
| Hexachlorophene (reference) | | 30 | +[2] |
| IKhP-45E | | + | + |

[1] The additive concentration is 0.25 wt %. [2] + means the absence of inhibition zone.

**Table 3.** The antimicrobial action of *S*-aryl thioacetates in a diesel oil [1]

| Oil | *S*-aryl thioacetate | Diameter of the zone of growth suppression of microorganisms, mm | |
|---|---|---|---|
| | | bacteria | fungi |
| D-11 | $PhCH_2SC(O)Me$ (**3**) | +[2] | 44 |
| Formulation | | + | 44 |
| D-11 | 3-$MeC_6H_4SC(O)Me$ (**6**) | + | 46 |
| Formulation | | 30 | 40 |
| D-11 | 4-$MeC_6H_4SC(O)Me$ (**7**) | 36 | 50 |
| Formulation | | 24 | 46 |
| D-11 | $PhSC(O)CCl_3$ (**14**) | 12 | 42 |
| Formulation | | 12 | 42 |

[1] The concentration of the biocide additive is 1.0 wt %. [2] + means the absence of inhibition zone.

According to some authors [13], the antimicrobial properties of the aryl esters of alkanethiosulfonic acids $RSO_2R^1$ which are structurally similar to the thioesters $RC(O)R^1$ are explained by their ability to react with thiol compounds of the cysteine type, which are vital for many microorganisms, leading to the "blockage" of their sulfhydryl groups and causing violation of metabolic processes of a bacterial cell. As is known, some enzymes lose their activity (reversibly or irreversibly) when treated with substances reacting with the sulfhydryl group. Such enzymes include, e.g., papain, urease, succinic acid dehydrogenase, and some enzymes involved in the metabolism of proteins and lipids (transaminase, *d*-aminooxidase, etc.) as well as carbohydrates (carboxylase). It was shown that the activity of such enzymes is tightly related to the presence of free sulfhydryl groups in their molecules; it is the disabling of these groups that leads to the inactivation of an enzyme, while animal cells are partially protected by glutathione present in them [14]. Some researchers reduce the mechanism of antibiotic action of allicin and its synthetic analogues, as well as other antibiotics capable of interacting with the sulfhydryl groups of cysteine, to this particular type of inactivation of bacterial enzymes [15].

However, a different point of view is offered at the same time, namely, that antibiotics (in particular, allicin) can prevent the anabolism of proteins by reacting with the cysteine sulfhydryl groups at the ends of a growing polypeptide chain, thus creating "dead ends" [16]. Certainly, the wide range of antimicrobial activity of the thioesters ArSC(O)R cannot be explained by any single mechanism of their action. We showed that aryl thioacetates had unequal action on the microorganisms belonging to different taxonomic groups. The same concentrations of the compounds inhibited the growth of fungi stronger than the growth of bacteria. We assume that such selectivity of action depends on biochemical differences between bacteria and fungi.

## CONCLUSIONS

The antimicrobial activity of a series of *S*-esters of thiocarboxylic acids was studied. The analysis of the structure–activity relationship showed that *S*-aryl esters of thioacetic acid containing a Cl, MeO, or Me group in the *para*-position on the benzene ring possess the highest activity. These compounds are comparable with the reference 8-hydroxyquinoline in fungicidal activity and can be recommended as biocide additives to petroleum products.

The tests of the cooling lubricant IKhP-45E CL with the additives of thioesters were performed. It was shown that these additives inhibit the growth of all the studied microorganisms; however, their activity against fungi is higher.

Experiments on the investigation of compatibility of some of the additives with oils were also performed. The thioesters impart stability to these oils against microbiological deterioration with preserving their physicochemical properties for a long period of time.

## REFERENCES

1. E. N. Kablov, Aviat. Mater. Tekhnol., No. 5, 7 (2012).
2. E. N. Kablov, A. V. Polyakova, A. A. Vasil'eva, et al., Aviat.Prom-st', No. 1, 35 (2011).
3. A. V. Polyakova, A. A. Krivushina, Yu. S. Goryashnik, and T. V. Yakovenko, Tr. VIAM, No. **7**, 6 (2013).
4. A. V. Polyakova, A. A. Vasil'eva, M. A. Linnik, and Yu. S. Goryashnik, in *Proceedings of VIII Scientific Conference on Hydroaviation "Hydroaviasalon-2010"* (TsAGI, Moscow, 2010), part II, p. 215 [in Russian].
5. E. L. Matveeva, O. A. Vasil'chenko, and D. A. Demyanko, Sist. Ozbroen. Viis'rova Tekh. **26**, 152 (2011).
6. Z. A. Avakyan, Prikl. Biokhim. Mikrobiol. **2**, 526 (1975).
7. J. Staunton and K. J. Weissman, Nat. Prod. Rep. **18**, 380 (2001).
8. H. Wingert, H. Sauter, S. Brand, et al., US Patent No. 5112860 (1990).

9. V. V. Khanzhin, Candidate's Dissertation in Medicine (Khar'kov, 2005).
10. D. Yu. Zalepugin, N. A. Tilkunova, Yu. S. Yashin, et al., Russ. J. Phys. Chem. B **4**, 1103 (2010).
11. A. M. Kuliev, M. A. Shakhgel'diev, and I. A. Aliev, Uchen. Zap. Azerb. Gos. Univ., Ser. Khim. Nauk, No. **3–4**, 10 (1975).
12. Feshin V.P., Voronkov M.G., Aliev I.A., et al., Zh. Org. Khim. **12**, 1040 (1976).
13. D. O. Hitzman and R. E. Linnard, Control of microbial growths in the storage and utilization of petroleum fuels, in *Proceedings of the Seventh World Petroleum Congress* (Elsevier, Amsterdam, 1967), vol. VIII, part 2, p. 183.
14. J. S. Lazarevic, A. S. Dordevic, B. K. Zlatkovic, J. Sci. Food Agric. **91**, 322 (2011).
15. A. Rabinkov, T. Miron, L. Konstantinovski, et al., Biochim. Biophys. Acta **1379**, 233 (1998).
16. M. J. Olusanmi and J. E. Amadi, Ethnobotan. Leaflets, No. **4**, 16 (2010).

*Translated by E. Boltukhina*