Study of the state of atmospheric air in the vicinity of non-ferrous metallurgy facilities and the power line tower damage

L A Begunova, V G Soboleva, E G Filatova

Department of chemistry and food technology, Irkutsk National Research Technical University, 83, Lermontova st., Irkutsk 664074, Russia

E-mail: lbegunova@mail.ru

Abstract. In the studies of the state of land areas performed using the advanced methods, in images from space, the industrial region around the city of Norilsk can be seen as a blurred spot that occupies an area of more than 900 km². Among diverse pollutants forming the picture, sulfur and nitrogen compounds, nitrates, sulfates, phenols, industrial dust, and heavy metals have a particular impact. The release of sour gases results in acid rains, which are among the major pollutants forming the whole picture. These substances affect humans, all objects of the environment, and sources of anthropogenic activities including engineering installations of power plant enterprises. The direct impact on the state of metal towers decreases significantly their lifetimes and increases the risk of emergencies. In this paper, the research data on the state of power line towers of different types are provided and the effect of acid precipitation on structures is shown.

Introduction

According to the estimates of ecologists, the precipitation acidification is observed on an area of about 400,000 km², which is more than the area of Germany (Figure 1). The technological processes performed at sulfide ore processing enterprises include the enrichment with most part of waste rock and pyrrhotite disposed in tailings; smelting of resulting sulfide concentrates to produce mattes; the conversion of mattes to produce nis mattes for nickel concentrates and rough copper for copper concentrates; nis mattes and rough copper refining to produce pure metals (Ni, Cu, Co) and noble metal concentrates [1-4]. The use of smelting processes in the main metallurgical stages is the only possible method for comprehensive extraction of noble metals in the form of mattes. The use of smelting processes leads to the air basin pollution: the sulfur emission into the atmosphere is estimated at more than 1,500,000 t/year [5-7]. The works performed by the Gipronickel Institute determined that, with the current ore processing technology with the formation of large volumes of gases with low SO₂ concentrations at the main metallurgical stages, the maximum near-ground sulfur dioxide concentration in the city of Norilsk is exceeded more than 30 times if the meteorological conditions are unfavorable [8-10]. In case the use of this technology is continued, the negative environmental impact is expected to increase more and more in the future. Currently, the 1 TLV isoline [11] is already at the distance of 75 km from the industrial complex (Figure 2). Thus, under unfavorable conditions, the established atmospheric air quality limits for humans are exceeded within an area of about 18,000 km² around plants. The 0.9 TLV isoline is at the distance of 85 km, and the 0.8 TLV isoline is at the distance of 100 km. A dashed line denotes the 100-km zone. Regarding residential
areas of the Norilsk industrial region, almost all of which are located within a radius of 25 km, it can be seen that they are located inside the 4 TLV isoline ring.

Figure 1. Pollution map in a satellite image of the Norilsk city and suburbs [5].

Figure 2. Near-ground SO$_2$ concentration isolines for the Norilsk industrial region.
Based on the presented data, it is apparent that such significant violation of the threshold limit value for sulfurous anhydride in atmospheric air makes a significant impact not only on humans but also on all infrastructure facilities. To confirm this, the studies were performed showing the effect of sulfur compounds on the state of power line towers and their elements.

**Materials and methods**

Different nondestructive steel corrosion testing methods used currently include capillary, radiation, magnetic, gravimetric, ultrasound ones, etc. In this work, the corrosion damage was evaluated by metallographic method [12-16].

The inspection of the state of power line towers operated since 1971 near the nickel plant performed by the specialists of OJSC NTEK showed that elements of metal structures are subject to accelerated corrosion owing to the impact of sulfurous and sulfuric acids contained in industrial atmosphere. The following metal structure elements operated since 1969-1971 at the industrial site of the nickel plant were controlled and studied:

1. P-22 LEP-201 tower stretchings made of a TK single-twist steel rope.
2. Middle sections of a P-22 LEP-201 tower lattice.
3. Profiles of a VL-35kV barrel-type two-chain tower (54 Ts feeder).

According to the design, tower stretchings are made of the TK single-twist steel rope of a diameter of 15.5 mm with a point contact of wires. Ropes were manufactured from ZhS galvanized wire [17] designated for mid aggressive and highly aggressive operating conditions.

**Results and discussion**

The control showed that, after 30 years of operation, traces of galvanization are absent, the surface of ropes and separate wires in a rope is oxidized, the surface wires of a rope are torn (the wire thickness at break sites is 0.5 - 0.8 mm) (Figure 3, a, b). The rope diameter at the highest wear sites is 11.5 - 10.7 mm. The number of nondamaged wires in a twist is 19 - 25 while this number is 36 according to the design [18]. The corrosion rate of ropes is 0.12-0.15 mm/year.

![Figure 3. TK-ZhS-type ropes: a) after 30 years of operation in the atmosphere medium of the Norilsk industrial region; b) control site of a rope at delivery.](image)

As specimens of P-22 tower lattice, elements of the middle section were selected (randomly, in available areas), namely, corners of \( \angle 36 \times 4 \) mm were located horizontally at the level of 8550 mm and 15,500 mm from the foundation. Based on the results of the specimen geometrical dimension measurements performed in three cross-sections for each specimen and the estimated element cross-section area determination, it was established that the tower element cross-section weakening after 30 years of operation was 32.3-39.4%, which is almost 2 times higher than the permitted limits [19].
corrosion rate is 3.6 mm$^2$/year for a profile of $\angle 36 \times 4$ mm at the level of 15,500 mm from the foundation and 2.9 mm$^2$/year at the level of up to 8550 mm. The estimated lifetime of elements determined based on the permissible cross-section weakening for a corner of $\angle 36 \times 4$ mm ($\mathcal{V}=54.4$ mm$^2 - 20\%S_n$) considering the actual corrosion rate is 15 years, i.e., after 1986 (15 years of operation), metal structure elements did not already meet the estimated strength conditions.

Specimens of VL-35kV barrel-type two-chain tower profiles were profiles of the bottom section at the level of ~2000 mm ($\angle 200 \times 16$ mm, $\angle 160 \times 14$ mm, $\angle 50 \times 5$ mm), a lower cross-arm ($\angle 63 \times 6$ mm and $\angle 50 \times 5$ mm) and lightning stand lattice (a corner of $\angle 50 \times 5$ mm cm).

The control established the following:

1) The state of elements of $\angle 160 \times 14$ mm, $\angle 50 \times 5$ mm of the bottom tower sections is unsatisfactory: wall thinning due to the corrosion wear is 25.7% for $\angle 160 \times 14$ mm and 86% for $\angle 50 \times 5$ mm; elements are deformed under the action of weight and bending loads (Figure 4). The estimated lifetime considering the actual corrosion rate for $\angle 50 \times 5$ mm is 8 years.

2) The state of lattice of a lower cross-arm is unsatisfactory: wall thinning due to the corrosion wear reaches 83-92% for profiles of $\angle 63 \times 6$ mm and $\angle 50 \times 5$ mm; due to the loss of structural strength, breaks of base metal occur in lattice at welding joints of profiles (Figure 5).

3) Elements of lightning stand are 100% worn throughout the depth and 76% worn along the shelf width of the profile of $\angle 50 \times 5$ mm (Figure 6). The estimated lifetime is 6.3 years.

![Figure 4. Wear and deformation of the bottom tower sections.](image)

![Figure 5. Damage of the lower cross-arm of a tower.](image)
Conclusions
1. In the vicinity of the Norilsk industrial region, in particular, at the industrial site of the nickel plant, elements of metal power line towers (tower stretchings, lattice, lightning stands) are subject to accelerated corrosion caused by the impact of sulfurous and sulfuric acids contained in industrial atmosphere.

2. Cross-section weakening for estimated metal tower elements exceeds the permitted corrosion wear percentage (20% of the element cross-section area, (L.2)) on average after 15 years of operation:
   - cross-section weakening for TK-ZhS ropes of P-22 towers (made of galvanized wire and designated for mid aggressive and highly aggressive operation conditions) after 30 years of operation in an atmosphere medium of the Norilsk industrial region is 26±31%;
   - cross-section weakening for middle section elements of a P-22 tower made of 09G2S steel after 30 years of operation is 32.3-39.4%, which is almost 2 times higher than the limits, and the estimated lifetime considering the current corrosion rate is 15 years;
   - cross-section weakening for a profile of \(50 \times 5\) mm in a VL-35kV barrel-type two-chain tower after 29 years of operation varies from 75.2% (in the bottom tower sections at the distance of up to 2 m from the foundation) to 100% (in lightning stand elements), and the estimated lifetime is 6.3-8 years.

3. The corrosion wear rate of metal structure elements increases as the distance from the ground surface increases.

4. According to the reconstruction design developed by Norilskproect back in 1977, all metal structures of OKU-1 sub power line towers should be protected by covering with two layers of chemically resistant KhSE enamel in a mixture (1:1) with chemically resistant KhSL [20] varnish and pre-priming with two layers of chemically resistant GF–020 primer.

   For the protection of tower stretchings, it was proposed to use steel ropes made of OZh galvanized wire designated for particularly aggressive operation conditions [21].

References
[1] Karmanovskaya N V 2020 Industrial and environmental control in Norilsk J. Geoecology 2 94–99
[2] Pyzheva Y I and Zander E V 2019 Regional Economy. Economic aspects of ecological problems solving for Russian cities J. Regional Economy 5 111–120
[3] Karmanovskaya N V et al 2018 The study of water flows of technological water cycle and wastewater of metallurgical production, concerning pollution content J. Periodico Tche Quimica 30(15) 550–555
[4] Leontiev L I and Tarasov A V 2017 Environmental problems of “Norilsk Nickel” and possible solutions. J. Ecology and industry of Russia 21(2) 15–19
[5] Information portal 2007-2019 Greenomak Electronic resource (Norilsk).
http://www.travellers.ru/city-norilsk-7. (Date of access: 04.04.2019)

[6] Kapsargin F P et al 2012 Assessment ecosystem based on remote sensing of the Atmosphere Science journal of the Siberian state aerospace University named after academician M.F. Reshetnev pp 73–76

[7] National Aeronautics and Space Administration: NASA website for global monitoring of sulfur dioxide. http://SO2.umbc.edu/omi/.

[8] Bulletin of the Environmental Information Center of the Krasnoyarsk Aluminum Plant. Issue 14 July 2008

[9] Kasikov A G 2017 Particulate emissions from Copper-Nickel production and the Consequences of their impact on human body in the far North J. Herald of the Kola Science Centre of the RAS 4(9) 58–63

[10] Kurkatov S V et al 2015 Assessment of the risk of atmospheric pollution impacts on the health of the population of Norilsk city J. Hygiene and sanitation 2 28–31

[11] Resolution of the Chief State Sanitary Doctor of the Russian Federation About the approval of hygienic standards GN 2.1.6.3492-17 Maximum permissible concentrations (MPC) of pollutants in the atmospheric air of urban and rural settlements dated December 22. N 165 Registered at the Ministry of Justice of the Russian Federation on January 9 2018 registration N 49557

[12] State standard 9.908-85 Unified system of protection against corrosion and aging (ESZKS). Metals and alloys. Methods for determination of corrosion and corrosion resistance indicators dated 01.01.1987 Developed and introduced by the USSR State Committee for Product Quality and Standards Management

[13] Bisong M S et al 2017 Damage modeling of weld structures in extreme conditions J. Science and education 3 67–71

[14] Kornev V M 2018 Embrittlement of steel structures at low temperatures and catastrophic failure J. Physical mesomechanics 21(2) 45–55

[15] Lepov V et al 2016 Some aspects of structural modeling of damage accumulation and fracture processes in metal structures at low temperature J. Modelling and Simulation in Engineering 7178028

[16] Tokareva E A et al 2011 Survee of technical condition of overhead transmission lines, operated in the Kola region J. Herald of the Kola Science Centre of the RAS pp 89–99

[17] State standard 3064-55 Steel ropes. Spiral rope type TK 1x37 = 37 wires. Strand 1 + 6 + 12 + 18 (Moscow: Publishing house of standards. Date of introduction 01.07.1956 the Council of Ministers of the USSR)

[18] State Standard 3241-91 Steel ropes. Technical conditions Moscow, IPK publishing house of standards. Date of introduction 01.01.93 // TC 146 “METIZES” was developed and introduced. It is approved and entered into force by the Resolution of the Committee for Standardization and Metrology of the USSR dated November 21, 91 N 1775

[19] Center for Scientific and Technical Information: 2002-2019. http://docs.cntd.ru/document/1200044192 Date accessed: 04/04/2019

[20] Guiding document 34.20.504-94 Typical instruction manual for overhead power lines with a voltage of 35-800 kV Approved by the Department of Electric Networks of RAO UES of Russia on September 19, 1994 (Moscow: SC ENAS)

[21] State standard 3064-80 Single lay rope, type TK, construction 1x37 (1 + 6 + 12 + 18). Assortment Moscow: IPK Publishing House of Standards. Date of introduction 01.01.1982. Decree of the USSR State Committee for Standards dated April 23, 1980. N 1833, the date of introduction is set from 01.01.82. The limitation of validity has been lifted by decision of the Interstate Council for Standardization, Metrology and Certification (IMS 2-92)