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Study of dust emissions at the waste storage facility of copper-molybdenum ore enrichment

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ABSTRACT

This study aimed of the effect of the moisture content of the surface layer of tailings on the emissions of solid suspended matter, as well as on the study of the efficiency of dust emission by aqueous dispersions of poloxamer. The dust suppression capacity was assessed by comparing the dust concentrations generated in the dust suppression bunker space as a result of the air flow action on untreated and dust suppressant treated samples. In an experiment on sand samples from the copper-molybdenum ore beneficiation tailings, it was found that a 2% poloxamer solution provides dust suppression efficiency of up to 98% and retains moisture in the samples for at least 14 days. These data are of interest for the creation and implementation of effective methods for managing pollution from tailings of the mining and processing complex and in other industrial sectors.

Keywords: tailings, dust emission, dust suppression, critical humidity, poloxamer.

INTRODUCTION

Mining enterprises and their tailings dumps, which represent unique types of landscapes after the utilization of processed mineral resources, face serious environmental problems. One of the most pressing is environmental pollution due to dust emissions containing heavy metals. As a result of wind and water erosion, waste particles migrate to adjacent areas and settle in soils [1–3], leading to changes in their chemical composition and deterioration of the ability to support vegetation [4–6], and also there is a leaching of both valuable and hazardous chemical components from copper ore processing tailings into groundwater [7].

One of the major studies on the long-term environmental impacts of ore mining and processing is the work carried out in the Copper Belt mining region of Zambia from 2002 to 2018 [8]. Copper and cobalt are mined in the region, while other trace elements (Pb, As, Cd, Hg, Pb, Zn) gradually accumulate in soils and river sediments. This work noted that one of the main sources of pollution is tailings dumps: water leakage from the Chingola tailings dam leads to the formation of iron-rich sediments containing 25% to 40% Fe_2O_3 and a number of trace elements (As, Co, Cr, Cu, Hg, Mo, Ni, Se and Zn); the collapse of the tailings dam led to massive siltation of a local watercourse in the Luanshiya mining region; A sandstorm over the dry beach of the active Mindolo tailings dam is polluting agricultural land in the surrounding area.

In general, heavy metal pollution can pose a threat to biological diversity, including plants, animals and microorganisms, which can affect the stability of ecosystems, also for humans, heavy metals such as lead, cadmium, mercury can accumulate in the body over time [9, 10], which can lead to chronic diseases and long-term health effects [11, 12].

Ingestion and inhalation of particulate matter with an aerodynamic diameter of less than or equal to 10 μm can cause respiratory disorders [13], cardiovascular diseases, neurological effects and cancer [14–16]. The needs to consider particle diameter highlighted, when assessing the impact on potential health effects in communities living under the direct influence of mining and metallurgical enterprises [17].

The aim of the study is to determine the critical moisture content of tailings, at which a sharp increase in specific dust emission in the surface occurs and the need arises to apply measures to moisten the surface layer or to fix it with a dust suppressor to ensure a long-term reduction in white dust emissions during non-sedimentary periods. In addition, aqueous solutions of poloxamer were studied to determine the most effective concentrations for its use as a dust suppressant at the tailings dump.

MATERIALS

The state-owned Erdenet Mining Corporation in Mongolia is one of the world's largest producers of copper and molybdenum. Ore entering the processing plant (PP) is processed using the traditional flotation method. The PP waste enters the tailings dump, where solid particles are separated from the pulp mass. The tailings dump is of the alluvial type by filling method and of the valley type by location, formed by the main alluvial and upland dams with crest marks of 1305 m above sea level. Filling of the tailings dump capacity is carried out according to the scheme: from the dam to the dump with the formation of a beach from the tailings, and the clarified water is returned to the PP for reuse.

Depending on the stability of the dam, winter and summer wash areas are distinguished. When the pulp is discharged in the winter in the northern part of the tailings storage facility, the sediment discharged into the summer zone – the southern part – dries up, and when there is a strong wind in the winter and spring, white dust emissions occur.

The climate of the region is continental, with an average annual temperature of 1.7 °C (according to data for the last 10 years). The average temperature of the coldest month is minus 15.7 °C, and the warmest is plus 17.5 °C. The average annual precipitation for this period was 402 mm, with about 66% of precipitation falling in the summer, and fluctuations by year ranged from 230 to 517 mm.

The average annual relative humidity is 56%, and the wind speed is 2.5 m/s. Strong winds, reaching up to 7 m/s, are observed in March, April, May and September. Prevailing wind directions include northwest (42%), north (16%) and northeast (10%).

The soil and water of the rivers near the tailings dumps are contaminated with heavy metals, as noted in publications [4, 18]. The concentration of Cu in the soils adjacent to the tailings dumps fluctuates from 50 to 4410 mg/kg, significantly exceeding the MAC value (100 mg/kg) [19]. Similar excesses were recorded for Mo, As and Zn. In the surface waters of the river sections, including the Erdenet, Govil and Zun rivers, the maximum permissible concentration of Cu was also exceeded, especially in the lower sections of the rivers: the maximum value was 0.03 mg/l with a maximum permissible concentration of 0.01 mg/l [20], the probable source of pollution of which was the leachate discharges of the tailings dumps dam.

The distribution of copper, arsenic, lead and zinc in the topsoil in the vicinity of the enterprise was investigated in [21]. Of the 19 microelements identified, the highest concentrations of Cu (1443–4866 mg/kg), As (26–52 mg/kg) and Mo (24–49 mg/kg) were observed in mining soils, exceeding the corresponding values specified in the National Standard of Mongolia [19]. Moreover, the study by Sodnomdarjaa [22] noted that the highest soil loss (8.31 t/ha month^{-1}) was observed in July 2018 near the tailings storage facility.

The white dust carried from the tailings dam covered an area of 1400 hectares. In the directions corresponding to the northwest, north and northeast, with a wind speed of over 5 m/s, the maximum spread of dust reached 25 km noted [23]. The particle size of white dust had two types: sandy 2–0.05 mm and silty 0.05–0.002 mm [24]; however, it had high concentration of As, Pb, Zn and Cu, which was higher than the Mongolian National Soil Quality Standard [19].

White dust concentration measurements taken in April (the dustiest month) of 2023 show total dust concentrations exceeding the norm by 1-3 times, and PM2.5 and PM10 levels exceeded the norm by 4-7 times at two air sampling points (Fig. 1) near the tailings dump [25]. Air pollution near residential areas such as Zhargalant Sum (30

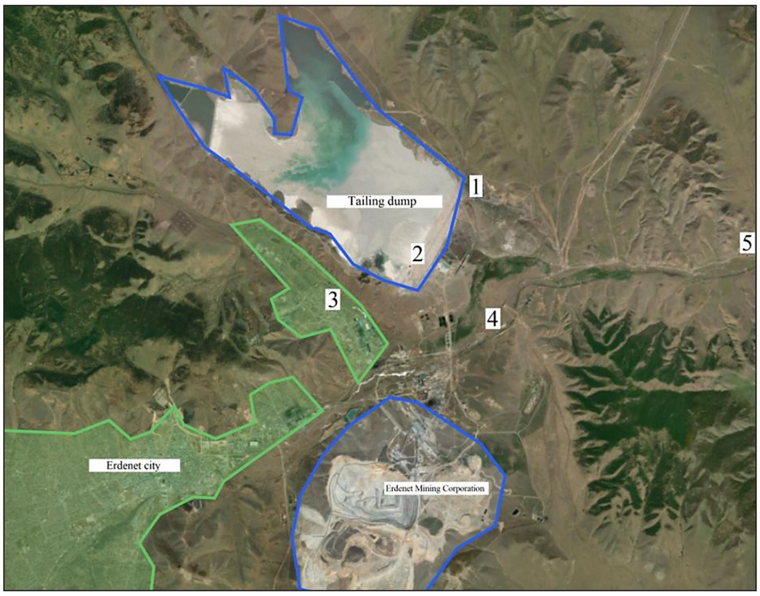

Figure 1. Locations of white dust concentration measurements: 1 – near the eastern security post, 2 – dam, 3 – Govil Bagh, 4 – Bayan-Tsagaan Bagh, 5 – Zhargalant Sum

km east of the city), Bayan Tsagaan Bagh (train station) and Govil Bagh remained within acceptable values (MPC of total dust – 500 μg/m^3 for an average measurement time of 20 min). Between 10:00 and 13:00 hours, dust generated at the tailings dump moved southeast towards the mountains. At this time, the relative humidity was 34%, the atmospheric pressure was 865 g/cm² (648 mm Hg), the wind speed fluctuated from 7 to 9 m/s, reaching 12 m/s in places, with a direction from northwest to north. Thus, the main source of air pollution in the Erdenet area with particulate matter is white dust originating from the tailings dam. The desire to reduce and control dust emissions from tailings dams is most often associated with minimizing negative impacts rather than eliminating them completely.

To reduce dust emission volumes, the following methods are used: isolating the dust-producing surface by sowing plants [26–28], applying liquid polymerizing coatings [29–31], fixing the surface dust layer by moistening with water [32–34], biological methods using soil mixtures with water, fertilizers and plant seeds [35], using aqueous solutions of polymers (polyvinyl acetate, polyethylene glycol [36], poloxamer [37], carboxymethyl cellulose [38], polymers based on methyl cellulose [39]), biopolymers (corn starch, xanthan gum, fava protein concentrate) [40–42], solutions of halides ($CaCl_2$) [43], wetting agents with surfactants [44], foam dust suppression with a polymer [45]. Tailings can also be used in the construction industry as sand, for the production of cement clinker, and as an additive to concrete [46, 47].

Compared with other methods, aqueous polymer-based dust suppressants provide more effective dust control at tailings dams located in regions with semi-arid climates. For example, in a study by Korean scientists [36] on the use of biocompatible polymers in tailings dams (polyethylene glycol and poloxamer), both polymers showed the ability to reduce dust emission and retain water. Poloxamer was particularly effective, reducing dust emission by 79% for PM10 and 84% for PM2.5 after two weeks. The polymers were also UV-resistant and improved the water-retaining properties of the tailings. The effectiveness of poloxamer is due to its amphiphilic properties and liquid state [48].

METHODS

During the industrial practice, samples of white sand were collected from the tailings storage facility of the Erdenet Mining Corporation, and analyses and experiments were conducted in the laboratory of the Research Center “Ekosistema” at the Empress Catherine II Saint Petersburg Mining University.

The granulometric composition of the sample was determined using a Horiba LA950 laser diffraction particle size analyzer. The laser diffraction method is based on the principle of deflecting a laser beam at different angles when it is reflected from particles of different sizes. The radiation sources in this particle size analyzer are a laser diode with a wavelength of 650 nm and an additional LED with a wavelength of 405 nm.

The moisture content of the samples was measured using an AND MX-50 moisture meter, which operates by analyzing the moisture that evaporates when the sample is heated.

The efficiency of dust emission reduction using water and an aqueous polymer solution was investigated on the experimental setup shown in Figure 2. This setup is a dust suppression bunker "BPP 001", in the lower part of which there is an opening for supplying air flow through a hose from an air blower, simulating the movement of the air flow. In the center of the bunker, through an opening in its upper part, a tube is installed for connecting a DustTrak DRX 8533 air dust analyzer. This analyzer uses the laser nephelometry method, which ensures accurate measurements of the mass concentration of dust in real time.

Experiments on this installation made it possible to evaluate the effectiveness of dust reduction methods and identify their potential benefits.Before conducting the experiment, the air temperature, relative air humidity and air flow speed are measured in the setup using the MES-200A meteorometer.

Experiments with the sample were carried out in the following sequence: a 10 g sample of tail sand is placed on the bottom of the setup and evenly distributed over the surface using an oval-shaped spatula, then the setup is hermetically sealed and, simultaneously with the supply of air at a speed of 5 m/s, the dust analyzer is started up.

In this research, a poloxamer solution was used to optimize water use, improve dust reduction efficiency, fix particles on the surface and prevent their transfer to the atmosphere. Poloxamer is a non-ionic triblock amphiphilic polymer consisting of two polyethylene oxide blocks on either side of a polypropylene oxide chain. All poloxamers are mild surfactants, but Poloxamer-184 is considered the mildest and non-irritating. Poloxamer-184 was used to evaluate its potential as a dust suppressant and stabilizer for the studied tailings storage facility. For this purpose, aqueous solutions with 5 different concentrations were prepared: 0.5%, 2%, 5%, 7%, 10%.

RESULTS

Granulometric analysis

The average particle size according to the results of granulometric analysis (Fig. 3) is 181.5 μm. The largest percentage content in the sample (about 7.7%) falls on particles with a diameter of 262 μm. The share of dust particles (less than 10 μm) is about 3.5%.

Determination of critical humidity

For further calculations, the total dust content was first measured with a sample in the bunker

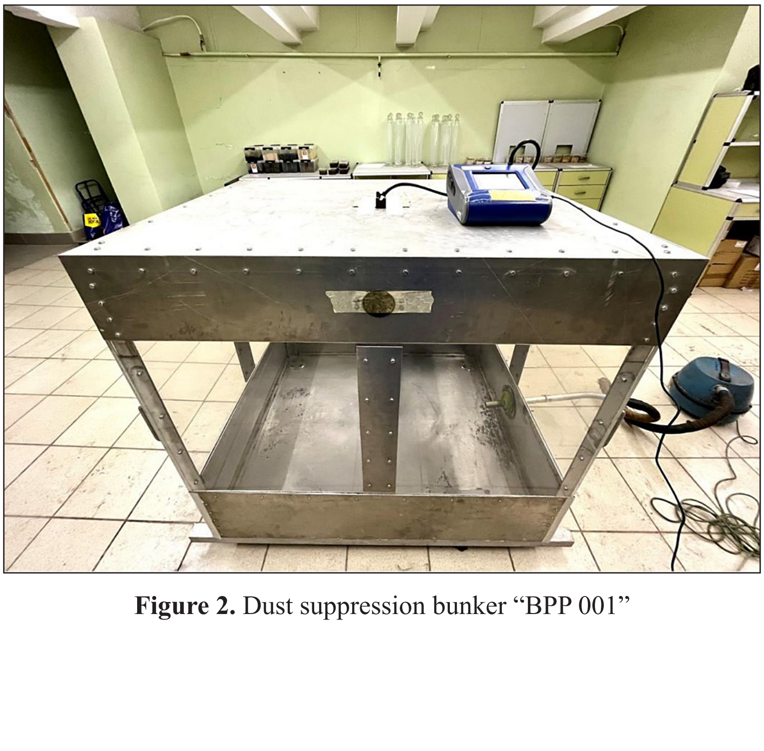

Figure 2. Dust suppression bunker "BPP 001"

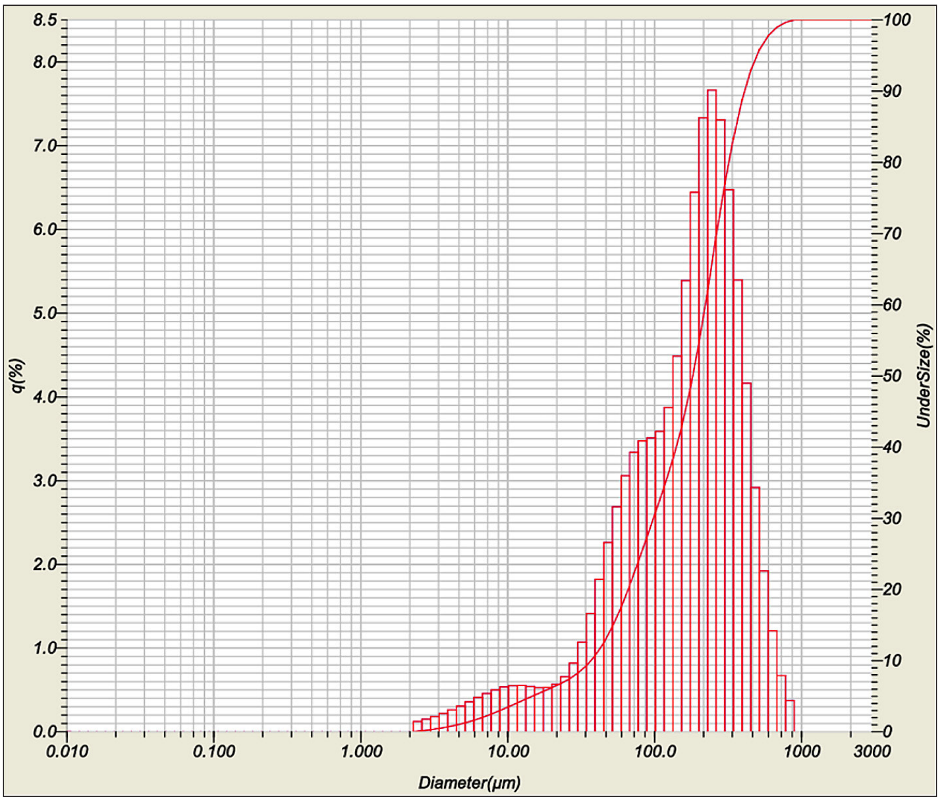

Figure 3. Result of granulometric analysis

without using dust suppressants. The air temperature and humidity in the bunker were 17.3 °C and 30%, respectively. All dust concentration measurements were performed for dust with a particle size of up to 10 µm (PM10) for 300 s.

To determine the humidity at which intensive dust emission from the tailings begins, a single sample was prepared with a mass ratio of water to sample of 1:8, from which 10 g of the sample was simultaneously experimented on in the bunker, and 5 g was used to measure the humidity.

The dust suppression efficiency was calculated using Equation (1):

$$\eta = \frac{\sum_{i=1}^{n}(1 - \frac{C_{1i}}{C_{0i}})}{n} \quad (1)$$

where: C_0 – concentration without dust suppression, mg/m^3; C_1 – concentration when using dust suppression agents, mg/m^3; n – number of measurements.

Next, based on the results obtained from several series of experiments, the average efficiency was calculated (Table 1) and a graph of the dependence on humidity was constructed (Fig. 4). The graph determined the critical humidity of ~ 3.35±0.01%, at which intensive dust emission of the initial tail sample begins. Below the critical humidity level, tailings are usually dry and prone to dust formation when exposed to wind or mechanical impact. That is, in this case, if the humidity of the beach sand of the tailings dump of the Erdenet Mining Corporation is maintained above 3.35% when treated with water, the tendency to dust formation will be reduced.

Table 1. Result of calculation of average efficiency of dust suppression by water

No.	Sample moisture content, ±0.01%	Average dust suppression efficiency, %
1	0.30 (without dust suppressor)	–
2	10.76	98.095±1.215
3	10.06	98.31±0.66
4	9.11	98±1.29
5	8.91	98.115±0.595
6	7.89	98.03±0.72
7	7.22	97.965±0.785
8	6.33	97.765±1.565
9	4.97	97.845±0.825
10	3.94	97.025±0.695
11	3.02	92.245±5.015
12	1.53	82.805±6.105

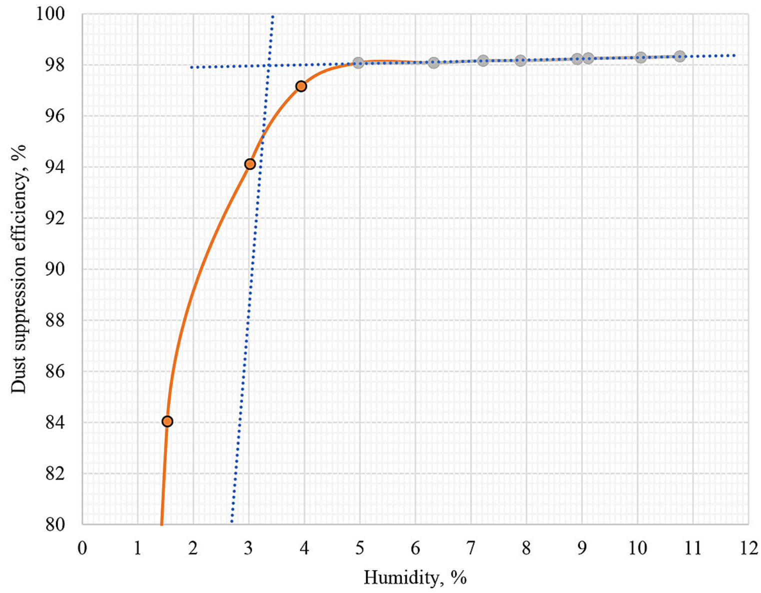

Figure 4. Graph of the dependence of dust suppression efficiency on sample humidity

Study of poloxamer as a dust suppressant

Samples of tailings treated with poloxamer solutions were experimented in a dust suppression bunker immediately after irrigation, as well as after 3, 7, and 14 days (Table 2 and Fig. 5).

Testing of samples after 3 days shows better efficiency than when measured immediately after spraying all five solutions (Fig. 6). During this time, the polymer layer dried and stabilized on the surface of the sample, providing more effective coverage and protection from dust or other external influences. Examination of the appearance after the experiment in the bunker shows that cracks formed only in the first sample.

Table 2. Dust suppression efficiency of poloxamer solutions

Concentrations of solutions, %	Average efficiency, %			
	Immediately	In 3 days	In 7 days	In 14 days
0.5	95.22±1.84	96.26±1.44	95.73±1.64	93.09±2.66
2	95.55±1.71	97.365±1.015	96.98±1.16	96.765±1.245
5	95.02±2.6	98.63±0.53	98.23±0.68	98.23±0.68
7	95.725±1.655	98.425±0.605	97.51±0.96	95.68±1.66
10	92.61±2.84	98.225±0.685	97.335±1.025	96.72±1.26

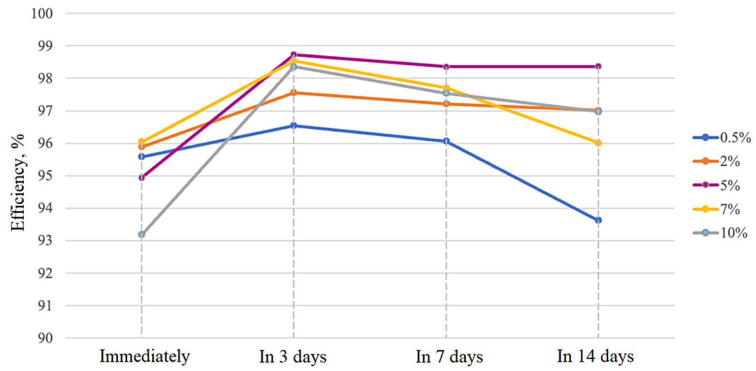

Figure 5. Dust suppression efficiency of poloxamer solutions with different concentrations

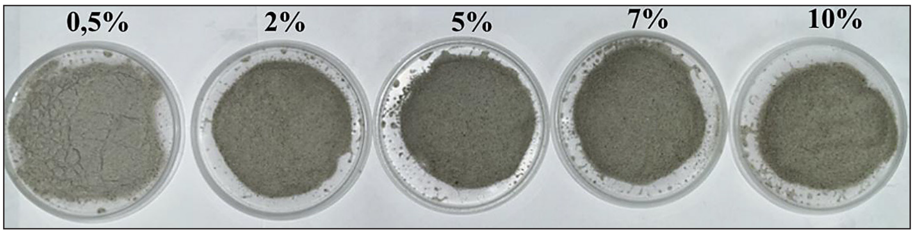

Figure 6. Samples after the experiment in the dust suppression bunker

Figure 7. Samples treated with 2% poloxamer solution

The results of the assessment of the dust suppression efficiency with poloxamer solutions showed, that the solutions of all studied concentrations goes a fairly high efficiency of application from 89.77% to 99.16% (taking into account the error) in the entire range of exposure time, but 0.5% solutions do not form a solid polymer-sand crust on the surface and are characterized by cracking, which creates a risk of wind destruction of the fixed layer and a decrease in the efficiency of reducing dust emissions from the surface of the dust-generating mass.

In particular, in order to reduce the consumption of poloxamer, a 2% solution can be practically implemented, which maintained the dust suppression efficiency at a level of 98.364–98.736% throughout the entire test period. In addition, Figure 7 shows that moisture is retained in the sample for 14 days, while when treated with the same amount of process water without the addition of polymers (3 ml), the sample dries completely to an air-dry state in less than one day.

CONCLUSIONS

The critical humidity of 3.35% was found, that determining the critical humidity in tailings as important for effective dust control. Results of experiments found that the best dust suppression efficiency was achieved with a 2% solution. This solution maintained dust suppression efficiency at a level of over 98% throughout the entire test period, which makes it the most effective in preventing tailings dust. In addition, samples treated with this solution showed resistance to external factors, retaining moisture for 14 days. These results support the potential of poloxamer as an effective binder to improve moisture retention and prevent dusting in tailings dumps.

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