JEE Journal of Ecological Engineering

Journal of Ecological Engineering 2023, 24(6), 86–97
https://doi.org/10.12911/22998993/162558
ISSN 2299–8993, License CC-BY 4.0

Received: 2023.03.01
Accepted: 2023.04.13
Published: 2023.05.01

Issues of the Impact of Granulated Sulfur Transportation on the Environmental Components

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ABSTRACT

Nowadays, sulfur is considered one of the primary resources of the chemical industry, most of which is produced as a refinery by-product during the processing of oil and natural gas. Sulfur production volumes are increasing every year, while the demand for it does not always match the growing supply, which leads to a serious problem of sulfur surplus in the world market. Granulated sulfur – the main commercial type of elemental sulfur – is transported in large quantities both by land and sea and can have a negative impact on the environment. At the moment, the issue of the negative impact of granulated sulfur on the environment has not been fully studied, which determines the relevance of this research. This review article presents the global market of granulated sulfur, paying attention to its safe transport – from the producer to the consumer. The potentially harmful factors of the impact of sulfur handling on elements of the natural environment, such as atmospheric air, water reservoirs, soil and vegetation, were also taken into account.

Keywords: granulated sulfur, dust suppression, transportation, sulfur dioxide, spillage, ignition

INTRODUCTION

Presently, sulfur, alongside with oil, gas, coal and sodium chloride, ranks among the top 5 most used products in the chemical industry [1]. About 90% of the world's industrial sulfur is used for the production of sulfuric acid; in addition, sulfur is used in agriculture, the rubber industry, the oil and petrochemical industries, for diluting drilling and oil solutions [2], the production of lubricants, antiknock additives and other industries [3].

In nature, sulfur has the form of a solid crystalline substance that is stable in the following modifications: rhombic of lemon-yellow color (with density $\rho = 2.07$ g/cm^3 and temperature of fusion $T_f = 112.8$ °C) and monoclinic of honey-yellow color ($\rho = 1.97$ g/cm^3, $T_f = 119.3$ °C). The main physical properties of sulfur include indissolubility in water and poor conductivity of heat and electricity. The chemical activity of sulfur depends on its valency and lies in the ability of sulfur to combine with almost all known chemical elements, with the exception of gold, platinum, nitrogen, crystalline iodine and inert gases. Interacting with CO_2 in the atmosphere at temperatures above 300 °C, sulfur is able to form oxides: sulfur dioxide SO_2 and sulfur trioxide SO_3, which serve as sources for the production of sulfurous and sulfuric acids, respectively, as well as sulfites and sulfates.

Elemental sulfur plays an important role in the functioning of the human body – it is part of hormones, vitamins, proteins and other compounds. Lack of sulfur in the human body can cause hair loss, as well as brittleness of the nails and bones [3]. However, sulfur compounds are considered toxic and have a negative impact on the environment, being one of the most dangerous pollutants in the world [4]. More than 96% of sulfur enters the atmosphere in the form of SO_2, the remaining 4% is divided between sulfates, H_2S, CS_2, COS and other compounds. In addition to the negative impact on the components of the environment, sulfur dust formed in the air can irritate the human respiratory system and mucous membranes, as well as cause eczema. Hydrogen sulfide is extremely toxic and adversely affects the central nervous and cardiovascular systems, liver, gastrointestinal tract and endocrine apparatus even at low concentrations [5]. Moreover, sulfur dust is explosive, therefore, when transferred, transported or stored in large quantities, sulfur can create a serious environmental risk [6, 7].

The work goal was to systematize the knowledge on the processes of reloading industrial sulfur at each point of handling and related environmental problems, as well as on the measures taken to prevent them. To achieve it, the literature in the field of production of granulated sulfur at oil and gas processing plants, its storage and subsequent transportation to consumers, were studied.

SULFUR AS A RESOURCE

Sulfur is a strategically important resource necessary for providing the population with food and consumption, since it is one of the 6 most important nutrients used to fertilize plants, improve soil fertility and increase harvest [8]. At the moment, the largest amount of industrial sulfur is obtained as a by-product in the processing of natural gas and oils with a high content of sulfur compounds [9].

The presence of sulfur in petroleum fractions can adversely affect the performance properties of the fuel, lead to corrosion of engines and have other negative effects, therefore, the desulfurization of petroleum products and the qualified use of isolated sulfur compounds is one of the most important tasks of the oil industry [10, 11].

The main commercial types of sulfur currently are: liquid, block and granulated sulfur. Liquid sulfur is obtained from gases in molten form, stored and transported in heated tanks. Block and granulated sulfur are produced from liquid sulfur by cooling and granulating [12, 13]. Sulfur in granular form is considered the most valuable on the world market due to its properties and advantages: a sufficiently high degree of purity, almost complete absence of water and hydrogen sulfide and a uniform particle size distribution [14].

The main sales sector for granulated sulfur is the production of sulfuric acid and artificial fertilizers (such as normal superphosphate, ammonium sulfate, ammonium-sodium sulfate, potassium sulfate, potassium magnesia, magnesium sulfate, nitrogen sulfate, sulfoammophos, etc.) [15, 16], sulfur asphalt, as well as its use in the pulp-and-paper and fabric industries [17]. Besides that, sulfur compounds have become widespread in the development of matches, sparklers and black blasting powder; production of medicines (ointments used to treat skin diseases); organic paints of various colors used for dyeing fibers, yarns and fabrics; luminophors in direct vision kinescopes, and rubber vulcanization. Furthermore, concentrated sulfuric acid is used in the production of many explosives (for example, nitroglycerin, trinitrophenol, etc.), with the exception of nitrocellulose [18]. Being an inorganic fungicide and acaricide, sulfur is one of the most popular chemical agents applied for plant protection against diseases and infestants and has long been used in agriculture to battle mycosis and phytivorous mites [19].

Today's sulfur industry (Fig. 1) is unique compared to other mining industries: since sulfur is produced primarily as a by-product, the supply and demand for sulfur tends to be out of balance, resulting in a sulfur surplus over the past many years. However, sulfur is a valuable commodity and the basis for the production of sulfuric acid, which is considered an important chemical for the global economy [20].

SULFUR PRODUCERS AND CONSUMERS

The world's sulfur reserves currently exceed 5 billion tons. In general, the entire world sulfur industry can be divided into two segments: specialized one and "supplementary" one. The specialized sector is focused on the extraction of native sulfur [21], it accounts for only about 10.5% of the total world production. The reserves of native sulfur are concentrated mainly in Iraq (335 million tons), USA (200 million tons), Mexico (100 million tons) and Chile (100 million tons). In addition, deposits of native sulfur are known in Russia, Ukraine, Poland and Turkmenistan. Japan has significantly large reserves of sulfur extracted from volcanic rocks [8].

The "supplementary sector" focuses on the extraction of sulfur as a forced by-product from the processing of sour oils and natural gas, the level of production of which depends on the volumes of the original feedstock and the sulfur content in it (Fig. 2). Nowadays, more than 95% of industrial sulfur is produced at oil and gas

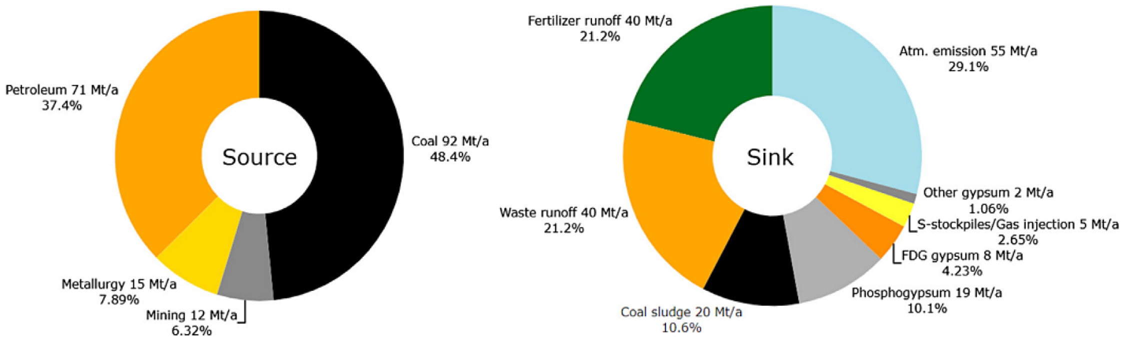

Fig. 1. Anthropogenic sources of sulfur and its sinks [20]

refineries during the purification of hydrocarbon raw materials [21]. In 2020, the global market for sulfur and sulfuric acid amounted to 256 million tons and is projected to increase to around 295 million tons in 2026 [22, 23].

Russia ranks fourth in the list of the largest sulfur producing countries in the world market, the sulfur production here amounts to 10.3% of the world volume [24]. China ranks first (13.9%), followed by the USA (12.8%), Canada (10.3%) and countries of the Middle East which share 12.8% in total. The main sulfur producing companies in the oil and gas sector in the world consist of ConocoPhillips, Valero Energy, ExxonMobil, Chevron, CITGO Petroleum, BP, Shell, Petroleos de Venezuela, as well as Gazprom [25].

The Russian sulfur market is almost completely monopolized by Gazprom: the company's gas processing enterprises produce approximately 85% of the product. The rest is accounted for by Norilsk Nickel and the production of sulfur in oil refining. According to the Rosstat's official data, about 6 million tons of sulfur were produced in Russia in 2015 and about 2–3 million tons are purchased annually by Russian holdings. The consumer sulfur market in Russia is also practically monopolized: more than 80% of all produced liquid sulfur is purchased for the production of mineral fertilizers by the PhosAgro group enterprises and approximately 13% is purchased by EuroChem. Only block and granulated sulfur is exported [25, 26]. The export of granulated sulfur produced by Gazprom is carried out in two directions: the southern direction from the ports of the Southern Federal District to Tunisia, Israel, Morocco, Brazil and the northern one – from the seaport of Ust-Luga to Morocco, Brazil, China, South Africa and other countries [27].

China is the largest sulfur consumer in the world (Fig. 3). Despite the fact that the country ranks first in the production of elemental sulfur worldwide, the Chinese production is not able to meet the local demand for sulfur, which exceeds 20 million tons per year. In this regard, more than 10 million tons are imported into China every year. Apart from China, the main world consumers of

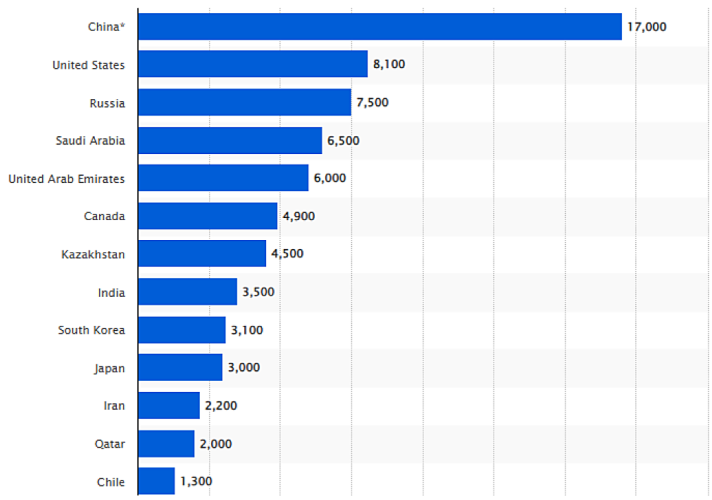

Fig. 2. Sulfur production in the world 2021 by country, in 1000 metric tons [22]

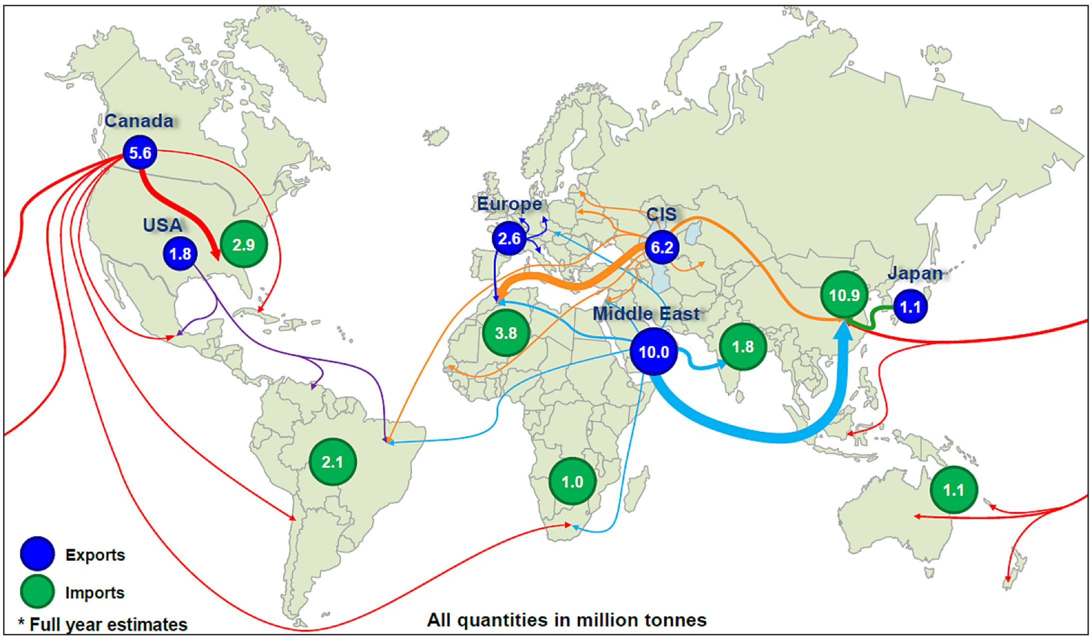

Fig. 3. World sulfur market (2012, total market volume 31 million tons) [28]

sulfur are the largest producers of mineral fertilizers, namely: the USA (more than 25% of the volume of sulfur consumption in the world), the Baltic countries and the CIS (9%), Morocco (8%), India (7%), Tunisia and Brazil (5% each). According to the statistics, the volume of world's sulfur consumption amounts to about 65-85 million tons per year. Almost all of the obtainable sulfur is used to manufacture sulfuric acid, which, in turn, is an important resource in the production of phosphate and complex fertilizers [4].

As mentioned above, Gazprom is the largest sulfur producer in Russia. The main outlets of Gazprom's sulfur production are located in Orenburg and Astrakhan at gas processing plants. The statistics show that the volume of sales at these enterprises amounted to 1.9 million tons in 2014, which is 81% of the total volume of Russian production [29, 30]. In terms of sulfur content in gas, the Astrakhan gas condensate field is considered unique – the amount of sulfur and hydrogen sulfide here reaches 25% and an average of 5 million tons of sulfur is produced annually with gas production of 12 billion m^3. Some Canadian deposits are characterized by even higher sulfur content, but they cannot boast of such production volumes [8].

SULFUR PRODUCTION AT GAS PROCESSING PLANTS

The Astrakhan gas processing plant was originally built specifically for the purpose of producing sulfur, which was considered a scarce and expensive product. Since the acid gas mixture extracted from natural gas contains a huge amount of hydrogen sulfide (more than 50%), it is processed at the plant in order to obtain elemental sulfur. The main method for sulfur recovery during gas processing is the Claus process developed by a German chemist in 1883 [31–33].

The Claus process allows recovering elemental sulfur from acid gas through a series of thermal and catalytic H_2S-SO_2 oxidation reactions. Extraction of elemental sulfur is of crucial importance, since H_2S is hazardous to the environment, extremely flammable and can dissolve in petroleum products, degrading their quality [34, 35]. The Claus process involves the partial combustion of H_2S using air or O_2 under enriched conditions to form elemental sulfur [36, 37].

During this reaction, a third of H_2S burns to form SO_2 (reaction 1); the reaction continues between SO_2 and unreacted H_2S in the appropriate ratio with the subsequent formation of elemental sulfur S_2 (reaction 2) [37]:

$$H_2S + 1{,}5O_2 \rightarrow H_2O + SO_2 \quad (1)$$

$$2H_2S + SO_2 \rightarrow 1{,}5S_2 + H_2O \quad (2)$$

The Claus process at the Astrakhan gas processing plant is carried out at the Enersul installation, which enables the extraction of elemental sulfur from acid gases generated during the purification of natural gas from sulfur [39, 40]. This unit (Fig. 4) is a complex consisting of a sulfur granulation equipment (with a capacity more than

2 million tons/year), conveyor systems designed to supply sulfur to the warehouse, 2 storage warehouses with a capacity of about 150 thousand tons each and systems for loading granulated sulfur into railway wagons and vehicles.

The process of handling granulated sulfur at the plant is schematically shown in Figure 5. Since granulated sulfur tends to generate dust during handling operations, certain dust suppression measures must be taken at the plant. For that matter, an anti-acid treatment of sulfur granules by a biocide is implemented at the Enersul system and storage warehouses (Fig. 6), and a dust suppressant solution is also used there [39, 40].

Fig. 4. Inside the sulfur granulation complex at the Astrakhan gas processing plant

GRANULATED SULFUR ISSUES

Transportation and storage

One of the options for the shipment of granulated sulfur from the capacities of the Astrakhan gas processing plant is transportation by road in specialized containers [41]. Granulated sulfur is packaged in MK 10-14 reusable containers (manufactured by the Russian company JSC "New Technologies in Transportation"), designed for 13–14 tons of sulfur (2.8 m in height, 2.5 m in diameter), and then delivered to the nearest port dump by KAMAZ trucks (Fig. 7) [31]. Flexible containers are designed for the safe transportation of bulk cargo, protect the cargo from atmospheric

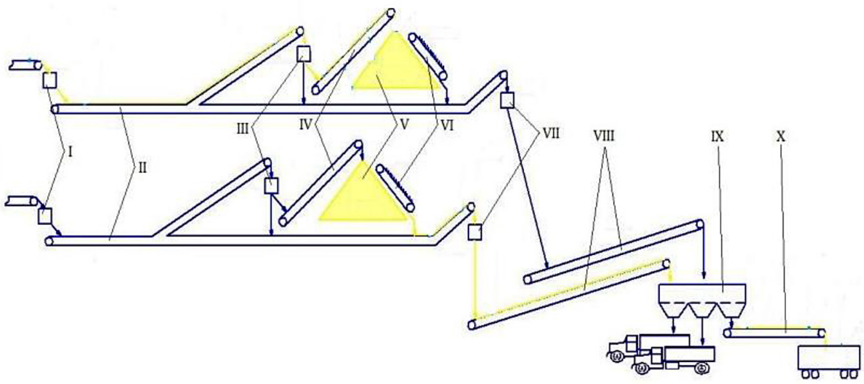

Fig. 5. The Enersul installation: I, III, VII – transfer towers; II – loading conveyors; IV – stacking units; V – storage areas; VI – stacking units; VIII – shipping conveyors; IX – unloading bunker; X – conveyor for supplying products to wagons [39]

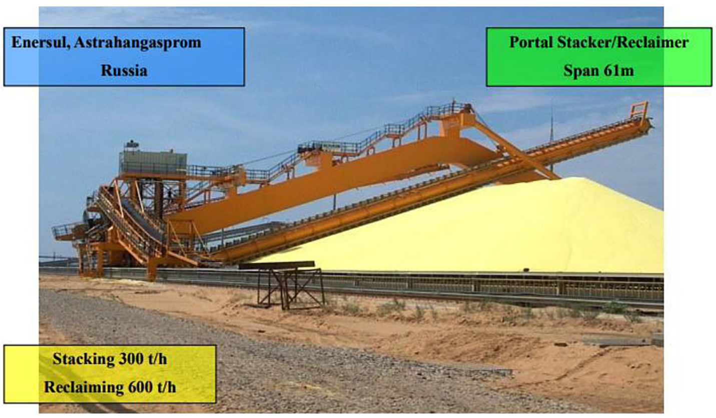

Fig. 6. The Enersul stacker (capacity 600 t/h)

precipitation and excessive accumulation of gases during transportation and storage [42].

The main way of transportation of block and granulated sulfur, both to Russian consumers and for export, is the transportation of industrial sulfur in railway wagons with lower hatches (Fig. 8) [43]. During handling of sulfur mandatory measures must be taken to prevent the formation of dust, such as: processing of the material with special liquid solutions; watering stacks and open points of loading and unloading sulfur; frequent removal of dust and cleaning of the working area [44].

According to the studied statistics, most of granulated sulfur produced in Russia is exported. This may be due to the high cost of products and the need to purchase additional equipment for its processing. However, the demand for granulated sulfur in the world market is consistently high [12]. One of the main points in the sulfur exporting cycle – a terminal that stores and loads industrial sulfur onto ships – is located on the territory of a commercial seaport. This terminal provides logistics services for the temporary storage and reloading of sulfur and mineral fertilizers from railway wagons to offshore boats. Thus far, the sulfur terminal has handled approximately 9.5 million tons per year.

The reloading process at the port terminal consists of three main automated units: a wagon unloading station, warehouses and a ship loading machine. Sulfur arrives at the terminal in railway wagons with a capacity of 60–80 tons and is transshipped on the platform of railcar dumper. From the receiving hopper, following the conveyor line, sulfur enters the warehouse, where it is formed into a pile by a scraper reclaimer (Fig. 10), and then led to the landing pier. Sulfur is transferred onto the ship by a ship-loading machine, which directs the cargo into the ship's hold by conveyors. An important feature of the sulfur terminal to consider is the fact that technological line is completely closed from the environment, which allows holding the transshipment of sulfur throughout the year without damaging the cargo.

Sulfur dust formation

A survey of a number of sources [45–50] show that an urgent problem in the transportation,

Fig. 7. Delivery of sulfur in specialized containers by road

Fig. 9. Construction of a complex for reloading industrial sulfur in the sea port

Fig. 8. Transportation of sulfur by rail

Fig. 10. Sulfur storage at the terminal [49]

reloading and storage of such bulk cargoes as granulated sulfur is their intense dusting during the handling processes, including in river and sea ports. As a result of dust entrainment by air flows, irretrievable cargo loss occurs, which leads to the deposition of sulfur dust on water area of the port and adjacent territories [51].

The loss of sulfur during loading and unloading operations can have a detrimental effect on both humans and the environment: atmospheric air, soil, and water bodies [52, 53]. Sulfur dust is explosive and flammable, prone to chemical spontaneous combustion, its particles, mixing with air in closed premises with a sufficient stoichiometric concentration of a dusty cloud, can cause fuel and air explosion (the lower explosive limit of sulfur dust is 2.3 g/m^3, the self-ignition temperature – 575 °C [54]); therefore, when carrying out reloading operations, it is mandatory to implement dust suppressing measures [55, 56]. Environmental safety during the transfer of dusty materials can be controlled by monitoring the maximum permissible concentration of dust in the air of the working area. For sulfur dust, MPC is 6 mg/m^3 [57, 58].

Ignition of sulfur

There are frequent cases of fire caused by friction during storage and transportation of granulated sulfur. When storing and transporting granulated sulfur, the equipment is exposed to sulfur dust. Sometimes, the friction between steel equipment and sulfur dust can start a fire and even lead to serious accidents if the sulfur is not handled properly [59]. There are many cases of sulfur ignition during its transportation in railway wagons (Fig. 11), which arise due to the exposure of the surface of the cargo in transport and the presence of an external source of ignition (for example, diesel locomotive sparks). To prevent the development of such situations during the transportation of granulated sulfur by rail, special protective covers are used, made of non-combustible or slow-burning materials [61].

Fig. 11. Ignition of sulfur in railway wagons [62, 63]

There is also a risk of fire during the production process in sulfur granulation plants. The accident in this case develops according to the steam cloud explosion model, accompanied by torch combustion and a shock wave, as a result of which buildings, structures and neighboring devices are destroyed. In case of major accidents, there is a danger of the formation of explosive and fire hazardous hydrocarbon-containing clouds of large volume, capable of moving throughout the entire territory of the industrial site and beyond it [61].

In addition, there are studies [62] confirming the danger of ignition of granulated sulfur as a result of its intense electrification. In order to exclude the possibility of static electricity occurring during sulfur granulation, measures of sulfur irrigation with water are taken at all points of its reloading, and in some cases, it is treated with a dust suppressant solution. It is noted that these methods of coping with negative effects of sulfur electrification and the formation of sulfur dust have significant drawbacks, specifically, the impossibility of using aqueous solutions in winter due to them freezing [63].

ENVIRONMENTAL IMPACT OF SULFUR

Utilization of off-grade sulfur

As things stand, the problem of utilization and recycling of sulfur-containing wastes still remains relevant [64]. The oil production, oil processing industry and transport structures are environmentally hazardous areas that have a negative impact on the environment as a result of the storage of large-tonnage sulfur waste, the growth of which increases every year with an escalation in the level of extraction and processing of mineral resources [65]. This causes an increase in the environmental threat, a decrease in soil fertility and a decline in the health of the population [66].

The formation of sulfur waste during transshipment processes is related to irreversible accidental releases of the material during the performance of various pieces of equipment. At the sulfur port terminal, sulfur losses occur during unloading of railway wagons and following transportation of sulfur by conveyor lines to the warehouse and to the ship loading machine. As a result of mechanical cleaning of premises, a certain mass of off-grade sulfur is formed, which becomes a waste product. Waste in the terminal also includes special wagon covers used to protect the cargo during transportation by rail, which are subject to further disposal. Given the formation of large volumes of off-grade sulfur and the need to store them at hazardous waste landfills, one of the promising areas for the use of substandard sulfur is the developing production of sulfur concrete [67].

Water pollution

Studies [68] show that during the reloading of sulfur in ports, a certain part of sulfur dust end up in the atmosphere and settles on the surface of water bodies within a radius of 2–3 km. In water, sulfur is oxidized by oxygen, both biotically and abiotically, with the final formation of sulfuric acid and sulfates. Due to this factor, there is a possibility of a local decrease in the pH of water and an increase in the concentration of metals. To this date, in various parts of the water body, on which the sulfur port terminal is located, local excesses of sulfates, chlorides, iron and magnesium are detected, with the multiplicity of exceeding the MPC lower than 10. In addition, the monitoring also registers an excess MPC of suspended particulate matter and water cloud number [53]. Groundwater can be polluted due to the oxidation of sulfur to sulfuric acid if rainwater runoff is not properly controlled. Fugitive sulfur dust can also be a problem if the structural unity of sulfur storage is not maintained [18].

Impact on vegetation and topsoil

The study of the content and migration of sulfur in the system atmosphere-plants-soil and vice versa, as well as the effect of sulfur dioxide on the agrobiologically properties of plants is an urgent problem [69]. When infiltrating into the atmosphere, sulfur and its compounds form sulfuric acid, which falls with atmospheric precipitation on the surrounding landscapes and becomes involved in the geochemical cycle. At first, the process of soil destruction is restrained by geochemical barriers; however, over time, with a constant supply of an oxidizing agent, the soil undergoes destruction [70]. An excess of sulfur in the composition of soils leads to acidification as well as leaching of aluminum and heavy metals, which can initiate the inhibition and death of flora and fauna [71, 72].

Sustainable handling of sulfur

Despite the fact that the process flow of the shipment of sulfur from the plant sites was developed in order to exclude any loss of sulfur, the ingress of sulfur into the environment during transportation is still inevitable. When forming piles in warehouses, unloading sulfur from railway wagons, loading sulfur into the hold of ships, a large amount of sulfur dust is formed, which pollutes the nearby territories and water areas [68]. When a large amount of sulfur dust is formed, there may be a danger of an explosion and fire, with involvement of additional masses of a fire hazardous substance and the chain development of an accident [73]. Therefore, environmental protection measures are necessarily introduced at all stages of the production and transportation of granulated sulfur (Table 1) to prevent the dust formation and the development of accidents when handling sulfur.

CONCLUSIONS

The review shows that the entire process of transportation and storage of granulated sulfur has potentially a negative impact on the components of the environment. It is accompanied by the process of dust formation, as a result of which cargo is lost and there is a danger of an explosion or fire. Exceeding the maximum allowable concentrations of sulfur dust and the development of the above-mentioned accidents may negatively affect both the environment and humans.

It was found that sulfur production currently exceeds its demand, which creates a problem with the storage of this material. The great volumes of sulfur are produced as by-product during the processing of sour crude oils and natural gas. Therefore, sulfur can create an environmental threat, while various compounds are formed at handling facilities, as sulfur dioxide, sulfuric anhydride, and others. A lot of studies indicated pollution of water bodies with sulfur compounds, their impact on the soil and vegetation and topsoil, as well as the formation of off-grade sulfur waste in production.

It was stated that the main problem in the transportation and storage of granulated sulfur is increased dust formation, which not only has a harmful effect on the atmospheric air, but can also cause fire and the development of accidents.

Table 1. Sustainable transportation and storage of sulfur at handling facilities (compiled by the authors)

Sulfur handling facility	Sulfur handling process	Impact on the components of the environment	Applied environmental protection measures
Oil refinery/gas processing plant	Exiting of granulated sulfur from the granulation plant	• Emission of dust-forming fractions of granulated sulfur into the air	• Anti-acid treatment of sulfur granules by a biocide
	Transportation of sulfur by conveyor to a temporary storage warehouse with intermediate transfer between conveyor sections	• Emission of dust-forming fractions of granulated sulfur into the air • Pollution of stormwater runoff due to flushing of sulfur deposited or lost during transportation • Possibility of fire due to electrification of sulfur	• Water irrigation of sulfur during reloading by conveyor transport
	Storage of granulated sulfur by pouring from a conveyor line into stacks in an open area	• Wind erosion of stacks • Possibility of fire during long-term storage • Possibility of explosion if a large amount of explosive sulfur dust is formed	• Irrigation of stacks and open points of loading and unloading with liquid solutions
	Loading granulated sulfur on land and railway transport	• Emission of dust-forming fractions of granulated sulfur into the air when loading into land and railway transport	• Sulfur treatment with a dust suppressant when loading onto land and railway transport
Land transport	Transportation in dump trucks	• Emission of dust-forming fractions of granulated sulfur into the air	• The use of specialized containers for the transportation of granulated sulfur by road and the elimination of dust formation during transportation
Railway transport	Transportation in railway wagons	• Possibility of ignition due to the exposure of the sulfur surface during transportation in wagons with the presence of a spark • Dust release due to damage of covers	• The use of special non-combustible or slow-burning covers for the surface of sulfur during transportation in railway wagons
Commercial seaport	Unloading granulated sulfur from road/railway transport	• Emission of dust-forming fractions of granulated sulfur into the air • Pollution of storm water runoff from sulfur deposited or lost during unloading	• Irrigation of sulfur with water using pulverizers • Frequent dust removal and work area cleaning
	Transportation of granulated sulfur by conveyor transport to a storage warehouse	• Emission of dust-forming fractions of granulated sulfur into the air	• Creation of a closed conveyor system to prevent sulfur dust from entering the environment • Sealing of loading points with protective covers, smooth joining of conveyor belts • Application of aspiration systems for suction of dust-loaded air
	Temporary storage of granulated sulfur	• Emission of dust-forming fractions of granulated sulfur into the air • Possibility of fire during long-term storage • Possibility of explosion if a large amount of explosive sulfur dust is formed	• Creation of a sulfur storage facility closed from the environment • Frequent dust removal and work area cleaning
	Transportation of granulated sulfur by a scraper reclaimer from a storage warehouse to a berth to a ship-loader	• Emission of dust-forming fractions of granulated sulfur into the air • Pollution of stormwater runoff by flushing sulfur deposited or lost during refueling	• Application of aspiration systems for suction of dust-loaded air • Frequent dust removal and work area cleaning
	Shipment of granulated sulfur by a ship-loader into the hold of a ship for further export	• Emission of dust-forming fractions of granulated sulfur into the air	• Application of a dust suppression aspiration system on a ship loading machine

Dust formation most often occurs due to the insufficient effectiveness of the measures taken to suppress dust at all stages of its transportation, from the producer to the consumer.

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