Environmental and economic performance assessment of elemental sulfur recovery unit installation project

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Abstract. The problem of air pollution is one of the global problems of mankind at the present time. The Irkutsk region has been one of the “leaders” in Russia with the highest excess in air concentrations of maximum permissible concentrations of pollutants during the past decades. The current situation has a very negative impact on the environmental well-being of both adults and children. In the conditions of the prevailing realities, an immediate modernization of production is required, aimed at eliminating or reducing such a prolonged negative impact. The construction and installation of a sulfur recovery unit at oil refineries complies with the latest environmental protection requirements and contributes to a significant reduction in emissions of hydrogen sulfide and sulfur dioxide. The environmental and economic feasibility of such production modernization is illustrated by the example of the Angarsk Petrochemical Company JSC.

The problem of air pollution is one of the most serious global problems which humanity has faced. At the end of 2017, the Irkutsk region ranked third in the rating of Rospotrebnadzor among the regions of Russia with the dirtiest air (Buryatia ranked first, Khabarovsk Krai ranked second). A year earlier, the dirtiest air was in the Irkutsk region. The rating was made with
account of the excess in air of the maximum permissible concentration (hereinafter referred to as MAC) of pollutants [1, 2].

One of the urgent problems for many industries and their operation is the entry of sulfur-containing compounds into the Earth’s atmosphere. Sulfur is liberated both during the refining process and in the use of petroleum products. Only refineries (hereinafter - refineries), and not end users of petroleum products, fully have the ability to eliminate or reduce such a negative impact. Manufacturers of products of high hazard class have a wide range of methods and techniques for preventing the release of hazardous substances into the environment. For example, the production of low-purity (high-sulfur) gasoline entails air pollution by transport during its traffic.

In order to burn associated petroleum gas (hereinafter - APG) which was not used in production, at the refineries the gas flares were created. As a result, the atmosphere received a huge amount of toxic to wildlife substances containing sulfur.

Scientists of various specialties unanimously note the large-scale negative impact of oil and gas production and refining activities on atmospheric air [3-8]. The effects of non-carcinogenic exposure to atmospheric air polluted with oxides of nitrogen, carbon, aromatic hydrocarbons [9] and gray-containing compounds have the greatest negative impact on the health of both adults and children. This dependence is confirmed by the results of sanitary and hygienic monitoring. It was found that diseases of the respiratory organs of the inhabitants of 243.5 thousand residents of the Irkutsk region can be caused by sulfur dioxide, 241.2 thousand people with carbon disulfide [10].

In the Resolution of the Chief State Sanitary Doctor of the Russian Federation No. 74, the enterprises, whose activities are related to the production of carbon disulfide, are assigned to enterprises of the first class of danger [11]. That means, they represent the greatest danger to the ecological well-being of the population.

The state is taking measures that facilitate the transition of petrochemical enterprises to environmentally friendly production. Such measures are one of the constituent methods of state regulation of the modern economy [12]. The implemented measures of state regulation in this area can be attributed to the group of extra-budgetary methods. This is due to the imposition of new duties that require financial expenditures from economic entities on the enterprises of oil and gas complex [13].

Existing methods of sulfur neutralization, which is a part of the flue gases, are based on the absorption of sulfur by various compounds. However, often the compounds obtained as a result of such measures are not used, but are released into the environment [14].
According to the results of the rating for 2016, about 181 tons of emissions entered the atmosphere of Angarsk, of which the maximum permissible concentrations of sulfur oxide were exceeded 3 times. In Angarsk, the highest concentration of hydrogen sulfide in the Irkutsk region is registered (the maximum permissible concentration is 8.4 times higher) [15]. Angarsk Petrochemical Company (hereinafter - "ANKhK" JSC) is one of the largest manufacturers of refined petrochemicals in Russia. It processes more than 9 million tons of oil per year [16]. Therefore, an assessment of the environmental and economic efficiency of refinery modernization through the construction of a sulfur recovery unit will be carried out on the example of "ANKhK" JSC.

"ANKhK" JSC evaluates the increase in environmental safety of production as one of the priority directions of the company [17].

In order to utilize hydrogen sulfide, "ANKhK" JSC carries out construction of an elemental sulfur recovery unit (hereinafter referred to as ESRU).

ESRU is a complex aimed at reducing the negative impact on the environment of hydrogen sulfide-containing gases, which are released during refining as a by-product. After cleaning, the content of hydrogen sulfide is 0.01%, ammonia - 0%, which determines the high environmental significance of the implementation of the technology.

The side gas, which contains hydrogen sulfide, is neutralized to produce elemental sulfur during the operation of the ESRU.

In 2017, the volume of emissions of "ANKhK" JSC to the atmosphere is 34,386.34 tons, which is 13% of the total emissions in the city [18]. After commissioning of ESRU, the amount of emissions from the processing of the evolved gases will decrease. As a result, the operating mode of flare devices, which were previously burning associated natural gas, will change.

The processing of raw materials of the designed ESRU is 6000 nm$^3$/h of sulfur-hydrogen. The list and characteristics of the substances that will enter the atmosphere from the sulfur production unit put into operation are listed in Table 1.
Table 1. Characteristics of substances secreted by ESRU into the atmosphere.

| Substance code | Name of contaminants | Maximum permissible single concentration, μg / m³ | Maximum permissible daily average concentration, μg / m³ | Approximately safe exposure level, μg / m³ | Hazard class |
|----------------|----------------------|-----------------------------------------------|-------------------------------------------------|------------------------------------------|-------------|
| 0301           | Nitrogen dioxide     | 250                                           | 100                                             | -                                        | 2           |
| 0303           | Ammonia              | 200                                           | -                                               | -                                        | 4           |
| 0330           | Sulfur dioxide       | 500                                           | 200                                             | -                                        | 3           |
| 0331           | Elemental sulfur     | -                                             | -                                               | 70                                       | -           |
| 0333           | Hydrogen sulphide    | 8                                             | -                                               | -                                        | 2           |
| 0337           | Carbon monoxide      | 5000                                          | 3000                                            | -                                        | 4           |
| 0401           | Saturated hydrocarbons of aliphatic series C₁-C₁₀ | 25000                                          | 10000                                           | -                                        | 4           |
| 3401           | Methyldiethanol amine | -                                              | -                                               | 50                                       | -           |

Emissions of pollutants from the projected unit for the production of elemental sulfur are presented in Table 2.

Table 2. The volume of emissions of pollutants into the atmosphere from ESRU.

| Name | Substance code | Name of pollutants | According to the project, t / year |
|------|----------------|--------------------|-----------------------------------|
| 1. Reconditioning unit of a sole solution of MDEA, sour waters stripping units | 0301 | Nitrogen (IV) oxide | 49,429 |
|      | 0330           | Sulfur dioxide     | 148,287                           |
|      | 0333           | Hydrogen sulphide  | 1,891                             |
The largest amount of emissions from ESRU enters the atmosphere through the chimney. Flue gases are formed by the products of combustion of fuel (nitrogen dioxide, carbon monoxide, saturated hydrocarbons $C_1$-$C_{10}$) and substances formed during the neutralization of associated gas from sulfur compounds (sulfur dioxide and hydrogen sulfide).

The main purpose of the modernization is to reduce the existing amount of emissions of the enterprise. Gas flares refineries pose a significant threat to environmental safety. Reducing the volume of combustible gases will lead to a reduction in emissions of substances into the environment.

The change in pollutant emissions from gas flares after the introduction of ESRU is presented in Table 3.

**Table 3.** The volume of pollutants emissions into the atmosphere from gas flares.

| Name                                    | Release and emission of pollutants |
|-----------------------------------------|------------------------------------|
| 0331 Elemental sulfur                   | 0,156                              |
| 0333 Hydrogen sulphide                  | 0,038                              |
| 0331 Hydrogen sulphide                  | 0,378                              |
| 0331 Elemental sulfur                   | 0,069                              |
| 0331 Elemental sulfur                   | 0,069                              |
| 0333 Hydrogen sulphide                  | 0,005                              |
| 0330 Sulfur dioxide                     | 0,204                              |
| 0331 Elemental sulfur                   | 0,069                              |
| 0333 Hydrogen sulphide                  | 0,005                              |
| 0330 Sulfur dioxide                     | 0,204                              |
| 0331 Elemental sulfur                   | 0,069                              |
| 0333 Hydrogen sulphide                  | 0,005                              |

2. Degassed sulfur tank TK-501

| 0331 Elemental sulfur                   | 0,069                              |
| 0333 Hydrogen sulphide                  | 0,005                              |

3. Storage tanks for liquid sulfur TK-501A / B / C / 0

| 0331 Elemental sulfur                   | 0,069                              |
| 0333 Hydrogen sulphide                  | 0,005                              |

4. Granulated sulfur warehouse

| 0337 Carbon monoxide                     | 24,714                             |
| 0401 Saturated hydrocarbons $C_1$-$C_{10}$ | 1,447                             |
| Substance code | Name of pollutants | Current position, tons/year | According to the project, tons/year |
|----------------|--------------------|----------------------------|----------------------------------|
| 0301           | Nitrogen (IV) oxide| 27,010                     | 24,353                           |
| 0330           | Sulfur dioxide     | 1904,045                   | 244,860                          |
| 0337           | Carbon monoxide    | 180,067                    | 162,355                          |
| 0401           | Hydrocarbons before. C1-C10 | 4,502 | 4,059 |
| 0301           | Nitrogen (IV) oxide| 5,576                      | 5,576                            |
| 0330           | Sulfur dioxide     | 7469,310                   | 3291,879                         |
| 0337           | Carbon monoxide    | 37,171                     | 37,171                           |
| 0401           | Saturated hydrocarbons C1-C10 | 0,929 | 0,929 |

The greatest positive change from the operation of gas torches will be observed in reducing the amount of sulfur dioxide emissions by 7.78 times (or 1,659.185 tons / year) in the first mode. This is the main environmental effect gained from the modernization.

As a result, the total reduction in sulfur dioxide emissions will be 5908.616 tons / year, existing emissions will be reduced by 2.5 times. In addition, there will be a decrease in emissions of saturated hydrocarbons, fuel oil ash, with a slight increase in the amount of nitrogen dioxide, ammonia, elemental sulfur, hydrogen sulfide, carbon monoxide, methylamine.

According to the modernization plan, the total emissions of pollutants will be 28,499.859 tons/year for the enterprise as a whole. The expected decrease in substances entering the atmospheric air is 5886.480 tons/year. As a result, total emissions to the atmosphere will be reduced by 17%.

Based on the justification presented in the article for the ecological efficiency of the refinery modernization project, it can be concluded that its implementation is advisable. The project will be one of the elements of increasing Russia's economic security [19].

The assessment of the environmental effectiveness from implemented modernization plan demonstrates the achievement of high results in reducing the negative impact on the environment (hereinafter referred to as NIE), especially on the atmospheric air. Reducing sulfur emissions into the atmosphere will reduce the incidence of respiratory diseases in the region.

At the same time there is an opportunity to completely get rid of payments for NIE by introducing the best technologies available. The amount
of potential income from the implementation of the project will be defined as savings due to exemption from payments for the NIE. The implementation of the modernization program is supposed to reduce the fee to 0. Therefore, in the face of changes in Russia's environmental policy, the introduction of ISRU will increase not only environmental but also economic efficiency. Otherwise, the state will apply incremental ratios when calculating payments for NIE. This will lead to a significant reduction in business profitability.

Thus, the construction of an elemental sulfur recovery unit meets the latest requirements in the field of environmental protection. This contributes to a significant reduction in emissions of hydrogen sulfide and sulfur dioxide. The upgrading should start now. From January 1, 2020, the calculation of payments for NIE will be changed by applying different coefficients, based on the environmental policy of the enterprise. This is aimed at stimulating the implementation of environmental projects.

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