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FORMING CIRCULAR ECONOMY LINKS IN CHEMICAL INDUSTRY: LIME, CAUSTIC ASH, SALT AND GYPSUM PRODUCTION IN THE URALS

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ABSTRACT

Chemical and construction materials industries are the resource intensive sectors regulated by both the legislation based on Best Available Techniques (BAT) and carbon-related legislation. In Russia, BAT concept regarded as an instrument for the industrial resource efficiency enhancement. Environmental Performance Indicators are included in BAT Reference Documents (BREFs) forming a basis for the assessment of greenhouse gases (GHG) emissions. To optimise two interrelated regulatory systems (BAT and GHG), BATs providing for the high resource efficiency are seen as the top priority for reducing emissions of ordinary pollutants and GHGs as well as and for forming inter-sector links typical for the circular economy.

The article describes the approaches to circular economy using as a reference an existing Russian industrial hub. Authors analyse industrial symbiosis of chemical installations (producing construction materials and chemical substances) and interconnecting material flows from various technological processes (soda ash, lime and gypsum production) and assess pollutant emissions generated in the new technological processes and use of chromium production waste as a secondary resource.

The article shows the possibility of complete absorption of carbon dioxide formed during the production of lime and decomposition (calcination) of sodium bicarbonate during soda ash production process. It is recommended to take into account the aspects of the secondary resource use while determining the sectoral (vertical) and inter-sectoral (horizontal) Best Available Techniques. Authors consider the possibilities for optimisation of technological regulation and application of General Binding Rules for the management of insignificant environmental industrial aspects.

Keywords: Best Available Techniques, resource efficiency, greenhouse gases, decarbonisation, General Binding Rules, circular economy

INTRODUCTION

The circular economy concept (CE) is becoming a characteristic feature of the environmental industrial policy in world’s largest economies. The CE principles stimulate industry to use energy, raw materials, water, etc. as efficiently as possible, minimise waste generation and production losses, and involve the accumulated waste in the economic turnover, thus attempting to form material and energy flows similar to those circulating in natural ecosystems [1]. At the same time, within an industrial

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symbiosis, installations interact with each other as components of a single (united) industrial and environmental system [2]. The CE principles are starting to be included in the laws and norms based on the Best Available Techniques (BAT) concept. Currently international and Russian experts regard BAT as a set of technological, technical and managerial solutions ensuring high resource efficiency and environmental performance. However, experts of the organisation for Economic Co-Operation and Development (OECD) projects (2017-2021) emphasise that the involvement of secondary resources in production processes during BAT determination process is already being discussed both by the Bureau for Integrated Pollution Prevention and Control of the European Union and by the environmental protection agencies and ministries in many countries [3, 4]. The goal of the article is to analyse environmental and technological solutions applied for the formation of an industrial symbiosis of chemical industries based on the circular economy principles, and to develop recommendations for considering them when updating sectoral and inter-sectoral Reference Documents on Best Available Techniques (BREFs).

NOVOTROITSK INDUSTRIAL HUB: A CASE STUDY

JSC Novotroitsk Chromium Compounds Plant (JSC NZKhS) located in the city of Novotroitsk, the Orenburg Region of the Russian Federation, has been implementing a full cycle chromium production for over 50 years: from ore processing to pure metallic chromium production as well as production of chromium compounds.

The key stage in the technological process is sodium monochromate manufacturing, since this compound is a prerequisite for a wide range of chromium-containing commercial products: sodium dichromate, chromium oxide, chromic acid anhydride and various colouring agents.

The sodium monochromate production process consists of the following stages:

- raw material (dolomite and chrome ore) processing, drying, classification and grinding;
- batch mixing (by adding soda ash);
- oxidative calcination;
- leaching;
- separation of sodium monochromate from sludge.

The main type of waste generated during chrome ores processing is sodium salt sludge; JSC NZKhS used to produce 2.5 tonnes of sludge per 1 tonne of sodium monochromate. Since one-two decades ago, there were no technologies for processing such wastes in the Russian Federation, sodium monochromate was disposed to sludge collector located not far from the industrial site.

In 2014, JSC NZKhS carried out large-scale modernisation activities, switching to the dolomite-free technology, which implies the abandonment of the inert filler due to the re-use of non-metallic residue. New technological solution made it possible to increase the energy efficiency of production (due to elimination of energy consumption for drying and crushing of dolomite) and resource efficiency (due to excluding dolomite and limestone from the production of calcium-containing minerals (up to 160 thousand tonnes per year) and increasing the rate of chromium extraction from ore). The specific amount of the generated waste decreased to 1.1 tonnes of sludge per 1 tonne of sodium monochromate.

The next stage in the development of the industrial hub was the design and launch of Novotroitsk Soda Ash Plant LLC (NSZ LLC), the industry with the main purpose to supply NZKhS JSC with soda ash, the batch component for sodium monochromate production, and to process sodium sulphate – a by-product of chromium compounds manufacturing. The whole process for designing industrial hub is shown below (see Fig. 1).

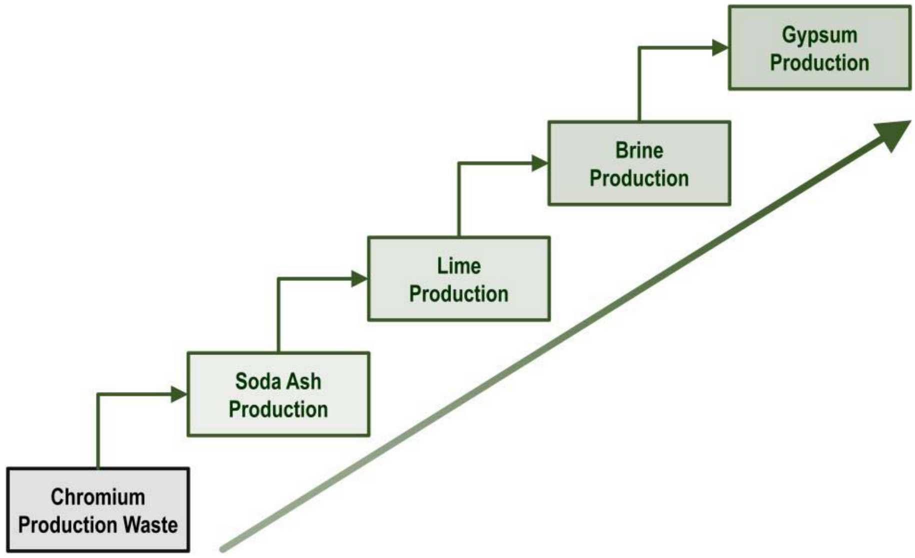

Figure 1. Novotroitsk Industrial Hub: Design and Development Stages

The traditional method for the soda ash production applied in Russia is the Solvay method based on the preparation of sodium bicarbonate ($NaHCO_3$) by dissolving ammonia in a purified sodium chloride solution saturated with carbon dioxide. The main disadvantages of this method lie in the low resource efficiency (1.6 tonnes of sodium chloride per 1 tonne of soda ash) and significant amount of sludge generated during the settling of the distilled liquid in sedimentation tanks.

However, NSZ LLC has implemented a modernised technology for the soda ash production (100 thousand tonnes per year in terms); it uses by-products of chromium compounds manufacturing as secondary material resources, thus following basic principles of the circular economy (Fig. 2).

NSZ LLC uses conditioned brine, lime and carbon dioxide as raw materials for soda ash production. Conditioned brine manufactured by special brine production line, while lime and carbon dioxide are the part of lime production process. Still waste liquid from ammonia regeneration and lime slaking waste are considered as secondary material resources and used to obtain conditioned brine and gypsum. Still waste liquid contains calcium chloride ($CaCl_2$) and sodium (NaCl); that is why it is processed in brine production line thus excluding generation of non-recyclable solid and liquid waste.

The sodium chloride brine production is a main component for soda ash manufacturing process and calcium sulphate dehydrate production; the latter is used during hemihydrate gypsum (alabaster) production.

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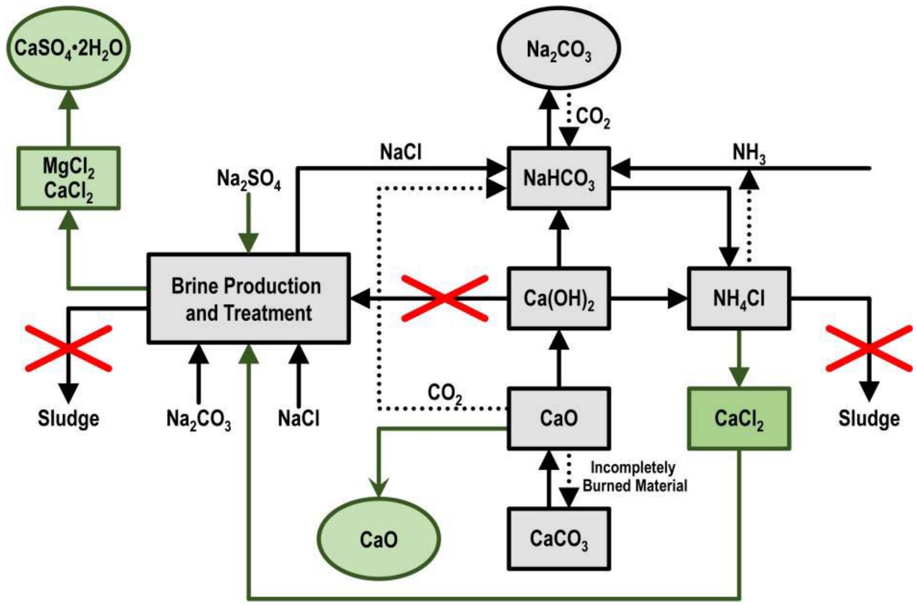

Figure 2. Flow chart of the Soda Ash Production

Comparison of traditional Solvay method and NSZ LLC approach to soda ash production shows that the technological solution applied by Novotroitsk company allows (1) to accept waste from a third-party and use it as a secondary resource for gypsum and soda ash production, (2) to reduce emissions greenhouse gases by directing carbon dioxide to the other production lines and (3) to eliminate industrial waste generation during soda ash production.

POLICY ANALYSIS

It should be noted that Novotoritsk industrial hub includes so-called category I installations subject to BAT regulation in accordance with Russian law. Within the legal framework established within the Russian Federation both concepts: (1) circular economy and (2) the best available techniques (by preventing negative impact on the environment via modernisation of industrial production or developing interconnected technological processes as it was done in Novotroitsk) are considered to be superior compared to end-of-pipe solutions (Fig.3) [3].

Russian BAT-related regulation is still developing. The optimisation of BAT-AELs and techniques occurs simultaneously with the improvement of procedures for assessing the environmental impact, approving projects of Environmental Performance Enhancement Programmes and issuing Integrated Environmental Permits. That is why the authors suggest to consider another regulative tool: the so-called standard rules or General Binding Rules (GBR). Despite the fact that the number of key environmental issues of each technological production process is relatively small, the total number of substances controlled in accordance with the requirements of the Russian legislation often reaches several dozens. For example, Novotroitsk industrial hub during lime, gypsum, brine and soda ash production emits into the air 2544 tonnes per year of 18 contaminants, while carbon monoxide, nitrogen oxides, ammonia and inorganic dust are responsible for 2524 tonnes per year (~99 %) of air emissions. But at the same time, the current Russian environmental legislation requires to assess emissions of 3,4-benz(a)pyrene, which – theoretically – could be formed and emitted to the air; the overall year emissions of this contaminate do not exceed 11.2×10^{-9} tonnes (11.2 mg) per year for the main activity (lime production in gas-fired kilns) and additional 5.8×10^{-5} tonnes (58 g) per year for various gas-fired boilers. It is clear that it is impossible to control such emissions by instrumental methods; therefore, amounts of such pollutants are re-calculated once a year (based on data on the fuel use).

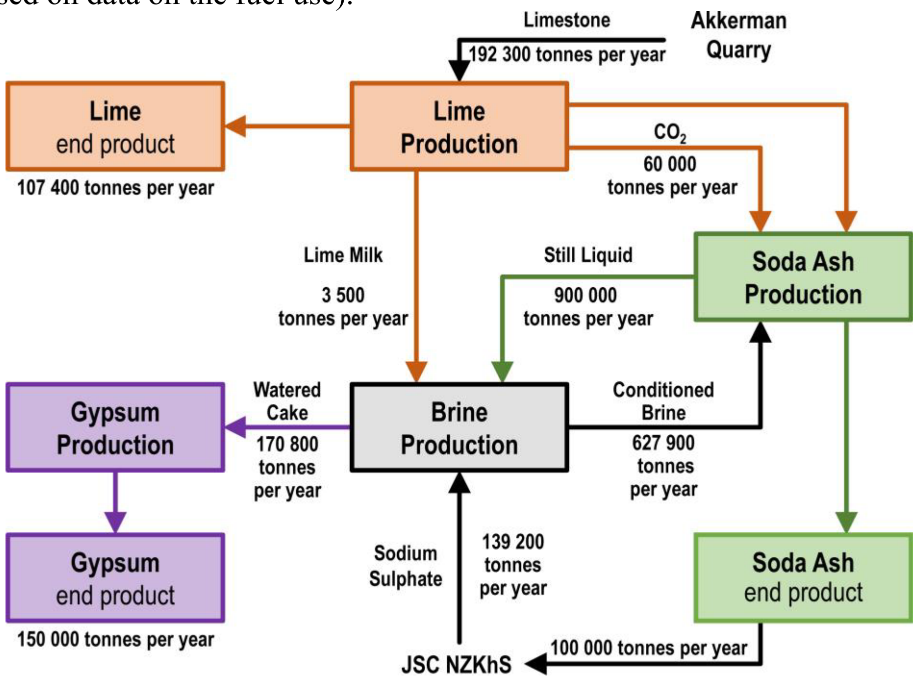

Figure 3. Interaction Scheme for Material Flows in Novotroitsk Industrial Hub

This practice of reporting emissions of contaminants, which are insignificant and actually uncharacteristic for the main production processes, leads to an excessive administrative burden on both the industrial site environmental engineers and the employees of supervisory authorities. The establishment of General Binding Rules for such insignificant, secondary, auxiliary processes and substances released in small quantities would allow practitioners to focus their efforts on increasing the resource efficiency, as well as preventing and controlling pollution caused by the operation of the main emission sources, responsible for 80-99 % of emissions (depending on the industry sector) [3, 5].

Another route for optimising the system of technological regulation lies in utilisation of CE principles while determining BAT while reviewing (updating) BAT Reference Documents (BREFs). In fact, this process has already begun: the inclusion of resource efficiency indicators (BAT-Associated Environmental Performance Levels, BAT-AEPLs) in BREFs certainly reflects the internationally accepted requirements for reducing the resource intensity of production processes [3, 6, 7, 8].

BAT should also include technologies centred on the replacement of natural resources by secondary materials [9]. At the first stage, this can be done by BREFs on solid inorganic substances manufacturing, cement and glass production. Simultaneously with the description of such approaches in BREFs, it is necessary to provide for the development of the legal framework and instruments for financial support.

The development of carbon legislation, the introduction of quotas on greenhouse gas emissions, the initiation of projects aimed at capturing and absorbing CO_2 will serve as

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stimuli for strengthening position of the environmental industrial policy as a tool for developing a circular economy in Russia [10, 11, 12].

CONCLUSION

The example of the Novotroitsk industrial hub shows the possibility of combining various industries that implement chemical-technological processes for the production of high-temperature materials (lime, gypsum) and solid inorganic substances (soda ash) as components of one industrial-ecological system (a term used in Russian) or an industrial symbiosis (a term used widely in many countries). Utilisation of accumulated waste as secondary material resources, efficient use of raw materials and materials, minimisation of new waste generation allow not only to implement circular economy principles, but at the same time to reduce the negative impact on the Novotroitsk environment. This is a very important point because Novotroitsk is a typical industrial town: iron and non-ferrous metallurgy, chemical and cement industries are historically located close to each other and contribute significantly towards the pollution of the atmospheric air.

The authors believe that the successful example of the Novotroitsk industrial hub confirms the possibility of transforming the Russian economy from the linear and resource intensive mode to the circular economy model. The results obtained deserve a wider dissemination, and the experience of JSC Novotroitsk Chromium Compounds Plant should be used as an example for possible modernisation of similar industrial site in future with the support of the Russian "green" investments system. The principles of the industrial symbiosis should be taken into account when updating sectoral and inter-sectoral Reference Documents on Best Available Techniques.

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