Study of the Environmental İmpact of Petroleum Product Waste Generated During Polyethylene Production at the SOCAR Polymer Plant

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Abstract

This paper provides a detailed analysis of the environmental impact of high- and low-pressure polyethylene production processes. It examines the morphological composition of waste generated during the synthesis, polymerization, and granulation stages. Particular attention is paid to the emission of volatile organic and inorganic compounds, the contamination of wastewater with heavy metals (catalyst residues), and the problem of microplastics in the form of industrial pellets. An analysis of the qualitative and quantitative composition of gaseous, liquid, and solid waste is carried out. The work contains statistical data, an analysis of waste generation dynamics, and an assessment of its toxicological impact on the atmosphere, hydrosphere, and lithosphere. The research showed that all stages of polyethylene production at the SOCAR Polymer plant comply with the standard.

Keywords: polyethylene, polymerization, petrochemical waste, volatile organic inorganic compounds, wastewater, Ziegler-Natta catalysts, microplastics, recycling**.**

1. Introduction

The production of synthetic polymers is one of the fastest growing sectors of the global chemical industry. Polyethylene (PE), thanks to its unique physical and chemical properties, low cost, and versatility, occupies a leading position among all plastics produced (Kayumov et al.203). Global polyethylene production exceeds 100 million tons per year and continues to grow, driven by demand for packaging materials, pipes, insulation, and consumer goods. In developed countries, per capita consumption was 85-90 kg per person, and this figure continues to grow annually. Along with the growth in polyethylene production, its negative impact on the environment has also increased (Kayumov 2014).

The technological cycle for producing polyethylene includes the processes of hydrocarbon pyrolysis, gas separation, polymerization (at high or low pressure), degassing, and granulation. Each of these stages produces specific types of waste: gaseous emissions containing ethylene and solvents; liquid effluents contaminated with oligomers and catalytic sludge; solid waste in the form of defective polymer, "lumps" and dust. Polymer materials are usually multicomponent systems created using various polymer components. Technological waste in the production of polymer materials arises during their synthesis and processing. They are divided into recyclable materials and technological waste that cannot be recycled. Such waste accounts for 5 to 35%. Based on the insoluble basis of the waste, the raw material is of high quality, not differing from the properties of the original polymer. No special equipment is required to process this waste, which is produced at the same plant. Waste generated during production is used in the processing of various products in addition to various products used as raw materials. In the production of multicomponent polymers, as well as in their practical use, there are processes of separating a number of harmful low-molecular substances from materials (Kayumov et al. 2014, Kayumov 2015).

Polymer materials with physical, chemical, structural, and technological properties based on various plastics and elastomers are widely used in various areas of the economy and medicine. This is associated with the generation of waste at all stages of the production and processing of polymer materials. Therefore, their disposal is a pressing issue, and their negative impact on human health and the environment has always been a global problem. The solution to environmental problems has led to strict requirements: the production of polymers must be environmentally friendly or at least have a minimal impact on the environment (Kayumov et al. 2018).

The purpose of this work is to identify harmful substances emitted into the atmosphere at SOCAR Polymer production facilities, study their concentration in the air, and assess the environmental impact of each of them on the surrounding environment.

2. Materials and methods

Polyethylene is the most widely used polymer in the world, accounting for more than 30% of the total plastics market (Kayumov B.A. et al .2019). The chemical formula of the monomer is ethylene (CH_2=CH_2).

$$nCH_2 = CH_2 \xrightarrow{P,t,cat} [-CH_2 - CH_2-]_n$$

Despite the chemical inertness of the product itself, the technological processes involved in its production (polymerization, separation, granulation) are associated with the generation of significant amounts of waste. Technological stages and sources of waste generation Polyethylene production is divided into two main types: LDPE (low-density polyethylene): Radical polymerization at high pressure. HDPE (high-density polyethylene): Ion-coordination polymerization at low pressure using catalysts (Almatayev et al. 2019). Specific types of waste are generated at each stage. The use of organometallic catalysts (Ziegler-Natta, chromium) leads to the formation of toxic sludge containing heavy metals.

In various countries, the production of polyethylene results in the release of many tons of waste into the atmosphere, which severely pollutes the environment. Fig. 1.

***Figure 1**. Emissions into the atmosphere during polyethylene production*

Industrial pellets (Nurdles): This is one of the most pressing problems. Small granules of raw material (2-5 mm in diameter) often spill during transportation and packaging, ending up in storm drains and from there into rivers and oceans. Fig. 2.

***Figure 2.** Emissions of pollutants into the atmosphere during polyethylene production (Karimkhojaev et al. 2020)*

The ethylene production process and the stages of atmospheric pollutant emissions are shown in Figure 3.

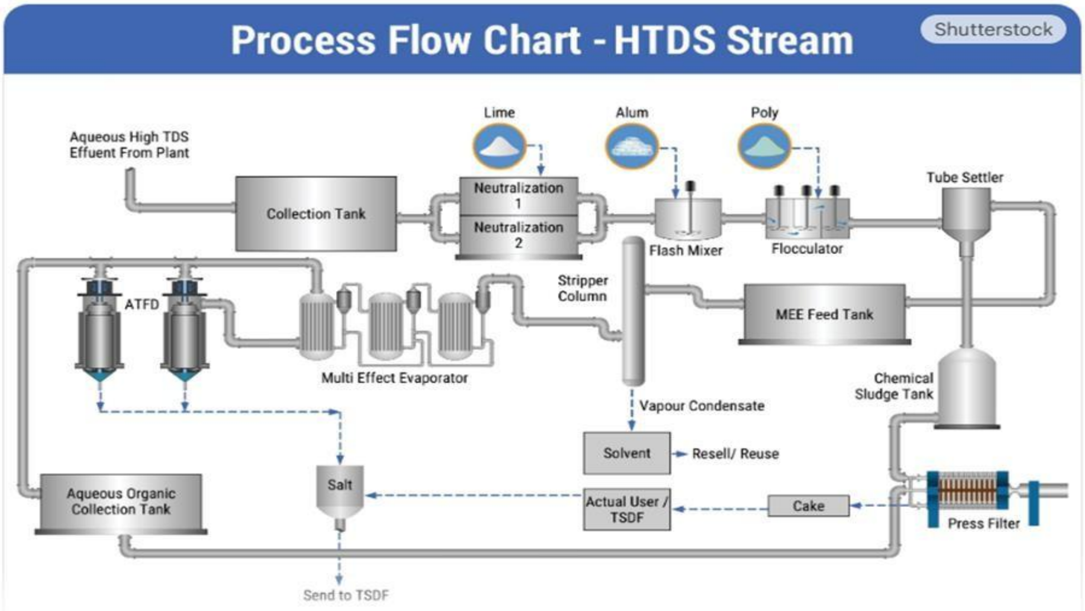

Figure 3. *Schematic diagram of waste generation sources in the process of ethylene suspension polymerization.*

We have access to information on the dynamics of polyethylene production from 2009 to 2023 (Claudia et al. 2020). The graph clearly shows that the growth in the production of plastic materials is increasing significantly year after year. Naturally, this is also a source of environmental pollution.

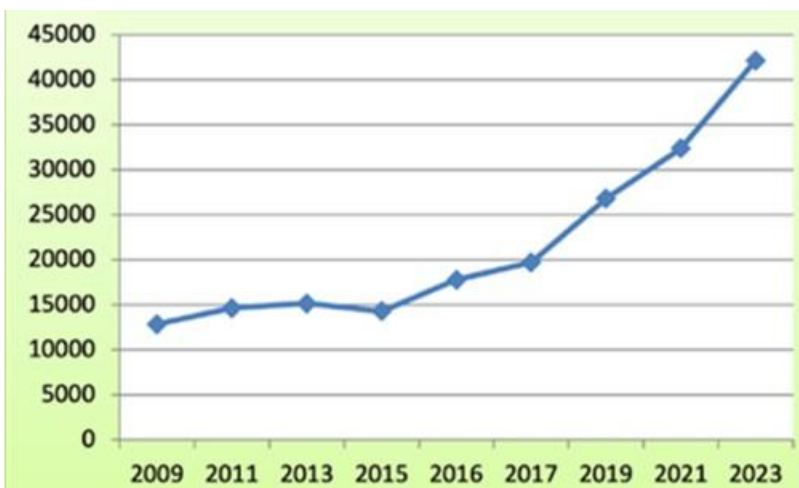

Figure 4. *Dynamics of polyethylene production in Azerbaijan in 2009-2023.*

The technological process of polyethylene production consists of three main stages. The first stage involves the preparation of raw materials, namely the purification of raw materials from impurities and contaminants, as well as the regeneration of catalysts used in purification. This stage is characterized by the highest formation of harmful substances that have a negative impact on the environment (Table 1). The data available in the literature on the total amount of pollutant emissions in polyethylene production is shown in table 1 (Pavlov et al. 2020).

Table 1. Emissions of pollutants into the atmosphere during polyethylene production

Pollutant	Hazard class	Mass of pollutant emissions per ton of product, kg/t	
		Minimum value	Maximum value
Suspended solids	-	-	0,072
Ethylene	4	2,45	6,7
Carbon monoxide	4	-	0,93
Butylene	4	0,011	0,053
Aliphatic	3	0,040	0,31
Hydrocarbons C1-C5 (excluding methane)	3	-	0,022
Aliphatic	3	0,0012	0,093
Hydrocarbons C6-C10	3	-	0,00018
Nitrogen dioxide	2	0,00021	0,16
Acetaldehyde	1	-	-

The second stage involves the synthesis of polyethylene in a reactor using initiators and catalysts – this stage is the main stage in the production of polyethylene. During the ethylene polymerization process, ethylene oxide may be formed, which can be purified and sold as a by-product, as well as benz(a)pyrene, which is classified as a Class I hazardous substance. It should be noted that pollutant emissions during the second stage are most often associated with malfunctions in the technological equipment.

At the final stage of production, called "granulation," polyethylene chips may form in the air, which when heated can release organic acids, formaldehyde, and acetaldehyde, as well as ethylene oxide. All these substances, when exceeding the maximum permissible concentration, lead to acute and chronic poisoning (V.A. Zaitsev 2018).

The Polypropylene and High-Density Polyethylene production areas at the SOCAR Polymer plant are designed to produce 200,000 tons of polypropylene and 120,000 tons of high-density polyethylene per year, respectively. Measurements were conducted by our team at 5 selected points in the production area of the SOCAR Polymer plant for PM10 (particulate matter), background radiation, dust, volatile organic compounds (VOC), sulfur dioxide (SO_2), nitrogen oxides (NOx), and noise levels in the ambient air. The coordinates of the measurement points were determined and the corresponding records were kept (Aliyev et al.2014, Claudia et al. 2020).

Environmental monitoring was organized in two phases (active and passive). The results of the studies conducted with mobile devices are presented in Table 2. For the determination of volatile organic compounds, Camsco tubes were used during passive monitoring; the gravimetric method was used for the determination of dust particles; and during active monitoring, a remote sensor "Qrawulf" device was used for the determination of CO, SO_2, NO, and NO_2 (Ivanov 2020, Johnson 2019). The collected samples were analyzed at Azecolab Company LLC, and the results of the laboratory analyses are presented in tables 2 and 3.

***Table 2**. Results of laboratory analysis conducted by Azecolab.*

Sernumber	Date	06.10.2025	Station indicators					Mobile device
1.	Parameters	Unit of measurement	Lesson 1. Between zones 02 and 03.	Section 2. Between units E-2 and E-5.	3. Between zones 01 and 05	4. Between object S-3 and zone 05	5. Near the nitrogen plant.	Gas analyzer
2.	NOx (nitric oxide)	mq/m^3	0,02	0,02	0,0	0,0	0,02	
3.	SO_2	mq/m^3	0,001	0,000	0,001	0,001	0,001	
4.	CO	mq/m^3	0,07	0,07	0,07	0,07	0,07	
5.	VOC	mq/m^3	0,02	0,02	0,02	0,02	0,02	
6.	General dust	mq/m^3	0,001	0,005	0,071	0,001	0,001	Dust meter
7.	Radiation	mkR/saat	11-13	10-12	10-11	11-13	10-11	Dosimeter
8.	Noise	dB	56-63	60-65	76-80	80-82	90-95	Sound measurement

***Table 3** Results of surveys conducted using mobile devices in polymer production areas.*

Gas sample								
Act No.	Date of analysis		Note					
	Started	Finished						
Order	06.10.2025	06.11.2025	Sample code					Regulatory document
	Parametrlər	Ölçü vahidi	St. 1. 19/00040	St. 2. 19/00041	St.3. 19/00042	St.4. 19/00043	St. 5. 19/00044	İSO 6976 ASTM D1945
1.	VOC	ppm	<1.00	<1.00	<1.00	300-990	9-17	
2.	CO carbon monoxide	Volume %	<0.01	<0.01	<0.01	<0.01	<0.01	
3.	SO_2 sulfur dioxide	Volume %	<0.01	<0.01	<0.01	<0.01	<0.01	
4.	N_2 (nitrogen)	Volume %	78,08	78,08	78,08	78,08	78,08	
5.	O_2 (oxygen)	Volume %	20,9	20,9	20,9	20,8	20,9	

Tables 4 and 5 show that nitrogen and volatile organic compounds, particulate matter, and nitrogen oxides in the air stream generated during the use and regeneration of catalysts in the technological process, which are mainly formed as a result of fuel combustion and contained in flue gases, are emitted into the atmosphere. If we consider the technological characteristics of the burner and the indicators of internal gas emissions in the process, we will see that they comply with environmental standards.

The tables below present the results of research and monitoring work on the topic “Study of the environmental impact of gas emissions generated during the production of polymers in the petrochemical industry” at SOCAR Polymer plants, which produce SOCAR polymers and are the most environmentally advanced project. An environmental analysis was conducted based on the results of the research work.

Table 4.

Composition of fuel gas (V,%) объемных процентах)) ilə)	
N_2	1,33
CO_2	4,11
CH_4	87,32
C_2H_6	3,22
C_3H_8	1,6
n-C_4H_{10}	1,01
H_2	1,41

Table 5.

The volume of waste gases sent for incineration in October.					
PP			YSPE		
Total (t)	431,67 ton	100%	Total (t)	286,15 т	100%
Propylene (t)	376,79 ton	87,29%	Ethylene, Ethane (t)	156,27 т	54,61%
Propane (t)	28,99 ton	6,72%	Hexene, Hexane (t)	3,81 т	1,33%
Hydrogen (kg)	69,75 kq	0,02%	Isobutane (t)	58,38 т	20,40%
Nitrogen (t)	6,40 ton	1%	Hydrogen (kg)	357,00 кг	0,12%
Ethylene (t)	16,20 ton	4%	Nitrogen (t)	67,05 т	23%
Others (isobutane, pentane, ethane, methane, etc.), (t)	3,22 ton	0,75%	Others (methane, butane, acetylene, etc.), (t)	0,29 т	0,1%

As can be seen from the tables, the measurement results at specified points at the polymer production plant are within acceptable limits for all parameters studied. Noise intensity was recorded at 80-

82 dB (slightly above normal). The noise level was recorded at 90-95 dB. The indicators for other measured parameters, including background radiation (10-13 μR/h) and total dust content (0.001-0.071 $\mu g/m^3$), are within the norm for the plant's territory. When considering hourly, daily, monthly, and annual indicators at SOCAR Polymer plants, they comply with the environmental standards set by the European Union (Kostin 2021).

The report scientifically substantiates the economic and environmental significance of organizing stationary or continuous environmental monitoring every two hours using a Hi-Flow sampler, personal Drager X2 gas analyzers with infrared cameras during the storage, transportation, and production of raw materials at a polymer manufacturing plant, gas leaks into the atmosphere from tank breathing valves and pipelines (flange connections), as well as the prevention of explosions, fires, and environmental pollution (Melnikova 2013).

3. Conclusion

The composition of harmful gases emitted into the atmosphere from SOCAR Polymer production areas and the concentration of each of them in the air were determined using modern gas analyzers: "Flow Meter," "Kamsko Tube," "Arex," and "Graewulf." PM10 dust particles, NOx, SO_2, CO, harmful gases, and volatile organic compounds were identified in the waste gases emitted into the atmosphere from the production areas, and environmental analyses were also carried out . It was established that the neutralization of waste gas mixtures produced during technological processes using a regenerative thermal oxidizer (RTO) burner, currently used in polymer plants, at the required level is of great environmental importance for the protection of atmospheric air. The implementation of a "zero emissions" strategy is an achievable goal for companies in the industry by 2030.

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