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PHYSICOCHEMICAL ANALYSIS OF OIL SLUDGE FROM THE ABSHERON PENINSULA

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This article presents the results of the analysis, study and study of the physicochemical properties of oil sludge from contaminated areas on the Absheron Peninsula. It was determined that the concentrations of heavy metals, especially lead (Pb), cadmium (Cd), vanadium (V) and nickel (Ni) in oil sludge samples taken from the Bibiheybat and Balakhani fields significantly exceed the current international and local environmental safety standards. FTIR and IR spectroscopic analysis were used for detailed analysis. IR spectra were analyzed using specialized software (Agilent MicroLab FTIR software). During this analysis, the main functional groups such as aliphatic hydrocarbons (C–H stretching vibrations), aromatic hydrocarbons (C=C stretching vibrations), carbonyl groups (C=O stretching vibrations), hydroxyl groups (-OH stretching vibrations) and carboxylic acids (–COOH vibrations) were identified. Thus, the detailed information obtained from the application of ICP-OES and FTIR spectroscopy methods for elemental and molecular analysis of oil sludge constitutes a fundamental scientific and technical basis for environmental management, pollution reduction, and effective cleanup measures on the Absheron Peninsula.

Keywords: *oil sludge, Absheron Peninsula, FTIR spectroscopy, ICP-OES, heavy metals, environmental pollution, remediation*

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Introduction

Oil sludge is one of the most hazardous wastes generated during oil extraction, transportation, storage and refining processes [1-4]. Due to its complex physicochemical composition, oil sludge contains a wide range of toxic hydrocarbons, heavy metals and other hazardous compounds that pose serious risks to the environment and human health [5-8]. The accumulation of oil sludge in industrial regions leads to long-term contamination of soil and groundwater resources, deterioration of ecosystems and reduction of biodiversity [9-11]. Therefore, the investigation of the physicochemical properties of oil sludge and the development of effective remediation and utilization technologies remain among the important environmental challenges worldwide.

Various physical, chemical and biological methods are currently applied for the treatment and disposal of oil sludge [12-16]. Physical methods mainly involve separation, filtration and thermal treatment processes; however, they often provide only partial purification and require significant energy consumption. Chemical methods are considered more effective for the removal of hydrocarbons and toxic compounds, although they may generate secondary pollutants and create additional environmental risks. Biological approaches are environmentally friendly, but they generally require long processing times and are not suitable for all types of oil sludge [17-21]. For these reasons, comprehensive physicochemical characterization of oil sludge is necessary for selecting appropriate treatment and remediation strategies.

The Absheron Peninsula is one of the oldest oil-producing regions in the world and has been subjected to intensive industrial activities for more than a century. As a result of long-term oil extraction and processing operations, large quantities of oil sludge and petroleum-contaminated waste have accumulated in different industrial areas, particularly in the Bibiheybat, Balakhani, Surakhani and Ramana fields. These wastes contain significant amounts of heavy metals and persistent organic pollutants that negatively affect environmental quality and ecological stability in the region [22, 23].

Modern analytical methods such as Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) and Fourier Transform Infrared Spectroscopy (FTIR) play an important role in the detailed characterization of oil sludge. ICP-OES allows accurate determination of elemental composition and heavy metal concentrations, while FTIR spectroscopy provides valuable information about the molecular structure and functional groups present in hydrocarbon-containing materials. The combined application of these methods enables comprehensive evaluation of both elemental and molecular characteristics of oil sludge samples [24-31].

The aim of the present study is to investigate the physicochemical properties of oil sludge samples collected from different oil fields of the Absheron Peninsula and to evaluate their environmental impact using ICP-OES and FTIR analytical methods. Special attention was given to the determination of heavy metal concentrations and identification of major functional groups associated with petroleum hydrocarbons and oxidized organic compounds. The obtained results may contribute to the development of effective environmental management and remediation strategies for oil-contaminated areas of the Absheron Peninsula.

Experimental Part

According to the results of the analyses (Table 1), it was determined that the concentrations of heavy metals – especially lead (Pb), cadmium (Cd), vanadium (V) and nickel (Ni) – in oil sludge samples taken from the Bibiheybat and Balakhani fields were significantly higher than the current international and local environmental safety standards.

Thus, the average concentration of Pb in the Bibiheybat area was 45.3 mg/kg, and in the Balakhani area it was 50.0 mg/kg. These values are approximately 4-5 times higher than the ecological normative limit of 10 mg/kg. The presence of lead at this level indicates a high level of pollution as a result of long-term industrial activities in these areas and a serious threat to the environment, especially soil and water environments.

The concentration of cadmium (Cd) in the Bibiheybet area was on average 1.2 mg/kg, and in the Balakhani area 1.5 mg/kg. These values exceed the normatively accepted maximum limit (0.5 mg/kg) by about 2-3 times. Cadmium, even at low concentrations, can bioaccumulate and have a toxic effect on living organisms, which further complicates the ecological situation in these areas.

Concentrations of vanadium (V) were particularly high in both areas. In Bibiheybet, it was determined at 105.7 mg/kg, and in Balakhani, it was determined at 110 mg/kg. Compared to the international regulatory limit of 50 mg/kg, the concentrations determined are more than twice as high. The high concentrations of this metal are mainly associated with crude oil and various industrial reagents used in production processes.

Concentrations of the element Nickel (Ni) were also significantly higher than normal in both areas. 98.5 mg/kg was determined in Bibiheybet, and 100 mg/kg in Balakhani. These indicators are more than three times higher than the ecological normative limit of 30 mg/kg. High levels of nickel in the soil negatively affect vegetation, complicate the ecological restoration of the soil, and cause long-term damage to local biodiversity.

Table 1. Elemental analysis results of samples taken from the relevant deposit

Bed	Element	Solidity (mg/kg)	Standart Sapma (mg/kg)	Regulatory Limit (mg/kg)
Bibiheybat	Lead (Pb)	45.3	2.1	10.0
	Cadmium (Cd)	1.2	0.05	0.5
	Mercury (Hg)	0.45	0.02	0.1
	Vanadium (V)	105.7	4.3	50.0
	Nickel (Ni)	98.5	3.9	30.0
	Sink (Zn)	56.4	1.8	100.0
	Mis (With)	35.9	1.5	25.0
	Iron (Fe)	200.0	10.0	300.0
	Sodium (Na)	150.0	7.0	200.0
	Calcium (Ca)	300.0	15.0	1000.0
	Silicon (Si)	1000.0	50.0	N/A
	Phosphorus (P)	30.0	1.5	N/A
Balakhani	Lead (Pb)	50.0	3.0	10.0
	Cadmium (Cd)	1.5	0.06	0.5
	Mercury (Hg)	0.5	0.03	0.1
	Vanadium (V)	110.0	5.0	50.0
	Nickel (Ni)	100.0	4.5	30.0
	Sink (Zn)	58.0	2.0	100.0
	Mis (With)	37.0	1.8	25.0
	Iron (Fe)	210.0	12.0	300.0
	Sodium (Na)	160.0	8.0	200.0
	Calcium (Ca)	320.0	16.0	1000.0
	Silicon (Si)	1100.0	55.0	N/A
	Phosphorus (P)	35.0	1.8	N/A
Ramana	Lead (Pb)	42.0	1.8	10.0
	Cadmium (Cd)	1.0	0.04	0.5
	Mercury (Hg)	0.4	0.01	0.1
	Vanadium (V)	102.0	4.0	50.0
	Nickel (Ni)	95.0	3.5	30.0
	Sink (Zn)	54.0	1.9	100.0
	Mis (With)	34.0	1.4	25.0
	Iron (Fe)	190.0	9.0	300.0
	Sodium (Na)	140.0	6.5	200.0
	Calcium (Ca)	290.0	14.0	1000.0
	Silicon (Si)	950.0	45.0	N/A
	Phosphorus (P)	28.0	1.2	N/A
Surakhani	Lead (Pb)	48.5	2.5	10.0
	Cadmium (Cd)	1.3	0.05	0.5
	Mercury (Hg)	0.42	0.02	0.1
	Vanadium (V)	108.0	4.5	50.0
	Nickel (Ni)	97.0	4.0	30.0
	Sink (Zn)	55.5	2.1	100.0
	Mis (With)	36.5	1.6	25.0
	Iron (Fe)	200.0	10.0	300.0
	Sodium (Na)	150.0	7.0	200.0
	Calcium (Ca)	310.0	15.5	1000.0
	Silicon (Si)	1005.0	50.5	N/A
	Phosphorus (P)	29.0	1.4	N/A

Results and discussion

The results of the detailed elemental analyses conducted are of serious importance for environmental management. The presence of heavy metals exceeding the norm highlights the importance of implementing remediation measures in these areas.

Oil sludge **molecular characteristics** Fourier Transform Infrared Spectroscopy (FTIR) method was applied for detailed evaluation. Agilent Technologies Cary 630 FTIR spectrometer was used for these analyses and the main advantages of this method, high sensitivity, rapid analysis and accurate determination of functional groups, were utilized.

A specially developed in-house method was used to perform FTIR analyses. This method was adapted to the characteristics of the samples and the spectral sensitivity requirements.

In the initial stage, the oil sludge samples brought to the laboratory were dried under special conditions (at a temperature of 105°C), removing moisture and bringing them to a homogeneous powder form. The dried and homogenized samples were then brought to a state suitable for molecular analysis.

For FTIR analysis, samples were mixed with potassium bromide (KBr) and pressed into homogeneous and transparent pellets in a special press. The potassium bromide used to prepare these pellets is transparent to infrared rays and thus provides high transmittance for spectrum acquisition. The sample/KBr mixture ratio was maintained at approximately 1:100 (sample:KBr) according to standards.

The prepared pellets were placed in a special sample holding chamber of the FTIR spectrometer. The spectra were recorded in the wavenumber range of 4000–400 cm^{-1}. In order to ensure high quality of spectral data, 32 scans (repeated measurements) were performed for each sample and the spectra were refined by taking the average value. The spectral resolution for all spectra was set to 4 cm^{-1}. This allowed for the precise identification of the functional groups present in the samples.

The spectrometer was calibrated regularly and calibration tests were performed using the device's software. The purpose of calibration is to ensure the accuracy of the device's spectral lines and the reliability of the measurements.

The obtained FTIR spectra were analyzed using special software (Agilent MicroLab FTIR software). The main peaks in the spectrum and their intensities were identified and associated with the corresponding functional groups. During this analysis, the following main functional groups were identified:

Aliphatic hydrocarbons (C–H stretching vibrations): These bands appear in the range of 2950–2850 cm^{-1} and confirm the presence of hydrocarbons mainly of petroleum origin. The high intensity of this band in the spectra indicated that the sludges contained crude oil (Figure 1).

Aromatic hydrocarbons (C=C stretching vibrations): Aromatic compounds are mainly detected in the spectra near 1600 cm^{-1}. High levels of aromatic hydrocarbons were observed especially in the Ramana area and highlighted industrial pollution. The presence of aromatic substances increases the environmental risks in those areas, as these substances have high persistence and toxic effects (Figure 2).

Carbonyl groups (C=O stretching vibrations): Carbonyl groups observed in the 1750–1700 cm^{-1} range confirm the presence of oxygen-containing organic compounds resulting from the oxidation of oil sludge. These oxidized organic compounds can increase the mobility of heavy metals, increasing the potential for contamination of soils and groundwater (Figure 3).

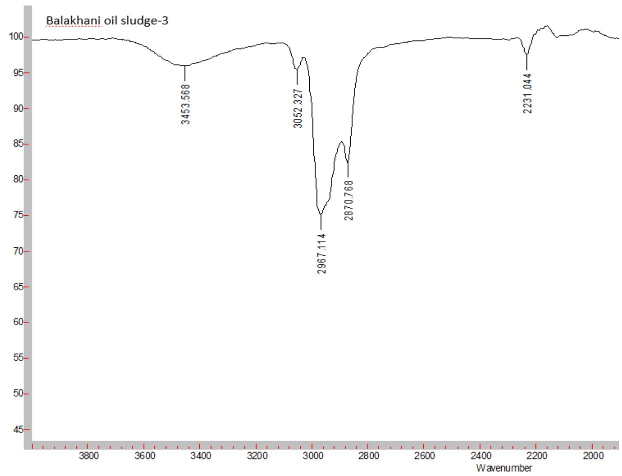

Fig 1. Aliphatic hydrocarbons (C–H stretching vibrations)

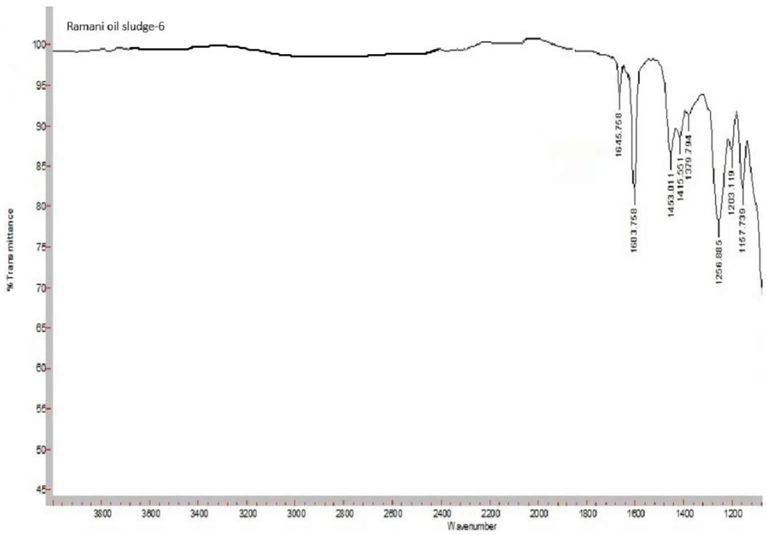

Fig 2. Aromatic hydrocarbons (C=C stretching vibrations)

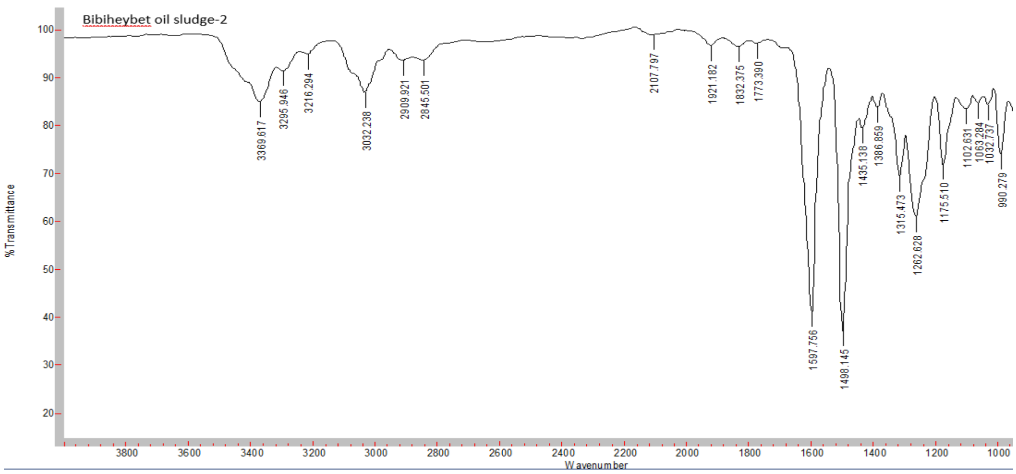

Fig 3. Carbonyl groups (C=O stretching vibrations)

Hydroxyl groups (-OH stretching vibrations): Hydroxyl groups are observed in the range of 3600–3200 cm^{-1} and indicate the presence of moisture and oxidized hydrocarbons in the samples. This is an important indication that the oil sludge has been exposed to moisture or atmospheric influences (Figure 4).

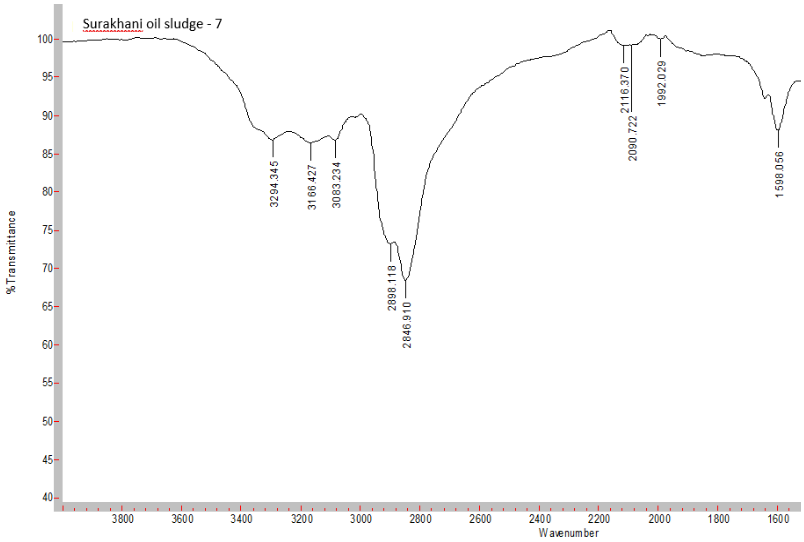

Fig 4. Hydroxyl groups (-OH stretching vibrations)

Carboxylic acids (–COOH vibrations): These functional groups were mainly observed in the range of 1300–1200 cm^{-1}. The presence of carboxylic groups not only makes the samples more aggressive and increases the mobilization of metals, but also increases the risk of corrosion.

The presence and intensity of functional groups determined by FTIR analysis are critical for assessing the environmental impact potential of oil sludge. In particular, high concentrations of aromatic compounds and carbonyl groups indicate the need for more sophisticated methods for remediation of contaminated sites.

Also, FTIR results are important for understanding the sources and processes of pollution at each site. For example, higher levels of aromatics in the Ramana area reflect the presence of specific industrial activities and emissions in that area. This information will be used both in the development of local environmental policies and in the effective planning of remediation strategies to be applied in the future.

Conclusions

Thus, the detailed information obtained as a result of the application of ICP-OES and FTIR spectroscopy for elemental and molecular analysis of oil sludges constitutes a fundamental scientific and technical basis for environmental management, pollution reduction, and effective remediation measures on the Absheron Peninsula.

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ABŞERON YARIMADASINDAKI NEFT ŞLAMLARININ FİZİKİ-KİMYƏVİ ANALİZİ

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Bu tədqiqat Abşeron yarımadasının çirklənmiş ərazilərindən götürülmüş neft şlamı nümunələrinin fiziki-kimyəvi xüsusiyyətlərinin analizi, tədqiqi və öyrənilməsi nəticələrini təqdim edir. Müəyyən edilmişdir ki, Bibiheybət və Balaxanı yataqlarından götürülmüş neft şlamı nümunələrində ağır metalların — xüsusilə qurğuşun (Pb), kadmium (Cd), vanadium (V) və nikel (Ni) — konsentrasiyaları mövcud beynəlxalq və yerli ekoloji təhlükəsizlik standartlarını əhəmiyyətli dərəcədə aşır.Ətraflı analiz məqsədilə FTIR və İQ (infraqırmızı) spektroskopiya üsullarından istifadə edilmişdir. İQ spektrlər Agilent MicroLab FTIR proqram təminatı vasitəsilə analiz olunmuşdur. Aparılan analiz zamanı alifatik karbohidrogenlər (C–H valent titrəyişləri), aromatik karbohidrogenlər (C=C valent titrəyişləri), karbonil qrupları (C=O valent titrəyişləri), hidroksil qrupları (-OH valent titrəyişləri) və karboksil turşuları (–COOH titrəyişləri) kimi əsas funksional qruplar müəyyən edilmişdir.Beləliklə, neft şlamının element və molekulyar analizində ICP-OES və FTIR spektroskopiya metodlarının tətbiqi nəticəsində əldə edilən detallı məlumatlar Abşeron yarımadasında ekoloji idarəetmə, çirklənmənin azaldılması və effektiv təmizləmə tədbirləri üçün fundamental elmi və texniki əsas təşkil edir.

Açar sözlər: *neft şlamı, Abşeron yarımadası, FTIR spektroskopiyası, ICP-OES, ağır metallar, ekoloji çirklənmə, rekultivasiya*