

O'ZBEKISTON RESPUBLIKASI

OLIY TA'LIM, FAN VA INNOVATSIYALAR VAZIRLIGI

FARG'ONA DAVLAT UNIVERSITETI

**FarDU.  
ILMIY  
XABARLAR**

1995-yildan nashr etiladi  
Yilda 6 marta chiqadi

6-2025  
TABIIY FANLAR

**НАУЧНЫЙ  
ВЕСТНИК.  
ФерГУ**

Издаётся с 1995 года  
Выходит 6 раз в год

|  |    |
|--|----|
| <b>S.Sh.Do'saliyeva, R.B.Karabayeva</b><br><i>Allium suworowii</i> o'simligi tarkibidagi saponinlarning sifat tahlili .....  | 7  |
| <b>J.E.Shamshiyev, O.M.Nazarov, T.Sh.Amirova</b><br>Mahalliy vinolarning flavonoidlar va suvda eruvchan vitaminlar tarkibi tahlili .....   | 10 |
| <b>F.X.Bo'riyev, S.S.Abduraxmanova, O.E.Ziyadullayev, F.Qo'shbaqov</b><br>Ayrim atsetilen spirtlar asosida $\alpha$ -yod, $\alpha, \beta$ -to'yinmagan ketonlar sintezi .....      | 15 |
| <b>M.Z.Nomozova, L.S.Kamolov, I.Nakhatov, N.N.Umirov, D.O.Ahmadova</b><br>Secondary metabolites of the fungus <i>Trichoderma asperellum</i> and their biological importance ....   | 22 |
| <b>Q.M.Sherg'oziyev, Sh.X.Karimov</b><br><i>Anabasis aphylla</i> L. o'simligining flavonoid tarkibi tahlili .....  | 28 |
| <b>G.A.Abdullaeva, Sh.Sh.Damiyeva, Sh.Sh.Turgunbaev</b><br>Синтез и исследование комплексного соединения Zn (II) с дифенилтиокарбазоном .....                                      | 32 |
| <b>M.M.Mamanazarov, E.Y.Yalgashev, L.A.Azimov, D.I.Abduvokhidov, J.I.Razzokov</b><br>Gliding-arc plasma regeneration of industrial ca-zeolite adsorbents .....                     | 39 |
| <b>G.D.Axmadjonova, O.M.Nazarov, X.N.Saminov</b><br><i>Mirabilis jalapa</i> L. o'simligining aminokislota va fenol birikmalari tarkibini o'rganish .....                           | 46 |
| <b>I.R.Asqarov, Sh.M.Qirg'izov, S.T.Jalilova</b><br>Evaluation of the antiradical properties of bay leaf .....   | 52 |
| <b>Sh.M.Kirgizov, M.M.Muminov, D.S.Turgunova</b><br>Antioxidant activity of a mixture of gleditsia and ailanthus flowers .....   | 57 |
| <b>D.A.Ga'furova, X.G.Kurbanov, M.K.Rustamov, H.M.Yusupova, D.N.Saxidova</b><br>Получение анионитов на основе поливинил хлорида для сорбции ионов молибдена (VI) ....              | 64 |
| <b>S.Y.Xushvaqov, K.A.Qodirova, D.J.Bekchanov</b><br>Tarkibida amino va sulfoguruh tutgan funksional ion almashinuvchi polimer<br>materiallarga brom ionlarining sorbsiyasi .....  | 73 |
| <b>T.Sh.Amirova</b><br>Matolarning kimyoviy tarkibiga ko'ra sertifikatlash va tasniflashning dolzarb muammolari .....  | 80 |
| <b>T.Sh.Amirova</b><br>Ipak matolarining iq spektri tahlili va kimyoviy xossalari .....  | 84 |
| <b>F.M.Turaqulov, X.E.Yunusov, S.S.Yarmatov, X.I.Burxonova, A.A.Sarimsaqov</b><br>Karboksimetilsellyuloza va seritsin asosida biokompozit gidrogelning olinishi va xossalari ..... | 89 |
| <b>N.T.Qaxxorov, R.S.Jo'rayev, O'M.Mardonov</b><br>"Dautosh" koni meniralin lazerli difraksiya usulida tekshirish va tarkibini o'rganish .....                                     | 98 |

## BIOLOGIYA

|  |     |
|--|-----|
| <b>M.P.Yuldashova, M.A.Djo'rabaeva</b><br>Baliqchilik ho'jaligi suvlarini sifat ko'rsatgichlarini aniqlashda indikator - saprob<br>suvo'tlaridan foydalanish ..... | 105 |
| <b>M.P.Yuldashova</b><br>Farg'ona vodiysi ayrim kanallari suvini sifat ko'rsatgichini aniqlashda indikator - saprob<br>suvo'tlaridan foydalanish .....             | 109 |
| <b>A.Q.Buronov</b><br>O'zbekistondagi qadimiy mahalliy bug'doy navlarida oqsil tarkibiga ma'sul nam-1 genlarini<br>molekulyar markerlar yordamida o'rganish .....  | 113 |
| <b>M.X.Akbarova</b><br>Farg'ona vodiysida tarqalgan <i>Scutellaria</i> L. turkumi turlarining petrofil<br>florosenotiplarda tarqalishi .....                       | 119 |
| <b>B.A.Abdualiyev</b><br>Uy parrandalarining gelmintlar bilan zararlanishida yovvoyi qushlarning roli .....  | 127 |



UO‘K 544.344.3:66.081.63; 662.767

**GLIDING-ARC PLASMA REGENERATION OF INDUSTRIAL Ca-ZEOLITE ADSORBENTS****РЕГЕНЕРАЦИЯ ПРОМЫШЛЕННЫХ Ca-ЦЕОЛИТНЫХ АДСОРБЕНТОВ С ИСПОЛЬЗОВАНИЕМ СКОЛЬЗЯЩЕГО ДУГОВОГО РАЗРЯДА****SANOAT Ca-SEOLIT ADSORBENTLARINING SIRPANMA YOY PLAZMASIDA REGENERATSIYASI****Mamanazarov Murodali Mamadali o‘g‘li<sup>1</sup>** <sup>1</sup> National University of Uzbekistan named after Mirzo Ulugbek, PhD in Technical Sciences**Yalgashev Elmurod Yaxshiboy o‘g‘li<sup>2</sup>** <sup>2</sup> Tashkent Institute of Chemical Technology, Independent Researcher**Azimov Lazizbek Azamat o‘g‘li<sup>3</sup>** <sup>3</sup> Institute of Pharmaceutical Education and Research, PhD in Chemical Sciences**Abdovokhidov Davronjon Izzatullo o‘g‘li<sup>4</sup>** <sup>4</sup> Institute of Fundamental and Applied Research under TIAME National Research University, Junior Researcher**Razzokov Jamoliddin Inotullayevich<sup>5</sup>** <sup>5</sup> Institute of Fundamental and Applied Research under TIAME National Research University, Doctor of Chemical Sciences, Senior Researcher**Abstract**

*This study presents a preliminary evaluation of gliding-arc plasma for regenerating coked Ca-zeolite adsorbents previously used in natural gas purification. Thermal analysis revealed ~24.7% total weight loss, indicating the presence of both soft and hard coke fractions. GAP treatment (2.5-15 min) enabled progressive mass reduction (up to 3.8%), accompanied by partial recovery of textural properties. The surface area increased from 84.3 m<sup>2</sup>/g (coked) to 98.4 m<sup>2</sup>/g after 15 min (~79% of fresh sample), while total pore volume rose from 0.19 to 0.30 cm<sup>3</sup>/g (~80% of fresh). Mechanical stability tests confirmed that crush strength and attrition resistance remained largely unaffected by plasma treatment. Compared to conventional thermal regeneration, which often requires hours of heating, gliding-arc plasma achieved significant recovery within minutes, highlighting its potential as an energy-efficient and environmentally friendly regeneration method.*

**Аннотация**

*В данной работе представлена предварительная оценка применения плазмы скользящего разряда для регенерации закоксованного цеолита Ca, ранее использованного при очистке природного газа. Термический анализ показал суммарную потерю массы около 24,7 %, что свидетельствует о присутствии как «мягких», так и трудноокисляемых («жестких») коксовых фракций. Обработка плазмой в течение 2,5-15 минут обеспечила постепенное снижение массы (до 3,8 %) и частичное восстановление текстурных характеристик. Удельная поверхность возросла с 84,3 м<sup>2</sup>/г (закоксованный образец) до 98,4 м<sup>2</sup>/г после 15 мин (~79 % от свежего образца), а общий объем пор увеличился с 0,19 до 0,30 см<sup>3</sup>/г (~86 % от свежего значения). Испытания механической прочности подтвердили, что прочность на раздавливание и устойчивость к истиранию практически не изменились после плазменной обработки. По сравнению с традиционной термической регенерацией, требующей длительного нагрева (часами), плазмы скользящего разряда позволяет достичь заметного восстановления всего за несколько минут, что подчеркивает её потенциал как энергоэффективного и экологически безопасного метода регенерации адсорбентов.*

**Annotatsiya**

*Ushbu tadqiqotda tabiiy gazni tozalashda qo'llanilgan va koks bilan to'yingan Ca-seolitni qayta tiklash uchun sirpanma yoy plazmasidan foydalanish imkoniyati dastlabki baholandi. Termik tahlil umumiy massaning qariyb 24,7 % kamayishini ko'rsatdi, bu esa yumshoq va qattiq koks fraksiyalarining mavjudligini tasdiqladi. 2,5-15 daqiqa davomida plazma bilan ishlov berish natijasida massaning bosqichma-bosqich kamayishi (3,8 % gacha) va tekstura xossalari qisman tiklanishi kuzatildi. Ustki yuzaning maydoni 84,3 m<sup>2</sup>/g (kokslangan namunada) dan 15 daqiqadan so'ng 98,4 m<sup>2</sup>/g gacha oshdi (~79 % yangi namunaga nisbatan), umumiy pora hajmi esa 0,19 dan 0,30 sm<sup>3</sup>/g gacha yetdi (~86 % yangi namunaga nisbatan). Mexanik mustahkamlik sinovlari plazma bilan ishlovdan so'ng granularlarning bosimga chidamliligi va ishqalanishga qarshiligi deyarli o'zgarmaganini ko'rsatdi. An'anaviy issiqlik regeneratsiyasi ko'pincha soatlab qizdirishni talab qilsa, sirpanma yoy plazma bir necha daqiqada sezilarli tiklanishga erishdi. Bu esa mazkur usulning energiya tejamkor va ekologik xavfsiz regeneratsiya texnologiyasi sifatidagi istiqbolini ko'rsatadi.*

**Key words.** *gliding arc plasma, Ca-zeolite, coke deposition, adsorbent regeneration, natural gas purification, surface area, pore volume, mechanical stability, thermal analysis.*

**Ключевые слова.** *плазма скользящего разряда, цеолит Ca, коксование, регенерация адсорбента, очистка природного газа, удельная поверхность, объем пор, механическая прочность, термический анализ.*

**Kalit so'zlar.** *sirpanma yoy plazmasi, Ca-seolit, koks hosil bo'lishi, adsorbentni regeneratsiya qilish, tabiiy gazni tozalash, yuzaning maydoni, pora hajmi, mexanik mustahkamlik, termik tahlil.*

## INTRODUCTION

Natural gas purification is an essential process in the energy industry, as raw natural gas streams often contain significant amounts of acidic impurities such as hydrogen sulfide (H<sub>2</sub>S) and water vapor. The removal of these contaminants is critical for meeting pipeline specifications, preventing corrosion, and ensuring environmental and operational safety [1, 2]. Among various technologies, adsorption-based processes have proven highly effective due to their simplicity, low cost, and energy efficiency [3].

Zeolites are widely used as adsorbents for natural gas sweetening and dehydration because of their crystalline microporous structure, high surface area, and strong affinity for polar molecules [4]. Calcium-modified zeolites (Ca-zeolites) in particular exhibit enhanced performance for H<sub>2</sub>S and water adsorption, making them attractive for industrial applications [5]. However, during prolonged operation, adsorbents undergo deactivation caused by coke deposition and other impurities, which block micropores and reduce adsorption capacity [6, 7]. Effective regeneration methods are therefore essential to restore zeolite performance and prolong adsorbent lifetime.

Conventional regeneration strategies, such as thermal treatment in oxygen or inert gas flows, can partially restore adsorption capacity but are often energy-intensive and may induce structural degradation after repeated cycles [8]. Alternative approaches, including solvent washing or chemical treatments, are less effective against strongly bound carbonaceous deposits and raise environmental concerns [9].

In this context, plasma-based regeneration has emerged as a promising technique. Non-thermal plasmas generate a rich mixture of reactive oxygen and nitrogen species capable of selectively decomposing carbonaceous deposits at relatively mild conditions [10]. In particular, gliding arc plasma (GAP) combines the high reactivity of non-equilibrium plasmas with operation close to atmospheric pressure, offering low energy consumption, rapid regeneration, and minimal structural damage to the adsorbent [11].

While plasma-assisted regeneration has been studied for zeolitic catalysts such as H-ZSM-5 or Y-zeolite [12-14], its application to adsorbent-grade Ca-zeolites used for natural gas purification has not been systematically investigated. Understanding how GAP interacts with coke-contaminated Ca-zeolites, and evaluating its efficiency in restoring adsorption performance, are essential steps for advancing this sustainable regeneration approach.

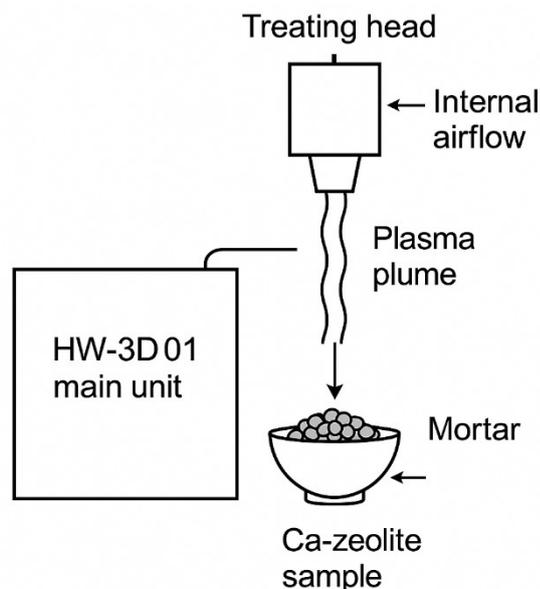
In this study, the GAP regeneration of coked Ca-zeolite previously employed for natural gas purification was investigated. The regeneration efficiency, mechanical stability, and physicochemical changes were assessed to evaluate the feasibility of gliding arc plasma as an environmentally friendly and effective regeneration strategy for adsorbent applications.

## METHODS AND MATERIALS

**Materials and Sample Preparation.** Ca-zeolite was employed as an industrial adsorbent for the removal of H<sub>2</sub>S and water vapor from natural gas streams. In practical operation, the material was subjected to approximately 1400-1500 adsorption-desorption cycles over a period of nearly two years. Each cycle consisted of three stages: (i) adsorption (6 h, natural gas feed containing H<sub>2</sub>S and H<sub>2</sub>O), (ii) desorption (2 h, regeneration with heated clean gas), and (iii) cooling (2 h). After

long-term service, the adsorbent became heavily coked and deactivated. Samples of this spent material (hereafter referred to as coked zeolite) were collected for regeneration experiments. Prior to laboratory characterization, the coked zeolite samples were dried at 110 °C for 12 h to remove residual moisture.

**Plasma Regeneration Procedure.** The regeneration of coked Ca-zeolite was carried out in an atmospheric-pressure gliding-arc plasma (GAP) reactor (model HW-3D01; 220 V AC, 50 Hz, output frequency 30 kHz, rated output power 500 W, output voltage 15 kV, input current 2.5-3 A). The reactor employs two divergent (horn-horn) electrodes driven by an AC high-voltage supply. During regeneration, a controlled flow of air was passed through the discharge region where the coked zeolite sample was positioned on a dedicated holder to ensure uniform exposure.



**Figure 1. Schematic of the gliding arc plasma (GAP) system employed for regeneration of coked Ca-zeolite.**

A schematic of the setup is provided in Figure 1. The system comprises a high-voltage power unit, the divergent-electrode assembly forming the gliding arc, a gas-flow control module, and a sample holder located within the arc path/afterglow region. Plasma exposures were conducted for 2.5, 5, 7.5, 10, 12.5, and 15 min to study the effect of treatment time on coke removal. Subsets of samples (2.5, 5, 10, and 15 min) were subsequently characterized for textural properties (BET surface area and total pore volume), while all-time points were used for mass-loss evaluation. After treatment, samples were cooled to ambient temperature and stored in sealed containers prior to analysis.

**Thermal Analysis (DTA/TGA).** Differential thermal analysis (DTA) and thermogravimetric analysis (TGA) were performed to investigate the nature and thermal stability of carbonaceous deposits on the coked zeolite. 10 mg of sample was heated from room temperature to 1000°C at a rate of 10°C/min in an air atmosphere. The mass loss profiles and corresponding thermal events were recorded, providing information on coke combustion temperature and quantity.

**Surface Area.** The specific surface area of fresh, coked, and plasma-regenerated Ca-zeolite samples was determined by a classical volumetric adsorption method. The device consisted of a calibrated glass burette, a gas reservoir, and a sample cell connected through stopcocks. A known amount of nitrogen gas was adsorbed at liquid nitrogen temperature, and the decrease in gas volume was recorded to estimate the monolayer capacity. The specific surface area was then calculated according to the BET equation. Changes in textural properties after coke deposition and plasma regeneration were analyzed to evaluate the efficiency of coke removal and pore restoration.

The mass loss of coked zeolite during GAP treatment was recorded at each regeneration interval (2.5, 5, 10, 15, 20 minutes). The relative decrease in sample weight was used as an indicator of carbonaceous deposit removal.

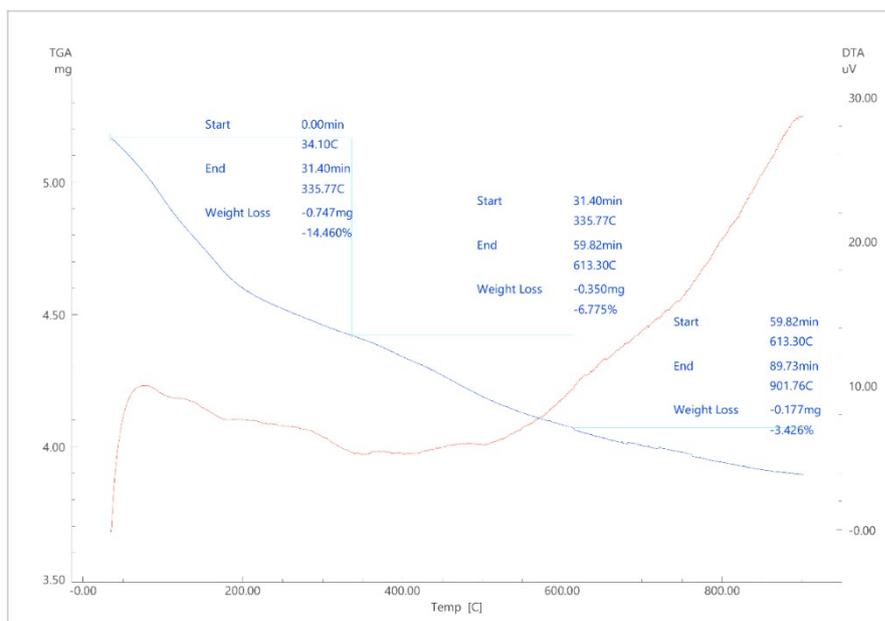
## RESULTS AND DISCUSSION

TGA and DTA were performed on the coked Ca-zeolite sample (see Figure 2). TGA profiles showed three distinct mass-loss stages associated with water/volatiles, soft coke, and hard coke. The first stage (34-335 °C) accounted for approximately 14.46% weight loss. This process is primarily associated with the desorption of physically adsorbed water, volatile organic residues, and the partial decomposition of light coke fractions. A weak exothermic feature was observed in the DTA curve, consistent with the onset of oxidative processes. Similar low-temperature weight losses related to moisture and volatile organics have been reported for spent zeolites in natural gas and fluid catalytic cracking applications [15].

The second stage (335-613 °C) resulted in an additional 6.78% weight loss, corresponding to the oxidation of the main coke fraction, which likely consists of polyaromatic hydrocarbon structures. In this region, the DTA curve exhibited a pronounced exothermic peak, confirming active combustion of carbonaceous deposits. This behavior agrees with previous findings where “soft coke” or polymeric hydrocarbon coke is oxidized in the 300-600 °C range [16, 17].

The third stage (613-902 °C) led to a further 3.43% mass loss, attributed to the decomposition of the most stable, graphite-like coke species strongly bound to the zeolite framework. Such high-temperature oxidation is characteristic of “hard coke” or graphitic-like deposits, typically requiring >600 °C for removal [16, 17]. At such elevated temperatures, partial dehydroxylation and dealumination of the zeolite lattice are also likely to occur, potentially compromising structural integrity [18].

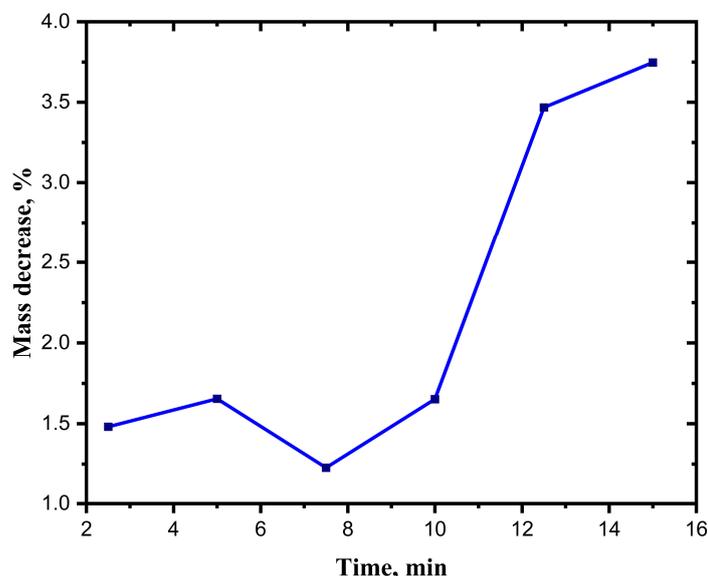
In total, the sample exhibited a 24.7% weight loss, highlighting the substantial coke accumulation after prolonged industrial operation. The consistently exothermic DTA signals across all stages confirmed that the mass losses were predominantly due to oxidative decomposition of carbonaceous deposits.



**Figure 2. TGA/DTA profiles of coked Ca-zeolite**

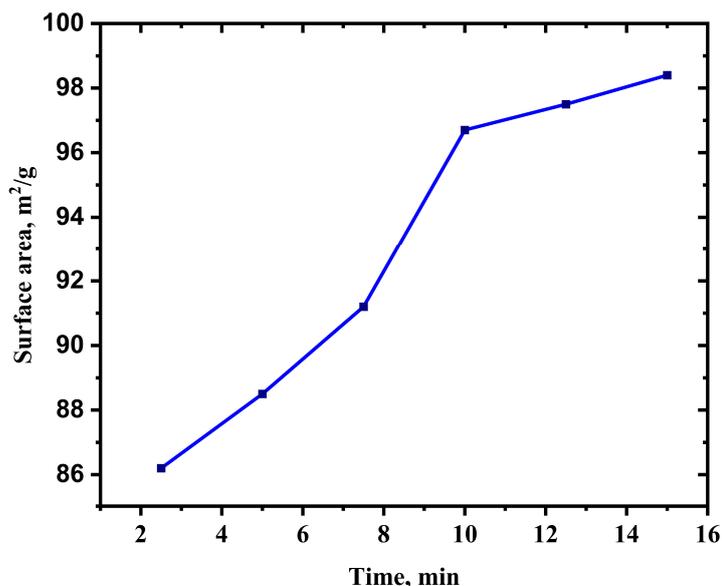
The efficiency of coke removal under GAP treatment was evaluated by measuring the mass change of the coked Ca-zeolite at different plasma exposure times (Figure 3). A gradual decrease in mass was observed with increasing treatment time, indicating progressive removal of carbonaceous deposits. At short exposures (2.5-10 min), mass reduction was relatively limited (1.2-1.65%), suggesting that only a portion of the loosely bound coke and volatile residues were oxidized. After 12.5 min, a significant increase in mass loss was recorded (3.47%), pointing to more extensive decomposition of stable coke fractions. At 15 min treatment, the cumulative mass decrease reached 3.75%, confirming that prolonged plasma exposure efficiently removed strongly bound carbonaceous deposits.

These results are consistent with the multi-step coke oxidation behavior revealed by TGA/DTA analysis, where different fractions of coke exhibited distinct stability ranges. Importantly, the mass reduction achieved under GAP treatment demonstrates that plasma can selectively oxidize coke at near-ambient bulk conditions, avoiding the severe thermal stress (>600 °C) required in conventional regeneration methods.



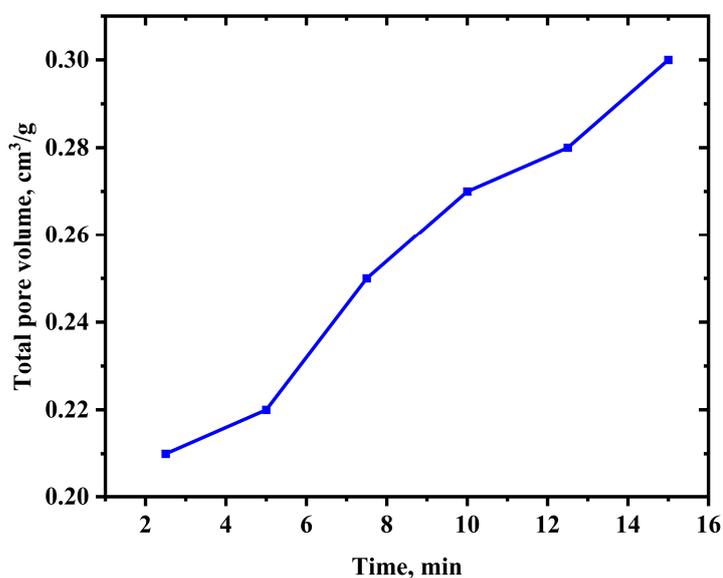
**Figure 3. Mass decrease of coked Ca-zeolite during GAP regeneration at different treatment times (2.5-15 min).**

Surface area analysis provided insight into the textural changes during regeneration (Figure 4). The fresh Ca-zeolite exhibited a surface area of 125.1 m<sup>2</sup>/g, whereas the coked sample decreased to 84.3 m<sup>2</sup>/g due to pore blocking by carbonaceous deposits. After plasma regeneration, surface area increased progressively to 88.5, 96.7, 97.3, and 98.4 m<sup>2</sup>/g after 2.5, 5, 10, and 15 minutes, respectively. The maximum recovery (98.4 m<sup>2</sup>/g corresponded to ~79% of the fresh sample's surface area, equivalent to ~35% of the surface area lost during coking being restored. The increase in surface area reflects the gradual removal of coke species from pore mouths and channel intersections, allowing molecules to access a greater fraction of the micropore network. Although full restoration to the fresh value was not achieved, the recovered fraction demonstrates the effectiveness of GAP in reopening blocked micropores under mild conditions. From an application perspective, recovering ~79% of the fresh surface area within only 15 minutes is highly significant, as conventional thermal regeneration often requires hours of treatment and risks structural damage. This level of recovery is sufficient to extend the operational lifetime of zeolite-based adsorbents in natural gas purification, reducing replacement frequency and operating costs.



**Figure 4. BET surface area of Ca-zeolite during GAP regeneration at different treatment times (2.5–15 min).**

The pore volume of the fresh zeolite was 0.35 cm<sup>3</sup>/g, while the coked sample decreased drastically to 0.19 cm<sup>3</sup>/g. At 15 min, the pore volume reached 0.3 cm<sup>3</sup>/g, representing ~80 % of the fresh zeolite value and ~71% recovery of the volume lost due to coking. This monotonic trend demonstrates that plasma treatment effectively reopens pore channels by removing obstructing coke. Importantly, the evolution of pore volume is consistent with the surface area results, both indicating progressive restoration of textural properties under GAP treatment.



**Figure 5. Pore volume of Ca-zeolite during GAP regeneration at different treatment times (2.5-15 min).**

The simultaneous increase in surface area and total pore volume confirms that regeneration is not only limited to external surfaces, but also involves reopening of blocked micropores and mesopores. Such complementary evidence strengthens the conclusion that GAP selectively oxidizes coke without damaging the zeolite framework, in contrast to conventional high-temperature calcination that often leads to partial dealumination.

### CONCLUSION

The regeneration of industrially spent Ca-zeolite, previously used for natural gas purification, was successfully investigated using GAP. TGA/DTA analysis revealed ~24.7% total weight

loss associated with soft and graphitic coke fractions, confirming severe deactivation after ~1500 industrial adsorption-desorption cycles.

Plasma treatment at atmospheric pressure enabled efficient removal of coke within very short timescales. After only 15 minutes of GAP exposure, the surface area increased from 84.3 m<sup>2</sup>/g (coked) to 98.4 m<sup>2</sup>/g, corresponding to ~79% of the fresh zeolite value and ~35% restoration of the surface area lost during coking. Pore volume rose from 0.19 to 0.3 cm<sup>3</sup>/g, representing ~84 % of the fresh level and ~61% recovery of the volume lost due to coking. Mass decrease trends confirmed selective oxidation of both soft and hard coke fractions.

A key advantage of GAP is its remarkable time efficiency compared to conventional thermal regeneration. While thermal oxidation often requires hours or even up to 24 h to restore adsorbent performance [7], GAP achieved significant recovery within 15 minutes. This suggests that longer plasma treatments may potentially surpass the performance of thermal methods, with reduced energy consumption and lower risk of framework degradation. These findings highlight GAP as a promising, energy-efficient, and environmentally friendly alternative to conventional regeneration. Although complete recovery to fresh values was not achieved in this initial study, further optimization of plasma parameters (gas composition, flow rate, treatment time) and multi-cycle operation may lead to even higher restoration of textural and adsorption properties. The results provide a solid basis for developing plasma-assisted regeneration protocols for zeolite-based adsorbents in industrial natural gas purification.

## REFERENCES

1. Speight J.G. *Natural gas: a basic handbook*. 2018: Gulf Professional Publishing.
2. Kohl A. and R. Nielsen. *Gas purification 5th ed*. Houston: Gulf Publishing Company. 1997.
3. Sircar S. *Pressure swing adsorption // Industrial & engineering chemistry research*, 2002. -V.41(6) -P. 1389-1392.
4. Weitkamp J. *Zeolites and catalysis // Solid state ionics*. 2000. V.131(1-2). -P. 175-188.
5. Georgiadis A.G., Charisiou N.D. and Goula M.A. *Removal of hydrogen sulfide from various industrial gases: A review of the most promising adsorbing materials // Catalysts*. 2020. -V.10(5) -P. 521.
6. Aminuddin M.S., Bustam M.A. and Johari K. *Latest technological advances and insights into capture and removal of hydrogen sulfide: a critical review // RSC sustainability*. 2024. -V2(4) -P. 757-803.
7. Zhou J., et al. *Regeneration of catalysts deactivated by coke deposition: A review // Chinese Journal of Catalysis*. 2020. -V41(7) -P. 1048-1061.
8. Daligaux V., Richard R., and Manero M.H. *Deactivation and regeneration of zeolite catalysts used in pyrolysis of plastic wastes a process and analytical review // Catalysts*. 2021. -V11(7) -P. 770.
9. Ennaert T., et al. *Potential and challenges of zeolite chemistry in the catalytic conversion of biomass // Chemical Society Reviews*. 2016. -V45(3): -P. 584-611.
10. Astafan A., C. Batiot-Dupeyrat, and L. Pinard. *Mechanism and kinetic of coke oxidation by nonthermal plasma in fixed-bed dielectric barrier reactor // The Journal of Physical Chemistry*. 2019. -V123(14) -P. 9168-9175.
11. Sop-Tamo B., et al. *Gliding arc plasma pre-treatment of kaolin in spatial post-discharge mode for removal of Reactive Red 2 dye from aqueous solution // Water Science and Technology*. 2018. -V78(7) -P. 1448-1458.
12. Hosseini H. *A brief review of progress in zeolite-catalyzed non-thermal plasma processes: applications, mechanisms, challenges, and prospective developments // Journal of Industrial and Engineering Chemistry*. 2025. -V2. -P. 22-40.
13. Pinard L., N. Ayoub, and C. Batiot-Dupeyrat. *Regeneration of a coked zeolite via nonthermal plasma process: a parametric study // Plasma Chemistry and Plasma Processing*. 2019. -V39(4). -P. 929-936.
14. Fan Y., et al. *Regeneration of the HZSM-5 zeolite deactivated in the upgrading of bio-oil via non-thermal plasma injection (NTPi) technology // Journal of Analytical and Applied Pyrolysis*. 2015. V111. -P. 209-215.
15. Bartholomew C.H. *Mechanisms of catalyst deactivation // Applied Catalysis A: General*. 2001. -V.212(1-2). -P. 17-60.
16. Karge H. *Coke formation on zeolites*, in *Studies in surface science and Catalysis*. 1991. -V.58. -p. 531-570.
17. Guisnet M. *"Coke" molecules trapped in the micropores of zeolites as active species in hydrocarbon transformations // Journal of Molecular Catalysis A: Chemical*. 2002. -V.182. -P. 367-382.
18. Silaghi M.-C., Chizallet C. and P. Raybaud. *Challenges on molecular aspects of dealumination and desilication of zeolites // Microporous and Mesoporous Materials*. 2014. -V191. -P. 82-96.