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GAS PYROLYSIS TECHNOLOGY: STUDY OF INFLUENCING FACTORS AND DEVELOPMENT OF OPTIMIZATION METHODS

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Abstract. *This article examines the technological factors affecting gas pyrolysis processes and explores methods for their optimization. Gas pyrolysis represents a critical thermal decomposition process with significant applications in petrochemical industry, waste management, and sustainable energy production. The findings demonstrate that integrated parameter optimization can substantially improve conversion efficiency, product selectivity, and overall process economics.*

Keywords: *gas pyrolysis, thermal decomposition, process optimization, catalytic conversion, temperature regimes, petrochemical technology, process parameters, conversion efficiency, industrial application, sustainable technology.*

Аннотация. *В данной статье рассматриваются технологические факторы, влияющие на процессы пиролиза газа, и исследуются методы их оптимизации. Пиролиз газа представляет собой критически важный процесс термического разложения, имеющий важное значение в нефтехимической промышленности, управлении отходами и производстве устойчивой энергии. Результаты показывают, что комплексная оптимизация параметров может существенно повысить эффективность преобразования, селективность продуктов и общую экономическую эффективность процесса.*

Ключевые слова: *пиролиз газа, термическое разложение, оптимизация процесса, каталитическое преобразование, температурные режимы, нефтехимические технологии, параметры процесса, эффективность преобразования, промышленное применение, устойчивые технологии.*

Annotatsiya. *Ushbu maqola gaz pirolizi jarayonlariga ta'sir qiluvchi texnologik omillarni o'rganadi va ularni optimallashtirish usullarini tahlil qiladi. Gaz pirolizi neft-kimyo sanoatida, chiqindilarni boshqarishda va barqaror energiya ishlab chiqarishda muhim qo'llaniladigan muhim termal parchalanish jarayonini ifodalaydi. Tadqiqot natijalari shuni ko'rsatadiki, integratsiyalashgan parametrlarni optimallashtirish konversiya samaradorligini, mahsulot tanlanishini va umumiy jarayon iqtisodiyotini sezilarli darajada yaxshilaydi.*

Kalit so'zlar: *gaz pirolizi, termal parchalanish, jarayonni optimallashtirish, katalitik konversiya, harorat rejimlari, neft-kimyo texnologiyasi, jarayon parametrlari, konversiya samaradorligi, sanoat qo'llanilishi, barqaror texnologiya.*

INTRODUCTION

Gas pyrolysis constitutes a fundamental thermochemical conversion process wherein hydrocarbon gases undergo thermal decomposition in the absence of oxygen, yielding valuable products including lighter hydrocarbons, hydrogen, carbon black, and other commercially significant compounds [1].

The technological and economic viability of pyrolysis operations depends critically on understanding and optimizing multiple interrelated process parameters that govern reaction kinetics, product distribution, and energy efficiency [2]. Contemporary industrial applications of gas pyrolysis span diverse sectors, from methane decomposition for hydrogen production to waste gas valorization and petrochemical feedstock processing [3]. Despite extensive research over several decades, the complexity of pyrolysis reactions and the sensitivity of outcomes to operational conditions necessitate continued investigation into optimization strategies.

Understanding these influencing factors is essential for advancing pyrolysis technology toward enhanced sustainability, improved product quality, and reduced environmental impact, particularly as global energy systems transition toward cleaner and more efficient conversion technologies [4].

METHODOLOGY AND LITERATURE REVIEW

The methodological approach employed in this study integrates comprehensive literature analysis with theoretical process evaluation to identify and characterize the principal factors affecting gas pyrolysis technology. Extensive review of peer-reviewed publications, technical reports, and industrial case studies was conducted across databases including Web of Science, Scopus, and specialized engineering journals, focusing on research published within the past two decades to ensure contemporary relevance [5]. The analytical framework categorizes influencing factors into five primary domains: thermal parameters, pressure conditions, catalytic systems, temporal factors, and feedstock characteristics. Temperature represents perhaps the most critical variable in pyrolysis processes, with research demonstrating that conversion rates and product selectivity exhibit exponential dependence on thermal regimes, typically ranging from 600°C to 1200°C depending on feedstock composition and desired outputs [6]. Lower temperatures generally favor production of liquid products and heavier hydrocarbons, while elevated temperatures promote gas formation and complete decomposition.

Pressure conditions similarly exert profound influence on reaction pathways and equilibrium positions, with studies indicating that reduced pressure environments often enhance certain decomposition reactions while elevated pressures may improve contact between reactants and catalysts in catalytic pyrolysis systems [7].

The selection and application of catalytic materials constitutes another crucial optimization parameter, as catalysts can dramatically reduce activation energy requirements, improve selectivity toward desired products, and enable operation at lower temperatures, thereby reducing energy consumption and operational costs. Research has identified various catalyst types including zeolites, metal oxides, activated carbon, and novel nanomaterials as effective promoters of pyrolysis reactions, each exhibiting distinct advantages for specific applications and feedstock compositions [8]. Residence time, defined as the duration reactants spend within the reaction zone, directly impacts conversion completeness and product distribution, with optimization requiring careful balance between sufficient reaction time for desired conversion and minimization of secondary reactions that may degrade product quality. Feedstock composition, including molecular structure, presence of impurities, and chemical functionality, fundamentally determines reaction mechanisms and feasible product ranges, necessitating tailored optimization strategies for different gas types [9].

RESULTS AND DISCUSSION

Analysis of the literature and theoretical evaluation reveals that successful optimization of gas pyrolysis processes requires integrated consideration of multiple parameters rather than isolated adjustment of individual variables. The interaction effects between temperature and residence time demonstrate particularly significant influence on process outcomes, with studies showing that higher temperatures can compensate for shorter residence times in achieving target conversion levels, though this relationship is nonlinear and feedstock-dependent. Catalyst selection emerges as a powerful tool for process optimization, with research indicating that appropriate catalytic systems can reduce required operating temperatures by 100-200°C while simultaneously improving selectivity toward valuable products and reducing coke formation that leads to equipment fouling [10]. The optimal temperature window for most gas pyrolysis applications falls within 700-900°C, representing a compromise between achieving adequate conversion rates and avoiding excessive energy consumption or unwanted secondary reactions.

Pressure optimization shows feedstock-specific patterns, with methane pyrolysis benefiting from reduced pressures that shift equilibrium toward product formation, while heavier hydrocarbon gases may require moderate pressures to maintain sufficient reactant density for efficient conversion. Economic analysis demonstrates that energy efficiency represents a critical optimization target, as thermal energy requirements constitute the primary operational cost in most pyrolysis systems, suggesting that process integration strategies including heat recovery and multi-stage reactor designs offer substantial potential for economic improvement. Product quality considerations often necessitate trade-offs with conversion efficiency, as operating conditions maximizing throughput may produce lower-purity outputs requiring additional separation and purification steps. The development of optimization methodologies should therefore incorporate multi-objective approaches that balance conversion efficiency, product selectivity, energy consumption, and operational stability. Advanced process control systems utilizing real-time monitoring and feedback mechanisms show promise for maintaining optimal conditions despite fluctuations in feedstock composition or other process disturbances.

CONCLUSION

This study demonstrates that gas pyrolysis process optimization requires systematic consideration of thermal regimes, pressure conditions, catalytic systems, residence time, and feedstock characteristics as interconnected variables rather than independent parameters. The analysis identifies temperature control as the most influential single factor, while catalyst selection offers the greatest potential for simultaneous improvement across multiple performance metrics.

Optimal operational windows vary significantly depending on feedstock composition and desired product profiles, necessitating application-specific optimization strategies. Implementation of integrated optimization approaches incorporating multi-parameter adjustment, advanced process control, and energy recovery systems can substantially enhance the economic and environmental performance of pyrolysis technologies. These findings provide valuable guidance for industrial practitioners seeking to improve existing pyrolysis operations and researchers developing next-generation thermal conversion processes.

Continued advancement of gas pyrolysis technology will require interdisciplinary collaboration combining chemical engineering, materials science, and process systems engineering to address remaining challenges in catalyst development, reactor design, and process integration.

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