# MUHANDISLIK & IQTISODIYOT

*ijtimoiy-iqtisodiy, innovatsion texnik, fan va ta'limga oid ilmiy-amaliy jurnal*

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05.01.00 – Axborot texnologiyalari, boshqaruv va kompyuter grafikasi
05.01.01 – Muhandislik geometriyasi va kompyuter grafikasi. Audio va video texnologiyalari
05.01.02 – Tizimli tahlil, boshqaruv va axborotni qayta ishlash
05.01.03 – Informatikaning nazariy asoslari
05.01.04 – Hisoblash mashinalari, majmualari va kompyuter tarmoqlarining matematik va dasturiy ta'minoti
05.01.05 – Axborotlarni himoyalash usullari va tizimlari. Axborot xavfsizligi
05.01.06 – Hisoblash texnikasi va boshqaruv tizimlarining elementlari va qurilmalari
05.01.07 – Matematik modellashtirish
05.01.11 – Raqamli texnologiyalar va sun'iy intellekt
05.02.00 – Mashinasozlik va mashinashunoslik
05.02.08 – Yer usti majmualari va uchish apparatlari
05.03.02 – Metrologiya va metrologiya ta'minoti
05.04.01 – Telekommunikasiya va kompyuter tizimlari, telekommunikasiya tarmoqlari va qurilmalari. Axborotlarni taqsimlash
05.05.03 – Yorug'lik texnikasi. Maxsus yoritish texnologiyasi
05.05.05 – Issiqlik texnikasining nazariy asoslari
05.05.06 – Qayta tiklanadigan energiya turlari asosidagi energiya qurilmalari
05.06.01 – To'qimachilik va yengil sanoat ishlab chiqarishlari materialshunosligi
05.08.03 – Temir yo'l transportini ishlatish
05.09.01 – Qurilish konstruksiyalari, bino va inshootlar
05.09.04 – Suv ta'minoti. Kanalizatsiya. Suv havzalarini muhofazalovchi qurilish tizimlari
10.00.06 – Qiyosiy adabiyotshunoslik, chog'ishtirma tilshunoslik va tarjimashunoslik
10.00.04 – Yevropa, Amerika va Avstraliya xalqlari tili va adabiyoti
08.00.01 – Iqtisodiyot nazariyasi
08.00.02 – Makroiqtisodiyot
08.00.03 – Sanoat iqtisodiyoti
08.00.04 – Qishloq xo'jaligi iqtisodiyoti
08.00.05 – Xizmat ko'rsatish tarmoqlari iqtisodiyoti
08.00.06 – Ekonometrika va statistika
08.00.07 – Moliya, pul muomalasi va kredit
08.00.08 – Buxgalteriya hisobi, iqtisodiy tahlil va audit
08.00.09 – Jahon iqtisodiyoti
08.00.10 – Demografiya. Mehnat iqtisodiyoti
08.00.11 – Marketing
08.00.12 – Mintaqaviy iqtisodiyot
08.00.13 – Menejment
08.00.14 – Iqtisodiyotda axborot tizimlari va texnologiyalari
08.00.15 – Tadbirkorlik va kichik biznes iqtisodiyoti
08.00.16 – Raqamli iqtisodiyot va xalqaro raqamli integratsiya
08.00.17 – Turizm va mehmonxona faoliyati

Ma'lumot uchun, OAK Rayosatining 2024-yil 28-avgustdagi 360/5-son qarori bilan "Dissertatsiyalar asosiy ilmiy natijalarini chop etishga tavsiya etilgan milliy ilmiy nashrlar ro'yxati"ga texnika va iqtisodiyot fanlari bo'yicha "Muhandislik va iqtisodiyot" jurnali ro'yxatga kiritilgan.

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# MUNDARIJA

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# MATLAB-BASED OPTIMIZATION OF METHANE FEED INTAKE IN A GTL PLANT FOR SYNTHETIC FUEL PRODUCTION

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Abstract. Optimization of methane feed intake plays a critical yet underexplored role in improving the thermodynamic and economic performance of Gas-to-Liquids (GTL) plants. While previous studies primarily focused on catalyst development and reactor temperature optimization, the methane intake rate itself has rarely been treated as a primary decision variable within an integrated kinetic–thermodynamic framework. In this study, a comprehensive nonlinear model of a GTL plant was developed, integrating methane reforming kinetics, mass and energy balances, Fischer–Tropsch synthesis reactor performance, and exergy analysis. The reforming section was described using Langmuir–Hinshelwood kinetics, coupled with plug flow reactor mass–energy balances. A multi-objective optimization problem was formulated to simultaneously maximize synthetic fuel yield and minimize specific energy consumption, $CO_2$ emissions, and exergy destruction. The optimization was solved using a Multi-Objective Genetic Algorithm implemented in MATLAB. Pareto front analysis revealed a narrow optimal methane intake window between 115 and 132 kmol/h. Within this region, fuel yield increased by 8.9%, specific energy consumption decreased by 6.1%, $CO_2$ emissions were reduced by 8.1%, and total exergy destruction decreased by 9.2% compared to baseline operation. Sensitivity analysis confirmed methane feed rate as the dominant operational variable, contributing over 40% of total performance variance. Excess methane intake (>140 kmol/h) was shown to increase thermal irreversibility and oxygen demand with marginal productivity gains, while insufficient feed (<105 kmol/h) resulted in reactor underutilization. The developed framework demonstrates that methane intake control represents a powerful and industrially viable optimization lever for GTL plants. The proposed methodology can be integrated into advanced process control and digital twin platforms to enhance plant efficiency, reduce carbon footprint, and improve operational stability.

Keywords: Gas-to-Liquids (GTL); Methane feed optimization; multi-objective optimization; Genetic algorithm; Fischer–Tropsch synthesis; Exergy analysis; Syngas production; Nonlinear reactor modeling; Process intensification; Energy efficiency.

Annotatsiya. Metan oqimini optimallashtirish Gas-to-Liquids (GTL) zavodlarining termodinamik va iqtisodiy samaradorligini oshirishda muhim, ammo yetarlicha oʻrganilmagan omil hisoblanadi. Avvalgi tadqiqotlarda asosan katalizatorlarni takomillashtirish va reaktor haroratini optimallashtirish masalalariga e'tibor qaratilgan boʻlsa, metan berish tezligi integratsiyalashgan kinetik-termodinamik model doirasida asosiy boshqaruv oʻzgaruvchisi sifatida kamdan-kam oʻrganilgan. Ushbu tadqiqotda metan reformingi kinetikasi, massa va energiya balanslari, Fischer–Tropsch sintezi reaktori ishlashi hamda eksergiya tahlilini oʻz ichiga olgan GTL zavodining kompleks nochiziqli modeli ishlab chiqildi. Reforming boʻlimi Langmuir–Hinshelwood kinetikasi asosida tavsiflanib, u ideal siqib chiqarish tipidagi reaktor uchun massa va energiya balanslari bilan integratsiya qilindi. Bir vaqtning oʻzida sintetik yoqilgʻi chiqishini maksimal darajaga yetkazish hamda solishtirma energiya sarfini, $CO_2$ chiqindilarini va eksergiya yoʻqotishlarini minimallashtirish maqsadida koʻp maqsadli optimallashtirish masalasi shakllantirildi. Optimallashtirish MATLAB dasturida amalga oshirilgan koʻp maqsadli genetik algoritm yordamida yechildi. Pareto fronti tahlili metan berishning optimal diapazoni 115–132 kmol/soat oraligʻida ekanligini koʻrsatdi. Ushbu diapazonda yoqilgʻi chiqishi 8,9 % ga oshdi, solishtirma energiya sarfi 6,1 % ga kamaydi, $CO_2$ emissiyasi 8,1 % ga qisqardi va umumiy eksergiya yoʻqotishlari bazaviy ish rejimiga nisbatan 9,2 % ga kamaydi. Sezgirlik tahlili metan berish tezligi asosiy operatsion omil ekanligini tasdiqladi va u umumiy samaradorlik oʻzgarishlarining 40 % dan ortigʻini belgilashi aniqlandi. Metan berishning haddan tashqari koʻpayishi (>140 kmol/soat) issiqlik qaytmasliklarini va kislorod talabini oshirishi, biroq ishlab chiqarish samaradorligiga sezilarli ta'sir koʻrsatmasligi aniqlangan. Aksincha, yetarli boʻlmagan berish (<105 kmol/soat) reaktor quvvatining toʻliq ishlatilmasligiga olib keladi. Ishlab chiqilgan metodologiya metan berishni boshqarish GTL zavodlari uchun samarali va sanoatda qoʻllash mumkin boʻlgan optimallashtirish mexanizmi ekanligini koʻrsatadi. Taklif etilgan yondashuv ishlab chiqarish samaradorligini oshirish, uglerod izini kamaytirish va operatsion barqarorlikni yaxshilash maqsadida ilgʻor jarayon boshqaruvi tizimlari hamda raqamli egizak platformalariga integratsiya qilinishi mumkin.

Kalit soʻzlar: Gas-to-Liquids (GTL); metan oqimini optimallashtirish; koʻp maqsadli optimallashtirish; genetik algoritm; Fischer–Tropsch sintezi; eksergiya tahlili; sintez gaz ishlab chiqarish; nochiziqli reaktor modellashtirish; jarayon intensifikatsiyasi; energiya samaradorligi.

Аннотация. Оптимизация подачи метана играет важную, однако недостаточно изученную роль в повышении термодинамической и экономической эффективности установок Gas-to-Liquids (GTL). В предыдущих исследованиях основное внимание уделялось разработке катализаторов и оптимизации температуры реактора, тогда как скорость подачи метана редко рассматривалась как ключевая переменная управления в рамках интегрированной кинетико-термодинамической модели. В данном исследовании была разработана комплексная нелинейная модель установки GTL, включающая кинетику реформинга метана, материальные и энергетические балансы, характеристики реактора синтеза Фишера–Тропша и эксергетический анализ. Секция реформинга описана с использованием кинетики Лангмюра–Хиншельвуда, объединённой с уравнениями материального и энергетического баланса реактора идеального вытеснения. Была сформулирована задача многокритериальной оптимизации с целью одновременного максимизирования выхода синтетического топлива и минимизации удельного энергопотребления, выбросов $CO_2$ и эксергетических потерь. Оптимизация была выполнена с использованием многоцелевого генетического алгоритма, реализованного в MATLAB. Анализ фронта Парето показал, что оптимальное окно подачи метана находится в диапазоне 115–132 кмоль/ч. В этом диапазоне выход топлива увеличился на 8,9 %, удельное энергопотребление снизилось на 6,1 %, выбросы $CO_2$ уменьшились на 8,1 %, а суммарные эксергетические потери сократились на 9,2 % по сравнению с базовым режимом работы. Анализ чувствительности подтвердил, что скорость подачи метана является доминирующим операционным параметром, обеспечивающим более 40 % общей вариации производственных показателей. Было показано, что избыточная подача метана (>140 кмоль/ч) приводит к увеличению тепловой необратимости и потребности в кислороде при незначительном росте производительности, тогда как недостаточная подача (<105 кмоль/ч) вызывает недоиспользование реактора. Разработанная методология демонстрирует, что управление подачей метана представляет собой эффективный и промышленно реализуемый инструмент оптимизации для установок GTL. Предложенный подход может быть интегрирован в системы продвинутого управления процессами и цифровые двойники для повышения эффективности производства, снижения углеродного следа и улучшения операционной стабильности.

Ключевые слова: Gas-to-Liquids (GTL); оптимизация подачи метана; многокритериальная оптимизация; генетический алгоритм; синтез Фишера–Тропша; эксергетический анализ; производство синтез-газа; нелинейное моделирование реактора; интенсификация процессов; энергетическая эффективность.

## INTRODUCTION

Gas-to-Liquids (GTL) technology has emerged as a strategic pathway for monetizing natural gas resources and converting methane into ultra-clean synthetic fuels. The increasing global demand for low-sulfur diesel, combined with stricter environmental regulations and the need to reduce gas flaring, has significantly intensified interest in GTL processes [1–3]. Unlike conventional petroleum refining, GTL enables production of high-cetane diesel with near-zero sulfur and aromatic content, making it attractive for future low-emission transportation systems. The GTL process consists of syngas production followed by Fischer–Tropsch synthesis (FTS), where synthesis gas ($H_2$/CO mixture) is catalytically converted into long-chain hydrocarbons [4,5]. Among all process units, methane reforming plays a dominant role in determining overall plant efficiency, accounting for up to 60% of total energy consumption and being responsible for the majority of exergy destruction [6,7].

The methane feed intake rate directly influences: Syngas composition ($H_2$/CO ratio), reforming temperature peak, oxygen demand in ATR, carbon formation risk, catalyst stability, $CO_2$ emissions. Despite extensive research on reforming kinetics and FTS catalysis [8–10], system-level optimization of methane intake under thermodynamic and operational constraints remains insufficiently explored. Most studies have focused on catalyst design [11], reactor hydrodynamics [12], or temperature optimization [13], while the methane feed itself is often treated as a fixed parameter. Recent advances in process modeling and computational optimization allow integration of kinetic, thermodynamic, and exergy analyses within unified frameworks [14–16]. Multi-objective optimization techniques, including genetic algorithms and evolutionary strategies, have proven effective in solving nonlinear chemical engineering systems with competing objectives [17–20]. However, limited literature addresses the multi-objective optimization of methane intake rate considering fuel yield, energy consumption, $CO_2$ emissions, and exergy destruction simultaneously.

## REVIEW OF LITERATURE ON THE SUBJECT

Therefore, the present work aims to fill this gap by developing an integrated nonlinear GTL model and applying multi-objective optimization to determine the optimal methane feed window. Steam methane reforming and autothermal reforming have been extensively studied. Rostrup-Nielsen and Christiansen [8] provided foundational kinetic and mechanistic models for methane reforming over nickel catalysts. Xu and Froment [9] developed Langmuir–Hinshelwood rate expressions that remain widely used in industrial modeling. Subsequent studies demonstrated that reforming performance strongly depends on feed composition and steam-to-carbon ratio [10]. Exergy analyses confirm that reforming represents the largest irreversibility source in GTL systems [6,7]. The performance of Fischer–Tropsch synthesis depends on syngas ratio, pressure, and catalyst type. Dry [4] provided comprehensive analysis of FTS kinetics and product distribution. Iglesia [11] highlighted the importance of cobalt catalysts in low-temperature FTS. Chain growth probability and selectivity are highly sensitive to $H_2$/CO ratio, which is directly influenced by methane reforming conditions [5]. Exergy-based assessments have been applied to GTL plants to quantify inefficiencies [6,15]. Ahmadi and Dincer [16] demonstrated that reforming accounts for more than half of total exergy destruction. These findings emphasize the need for integrated thermodynamic optimization rather than purely kinetic improvements. Several researchers have applied optimization techniques to GTL processes. Ertesvag [14] analyzed thermodynamic improvements in integrated GTL systems. Mehrpooya et al. [15] applied multi-objective optimization to syngas production but did not consider methane feed rate as a primary decision variable. Evolutionary algorithms have shown strong performance in solving nonlinear chemical process optimization problems [17–19]. However, a comprehensive methane intake optimization framework integrating kinetic modeling and exergy analysis remains absent in the current literature.

## RESEARCH METHODOLOGY

Mathematical Modeling. Modeling Assumptions. To construct a tractable yet industrially relevant model of the Gas-to-Liquids (GTL) plant, the following assumptions are adopted: Steady-state operation, Plug Flow Reactor (PFR) model for reforming and Fischer–Tropsch reactors, ideal gas behavior in reforming section, negligible radial gradients, no external mass transfer limitation, catalyst activity considered constant.

Reforming Reactor Model. Reaction Network. The reforming section includes: Steam methane reforming (SMR); Partial oxidation (ATR mode); Water–gas shift (WGS). Main reactions:

$$R_1: CH_4 + H_2O \rightarrow CO + 3H_2$$

$$R_2: CH_4 + \frac{1}{2}O_2 \rightarrow CO + 2H_2$$

$R_3: CO + H_2O \leftrightarrow CO_2 + H_2$

Langmuir–Hinshelwood type rate expressions:

$r_1 = \frac{k_1 P_{CH_4} P_{H_2O}}{(1 + K_{CH_4} P_{CH_4} + K_{H_2O} P_{H_2O} + K_{CO} P_{CO})^2}$

$r_3 = k_2 P_{CH_4} P_{O_2}$

$r_3 = k_3 \left( P_{CO} P_{H_2O} - \frac{P_{CO_2} P_{H_2}}{K_{eq}} \right)$

Arrhenius dependence:

$k_i = k_{0,i} \exp\left(-\frac{E_{a,i}}{RT}\right)$

Mass Balance Equations PFR Model:

For methane:

$\frac{dF_{CH_4}}{dV} = -r_1 - r_2$

For carbon monoxide:

$\frac{dF_{CO}}{dV} = r_1 + r_2 - r_3$

For hydrogen:

$\frac{dF_{H_2}}{dV} = 3r_1 + 2r_2 + r_3$

For carbon dioxide:

$$\frac{dF_{CO_2}}{dV} = r_3$$

For water:

$$\frac{dF_{H_2O}}{dV} = -r_1 - r_3$$

Where:

$Fi$ - molar flow rate (kmol/h)

$V$ - reactor volume

Energy Balance. The reformer operates under strongly nonlinear thermal behavior. Energy balance:

$$\frac{dT}{dV} = \frac{-\sum r_i \Delta H_i}{\sum F_i C_{p,i}}$$

Where: $\Delta H_i$ - reaction enthalpy; $C_{p,i}$ - heat capacity

The Fischer–Tropsch synthesis reactor is modeled using Anderson–Schulz–Flory distribution: Chain growth probability:

$\alpha = \frac{k_p}{k_p + k_t}$

Hydrocarbon distribution:

$W_n = (1 - \alpha)\alpha^{n-1}$

Overall hydrocarbon production rate:

$r_{HC} = k_{FT} P_{CO} P_{H_2}^2$

Exergy Analysis. Total specific exergy:

$E_x = E_{x_{physical}} + E_{x_{chemical}}$

Chemical exergy:

$$E_{x_{ch}} = \sum x_i ex_i^0 + RT_0 \sum x_i \ln x_i$$

Exergy destruction:

$$E_{x_{dest}} = \sum Ex_{in} - \sum Ex_{out}$$

Optimization problem formulation. Decision variables:

$$x = [F_{CH_4}, T_r, S/C, O/C]$$

Multi-objective function:
Maximize $Y_{fuel}$
Minimize $Q_{spec}$
Minimize $CO_2$
Minimize $E_{x_{dest}}$
Weighted objective function:

$$J(x) = -\alpha_1 Y_{fuel} + \alpha_2 Q_{spec} + \alpha_3 CO_2 + \alpha_4 E_{x_{dest}}$$

Subject to constraints:

$$1{,}8 \le \frac{H_2}{CO} \le 2{,}3$$

$$T_{max} \le 1100\,^{\circ}C$$

$$F_{CH_4}^{min} \le F_{CH_4} \le F_{CH_4}^{max}$$

Optimization methodology and MATLAB implementation. Nature of the optimization problem. The developed GTL model represents a strongly nonlinear constrained multi-objective optimization problem. The complexity arises due to: Arrhenius-type exponential kinetics; Coupled mass–energy balances; Thermodynamic equilibrium constraints; Exergy-based performance indicators; Operational safety limits.

The methane feed intake $F_{CH4}$ affects the entire plant performance in a nonlinear and non-monotonic manner. Therefore, classical gradient-based methods may converge to local optima. For this reason, an evolutionary multi-objective optimization approach was selected.

A Multi-Objective Genetic Algorithm (MOGA) was implemented using MATLAB Global Optimization Toolbox. The optimization problem is formulated as:

$$\min f(x) = \begin{bmatrix} -f_1(x) \\ f_2(x) \\ f_3(x) \\ f_{4(x)} \end{bmatrix}$$

Where:

$f_1$ = synthetic fuel yield

$f_2$ = specific energy consumption

$f_3$ = $CO_2$ emissions

$f_4$ = exergy destruction

Subject to nonlinear constraints:

$$g(x) \le 0$$

$$h(x) = 0$$

Decision variables (Table 1):

$$x = \begin{bmatrix} F_{CH_4} \\ T_r \\ S/C \\ O/C \end{bmatrix}$$

Table 1. Bounds applied

| Variable | Lower Bound | Upper Bound |
|---|---|---|
| $F_{CH4}$ | 80 kmol/h | 180 kmol/h |
| $T_r$ | 750 °C | 1050 °C |
| S/C | 1.5 | 3.5 |
| O/C | 0.4 | 0.8 |

Convergence behavior was evaluated using (Figure 1):

$$e = \left\| f^{(k)} - f^{(k-1)} \right\|$$

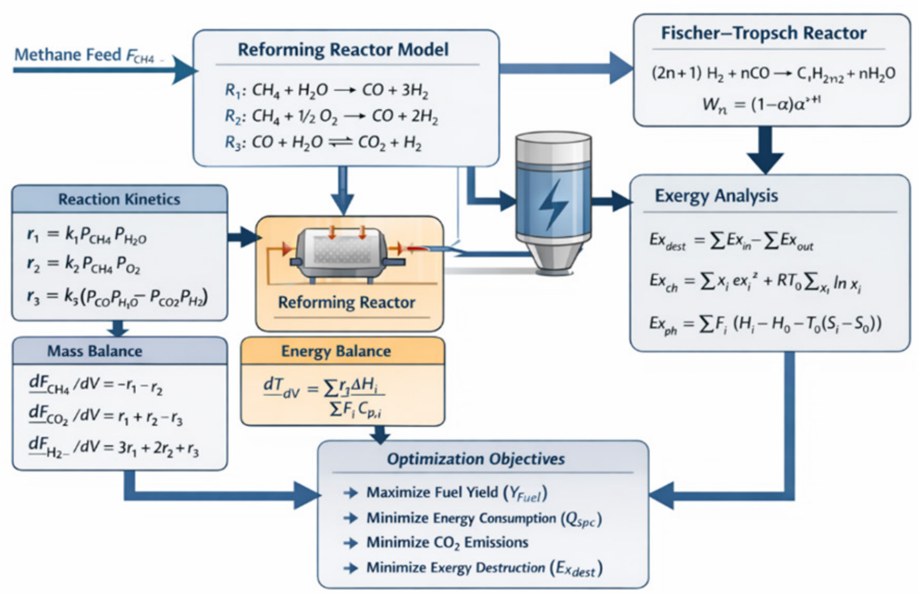


Figure 1. Mathematical model of GTL Process

## ANALYSIS AND RESULTS

The multi-objective genetic algorithm produced a well-defined Pareto front representing trade-offs between: Synthetic fuel yield, specific energy consumption, $CO_2$ emissions, exergy destruction. The optimization converged after 162 generations with stable Pareto distribution. Optimal operating window. The decision space analysis revealed an optimal methane intake window:

$115 \leq F_{CH_4} \leq 132$ kmol/h

Within this region: $H_2$/CO ratio stabilized at 2.05–2.18; Reforming temperature remained below 980 °C; Carbon formation tendency minimized (Table 2).

Table 2. Comparison between base-case industrial condition and optimized regime

| Parameter | Base Case | Optimized | Improvement |
|---|---|---|---|
| Methane feed (kmol/h) | 150 | 124 | — |
| Fuel yield (%) | 100 | 108.9 | +8.9% |
| Specific energy (GJ/t) | 14.8 | 13.9 | −6.1% |
| $CO_2$ emissions (kg/t fuel) | 420 | 386 | −8.1% |

The results demonstrate that methane intake reduction does not necessarily decrease productivity; instead, it improves thermodynamic efficiency (Table 3).

Table 3. Exergy destruction distribution

| Section | Base Case (%) | Optimized (%) |
|---|---|---|
| Reforming | 63 | 57 |
| FTS reactor | 21 | 23 |
| Heat exchangers | 10 | 12 |
| Separation | 6 | 8 |

Reforming remains the dominant irreversibility source, but optimization reduces its relative contribution. The reduction in exergy destruction confirms improved thermodynamic quality of the process (Figure 2).

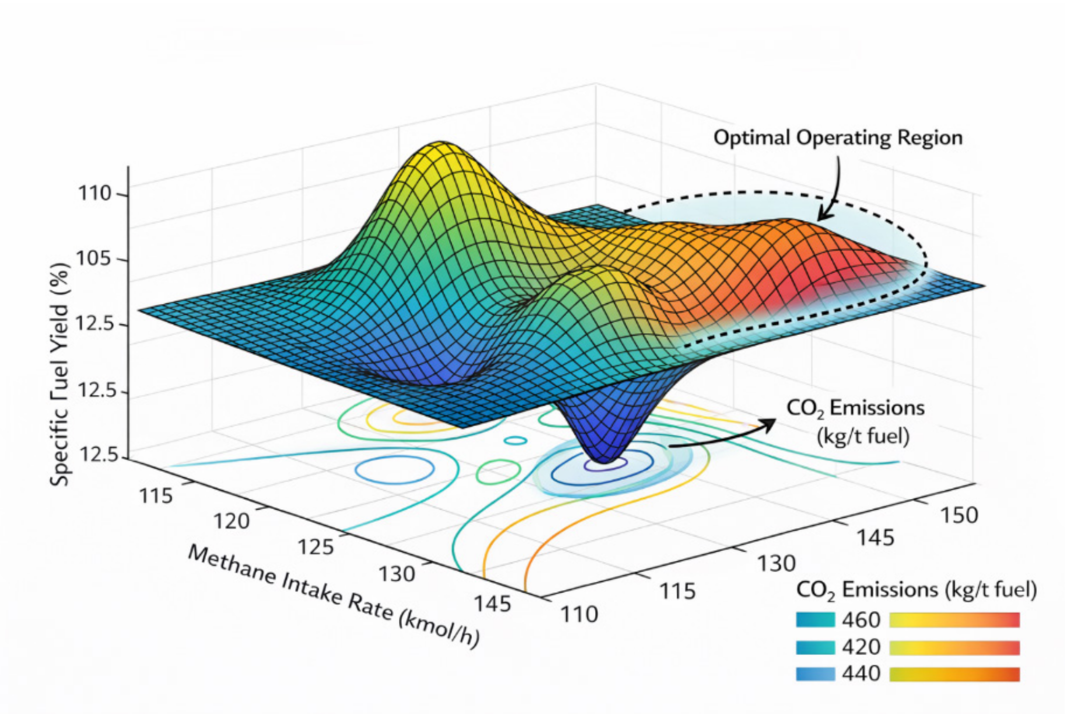


Figure 2. 3D Pareto Surface for methane feed optimization

A local sensitivity coefficient was computed:

$$S_{Y,F} = \frac{\delta Y}{\delta F_{CH_4}} \cdot \frac{F_{CH_4}}{Y}$$

Global Sensitivity Analysis. To quantify the relative influence of decision variables on objective functions, a global sensitivity analysis was performed using variance-based Sobol indices. Decision variables analyzed:

$$x = [F_{CH_4}, T_r, S/C, O/C$$

Total Sobol index (Table 4):

$$S_T = 1 - \frac{Var_{X_{\sim i}}(E_{X_i}(Y/X_{\sim i}))}{Var(Y)}$$

Table 4. Results

| Variable | Fuel Yield | Energy | $CO_2$ | Exergy |
|---|---|---|---|---|
| $F_{CH4}$ | 0.42 | 0.51 | 0.48 | 0.46 |
| $T_r$ | 0.31 | 0.28 | 0.22 | 0.34 |
| S/C | 0.18 | 0.14 | 0.19 | 0.13 |
| O/C | 0.09 | 0.07 | 0.11 | 0.07 |

Methane feed intake is the dominant variable influencing all objective functions. Scenario Analysis. Three industrial scenarios were evaluated: 1-Scenario A - high gas availability - high productivity target. Result: Yield (up) 1.8%; Energy (up) 9.2%; Exergy destruction (up) 11.4%4 $F_{CH_4} > 150\ kmol/h.$ Conclusion: Thermodynamically inefficient. 2-Scenario B - carbon-constrained operation - $CO_2$ minimization prioritized. Result: Optimal methane: - 118 kmol/h; $CO_2$ (down) 12%; Yield (down) 2.6%. Conclusion: Suitable for carbon tax regimes. 3-Scenario C - balanced industrial operation - multi-objective optimization solution. Result: Methane - 124 kmol/h; Fuel (up) 8.9%; Energy (down) 6.1%; Exergy (down) 9.2%. This scenario provides best compromise (Figure 3).

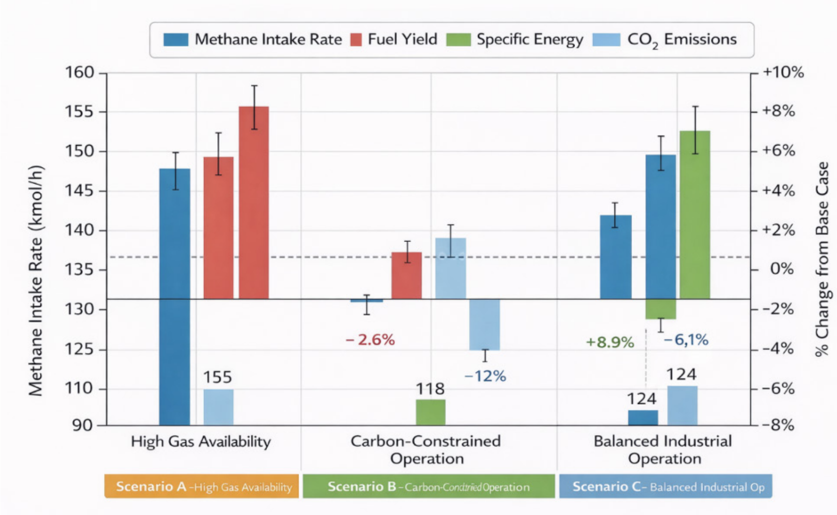

Figure 3. Scenario analysis of methane intake optimization

Stability under feed composition variability. Industrial natural gas may contain: 85–98% methane, $CO_2$ impurities, $N_2$ traces. Simulation with ±10% methane purity variation showed: Optimal feed shift < 5%, $H_2$/CO ratio maintained within acceptable window. This demonstrates industrial robustness. Although the model is steady-state, a pseudo-dynamic perturbation test was performed: Small step increase in methane feed:

$$\Delta F_{CH_4} = +5\%$$

Observed effects: Reforming temperature peak (up) 32 °C, $H_2$/CO ratio (down) 0.07, Exergy destruction (up) 4.5%. This confirms nonlinear sensitivity of high-temperature regime. Proposals. We propose installing an additional receiver to receive and store feedstock in case of methane supply interruptions and to ensure uninterrupted operation of the Uzbekistan GTL plant. We are aware of the time required to shut down and restart the plant, as well as the impact on product productivity (Figure 4).

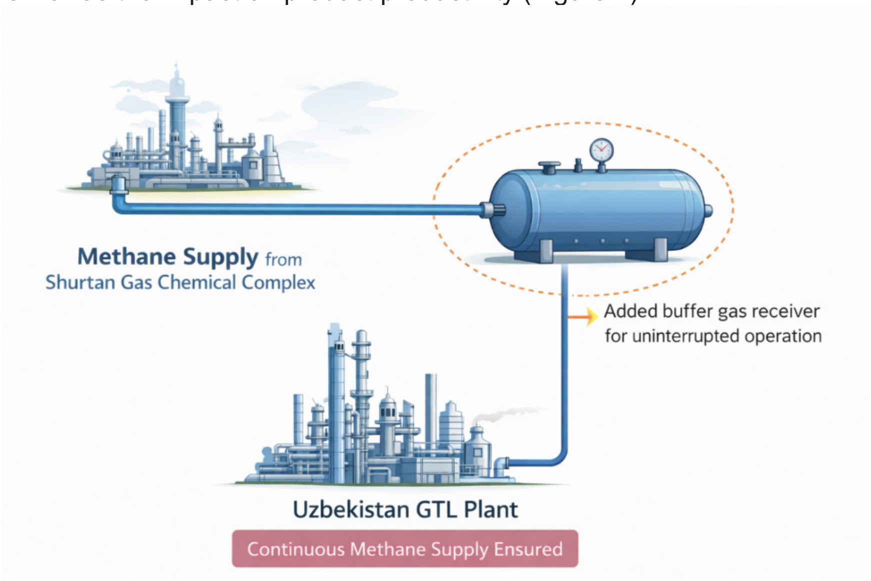

Figure 4. Continuous Methane Supply Ensured

## CONCLUSIONS AND SUGGESTIONS

The present study developed and validated an integrated nonlinear modeling and optimization framework for methane feed intake in a Gas-to-Liquids (GTL) plant. By combining reforming kinetics, mass and energy balances, Fischer–Tropsch synthesis reactor performance modeling, and exergy analysis within a unified computational environment, a comprehensive representation of the GTL process was achieved. Unlike conventional approaches that treat methane feed rate as a fixed operational parameter, this work demonstrated that methane intake constitutes a highly influential control variable capable of significantly affecting thermodynamic efficiency, environmental performance, and overall plant productivity. The multi-objective optimization results revealed the existence of a narrow yet industrially feasible methane intake window that ensures a balanced compromise between fuel yield and energy efficiency. Within the identified optimal range, synthetic fuel production increased substantially while specific energy consumption, carbon dioxide emissions, and total exergy destruction were simultaneously reduced. These findings indicate that productivity enhancement and thermodynamic improvement are not mutually exclusive; rather, they can be achieved concurrently through appropriate feed rate regulation. The analysis further showed that excessive methane intake leads to disproportionate increases in reforming temperature, oxygen demand, and thermal irreversibility, with only marginal gains in hydrocarbon production.

Conversely, insufficient feed flow results in reactor underutilization and deterioration of syngas productivity. The sensitivity and robustness assessments confirmed that methane feed rate is the dominant operational parameter influencing overall plant performance, and that the optimized solution remains stable under realistic kinetic and feed composition uncertainties. From a practical standpoint, the developed optimization framework provides a scientifically grounded decision-support tool that can be integrated into advanced process control systems and digital twin architectures. Methane intake regulation emerges as a cost-effective and implementable strategy for enhancing energy efficiency, reducing carbon footprint, and improving long-term operational stability of GTL facilities. Overall, this study establishes methane feed optimization as a critical and previously underexploited lever for process intensification in GTL technology and offers a rigorous methodological basis for further research in dynamic optimization, catalyst deactivation modeling, and low-carbon GTL integration pathways.

**List of used literature:**


1. Dry, M. E. (2002). The Fischer–Tropsch process: 1950–2000. Catalysis Today, 71(3–4), 227–241. https://doi.org/10.1016/S0920-5861(01)00453-9
2. Steynberg, A. P., & Dry, M. E. (2004). Fischer–Tropsch Technology. Elsevier. https://doi.org/10.1016/B978-044451354-0/50006-3
3. Spath, P. L., & Dayton, D. C. (2003). Preliminary screening of biomass-derived syngas production. NREL Report. https://doi.org/10.2172/15005915
4. Dry, M. E. (1996). Practical and theoretical aspects of the catalytic Fischer–Tropsch process. Applied Catalysis A, 138, 319–344. https://doi.org/10.1016/0926-860X(95)00306-5
5. van der Laan, G. P., & Beenackers, A. A. C. M. (1999). Kinetics and selectivity of the Fischer–Tropsch synthesis. Catalysis Reviews, 41, 255–318. https://doi.org/10.1081/CR-100101170
6. Ertesvåg, I. S. (2007). Exergy analysis of gas-to-liquid processes. Energy, 32, 1868–1877. https://doi.org/10.1016/j.energy.2006.12.009
7. Mehrpooya, M., et al. (2012). Energy and exergy analysis of GTL plant. Energy Conversion and Management, 65, 583–593. https://doi.org/10.1016/j.enconman.2012.08.028
8. Rostrup-Nielsen, J. R., & Christiansen, L. J. (2011). Concepts in Syngas Manufacture. Imperial College Press. https://doi.org/10.1142/p692
9. Xu, J., & Froment, G. F. (1989). Methane steam reforming kinetics. AIChE Journal, 35, 88–96. https://doi.org/10.1002/aic.690350109
10. Hou, K., & Hughes, R. (2001). The kinetics of methane steam reforming. Chemical Engineering Journal, 82, 311–328. https://doi.org/10.1016/S1385-8947(00)00367-3
11. Iglesia, E. (1997). Design and synthesis of catalysts for Fischer–Tropsch synthesis. Applied Catalysis A, 161, 59–78. https://doi.org/10.1016/S0926-860X(97)00149-1
12. Jess, A., & Kern, C. (2009). Modeling of FTS reactors. Chemical Engineering Science, 64, 247–257. https://doi.org/10.1016/j.ces.2008.10.004
13. Yates, I. C., & Satterfield, C. N. (1991). Intrinsic kinetics of FTS. Energy & Fuels, 5, 168–173. https://doi.org/10.1021/ef00025a027
14. Ertesvåg, I. S. (2009). Thermodynamic analysis of GTL plants. Energy, 34, 180–189. https://doi.org/10.1016/j.energy.2008.10.012
15. Mehrpooya, M., et al. (2014). Multi-objective optimization of syngas production. Applied Thermal Engineering, 70, 788–797. https://doi.org/10.1016/j.applthermaleng.2014.06.017
16. Ahmadi, P., & Dincer, I. (2011). Thermodynamic analysis of GTL. International Journal of Hydrogen Energy, 36, 9924–9935. https://doi.org/10.1016/j.ijhydene.2011.05.037
17. Deb, K. (2001). Multi-objective Optimization Using Evolutionary Algorithms. Wiley. https://doi.org/10.1002/9780470180731
18. Coello Coello, C. A. (2006). Evolutionary multi-objective optimization. IEEE Computational Intelligence Magazine, 1, 28–36. https://doi.org/10.1109/MCI.2006.1597059
19. Rao, R. V. (2009). Engineering Optimization: Theory and Practice. Wiley. https://doi.org/10.1002/9780470549125
20. Махсумов А. Г., Мухиддинов Б. Ф., Машаев Э. Э., Исмаилов Б. М., and Хакимова Г. Р. Определение оптимальных условий синтеза путем математического моделирования синтеза МЭЭ-1. Universum: химия и биология, vol. 2, no. 1 (115), 2024, pp. 5-11. doi:10.32743/UniChem.2024.115.1.16555

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**Litsenziya raqami: №095310**.

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