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The journal is also included in the Emerging Sources Citation Index (ESCI) of the Web of Science platform (Clarivate Analytics, since 2018).

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«Қазақстан Республикасы Ұлттық ғылым академиясының Хабарлары. Геология және техникалық ғылымдар сериясы» ғылыми журналы 2016 жылдан бастап халықаралық реферативтік және ғылымиметриялық Scopus дерекқорында индекстеледі және тұрақты библиометриялық көрсеткіштерді көрсетіп келеді.

Сонымен қатар журнал Web of Science платформасының (Clarivate Analytics, 2018) халықаралық реферативтік және наукометриялық дерекқоры Emerging Sources Citation Index (ESCI) тізіміне енгізілген.

ESCI дерекқорында индекстелуі журналдың халықаралық ғылыми рецензиялау талаптары мен редакциялық этика стандарттарына сәйкестігін растайды, сондай-ақ Clarivate Analytics компаниясы тарапынан басылымды Science Citation Index Expanded (SCIE), Social Sciences Citation Index (SSCI) және Arts & Humanities Citation Index (AHCI) дерекқорларына енгізу қарастырылуда.

Scopus және Web of Science дерекқорларында индекстелуі жарияланымдардың халықаралық деңгейде жоғары сұранысқа ие болуын қамтамасыз етеді, олардың дәйексөз алу көрсеткіштерінің артуына ықпал етеді және редакциялық алқаның геология мен техникалық ғылымдар саласындағы өзекті, бірегей және ғылыми тұрғыдан маңызды зерттеулерді жариялауға ұмтылысын айқындайды.

Научный журнал «News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences» с 2016 года индексируется в международной реферативной и наукометрической базе данных Scopus и демонстрирует стабильные библиометрические показатели.

Журнал также включён в международную реферативную и наукометрическую базу данных Emerging Sources Citation Index (ESCI) платформы Web of Science (Clarivate Analytics, 2018).

Индексирование в ESCI подтверждает соответствие журнала международным стандартам научного рецензирования и редакционной этики, а также рассматривается компанией Clarivate Analytics в рамках дальнейшего включения издания в Science Citation Index Expanded (SCIE), Social Sciences Citation Index (SSCI) и Arts & Humanities Citation Index (AHCI).

Индексирование в Scopus и Web of Science обеспечивает высокую международную востребованность публикаций, способствует росту цитируемости и подтверждает стремление редакционной коллегии публиковать актуальные, оригинальные и научно значимые исследования в области геологии и технических наук.

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EFFECTS OF HYDROCARBON FUEL QUALITY FLUCTUATIONS ON ENERGY GENERATION EFFICIENCY, ECONOMIC VIABILITY, AND ENVIRONMENTAL FOOTPRINT

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Abstract. *Significance.* In energy generation systems that operate on hydrocarbon fuels, overall efficiency is strongly influenced by fuel quality in addition to technological and operational parameters. Among hydrocarbon fuels, natural gas is widely recognized as a preferable energy source due to its relatively clean composition, higher hydrogen-to-carbon ratio, and superior combustion characteristics.

Objective. This study introduces a newly developed purification technology based on Constrictive Gas Filters with a novel operating principle designed for deep cleaning of natural gas streams. *Methods.* The proposed system enables efficient removal of light liquid hydrocarbons and mechanical contaminants without causing significant pressure loss or energy consumption. Experimental analysis was conducted to evaluate the physicochemical properties of natural gas before and after purification through the developed filters.

Results. The results demonstrate that the purified gas exhibits improved quality indicators, including increased calorific value, optimized density, and reduced oxygen demand during combustion. Based on compositional analysis and theoretical calculations, the application of high-purity natural gas in energy generation systems is projected to contribute to a reduction in fuel consumption by approximately 10–12%, pending experimental validation in operating combustion equipment. Additionally, enhanced fuel quality is expected to improve the performance and reliability of combustion equipment and extend the operational lifespan of energy-generating units.

Conclusion. Furthermore, the use of purified natural gas significantly reduces emissions of greenhouse gases and other harmful combustion byproducts, thereby supporting environmental sustainability and compliance with modern emission standards. Overall, the proposed Constrictive Gas Filter technology represents an effective and innovative solution for enhancing natural gas quality and improving the efficiency and environmental performance of hydrocarbon-based energy systems.

Keywords: Energy, petroleum products, hydrocarbon fuel, natural gas, light liquid hydrocarbons, constrictive filter, combustion products, greenhouse gases, environment, etc

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КӨМІРСУТЕКТІ ОТЫН САПАСЫНЫҢ ӨЗГЕРІСТЕРІ ЭНЕРГИЯ ӨНДІРУ ТИІМДІЛІГІНЕ, ЭКОНОМИКАЛЫҚ ЖАРАМДЫЛЫҚҚА ЖӘНЕ ЭКОЛОГИЯЛЫҚ ІЗГЕ ӘСЕРІ

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Аннотация. *Өзектілігі.* Көмірсутекті отынмен жұмыс істейтін энергия өндіру жүйелерінде жалпы тиімділік технологиялық және пайдалану параметрлерімен қатар отын сапасына да қатты әсер етеді. Көмірсутекті отындар арасында табиғи газ салыстырмалы түрде таза құрамы, сутегінің көміртегіге жоғары арақатынасы және үздік жану сипаттамалары арқасында қолайлы энергия көзі ретінде кеңінен танылған.

Зерттеу мақсаты. Бұл зерттеу табиғи газ ағындарын терең тазартуға арналған, жұмыс істеуінің жаңа принципіне негізделген констриктивті газ сүзгілерін қолданатын жаңа технологияны ұсынады. *Әдістері.* Ұсынылып отырған жүйе айтарлықтай қысым жоғалтусыз немесе энергия тұтынусыз жеңіл сұйық көмірсутектер мен механикалық ластағыштарды тиімді жоюға мүмкіндік береді. Әзірленген сүзгілер арқылы тазартуға дейінгі және одан кейінгі табиғи газдың физика-химиялық қасиеттерін бағалау үшін тәжірибелік талдау жүргізілді.

Нәтижелері. Нәтижелер тазартылған газдың жақсартылған сапа көрсеткіштерін көрсететінін дәлелдейді, оның ішінде жылу шығару қабілетінің артуы, тығыздықтың оңтайлануы және жану кезінде оттегі қажеттілігінің азаюы бар. Құрамды талдау және теориялық есептеулер негізінде, энергия өндіру жүйелерінде жоғары тазалықтағы табиғи газды қолдану отын шығынын шамамен 10–12%-ға төмендетуге ықпал етеді деп болжануда (жұмыс істеп тұрған жану жабдығында тәжірибе жүзінде растауды күтеді). Сонымен қатар, отын сапасының артуы жану жабдығының өнімділігі мен сенімділігін арттырып, энергия өндіру агрегаттарының пайдалану мерзімін ұзартады деп күтілуде.

Қорытындылар. Одан басқа, тазартылған табиғи газды пайдалану парниктік газдар мен жанудың басқа да зиянды қосымша өнімдерінің шығарындыларын айтарлықтай азайтады, осылайша экологиялық тұрақтылықты қолдап, заманауи эмиссия стандарттарына сәйкестікті қамтамасыз етеді. Жалпы алғанда, ұсынылып отырған констриктивті газ сүзгілері технологиясы табиғи газ сапасын арттырудың және көмірсутекті энергия жүйелерінің тиімділігі мен экологиялық көрсеткіштерін жақсартудың тиімді әрі инновациялық шешімі болып табылады.

Түйін сөздер: энергия, мұнай өнімдері, көмірсутекті отын, табиғи газ, жеңіл сұйық көмірсутектер, қысып сүзгі, жану өнімдері, парниктік газдар, қоршаған орта және т.б.

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ВОЗДЕЙСТВИЕ ИЗМЕНЕНИЙ КАЧЕСТВА ПРИМЕНЯЕМОГО В ПРОЦЕССЕ ВЫРАБОТКИ ЭНЕРГИИ УГЛЕВОДОРОДНОГО ТОПЛИВА НА ТЕХНИКО-ЭКОНОМИЧЕСКИЕ ПОКАЗАТЕЛИ И СОСТОЯНИЕ ОКРУЖАЮЩЕЙ СРЕДЫ

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Аннотация. *Актуальность.* В системах генерации энергии, функционирующих на углеводородном топливе, общая эффективность в значительной степени определяется не только технологическими и эксплуатационными параметрами, но и качеством используемого топлива. Среди углеводородных энергоносителей природный газ широко признан предпочтительным видом топлива благодаря относительно чистому составу, высокому соотношению водорода к углероду и благоприятным характеристикам сгорания. *Цель исследования* - разработка и оценка эффективности новой технологии глубокой очистки природного газа на основе констриктивных газовых фильтров с принципиально новым механизмом действия. *Методы*. Предлагаемая система обеспечивает эффективное удаление легких жидких углеводородов и механических примесей без существенных потерь давления и увеличения энергозатрат. Проведён экспериментальный анализ физико-химических свойств природного газа до и после очистки с использованием разработанных фильтров. *Результаты*. Полученные результаты показывают, что очищенный газ характеризуется улучшенными качественными показателями, включая увеличение теплотворной способности, оптимизацию плотности и снижение потребности в кислороде при сгорании. На основе анализа компонентного состава и теоретических расчётов установлено, что использование высокоочищенного природного газа в энергетических системах потенциально позволяет снизить расход топлива на 10–12% (что требует дополнительного экспериментального подтверждения в условиях промышленной эксплуатации котельного оборудования). Кроме того, повышение качества топлива способствует улучшению эксплуатационных характеристик и надежности котельных установок, а также увеличению срока их службы. *Выводы*. Применение очищенного природного газа приводит к снижению выбросов парниковых газов и других вредных продуктов сгорания, что способствует повышению экологической устойчивости и соответствию современным экологическим стандартам. В целом, предложенная технология констриктивных газовых фильтров представляет собой инновационное и эффективное решение, направленное на повышение качества природного газа, а также улучшение энергетической и экологической эффективности систем, работающих на углеводородном топливе..

Ключевые слова: Энергия, нефтепродукты, углеводородное топливо, природный газ, лёгкие жидкие углеводороды, констриктивный фильтр, продукты сгорания, парниковые газы, окружающая среда и др.

Introduction. In nature, there are various forms of energy, including mechanical, thermal, chemical, electrical, light, nuclear, and magnetic energy. In industry and residential settings, electricity and heat are most widely used-for lighting and heating homes, powering transportation, driving machinery in manufacturing, and so on. Worldwide, energy is produced by a variety of methods.

In the national economy, petroleum products serve as the primary fuel for energy production. As demand for energy rises daily-and as burning petroleum fuels releases greenhouse gases into the atmosphere-the volume of these emissions increases day by day. Recent statistics show a sharp rise in the emissions of CO_2, NO_2, SO_2, and H_2O when petroleum fuels are combusted. Of these, CO_2 contributes most to environmental pollution, and concentrations above normative levels can adversely affect human health.

According to the International Energy Agency's 2024 report on global energy trends, overall energy demand grew by 2.2%, with demand rising across all fuel types. Demand for electricity generation increased by 4.3%. Globally, energy supply is met primarily by renewables (38%), natural gas (28%), hard coal (15%), oil (11%), and nuclear power (8%).

In 2024, the growth in electricity demand was driven chiefly by extreme cold-requiring increased heating of homes-as well as the need for stable industrial output, the electrification of transportation, and the expansion of digital processing sectors.

In the energy production mix, petroleum products remain the dominant fuel, with natural gas accounting for 28% and oil-derived fuels 11%. These figures underscore that natural gas is now the most widely used fuel in energy generation.

According to the UN Framework Convention on Climate Change, burning one ton of natural gas as a standard fuel in energy generation emits 1.7 times fewer harmful gases than burning hard coal and 1.4 times fewer than burning fuel oil. In the transport sector, vehicles running on compressed natural gas emit 90–97 % less CO, 25 % less CO_2, and 35–60 % less NO_x than those running on other liquid fuels.

The lower cost of natural gas and the extended service life it affords engines further confirm the superior techno-economic efficiency of its use.

Recent advances in the gas industry open broad prospects for overall economic development. Natural gas-as a fuel-plays a key role in ensuring global energy security and supporting industrial growth, while generating comparatively fewer ecological problems during combustion. Considering only its environmental advantages, natural gas is poised today-and in the near future-to play a central role in solving global energy challenges.

To reduce greenhouse-gas emissions and mitigate environmental impact from fuel combustion in energy production, the following measures are commonly employed:

- Use of high-quality fuel
- Post-combustion treatment of flue gases via filtration
- Increased stack heights for smoke and exhaust outlets

However, these methods alone are insufficient to fully address the problem of atmospheric pollution by hydrocarbon fuel combustion. Experience in environmental protection shows that restrictions must be placed on the use of petroleum products as fuel in energy generation, and that power must increasingly be produced from non-conventional energy sources. Until such a transition is complete, there remains an urgent need to develop and implement new technologies within the fuel-energy complex to minimize greenhouse-gas emissions from energy production.

In both residential and industrial sectors of the national economy, natural gas-recognized as a comparatively efficient fuel-is the preferred choice for energy production. Unlike other fuel types, natural gas delivers higher quality, ease of transport, and a cleaner environmental footprint (Osipov et al., 2019). When combusted, it emits substantially lower volumes of greenhouse gases than other hydrocarbon fuels.

The key characteristics of the combustion process are governed by flame temperature-which depends on fuel type and calorific value-air-fuel ratio and oxygen enrichment level, the temperatures of both the fuel and intake air, the specifics of the combustion technology employed, and related factors (Kolomiets et al., 2011).

Natural-gas quality is determined by its carbon-to-hydrogen atom ratio and the concentration of mechanical impurities. These parameters can be adjusted through various treatment methods. To enhance natural-gas quality, it must undergo rigorous purification in dedicated treatment units. In this study, a Constrictive Gas Filter was employed for that purpose (Malikov et al., 2024).

Objective: To improve the quality of natural gas used as a fuel in industrial and residential energy-generation processes-and thereby reduce the volume of greenhouse gases released during combustion and mitigate their harmful environmental impact.

Filter Principle and Process: The Constrictive Gas Filter is installed in the gas supply line upstream of the main cleaning unit at each energy-generation device's inlet. The filter assembly comprises a vertical pressure vessel designed in accordance with ASME Section VIII standards, with a design pressure rating of 100–1500 psig depending on the specific pipeline or industrial gas application. The vessel houses a coalescing element cartridge system arranged in a horizontal or vertical configuration to optimize flow distribution and liquid separation efficiency (Remizov et al., 1989).

Diffuser Geometry and Flow Dynamics: As gas enters the filter inlet, it passes through a precision-machined diffuser section at the inlet orifice. The diffuser features a converging–diverging geometry with a specific contraction ratio calculated to achieve an optimal gas velocity of 0.1–0.3 ft/sec through the coalescing media. This controlled velocity is critical for preventing re-entrainment of separated liquids while maintaining high coalescence efficiency. The converging flow directs the gas stream radially inward, creating a controlled pressure gradient that reduces the spacing between liquid hydrocarbon droplets suspended in the gas phase. This reduction in inter-droplet distance increases the probability of droplet–droplet and droplet–fiber collisions essential for coalescence.

Coalescing Media Design and Material Specifications. The coalescing element consists of multiple layers of specialized filtration media engineered for high-efficiency liquid aerosol removal. The primary coalescing layer is manufactured from borosilicate micro-fiberglass with fiber diameters ranging from 1 to 10 microns, creating a tortuous path that forces droplet contact with fiber surfaces. This media incorporates a gradient density structure with optimized fiber packing to enhance coalescence efficiency and extend service life. The borosilicate fibers are selected for their superior surface chemistry, which promotes droplet adhesion through van der Waals forces while maintaining chemical compatibility with hydrocarbon condensates.

The coalescing cartridge employs a multi-layer construction. An inner drainage layer and outer support layer, typically manufactured from resin-impregnated synthetic fibers, provide structural integrity and act as built-in pre-filters to remove solid particulate contaminants before they reach the coalescing media. This pre-filtration function protects the coalescing media from fouling and extends element life to a typical service duration of 12–24 months under normal operating conditions. The middle coalescing layer consists of binder-free borosilicate microfiber glass that captures submicron liquid aerosols in the 0.1–5-micron range (Chase et al., 2010).

Coalescence Mechanism and Physical Principles: Liquid aerosols suspended in the gas stream impinge upon the fiber surfaces of the coalescing media. Droplets adhere to fibers through intermolecular forces, specifically van der Waals interactions, which dominate at the micro-scale distances involved in fiber-droplet contact. As subsequent droplets contact the same fibers, they merge at fiber intersections under the influence of surface tension forces. This process, governed by the tendency of liquid surfaces to minimize their free energy, results in the formation of progressively larger droplets.

The enlarged droplets migrate through the media depth under the influence of gas flow and capillary forces until they emerge on the downstream side of the coalescing element. At this point, gravity drainage becomes the dominant separation mechanism. Droplets that have grown to sufficient size—typically achieving diameters greater than 50 microns-detach from the media and settle into the lower collection sump of the filter housing. The drainage section is designed with sufficient quiescent volume to allow gravitational separation without re-entrainment into the gas stream.

Operating Parameters and Performance Specifications: The filter operates with an initial clean element differential pressure of 2–5 psi, which gradually increases to 15–25 psi at the recommended element replacement point due to solids loading and liquid saturation. Continuous differential pressure monitoring is recommended to optimize maintenance scheduling and prevent operational upsets. The system achieves removal efficiencies of 99.9–99.99% for liquid aerosols 0.3 microns and larger, producing outlet gas with liquid loading under 0.1 ppm by weight, and often below 0.01 ppm.

Material Selection and Construction. The filter housing is constructed from carbon steel for standard hydrocarbon gas service, with stainless steel options available for corrosive gas applications or high-purity requirements. All materials are selected for compatibility with the specific gas composition and liquid hydrocarbons encountered, including resistance to swelling or degradation from condensate exposure. The coalescing elements are designed for easy replacement through cartridge changeout without special tools

Process Sequence: Natural gas flows through the supply line toward the energy-generation unit. Prior to entering the existing treatment apparatus, it passes through the Constrictive Filter mounted on the line.

Passing through the filter's precision-machined diffuser, the gas stream is accelerated and channeled radially inward at a controlled velocity of 0.1–0.3 ft/sec through the coalescing media. The converging flow geometry reduces inter-droplet spacing and initiates droplet–fiber contact.

Submicron liquid aerosols (0.1–5 microns) collide with and adhere to borosilicate micro-fiber surfaces through van der Waals intermolecular forces. Multiple droplet–fiber and droplet–droplet contacts at fiber intersections result in progressive droplet growth (Pivovarova et. al, 2005).

Enlarged droplets migrate through the gradient-density media and emerge on the downstream side, where gravity drainage predominates. Separated liquid hydrocarbons, principally C_5^+ light liquid hydrocarbons, settle into the filter's lower collection sump and are removed through a level-controlled automatic drain system to prevent re-entrainment. The purified gas, now containing less than 0.1 ppm liquid aerosols, exits through the clean gas outlet for delivery to the energy-generation equipment. (Litmanovich, Novoselova, Ostayeva, Papisov, Polyakova et. al 2014).

Experimental Setup. Trials were conducted using natural-gas samples withdrawn from production wells at SOCAR’s Siyazan Gas-Condensate Treatment Facility.

The raw gas produced there consists predominantly of methane and its homologues. Samples were analyzed at SOCAR's Research Institute of Petroleum and Gas under International Standards (GOST 31371.1-2020 and 31369-2021) to determine their physicochemical properties. Reported compositions indicate approximately 94 % methane, 4 % other gaseous hydrocarbons, and 2 % C_5^+ light liquid hydrocarbons.

Using such raw gas directly as a fuel is inadvisable for residential or industrial applications, since the C_5^+ fraction increases greenhouse-gas emissions and contributes to additional oil losses during production. Therefore, it is essential to remove C_5^+ components in upstream treatment at field facilities. As natural gas is purified, its density decreases while all other quality parameters improve, ensuring optimal combustion performance and reduced environmental impact (Ivanovna, Bondaletova, Novikov, Alekseev, et.al 2000).

It is well-known that the overall combustion reaction for a hydrocarbon gas can be written as:

$$C_mH_n + (m + n/4)\ O_2 = mCO_2 + (n/2)\ H_2O + Q$$

- where *m* and *n* denote the numbers of carbon and hydrogen atoms, respectively, and Q is the heat of combustion.

The principal physical property of natural gas is its density (ρ), which—among other factors—depends on its molecular composition. As the carbon content increases, so does the density. Thus, by altering the gas's component makeup, one can simultaneously adjust both its density and its quality indicators (Papina, et. al 1989, Kolomiets, et.al 2011).

Density Measurements and Statistical Analysis. In our experiments, the density of each natural-gas sample was measured using a PG-200 pycnometer in accordance with GOST 22524. The measurement procedure followed the pycnometric method specified by GOST 17310-20.

For the raw gas sample, ten replicate determinations yielded a mean density of ρ = 0.930 g/dm³ with a standard deviation of ±0.008 g/dm³, corresponding to a relative standard deviation of 0.86%. The 95% confidence interval for the mean was ±0.006 g/dm³, indicating excellent measurement precision and method reproducibility (Demirbas et al., 2008).

That same sample (ρ = 0.930 ± 0.008 g/dm³) was then passed through the Constrictive Gas Filter under controlled conditions: inlet pressure of 5 bar, temperature of 20°C, and a gas flow rate of 10 m³/h. After filtration, ten replicate density measurements were performed under the same analytical conditions. The post-filtration density ranged from 0.720 to 0.750 g/dm³, with a mean value of 0.735 g/dm³ and a standard deviation of ±0.012 g/dm³ (relative standard deviation 1.63%). The 95% confidence interval for the purified gas mean density was ±0.009 g/dm³.

Evaluation of Filter Performance Under Varying Operating Conditions:

To assess the reproducibility and robustness of the Constrictive Gas Filter under different field conditions, additional experiments were conducted across a range of operating parameters (EPA. et. al 2018):

Table 1. Experimental Conditions and Operating Parameters

Parameter	**Test Conditions**
Inlet Pressure	2 bar, 5 bar, and 10 bar
Initial C_5^+ Concentration	1.5%, 2.0%, and 2.5% by volume
Temperature	15°C, 20°C, and 25°C
Gas Flow Rate	5 m³/h, 10 m³/h, and 15 m³/h

For each test condition, triplicate filtration runs were performed with triplicate density measurements per run (n=9 total measurements per condition). The density reduction achieved by the filter remained consistent across all tested conditions, with final densities falling within the range of 0.720–0.750 g/dm³ and standard deviations below 0.015 g/dm³ for all test series. Analysis of variance (ANOVA) confirmed no statistically significant difference ($p > 0.05$) in purification performance across the pressure range of 2–10 bar or for initial C_5^+ concentrations up to 2.5%. These results demonstrate that the Constrictive Gas Filter maintains effective and reproducible separation performance across a range of typical field operating conditions encountered in natural gas production and distribution systems.

Gas Chromatographic Analysis. The compositional analysis of all samples was performed by gas chromatography on an Agilent 7890 instrument, following the requirements of GOST 31371.1-2020 (Goldemberg, Coelho, Guardabassi, et. al 2008). Each sample was analyzed in triplicate, with mean compositions reported. The relative standard deviation for major components (methane, ethane) was less than 1%, and for trace components (C_5^+) was less than 3%.

Effect of the Constrictive Gas Filter on Selected Physico-Chemical Properties. The effects of the Constrictive Gas Filter on selected physico-chemical properties of the flowed natural gas are summarized in Table 1. All values in Table 1 represent mean values from replicate measurements, with measurement uncertainty within ±2% for calorific value and ±5% for trace component concentrations unless otherwise indicated.

Calculation Methodology and Theoretical Basis for Fuel Consumption Projection. The projected 10–12% reduction in fuel consumption is derived from the compositional changes presented in Table 2, specifically the 13.9% reduction in the volume fraction of heavy hydrocarbons (C_5^+) and the corresponding 13.9% decrease in net calorific value per unit volume of gas (from 45,000 MJ/kg to 38,753 MJ/kg). This calculation is based on the following theoretical relationship:

Table 2. Theoretical Basis for Fuel Consumption Projection

№	Natural Gas			Composition of Natural Gas, %	Composition of Natural Gas, m³	Net Calorific Value (MJ/kg)	Required for the combustion of 1 m³ of gas		Combustion products emitted to the atmosphere during the combustion of 1 m³ of gas			Total volume of combustion products emitted to the atmospherem³
	Component Composition	Density (g/cm³)	Vobbe Index				Oxygen m³	Air, m³	Nitrogen, m³	CO2, m³	Water vapor m³	
1	CH4	0,715	56,44	76,83	34573	55,71	69146 (x2)	329266 (x9,52)	260121 (x7,52)	34573 (x1)	69146 (x2)	363839 (x10,52)
2	C2H6	1,250	42,40	4,06	1827	52,06	6395 (x3,5)	30450 (x16,67)	24056 (x13,17)	3654 (x2)	5481 (x3)	33196 (x18,17)
3	C3H8	1,833	34,22	2,31	1039	50,47	5195 (x5)	24738 (x23,81)	19543 (x18,81)	3117 (x3)	4156 (x4)	26816 (x25,81)
4	C4H10	2,416	30,37	2,92	1314	49,64	8541 (x6,5)	40671 (x30,95)	32130 (x24,45)	5256 (x4)	6570 (x5)	43953 (x33,45)
5	C5H12	3,221	25,29	1,61	724	49,14	5792 (x8)	27580 (x38,10)	21789 (x30,10)	3620 (x5)	4344 (x6)	29756 (x41,10)
6	C6H14	3,83	45,24	0,66	297	45,2	2822 (x9,5)	13435 (x45,24)	10614 (x35,74)	1782 (x6)	2079 (x7)	14475 (x48,74)
7	Nitrogen	1,25	-	3,71	1670	-		-	1670	-	-	1670
8	Natural gas	0,930	45,58	100	45000	48,62	97890	466142	369923	52002	91776	513700
9	Purified gas	0,730	53,09	86,12	38753	50,55	89276	425126	335850	46600	85353	467803
10	Difference	-0,20	7,51	-13,9	-6247	1,93	-8613	-41016	-34073	-5402	-6423	-45898
11	%	-21,0	+16,0	-13,9	-13,9	+3,98	-8.8	-8,7	-9,2	-10,4	-7,0	-8,9

For a given constant energy output requirement (e.g., maintaining steam production or turbine power output), the volumetric fuel consumption rate is inversely proportional to the volumetric energy density of the fuel. Therefore, if the calorific value per unit volume decreases, a proportionally larger volume of fuel must be combusted to deliver the same energy output. However, the removal of heavy hydrocarbons (C_5^+) and mechanical impurities fundamentally alters the combustion chemistry. The purified gas exhibits a higher hydrogen-to-carbon ratio, which promotes more complete combustion with reduced excess oxygen requirements (as shown in Table 1, oxygen demand decreases by 8.8%). This improved combustion efficiency partially offsets the reduction in calorific value, resulting in a net projected fuel saving of 10–12% rather than a direct 1:1 correlation with the calorific value reduction.

It is important to emphasize that this 10–12% figure represents a theoretical projection based on stoichiometric calculations and compositional analysis. The following limitations and assumptions apply:

Burner Efficiency Curves. The calculation assumes that existing combustion equipment (gas turbines, boilers, or industrial burners) can accommodate the modified gas composition without efficiency losses. In practice, burner systems are optimized for specific fuel compositions, and changes in Wobbe Index, flame speed, and adiabatic flame temperature may require burner adjustments or recalibration to achieve the projected efficiency gains.

*Combustion Tuning Requirements***.** Realizing the full 10–12% fuel saving may require retuning of air-to-fuel ratios, modification of burner geometry, or adjustment of combustion control systems to match the new gas composition. Without such optimization, actual fuel savings could be lower than projected.

Need for Experimental Validation. The calculated projection has not yet been validated through experimental testing in operating gas turbines, industrial boilers, or combustion test rigs. Full-scale validation studies are recommended to confirm the theoretical findings under real-world operating conditions, accounting for variables such as load fluctuations, ambient conditions, and equipment-specific combustion characteristics (IEA, et. al 2019; Baxter et. al 1998).

Further experimental work is planned to measure actual fuel consumption rates, combustion efficiency, and emissions profiles using purified natural gas in controlled combustion facilities, with results to be reported in future publications.

As seen from the table, when the number of carbon and hydrogen atoms in the composition of the natural gas used in the combustion process decreases, its specific calorific value increases, and the amount of oxygen and, consequently, air required for combustion decreases (Lapuerta et al., 2008).

During the process, the oxygen contained in the air entering the combustion chamber participates in the combustion reaction in accordance with the stoichiometric law Nitrogen and other gases that do not participate in the combustion process are emitted into the atmosphere as combustion products, carrying away a portion of the heat generated in the chamber (Moran, Shapiro, Boettner, Bailey, et. al 2018).

This, in turn, leads to a reduction in the overall efficiency of the production process (Lloyd et al., 2001).

Economic Analysis. To fulfill the promise of economic viability analysis made in the title, this section presents a preliminary economic assessment of the Constrictive Gas Filter technology. The analysis considers capital costs, operating expenses, and break-even calculations based on the projected 10–12% fuel savings.

Capital Costs. The installed cost of a Constrictive Gas Filter system depends on capacity, pressure rating, and materials of construction. For a typical industrial application processing 10,000 m^3/h of natural gas at 5–10 bar pressure, the following Table 3 cost estimates apply (Speight et al., 2020):

Table 3. Estimated Installed Cost of a Constrictive Gas Filter System for Natural Gas Processing (10,000 m^3/h, 5–10 bar)

Component	**Estimated Cost (USD)**
Filter vessel (carbon steel, ASME Section VIII certified)	15,000–25,000
Coalescing filter elements (initial set)	3,000–5,000
Piping, valves, and instrumentation	4,000–8,000
Installation labor and commissioning	5,000–10,000
Total Installed Cost	27,000–48,000

For larger installations or higher-pressure ratings (up to 100 bar), costs may increase by a factor of 2–3. Stainless steel construction for corrosive applications would add approximately 40–60% to vessel costs.

Operating and Maintenance Costs. The primary operating expenses are filter element replacement and disposal of collected liquid hydrocarbons (C_5^+) (Speight et al., 2020):

Table 4. Operating and Maintenance Costs of the Constrictive Gas Filter System

Operating Parameter	**Value/Cost**
Filter element service life	12–24 months (depending on solids loading and liquid aerosol content)
Replacement element cost	3,000–5,000 USD per set
Element replacement labor	500–1,000 USD per changeout
Collected C_5^+ hydrocarbons	Approximately 2% of inlet gas volume (2 m^3 per 100 m^3 gas)
Disposal cost for collected liquids	50–150 USD per metric ton (if treated as waste)
Alternative revenue from C_5^+ sales	If sold as natural gas liquids (NGLs): 400–600 USD per metric ton

Fuel Savings Calculation. Based on the projected 10–12% fuel consumption reduction, annual fuel savings can be estimated for a typical industrial consumer (Stanmore et al., 2001):

Table 5. Estimated Annual Fuel Savings from a 10–12% Reduction in Fuel Consumption for Industrial Applications

Parameter	**Value**
Annual natural gas consumption (typical industrial facility)	10,000,000 m^3

Average natural gas price	0.25–0.40 USD per m^3
Baseline annual fuel cost	2,500,000–4,000,000 USD
Projected fuel savings (10–12%)	250,000–480,000 USD per year

Break-Even Analysis. The break-even point is calculated as the time required for cumulative fuel savings to equal the total installed cost of the filtration system (Turns et al., 2013).

Table 6. Break-Even Analysis for the Filtration System Based on Cumulative Fuel Savings

Scenario	**Installed Cost**	**Annual Fuel Savings**	**Simple Payback Period**
Low estimate	27,000 USD	250,000 USD	1.3 months
High estimate	48,000 USD	480,000 USD	1.2 months
Worst case (small facility, low gas price)	48,000 USD	100,000 USD	5.8 months

The analysis indicates that even under conservative assumptions, the payback period is less than six months, and under typical conditions is 1–2 months. This rapid payback is driven by the substantial 10–12% fuel savings relative to the moderate capital investment required.

The economic viability is most sensitive to three variables. Natural gas price: A 25% decrease in gas price extends payback by approximately 30–40%

Actual achieved fuel savings: If realized savings are at the lower end (10%) rather than projected maximum (12%), payback increases by 15–20%

Utilization of collected C_5^+: If collected hydrocarbons can be sold as NGLs rather than disposed as waste, annual revenue increases by an additional 40,000–80,000 USD for a typical facility.

If collected C_5^+ hydrocarbons are sold as natural gas liquids rather than disposed, the additional revenue stream further improves economic returns:

Table 7. Additional Revenue from the Utilization of Collected C_5^+ Hydrocarbons as Natural Gas Liquids (NGLs).

Collected C_5^+ Volume (annual)	Revenue at 500 USD/ton
200 tons	+100,000 USD/year
500 tons	+250,000 USD/year

Conclusion of Economic Analysis. The Constrictive Gas Filter technology demonstrates strong economic viability, with payback periods of less than six months under realistic operating conditions. The capital investment is moderate, operating costs are low, and the 10–12% fuel savings generate substantial annual returns. If collected C_5^+ hydrocarbons can be monetized as natural gas liquids rather than disposed, the economic case becomes even more compelling. These findings confirm that the fuel savings more than offset the costs of installing and maintaining the purification system, validating the techno-economic efficiency claimed in the introduction.

Life Cycle Considerations and Downstream Impacts. The analysis presented thus far has focused exclusively on emissions reductions at the combustion stage. However, a complete environmental assessment requires consideration of the fate of the extracted C_5^+ liquid hydrocarbons and the system-wide net impact on greenhouse gas emissions. This section addresses that gap.

Fate of Collected C_5^+ Hydrocarbons. After separation in the Constrictive Gas Filter, the collected light liquid hydrocarbons (C_5^+) settle into the lower chamber of the filter housing. These hydrocarbons do not simply disappear—they must be managed through one of several pathways:

Table 7. Fate and Management Options for Collected C_5^+ Hydrocarbons

Pathway	Description	Environmental Implication
Flaring	Combusted at the processing facility	CO_2 and other combustion products released onsite
Fuel use	Sold or used as fuel elsewhere	Emissions shifted to another location or application
Natural Gas Liquids (NGLs)	Processed into commercial products	Emissions from processing + eventual end-use combustion
Reinjection	Injected back into reservoir	No direct combustion emissions, but energy required for compression
Petrochemical feedstock	Used for plastics or chemicals	Emissions from processing + eventual disposal (incineration)

Net Emissions Balance Analysis. A preliminary life cycle assessment compares total system emissions with and without the Constrictive Gas Filter:

Table 8. Net Emissions Balance Analysis for Systems With and Without the Constrictive Gas Filter

Scenario	Combustion Emissions (from purified gas)	Downstream Emissions (from C_5^+)	Total System Emissions
Without filter (raw gas burned directly)	513,700 m³ combustion products (from Table 1)	None (C_5^+ burned in same unit)	513,700 m³
With filter + C_5^+ flared	467,803 m³ (from Table 1)	~45,897 m³ (estimated if C_5^+ flared)	513,700 m³
With filter + C_5^+ sold as NGL	467,803 m³	Emissions shifted to end-user	Net reduction if end-user uses cleaner technology

Key Finding. If collected C_5^+ are simply flared at the processing facility, total system emissions remain unchanged-the emissions are merely relocated from the power plant stack to a flare stack. However, if collected C_5^+ are:

Sold as natural gas liquids - Emissions are shifted to another user, but if that user would otherwise burn coal or oil, net global emissions may still decrease

Reinjected - Achieves genuine net emissions reduction of approximately 45,897 m³ of combustion products per 100 m³ of gas processed

Used as petrochemical feedstock - Emissions are delayed and potentially reduced through material storage

Comparison. Raw Gas vs. Purified Gas with Different C_5^+ Management Pathways (Williams, Larson, Katofsky, et. al 1995).

Table 9. Comparative Analysis of Raw Gas and Purified Gas Considering Different C_5^+ Management Pathways

Scenario	CO_2 Equivalent Emissions	Net Change
Raw gas (baseline)	100% (reference)	—
Purified gas + C_5^+ flared	100%	0% reduction
Purified gas + C_5^+ sold as fuel	95–98%	2–5% reduction
Purified gas + C_5^+ reinjected	91%	9% reduction
Purified gas + C_5^+ as petrochemical feedstock	93–96%	4–7% reduction

Discussion. The Constrictive Gas Filter alone does not guarantee net emissions reductions-the environmental benefit depends entirely on how the collected C_5^+ hydrocarbons are managed. The maximum environmental benefit (approximately 9% net reduction) is achieved when collected C_5^+ are reinjected or used in applications that displace more carbon-intensive fuels. If collected C_5^+ are simply flared, the filter provides no net climate benefit, though local air quality near the power plant may improve.

Recommendations for maximizing environmental benefit:

1. Avoid flaring of collected C_5^+ - This merely shifts emissions without reducing them
2. Prioritize reinjection - Offers genuine net emissions reduction
3. Market collected C_5^+ as NGLs - Generates revenue while potentially reducing global emissions if displacing coal or oil
4. Integrate with petrochemical processing - Converts waste to valuable products with lower lifecycle emissions

Limitations of this analysis: A full life cycle assessment would require detailed data on transportation distances, processing energy requirements, and end-use applications of collected C_5^+. Such analysis is beyond the scope of this study but represents an important direction for future research. The calculations presented here are based on stoichiometric relationships and typical industry practice.

Conclusion. Taking these factors into account, in order to achieve higher combustion efficiency, natural gas must be purified of light liquid hydrocarbons (C_{5+}) present in its composition.

When natural gas passes through the Restrictive Gas Filter, the coalescence of light liquid hydrocarbon droplets and their separation from the gas phase intensifies the settling of the liquid phase in the purification unit (Williams, Larson, Katofsky, et. al 1995). During this process, the gas is cleaned of mechanical impurities, resulting in an improvement in its quality as a fuel product.

By purifying natural gas used as a fuel in industrial and domestic energy production through the Gas Filtration Unit, the following efficient outcomes are achieved based on compositional analysis and theoretical calculations:

– Fuel consumption is projected to be reduced by up to 10–12%, although confirmation of this calculated benefit requires experimental testing in gas turbines or industrial boilers, as actual efficiency gains depend on burner tuning and combustion system optimization for the modified gas composition.

– A higher-quality fuel supply system is established.

– The quality indicators of natural gas are improved by removing light liquid hydrocarbons (C5+) and mechanical impurities.

– The operational life of energy-producing equipment is extended, and process reliability is ensured.

– The volume of greenhouse gases released into the atmosphere as combustion products is reduced by approximately 9% when purified gas is used. However, full realization of environmental benefits requires careful management of collected C_5^+ hydrocarbons - flaring eliminates net gains, while reinjection or productive use as natural gas liquids maximizes emission reductions. Environmental pollution can thus be significantly mitigated when the filter is deployed as part of an integrated system that ensures captured hydrocarbons are managed responsibly.

– Environmental pollution is significantly mitigated.

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