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ECONOMIC EFFICIENCY OF FLOTATION REAGENTS DERIVED FROM SHURTAN GAS CHEMICAL COMPLEX BY-PRODUCTS

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Abstract:This article examines the economic efficiency of flotation reagents produced from secondary hydrocarbon products and industrial by-products of the Shurtan Gas Chemical Complex (SGCC). Particular attention is paid to the possibility of replacing imported flotation reagents, including the widely used frother T-92, with locally produced reagent compositions based on available petrochemical and gas-processing raw materials. The economic effectiveness of such reagents is evaluated through several interconnected indicators: raw-material cost, reagent consumption, transportation and import-related expenses, mineral recovery efficiency, concentrate quality, and the possibility of utilizing industrial by-products as secondary raw materials. Previous studies conducted in Uzbekistan have demonstrated that locally developed composite flotation reagents can provide flotation performance comparable to, and in some cases higher than, imported analogues. The use of SGCC-derived hydrocarbon fractions can therefore create a dual economic effect by reducing dependence on imported reagents and increasing the added value of secondary industrial products. The study emphasizes that the economic assessment of flotation reagents should consider not only their purchase price but also their influence on metal recovery, reagent consumption per tonne of ore, logistics costs, and the overall profitability of mineral-processing operations.
Keywords: flotation reagent, Shurtan Gas Chemical Complex, economic efficiency, import substitution, industrial by-products, flotation, T-92, mineral processing, hydrocarbon fractions, copper-molybdenum ore, local raw materials, cost efficiency.

INTRODUCTION

The flotation process is one of the most widely used methods for the beneficiation of non-ferrous, precious, and rare-metal ores. Its technological efficiency depends not only on the mineralogical characteristics of the ore and the operating parameters of flotation equipment, but also on the type, composition, dosage, and physicochemical properties of flotation reagents. Collectors, frothers, depressants, activators, and regulators determine the selectivity of mineral separation, the stability of the froth phase, and ultimately the recovery of valuable components into concentrate. Therefore, the selection of an economically and technologically effective reagent system is one of the key factors determining the profitability of mineral-processing enterprises.In the mining and metallurgical industry of Uzbekistan, imported flotation reagents have traditionally played an important role. In particular, the T-92 frother has been used in the flotation beneficiation of copper-molybdenum ores. However, dependence on imported reagents increases production costs through purchase prices, foreign-exchange exposure, transportation expenses, customs-related costs, and risks associated with international supply chains. Research conducted in Uzbekistan has therefore focused on the

development of local flotation reagents capable of replacing imported analogues without reducing technological performance [1]. Matkarimov et al. point out that waste and secondary products from oil refining, chemical production, and gas-processing enterprises, including the Shurtan facilities, can serve as potential raw materials for localized production of surface-active compounds and analogues of conventional flotation reagents [1].

The Shurtan Gas Chemical Complex is particularly important in this context because its production processes generate hydrocarbon-containing secondary fractions that can potentially be converted into surface-active substances. Research on locally synthesized reagents has included the use of α-olefin fractions with carbon chains in the C10–C20 range obtained from low-molecular polyethylene production streams associated with Shurtan gas-chemical processing. These materials have been investigated for the synthesis of flotation frothers and compared with the standard T-92 reagent [2]. Such an approach transforms an underutilized secondary product into a potentially valuable reagent for the mining industry, creating a connection between the gas-chemical and metallurgical sectors within a circular-production model.The economic importance of this approach extends beyond the direct replacement of an imported chemical product. When industrial by-products are used as raw materials for flotation reagent production, several components of economic benefit may arise simultaneously. First, the cost of primary raw materials may be reduced because secondary hydrocarbon streams are used instead of newly produced chemical feedstocks. Second, domestic production can reduce transport and import-related costs. Third, the use of local raw materials reduces the sensitivity of mineral-processing enterprises to exchange-rate fluctuations and external supply disruptions. Fourth, economically valuable products can be obtained from streams that might otherwise have limited commercial use or require additional handling and disposal.

The current scale of expenditure on flotation reagents illustrates the economic significance of localization. Official procurement information from Almalyk Mining and Metallurgical Complex shows that T-92 flotation reagent continues to represent a substantial procurement item. For example, a 2025 procurement record for T-92 listed a contract value of USD 594,000, while in March 2026 another T-92 procurement contract was recorded at approximately UZS 4.75 billion [3]. These figures should not be interpreted as unit costs because the published entries do not specify the corresponding quantities in the cited records; nevertheless, they demonstrate that flotation reagents constitute a financially significant consumable in large-scale mineral processing.From the standpoint of industrial economics, however, the cheapest reagent is not necessarily the most economically efficient reagent. The economic result of a flotation reagent must be evaluated together with its technological performance. A reagent with a lower purchase price may become economically disadvantageous if it leads to lower metal recovery, higher dosage, unstable froth formation, or deterioration of concentrate quality. Conversely, a locally produced reagent may provide substantial economic benefits if it combines lower production and logistics costs with equal or improved recovery of valuable metals.

This principle is supported by experimental and industrial results obtained with locally developed composite flotation reagents. According to research implementation data published by the Higher Attestation Commission of Uzbekistan, KXF-VS-type composite reagents developed from local raw materials and industrial wastes were introduced at Almalyk Mining and Metallurgical Complex. In reported comparative tests, copper recovery reached 77.57% with the locally developed reagent,

compared with 75.70% using standard T-92 under the referenced test conditions. For molybdenum, the corresponding reported recovery values were 52.41% and 43.80%, respectively [4]. The same source states that these reagents were economically efficient as import-substituting alternatives to T-92.Detailed economic calculations from related research further indicate that the cost difference between locally developed composite frothers and imported T-92 can be substantial. One reported calculation for a KXF-VS-1-type reagent considered an annual volume of 2,500 m^3 and estimated the local reagent at approximately USD 290 per cubic metre in the corresponding calculation, whereas T-92 was evaluated at approximately USD 770 per cubic metre under the referenced period's assumptions [4]. Because chemical and exchange-rate conditions change over time, these historical figures should not be treated as current market prices; rather, they demonstrate the methodology and potential magnitude of economic benefits from localization.

For flotation reagents derived specifically from Shurtan Gas Chemical Complex by-products, economic efficiency can therefore be expressed through a broader analytical model:

Economic efficiency = savings in reagent procurement + reduction in import and logistics costs + value of additional recovered metal + value created from secondary raw materials − additional production and processing costs.

This relationship demonstrates that an economically effective flotation reagent must be evaluated across the entire technological chain. If a locally synthesized reagent reduces reagent expenditure but requires a substantially higher dosage, its actual economic advantage may be limited. Similarly, if the new reagent provides higher metal recovery, even a modest improvement in extraction can create considerable additional revenue when millions of tonnes of ore are processed annually.The recovery factor is particularly important in copper-molybdenum and polymetallic ore beneficiation. Even a small increase in copper, molybdenum, gold, or silver recovery can generate substantial additional output at industrial scale. Recent investigations of new locally produced composite frothers for the Kalmakyr copper-molybdenum ore have reported high recoveries of copper and associated precious metals while maintaining existing flotation regimes, supporting the technological feasibility of replacing imported frothers with domestic formulations.

Another significant aspect is the environmental-economic effect. The utilization of secondary hydrocarbon products from SGCC reduces the amount of industrial by-products requiring storage or disposal and converts them into marketable chemical products. This can reduce waste-management costs while simultaneously increasing resource efficiency. Therefore, the production of flotation reagents from SGCC secondary materials corresponds to the principles of circular economy, resource-saving technology, and industrial symbiosis.The localization of flotation reagent production also has strategic importance for Uzbekistan. The mining and metallurgical industry is one of the country's major industrial sectors, and stable access to beneficiation reagents is necessary for uninterrupted production. Dependence on imported reagents exposes mining companies to changes in international prices, transport restrictions, currency fluctuations, and geopolitical disruptions. Establishing domestic production based on Shurtan gas-chemical by-products can reduce these risks and strengthen supply-chain resilience.

At the same time, economic efficiency cannot be established solely through laboratory flotation results. A complete assessment requires industrial-scale data on reagent consumption in grams per

tonne of ore, annual ore-processing volume, cost of synthesis, energy consumption, auxiliary chemicals, storage requirements, transportation distance, metal recovery, concentrate grade, and market prices of the recovered metals. These variables should be incorporated into a comparative cost-benefit model for the locally produced reagent and the imported analogue.Thus, the development of flotation reagents from secondary hydrocarbon products of the Shurtan Gas Chemical Complex represents a promising direction for combining import substitution, industrial waste utilization, and improved mineral-processing economics. The **main objective of this study** is to assess the economic efficiency of SGCC-derived flotation reagents by comparing their production and application costs with imported analogues and by evaluating their influence on reagent consumption, valuable-metal recovery, production profitability, and the overall economic performance of flotation beneficiation.

MATERIALS AND METHODS

The methodological approach of the present study was developed to evaluate the technological and economic efficiency of flotation reagents produced from secondary hydrocarbon products of the Shurtan Gas Chemical Complex (SGCC) in comparison with the conventional imported frother T-92. The study combines flotation-performance assessment with economic analysis, since the commercial effectiveness of a reagent cannot be determined solely by its purchase price. A complete evaluation must also consider reagent consumption, recovery of valuable components, concentrate quality, transportation and import costs, availability of local raw materials, and the additional costs associated with reagent synthesis and preparation.The main raw material considered for the production of the local flotation reagent was the hydrocarbon-containing secondary fraction formed during polyethylene production at SGCC. Previous technological studies have reported the use of α-olefin fractions in the **C10–C20 range**, obtained from the low-polymeric fraction of polyethylene production, for the synthesis of surface-active flotation reagents. These compounds were investigated as potential alternatives to the standard T-92 frother because of their ability to reduce surface tension and participate in stable froth formation during sulfide-ore flotation [5].

For comparative purposes, the imported flotation reagent T-92 was selected as the reference reagent. The relevance of this comparison is supported by current industrial procurement data from Almalyk Mining and Metallurgical Complex (AMMC). The enterprise's 2026 procurement plan indicates an annual requirement of **81.6 tonnes of T-92**, distributed equally across the four quarters of the year [6]. In addition, public procurement data show that AMMC concluded a contract for T-92 flotation reagent worth approximately **UZS 4.746 billion** on 10 March 2026 [7]. These data demonstrate that frother procurement represents a financially significant operating cost and therefore provide a practical basis for assessing the economic potential of domestic substitution.The experimental comparison should be conducted using representative samples of copper-molybdenum or other sulfide ores processed under identical flotation conditions. The mineral feed should be prepared using the same crushing, grinding, pulp-density, pH, conditioning-time, aeration, and flotation-time parameters for both the SGCC-derived reagent and the reference T-92 reagent. This approach allows differences in flotation performance to be attributed primarily to the reagent system rather than to changes in operating conditions.

The flotation tests should be performed at several reagent dosages in order to determine the minimum technically effective consumption of each reagent. Reagent consumption is expressed in

grams per tonne of processed ore (g/t). The dosage should be gradually varied until the optimal relationship between froth stability, concentrate quality, recovery of valuable components, and reagent consumption is established. Such dosage optimization is economically important because a reagent that performs effectively at a lower consumption rate can generate considerable annual savings even when its unit production price is close to that of the reference reagent.

The technological efficiency of the reagents should be assessed primarily through the recovery of valuable components into concentrate. Metal recovery can be calculated using the following equation:

$$R = (C \times c / F \times f) \times 100$$

where **R** is the recovery of the valuable component, %; **C** is the mass of concentrate; **c** is the concentration of the valuable component in the concentrate; **F** is the mass of the initial feed; and **f** is the concentration of the valuable component in the initial ore.

The concentrate grade should also be analyzed because increased recovery is economically useful only when an acceptable level of concentrate quality is maintained. Therefore, the economic assessment should simultaneously consider recovery, concentrate grade, and reagent consumption. If a local reagent increases recovery but significantly reduces concentrate quality, additional downstream processing costs may partly offset the economic benefit.Froth stability, bubble size, flotation kinetics, and the rate of valuable-mineral transfer to the concentrate should additionally be monitored. The SGCC-derived reagent should be considered technologically competitive when it provides a stable froth regime and metal recovery equal to or higher than that obtained using T-92 under comparable process conditions.

The first component of the economic analysis is the **specific reagent cost per tonne of ore**, calculated as:

$$SRC = Q \times P$$

where **SRC** is the specific reagent cost per tonne of ore; **Q** is reagent consumption, kg/t; and **P** is the unit cost of the reagent, UZS/kg or USD/kg.

For imported T-92, the unit cost should include not only the contract purchase price but also expenses related to transportation, customs procedures where applicable, storage, insurance, currency conversion, and other procurement-related costs. For the SGCC-derived reagent, the economic calculation should include the cost of secondary raw materials, auxiliary chemicals, electricity and heat, labor, synthesis, purification, packaging, storage, quality control, and transportation from the production site to the mineral-processing plant.

The annual reagent cost is calculated as:

$$ARC = SRC \times M$$

where **ARC** is the annual reagent cost and **M** is the annual quantity of processed ore in tonnes.

This indicator allows the economic comparison to be scaled from laboratory or pilot-test conditions to industrial production. Even a relatively small difference in reagent consumption per tonne can become economically significant when millions of tonnes of ore are processed annually.

A second important indicator is the **direct import-substitution effect**. It can be calculated as the difference between the annual cost of the imported reagent and the annual cost of the locally produced SGCC-derived reagent:

$$E_1 = C_i - C_l$$

where E_1 is the direct annual economic benefit from import substitution; C_i is the total annual cost of the imported reagent; and C_l is the total annual cost of the local reagent.

However, this calculation alone does not fully represent the economic effect because the reagent can also influence metal recovery. Therefore, an additional economic component should be calculated from any increase in the production of valuable metals. The additional metal output can be estimated as:

$$\Delta M = F \times G \times (R_2 - R_1)$$

where ΔM is the additional amount of recovered metal; F is the mass of ore processed; G is the average grade of the valuable component in the ore; R_2 is recovery using the SGCC-derived reagent; and R_1 is recovery using the reference reagent.

The additional revenue generated by improved recovery can then be calculated as:

$$E_2 = \Delta M \times P_m$$

where E_2 is additional revenue and P_m is the market price of the recovered metal.

Accordingly, the total annual economic effect may be expressed as:

$$E_{total} = E_1 + E_2 + E_w - C_{add}$$

where E_{total} is the total economic effect; E_1 is savings from reagent substitution; E_2 is additional income from improved metal recovery; E_w is the economic value associated with the utilization of SGCC secondary products or reduced waste-management costs; and C_{add} represents additional costs required for reagent synthesis, processing, quality control, equipment depreciation, and implementation.

An important methodological element is the calculation of economic efficiency per tonne of processed ore. This enables comparison between enterprises or flotation circuits with different production capacities. The indicator may be expressed as:

$$EE = E_{total} / M$$

where EE is economic efficiency per tonne of processed ore and M is total processed ore volume.

The study should also include a **break-even analysis**. The maximum economically acceptable production cost of the SGCC-derived reagent can be determined by identifying the price at which the total cost and technological effect become equivalent to those of T-92. If the actual production cost of the local reagent remains below this threshold, its industrial application can be considered economically justified.

A sensitivity analysis should additionally be performed because the final economic result depends on several variables that may fluctuate over time. These include the exchange rate, imported T-92 price, cost of SGCC raw materials, reagent dosage, ore-processing volume, metal prices, recovery improvement, electricity tariffs, and transportation costs. Three scenarios can be applied: conservative, baseline, and optimistic. Under the conservative scenario, higher local production costs and minimal recovery improvement are assumed; the baseline scenario uses average operating parameters; and the optimistic scenario assumes lower reagent consumption and a measurable improvement in metal recovery.The methodological importance of optimizing reagent consumption is supported by recent Uzbekistan-based industrial research. In 2025, flotation frothers synthesized from industrial by-products were reported to reduce reagent consumption by up to **50 g/t** compared with a T-92 dosage of approximately **190 g/t** in relevant testing conditions. The same research also reported improvements of approximately 3–4% in the beneficiation of some precious and non-ferrous metals compared with

conventional T-80 and T-92 reagents [8]. Although these results relate to other locally synthesized reagent formulations and should not automatically be attributed to the SGCC-derived reagent, they demonstrate the magnitude of the economic effect that can result from lower dosage and improved recovery.

In addition to direct financial indicators, the methodology incorporates the economic value of **industrial waste utilization**. SGCC secondary hydrocarbon streams that have limited direct commercial application can serve as chemical feedstock for flotation reagent production. This reduces the need for primary raw materials and can partially decrease expenses associated with waste storage, handling, or disposal. Previous research indicates that low-molecular polyethylene-containing waste is generated as a by-product of polyethylene production at the Shurtan Gas Chemical Complex, providing a locally available material base for the development of new chemical products [5].Finally, the economic feasibility of industrial implementation should be evaluated using the payback period where additional production equipment or technological modifications are required. The simple payback period may be calculated as:

PP = I / Eannual

where **PP** is the payback period in years; **I** is the initial investment required to organize production of the SGCC-derived flotation reagent; and **Eannual** is the expected annual net economic effect.

Thus, the proposed methodology provides a comprehensive framework for evaluating SGCC-derived flotation reagents through both technological and economic criteria. The reagent is considered economically efficient when it demonstrates an acceptable or improved flotation performance, requires equal or lower specific consumption, reduces dependence on imported T-92, utilizes locally available secondary raw materials, and generates a positive total annual economic effect after all production and implementation costs are taken into account.

RESULTS

The results of the analysis indicate that the production of flotation reagents from secondary hydrocarbon streams of the Shurtan Gas Chemical Complex has a potentially significant economic basis due to the availability of locally generated low-molecular polymer fractions, the possibility of obtaining α-olefin-containing products from these streams, and the continuing industrial demand for imported flotation frothers in Uzbekistan.One of the most important results concerns the availability of a sufficient local raw-material base. Recent technological calculations for the processing of low-molecular polymer waste generated at the Shurtan Gas Chemical Complex showed that approximately 1,200 tonnes of such waste may be processed annually. After separation, about 1,140 tonnes of liquid fraction can be obtained. Further fractionation of this liquid phase produces approximately 752.4 tonnes of light fraction and 387.6 tonnes of α-olefin oil annually. Thus, the α-olefin-containing fraction accounts for approximately 32.3% of the initial low-molecular polymer waste [9].

This result is particularly important from the standpoint of flotation-reagent localization. The presence of several hundred tonnes of α-olefin-containing secondary material indicates that SGCC waste is not merely a laboratory-scale raw material but may represent a potentially industrially relevant feedstock. Previous investigations have specifically identified C10–C20 α-olefins obtained from the low-polymeric fraction of polyethylene production at Shurtan as a component for the synthesis of

flotation surface-active substances. A sulfonated C10–C20 olefin product was included among the synthesized reagents and compared with the conventional T-92 frother in physicochemical and flotation-related studies [9].The economic importance of this raw-material source becomes clearer when compared with the existing demand for imported flotation reagents. According to the 2026 procurement plan of Almalyk Mining and Metallurgical Complex, the planned annual requirement for T-92 flotation reagent amounts to **81.6 tonnes**, or 20.4 tonnes per quarter [11]. The availability of approximately 387.6 tonnes per year of α-olefin oil from SGCC low-molecular polymer waste therefore indicates, in purely material terms, that the secondary raw-material stream is of a scale capable of supporting meaningful domestic reagent production. This does not mean that the entire α-olefin fraction can be converted directly into finished flotation reagent, because actual reagent yield depends on synthesis efficiency, formulation, purification, and technological specifications. Nevertheless, the comparison demonstrates that the local feedstock base is quantitatively significant.

The financial relevance of substitution is also confirmed by public procurement data. On 10 March 2026, Almalyk Mining and Metallurgical Complex recorded a contract for Oxal T-92 flotation reagent with a value of **UZS 4.746 billion** [12]. Since the corresponding quantity is not stated in the cited procurement entry, this contract value cannot be used to calculate a reliable unit price per tonne. However, it clearly demonstrates that flotation frothers represent a substantial recurring expenditure for mineral-processing enterprises. Therefore, even partial substitution of imported T-92 with a technically equivalent locally manufactured reagent could create a meaningful direct economic effect.Another important result was obtained from comparison with other locally synthesized flotation reagents developed from industrial by-products in Uzbekistan. Although these formulations are not identical to the SGCC-derived C10–C20 α-olefin reagent and should not be treated as direct experimental results for the Shurtan product, they provide an important industrial benchmark for estimating the potential economic significance of reagent localization.

Research reported by the Higher Attestation Commission of Uzbekistan showed that locally synthesized SK-1 and SK-2 frothers produced from industrial secondary materials were able to reduce reagent consumption by as much as **50 g/t** relative to a T-92 dosage of approximately **190 g/t** in the referenced beneficiation process. The same research reported that the use of SK-1 and SK-2 could increase the beneficiation performance for Au and Ag by approximately **3–4%** compared with T-80 and T-92 under the studied conditions [10].A reduction from 190 g/t to approximately 140 g/t corresponds to a decrease of about **26.3%** in specific frother consumption. At industrial ore-processing capacities, such a reduction can translate into substantial annual reagent savings. The magnitude of the economic effect will depend on annual ore throughput, reagent production cost, and the extent to which the lower dosage can be maintained under continuous industrial operating conditions.

Additional industrial evidence for the economic potential of localized flotation reagents comes from composite chemical frothers introduced at Almalyk Mining and Metallurgical Complex. In one reported implementation, copper recovery reached **77.57%** with the locally developed composite flotation reagent compared with **75.70%** using standard T-92. For molybdenum, reported recovery reached **52.41%** with the local reagent compared with **43.80%** using T-92 [10].

Table 1. Published indicators relevant to the economic assessment of locally produced flotation reagents

Indicator	Reported result	Economic significance
SGCC low-molecular polymer waste available for processing	1,200 t/year	Local secondary raw-material base
Liquid fraction obtained	1,140 t/year	Feedstock suitable for further fractionation
α-Olefin oil obtained	387.6 t/year	Potential raw material for surface-active reagent synthesis
Share of α-olefin oil in initial waste	32.3%	Indicates significant recoverable secondary product
AMMC planned T-92 demand in 2026	81.6 t/year	Demonstrates continuing industrial demand for imported frother
T-92 procurement contract, March 2026	UZS 4.746 billion	Indicates substantial reagent-related expenditure
Reference T-92 dosage in local industrial-waste reagent study	190 g/t	Benchmark consumption
Potential dosage saving with SK-1/SK-2	up to 50 g/t	Approximately 26.3% reduction relative to 190 g/t
Reported improvement in Au/Ag beneficiation	3–4%	Potential additional revenue from valuable-metal recovery
Copper recovery with local composite reagent	77.57%	Higher reported extraction under referenced test conditions
Copper recovery with T-92	75.70%	Reference value
Molybdenum recovery with local composite reagent	52.41%	Higher reported extraction under referenced conditions
Molybdenum recovery with T-92	43.80%	Reference value

The comparative results demonstrate that the economic effectiveness of localization can arise through at least three mechanisms. The first is the reduction of the specific cost of the flotation reagent itself. Local production can eliminate or reduce expenses related to international transportation, import procedures, foreign supplier margins, and exchange-rate exposure. The second mechanism is lower specific reagent consumption. If the required dosage of a locally produced frother is lower than that of T-92, total chemical consumption per tonne of processed ore declines. The third mechanism is improved mineral recovery, which may generate additional concentrate and therefore additional revenue.The importance of improved recovery is particularly high in large-scale mineral processing. For example, the difference between copper recovery values of 77.57% and 75.70% represents an increase of **1.87 percentage points** under the cited test conditions. Similarly, the difference between 52.41% and 43.80% molybdenum recovery amounts to **8.61 percentage points**. These results belong to previously developed local composite reagents rather than specifically to the SGCC-derived α-olefin

reagent; nevertheless, they demonstrate that import substitution in flotation chemistry can potentially produce economic benefits not only by reducing reagent expenditure but also by increasing the recovery of valuable metals.

For SGCC-derived reagents specifically, the available evidence currently provides stronger support for **raw-material and physicochemical feasibility** than for a fully documented industrial economic effect. Research confirms that polyethylene-production waste from Shurtan can provide C10–C20 α-olefin material for flotation-reagent synthesis and that the synthesized products have been investigated in comparison with T-92 [9]. However, the sources examined do not provide a complete industrial dataset containing, for the same SGCC-derived reagent, reagent dosage, annual production cost, industrial metal recovery, concentrate grade, and operating expenditure. Consequently, a precise annual net economic effect for the SGCC-derived reagent should not be calculated without additional pilot or industrial data.Nevertheless, the material-balance results indicate favorable conditions for localization. An annual α-olefin oil output of approximately 387.6 tonnes is several times larger than AMMC's stated annual T-92 requirement of 81.6 tonnes on a simple mass-comparison basis. Even after accounting for conversion yield, auxiliary components, purification losses, and formulation requirements, this difference indicates that the Shurtan secondary hydrocarbon stream could potentially support a substantial reagent-production program if the synthesized product satisfies flotation-performance and safety requirements.

Another result relates to resource efficiency. The conversion of low-molecular polymer waste into α-olefin oil and subsequently into a surface-active flotation reagent creates additional value from a material that is generated as a secondary industrial stream. Under the reported processing scheme, only about 5% of the initial low-molecular polymer waste remains as polymer fraction, while the majority can be separated into light fraction and α-olefin-containing products [9]. This supports the possibility of combining reagent localization with waste valorization.From an economic perspective, this creates a dual effect. The first component is the substitution of imported flotation chemicals. The second is the monetization of a secondary product from the gas-chemical industry. Such industrial symbiosis can increase the overall value obtained from hydrocarbon raw materials while simultaneously reducing the dependence of the mining sector on imported chemical reagents.

The results also show that the most appropriate indicator for evaluating SGCC-derived reagents is not simply their selling price. A broader measure should be used:

Net economic effect = reagent-cost savings + value of additional recovered metals + value of utilized secondary raw materials − synthesis and implementation costs.

This approach is particularly important because the contribution of enhanced metal recovery may exceed the direct savings from reagent substitution. Conversely, if a local reagent is inexpensive but requires substantially higher consumption or produces lower recovery, its apparent price advantage may disappear.

Thus, the available results demonstrate that flotation reagents based on SGCC secondary hydrocarbon products have a credible economic foundation. The Shurtan complex provides a quantitatively significant α-olefin-containing secondary stream; Uzbekistan's mining sector continues to consume substantial quantities of imported T-92; and domestic research with other locally produced flotation reagents has demonstrated the technical possibility of reducing reagent consumption and

improving metal recovery. However, final confirmation of the economic efficiency of the specific SGCC-derived reagent requires industrial-scale testing in which reagent dosage, synthesis cost, concentrate quality, metal recovery, and annual operating savings are measured simultaneously.

DISCUSSION

The results obtained in this study indicate that the economic feasibility of producing flotation reagents from secondary hydrocarbon streams of the Shurtan Gas Chemical Complex should be considered from both technological and industrial-economic perspectives. The availability of a substantial α-olefin-containing secondary fraction, the continuing demand for imported T-92 frother, and positive results previously obtained with other locally synthesized flotation reagents create a strong rationale for further development of SGCC-based reagents. However, the transition from raw-material availability to a commercially viable flotation reagent requires careful consideration of reagent chemistry, flotation selectivity, industrial-scale process stability, production cost, and supply-chain requirements.One of the most important findings is that local availability of raw material can create an economic advantage only when the secondary feedstock can be converted into a reagent with reproducible physicochemical properties. Flotation is highly sensitive to reagent concentration, molecular structure, pulp chemistry, aeration intensity, mineralogical composition, and water quality. Research on copper and molybdenum flotation shows that collector-to-frother ratios, pulp pH, ionic composition, mineral liberation, and other operating parameters can significantly influence recovery and concentrate quality [13]. Therefore, the economic advantage associated with low-cost SGCC feedstock could be lost if considerable additional processing is required to achieve the necessary chemical consistency.

This issue is particularly relevant for industrial by-products because their chemical composition may vary according to production conditions at the gas-chemical complex. For a reagent to replace T-92 reliably, specifications must be established for the concentration of active surface-active components, molecular-weight distribution, density, viscosity, flash point, storage stability, and frothing behavior. Standardization is therefore not merely a technical requirement but an important component of economic efficiency. Variability in reagent quality can lead to unstable flotation performance, higher dosage requirements, loss of valuable minerals to tailings, or excessive froth formation, all of which increase operating costs.The results also demonstrate that reagent price alone should not be used as the principal criterion for economic evaluation. In industrial flotation, the value of recovered copper, molybdenum, gold, or silver may substantially exceed the cost of the frothing reagent. Consequently, a small improvement in recovery can have a larger economic effect than a considerable reduction in reagent purchase price. Conversely, a low-cost reagent that decreases recovery by even a small percentage may become economically unacceptable when applied to a large ore-processing operation.

This interpretation is consistent with established flotation practice. In porphyry copper systems, frother consumption is generally relatively small in mass terms, while flotation recovery strongly determines the amount of valuable metal ultimately obtained from the ore [13]. Typical frother consumption can be in the range of tens to hundreds of grams per tonne, meaning that the reagent itself represents only one component of the overall economic value created in flotation. Accordingly, evaluation of SGCC-derived reagents must prioritize the relationship between **specific reagent cost**

and the economic value of metal recovered, rather than reagent cost alone.The reported results obtained with local composite reagents in Uzbekistan provide a useful benchmark. Previously developed local frothers have demonstrated that domestic reagent systems can achieve recovery values comparable to or higher than T-92 in certain copper-molybdenum flotation tests. Other Uzbek research on locally derived frothers has also shown that industrial secondary materials can serve as technically acceptable raw materials for flotation chemicals [14]. For example, laboratory testing of a locally synthesized TMSB-type reagent on Kalmakyr ore produced copper recovery comparable with T-92 while demonstrating differences in molybdenum recovery and reagent dosage. These findings support the general concept of local reagent development but also demonstrate that each formulation must be evaluated individually rather than assuming that all locally derived reagents will automatically outperform imported products.

This distinction is especially important for the interpretation of the present study. The industrial recovery improvements reported for SK-series or other composite reagents cannot be directly attributed to an SGCC-derived α-olefin reagent unless the same reagent is tested under identical conditions. Therefore, these published values should be used as comparative evidence of the **potential of localization**, not as direct proof of the industrial efficiency of the specific SGCC formulation. Final conclusions require pilot-scale or industrial trials involving the exact reagent synthesized from Shurtan secondary hydrocarbon material.Another important aspect is the relationship between reagent dosage and recovery. An SGCC-derived reagent may require a slightly higher dosage than T-92 but still be economically attractive if its unit production cost is sufficiently lower or if it improves valuable-metal recovery. Conversely, a lower dosage does not automatically indicate superior economic performance if the concentrate grade deteriorates or subsequent processing costs increase. Thus, reagent selection should be based on a multi-criteria optimization problem involving consumption, recovery, concentrate grade, froth characteristics, downstream processing requirements, and total cost.

The use of SGCC secondary products also has an important industrial-symbiosis dimension. Industrial symbiosis involves using the waste or by-products of one enterprise as an input resource for another production process. Studies of chemical industrial parks show that such exchanges can simultaneously produce economic and environmental benefits by reducing virgin-resource consumption, decreasing waste-treatment requirements, and creating additional commercial value from secondary materials [15]. In the present case, the gas-chemical sector can serve as a supplier of secondary hydrocarbon feedstock to the mining-chemical sector, thereby linking two major industrial value chains.From this perspective, flotation-reagent production can increase the total value extracted from the original hydrocarbon raw material processed at SGCC. A low-molecular polymer fraction that has limited direct application may be transformed first into an α-olefin-containing intermediate and then into a higher-value surface-active chemical product. Such processing represents a movement from waste management toward waste valorization. Modern industrial-symbiosis research emphasizes that economic benefits are strongest when secondary material flows can be matched with a stable industrial demand and when processing and transport costs remain lower than the value of the substituted primary product [16].

The existence of stable demand for flotation frothers in Uzbekistan strengthens this economic argument. Large-scale copper-molybdenum beneficiation requires continuous reagent supply, meaning

that the domestic mining sector represents a relatively predictable market. If SGCC-based reagent production is organized near existing petrochemical infrastructure and delivered to major mineral-processing facilities through domestic logistics networks, foreign transport costs and some external supply-chain risks can be reduced.Import substitution also produces an indirect macroeconomic benefit. Purchasing T-92 and other imported flotation reagents requires foreign-currency expenditure. Domestic reagent production based on local feedstocks could retain a larger share of value added within Uzbekistan and reduce exposure to exchange-rate fluctuations. This advantage becomes more significant during periods of national currency depreciation, international logistics disruption, or temporary shortages of imported chemicals.

However, complete import substitution should not necessarily be considered the only objective. An economically rational strategy may initially involve **partial substitution**, where the SGCC-derived reagent is blended with conventional reagents or introduced in selected flotation circuits. This would allow the enterprise to evaluate long-term performance while reducing technological risk. If pilot and industrial results confirm stable recovery and concentrate quality, the domestic reagent share can then be increased gradually.The results further suggest that transportation distance must be included in the economic assessment. Although SGCC secondary materials are domestic, transportation from Shurtan to a reagent-production facility and subsequently to mining operations such as Almalyk creates logistics costs. If the reagent is manufactured near the raw-material source, final product transportation must be considered; if production is located closer to the mining operation, the secondary feedstock must be transported instead. The optimal location should therefore be selected through a comparative logistics analysis.

Production scale is another critical factor. Laboratory synthesis frequently involves higher specific costs than continuous industrial production, while economies of scale can reduce energy, labor, purification, and packaging costs. At the same time, construction of a dedicated production line requires capital expenditure. Therefore, annual demand must be sufficiently high to justify investment in reactors, separation equipment, storage tanks, quality-control systems, safety infrastructure, and environmental protection systems.A staged implementation strategy would therefore be preferable. The first stage should involve laboratory optimization of the SGCC-derived formulation. The second stage should consist of pilot production and semi-industrial flotation testing. The third stage should involve prolonged industrial testing in a selected flotation circuit. Only after obtaining stable results for reagent consumption, metal recovery, concentrate quality, and operating cost should full-scale production be considered.

Sensitivity analysis is also essential because the economic advantage of domestic production may vary over time. If the international price of T-92 decreases substantially while domestic energy and chemical-input costs rise, the direct procurement advantage of the local reagent may narrow. Conversely, depreciation of the national currency or growth in international freight costs would strengthen the economic case for localization. Metal prices can also significantly change the value of recovery improvements. A 1% increase in recovery is economically much more valuable when copper or molybdenum prices are high.Therefore, the decision criterion should not be based on a single-point estimate. Economic efficiency should be tested under multiple scenarios. Under a conservative scenario, no significant increase in recovery should be assumed and the evaluation should rely mainly

on procurement savings. Under the baseline scenario, experimentally demonstrated average recovery and reagent-consumption values should be used. Under an optimistic scenario, improved recovery, lower dosage, and industrial-scale production efficiencies may be considered. Such a scenario-based analysis would provide management with a more realistic understanding of investment risk.

Environmental and occupational safety considerations should also be included in the discussion. Frothers and other flotation reagents may have specific toxicity, volatility, flammability, and handling requirements. Local production cannot be considered economically efficient if it leads to substantially higher environmental-control costs or creates unacceptable occupational risks. The SGCC-derived reagent should therefore undergo toxicological, fire-safety, biodegradability, wastewater, and air-emission assessments before full-scale implementation.The environmental benefit of converting secondary polymer streams into flotation chemicals may nevertheless be substantial. Industrial-symbiosis studies demonstrate that by-product exchange can reduce both waste disposal and primary-resource consumption while generating additional economic returns [15], [16]. In the case of SGCC, this may reduce the volume of secondary hydrocarbon material requiring alternative management while decreasing the need for newly produced chemical feedstocks for frother manufacture.

A further strategic advantage relates to technological independence. Mineral beneficiation plants require uninterrupted chemical supply to maintain production. A shortage of frother can affect flotation stability and ultimately reduce plant throughput or recovery. Establishing domestic manufacturing capacity provides an additional source of supply and therefore increases the resilience of mining operations. This strategic value may not be fully reflected in direct financial calculations but should be considered in investment decisions.The discussion also highlights the importance of cooperation between the gas-chemical, chemical-research, and mining sectors. SGCC possesses the raw-material stream; chemical research organizations possess expertise in synthesis and formulation; and mining enterprises possess industrial flotation facilities and operational data. Effective commercialization requires integration of these capabilities. Without such cooperation, promising laboratory formulations may fail to reach industrial application.

Overall, the results support the hypothesis that SGCC secondary hydrocarbon products can form the basis of an economically promising flotation-reagent production system. The strongest advantages are the availability of domestic secondary raw materials, potential reduction in imported reagent expenditure, creation of additional value from industrial by-products, and the possibility of improving supply security. At the same time, the available evidence does not yet justify claiming a precise industrial economic benefit for the specific SGCC-derived reagent.The decisive next step is therefore an integrated industrial trial in which the SGCC reagent and T-92 are tested simultaneously on the same ore under identical operating conditions. The trial should record reagent dosage, recovery of Cu, Mo and associated precious metals, concentrate grade, flotation kinetics, froth stability, energy use, reagent-production cost, logistics expenditure, and downstream-processing consequences. Only such a comprehensive dataset can establish whether the reagent provides a sustainable economic advantage at industrial scale.

In conclusion, the potential economic efficiency of SGCC-derived flotation reagents is based on more than simple import replacement. Their strategic value lies in linking waste valorization, domestic chemical production, mineral recovery improvement, foreign-exchange savings, and supply-chain

resilience within a single industrial system. If technological performance is confirmed at pilot and industrial scales, such reagents could become an economically and strategically important example of industrial symbiosis between Uzbekistan's gas-chemical and mining-metallurgical sectors.

CONCLUSION

The results of this study demonstrate that the production of flotation reagents from secondary hydrocarbon products of the Shurtan Gas Chemical Complex represents a promising direction for increasing the economic efficiency of mineral-processing operations in Uzbekistan. The main economic advantage of this approach is associated with the possibility of combining import substitution, utilization of locally available industrial by-products, reduction of foreign-currency expenditure, and creation of additional value within domestic industrial value chains.The analysis showed that low-molecular polymer waste generated during polyethylene production at SGCC can serve as an important secondary raw-material source. Processing approximately 1,200 tonnes of such waste may yield significant quantities of liquid hydrocarbon fractions, including approximately 387.6 tonnes of α-olefin oil. This demonstrates that the available raw-material base is potentially sufficient for developing industrial-scale production of surface-active substances, including flotation-reagent components.

The economic importance of local production becomes particularly evident when compared with the continuing industrial demand for imported T-92 flotation reagent. Large mining and metallurgical enterprises require significant quantities of frothers every year, and their procurement represents a substantial recurrent operating expenditure. Localization of even part of this demand could reduce exposure to imported reagent prices, international logistics costs, exchange-rate fluctuations, and external supply disruptions.However, the economic efficiency of an SGCC-derived flotation reagent cannot be evaluated solely according to its production or purchase price. The decisive criteria must include specific reagent consumption per tonne of ore, recovery of valuable components, concentrate grade, stability of the flotation process, reagent-production costs, transportation expenditure, storage requirements, and downstream metallurgical consequences.

Previous Uzbekistan-based studies demonstrate that locally produced flotation reagents can compete with conventional imported frothers. Certain domestic formulations have shown lower specific consumption, improvements in the recovery of valuable metals, and positive economic effects under laboratory, pilot, or industrial conditions. These results confirm that import substitution in flotation chemistry is technically feasible and may generate substantial economic benefits. Nevertheless, these results should not automatically be attributed to the specific SGCC-derived α-olefin formulation. Each new reagent requires independent technological and economic validation.The use of SGCC secondary hydrocarbon materials can also create an important circular-economy effect. Instead of treating low-molecular polymer fractions only as industrial waste, they can be processed into intermediate chemical products and subsequently transformed into higher-value flotation reagents. This creates an industrial symbiosis mechanism in which a secondary stream from the gas-chemical industry becomes a useful input for the mining and metallurgical industry.

Such an approach generates several forms of economic value simultaneously. First, it decreases demand for imported flotation chemicals. Second, it creates a commercial application for industrial by-products. Third, it can reduce waste-management requirements. Fourth, domestic production may

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improve the reliability and resilience of flotation-reagent supply. Finally, when the locally produced reagent improves recovery, the value of the additional recovered copper, molybdenum, gold, silver, or other metals may significantly exceed the direct savings in reagent costs.For this reason, the most appropriate evaluation indicator is the total economic effect rather than the difference between reagent prices alone. The total effect should include savings from import substitution, additional revenue from improved mineral recovery, the economic value of secondary-material utilization, and all additional expenses associated with synthesis, energy consumption, labor, equipment depreciation, quality control, logistics, and industrial implementation.

A staged implementation strategy is recommended. At the first stage, the chemical composition, surface activity, frothing properties, stability, and optimal formulation of the SGCC-derived reagent should be established under laboratory conditions. At the second stage, pilot-scale flotation tests should determine optimal dosage and evaluate recovery and concentrate quality. At the third stage, prolonged industrial trials should be conducted in comparison with T-92 under identical technological conditions.Industrial trials should record not only metal recovery but also reagent consumption, flotation kinetics, froth stability, concentrate grade, water chemistry, energy consumption, downstream processing characteristics, and total operational expenditure. These parameters would provide the data required for an accurate cost-benefit analysis and determination of the payback period for domestic reagent production.

It is also advisable to begin with partial substitution of T-92 rather than immediate complete replacement. The SGCC-derived reagent may initially be tested in combination with conventional frothers or in selected flotation circuits. This reduces technological risk and allows long-term operating performance to be assessed before expanding production.Quality standardization represents another important condition for commercialization. The chemical composition of secondary hydrocarbon streams may vary according to technological conditions at the gas-chemical complex. Therefore, specifications should be established for active-component concentration, density, viscosity, surface tension, foaming capacity, storage stability, fire safety, and environmental properties. Consistent product quality is essential for achieving stable flotation results.Overall, flotation reagents derived from SGCC secondary products have the potential to become economically efficient import-substituting chemicals for Uzbekistan’s mining industry. Their greatest strategic value lies in the integration of domestic raw materials, waste valorization, chemical manufacturing, mineral beneficiation, and supply-chain resilience within a unified industrial system.

Therefore, the development of SGCC-based flotation reagents should be considered not only as a method of reducing expenditure on imported T-92 but also as a broader industrial-development opportunity. If industrial-scale trials confirm stable technological performance and favorable production economics, the proposed approach could contribute to increasing the competitiveness of Uzbekistan’s mining-metallurgical industry, reducing foreign-currency expenditures, improving resource efficiency, and expanding the production of high-value chemical products from local secondary raw materials.

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