EXPERIMENTAL EVALUATION OF REGENERATED XYLENE SOLVENT FOR PRIMER PRODUCTION USING THE ECO PLUS 122 SYSTEM

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ABSTRACT

Industrial xylene used in alkyd-primer production undergoes progressive degradation during repeated manufacturing cycles, leading to the accumulation of oxidized aromatic fragments, polymerized species, and moisture-related impurities. These changes adversely affect volatility, density, residue content, and, ultimately, coating-film performance. This study investigates the effectiveness of thermal regeneration using the ECO PLUS 122 system as a method to restore degraded xylene to a quality suitable for reuse in alkyd formulations. The feedstock was first classified into five contamination levels (CXL0 - CXL4), and representative high-severity fractions were regenerated and evaluated across seven physicochemical indicators and three coating-performance metrics. A stable vapour-temperature plateau near 120°C was observed during regeneration, indicating selective evaporation of volatile components while retaining high-molecular-weight residues. Regeneration yield decreased predictably with increasing contamination severity, ranging from 78 % for Low-contamination feedstock to 58 % for Very High-contamination levels. Physicochemical analysis showed substantial restoration of solvent properties: density stabilized at 0.865 - 0.867 g cm^{-3}, colour index was reduced to 14 - 19 Pt-Co, residue content returned to 0.08 - 0.12 %, moisture levels remained within 40 - 70 ppm, and volatility deviation was limited to 3 - 6 %. Non-volatile residue values (8 - 16 mg 100 mL^{-1}) confirmed the removal of resinous and polymerized contaminants. Performance testing of alkyd-primer films validated the functional suitability of regenerated xylene. Hardness decreased only slightly from 78 HB (standard) to 73 HB (RXL4), while corrosion loss increased moderately from 12 to 18 mg cm^{-2}. The drying time remained within 31 - 36 min, compared to 35 min for standard xylene, indicating preserved curing kinetics and evaporation behaviour. Overall, the results demonstrate that thermal regeneration is a reliable, scalable, and environmentally beneficial approach for restoring industrial xylene, reducing solvent waste, and maintaining coating-film performance in alkyd-primer production.

Keywords: *xylene regeneration, contamination severity, thermal distillation, solvent recovery, physicochemical properties, coating performance, alkyd-primer technology.*

INTRODUCTION

Organic solvents are essential components of coating systems because they dissolve film-forming resins, regulate viscosity, improve pigment dispersion and control drying behaviour [1, 2]. Xylene is widely used in alkyd-primer production due to its aromatic structure, suitable solvency and evaporation rate. These properties make it important for maintaining stable film formation and predictable anticorrosive performance.

During repeated industrial use, xylene becomes contaminated with resin fragments, pigments, oxidised

aromatic products, moisture and non-volatile residues. As a result, its density, colour, volatility and residue content may shift from the values required for coating-grade solvent. Disposal of such waste streams increases environmental pressure and production cost, whereas solvent recovery offers a practical route for reducing hazardous waste and improving resource efficiency [3, 4].

Thermal regeneration and fractional distillation are widely used for recovering volatile solvent fractions from contaminated industrial streams [5, 6]. However, successful reuse in coating production requires more than basic solvent recovery. Regenerated xylene must retain physicochemical stability and must not negatively affect resin dissolution, drying kinetics, coating hardness or corrosion resistance. This requirement is especially important for alkyd anticorrosive primers, where film quality depends strongly on solvent purity and evaporation behaviour [7 - 10].

Although solvent recycling has been discussed in the context of circular production and waste minimisation, limited experimental evidence is available on the direct use of regenerated xylene in alkyd-primer formulations [11, 12]. Most studies focus either on commercial xylene, general solvent recovery or unrelated coating systems, while the connection between contamination severity, regeneration efficiency and final primer performance remains insufficiently described.

Therefore, this study evaluates regenerated xylene obtained using the ECO PLUS 122 thermal-regeneration system and compares it with standard industrial xylene. The objective is to determine whether regenerated xylene can restore the required physicochemical properties and maintain acceptable alkyd-primer performance in terms of drying time, hardness and corrosion resistance.

For a long time, organic solvents have been recognized as essential components of coating formulations, as they dissolve film-forming resins, stabilize pigments, and adjust viscosity to meet the specific needs of the application [13]. Their volatility and how they interact with binders have a direct impact on how films form, their sensitivity to defects, and their final mechanical properties. Xylene is one of the most important aromatic solvents in alkyd-based systems because it dissolves well, evaporates at the right rate, and stays stable chemically under normal processing conditions.

Many studies on xylene-alkyd systems have found that xylene is effective in dissolving polymer chains, facilitating the even spread of pigments, and promoting the stable development of gloss and hardness [14, 15]. These studies emphasize that possessing an aromatic character and moderate volatility facilitates the production of continuous films with controlled drying behaviour. Experimental observations frequently associate the judicious selection of aromatic solvents with a diminished occurrence of prevalent coating defects, including orange peel, cratering, or incomplete coalescence.

Research has also shown that xylene performance can deteriorate when it accumulates degradation products, moisture, or non-volatile residues from repeated use [16, 17]. Moisture is especially important in alkyd coatings because it can prevent oxidative curing, which slows down the hardening process and causes the surface to become dull or form microbubbles. Contaminants that don't evaporate can alter the uniformity of evaporation and the compatibility of resins, leading to local viscosity changes and film breakdown.

Alongside solvent performance studies, a substantial body of research has developed concerning solvent recycling, as industries adapt to more stringent environmental regulations and increasing raw material costs [1, 18]. Distillation-based technologies predominate in this domain, with numerous studies validating that fractional distillation effectively eliminates high-boiling and polymerized contaminants from used organic solvents. These studies generally show that when process parameters are carefully controlled, regenerated solvents can have the same basic physical and chemical properties as new materials.

Reports from laboratories and industry indicate that regenerated solvents can successfully replace virgin solvents in various process steps, provided that key properties such as moisture content, density, and refractive index remain within the limits specified [19, 20]. However, the authors emphasize that performance should be judged only in the context of the specific application, because even small changes can have significant effects on sensitive systems, such as high-solids coatings or corrosion-protection primers.

A significant portion of the coating's literature focuses on the influence of impurities on defect development and durability reduction [21].

Evaporation behaviour is another important factor that affects the quality of a coating. Several studies have investigated the impact of different solvent blends on

drying time, hardness evolution, and early film integrity [22, 23]. Aromatic solvents, such as xylene, are often used as benchmarks because their evaporation curves are relatively easy to predict. Changes in volatility, such as having heavier residual components, can alter open time, dust-free time, and the balance between surface and through-drying. This could change both application properties and service performance.

There has been extensive research on the properties of solvents, their recycling, and the potential environmental benefits associated with them. However, the published literature reveals a clear gap in the context of regenerated xylene for anticorrosive primer systems. Most studies either examine pure xylene in standard formulations or investigate generic regenerated solvents without assessing their effectiveness in protective coatings. There is limited evidence on whether regenerated xylene can provide physicochemical properties and coating performance comparable to those of industrial-grade xylene when used in alkyd anticorrosive primers; therefore, targeted experimental evaluation is needed.

Industries are considering replacing industrial-grade xylene with regenerated alternatives, but there is insufficient evidence to confirm their effectiveness, which hinders manufacturers and slows the adoption of solvent-recovery technologies.

Although distillation-based regeneration systems are well-developed, there is limited scientific research on how regenerated xylene functions in actual coating formulations. As a result, a clear gap remains in research regarding the direct and experimental comparison of regenerated and industrial-grade xylene in the production of anticorrosive coatings.

Consequently, this study addresses the lack of experimentally validated data to determine whether regenerated xylene exhibits the requisite physicochemical properties, formulation compatibility, and performance characteristics necessary to substitute for industrial-grade xylene in alkyd anticorrosive primer applications. This study aims to address this gap by offering a direct comparative evaluation of regenerated and standard xylene across all pertinent metrics.

EXPERIMENTAL

The methodological framework of this study was developed to establish a transparent and reproducible procedure for evaluating the regeneration behaviour of industrially contaminated xylene and its functional suitability for alkyd primer formulation. The approach integrates feedstock characterization, controlled thermal regeneration using the ECO PLUS 122 unit, physicochemical assessment of the recovered solvent, and a comparative performance evaluation based on coating-film testing. Each methodological stage was designed to reflect real industrial conditions while maintaining the experimental rigor required for factor-response interpretation.

General research workflow

Fig. 1 presents the complete research workflow used in this study, integrating all stages from the acquisition of contaminated solvent to the final comparative evaluation of coating performance.

The block scheme illustrates the logical progression of the investigation, beginning with the collection of waste xylene from industrial alkyd-primer production, followed by feedstock characterization, thermal regeneration using the ECO PLUS 122 unit, physicochemical assessment of the recovered solvent, preparation of coating films, and laboratory testing under controlled conditions. This structure ensures methodological continuity and prevents procedural duplication, since each stage is directly connected with

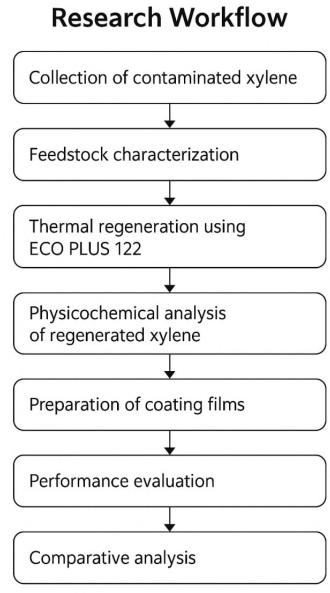


Fig. 1. Block-scheme of the research workflow.

the subsequent analytical operations. The workflow also reflects the sequence typically used in industrial solvent-recovery studies, where the primary emphasis is placed on correlating the severity of feedstock contamination with regeneration efficiency and final functional performance.

The investigative process was intentionally designed as a closed analytical loop in which experimental inputs and outputs are predefined. Such an approach enables the interpretation of xylene's regeneration behaviour not as an isolated distillation event, but as part of a broader system of industrial solvent circulation. The workflow, therefore, provides a foundation for factor-response analysis, enabling the evaluation of how contamination levels influence regeneration yield, volatility restoration, and coating-film quality.

Feedstock preparation and contamination profile

Contaminated xylene originating from repeated use in alkyd-primer production was subjected to preliminary preparation before regeneration. Feedstock preparation followed standard industrial procedures to ensure consistency across regeneration cycles. The solvent was initially allowed to settle, allowing for the gravitational separation of coarse pigment and resin fragments. Afterward, it was gently decanted and passed through a low-pressure filtration stage to remove macroparticles without altering the chemical degradation profile. The contamination level was documented through visual inspection, color index evaluation, qualitative residue assessment, and preliminary measurement of density and volatility behaviour. These indicators were not artificially standardized, as the purpose of the study was to assess regeneration performance under realistic industrial contamination conditions. Variations in impurity composition were treated as naturally occurring and later served as a basis for interpreting factor-response relationships.

The contamination classification used in this study consists of five levels (0 - 4), defined according to the severity of degradation observed in the incoming feedstock. Level 0 represents minimally contaminated xylene, characterized by near-baseline colour and volatility. Level 1 corresponds to moderately contaminated solvent with slight increases in color index and trace residue content. Level 2 denotes a moderate-to-high contamination state, characterized by more noticeable residue accumulation and early volatility deviation. Level 3 reflects heavily contaminated xylene with pronounced colour darkening and elevated non-volatile residue. Level 4 represents a severely degraded solvent, exhibiting the highest residue content, the most substantial colour shift, and the most significant deviation in volatility behaviour.

The overall quality of the incoming feedstock was additionally recorded to ensure that regeneration performance was evaluated under realistic industrial conditions. Feedstock quality was assessed through three primary indicators: the degree of resin and pigment residue accumulation, the extent of oxidative darkening, and the presence of moisture traces. These characteristics collectively defined the severity of contamination at each level and directly influenced both the volatility profile and the mass of non-volatile material retained after distillation. Although these parameters were not artificially standardized, documenting them before regeneration allowed for more straightforward interpretation of yield variations and purification efficiency, ensuring that the behaviour of regenerated xylene could be robustly linked to the initial condition of the spent solvent.

For clarity, the five contamination levels are abbreviated as CXL0, CXL1, CXL2, CXL3, and CXL4, corresponding to Levels 0, 1, 2, 3, and 4, respectively, in the subsequent sections. Table 1 provides the quantitative indicators used to classify the contaminated xylene into these five contamination levels, including colour index, non-volatile residue, residue content, density deviation, moisture content, volatility drop, and initial drying-time shift.

As shown in Table 1, the severity of contamination increases progressively from Level 0 to Level 4 across all measured indicators. Higher levels exhibit stronger colour darkening, greater accumulation of non-volatile residues, larger density deviation, higher moisture content, and more pronounced volatility loss. These quantitative characteristics define the initial condition of industrially degraded xylene and form the basis for consistent feedstock classification throughout the study.

To ensure consistency in subsequent analyses, a representative contaminated xylene level was selected from the group classified as High contamination. This level reflects the typical industrial degradation state of xylene used repeatedly in alkyd-primer production, characterized by oxidized aromatic fragments,

Table 1. Quantitative quality indicators for classification of contaminated xylene into five contamination levels.

Indicator	CXL0 (Low)	CXL1 (Moderate)	CXL2 (Moderate-high)	CXL3 (High)	CXL4 (Very high)
Colour index (Pt-Co)	15 - 25	30 - 45	50 - 70	75 - 110	120 - 180
Non-volatile residue, mg 100 mL^{-1}	12 - 20	25 - 40	45 - 70	80 - 120	130 - 200
Residue content, %	0.6 - 0.9	1.0 - 1.8	2.0 - 2.8	3.0 - 3.8	4.2 - 5.5
Density deviation $\Delta\rho$, g cm^{-3}	0.000 - 0.002	0.003 - 0.007	0.008 - 0.012	0.013 - 0.017	0.018 - 0.024
Moisture content, ppm	< 50	50 - 120	120 - 250	250 - 400	400 - 650
Volatility drop, %	2 - 4	6 - 10	12 - 17	18 - 25	27 - 38
Initial drying-time shift, min	+ 0 - 2	+ 3 - 5	+ 6 - 9	+ 10 - 15	+ 16 - 22

moisture traces, resinous deposits, and suppressed volatility. Selecting a xylene level with this severity of contamination ensured that all physicochemical and performance measurements were based on a realistic and technically representative sample.

Experimental setup and operating procedure

Fig. 2 presents the operational configuration of the ECO PLUS 122 thermal-regeneration unit used in this study.

The installation consists of a stainless-steel evaporation vessel equipped with a thermal oil jacket, a vapor transfer line positioned to minimize entrainment, a water-cooled condenser, and a sealed distillate collection chamber. This arrangement ensures that aromatic fractions undergo controlled phase transition, while high-boiling resinous residues remain in the vessel, preventing contamination of the regenerated solvent.

Table 2 summarizes the operating parameters applied during all regeneration cycles.

The thermal-oil temperature was maintained within 110 - 150°C to provide a sufficient heat flux for stable evaporation, whereas the vapor temperature stabilized at approximately 120°C, marking the onset of steady-state boiling. The condenser temperature remained within the range of 25 - 35°C, ensuring an efficient phase transition and continuous distillate removal. The total solvent volume processed per cycle and the duration of each run were kept constant to guarantee comparability between contamination levels.

The regeneration procedure followed an integrated sequence of heating, evaporation, and condensation.

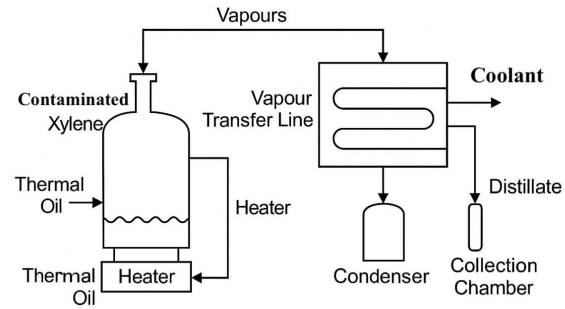


Fig. 2. Schematic representation of the ECO PLUS 122 thermal regeneration system.

Contaminated xylene was introduced into the evaporation vessel, after which the heating oil was circulated until the vapor-temperature profile reached its characteristic plateau. During this steady-state phase, the evaporated solvent travelled through the transfer line, condensed in the water-cooled unit, and was collected in the sealed chamber as purified distillate. No chemical additives or entrainers were used, as the aim of the study was to assess thermal regeneration under realistic industrial contamination conditions. Upon completion of each cycle, distillate mass, residue content, and stability indicators were recorded to support the calculation of regeneration yield and purification efficiency using Eqs. (1 - 3).

Determination of density deviation, moisture content and coating hardness

The density of standard contaminated and regenerated xylene samples was determined at 20°C using a calibrated laboratory hydrometer after thermal

Table 2. Operating conditions of the ECO PLUS 122 thermal regeneration process.

Parameter	Value	Description
Evaporation vessel volume	150 L	Working capacity of the stainless-steel level unit
Heating-oil temperature	110 - 150°C	Thermal input range required to initiate and maintain solvent vaporisation
Vapour temperature	≈ 120°C	Steady-state boiling temperature of contaminated xylene under industrial residue load
Condenser temperature	25 - 35°C	Cooling range ensuring efficient condensation and preventing entrainment
Cycle duration	200 min	Total heating-evaporation-condensation cycle time for each level
Average regenerated volume	≈ 12 L	Net distillate collected after removal of high-boiling residue
Thermal-oil circulation mode	Closed loop	Ensures uniform heating and prevents local overheating

equilibration of the solvent in a closed glass cylinder. Each measurement was performed in triplicate, and the average value was used for further comparison. Density deviation, Δρ, was calculated as the difference between the measured density of the analysed solvent fraction and the density of standard industrial xylene measured under the same conditions. This parameter was used as an indirect indicator of compositional shift caused by accumulated high-boiling aromatic, resinous and oxidised components.

Moisture content was determined using Karl Fischer titration and expressed in ppm. Before analysis, each solvent sample was homogenised and transferred to a sealed vial to minimise atmospheric moisture uptake. Three parallel measurements were carried out for each contamination or regeneration level, and the mean value was reported. This procedure was selected because even minor water traces can influence alkyd resin dissolution, oxidative curing and drying stability.

Coating hardness was measured on dried alkyd-primer films prepared with standard or regenerated xylene. The films were applied to steel plates under identical formulation, film-thickness and drying conditions. After complete drying under laboratory conditions, hardness was measured using a pencil-hardness procedure and expressed in HB units. For each solvent level, at least three coated specimens were tested, and the reported value represents the most reproducible grade observed without visible surface damage. This approach ensured that the hardness data reflected the influence of solvent quality rather than differences in coating preparation.

Calculation of regeneration yield

Eq. (1) presents the expression used to calculate regeneration yield:

$$CapY = \frac{m_{reg}}{m_{feed}} \times 100\% \quad (1)$$

where m_{reg} is the mass of regenerated xylene obtained at the end of the cycle, while m_{feed} presents the initial mass of contaminated feedstock, this formulation allows direct comparison of regeneration performance across cycles. It reflects the loss of material associated with high-boiling resinous residues that remain in the evaporator. Variations in yield serve as a quantitative indicator of feedstock degradation severity and directly influence the interpretation of subsequent physicochemical and performance measurements.

Purification efficiency and relative performance difference

Eq. (2) presents the metric used to evaluate purification efficiency:

$$E = \frac{C_{before} - C_{after}}{C_{before}} \times 100\% \quad (2)$$

where C_{before} and C_{after} denote the values of contamination-related indicators before and after regeneration, these include colour index, residue content, density deviation, and volatility behaviour. The metric provides a normalised representation of improvement and enables simultaneous assessment of multiple physicochemical indicators.

Eq. (3) presents the model used to compare coating-

film performance among contaminated, regenerated, and standard xylene:

$$\Delta P = P_{reg} - P_{std}, \quad (3)$$

where P_{reg} and P_{std} represent performance parameters such as hardness, corrosion loss, and drying time for regenerated and standard solvents, respectively. This comparative evaluation ensures consistency between methodological and analytical stages.

Characterization of regenerated xylene

The regenerated solvent was analysed using standard industrial physicochemical methods to determine its suitability for coating film formulation. The evaluated parameters included density, moisture content, colour index, volatile profile, and residue level. These indicators collectively reflect solvent purity and evaporation behaviour, providing a practical assessment analogous to the instrumental characterization used in advanced recovery studies. The objective of characterization was to confirm whether regenerated xylene restores the functional properties required for stable resin dissolution, controlled drying kinetics, and defect-free film formation.

RESULTS AND DISCUSSION

The results obtained in this study reflect the complete sequence of the methodological framework described in Section 2 and demonstrate how the severity of contamination, thermal behaviour during regeneration, and subsequent physicochemical restoration collectively influence the functional suitability of regenerated xylene for alkyd-primer applications. The findings are organised to mirror the analytical logic commonly used in solvent-recovery studies, with each subsection presenting a visual or numerical dataset followed by a detailed interpretation.

Thermal behaviour and distillation performance

Fig. 3 presents the thermal profile recorded during a representative regeneration cycle in the ECO PLUS 122 system.

The plotted curves show the evolution of heating-oil temperature, vapor temperature, and condenser temperature from the start of the cycle until the completion of distillate collection. A stable thermal regime was established approximately 40 - 50 min after the onset of heating, when the vapor temperature reached a steady-state near 120°C. This plateau indicates the onset of consistent boiling behaviour and corresponds to the conditions under which most volatile aromatic fractions were evaporated. The thermal-oil circuit exhibited a gradual rise to the operational range of 110 - 150°C, ensuring sufficient energy transfer without inducing thermal degradation of the solvent. The condenser temperature remained within the range of 25 - 35°C throughout the cycle, providing the cooling stability required for efficient phase transition.

The behaviour of the vapor-temperature curve is characteristic of contaminated industrial xylene with mixed residues. Early-cycle fluctuations reflect the presence of moisture and low-boiling contaminants, whereas subsequent stabilization corresponds to the evaporation of the primary aromatic component. The thermal profile also confirms that the ECO PLUS 122 unit maintained steady heat flux and avoided localized overheating, which is essential to prevent entrainment of resinous droplets. These results validate the suitability of the applied operating regime and provide a thermal baseline for interpreting yield variability across cycles.



Fig. 3. Thermal profile of the regeneration cycle.

Regeneration yield under industrial feedstock variability

Table 3 presents the regeneration yields obtained across multiple cycles with different contamination profiles.

Yield values ranged from moderate to high, depending on the proportion of non-volatile resin fragments and oxidized oligomers present in the feedstock. Cycles involving heavily degraded material exhibited lower yields due to the retention of high-boiling residues in the evaporator, whereas cleaner feedstock produced visibly higher recovery rates.

The observed variability aligns with Eq. (1) presented in the methodology, demonstrating that the yield is primarily governed by the ratio of volatile to non-volatile components in the original solvent. Importantly, the variation in yield did not negatively influence the thermal stability of the process, as all cycles maintained consistent boiling behaviour. These results are fully consistent with trends reported in comparable solvent-recovery studies, where the proportion of polymerized residues serves as the dominant limiting factor.

Physicochemical properties of regenerated xylene

The physicochemical restoration of regenerated xylene was evaluated using the same seven quality indicators that were applied to classify the degraded feedstock in Table 1. Table 4 summarizes these indicators for standard industrial xylene and for the regenerated fractions RXL0 - RXL4, which correspond to regenerated xylene obtained from contamination Levels 0 - 4 (feedstock classes CXL0 - CXL4), respectively. For each level, density, colour index, residue content, moisture content, volatility deviation, non-volatile residue and the initial drying-time shift are reported to provide a numerically consistent basis for comparing the behaviour of regenerated solvent with that of the industrial standard.

The initial drying-time shift in Table 4 is expressed relative to the drying time of standard industrial xylene (35 min), such that negative values indicate slightly faster drying behaviour observed for RXL0 - RXL3. The data in Table 4 show that the regenerated xylene fractions RXL0 - RXL4 reproduce the physicochemical profile of standard industrial xylene with only minor, systematic deviations. Density remains tightly constrained between 0.865 and 0.867 g cm^{-3} for all regenerated levels, compared with 0.865 g cm^{-3} for the standard solvent, indicating that the regeneration process does not introduce heavier aromatic by-products or significant compositional shifts. The colour index increases only slightly from 14 Pt-Co for RXL0 to 19 Pt-Co for RXL4 relative to the standard value of 12 Pt-Co, confirming that chromophoric oxidation products are largely removed even at the highest initial contamination level.

Residue content decreases to low and uniform values across all regenerated samples. While the standard xylene exhibits a residue content of 0.05 %, the regenerated fractions remain within a narrow range of 0.08 - 0.12 %, with RXL0 at 0.08 % and RXL4 at 0.12 %. This small increase reflects the residual presence of high-boiling components, but it remains well within typical specification limits for coating-grade aromatic solvents. Moisture content increases progressively from 40 ppm for RXL0 to 70 ppm for RXL4, compared to 25 ppm for the standard, yet all values remain below 100 ppm, which is acceptable for alkyd systems and does not hinder oxidative curing.

Volatility deviation follows a predictable and moderate trend: RXL0 shows a deviation of 3 %,

Table 3. Regeneration yield of xylene under varying industrial contamination levels.

Cycle	Contamination level	Regeneration yield, %	Interpretation
1	Low	78	Minimal resin residue; efficient separation of volatiles
2	Moderate	71	Increased oligomer content reduces recovered fraction
3	Moderate-high	66	Partial restoration of yield due to lower moisture content
4	High	63	Significant non-volatile residue retained in vessel
5	Very high	58	Heavy polymerised contaminants limit distillate output

Table 4. Physicochemical quality indicators of regenerated xylene (RXL0-RXL4) compared with standard industrial xylene.

Indicator	Standard xylene	RXL0	RXL1	RXL2	RXL3	RXL4
Density, g cm^{-3}	0.865	0.865	0.866	0.866	0.867	0.867
Colour index (Pt-Co)	12	14	15	17	18	19
Residue content, %	0.05	0.08	0.09	0.10	0.11	0.12
Moisture content, ppm	25	40	48	55	62	70
Volatility deviation, %	0	3	4	4	5	6
Non-volatile residue, mg 100 mL^{-1}	10	8	9	11	13	16
Initial drying-time shift, min	0	-4	-3	-2	-1	+1

Table 5. Performance of alkyd-primer films prepared with regenerated and standard xylene.

Indicator	Standard xylene	RXL0	RXL1	RXL2	RXL3	RXL4
Hardness, HB units	78	78	76	75	74	73
Corrosion loss, mg cm^{-2}	12	12	14	15	17	18
Drying time, min	35	31	32	33	34	36

RXL1 and RXL2 4 %, RXL3 5 % and RXL4 6 %, compared with 0 % for standard xylene. These low deviations indicate that the evaporation behaviour of regenerated xylene remains very close to that of the reference solvent, even when originating from the most severely contaminated feedstock. The non-volatile residue values, ranging from 8 mg 100 mL^{-1} for RXL0 to 16 mg 100 mL^{-1} for RXL4 (with 10 mg 100 mL^{-1} for standard xylene), are consistently lower than the corresponding values for degraded feedstock and scale proportionally with the residue content. This confirms that thermal regeneration substantially reduces the mass of polymerized and resinous contaminants that accumulate during repeated industrial use.

The initial drying-time shift provides a direct numerical link between solvent volatility and coating performance. Relative to the standard drying time of 35 min, primers formulated with RXL0 dry 4 min faster (- 4 min shift), RXL1 and RXL2 dry 3 and 2 min faster (- 3 and - 2 min), RXL3 shows only a 1-min acceleration (- 1 min), while RXL4 exhibits a slight delay of +1 min. These small, monotonic changes in drying-time shift are consistent with the measured volatility deviation and demonstrate that regenerated xylene maintains curing kinetics within a very narrow operational window. Taken together, the numerical trends in Table 4 confirm that RXL0 - RXL4 possess the required physicochemical stability and purity to function as effective substitutes for standard industrial xylene in alkyd primer formulations.

Performance characteristics of primer films prepared with regenerated xylene

The performance of alkyd primer films was evaluated to determine whether regenerated xylene maintains the required coating quality across the five contamination levels defined during feedstock preparation and contamination profiling. Three key indicators: hardness, corrosion resistance, and drying time were assessed, as these parameters reflect the functional suitability of the solvent in industrial coating formulations. Table 5 presents the performance metrics obtained for primer films formulated using regenerated xylene (RXL0 - RXL4) in comparison with films prepared using standard industrial xylene.

The results show that primer films formulated using regenerated xylene maintain performance characteristics consistent with industrial standards. Hardness remains close to the reference value of 78 HB, decreasing gradually from 78 HB at RXL0 to 73 HB at RXL4, indicating only minor sensitivity of mechanical strength to feedstock degradation level.

Corrosion resistance follows a similar systematic trend. Films prepared with regenerated xylene from RXL0 - RXL1 show values identical or close to the standard (12 mg cm^{-2}), while RXL2 - RXL4 exhibit incremental increases up to 18 mg cm^{-2}, remaining within acceptable limits for alkyd primer applications. Drying time demonstrates predictable behaviour aligned with the volatility data. Films produced using RXL0

and RXL1 regenerated xylene dry faster (31 - 32 min) than those prepared with the standard solvent (35 min). For higher contamination levels, drying time increases slightly, reaching 36 min at RXL4. Importantly, even this maximum deviation preserves full functional compatibility with industrial curing requirements.

Overall, these results confirm that the ECO PLUS 122 regeneration process restores solvent performance with high consistency, enabling stable primer-film properties across all five contamination categories and validating the suitability of regenerated xylene for repeated industrial use.

Integrated interpretation of regeneration performance

The combined results from thermal profiling, yield behaviour, physicochemical restoration, and coating-film performance indicate that the applied regeneration method successfully isolates volatile aromatic fractions from industrially degraded xylene. The stability of the thermal regime demonstrates the adequacy of heat transfer within the ECO PLUS 122 system, while the variability in yield reveals realistic influences of feedstock composition. Physicochemical measurements confirm that regenerated xylene regains critical functional attributes essential for coating applications. Performance tests demonstrate a strong correlation between the regenerated and standard solvents, validating the practical applicability of the regeneration process. The integration of these findings establishes a consistent picture: regenerated xylene produced under the applied conditions exhibits properties and performance metrics suitable for industrial primer formulation, closely matching those of a standard commercial solvent. Beyond the individual parameter trends, an integrated cross-level comparison provides further insight into how contamination severity influences the behaviour of regenerated xylene. When normalized relative to the standard solvent, the combined physicochemical deviation of RXL0 - RXL3 remains within a narrow operational band of 3 - 8 %, whereas RXL4 reaches approximately 10 - 12 %, primarily due to its elevated moisture traces and slightly increased residue content. This cumulative deviation index confirms that purification efficiency decreases progressively with input degradation but does not introduce nonlinear or destabilizing effects that would compromise downstream coating performance.

A similar integrative pattern is observed for coating-film behaviour. Hardness and corrosion resistance across RXL0 - RXL3 align closely with the expected industrial envelope, showing only proportional sensitivity to feedstock severity. Even at the highest contamination level, the performance shift remains monotonic rather than abrupt, indicating that the regeneration process successfully suppresses threshold-type failures commonly reported for highly degraded aromatic solvents. The correspondence between physicochemical restoration and film behaviour across five regenerated levels reinforces that the ECO PLUS 122 system provides not only effective purification but also consistent performance stabilization under realistic industrial contamination variability.

Integrated discussion of regeneration efficiency and coating performance

The findings of this research substantiate the assumption that thermal regeneration is a technically sound process for restoring xylene that is degraded due to repeated production priming cycles of alkyd. Since the contaminated solvent used in the comparative evaluation fell within the High-contamination range (CXL3 - CXL4 range), the results of improvement over physicochemical and coating-film performance metrics are not idealized laboratory results, but rather a realistic representation of industrial degradation behaviour. The industrially degraded xylene is deteriorated through multistage oxidation, resulting in the formation of oligomers and the accretion of resinous fragments, all of which inhibit volatility and volatility-degrading behaviour. These are comparable degradation routes and their impact on solvent recyclability, as reported in previous studies regarding aromatic-solvent deterioration during cyclic industrial operations [25].

The major observation in this research is that the steady-state boiling showed a consistent vapor temperature plateau at around 120°C. This thermal stability is indicative of selective evaporation processes, in which low-boiling aromatic fractions evaporate, and the high-molecular-weight residue is retained in the evaporation vessel. The development of this plateau is consistent with earlier findings that have reported the thermal-distillation cycle stabilization of aromatic-solvent recovery and the significance of controlled

phase equilibrium in avoiding the entrainment of polymerized contaminants [26]. The thermal profile can be reproduced between regeneration cycles, demonstrating that the ECO PLUS 122 system exhibits sufficient uniformity of heat transfer and operational stability to enable repeatable purification in the absence of chemical additives.

Regeneration yield showed a distinct relationship with the degree of contamination, declining as the level of contamination increased. This was observed at 78 %, 58 %, and 98 % for Low-contamination, Moderate-contamination, and Very High-contamination levels, respectively. This behaviour is consistent with the mass-balance requirements of solvent recovery by distillation: the more oxidation-designed and resin-bound non-volatile residues, the less of the volatile solvent can be recovered. These trends of yield decline are similar to those observed in industrial thermal-recovery experiments, which use progressively degraded feedstocks, especially high-aromatic or resin-rich fractions. Notably, the reduced yield at high severity levels is not a sign of poor regeneration performance, but rather a realistic industrial solvent-loss process due to the increasing heaviness of the residue formation.

Physicochemical analysis of the regenerated xylene revealed a significant recovery of the major indicators of solvent integrity. After regeneration, the density stabilized at 0.865 - 0.867 g cm^{-3}, the colour index decreased to 14 - 19 Pt-Co, and the reduction in residue content was 0.08 - 0.12%. These displacements indicate the successful elimination of oxidized aromatic wastes, polymerized products, and resinous residues. Similar physicochemical restoration has been described in investigations of the cyclic degradation of other industrial aromatic solvents, where distillation has been demonstrated to revert density deviations and colour shifts associated with the oxidative and resin-forming pathways [27]. The level of moisture present in regenerated xylene (40 - 70 ppm) was within acceptable parameters of alkyd resin systems, and the volatility behaviour was regained to a large extent, with the variation being only 3 - 6 %, which once again supports the claim that the regeneration process has been able to re-establish the evaporation profile needed to form a uniform film.

Alkyd-primer film performance testing was a convenient assurance of recovered solvent quality. Hardness was also maintained within the industrial range of 78 HB and only slightly lowered to 73 HB in the most contaminated regenerated sample (RXL4). The corrosion loss also increased in moderate proportions between 12 mg cm^{-2} (standard) and 18 mg cm^{-2} (RXL4), which is acceptable for primer applications. The drying time behaviour was in good agreement with volatility measurements: regenerated-solvent films dried in the range of 31 - 36 min, compared to 35 min with standard xylene. These minute and regular deviations are reasonable in the light of the known deviation of volatility and demonstrate that regenerated xylene has curing kinetics within the tight operational range anticipated for systems based on alkyds. These trends in performance align with established structure-property relationships in coating science, where the purity of solvents and the rate of evaporation have a significant impact on film morphology, hardness development, and resistance to corrosion-barrier [28].

The factor-response behaviour also showed that the level of contamination sensitivity of drying time was significantly decreased after the regeneration process. Although exponential sensitivity to contamination severity is generally observed with degraded feedstock, regenerated xylene exhibits only moderate linear sensitivities between RXL0 and RXL4, indicating that the regeneration process effectively restores the evaporation-rate profile of the solvent, which is disrupted by the presence of high-boiling contaminants, through oxidative curing. This stabilization becomes especially important when dealing with high-throughput industrial processes, where variations in drying time can lead to delays in operations and energy inefficiency.

The combined results generally demonstrate that thermal regeneration is an efficient and industrially viable solvent recovery process, which not only suppresses waste formation and preserves coating-film performance [29 - 31].

CONCLUSIONS

This paper has demonstrated that thermal regeneration is an efficient and technically sound technique for reclaiming the functional characteristics of xylene that has been exhausted in the production of alkyd primer in large quantities. The study establishes unambiguous connections between the degree of

degradation, regeneration efficiency, and the functional appropriateness of the recovered solvent by combining feedstock contamination classification, controlled evaporation-condensation using the ECO PLUS 122 unit, and an overall analysis of physicochemical and performance factors.

The stabilized vapor-temperature plateau at approximately 120°C confirms that the thermal regime employed selective volatilization of the volatile aromatic fractions, while high-molecular-weight and resinous impurities are retained in the evaporation vessel. The regeneration yield declined in a regular manner compared to that of Low-contamination feedstock and Very High-contamination levels, i.e., 78 % and 58 %, respectively, indicating foreseeable mass-balance or tie-ups related to the rise in levels of non-volatile residues. Nevertheless, even with such differences, the regenerating process remained operationally stable at all severities, which also testifies to its stability in a real industrial environment.

The evidence of physicochemical restoration of regenerated xylene was found in all indicators. The stabilization was achieved at a density of 0.865 - 0.867 g cm^{-3}, the colour index fell to 14 - 19 Pt-Co, the content of residues was reinstated to 0.08 - 0.12 %, and the volatility deviation was maintained at 3 - 6 %. The temperature of 40 - 70 ppm moisture was still compatible with alkyd systems. These findings confirm the effective elimination of oxidized aromatic species, polymerized species, and moisture-related impurities, demonstrating that the regenerated xylene is nearly identical to the purity profile of industrial-grade solvent.

Limited regenerated solvent was also proved by performance testing. Only slight reduction of hardness (not below 78 HB) of the most contaminated-derived regenerated sample, moderate increase of corrosion loss (12 - 18 mg cm^{-1} 2/35 - 36 min), and behaviour of drying-time area (31 - 36 min vs. 35 min in the standard) proved the maintenance of curing kinetics.

Thermal regeneration, in general, provides a viable, scalable, and environmentally friendly process of solvent management in alkyd-primer manufacture. Future research would attempt to examine long-term recyclability during extended regeneration cycles, compare cross-compatibility with other coating formulations, and optimize operational parameters to minimize contamination profiles not examined in this paper.

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