

Forensic Evaluation of Ink Removal Using Vinegar and Ethanol on Contract Bond Paper Under Temperature Variation

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Abstract- The present study focuses on the forensic evaluation of ink removal using vinegar and ethanol on contract bond paper under varying temperature conditions. The study aims to investigate the effects of these chemical agents on ink visibility, paper characteristics, and the detectability of potential alterations in written documents. Vinegar, containing acetic acid, and ethanol are examined as treatment agents to determine their effects on ink markings and the physical integrity of contract bond paper at different temperatures. The evaluation considers observable changes such as ink fading, residual ink traces, paper discolouration, surface texture, and fibre damage. Untreated paper samples serve as controls for comparison. Forensic examination methods, including visual inspection and microscopic analysis, may be used to identify characteristics associated with chemical treatment. The study also considers temperature as a factor that may influence the interaction between the treatment agents, ink, and paper substrate. The findings are expected to contribute to the understanding of document alteration and the limitations of detecting chemically treated ink entries in questioned documents. This research may provide useful insights for forensic document examiners in assessing the authenticity and integrity of contract documents. The conclusions will be based on the experimental results obtained.

Keywords- Forensic document examination, ink removal, vinegar, ethanol, contract bond paper, temperature variation, questioned documents, ink alteration, paper integrity, chemical treatment.

I. INTRODUCTION

Documents occupy a foundational role in legal, financial, administrative, and academic systems. The evidentiary weight they carry depends almost entirely on the permanence and authenticity of the ink used to record information on them. Contract bond paper, in particular, is a widely preferred substrate for high-stakes legal agreements owing to its dense fiber structure, superior surface sizing, and professional finish. Unlike standard office paper, bond paper offers a firmer and more controlled base for signatures and contractual content, making it a material of choice in formal documentation. When ink is applied to bond paper, it integrates with the surface sizing of the paper to create a record intended to be both permanent and tamper-resistant.

Despite this intended permanence, the integrity of such documents remains vulnerable to deliberate interference. Chemical erasure of written content has increasingly emerged as a concern in forensic document examination. Household chemicals such as vinegar and ethanol, often referred to as forms of kitchen chemistry, require no technical expertise and are freely accessible, making them convenient tools for fraud, forgery, or the manipulation of legal records. The ability of these substances to interact with ink components and affect

their visibility, stability, and recoverability without always leaving an immediately obvious trace makes them especially problematic from an investigative standpoint.

Chemical ink erasure operates through dissolution or neutralization rather than physical scraping or abrasion. Writing inks are generally composed of colorants such as dyes or pigments, vehicles or solvents like glycols or water, and binders and additives that control flow and drying behavior. Under ordinary conditions, these components sit stably within the paper fibers. When a solvent such as vinegar or ethanol is applied, it either dissolves the colorant molecules or disrupts the molecular bonds holding the dye in place, rendering the ink colorless or lifting it off the surface. The nature and extent of this interaction are determined by the chemical affinity between the solvent and the specific ink formulation present on the paper.

An important dimension of this research is the differential impact that each chemical has on the paper substrate itself. Vinegar, functioning as a weak acid, was found to remove ink from bond paper relatively effectively while leaving the fiber structure largely intact. Ethanol, by contrast, demonstrated a more aggressive profile, frequently dissolving the sizing agents and compromising the structural integrity of the contract bond paper, often leaving the surface visibly

weakened or pilled. This distinction has significant forensic implications because a visually undisturbed paper surface after erasure, as seen with vinegar, may mislead a casual examiner into concluding that no tampering has occurred.

The progression of such alterations is further shaped by environmental conditions. Since erasure is fundamentally a chemical process, variables such as storage temperature and light exposure can influence how it develops over time. This study specifically investigates how storing documents at room temperature versus refrigerated conditions affects the stability and concealment of erasures.

In many forensic cases, altered documents may appear completely normal under ordinary light, making visual inspection alone insufficient for detecting tampering. Non-destructive examination methods such as oblique illumination, ultraviolet light, and infrared photography are therefore essential for revealing faded or concealed residues without inflicting additional harm on the document.

The central aim of this research is to assess how effectively vinegar and ethanol remove different types of ink from contract bond paper, and to observe how the paper substrate responds to each chemical agent under varying temperature conditions. By mapping these patterns, the study seeks to equip forensic investigators and law enforcement professionals with a clearer understanding of how to identify chemical tampering and select the most appropriate analytical technique for document examination.

1. Classification Of Writing Inks

Writing inks used in documents can be broadly classified based on their chemical composition and permanence properties. Understanding these classifications is essential to interpreting how each ink type responds to chemical exposure.

2. Dye-Based Inks

Dye-based inks contain soluble colorants dissolved in liquid carriers such as water or alcohol. They penetrate paper fibers deeply and are generally more susceptible to solvent-based removal. Their molecular structure allows solvents to break the dye's bonding with the cellulose matrix relatively easily, making them the most vulnerable category in chemical erasure scenarios.

3. Pigment-Based Inks

Pigment-based inks contain insoluble particles suspended in a binder medium. Because the pigment particles remain predominantly on the surface of paper fibers rather than penetrating them, these inks demonstrate considerably higher resistance to chemical removal.

The binder acts as a protective barrier against common household solvents.

4. Ballpoint Pen Inks

Ballpoint pen inks typically consist of dyes dissolved in viscous organic solvents combined with resins. They demonstrate moderate resistance to erasure but can dissolve when exposed to alcohol-based chemicals. Their interaction with household solvents tends to produce blurring and gradual fading rather than complete removal.

5. Gel Pen Inks

Gel inks contain pigments suspended in water-based gels. Their resistance to chemical removal depends on the pigment composition and the strength of the binder used. Pigment-based gel inks, in particular, have shown strong durability against both acidic and solvent-based erasing agents.

6. Types Of Erasable Inks

Erasable inks are specially designed writing formulations that permit removal through mechanical friction or chemical exposure. Understanding their mechanisms allows forensic practitioners to differentiate between intentional document tampering and legitimate writing behavior. The main categories include thermochromic inks, which disappear when exposed to heat due to molecular rearrangement of color pigments; water-erasable inks, which can be removed through moisture due to weak dye-paper bonding; chemical-sensitive inks, which react with specific solvents that dissolve dye carriers; and mechanically erasable inks, which are removed through abrasion without significant fiber damage.

7. History Of Ink And Document Alteration

Ink has evolved significantly from ancient natural formulations to modern synthetic chemical compositions. Early civilizations used carbon-based inks prepared from soot and plant extracts. During the medieval period, iron gall ink became widely used in official documentation due to its permanence and resistance to fading. The nineteenth century introduced aniline dye inks, which improved writing smoothness but reduced permanence. The twentieth century

marked the development of ballpoint pen inks, followed by gel-based and pigment-based inks, enhancing both durability and writing efficiency.

Erasable inks were commercially introduced in the late twentieth century to support correction-friendly writing systems in academic and office environments. However, their misuse in document alteration has since created forensic challenges that require specialized detection and recovery techniques. From a forensic perspective, permanent inks provide stronger evidentiary reliability, whereas erasable inks increase the probability of detecting tampering through chemical recovery methods.

II. REVIEW OF LITERATURE

A literature review is a critical analysis and synthesis of existing scholarly work (articles, books, theses) on a specific research topic. It summarizes what is already known, identifies research gaps or contradictions, and establishes the theoretical context for new research, proving its necessity and relevance

A study conducted by H. Kelly and J. Wiggins (2012), titled “Detection of Chemical Erasures in Documents” examined ink removal methods. The objective was to identify signs of chemical tampering. The universe included altered documents. The research design was experimental. Samples included chemically treated ink entries. Data collection used spectroscopy and microscopy. Major findings showed that chemical erasure leaves detectable residues. The study suggested routine screening for alterations.

A study conducted by C. Neumann et al., (2011), titled “Forensic Examination of Ink by Spectroscopic Techniques” focused on non-destructive analysis. The objective was to detect ink alterations without damaging documents. The universe included questioned documents. The research design was observational and analytical. Samples included various ink types on paper. Data collection used UV-Visible and infrared spectroscopy. Major findings indicated that altered ink leaves detectable spectral signatures. The study suggested using spectroscopy in routine forensic examination.

A study conducted by M. Ezcurra et al., (2010), titled “Analysis of Ballpoint Pen Inks by Gas Chromatography” examined solvent extraction behavior. The objective was to

study how solvents affect ink composition. The universe included ink on paper substrates. The research design was experimental. Samples consisted of ink lines treated with solvents such as ethanol. Data collection used GC-MS analysis. Major findings showed that solvents can partially remove or redistribute ink components. The study suggested caution when interpreting altered documents.

A study conducted by L. Bügler et al., (2008), titled “Ink Analysis Using Thin-Layer Chromatography” aimed to separate ink components. The objective was to evaluate TLC for forensic use. The universe included writing inks on paper. The research design was experimental. Samples included multiple ink brands. Data collection used chromatographic separation. Major findings showed distinct dye patterns for different inks. The study suggested TLC as a cost-effective forensic tool.

A study conducted by J. M. Weyermann et al., (2007), titled “Ink Dating Using Mass Spectrometry” aimed to analyze ink aging using advanced instrumentation. The objective was to identify chemical markers for ink dating. The universe included ballpoint inks deposited on paper. The research design was experimental laboratory-based. Samples included ink entries aged under controlled and natural conditions. Data collection used mass spectrometry techniques. Major findings revealed that solvent loss patterns can indicate relative ink age. The study suggested further standardization of analytical protocols.

A study conducted by D. Ellen, (2006), titled “Scientific Examination of Documents: Methods and Techniques” focused on document analysis methods. The objective was to review forensic techniques. The universe included questioned documents. The research design was descriptive. Samples included case-based examples. Data collection involved multiple forensic tools. Major findings highlighted detection of erasures and chemical alterations. The study suggested multidisciplinary approaches.

A study conducted by A. Aginsky, (2004), titled “Determination of Ink Age by Solvent Loss Analysis” examined solvent evaporation. The objective was to estimate ink age using chemical changes. The universe included ballpoint pen entries. The research design was experimental. Samples consisted of ink stored under different conditions. Data collection used chemical extraction and analysis. Major

findings indicated predictable solvent loss trends. The study suggested environmental control during evidence storage.

A study conducted by S. Locicero et al., (2004), titled “Dating of Ballpoint Pen Ink by Gas Chromatography” focused on ink dating reliability. The objective was to validate GC methods. The universe included ink samples on paper. The research design was laboratory-based. Samples included fresh and aged inks. Data collection used GC-MS. Major findings showed variability depending on storage conditions. The study suggested combining techniques for accuracy.

A study conducted by R. L. Brunelle and K. R. Crawford, (2003), titled “Advances in the Forensic Analysis and Dating of Writing Ink” focused on improving ink identification techniques. The objective was to evaluate modern analytical tools for ink differentiation. The universe included various commercial inks on paper. The research design was analytical and comparative. Samples included different brands of inks applied under controlled conditions. Data collection involved chromatography and spectroscopic methods.

Major findings showed that ink composition varies significantly across brands, aiding forensic discrimination. The study suggested integrating multiple analytical techniques for reliable conclusions.

A study conducted by R. N. Jones, (1999), titled “The Interaction of Ink and Paper in Forensic Science” explored substrate effects. The objective was to understand ink penetration in paper. The universe included different paper types. The research design was experimental. Samples included ink applied to varying paper qualities. Data collection involved microscopic and chemical analysis. Major findings showed that paper porosity affects ink removal difficulty. The study suggested considering paper type in forensic analysis.

A study conducted by A. A. Cantu, (1995), titled “A Study of the Aging of Ballpoint Pen Ink by Thermal Degradation” aimed to examine how ink changes under heat exposure. The objective was to understand the effect of temperature on ink aging for forensic dating. The universe of study included ballpoint pen inks applied on paper substrates. The research design was experimental, involving controlled heating conditions. The sample consisted of multiple ink samples of varying compositions, though exact sample size varied across

trials. Data collection was performed using chromatographic analysis. Major findings indicated that increased temperature accelerates solvent evaporation and dye degradation. The study suggested that environmental conditions must be considered when interpreting ink age in forensic cases.

Previous studies by researchers have mainly focused on ink aging, composition, and analytical detection techniques. While some research examines solvent effects (e.g., ethanol), there is limited work on the intentional removal of ink using simple household chemicals. In particular, vinegar (acetic acid) has been largely neglected, and there is a lack of studies investigating the combined effect of vinegar and ethanol under different temperature conditions. Additionally, most research does not focus on specific substrates like contract bond paper or evaluate the forensic detectability of such chemical alterations. Therefore, a clear gap exists in studying ink removal using common chemicals under temperature variation and its forensic implications, which your research aims to address.

III. METHODOLOGY

Research methodology is the systematic, theoretical analysis of the methods and procedures applied to a research project. It encompasses the overall strategy, including research design, data collection, and analysis techniques, providing a rationale for why specific methods—such as quantitative, qualitative, or mixed-methods—are chosen to ensure study validity and reliability. More than just techniques, it defines the logical framework for how a study is conducted

1. Need For The Study

In recent years, the alteration of documents using easily available household chemicals has become more prevalent across academic records, financial papers, formal agreements, and legal instruments. Such alterations may not be immediately visible to the naked eye and therefore demand scientific examination to detect. Contract bond papers are particularly sensitive to external agents such as solvents and temperature changes, meaning that critical details such as names, dates, and signatures can be deliberately erased or caused to fade through unauthorized chemical treatment. Standard visual examination under ordinary conditions is often insufficient to reveal the extent of such tampering, which underscores the need for non-destructive optical examination techniques capable of recovering hidden or

degraded information without causing further harm to the document.

Although several studies have examined ink analysis using laboratory-grade chemicals, very few have investigated the specific effects of commonly available substances such as vinegar and ethanol on ink removal and subsequent recovery. This study is important because it provides experimental observations grounded in realistic tampering scenarios, using materials that are genuinely accessible in everyday life. The findings are intended to strengthen the techniques available to forensic document examiners and support investigators in identifying chemical erasures with greater confidence.

2. Aim Of The Study

The aim of this study is to examine the effectiveness of vinegar and ethanol in removing ink from legal bond paper, to evaluate the performance of non-destructive optical examination techniques in recovering erased ink, and to assess how temperature conditions influence both the stability of erasures and the prospects for information recovery.

3. Objectives

- To compare the effectiveness of vinegar and ethanol in removing different types of ink from contract bond paper.
- To observe how different categories of writing ink respond to chemical erasure with respect to fading patterns and residual visibility.
- To study the influence of time and temperature on erased ink behavior, comparing outcomes between room temperature and refrigerated storage conditions.
- To evaluate the effectiveness of non-destructive optical examination methods, including ultraviolet illumination, infrared imaging, and oblique lighting, in recovering chemically erased ink entries from contract bond paper.

4. Research Questions

- Is it possible to restore degraded bond paper writing using optical examination methods without causing further damage to the document?
- Which optical method performs best in restoring images degraded by specific household chemicals?
- Do different optical examination methods produce varying levels of recovery effectiveness on contract bond paper?

- Can these methods help forensic specialists recover critical information from altered legal contracts?

5. Research Design

Research design is the comprehensive, structured blueprint or framework guiding a study, essential for aligning research questions with actionable methodologies. It acts as a roadmap for collecting, measuring, and analyzing data to ensure the study is valid, reliable, and addresses the research problem efficiently. This study follows an experimental and mixed-method research design, aimed at examining how effectively optical examination techniques can restore faded or chemically erased ink entries on contract bond paper.

Before any chemical treatment was introduced, samples were prepared with known ink types and confirmed to be clearly readable under standard visual examination. This baseline documentation was essential for accurately assessing the degree of degradation observed at later stages. The samples were then divided into distinct experimental groups and subjected to controlled degradation through the application of specific household chemicals and exposure to different storage temperature conditions.

6. Universe, Sample Size, And Sampling Technique

The universe of this study comprises the writing inks and contract bond papers used in routine transactions and legal agreements. A total of 24 experimental sets were derived from 12 ink types treated with 2 chemicals, resulting in the following sample distribution: eight samples of ballpoint pen inks, eight samples of gel pens using pigment-based formulations, and eight samples of dye-based inks, each group being treated with either vinegar or ethanol. A purposive, non-probability convenience sampling technique was applied to select the ink types and bond papers based on their suitability for the experimental conditions being tested. All materials were sourced from stationery shops and commercial outlets where contract bond paper is readily available.

7. Inclusion Criteria

The inclusion criteria specified that only samples prepared on contract bond paper with clearly visible printed or written information were accepted for study. Samples had to be capable of experimental degradation using household chemicals and had to represent typical high-quality legal substrates.

8. Exclusion Criteria

The exclusion criteria ensured that papers showing signs of previous degradation, physical damage such as tears or folds, or pre-existing staining before the experiment were not included. Similarly, inks that were already faded or had been exposed to moisture prior to chemical treatment were excluded in order to maintain uniformity in experimental conditions and protect the reliability of findings.

9. Tools Of Data Collection And Procedure

Several instruments were used to examine the degraded samples without causing additional harm to the paper. A ultraviolet light source was employed to detect differences in fluorescence and contrast in the degraded areas. An infrared imaging system was used to bring out details that were too faint to observe under normal lighting. An oblique lighting setup was used to enhance surface features and highlight areas where physical alterations had occurred. Visible light sources served as the baseline for standard visual examination. A digital camera was used to photograph each sample under different light conditions, enabling comparative visual documentation. Gloves and sealed bags were used for sample handling and storage to avoid contamination. Observation sheets were maintained to record findings and visible changes noted throughout the process. Vinegar and ethanol at 95% concentration served as the two chemical agents for inducing controlled degradation.

Contract bond paper samples were prepared using 12 different ink types, each assigned a unique identification code for systematic documentation. Only samples with clearly readable writing were included. Photographs and initial observations were recorded to establish the baseline condition of each sample. The samples were then divided into two groups: one treated with vinegar and the other with ethanol, applied carefully using cotton swabs so that the inked area was affected without disturbing surrounding paper fibers. After chemical application, visible reactions of the bond paper were recorded, including surface changes such as the fiber disruption caused by ethanol. Following treatment, the samples were stored under two temperature conditions, room temperature at approximately 25 degrees Celsius and refrigerated storage at 4 degrees Celsius, to compare how temperature affects the stability of the alterations. Each sample was then systematically examined using ultraviolet illumination, infrared imaging, oblique lighting, and standard visible light examination.

10. Data Presentation And Analysis

Results from the examination of degraded contract bond papers were processed and documented through systematic visual observation. Print visibility was graded on a four-point scale: Clear, Partially Visible, Faint, and Not Visible. The degree of substrate damage was also assessed, ranging from no destruction to complete destruction of the paper fibers. Samples were examined sequentially under each optical technique, and all observations were organized to capture the type of damage, the optical method applied, and the resulting level of print visibility. A descriptive comparative approach was adopted to evaluate patterns across chemicals, ink types, and storage temperatures.

11. Report Design

Report Design serves as the master plan for how a study is organized and communicated. For this specific project, the content is organized into the following five sections:

12 . Limitations

- The study is limited to the use of only two chemical agents, vinegar and ethanol, and does not consider other potential ink removal substances.
- The findings are restricted to contract bond paper and may not be applicable to other types of paper with different properties.
- The experiments are conducted under controlled laboratory conditions, which may not fully represent real-life document tampering situations.
- The range of temperature variation considered in the study is limited and does not include extreme or highly fluctuating environmental conditions.
- The study may focus on specific types of ink, such as ballpoint pen ink, and therefore the results may not be generalizable to other ink types.
- The duration of observation is relatively short, which may not capture long-term effects of chemical treatment and natural aging
- The analytical techniques used for detection may have limitations in identifying very subtle or microscopic alterations.
- There is a possibility of human or experimental error during the application of chemicals and measurement procedures.

- The sample size used in the study may be limited, affecting the statistical reliability of the results.
- The research is based on simulated samples rather than actual forensic case documents, which may limit its practical applicability.

IV. CHAPTER IV DATA ANALYSIS AND

1. Interpretation

Data analysis involved the systematic organization, summarization, and interpretation of collected observations to address the research questions. A descriptive approach was adopted to evaluate the effects of different degradation methods on contract bond paper written with various ink types, and the efficiency of non-destructive optical examination techniques in recovering information after degradation under different storage conditions.

Effects Of Chemical Degradation On Contract Bond Paper

Samples written with dye-based, pigment-based, ballpoint, and gel inks were exposed to two chemical agents: vinegar (acetic acid) and ethanol (95% ethyl alcohol). The impact on the paper substrate was assessed using a destruction scale ranging from no destruction at one end to complete destruction at the other, with intermediate stages of very slight, mild, moderate, and severe damage.

Degradation Agents	Ballpoint Ink	Gel Pen(Pigment)	Dye-Based Ink	Paper Substrate Condition
Vinegar(Acetic Acid)	Complete Erasure(100%)	Mild Erasure(35%)	Complete Erasure(100%)	No Destruction(0%)
Ethanol(95% alcohol)	Severe Erasure(85%)	Very Slight Erasure(15%)	Severe Erasure(75%)	Complete Destruction(100%)

Observations On Vinegar-Treated Samples

Vinegar caused considerable ink removal while leaving the paper fibers largely intact. The findings across ink types were as follows:

- Dye-based inks experienced near-complete removal upon vinegar application, achieving approximately 100% erasure with zero fiber destruction. The acidic solution efficiently disrupted the dye components without weakening the high-quality bond paper fibers.
- Ballpoint inks showed moderate fading and edge blurring while the paper remained structurally intact, indicating that vinegar primarily affected the ink vehicle rather than the cellulose matrix.
- Pigment-based and gel inks demonstrated only mild to moderate fading. Pigmented formulations are more resistant to acidic agents, so a larger proportion of the writing remained legible after treatment.

Taken together, vinegar functioned as a selective solvent that was particularly effective against dye-based inks while posing comparatively little risk to the structural integrity of the paper. This quality makes it forensically significant, as a visually undisturbed paper surface after vinegar erasure may lead an examiner to conclude that no tampering has taken place.

Observations On Ethanol-Treated Samples

Ethanol demonstrated a dual destructive effect, affecting both the ink and the physical structure of the paper substrate. The key observations were:

- The paper substrate experienced severe to complete destruction, characterized by surface fiber pilling, thinning, and structural breakdown of the contract bond paper. In the most severe cases, destruction reached 100%.
- Dye-based and ballpoint inks were partially dissolved, but the associated fiber damage made the document surface fragile and in some cases unusable.
- Pigment-based and gel inks were less directly affected in terms of ink removal, yet ethanol still caused significant mechanical and chemical damage to the paper surface regardless.

These observations confirm that ethanol is a considerably more aggressive solvent in terms of its impact on the sizing and fiber structure of contract-grade paper. From a forensic standpoint, ethanol is a less effective erasing tool for forgery purposes precisely because its destruction is visible and easily detectable upon examination.

Influence Of Storage Temperature On Ink Recovery

After chemical treatment, the samples were stored under two distinct conditions: room temperature at 25 degrees Celsius and refrigerated storage at 4 degrees Celsius. Ink visibility was then assessed using non-destructive optical methods and classified on a four-point scale of clear, partially visible, faint, and not visible.

Observations On Vinegar-Treated Samples Across Temperature Conditions

Vinegar-treated samples exhibited clear temperature-dependent behavior across all optical examination methods. The key observations were:

Samples stored at room temperature: Dye-based inks shifted from partially visible to

faint or completely invisible over time. This suggests that chemical degradation continued beyond the initial application, with residual dye diffusing further into the paper. Under ultraviolet illumination and oblique lighting, these samples produced only faint signals, while infrared examination yielded no detectable residue.

Samples stored at 4 degrees Celsius (refrigerated): The same inks remained partially visible for longer periods, with more residual traces detectable under ultraviolet and oblique lighting. Reduced temperature slowed both diffusion and secondary degradation, preserving faint ink traces that would otherwise have disappeared. Pigment-based and gel inks retained clear to partial visibility under both conditions, but showed marginally better preservation when refrigerated.

Observations On Ethanol-Treated Samples Across Temperature Conditions

Ethanol-treated samples responded differently depending on storage temperature:

Samples stored at room temperature: Physical deterioration of the paper accelerated, with micro-fracturing of fibers and increased light scattering observed. In some cases, surface fibers bearing ink detached entirely, resulting in simultaneous loss of both substrate and writing. Visibility shifted rapidly toward not visible under standard examination.

Samples stored at 4 degrees Celsius (refrigerated): The progression of physical damage was noticeably slowed. While ethanol remained fundamentally destructive to the paper,

refrigerated samples showed delayed and reduced deterioration, and some writing strokes remained faintly visible under specialized lighting conditions, including oblique illumination.

Performance Of Non-Destructive Optical Examination Techniques

Across all ink types, chemicals, and storage conditions, the non-destructive optical methods consistently produced the following observations:

Ultraviolet Illumination: Ultraviolet examination proved to be the most effective optical technique for recovering faint ghost residues of erased ink. The method worked best on vinegar-treated samples stored under refrigerated conditions, where residual traces of dye remained detectable. Samples stored at room temperature produced fainter responses, while those treated with ethanol showed mixed results depending on the degree of physical damage to the paper surface.

Shorter ultraviolet wavelengths consistently produced superior contrast compared to longer wavelengths, making them the preferred range for detecting chemically erased entries on bond paper.

Infrared Imaging: Infrared examination proved largely ineffective for detecting entries erased with vinegar on bond paper.

The chemical reaction associated with vinegar appears to effectively neutralize the infrared-absorbent properties of the ink, leaving insufficient residue for the method to detect. For ethanol-treated samples, infrared provided limited but slightly better results in identifying structural changes at the surface level.

Oblique Lighting: Oblique lighting emerged as the most reliable technique for identifying ethanol-treated areas. It effectively revealed the physical pilling and thinning of bond paper fibers caused by ethanol exposure, even in cases where other methods failed to detect any trace.

For vinegar-treated samples, oblique lighting provided a secondary level of visibility and was useful as a confirmatory examination method.

Standard Visual Examination: Vinegar-treated papers frequently appeared completely clean under ordinary light, confirming that visual inspection alone is insufficient for detecting this type of tampering. Ethanol-treated papers were more readily identified through visual examination due to the visible surface damage they sustained, though subtle signs of tampering still required supplementary optical analysis.

Integrated Findings Across Ink, Chemical, And Temperature Variables

When the combined outcomes across all variables are considered together, several consistent patterns emerge that are meaningful for forensic document examination:

- Dye-based inks treated with vinegar showed rapid and substantial fading at room temperature, while refrigerated storage preserved more residual traces that remained detectable under ultraviolet light. Ethanol treatment caused partial dissolution alongside severe paper weakening, with both processes slowed but not prevented by refrigeration.
- Pigment-based inks showed limited response to vinegar, with ink persisting mostly intact under both temperature conditions. Ethanol produced some ink change alongside notable structural compromise of the paper surface, though the effect was slightly reduced at lower temperature.
- Ballpoint inks showed moderate fading and blurring under vinegar treatment, with higher residual writing detectable at 4 degrees Celsius. Ethanol began dissolving the ink vehicle alongside rapid paper damage, with cooled storage only partially reducing the extent of harm.
- Gel inks exhibited mild to moderate fading under vinegar, with the paper remaining intact under both storage conditions and better preservation observed under refrigeration. Ethanol produced surface fiber damage with limited pigment change, with its effects slowing at lower temperature but remaining disproportionately harmful to the paper structure.

These findings collectively demonstrate that reduced temperature functions as a protective factor primarily by slowing chemical reactions and mechanical degradation. This in turn enhances the likelihood of information recovery at a later stage, provided that appropriate optical examination tools are employed.

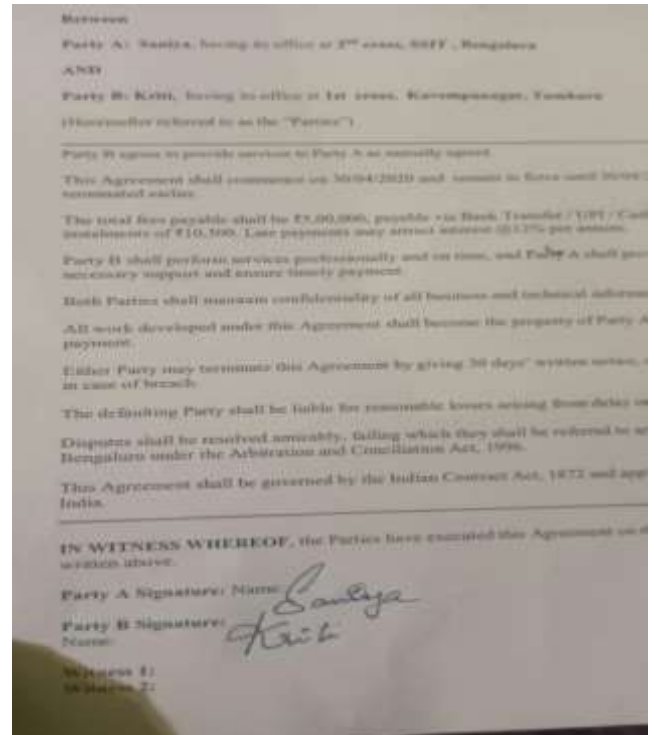


Figure 1: Using Gel Pen Before removing the ink using vinegar

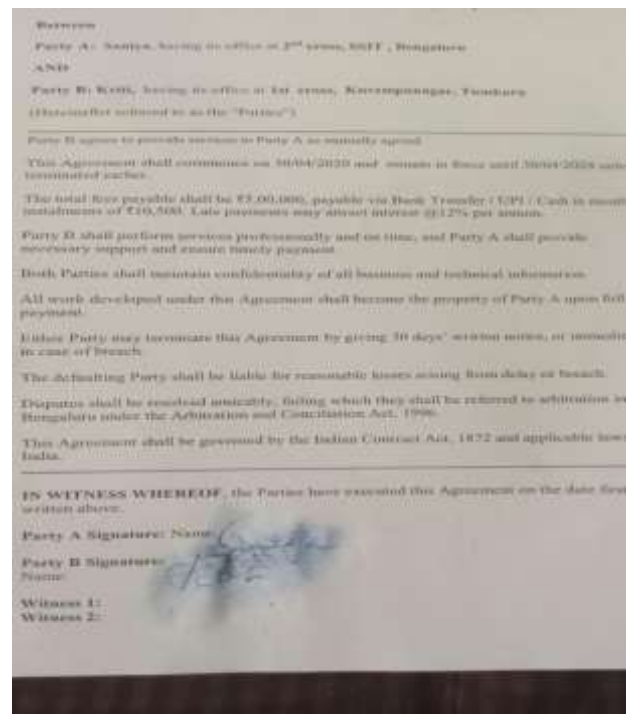


Figure 2: After removing and kept in normal room temperature

Discussions

The experimental results, as illustrated in Figure 1 and Figure 2, demonstrate a significant degradation of gel pen ink when treated with vinegar (acetic acid) and subsequently exposed to room temperature. The transition from a legible signature to a faint, nearly invisible mark suggests a chemical interaction between the acidic medium and the ink components.

Chemical Analysis of Ink Erasure

Most gel pen inks are composed of pigments or dyes suspended in a water-based polymer gel. Unlike traditional oil-based ballpoint inks, gel inks are designed to flow more freely. The application of vinegar—a weak acid with a pH of approximately 2.4 to 3.0—likely acted as a solvent that disrupted the chemical bonds of the dye molecules. Acetic acid can cause protonation of certain dye structures, which alters their light-absorption properties (chromophores), effectively "bleaching" the color or making it water-soluble enough to be lifted from the paper fibers.

The Role of Temperature and Time

A comparison between the two figures reveals that the erasure process is not instantaneous but continues as the specimen is kept at normal room temperature. This suggests a rate-dependent reaction. As the vinegar evaporates or settles into the cellulose fibers of the paper, it continues to react with the remaining pigment. The lack of visible residue in Figure 2 indicates that the acetic acid was successful in either:

- Breaking down the pigment into colorless sub-products.
- Weakening the ink's adhesion to the paper, allowing it to fade as the moisture evaporated.

V. MAJOR FINDINGS, SUGGESTIONS AND CONCLUSION

Major Findings Of The Study

The findings presented here represent the core outcomes of the research. They directly address the research questions posed at the outset and provide factual conclusions drawn from the experimental data.

- Ethanol at 95% concentration proved to be the most physically destructive agent tested, resulting in complete degradation of contract bond paper fibers, including severe surface pilling and thinning that was visible to the naked eye.

- Vinegar demonstrated a significant advantage in the context of document forgery, as it was capable of removing ink entries from bond paper without leaving visible physical damage to the substrate. This makes vinegar a forensically more concerning erasing agent than ethanol from the perspective of concealment.
- Contract bond paper exhibited high durability against weak acidic agents like vinegar but demonstrated poor resistance to organic solvents such as ethanol, which dissolve the sizing agents integral to the paper's structural quality.
- The effectiveness of non-destructive optical examination in retrieving erased information was found to be strongly dependent on the storage temperature of the document following chemical treatment.
- Samples stored at room temperature after chemical erasure presented considerably greater difficulty in information recovery due to higher evaporation rates and continued diffusion of residual dye. In contrast, refrigerated samples retained a higher degree of partial recoverability under forensic optical methods.
- Ultraviolet illumination, particularly at shorter wavelengths, emerged as the most effective optical tool among those tested for detecting ghost residues of erased ink on contract bond paper, consistently producing the strongest contrast and highest recovery rates.

Suggestions

- Ultraviolet light sources at shorter wavelengths should be prioritized in the forensic examination of suspect contract bond papers. A standardized sequential examination protocol beginning with visual inspection, followed by oblique lighting, then ultraviolet, and finally infrared examination, would help maximize information recovery.
- Oblique lighting should be the initial technique of choice when trying to identify which chemical agent was used in a tampering incident, as pronounced fiber destruction and surface pilling are strong indicators of ethanol exposure.
- Documents suspected of chemical exposure must be handled with considerable care to prevent further mechanical damage to already weakened fibers. Appropriate protective measures should be followed to avoid direct contact with any concentrated solvents during handling.
- Legal professionals would benefit from adopting pigment-based gel inks for signatures on contract bond

papers, given the evidence here that such inks offer substantially better resistance to common household erasing agents.

- Paper manufacturers should explore the development of forensically resilient bond papers incorporating chemical-sensitive security layers that visibly respond, such as through a color change, when exposed to acids or alcohols.
- Future research should systematically categorize the reactions of a wider range of high-quality bond papers to a broader spectrum of household chemicals, with the aim of establishing clearer and more comprehensive forensic standards.
- Longitudinal studies tracking how both natural environmental exposure and deliberate chemical treatment affect the long-term stability of forensic markers on contract bond paper would be a valuable contribution to the discipline.

VI. CONCLUSION

This study clearly demonstrates that the ability to recover information from chemically erased contract bond papers using non-destructive optical techniques depends significantly on two interconnected factors: the chemical used for erasure and the conditions under which the document was subsequently stored. Vinegar produces a comparatively clean erasure that leaves the paper structurally intact, while ethanol causes irreversible physical damage to the paper fibers that is far more readily detectable through standard examination.

Among the examination techniques evaluated, ultraviolet illumination, particularly at shorter wavelengths, proved to be the most reliable approach for detecting ghost residues of original ink. Infrared examination, by contrast, showed limited utility for this specific substrate and chemical combination. The study also underscored the importance of storage temperature: refrigerated documents consistently retained ink traces more effectively and yielded better results under optical examination compared to those stored at room temperature.

A meaningful contribution of this study is its detailed mapping of how each chemical interacts with contract bond paper, with vinegar achieving high ink removal alongside minimal surface impact, and ethanol causing complete

breakdown of the paper sizing. This distinction reinforces the need for forensic examiners to adjust their analytical approach depending on the suspected erasing agent in a given case. Overall, the research affirms both the value and the inherent limitations of non-destructive optical techniques in this context. These methods perform well under controlled degradation conditions but face considerable challenges when substrate damage is severe, pointing to the ongoing need for advanced forensic imaging tools capable of handling more extreme forms of document tampering.

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