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Recovery of Information from Experimentally Degraded Thermal Papers using Non-Destructive Optical Examination Techniques.

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CHAPTER – 1. INTRODUCTION

Thermal paper is a kind of special paper that reacts to heat. This paper has a special layered coating on its surfaces of the base knows as thermal layer with dyes and developers. When a printer applies specific heat to it, these chemicals react and form information, such as text, images or a bar-code. For this printer need just sufficient heat is needed to generate information's. The thermal printer machine has a thermal print head with electronic circuits, these heats up spots directly on the paper and turns the coated layer black or blue, creating the required text or image.
The first thermal paper was originated in the United States of America (USA) in
The 1960's by NCR Corporation and 3M, using dye chemistry and metallic salts
.Appleton Papers were the first manufactured thermal paper in the 1960's. Texas Instruments released the first thermal paper printer named the Silent 700.Other notable companies, including Hewlett-Packard and Nintendo, created their own prototype of thermal paper and corresponding printers over the last several decades . Working of thermal paper print: is like a heat-activated chemical reaction rather than ink deposition. The print depends on the special chemical coating present on the surface of thermal paper. Chemically it contains thermal sensitive layers made up of three key components:

A. Leuco dyes (colorless dyes)

B. Developers (weak acids such as Bis-phenol A or Bis-phenol S)

C. Sensitize (to lower the activation temperature)

Under normal conditions, the leuco dye remains constant no such reactions are shown. When the thermal printer operates, its print head applies the localized heat of (approximately 70– 200 °C) to the specific areas of paper corresponding to text or images. The heat causes the sensitize to react, allowing the leuco dye and developer to come into close contact forming the compound. This triggers an acid–base reaction in which the developer donates a proton to the leuco dye. As a result, the leuco dye undergoes a structural change, converting from its colorless (leuco) form into a colored form, typically black or dark blue. This chemical transformation produces the visible printed image.Once the paper cools, the reaction becomes relatively stable, and the colored form of the dye remains fixed in place due to sudden exposure of specific heat. However, because the image is formed through a reversible chemical process rather than permanent ink, it remains chemically sensitive and it can fade due to several factors of heat, light, temperature and chemicals exposure.The advantages of using thermal papers: it is one of the fast, quick, and easy methods of printing and it is called Direct Thermal Printing. It is highly used in cash receipts, POS (point-of-sale) machines, movie or event

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tickets, labels, restaurant bills, some fax machines, and for bar-code scanning. For example, Retail POS systems often use 80mm wide thermal rolls, while mobile devices may use 57mm rolls.

Thermal paper is widely used in:

1. Sales transaction systems for retail and hospitality sectors.
2. Banking transaction terminals and card-based payment systems.
3. Logistics labeling and shipment monitoring systems.
4. Event admission ticketing systems and parking meter devices.
5. Healthcare labeling and patient identification wristbands.

The Major disadvantages of using thermal receipt are like

A. Limited Print Media: mostly of the print were designed for normal printing with large information but can't do the ideal printing process as photographs, standard documents or full-color graphics, it is restricted to specific actions only.
B. Monochrome Printing: only points black, blue and white, not suitable like brochures or marketing purposes.
C. Thermal Paper fading: These prints on thermal paper can fade over time, when exposed to heat and other factors. It is not an ideal use for long term purposes, which are necessary to day to day life.
D. Limited Customization in Design: this needs specific software and codes to design, for complex designs need more form of complexity of code to make the print feasible.

A major case of research provided that this thermal paper coated with harmful chemicals such as BPA. Even its relative chemical BPS is also found out to be chemically harmful just by holding receipts for 10 seconds. This chemical can enter through our skins it is carcinogenic in nature like breast cancer and prostate related Cancers. Even thermal papers are concerned for the environment issues.

1. These papers are not easily recyclable; most end up in landfills due to components such as BPA and BPS.
2. Eventually these harmful chemicals BPA and BPS, which can contaminate soil and water when receipts are discarded into the environment.
3. Carbon emissions caused by thermal paper, when these papers were burned using fossil fuels and releasing greenhouse gases.
4. Ecosystem harm when improper disposals can affect plants, animals, and water bodies.

At present in the society it is being to adapting a new form of thermal paper where BPA and BPS were not present, which can also make use of the increase of thermal papers in future with help of alternative eco-friendly components of making of thermal papers.

Nowadays, receipts printed on thermal paper are used more often for issuing tickets to

Passenger buses and trains, as well as for the dispensing cash from ATM's and providing receipts from banks. Thermal paper tickets usually include useful information such as the date and time of the transaction, the location, transaction details, and machine IDs. This data can help reconstruct events or confirm actions taken by individuals. For example, receipts from ATM services can verify that a person withdrew cash from that ATM at a specific time for specific uses. Additionally, receipts from public transport, like buses and trains, can show evidence of the trip route, boarding time, and ticket numbers with date. The same goes for receipts from gas stations, which can prove that a vehicle, linked to a suspect, was refueled at a particular time and all the toll receipt linked thorough the person moved through specific point of location point to point. Another type of document that thermal receipt printers can create is receipts from supermarkets of retail purchases which may link to the crime scene of importance. These receipts include information about what someone bought, along with the date and location of the transaction. This information can be crucial since a suspect may purchase tools, products, or equipment needed to commit a crime. Additionally, thermal receipt printers can generate bills for restaurants or food deliveries from various establishments. These bills contain details about a person's location, the time of the order, and the payment amount. They can demonstrate that someone was at a specific place during a specific time had specific

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food for the meals. Lastly, these printers also produce parking tickets and check points at border booth or tourist spots where receipts, which are printed on thermal paper. These documents can indicate when a specific vehicle arrived at or left a particular location. These locations can help investigators to look through the nearby cameras or CCTV footage to link the major for of evidence. In certain cases extraction of the fingerprints from the thermal papers receipts will be helpful to link the suspects directly.

Overall, thermal paper receipt printers can provide valuable information of evidence for forensic investigations by showing when and where certain events occurred or linked to the certain scenarios. The experiments carried out in this study mainly focuses on the recovery of the faded prints from experimentally faded due to exposure to sudden heat. The provide valuable data on the degradation process of thermal paper prints will be helpful foe forensic investigators to assess the methods directly when they are being encountered with such situations . In most cases where there is a need for forensic evidence, the damaged thermal receipts are usually faded and partly destroyed, rendering them unreadable upon inspection. Under such circumstances, it is necessary to apply non-destructive techniques for the analysis, because of such reasons of sensitivity of the thermal paper analysis it becomes crucial to apply non-destructive techniques such as exposing them to ultraviolet light, infrared photography, and oblique illumination to enhance and restore the faded or damaged prints without causing further damage to the document. At present scenarios labs uses advanced technology from the VSC (Video Spectral Comparator). The objective of this current research is to determine the effectiveness of different non-destructive optical methods in extracting readable information from experimentally degraded thermal paper prints and also to observe how different thermal paper reacts to different forms of destruction's. This also helps the forensic investigator or any law enforcement agencies to determine from which form of destruction occurred and from which form of analysis should be done for specific form of destruction.

CHAPTER – 2.REVIEW OF LITERATURE

The literature review will be categorized into various sections. In the first category, we have scientific research that examines the chemical composition and characteristics of thermal paper. The second category will be responsible for the identification of factors causing thermal print degradation. Lastly, the third category will deal with the forensic aspect of thermal print restoration techniques and visualization methods.

The article was published by the technical team at Aiyin Thermal Printer Manufacturer,on the topic **"5 Reasons Why Thermal Print Fades" (2025),** aims to detects the reasons for fading in thermal prints. It seeks to educate the users about various factors affecting print quality based on the environment factors in which the print is exposed. This research focuses on the direct thermal method and the thermal transfer printing method, both commonly used for items like receipts, shipping labels, tickets, and medical ID wristbands. The research design chosen is descriptive. The article specifies sample size could be range from the uses among practitioners because it is a professional piece intended for practitioners. However, it covers all types of thermal print materials and their exposure conditions, such as heat, ultraviolet rays, moisture, humidity, chemical effects, and friction. Data were gathered through qualitative observations, industry examples, and practical experience in the production based and use of thermal printers and media. Key findings indicate that direct thermal prints are especially susceptible to fading because the leuco dye coatings of thermal layer are chemically active and degrade with heat, UV radiation, moisture, chemicals, and abrasion. In contrast, thermal transfer prints are generally more durable, potentially lasting 3 to 10 years or longer, as the ink physically transfers to the media. The study also emphasizes that storage conditions and variations in media quality can influence print life. Recommendations include choosing thermal transfer printing for long-term archiving, minimizing exposure to extreme heat, light, and moisture, using high-quality thermal media and protective lamination's, and understanding application requirements to make informed printing choices. These steps can help reduce fading and ensure thermal prints stay readable for a longer time.

The article was published by Amanda Cox, titled **"How to Store Thermal Paper and Labels"** published in **(2024),** discusses the best ways to store the thermal papers to maintain its quality and durability with different conditions. It aims to identify the environmental and chemical factors that lead to the deterioration of the paper. This study covers various thermal papers and labels commonly used in sectors like retail, logistics, warehousing and both in print and non-print contexts. The methodology focuses on descriptive and explanatory research to share knowledge about proper storage of these papers. The sample size is specified depends on the material of thermal papers being subjected to because it is a general study related to categories of thermal paper and labels susceptible to damage from extreme conditions like heat, moisture, and chemical reactions. The data collected is mostly qualitative. The major findings indicate that exposure to heat above 60 degrees Celsius, ultraviolet light and humidity levels over 60%, and chemicals such as plasticizers, solvents, adhesives, and oils significantly speed up fading, discoloration, smudging, and coating breakdown of thermal paper. Under optimal storage conditions, printed thermal paper typically has a shelf life of 7 to 10 years. In contrast, non printed thermal paper usually lasts 5 to 7 years, particularly when stored improperly. Based on these findings, the author suggests several recommendations in the conclusion. These include following FIFO inventory management, keeping the paper in its original packaging, maintaining a controlled temperature between 15-25℃, ensuring humidity levels of 45-65%, avoiding ultraviolet light and chemicals, using desiccants in high humidity, and utilizing protective packaging. All these practices are crucial for the usability, reliability, and economic efficiency of thermal paper and labels.

In the paper titled **"Stability of the Cash Register Receipt Depending on the Thermal Paper Used,"(2024)** Published by Plazonić et.al. Aimed to evaluate how the different type of thermal paper, either white or blue, affects the stability of cash register receipts. This topic has become important for record-keeping, warranties, and documentary value. The study focused on thermal papers commonly used in supermarkets in Zagreb, Croatia. The research followed an experimental approach. The study tested two different types of thermal paper: white and blue. Researchers analyzed the physical properties of 10 samples of each color that is of blue and white respectively. During data collection, they took precise measurements in a lab according to standardized procedures set by International Organization Standardization/ British Standards. They evaluated properties like thickness, smoothness, brightness, and color properties using colorimetric instruments based on the CIE (International Commission on Illumination) Lab scale. They also used spectrophotometric evaluation with the Delta E 2000(CIEDE2000): ΔE^*00 calculations after exposing the samples to water, sunlight, and rubbing the thermal papers. The main findings highlighted some important insights, such as the blue thermal paper showed better chemical and sunlight stability than the white thermal paper. In addition, blue thermal paper maintained better legibility when exposed to both water and sunlight compared to white thermal paper receipts. However, white thermal paper demonstrated slightly better rubbing stability. Overall, blue thermal paper proved to have advantages in printing stability. The authors suggest using blue thermal paper instead of white for thermal printings.

In the article**, "Characterization and Comparison of Thermal Papers of Various Sources Using X-Ray Diffraction Technique: A Forensic Aspect,"** in the year **(2024)** published in the International Journal for Multidisciplinary Research (IJFMR) by Ridamjeet Kaur et.al. Explored how to identify and differentiate thermal papers from different sources using a non- destructive X-ray diffraction technique for forensic documentation and paper analysis. The study focused on various thermal papers found in forensic contexts, including bus tickets, ATM slip, and receipts. These were collected from several sectors, such as the Chandigarh Transport Union, Haryana Roadways, different banks, and shops, totaling 10 thermal papers from various sources. The researchers used a qualitative design based on experimental and comparative methods. They collected data by systematically examining the samples and conducting XRD tests in a controlled laboratory using a MiniFlex 300/600 diffractometer. One of the key findings was that thermal papers from the same source exhibited similar XRD patterns, which suggested standardization, while papers from different sources had distinct XRD patterns. The conclusions indicated that XRD has strong potential for differentiating the sources of thermal papers. This could lead to further research on how Different storage conditions such as light, heat, and humidity affect the degradation of thermal papers.

The authors Frankowski et.al published their article **"The Presence of Bis-phenol A in Thermal Paper in the Face of Changing European Regulations - A Comparative Global Research"** in Environmental Pollution in the year (2020). They conducted a study to examine the presence of Bis-phenol A and its alternatives in thermal paper receipts worldwide. This research considered new European Union rules that limit the use of BPA. The study included thermal paper receipts collected from commercial outlets like supermarkets, restaurants, shops, and petrol stations in 39 countries across six continents. The research was descriptive and analytical with a cross-sectional design, involving a sample of 220 thermal paper samples. The researchers gathered specific data through systematic sampling of both printed and non-printed receipts. They performed further laboratory tests using an optimized water-based extraction technique. The main findings showed that BPA was the most commonly used color developer globally, making up 69% of the sampled materials. Bis-phenol S, known as BPS, accounted for 20% of the samples, especially in Japan and the USA. Other Bis-phenol alternatives were found in very small amounts. Additionally, thermal printing did not affect the levels of Bis-phenol in any samples. The study concluded that even though BPA is being phased out in Europe due to regulations, leading to an increased use of BPS, this is concerning because neither BPA nor BPS is biodegradable.

The author, Praveen Kumar Yadav, reviewed the problems and solutions related to developing latent fingerprints on thermal papers in his article **"Development of fingerprints on thermal papers: A review,"** published in the Egyptian Journal of Forensic Sciences in 2019. Thermal papers are increasingly common in forensic science due to their use in receipts, tickets, and ATM slips. The researcher examined a variety of thermal papers and created a research design based on descriptive research. He used published results from earlier experiments conducted by various researchers. Instead, it incorporated multiple published papers that addressed different types of thermal papers and latent fingerprints. Data collection relied on extensive secondary sources such as peer-reviewed

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forensic science journals and experimental studies on fingerprint visualization methods. The major findings showed that traditional techniques for developing latent fingerprints do not work on thermal paper because heat can darken the thermal sensitive layer. However, methods like controlled heat, steam treatment, iodine fuming, UV, and NIR visualization, as well as removing the thermal layer with a solvent and using chemical reagents with ninhydrin and PVP, DFO/PVP mixtures, and DMAC, proved to have varying levels of success depending on the age of the fingerprint and type of paper used. The review concluded that while developing fingerprints on thermal paper is challenging, reliable visualization can be achieved by carefully choosing between non-destructive approaches and modified techniques. Future standardized experiments are needed to establish a widely accepted protocol for fingerprint development on thermal papers in forensic practices.

Kapil Kumar et.al. wrote a paper titled **“A New Non-Destructive Method for Retrieval of Completely Removed Printed Text on Thermal Papers.”** It was published in the International Journal of Research and Scientific Innovation in 2016. The goal of the paper was to propose a chemical- free, non-destructive forensic technique for retrieving information from completely faded thermally printed text on ATM receipts, POS slips, fax copies and card payment receipts, this made up the entire focus of their study. The study used an experimental research design with a sample of 50 naturally faded thermal papers collected from various locations. This sample was not divided further. Data collection involved using a Video Spectral Comparator VSC-6000/HS under different lighting conditions, including visible, transmitted, spot, side, and ultraviolet light. The researchers then applied systematic digital image enhancement techniques such as image inversion, grayscale adjustment, gamma correction, and noise reduction. The main findings showed that using ultraviolet light at a medium wavelength of 312 nm, along with image enhancement tools, successfully retrieved completely removed text from all samples, including receipts up to eight years old. However, using visible light for examination yielded negative results. The results of the study indicated that the proposed method maintains integrity, avoids chemical damage, and produces permanent readable images. This could be very helpful in forensic investigations, especially in cases of financial fraud, document examination, and timeline reconstruction. It should also be included in the work of forensic document examination laboratories, particularly when examining faded thermal paper.

The white paper, **"Selection, Usage and Archiving Guide to Thermal Paper,"** published by Brother International Australia in 2012, examines that makeup, performance, use, durability, and archiving potential of transaction and legal documents that use thermal paper products. The primary goal of the study was to help people evaluate different thermal papers by looking at how various types respond to external factors like heat, ultraviolet rays, moisture, friction, and plasticizers. The study included all high-quality thermal paper products available on the market that are used for transaction documentation across various industries, including public safety, insurance, field services, and accounting. It borrowed its design from an experimental method of data collection. The study used several samples of thermal paper products, labeled as Samples A to U, which included standard, premium, top-coated, and non-top-coated papers. Some samples varied in size for different tests, such as temperature sensitivity, ultraviolet sensitivity, dashboard exposure, and plasticizer contact tests. Data were collected through controlled laboratory testing that involved high-temperature exposure between 74°C and 91°C, ultraviolet light exposure using Class B UV lamps, long-term dashboard simulation, and plasticizer contact tests. Visual and legibility assessments were also conducted over time. The major findings showed that premium and top-coated thermal papers offer better resistance to heat, UV radiation, moisture, abrasion, and chemical degradation. The image legibility lasted up to 20 to 25 years under proper storage conditions. The study highlighted that poor printer density settings and improper document storage significantly speed up image fading and discoloration. It recommended high-density printing and using top-coated or synthetic thermal media for documents needing long-term preservation. Additionally, it advised avoiding plasticizers and chemical exposure while storing documents in cool, dark, and dry places to ensure maximum archival life and reliability of thermal paper records.

The research article by Yuan-Shing Perng, L.-C. Wang, and Y.-M.Chen, titled **“Effects of Thermal-Paper Coating Formulations on Image Durability”** (2012), aimed to explore how different formulations in thermal paper coatings affect the durability of images in tough conditions like light, heat, and humidity. The main goal of the study was to find the best materials and particle sizes for the mixture of leuco dyes and developers to help preserve the lifespan of thermal images. The research included both commercially used and lab-prepared thermal papers related to recording and printing materials. The experimental design was comparative and took place in a lab setting. The sample included seven commercial thermal papers and the base papers made in the lab. Different coatings like hollow plastic pigments, calcined clay, and combinations of both were used, along with leuco dyes and developers of various particle sizes. Data collection involved controlled tests in a lab environment. They conducted surface durability tests and optical and image durability tests through a series of standardized tests and exposure to conditions like ultraviolet light, dry conditions at 60 degrees Celsius for 14 days, high heat for 14 days at the same temperature, and high humidity at 40 degrees Celsius with 90% saturation. The key findings showed that domestically produced thermal papers performed better than commercial ones.

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They displayed higher tensile strength and lower fading rates. Additionally, products treated with hollow plastic pigments showed improved light-fastness, heat resistance, and humidity resistance. The optimal particle sizes were 0.5 to 1.0 µm for dye-doped leuco dyes, 1.0 to 1.5 µm for Sensitizers to boost light-fastness, and sizes smaller than 0.5 µm for achieving the best results for heat. The study concluded by recommending optimizations in pigment-based coating formulations and adjustments in dye and sensitizer particle sizes to improve durability and reduce fading rates of thermal images, thereby enhancing the quality and performance of thermal papers.

This research is summarized from the thesis titled **“Chemical Processing of Fingerprints on Thermal Paper”** by Megan Elizabeth Dutton, 2011. The research aimed to evaluate muriatic acid and acetic acid fuming for developing latent fingerprints on the thermal side of thermal paper. It also assessed ninhydrin for developing fingerprints on the non-thermal side after fuming. The study focused on thermal paper receipts commonly found in forensic investigations. Fingerprints were collected from 24 randomly chosen individuals who provided 30 sets of fingerprints over 10 days. Prints ranged in age up to 40 days, with each set containing impressions on both thermal and non-thermal surfaces.The sample included several thousand individual fingerprint impressions produced using a depletion series method to simulate diminishing residue. Data collection involved carefully depositing fingerprints followed by chemical processing with muriatic acid fuming, acetic acid fuming, and ninhydrin. Quality scoring followed this using a standardized scale. The main results showed that fingerprint quality declined significantly after about 35 days. Muriatic acid performed better on fresh and first-generation fingerprints, while acetic acid was more effective on older and depleted prints. The non-thermal side showed better results when using ninhydrin. This study suggested using acid fuming techniques, particularly acetic acid for old thermal paper evidence. It also highlighted the need for prompt processing of receipts in forensic cases and encouraged further research to find ways to extend the usable age of fingerprints on thermal paper.

While many studies have explored the makeup and general degradation of thermal paper, few have looked at ways in which it is possible to systematically recover information about degraded thermal prints caused by naturally but, this study focuses on how different forms of heat and chemical means can affect the thermal papers of different kinds (printed from 5 different machines) , using non-destructive optical examination methods. Previous studies, on the other hand, mainly concentrate on discussing health issues associated with environmental factors, including heat, light, and humidity, on thermal print fading, but few conduct experiments that can demonstrate how the various types of damage to thermal prints may affect the visibility and recovery of information. There has been a lack of experimental research comparing the effect of the various kinds of optical examination techniques including UV illumination, infrared imaging, and oblique lighting and their effects in the recovery of thermal prints with relation to different destruction methods. Consequently, more research is necessary to experimentally determine how non-destructive optical examination methods may help forensic examiners recover information from damaged thermal receipts.

CHAPTER – 3.METHODOLOGY

The methodology involves the experimental and qualitative research approach the sampling strategy, data collection, and the use of optical methods in retrieving the images printed on degraded thermal papers. In this experiment, most of the efforts will be devoted to the determination of the efficacy of non-invasive optical examination in restoring images that have been lost or faded from the thermal paper receipts from degraded through experimentally and also look through how different forms of heat and chemicals affects the thermal papers. In order to accomplish this, samples of thermal paper will first be subjected to degradation of the information through heat, dry heat, vapors heat and chemical exposure and later under different instrumentation's the recovery of the prints will be detected.

Need for the study:

Thermal receipt papers are commonly utilized in sales transactions, banking operations, transport services, and ATM terminals. The common usage of thermal receipts makes them a prevalent source of documentation in forensic examinations. Nevertheless, thermal receipts are very sensitive to external factors such as heat, light, humidity, friction, and solvents. As a result, the printed information is prone to fading and disappearing. Important data like transaction information, dates, and identification numbers might be unreadable due to deterioration due to different factors. Ordinary methods of examination would not make the faded prints visible. Hence, the need for non- destructive optical examination techniques becomes essential for recovering hidden or degraded information without causing further damage to the document.

This study is necessary to:

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- Evaluate the efficiency of various non-invasive optical methods used for retrieving lost thermal prints.
- Scientific information that can help forensic document examiners retrieves information from degraded receipts.

Aim of the study:

To investigate the efficiency of non-destructive optical techniques for retrieving information from deteriorated thermal paper prints and find out which optical technique is more suitable for visualizing faded or damaged information.

Objectives:

- To observe how different destructive methods affect the thermal paper.
- To evaluate the efficacy of non-destructive optical inspection approaches in retrieving prints on thermal papers that have deteriorated or faded.
- To analyze the clarity and readability of recovered thermal paper prints under various optical lighting systems.

Statement of Research Queries:

- Is it possible to restore degraded thermal paper images using optical inspection methods without destroying them?
- What optical method works best in restoring degraded thermal images?
- Are there differences in the results of print recovery for various optical examination methods?
- Will these methods help forensic specialists recover information from degraded thermal receipts?

Research design:

This experiment is based on the experimental research design and descriptive research design, used to examine the restoration of faded thermal receipt prints using optical testing methods. The thermal receipts used in this research will be obtained by selected known printed machine thermal paper and readable before undergoing any form of alteration. The information present on the paper will not be disclosed to anyone it will be kept as confidential. Obtaining the thermal receipts in a fresh condition aids the researcher document their quality before undertaking the test. The thermal receipts collected will be grouped into four different experimental groups and subjected to controlled degradation using thermal and chemical processes. These forms of degradation are likely to affect the thermal receipts in practical settings.

Universe, sample size and techniques:

The universe of this study shall be the thermal receipt paper used for transactions such as shopping from stores across Mangluru city, fueling up at gas stations, withdrawing money from ATM's, among others.
There will be a total of 40 thermal receipts that will be collected in this research study in which 8 samples each of 5 different machines which includes receipt’s from.

Sl.no	Company name of the machine	Number of samples	Collected from
1	SBI ATM(Automated teller machine)	8	SBI Dustbin
2	Epson m352a2	8	Meat retailers
3	Prathi nidi	8	BUS ticket
4	Ezo	8	Hotel
5	Gobbler, HOP E 801(USB+LAN)	8	Medicals

They will all be divided into the various experimental treatments in order to investigate the effect of the different degradation techniques. From the total samples, 10 thermal receipts will be degraded through thermal high heat degradation(200℃), while 10

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receipts will be subjected to degraded under low heat(100°C), 10 samples will be degraded through vaporizing heat and another 10 receipts will be chemically degraded using (stabilized hydro alcoholic fragrance formulation).In this research, the sampling process will utilize the purposeful using non probability convenience sampling technique in order to collect the fresh thermal receipts from transactions carried out by customers within commercial establishments. Using this technique, will purposefully sample the receipts based on their suitability to participate in the experiment. The thermal receipts will be sourced from retail stores, super markets, fuel stations, ATM's and other transaction points where thermal receipts are common. Receipts will be selected to ensure they contain clear printed information suitable for experimental degradation and optical examination.

Inclusion criteria.

- Thermal receipts that are printed with printed information visible.
- Thermal receipts that have been obtained from buses, retail shops, grocery stores, hotels, medical stores and ATM machines.
- Thermal receipts that can be degraded experimentally.

Exclusion criteria.

- Thermal receipts that have been previously degraded before being used for the experiment.
- Thermal receipts that cannot be studied using optical devices.
- Torn thermal paper or damaged thermal paper.

Tools of data collection and procedure:

For the examination of degraded thermal paper prints requires the use of several tools and instruments without causing damage to the papers. A UV light source is used to examine the fluorescence and contrast difference in the degraded prints and to retrieve information from degraded prints. An IR imaging system is used to see invisible printed details due to their faint nature. An oblique lighting system is applied to make surface features clear and to differentiate between any altered areas of printing on the papers. Visible light sources are also be used for normal examination purposes. Moreover, a digital camera was being required to take pictures of the samples under different light sources. Mainly for handling and storing of the thermal papers gloves and zip-lock bags were being used. A magnifying glass or microscope will help in examining the details of the prints. Mainly to degrade the thermal paper which is easily available to reach are used such as to heat iron box, other heating sources for latent heat of vaporization and body spray which conation (stabilized hydro alcoholic fragrance formulation). Observation tables were used to record experimental observations and visual changes.

The thermal receipts would be collected right away from the places where they have been issued including retail stores, supermarkets, gas stations, and ATM's. Every receipt were assigned an ID number for proper documentation based on convenience .Only those receipts that have readable information on them were be chosen so that the experiment could be carried out consistently. Those receipts that are faded or torn will not be included in the experiment.

The thermal receipts were obtained soon after printing from commercial vendors to keep them fresh and have a high-quality first print appearance. The receipts were be assigned numbers in order to document their state and track them properly during experiments. The initial condition of the printout was noted through the observation and photography of the thermal receipt. The thermal receipts were split into four sets, which will correspond to physical and chemical methods of degradation as of 1st set with high heat applied through iron-box and 2nd set with low heat applications same as of iron box and 3rd sets of thermal papers will undergoes with latent heat of vaporization and final set will be gone through sprayed from perfume bottle which contains (ethyl alcohol 95%, purified water, propylene glycol, tertiary butyl alcohol and butylated hydroxyl toluene) then this printed information on thermal receipts were be degraded. The observations were noted, how different thermal papers were reacting to the different form of destruction. Under these conditions, the thermal receipts will be exposed to UV illumination, infrared imaging, oblique lighting, and visible light examination. The observations concerning print clarity and contrast were carefully recorded. Additionally, the pictures of each sample in different optical states were being taken.

Data presentation and analysis:

The results acquired from the examination of degraded thermal paper receipts are processed and reported based on systematic visual observation and documentation of the print visibility by various optical examination methods. An identification number were allotted for each sample, and the results pertaining to the print visibility will be documented post exposure of the samples to varied forms of degradation, which include different thermal and chemical degradation. The print visibility will be graded based on four

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scales, which are: Clear, Partially Visible, Faint, and not-visible. The degraded samples were observed and scaled from no destruction, very slightly destruction, mild destruction, moderate destruction, severe destruction and complete destruction of the information which are present while printing. Then the samples were subjected to ultraviolet illumination, infrared imaging, oblique lighting, and visual light examination. The data collected from observations were be presented using a Table to present information on the kind of damage observed, the optical technique applied and the level of visibility of the degraded prints. Tabular data will be presented to show the frequency at which certain visibility levels have been observed based on the best optical technique. Photography of the receipts when exposed to varied lighting conditions will be used as a tool to visually represent the enhanced print visibility. Through these processes, we can establish which optical examination method enhances the visualization of thermal prints and which technique is best suited for detecting certain kinds of damage to thermal prints.

Report design:

The structure of this study will involve five chapters in order to present information in an organized manner. Chapter I includes information on thermal paper. Chapter II includes literature review that covers prior research carried out on the issue .Chapter III gives an explanation of the methodology employed in this research, which includes details on the experimental design, sampling procedure, instruments used in optical examination, and procedures involved in studying the effects of thermal, mechanical, and chemical damage on thermal receipts. Data analysis is done in Chapter IV by presenting observed results in tabular form, graphical representation, and photographs.

Chapter I: Introduction

This chapter offers a brief introduction to thermal paper. It discusses the composition, functioning, and applications of thermal paper. The applications include its use for commercial purposes such as receipts in retail shops, filling stations, and automatic teller machines (ATM's). This chapter will also discuss the importance of thermal receipts in forensics. It will discuss the problem statement, objective of the study, scope of the study, and significance of the study in forensics.

Chapter II: Review of the Literature

The current chapter provides a literature review of the scientific papers published in the area of investigation of thermal paper and its examination. Specifically, the earlier research concerning the deterioration of thermal prints, the influence of environmental factors, including mechanical wear and chemical exposure, as well as different approaches to recovery of faded thermal prints is analyzed. In addition, the studies focused on forensic examination of thermal receipts and documents are considered.

Chapter III: Methodology

This chapter focuses on describing the research methodology employed in carrying out the research, starting from the experimental research design that was employed in the study of the degraded thermal paper receipts. It discusses the population of the study, sample size, as well as the purposive sampling approach applied during the collection of the thermal receipts. In addition, the chapter outlines the tools and equipment applied in the optical examination of the receipts including the use of UV, infrared, oblique, and visible lighting examinations.

Chapter IV: Data analysis

This chapter deals with the analysis of the data gathered as well as the observation made during the optical examination of the thermal receipts in their deteriorated forms. The readability of the prints will be evaluated based on their visibility as judged by a graded scale that includes clear prints, partially visible, faint, and invisible prints. The chapter will also compare the efficiency of various optical examinations used for the restoration of degraded prints.

Chapter V: Findings, Suggestions and Conclusion

This chapter is a brief account of the major conclusions derived from the study by analyzing the results obtained from experiments. This chapter will elaborate on the impact of various forms of degradation (thermal, mechanical, and chemical) on the legibility of printed images on thermal papers and how optical non-destructive methods may be useful in restoring the damaged records. Furthermore, some practical recommendations will be provided to forensic investigators concerning the handling and examination of thermal receipts during criminal cases.

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LIMITATIONS

Some of the limitations identified by the researcher during and after the course of the study are presented below.

- The study was limited by fewer samples which obtained from limited number of registers of the thermal papers.
- The exact number of thermal paper types, machines which are printed and chemical composition is unknown with collective data. thermal paper available in the markets varies
- Degradation process heat moisture and chemical exposure were performed under controlled laboratory conditions, the real environmental stressors are time consuming in nature.

CHAPTER IV - DATA ANALYSIS AND INTERPRETATION

Data analysis is a process of systematically collecting, organizing, examining and analyzing of data. It helps to understand the data which is being collected in simplest manner. This stage involves presenting the observations and analysis it in systematic manner.

Data interpretation is the stage which follows the major findings and differences of the data analysis which assist to detect the theoretical and real world situations. It will enable the researcher to draw major findings and conclusions.

The data collected evaluate the effects of heat-induced degradation and changes in thermal paper and also to find the efficiency of non-destructive optical techniques in recovering the information. It mainly focuses on descriptive statistical approach of observed data.

4.1 Analysis of the effects of different degradation methods on thermal papers.

The samples collected form the different machine printed thermal papers are SBI, ATM (Automated teller machine), Epson m352a2, Prathi nidi, Ezo and Gobbler HOP E 801(USB+LAN). The destructive methods used are such as high heat (200°C), low heat (100°C), latent heat of vaporization (>100°C) and chemical exposures (stabilized hydro alcoholic fragrance formulation) to degraded the thermal paper. The destruction scale no destruction, very slightly destruction, mild destruction, moderate destruction, severe destruction and complete destruction. Based how thermal paper reacted to different destructive methods, scales are being provide as such as give in below table.

Table no 4.1.01: Effects of different degradation methods on different thermal papers.

Degradation methods	**SBI ATM**	**Epson**	**Prathi nidi**	**Ezo**	**Gobbler**
High heat(200°C)	Complete destruction (100%)	Complete destruction (100%)	Mild destruction (35%)	Complete destruction (100%)	Complete destruction (100%)
Low heat(100°C)	Severe destruction (75%)	Severe destruction (75%)	Very slight destruction (15%)	Complete destruction (100%)	Moderate destruction (55%)
Latent heat of vaporization	Moderate destruction (55%)	Moderate destruction (55%)	Very slight destruction (15%)	Complete destruction (100%)	Severe destruction (75%)
Chemically sprayed	Complete destruction (100%)	Complete destruction (100%)	Complete destruction (100%)	Complete destruction (100%)	Complete destruction (100%)

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The data shown in the table 4.1.01 indicates that how different types of thermal papers as of SBI, ATM(Automated teller machine), Epson m352a2,Prathi nidi, Ezo and Gobbler HOP E 801(USB+LAN) are get affected by different degradation methods such as high heat (200℃), low heat (100℃), latent heat of vaporization (>100℃) and chemically sprayed (Stabilized hydro alcoholic fragrance formulation).

The higher heat exposure (200℃) results in complete destruction (100%) of thermal papers printings, including SBI ATM, Epson, Ezo and Gobbler machine printed papers information. However, Prathi Nidi exhibits mild degradation (35%), indicating that higher resistance to extreme thermal conditions. This suggests that thermal paper coating composition of Prathi Nidi is more stable under direct high heat and retail information stronger when compared to other thermal papers. Under low heat (100℃), Ezo printed thermal paper shows complete destruction (100%) following SBI ATM and Epson thermal papers each showed severe destruction (75%), Gobbler thermal shows moderate destruction (55%) and Prathi Nidi shows very slight destruction (15%) under low heat Prathi Nidi and Gobbler shows more stability in retaining information than compared to Ezo, SBI ATM and Epson thermal papers. The thermal papers are induced to latent heat of vaporization, Ezo shows complete destruction (100%) following that Gobbler thermal papers displays severe destruction (75%), SBI ATM and Epson thermal papers each showed Moderate destruction (55%) and Prathi nidi shows very slight destruction (15%). The results indicates that Prathi nidi, SBI ATM and Epson show more stability in retaining information than compared to Gobbler and Ezo thermal papers. The thermal papers exposed to chemically sprayed with stabilized hydro alcoholic fragrance formulation, resulted in complete degradation (100%) of information across all paper types Prathi Nidi, SBI ATM, Epson, Ezo and Gobbler indicating that stabilized hydro alcoholic fragrance formulation is the most effective in causing irreversible damage to thermal paper when compared to high heat, low heat and latent heat of vaporization of the destruction methods.

SBI ATM and Epson thermal papers both exhibits complete destruction (100%) towards high heat and chemical sprayed, following that (75%) severe destruction for low heat and (55%) modern destruction to latent heat of vaporization, both the papers shows similar characteristics respectively. Prathi nidi shows complete destruction (100%) for chemical sprayed, following mild destruction (35%) for high heat and very slight destruction (15%) for low heat and latent heat of vaporization respectively. Ezo shows complete destruction (100%) for all destruction methods high heat, low heat, latent heat of vaporization and chemically sprayed. Gobbler thermal paper shows complete destruction (100%) for high heat and chemically sprayed respectively, following that severe destruction (75%) for latent heat of vaporization and moderate destruction (55%) for low heat destruction methods.

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Figure 1 : SBI ATM thermal paper under heat 200℃

Figure 2 : SBI ATM thermal paper under High Low heat 100℃

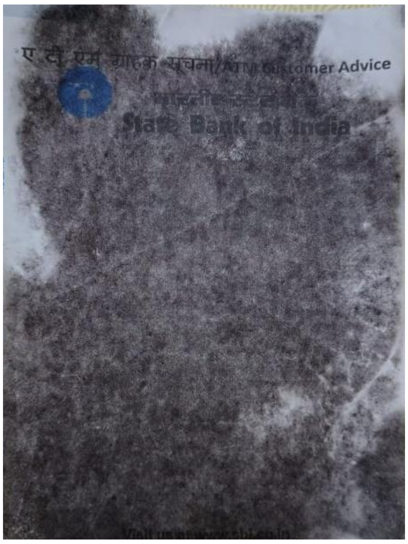

Figure 3 :latent heat of vaporization (>100℃)

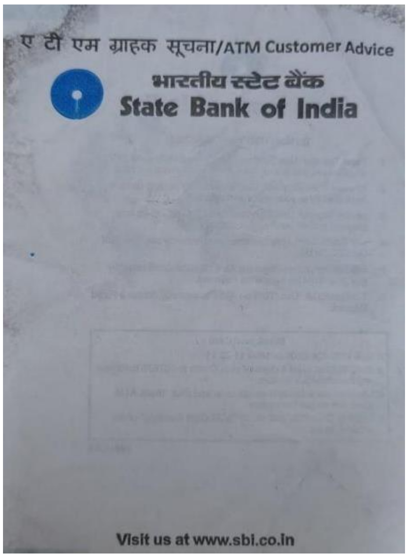

Figure 4 :chemically sprayed (stabilized Hydro alcoholic fragrance formulation)

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4.2. Analysis of different thermal papers under non-destructive optical examination techniques.

The samples collected form the different machine printed thermal papers are SBI, ATM (Automated teller machine), Epson m352a2, Prathi nidi, Ezo and Gobbler HOP E 801(USB+LAN). The destructive methods used are such as high heat (200°C), low heat (100°C), latent heat of vaporization (>100°C) and chemical exposures (stabilized hydro alcoholic fragrance formulation) to degraded the thermal paper. The visibility scale used is of clear visibility, partially visible, faint visibility and not visible information under different destruction methods. Based how thermal paper reacted to different destructive methods, scales are being provide as such as give in below table.

Table no 4.2.01: Analysis of different degradation methods with non-destructive optical examination techniques on SBI ATM thermal papers.

SBI ATM Thermal paper	Type of destruction	UV A	UV B	UV C	IR	Oblique lighting	Visual examination
S1	High heat (200°C)	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
S2	High heat (200°C)	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
S3	Low heat (100°C)	Faint visibility	Faint visibility	Faint visibility	Faint visibility	Faint visibility	Faint visibility
S4	Low heat (100°C)	Faint visibility	Faint visibility	Faint visibility	Faint visibility	Faint visibility	Faint visibility
S5	Latent heat of vaporization (>100°C)	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
S6	Latent heat of vaporization (>100°C)	Not visible	Faint visibility	Faint visibility	Not visible	Not visible	Faint visibility
S7	Chemically sprayed	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
S8	Chemically sprayed	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible

The data shown in the table 4.2.01 indicates that SBI ATM thermal papers are subjected to different destruction methods for 2 samples each subjected into high heat (200°C), low heat (100°C), latent heat of vaporization (>100°C) and chemically sprayed (stabilized hydro alcoholic fragrance formulation) respectively of total collectively 8 samples.

The sample S1 and S2 are subjected to high heat (200°C) resulting in no visibility under any optical examination techniques such as UV (A,B,C) ,infrared, oblique lighting or even direct visual examination. This indicates that exposure to extreme heat causes irreversible alteration of the thermo sensitivity layer leading to total information loss.

Samples S3 and S4 exposed to low heat (100°C) demonstrated faint visibility and shows partial recovery under all optical examination methods including visual examination; this suggests that although degradation occurs at (100°C) temperature sufficient contrast remains between the printed regions and the background to allow limited retrieval of information.

In the samples S5 and S6 exposed to latent heat of vaporization (>100°C) in that S5 shows no visibility in either UV (A,B,C) ,infrared, oblique lighting or even direct visual examination but, in S6 show faint visibility under UV B, UV C and visual examination, following not visible under UV A, infrared and oblique lighting. The different in the results from the same printed

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thermal paper shows that distribution of the thermal layers among S5 and S6 are different in nature.

The sample S7 and S8 were subjected to chemically sprayed stabilized hydro alcoholic fragrance formulation shows under different optical techniques shows the results not visible in either UV (A,B,C) ,infrared, oblique lighting and visual examination. Indicating that the destruction effect of chemical is deeper into the thermal layers and causing total loss of retrievable information.

The optical examination UV A shows no visibility for SBI ATM thermal paper for high heat (200°C), latent heat of vaporization (>100°C) and chemically sprayed of samples S1,S2, S5, S6.S7 and S8 respectively but shows faint visibility for low heat (100°C) for the sample S3 and S4 indicating that UV A is very less effective in retrieving the information from the SBI thermal paper across different destruction methods.

The UVB and UVC both the examination shows faint visibility to low heat(100°C) and latent heat of vaporization (>100°C) for samples S3,S4 and S6. No visibility to high heat (100°C), latent heat of vaporization and chemical display of samples S1,S2,S5,S7 and S8 respectively indicating that UVB and UVC is less effective in retrieving the information from the SBI thermal paper across different destruction methods.

The IR examination of the SBI thermal papers shows faint visibility to low heat (100°C) for the samples S3 and S4. For high heat (200°C), latent heat of vaporization(>100°C) and chemical sprayed, the visibility is not present for samples S1,S2,S5,S6,S7 and S8 respectively indicating that IR examination is not effective in retrieval of information from SBI ATM thermal papers.

The oblique lighting shows no visibility for SBI ATM thermal paper at high heat (200°C) ,latent heat of vaporization (>100°C) and chemically sprayed of samples S1,S2, S5, S6.S7 and S8 respectively but shows faint visibility for low heat (100°C) for the sample S3 and S4 indicating that oblique lighting is very less effective in retrieving the information from the SBI thermal paper across different destruction methods.

The visual examination shows faint visibility to low heat (100°C) and latent heat of vaporization (>100°C) for samples S3, S4 and S6. No visibility to high heat (100°C), latent heat of vaporization and chemical display of samples S1,S2,S5,S7 and S8 respectively

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Indicating that visual examination is less effective in retrieving the information from the SBI thermal paper across different destruction methods.

Table no 4.2.02: Analysis of different degradation methods with non-destructive optical examination techniques on Epson thermal papers.

The data shown in the table 4.2.02 indicates that Epson thermal papers are subjected to different destruction methods for 2 samples each subjected into high heat (200°C), low heat (100°C), latent heat of vaporization (>100°C) and chemically sprayed (stabilized hydro alcoholic fragrance formulation) respectively of total collectively 8 samples.

Epson Thermal paper	**Type of destruction**	**UV A**	**UV B**	**UV C**	**IR**	**Oblique lighting**	**Visual examination**
E1	High heat (200°C)	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
E2	High heat (200°C)	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
E3	Low heat (100°C)	Not visible	Partially visible	Partially visible	Not visible	Faint visibility	Partially visible
E4	Low heat (100°C)	Not visible	Partially visible	Partially visible	Not visible	Faint visibility	Partially visible
E5	Latent heat of vaporization (>100°C)	Not visible	Faint visibility	Faint visibility	Not visible	Faint visibility	Faint visibility
E6	Latent heat of vaporization (>100°C)	Not visible	Faint visibility	Faint visibility	Not visible	Faint visibility	Faint visibility
E7	Chemically sprayed	Not visible	Not visible	Not visible	Not visible	Faint visibility	Faint visibility
E8	Chemically sprayed	Faint visibility	Faint visibility	Faint visibility	Not visible	Faint visibility	Partially visible

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The sample E1 and E2 are subjected to high heat (200°C) resulted into no visibility under any optical examination techniques such as UV (A,B,C) ,infrared, oblique lighting or even direct visual examination. This indicates that exposure to extreme heat causes irreversible alteration of the thermo sensitivity layer leading to total information loss.

The samples E3 and E4 are subjected to low heat (100°C) under UV B, UV C and visual examination shows partial visibility of the thermal paper prints, then faint visibility is seen in oblique lighting technique and no visibility is observed under UV A and IR spectroscopy examination. Indicating that under low heat (100°C) the recovery of the information is moderately possible from Epson thermal papers.

The samples E5 and E6 are subjected to latent heat of vaporization (>100°C) under UV B, UV C, oblique lighting and visual examination shows faint visibility. No visibility is seen under UV A and IR spectroscopy. Indicating that samples under latent heat of vaporization (>100°C) extraction of information is possible through all the optical techniques UV B, UV C, oblique lighting and visual examination except UV A and IR spectroscopy technique in Epson thermal paper .

In the samples E7 and E8 exposed to chemically spray stabilized hydro alcoholic fragrance formulation in that E7 shows faint visibility to oblique lighting and visual examination. Under UV (A, B, C) and IR spectroscopy no such visibility are found. The results show that (chemically sprayed stabilized hydro alcoholic fragrance formulation) is more effective in destruction of information of Epson thermal paper.

The optical examination UV A shows no visibility for samples (E1 to E7) of Epson thermal paper under all the destructive techniques, except chemically treated sample number E8. it shows that UV A is very less effective in restoration of information of Epson thermal paper under different thermal degradation conditions.

The UVB and UVC both the examination shows faint visibility to latent heat of vaporization (>100°C) and chemically sprayed stabilized hydro alcoholic fragrance formulation of samples E5,E6 and E8 respectively, then shows partial visibility to (100°C) low heated samples E3 and E4 . But, no visibility for high heat (200°C) and chemically sprayed ones E1, E2 and E7 respectively. Indicating that chemically sprayed stabilized hydro alcoholic fragrance formulation can be varied based on thermal paper nature and is less effective in recovery of information from Epson thermal paper.

The IR spectroscopy shows no visibility for all the samples (E1 to E8) of Epson thermal paper under all the destructive techniques high heat (200°C), low heat (100°C), latent heat of vaporization (>100°C) and chemically sprayed (stabilized hydro alcoholic fragrance formulation) . It shows that IR examination is not at all effective in restoration of information of Epson thermal paper under different thermal degradation conditions.

The oblique lighting examination shows faint visibility to the samples from E3 to E8 of Degradation methods low heat (100°C), latent heat of vaporization (>100°C) and chemically Sprayed (stabilized hydro alcoholic fragrance formulation) respectively. Under high heat (200°C) shows no visibility of samples E1 and E2.Indicating that oblique lighting is more effective in restoration of Epson thermal paper when compared to rest of the optical examination techniques.

The visual examination techniques shows partial visibility for low heat (100°C) and chemically sprayed (stabilized hydro alcoholic fragrance formulation) of samples E3, E4 and E8 respectively. For latent heat of vaporization (>100°C) and chemically sprayed (stabilized hydro alcoholic fragrance formulation) shows faint visibility of samples E5, E6 and E7 respectively. Under high heat (200°C) shows no visibility of samples E1 and E2.Indicating that visual examination is more effective in restoration of Epson thermal papers.

Table no 4.2.03: Analysis of different degradation methods with non-destructive optical examination techniques on Prathi Nidi thermal papers.

The data shown in the table 4.2.03 indicates that Prathi Nidi thermal papers are subjected to different destruction methods for 2 samples each subjected into high heat (200°C), low heat (100°C), latent heat of vaporization (>100°C) and chemically sprayed (stabilized hydro alcoholic fragrance formulation) respectively of total collectively 8 samples.

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Prathi nidi Thermal paper	Type of destruction	UV A	UV B	UV C	IR	Oblique lighting	Visual examination
P1	High heat (200°C)	Faint visibility	Partially visible	Partially visible	Faint visibility	Partially visible	Partially visible
P2	High heat (200°C)	Faint visibility	Partially visible	Partially visible	Faint visibility	Partially visible	Partially visible
P3	Low heat (100°C)	Partially visible	Partially visible	Partially visible	Faint visibility	Partially visible	Partially visible
P4	Low heat (100°C)	Partially visible	Faint visibility	Partially visible	Faint visibility	Partially visible	Partially visible
P5	Latent heat of vaporization (>100°C)	Partially visible	Partially visible	Partially visible	Not visible	Partially visible	Partially visible
P6	Latent heat of vaporization (>100°C)	Partially visible	Partially visible	Partially visible	Not visible	Partially visible	Faint visibility
P7	Chemically sprayed	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
P8	Chemically sprayed	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible

The sample P1 and P2 are subjected to high heat (200°C) resulting in partial visibility under UV B, UV C , Oblique lighting and visual examination. Then UV A and IR spectroscopy shows faint visibility. Indicating that Exposure to high heat (200°C) did not result in complete loss of information unlike other thermal paper types. Instead, prints remained recoverable with information to a certain extent.

The samples P3 and P4 are subjected to low heat (100°C) sample P3 shows partial visibility under UV A, UV B, UV C , Oblique lighting and visual examination only IR spectroscopy indicates faint visibility. Sample P4 shows partial visibility under UV A, UV C, Oblique lighting and visual examination UV B and IR spectroscopy indicated faint visibility. It Indicates that under low heat conditions (100°C), recovery remained effective with most optical methods yielding partially visible results infrared examination consistently showed only faint visibility indicating limited sensitivity.

The samples P5 and P6 subjected to latent heat of vaporization (>100°C) demonstrated that sample P5 shows, partial visibility under UV A,UV B, UV C , Oblique lighting and visual examination only IR spectroscopy indicated no visibility. Sample P6 shows partial visibility under UV A, UV B, UV C and Oblique lighting. Visual examination shows faint visibility and IR spectroscopy indicated no visibility. It indicates that continued recover ability and the UV (A, B,C) and oblique lighting with partial visible results. However infrared examination failed complete under these conditions, suggesting that moisture exposure alters the optical properties relevant to IR detection.

The sample P7 and P8 are subjected to chemically sprayed (stabilized hydro alcoholic fragrance formulation) resulted into no visibility under any optical examination techniques such as UV (A,B,C) ,infrared, oblique lighting or even direct visual examination. This indicates that exposure to chemically sprayed irreversible alteration of the thermo sensitivity layer leads to total information loss.

The optical examination UV A shows partial visibility under low heat (100°C) and latent heat of vaporization (>100°C) for samples P3, P4, P5 and P6 respectively. For high heat (200°C) it shows faint visibility of samples P1 and P2 and for samples P7 and P8 shows no visibility were chemically destruction occurred. It indicates that UV A showed moderate effectiveness, providing partially visible results in low heat and latent heat conditions but reduced performance under high heat exposure and chemically exposed conditions.

UV B shows partially visible for the high heat (100°C), low heat (100°C) and latent heat of vaporization (>100°C) for the samples P1, P2, P3, P5 and P6 samples respectively. For low heat (100°C) shows faint visibility of the sample P4 and for chemically treated samples are exhibits no visibility of the samples P7 and P8 .UV C Shows partially visible for the high heat (100°C), low heat (100°C) and latent heat of vaporization (>100°C) for the samples P1, P2, P3, P4, P5 and P6 samples respectively and for chemically treated samples are exhibits no visibility of the samples P7 and P8. UV B and UVC emerged as the most effective techniques consistently providing partially visible results across all heat related degradation conditions
.These wavelengths demonstrated superior sensitivity in detecting degrading prints.

IR spectroscopy shows faint visibility for high heat (200°C) and low heat (100°C) from P1, P2 P3 and P4 respectively. In case of latent heat of vaporization (>100°C) and chemically sprayed (stabilized hydro alcoholic fragrance formulation) shows no visibility of the samples P5, P6, P7 and P8. Infrared examination shows limited effectiveness, producing faint visibility only under low heat conditions and failing entity entirely under moisture based degradation; this highlights it restricted applicability for this paper type.

Oblique lighting shows partial visibility under high heat (200°C), low heat (100°C) and Latent heat of vaporization (>100°C), of the samples ranging from P1 to P6. But, chemically sprayed (stabilized hydro alcoholic fragrance formulation) shows no visibility of the samples P7 and P8. Oblique lighting proved to be a reliable non - UV method, consistently enabling partial visibility across all thermal degradation samples, except chemical exposure indicating its usefulness in detecting surface level variations.

Visual examination Shows partially visible for the high heat (100°C), low heat (100°C) and latent heat of vaporization (>100°C) for the samples P1, P2, P3, P4 and P5 samples.
Respectively and for latent heat of vaporization (>100°C) and chemically treated samples are exhibits no visibility of the samples P6, P7 and P8 respectively. Visual examination demonstrated relatively high effectiveness, with most samples remaining partially visible under heat based degradation, through visibility decreased and certain moisture conditions.

Table no 4.2.04: Analysis of different degradation methods with non-destructive optical examination techniques on Ezo thermal papers.

The data shown in the table 4.2.03 indicates that Ezo thermal papers are subjected to different destruction methods for 2 samples each subjected into high heat (200°C), low heat (100°C), latent heat of vaporization (>100°C) and chemically sprayed (stabilized hydro alcoholic fragrance formulation) respectively of total collectively 8 samples.

Ezo Thermal paper	**Type of destruction**	**UV A**	**UV B**	**UV C**	**IR**	**Oblique lighting**	**Visual examination**
Z1	High heat (200°C)	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
Z2	High heat (200°C)	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
Z3	Low heat (100°C)	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
Z4	Low heat (100°C)	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
Z5	Latent heat of vaporization (>100°C)	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
Z6	Latent heat of vaporization (>100°C)	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
Z7	Chemically sprayed	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
Z8	Chemically sprayed	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible

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The samples from Z1 to Z8 all the samples are subjected to high heat (200°C), low heat (100°C), latent heat of vaporization (>100°C) and chemically sprayed (stabilized hydro Alcoholic fragrance formulation) resulted into no visibility under any optical examination techniques such as UV (A, B, C), infrared, oblique lighting or even direct visual examination. This indicates that exposure to any forms of given destruction causes irreversible alteration of the thermo sensitivity layer leading to total information loss showcasing the Ezo papers sensitivity.

All the optical examination techniques shows no visibility for all the samples from Z1 to Z8E1 of Ezo thermal paper under all the destructive techniques high heat (200°C), low heat (100°C), latent heat of vaporization (>100°C) and chemically sprayed (stabilized hydro alcoholic fragrance formulation) . It shows that no optical technique is effective in restoration of information of Ezo thermal paper under all thermal degradation conditions.

Table no 4.2.05: Analysis of different degradation methods with non-destructive optical examination techniques on Gobbler thermal papers.

The data shown in the table 4.2.03 indicates that Gobbler thermal papers are subjected to different destruction methods for 2 samples each subjected into high heat (200°C), low heat (100°C), latent heat of vaporization (>100°C) and chemically sprayed (stabilized hydro alcoholic fragrance formulation) respectively of total collectively 8 samples.

Gobbler Thermal paper	**Type of destruction**	**UV A**	**UV B**	**UV C**	**IR**	**Oblique lighting**	**Visual examination**
G1	High heat (200°C)	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
G2	High heat (200°C)	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
G3	Low heat (100°C)	Faint visibility	Partially visible	Partially visible	Faint visibility	Faint visibility	Partially visible
G4	Low heat (100°C)	Faint visibility	Partially visible	Partially visible	Faint visibility	Faint visibility	Partially visible
G5	Latent heat of vaporization (>100°C)	Faint visibility	Faint visibility	Faint visibility	Faint visibility	Faint visibility	Faint visibility
G6	Latent heat of vaporization (>100°C)	Faint visibility	Faint visibility	Faint visibility	Faint visibility	Faint visibility	Faint visibility
G7	Chemically sprayed	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
G8	Chemically sprayed	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible

The sample G1 and G2 are subjected to high heat (200°C) resulting in no visibility under any optical examination techniques such as UV (A,B,C) ,infrared, oblique lighting or even direct visual examination. This indicates that exposure to extreme heat causes irreversible alteration of the thermo sensitivity layer leading to total information loss.

The samples G3 and G4 are subjected to low heat (100°C) resulting in partial visibility as seen in UV B, UV C and visual examination and UV A, IR and Oblique lighting shows faint visibility. Under low heat conditions indicating that moderate thermal degradation retain sufficient contrast for retrieval of information.
The samples G5 and G6 exposed to latent heat of vaporization (>100°C) show faint visibility across all the oblique lighting techniques as of UV A,UV B, UV C, IR, Oblique lighting and visual examination. Suggesting that moisture induced degradation reduces contrast and clarity of the prints.

The samples G7 and G8 exposed to chemically sprayed (stabilized hydro alcoholic fragrance formulation)shows no visibility across

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all the oblique lighting techniques as of UV A,UV B, UV C, IR, Oblique lighting and visual examination. This confirms the high destructive effect of chemical exposure on thermal paper.

The optical examination UV A shows faint visibility across low heat (100°C) and latent heat of vaporization (>100°C) of the samples from G3 to G6 respectively. Under high heat and chemically sprayed no visibility seen of the samples G1, G2, G7 and G8 respectively. Indicating that retrieval of information can be done through low heat (100°C) and latent heat of vaporization (>100°C) forming moderate effectiveness.

UV B and UV C both the examination techniques provided partial visibility for low heat (100°C) for the samples G3 and G4, also faint visibility for the latent heat of vaporization (>100°C) of the samples G5 and G6.Under high heat and chemically sprayed no visibility seen of the samples G1,G2,G7 and G8 respectively. These wavelengths demonstrated superior sensitivity in detecting degraded prints.

IR and oblique lighting both the examination techniques shows faint visibility across low heat (100°C) and latent heat of vaporization (>100°C) of the samples from G3 to G6 respectively. Under high heat and chemically sprayed no visibility seen of the samples G1, G2, G7 and G8 respectively. Indicating that retrieval of information can be done through low heat (100°C) and latent heat of vaporization (>100°C) forming moderate effectiveness.

The visual examination techniques provided partial visibility for low heat (100°C) for the samples G3 and G4, also faint visibility for the latent heat of vaporization (>100°C) of the samples G5 and G6.Under high heat and chemically sprayed no visibility seen of the samples G1,G2,G7 and G8 respectively. These wavelengths demonstrated superior sensitivity in detecting degraded prints.

DISCUSSION

This study is done to understand the efficiency of non-destructive optical techniques for retrieving information from deteriorated thermal paper prints and find out which optical technique is more suitable for visualizing faded or damaged information, from different brands which are common among the society such as SBI ATM (Automated teller machine), Epson m352a2, Prathi nidi, Ezo and Gobbler HOP E 801(USB+LAN) thermal paper prints. Under multiple environmental conditions such as high heat (200°C), low heat (100°C), latent heat of vaporization (>100°C) and chemically sprayed (stabilized hydro alcoholic fragrance formulation).The findings reveal that both material composition and type of degradation plays a major role in determining the success of forensic retrieval of information to aid the investigation. A clear pattern emerges where in thermal degradation shows dependent behavior. Most conventional thermal papers (SBI ATM, Epson and Gobbler) retain partial Recover ability at 100 °C, beyond which a sharp transition to irreversible degradation occurs at 200 °C. However, Prathi nidi thermal paper deviates significantly from these trends, demonstrating remarkable resistance even at elevated temperatures, thereby suggesting the presence of modified or enhanced thermal sensitivity coating. Moisture induced degradation that is latent heat of vaporization (>100°C) induced an additional layer of complexity unlike dry heat, steam exposure results inconsistent degradation reducing contrast and thereby limiting the effectiveness of optical techniques this effect is particularly evident in (Gobbler and Epson) thermal paper samples where visibility shifts from partial to faint under identical thermal ranges highlighting the critical role of humidity in forensic degradation processes.

Among the optical techniques UV B, UV C and oblique lighting consistently outperformed all other methods demonstrating superior sensitivity in recovering degraded prints. The shorter wavelengths likely enhance contrast by interacting more effectively and the contrast based observation with reduced chemical differences .In contrast infrared examination exhibits inconsistent to negligible utility particularly failing completely for Epson and Ezo thermal papers thereby indicating that IR based recovery are highly dependent on material specific properties.
Chemical degradation emerged as the most destructive factor, unlike thermal degradation chemical exposure washes out the thermal layer making it as an irreversible loss of retrieval information and no such nondestructive optical techniques were effective against chemical degradation. This highlights a crucial limitation in forensic methodology where dealing with chemically alters documents and retrieval of such information founds difficult.
The study also identifies Ezo thermal paper as an extreme outliner exhibiting total vulnerability across all conditions. Its inability to retain any recoverable information even at modern temperatures suggests a fundamental different and less stable chemical composition. In contrast Prathi nidi represent the opposite extreme, demonstrating superior resilience and extended recovery ability when exposed to sudden thermal heats.

CHAPTER V. MAJOR FINDINGS OF THE STUDY

The findings in the study which are noticed while researching are a part of the study. It includes important results from the research and answering research statements. Findings can be shown in simplest format for easy understanding of the research; it can be of in

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simplest language, statistical, tables, charts and graphs. Research findings form the basic building structure of the study. They state the facts about the study with were processed and also it can be demonstrated with re-searching the study. Findings provide the researcher wants to do and what are the outcomes that are awarded are the expected outcomes are in favors or not. Also confirms the satisfactory of the objectives being framed.

The study has some major findings:

- The results highlighted that chemically treated are most effective methods for complete destruction of thermal paper information.
- Thermal degradation varies significantly among paper types, with Prathi Nidi showing some superior resist compare to the other brands of thermal papers.
- The transition from partial to complete degradation for most paper occurs between 100℃ and 200℃. Additionally the effect of steam suggests that moisture plays a significant role in accelerating degradation in certain paper types.
- The results indicate that the effectiveness of retrieval of information from SBI ATM thermal paper through nondestructive optical examination techniques is highly dependent on the degree and type of degradation.
- Exposure to (200℃) and chemical agents represents threshold beyond which retrieval becomes impossible. In contrast samples degraded at (100℃) certain partial recover ability in SBI ATM thermal papers.
- UV B and UV C emerged as the most effective optical tool among those tested. Fainted Prints in moisture effects sample. All techniques demonstrated limitations when the degradation reached advanced stages.
- The results indicate that Epson thermal paper exhibits better responsiveness to UV B and UV C illumination, particularly under moderate degradation conditions such as low heat exposure.
- Infrared examination was shown to be inefficient for Epson thermal paper highlighting differences in material composition compared to other thermal papers.
- The effectiveness of UV illumination follows a clear trend with shorter wavelengths UV C and UV B providing superior vision compared to longer wavelengths UVA additionally chemical degradation does not always result in complete information loss as partial recovery was observed in certain samples.
- The results indicate that Prathi Nidi thermal paper exhibits significantly higher resistance to thermal degradation compared to other paper types. Even at 200 °C particle recovery of pints was possible using appropriate optical techniques
- Notable findings in the loss of infrared effectiveness under latent heat conditions, suggesting that moisture exposure specifically affect the properties required for IR based detection.
- The effectiveness of optical methods follows a clear trend which UVB, UVC and oblique lighting providing the best results followed by UVA and visual examination, while infrared remains the least effective.
- Visual Examination relevance: In several cases visual examination produced results comparable to optical techniques emphasizing the importance of examiner expertise.
- The results clearly indicate that Ezo thermal paper exhibits the lowest resistance to environmental stress among all tested samples. Unlike other paper types, it does not retain any level of recover ability under the thermal or moisture based degradation.
- A significant observation is the absence of any intermediate stage of degradation The transition from intact to complete degraded occurs rapidly, leaving no opportunity for partial retrieval using nondestructive techniques.
- The findings also highlight that all tested optical methods are ineffective for this paper type once degradation occurs indicating a limitation for forensic recovery approaches.
- The results indicate that Gobbler thermal paper exhibits moderate resistance to thermal degradation. While it allows partial recovery at100℃, exposure to 200℃ results in complete loss of information.
- A notable observation is the reduced effectiveness of all optical methods under the moisture based degradation, indicating that a latent heat significantly affects print clarity.
- UV B and UV C were identified as the most effective techniques, outperforming other optical methods in retrieving degraded prints. However, this effectiveness is limited under severe degradation conditions.
- Material based variable significant differences exist between paper brands; Prathi Nidi is the highest durability, Gobbler and Epson moderate durability, SBI ATM moderate to low durability and Ezo extremely low durability.

SUGESSTIONS

- Priority should be given to you UV B and UV C light sources during examination of degraded thermal documents and sequential examination protocols from visual, oblique, UV and IR should be standardized to maximize retrieval efficiency.
- Cases involving chemical exposure should be immediately flagged as a high risk for non-recover-ability and while handling

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the thermal papers one should be careful of the transfer of chemicals is faster towards body proper safety protocol's should be followed .

- Manufacturers should consider developing forensic resilient thermal papers for critical applications such as banking and legal documentation.
- Incorporation of protective top coatings may enhance resistance to environmental degradation.
- The research should be done in the field to categorize and standardize the thermal papers based on the uses and harmful exposures.
- The more studies can be done to analysis how different factors natural or man-made factors affect the thermal papers.

CONCLUSION

The study conclusively demonstrates that the effectiveness of nondestructive optical examination techniques in retrieving information from degraded thermal papers is highly dependent on both environmental conditions and material composition. While moderate thermal degradation allows partial recovery, extreme heat and chemically exposures results in irreversible information loss.

Among the techniques evaluated UV B, UV C emerged as the most reliable and effective tools, whereas Infrared examination showed limited applicability. The finding also highlights the critical influence of moisture in accelerating degradation and reducing retrieval clarity.

A significant contribution of this study lies in inter band variability, with Prathi nidi demonstrating exceptional resistance and Ezo exhibiting complete vulnerability. This variability underscores the necessity for tailored Forensic approaches based on material characteristics. Overall the research establishes both the potential and limitations of non-destructive optical techniques in forensic document examination. The effective under controlled degradation conditions, these methods faces critical challenges under severe thermal or chemical induced damages, there by emphasizing the need for continued innovation in recovery of degraded thermal paper with advanced forensic imaging technologies.

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ANNEXURE

Figure 1: UV Cabinet for chromatography

Figure 2 : IR chamber for chromatography

Figure 3: Oblique lighting for chromatography

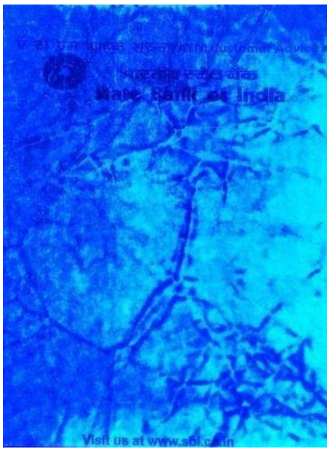
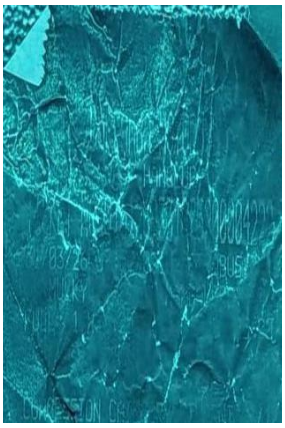


Figure 4: SBI ATM thermal under heat (200°C)



UV Figure 5: Prathi nidi, UV B low heat (100°C) High

Figure 6: Ezo thermal paper under UV C under latent heat of vaporization (>100°C)

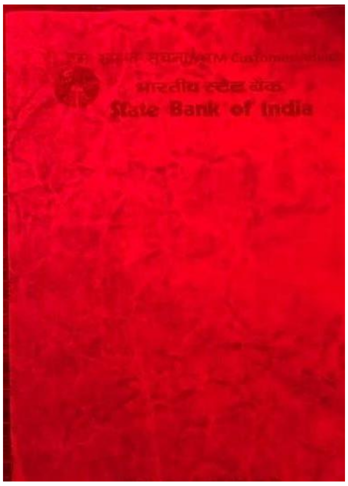


Figure 7: SBI ATM under IR Spectroscopy Under high heat (200°C)

Figure 8: Epson thermal paper under Oblique lighting under chemically sprayed