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Article

A study on fire risk and its mitigation in gravure printing press

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Abstract: The gravure printing process is widely utilized for large-scale, high-quality, multi-colored printing tasks executed at high press speeds. This includes a diverse range of products such as art books, greeting cards, currency, stamps, wallpaper, magazines, and more. This thesis addresses the fire risks associated with gravure printing, acknowledging the use of highly flammable materials and the potential for static charge-related incidents. Despite its prevalence, there is limited research on fire prevention and control in gravure printing. The study employs field observations, stakeholder interviews, and an extensive review of literature on fire risk and control in printing press operations in India. It analyzes the causes of fires using the fire triangle model, emphasizing the role of heat, combustible materials, and oxygen in fire incidents within the printing press environment. The thesis categorizes preventive measures into fire prevention and fire suppression actions, focusing on reducing fire load, static charge mitigation, and implementing firefighting systems. It observes that poor housekeeping, lack of awareness, and inadequate emergency control plans contribute significantly to fire hazards in press facilities. Additionally, the research identifies key factors such as high press temperatures, low humidity, improper storage, and inadequacies in firefighting systems as potential causes of fires. It emphasizes the need for optimal environmental conditions, proper storage practices, and effective firefighting infrastructure within press facilities. The study concludes with comprehensive guidelines for loss prevention and control, including management programs, housekeeping, operator training, pre-emergency planning, preventive maintenance, and plant security. It also addresses safety measures specific to gravure printing presses, such as automatic sprinkler systems, fire hydrant system, carbon dioxide flooding systems, and portable fire extinguishers. In summary, this thesis provides valuable insights into the multifaceted nature of fire risks in gravure printing presses and recommends a holistic approach for effective fire prevention and control.

Keywords: gravure printing; fire risk; risk mitigation and control; corrective and preventive actions

1. Introduction

The gravure printing process is employed for large-scale, high-quality, and multi-colored printing tasks conducted at elevated press speeds, encompassing a diverse array of products such as art books, greeting cards, advertising materials, currency, stamps, wallpaper, wrapping paper, magazines, wood laminates, and rubber or plastic substrates. In gravure printing, a rotating printing plate or cylinder immersed in an ink bath features recessed cells that are etched or engraved to varying depths and sizes. A doctor blade removes excess ink, and the remaining ink in the recessed cells transfers the image to the paper [1]. Capillary action of the substrate, along with pressure from impression rollers, draws the ink out of the cell cavity and onto the substrate as shown in **Figure 1**.

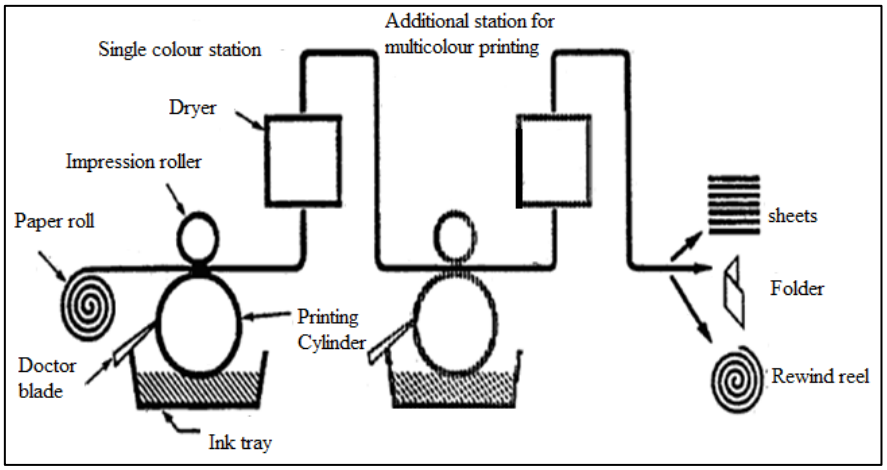

Figure 1. Gravure printing process.

Typically, cylinders for gravure printing are constructed from steel and plated with copper, featuring a light-sensitive coating. While most cylinders are now engraved using laser technology, some are still engraved using a diamond stylus or a chemical etch. Before etching, a resist in the form of a negative image is applied to the cylinder to protect non-image areas from the etching chemical. Following etching, the resist is stripped off, a process akin to manufacturing printed circuit boards. The engraved cylinder undergoes proofing, testing, potential reworking, and is finally chrome plated. Corrections and touch-ups may still be performed using traditional methods [2].

Gravure presses come in flat and rotary types, with rotogravure presses operating at speeds up to 610 m/min and webs as wide as 3.1 m used in publication plants. Larger webs, up to 3.8 m wide, are employed for floor covering, while presses for packaging materials usually have smaller webs (1–1.5 m wide) with up to eight printing units.

Solvent-based inks are commonly used in gravure printing as processes using solvent inks can run faster as these inks dry more quickly.

The gravure printing press poses an increased risk of fire due to the use of highly flammable materials such as solvents and inks with very low flash points. The substrates used for printing, such as paper or polymer film, are also combustible. The press area is filled with volatile organic compounds (VOCs), specifically solvent vapor, which is highly prone to ignition [3–6].

The friction between the substrate and printing or guiding rollers generates a substantial amount of static charge. The accumulation of high static charge can lead to sparks, becoming a potential cause of fire in the press area. Even a small spark, arising from static charge or friction between surface contacts of moving press parts, can trigger an instantaneous and devastating fire, particularly in an environment conducive [6].

Fires in gravure printing presses are a recurrent and widespread occurrence, leading to significant property damage and, tragically, human casualties worldwide. Despite the prevalence of these incidents, there has been a noticeable lack of prior research focused on fire prevention and control specific to gravure printing presses some papers cited on environmentally friendly printing processes [7]. This research endeavors to fill this gap by conducting a comprehensive field study and survey

involving printing presses and relevant stakeholders. The aim is to amalgamate valuable insights and knowledge to enhance the control and prevention of fire risks associated with gravure printing presses.

2. Materials and method

This research is conducted through a combination of field observations, interviews with key stakeholders involved in the operation and control of gravure printing presses in India, and a comprehensive review of literature, including case studies on fire incidents and control in printing press environments.

3. Cause of fire in printing press through fire triangle analysis

In the intricate dynamics of the fire triangle, the confluence of three pivotal elements—heat, combustible material, and oxygen—serves as the catalyst for the ignition of a fire. This phenomenon unfolds as a natural consequence when these elemental forces come together in harmonious synergy. In the specialized realm of a gravure printing press, the perpetual presence of two fundamental elements, namely oxygen and combustible material, forms the foundational backdrop. Oxygen is omnipresent in the atmosphere inside the printing press and combustible materials like paper used as printing substrate, inks, solvents etc. are used for printing process. Only the third element that is heat is not present all the time, it is generated from the abnormal operation in the press and once it is generated it is difficult to prevent the occurrence of fire in the printing press, hence it is the focus of debate in this thesis.

Fires within the press are frequently instigated by the introduction of the third elemental player, heat, which emanates from a spectrum of diverse processes. The genesis of this heat can be traced back to the frictional interplay between moving parts or the generation of sparks arising from a static charge—a phenomenon that manifests with notable frequency. This static charge materializes due to the friction between metallic rollers and a swiftly moving substrate during the press operation, creating an environment ripe for the occurrence of fires [8].

Adding to the intricate tapestry of potential ignition sources, the incorporation of solvents in the printing ink amplifies the risk. These solvents introduce volatile organic compounds into the normal atmospheric conditions, establishing an environment that is remarkably conducive to the initiation and swift progression of fires. The volatile nature of these compounds, combined with the inherent conditions of high-speed press operations, elevates the vulnerability of the printing press to fire incidents, underscoring the critical importance of vigilant safety measures in this complex industrial setting. The aim should be always to reduce the fire load, reduce the static charge as much as possible, drive out the solvent vapors from the press area, reduce the friction between moving parts etc.

4. Observation of fire risks during field study

The field study on fire risks during press visits across various regions in the country revealed several critical observations that contribute to the causes of fires in press facilities. Among these observations, poor housekeeping practices were

identified as a significant factor, emphasizing the importance of maintaining a clean and organized workspace to prevent fire hazards. The lack of awareness among personnel was also noted as a contributing factor, highlighting the need for comprehensive training programs to educate individuals on fire safety protocols.

Additionally, the study identified inadequacies in emergency control plans, emphasizing the importance of having robust and well-defined procedures to handle fire incidents promptly. Improper preventive maintenance practices, such as neglecting equipment upkeep, were identified as another potential cause, stressing the need for regular maintenance schedules to mitigate fire risks. The inadequacy of vapor extraction systems and static charge neutralizers were recognized as potential contributors, underscoring the importance of implementing effective ventilation and static control measures. Other notable factors included high press temperatures, low relative humidity in press areas, improper segregation of fire loads, absence of fire doors, and inadequacies in firefighting systems [9]. These findings emphasize the necessity of maintaining optimal environmental conditions, proper storage practices, and ensuring the presence of effective firefighting infrastructure within press facilities [10].

The study also highlighted the risks associated with the use of sparking tools in the press area for cleaning and maintenance activities. This emphasizes the need for implementing safer alternatives and ensuring that personnel are trained to use tools that do not pose a fire hazard. Finally, the improper monitoring of critical parameters like temperature inside the press room, humidity inside the press room, level of static charge generated from the printing operation, level of volatile organic compounds (VOC), etc. related to fire in the press area was identified as a potential issue, indicating the importance of implementing robust monitoring systems to detect and address fire risks promptly. Overall, the field study provided valuable insights into the multifaceted nature of fire risks in press facilities, calling for a comprehensive approach to mitigate these risks effectively.

5. Prevention and control measures

The guidelines for loss prevention and control provided here are not exhaustive and were crafted with an average hazard level in mind. Elevated hazard levels necessitate additional loss prevention and control measures.

5.1. Management programs

Implementing robust management programs is essential for effective fire prevention and control. These programs should include:

Housekeeping: Poor housekeeping leads to mixing of material and accumulation of combustible material in unwanted places which may be a biggest reason of fire spread once it is initiated for any reason. Vigilantly manage the accumulation of paper, plastic waste, ink residue, and starch dust within the facility. For instances of excessive dust generation, consider installing automatic and properly protected dust collection equipment to mitigate potential fire hazards.

Operator training program: Ensure that all operators are thoroughly educated on the hazards inherent in their tasks and are well-versed in the operation of safety control

equipment. Strictly prohibit any deviations from established written procedures to maintain a consistent and safe working environment.

Pre-emergency planning: Develop and consistently update a comprehensive pre-emergency plan that clearly defines all aspects of emergency response and business continuity. This plan should serve as an indispensable tool to guide the facility's response in the event of a fire or other emergencies. Regular overviews of the plan can aid in customizing emergency response strategies based on the specific characteristics of the facility.

Preventive maintenance and inspection program: Establish a proactive preventive maintenance and inspection program, ensuring the availability of spare parts for key equipment with high attrition rates. This approach facilitates seamless repairs and maintenance, allowing the plant to operate at full capacity. Incorporate modern inspection techniques, such as nondestructive testing, infrared scanning, and vibration analysis, to assess and maintain process equipment. Keep an inventory of spare parts on-site for components like gears, rolls, and bearings that may wear and require replacement.

Plant security and surveillance: Safeguard the facility by restricting access through secure fencing, complemented by guards stationed at all points of entry. Implement recorded watchman services in areas that are not under constant supervision to enhance overall security. Additionally, manage other management programs, including those related to welding, cutting, and “hot work” permits, as well as smoking regulations, to maintain a safe working environment.

5.2. Other miscellaneous safety measures

In the realm of web-fed rotary press machines, many utilize automatic paper splicing for feeding successive rolls. However, caution is advised as less number of rolls of paper may be present near the machine.

Printing presses, especially high-speed multicolor machines, pose a substantial mechanical risk. The electric power-supply equipment for these presses may be unique, and specific attention must be given to solvent recovery equipment, which involves exposures to pressure vessels.

For water-cooled presses, implement water flow supervision configured to alarm and shut down operations during cooling water failure. Recommendations may be tailored based on the types of inks and solvents handled, the nature of the occupancy near the press, and the level of protection provided.

Limiting the number of presses in one area, considering both value and production exposure, is advised. The press room should be safeguarded with an approved automatic wet-pipe sprinkler system. Install sprinklers not only in the press area but also in the control room, ink storage room, ink mixing room, and any concealed spaces shielded from ceiling sprinkler discharge. Design the sprinkler system in accordance with NFPA (national fire protection association) 13 and PRC.12.1.1.0, classifying it as Extra Hazard Group 1 for inks with a flash point less than or equal to 37.8 ℃ [11–13]. In congested press areas, consider enhancing protection with a foam-water sprinkler system.

For presses using inks with a flash point less than or equal to 37.8 ℃, implement

an automatic fixed-pipe carbon dioxide extinguishing system with a connected reserve, following NFPA 12 and PRC.13.3.1 [13]. Design the system to cover all parts of the press, including ink reservoirs. Use rate-of-rise, rate-compensated detectors for automatic operation, and provide a connected-reserve carbon dioxide supply with a remote manual release. Wherever possible water-based inks should be used.

In cases where local application carbon dioxide protection systems are installed on large press assemblies, arrange them to operate independently based on printing press spacing so that the local fire can be put off by partial CO_2 flooding without hampering the whole press operation. Upon system activation, an alarm should sound, initiating a complete shutdown of the press. This shutdown should include ventilation fans, drive motors, ink pumps, dryers, and damper closure. Extend the carbon dioxide system to include exhaust ductwork, dryers, connecting ductwork, ink mixing and storage rooms, and the control room. Strategically place carbon dioxide hose reels for additional coverage.

Certain newer press configurations, accommodating double-width sheets or featuring vertical stacking of multicolor units, present challenges for conventional protection piping. Address these challenges by adapting protection measures accordingly.

For presses using inks with a flash point greater than 37.8 ℃, deploy automatic sprinklers for areas shielded from overhead sprinkler protection. Additionally, install sprinklers below platforms and in roll paper reel-transfer areas beneath the presses.

Ensure the press room is equipped with adequate portable class B and C fire extinguishers following NFPA 10, strategically placed throughout the area [13].

To maintain a safe working environment, take proactive measures to minimize ink mist and dust accumulation in the press area and exhaust ducts. Prevent the accumulation of paper scraps, flammable liquids, and cleaning rags. Regularly lubricate all rotating equipment to reduce heat buildup caused by excess friction.

5.3. Fire prevention through electrical installation and control

Ensure the proper installation of equipment in compliance with NFPA 70 standards [13]. Manage large concentrations of cables by placing them in conduit or protecting them with an approved fire-retardant coating.

For operations involving flammable inks, take the following protective measures:

Given that printing presses are potential generators of static electricity, it is crucial to eliminate static charges that may accumulate and reach levels capable of igniting flammable vapor [14,15].

Ground the entire press framework electrically. Outfit the full width of the web, especially at the delivery side of each impression roller, and select points on the press with high-voltage static eliminators or neutralizers to eliminate nuisance static. Note that some static eliminators use radioactive materials that ionize the air. Electrostatic assist must be avoided in metallic colors.

Humidification proves to be an effective method for controlling static electricity, especially in high-speed printing environments. If employed, maintain a relative humidity level between 45% and 60%.

For drying inks, prefer indirect heating methods. Locate heat sources, such as

electrical elements or direct/indirect gas or oil-fired heat exchangers, at least 6.1 m horizontally and 2.4 m vertically from the ink troughs where practical. To minimize the intake of flammable vapor into the combustion chamber, consider placing the dryer burner in the air intake.

Implement a system of combustion safeguard controls and ventilation for dryers, following NFPA 86 guidelines [16,17]. The ventilation system and associated ductwork should prevent vapor accumulation above 25% of their lower explosive limit.

Include safety interlocks to automatically shut down the ink pumping system in case of press ventilation system failure. When a vapor detection system using listed equipment is installed, ventilation requirements may be reduced. Set the system to sound an alarm at approximately 25% and shut down the press at around 50% of the lower explosive limit of the solvent.

In cases where flammable inks are used, there is a potential for explosions. Address the fume issue through one of three methods: direct exhaust, a solvent recovery system, or catalytic fume incineration. The use of direct exhaust is diminishing due to material costs and stricter environmental guidelines, with catalytic fume incinerators gaining popularity. Refer to NFPA 86 for protection guidelines related to these incinerators [17].

Improper handling of fumes poses an explosion risk, which could lead to severe secondary dust explosions. These explosions may result from accumulations of starch and paper dust on structural members and improperly cleaned equipment.

5.4. Preventive measures during press room construction

When constructing press rooms, take preventive measures to enhance safety:

1) Press location: Place presses that use highly flammable inks in a separate building or an aboveground room with a 0.14–0.21 bar explosion-resistant wall, having a minimum fire-resistance rating of two hours. Situate this room on at least one outside wall to facilitate explosion relief. Implement explosion venting as per NFPA 68 guidelines [17].
2) Floor construction: Construct the press room floor using non-sparking, conductive concrete, with sufficient pitch for effective drainage of flammable liquids. If there is a floor above the pressroom, ensure it is liquid-tight.
3) Ventilation: Provide continuous ventilation, not less than 0.305 $m^3/min/m^2$ of floor, to remove solvent vapor directly from solvent-wetted surfaces of presses, even when they are not in operation to reduce VOC level inside the press area which leads to lowering the fire risk. Install a separate room ventilation system along the floor, particularly under ink fountains and color pans, to eliminate flammable vapor-air mixtures. Locate suction pickups within 152 mm of the floor. Avoid concealed spaces, but, if necessary, ensure continuous venting to prevent solvent vapor accumulation. Install noncombustible draft curtains, at least 1.2 m deep, between presses to limit the number of operating sprinkler heads.
4) Storage and transfer of flammable inks and solvents: In any printing operation, select inks based on paper stock and printing process. All inks consist of pigment,

resin, solvent, and additives. Gravure inks, resembling paint, contain resin, coloring agent, and solvent with flash point temperatures of 6.7–49 ℃, making them class I flammable liquids.

Storage: Store, mix, and dispense flammable inks and solvents in a suitably protected flammable-liquid storage room or a detached building following NFPA 30 standards [17].

Quantity limitations: Limit ink supply in the press area to no more than a workday's worth. Retain one shift's supply in the press area stored in an approved vented cabinet. Position cabinets at least 3.0 m away from presses.

Tank systems: Design piping systems for tanks with appropriate materials, routing, and valving. Evaluate ink transfer methods. Install automatic ink supply systems with safety shutoff valves or positive displacement pumps that activate upon automatic sprinkler, special extinguishing system, or vapor detection operation.

5) Cleaning practices: Use safety solvents for cleaning presses. When cleaning hot surfaces, employ a liquid with a flash point at least 14 ℃ above the surface temperature. Always use non-sparking tools for cleaning and maintenance activities.

6. Conclusion

This thesis addresses the pressing issue of fire risks in gravure printing processes. Despite the widespread occurrence of fire incidents and the inherent dangers of highly flammable materials, there has been a noticeable lack of dedicated research in this area. The research, conducted through field studies and stakeholder interviews in India, employs the fire triangle model to identify critical factors contributing to fires in printing presses. Preventive measures, categorized into fire prevention and suppression actions, are highlighted, focusing on reducing fire load, mitigating static charge, and implementing firefighting systems. The field study emphasizes poor housekeeping, lack of awareness, and inadequate emergency control plans as significant contributors to fire hazards. Key risk factors, including high press temperatures, low humidity, and deficiencies in firefighting systems, are identified. The thesis concludes with comprehensive guidelines for loss prevention, encompassing management programs, operator training, pre-emergency planning, preventive maintenance, and safety measures specific to gravure printing presses.

In essence, this research provides valuable insights into the multifaceted nature of fire risks in gravure printing presses and advocates a holistic approach to effective fire prevention and control. The recommendations aim to enhance safety protocols and practices, contributing to the mitigation of fire risks in these critical manufacturing environments. Future scope of study would be a details analysis of the factors which are the root cause of fire and preventive actions derived from the root cause to protect the gravure printing press from fire risk.

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administration; funding acquisition, HSM. All authors have read and agreed to the published version of the manuscript.

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