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ANALYSIS OF SAFETY HAZARDS AND CERTAIN ERGONOMIC AND SAFETY SOLUTIONS IN COMPRESSED AIR SYSTEMS: FROM CASE STUDIES TO PREVENTIVE MEASURES

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Abstract This paper aims to present a detailed analysis of the safety risks that are related to the use of compressed air systems in industrial environments with an emphasis on a fatal accident that occurred due to an explosion of an air tank. From the analysis of the multiple case studies and the reference to safety and ergonomic guidelines, a framework for the improvement of safety in workplaces that use compressed air is proposed. The objectives of the study are to establish some of the safety issues that may arise when using compressed air equipment, come up with some ergonomic recommendations to address these issues and improve the interaction between the workers and the compressed air equipment.

Keywords: Compressed air systems; hazards; safety; ergonomics.

1. INTRODUCTION

Compressed air is used in a number of applications in industries such as operating tools, painting, cleaning, and for many other uses. Although it has some safety benefits including the lack of shock risks, it poses a number of dangers if not controlled effectively. Compressed air as a utility in industries has become a necessity in increasing production and efficiency, but the risks involved in its misuse cannot be overlooked. The fatal air tank explosion is one of the examples of the disastrous results of negligence in safety and maintenance procedures.

The objective of this research is to determine the major safety issues related to compressed air systems and equipment with an emphasis on a fatal incident of an air tank explosion. This paper aims at presenting the safety issues related to compressed air systems, present practical ergonomic measures that can be used in reducing these risks in the workplace, as well as to stress the need to learn from previous accidents, in order to avoid future incidents.

2. METHODOLOGY

It is therefore important to know some of the hazards that are related to compressed air systems in order to protect the workers and avoid accidents. There have been numerous cases that can illustrate the risks that are associated with the incorrect application and management of these systems. The majority of these concerns can be met if there is a consideration of a number of research and data

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sources that can help in identifying the best practices and safety measures. This research synthesizes information from multiple sources, including:

◦ Occupational Safety and Health Administration (OSHA) data [1-3]
◦ Bureau of Labor Statistics report [4]
◦ California Fatality Assessment and Control Evaluation (CA/FACE) program report [5]
◦ National Institute for Occupational Safety and Health (NIOSH) [1]

We will analyze several case studies to illustrate potential dangers with a more detailed examination of a fatal incident that occurred in a California car wash in 2005 and will propose evidence-based safety and ergonomics measures.

3. CASE STUDIES OF COMPRESSED AIR INCIDENTS

3.1. Fatal Air Tank Explosion

A 46-year-old Hispanic car wash supervisor died (July 23, 2005, California) from an explosion of an air tank in an equipment room [1]. The incident happened at a car wash and gas station that is located in one compound. The victim had been working at this facility since 1999 when it was bought by the present owner of the facility. Before that, he had been working for the same owner at another branch for 10 years. The total working experience of the victim in this particular industry was 16 years.

The vertical 80-gallon tank, rated for 200 PSI, had been manufactured in 1982 and used for 23 years prior to the incident. Analysis revealed products of combustion in the tank, indicating an explosion rather than a pressure-induced rupture.

There was no documentation of tank maintenance except for a Cal/OSHA inspection two years prior to the incident. Studies have shown that using oil of incorrect viscosity can lead to oil residue accumulation in compressors, which can cause combustion and explosions. According to the death certificate, the victim died due to exsanguination, retroperitoneal, pervesical, and abdominal hemorrhage, fractured left acetabulum, and explosive force injuries.

3.2. Fatal Explosion

One more case of tank explosion is mentioned below. A firefighter passed away (June 2023, Ohio) due to the accident that occurred from the explosion of a compressed air tank which underlines the possibility of severe failures in compressed air systems.

3.3. Intentional Misuse

In an industrial equipment manufacturing plant, a worker was killed (2023, Japan) by another worker who injected him with compressed air [2]. This case shows that there should be strict guidelines and people should be made aware of the hazards of using compressed air.

3.4. Eye Injury

OSHA data reports a worker sustaining an eye injury (2008) when using a compressed air machine. Air and debris entered the worker's eye, causing scratches [2].

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3.5. Debris Impact

OSHA data describes an incident where a worker was struck and injured (2014) by debris during high-pressure cleaning operations [2].

3.6. Bone Fractures

A mine worker suffered broken bones (2015, mining site) requiring surgery after using compressed air (at approximately 85 psi) to test for leaks during a nitrogen pipe inspection [2]. A pipe fitting separated from the manifold, knocking the worker off his feet.

4. ROOT CAUSES ANALYSIS OF THE INCIDENTS

It is therefore important to perform a root cause analysis of the incidents that occur with compressed air equipment to determine the causes and come up with measures to prevent such occurrences in the future in order to improve the safety of workers.

4.1. Inadequate Maintenance

There was no record of tank maintenance in the California incident apart from a Cal/OSHA inspection two years before the incident. This lack of maintenance supervision exposed the air tank to possible unnoticed wear and tear and possible faults. Therefore, there was no proactive maintenance and inspection measures that were conducted within the tank and thus hazardous conditions were able to build up in the tank over time.

4.2. Improper Oil Usage

It has been established that using oil of the wrong viscosity results in oil sludge build up in compressors which may lead to fire and explosions. This residue can cause localized overheating of the compressor and therefore increase the chances of spontaneous combustion at high pressure.

4.3. Lack of Training and Awareness

Several events happened because people were not well informed on how to use compressed air systems safely and the risks that come with it. The workers who are not well informed about the risks may misuse the equipment and this may result in severe injuries or even death. It is therefore important that employees undergo through intensive training in order to enable them to operate the compressed air systems safely and efficiently.

4. 4. Equipment Failure

Worn-out equipment and poor or infrequent maintenance can result in disastrous outcomes, as indicated in the case studies. With time, the most important parts of a structure, machine, or tool become fragile and vulnerable to breakage or mechanical failure.

5. HAZARDS ASSOCIATED WITH COMPRESSED AIR

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5.1. High Pressure Risks

Compressed air systems work at high pressure, and this poses a great danger of causing severe injuries or even death if they are not well-regulated. This is evident in the case of the air tank explosion in California. High-pressure air compressors can go as high as 6000 PSI and are used in different fields such as industrial uses, SCUBA diving, and firefighting, among others; however, the dangers that come with the use of these compressors cannot be ignored. It is important to follow safety measures in order to avoid major accidents. For example, the National Fire Protection Association (NFPA) and Occupational Safety and Health Administration (OSHA) have set measures that must be followed in order to safely operate high-pressure air systems. Non-adherence to these regulations may cause severe consequences, such as explosions or injuries, as has been seen in cases where proper safety measures were not taken.

Exceeding the safe pressure limit can lead to several hazards:
◦ *Injuries to the eyes and skin*. The high-pressure air can blow dirt or other contaminants into the eyes or skin, which may lead to cuts or abrasion.
◦ *Embolism*. When compressed air gets into the skin or when the air gets into the body through a wound, it leads to an air embolism, which is dangerous and may be fatal.
◦ *Clothing entanglement*. This is because compressed air can make the clothes expand or flap, and this may lead to them getting caught in the machines or tools.

5.2. Particulate Matter

Compressed air that is not filtered may contain dust, oil and other contaminants which are dangerous to the eyes and respiratory system of workers. These airborne pollutants can get into the eyes, nose and mouth and if inhaled, they may lead to irritation, inflammation and other respiratory problems in the long run.

Exposure to contaminated compressed air can lead to several problems:
◦ *Eye irritation*. Dust and other particulate matter can cause eye irritation, redness and discomfort and may result in short or long term vision problems if not treated.
◦ *Respiratory tract irritation*. Breathing in contaminated air can cause inflammation of the nasal passages, throat and bronchi, which results in symptoms such as coughing, sneezing and shortness of breath. It can worsen the existing respiratory diseases or cause new ones if one is exposed for a long time.
◦ *Skin irritation*. Some of the contaminants that may be present in the air include oil mist which may lead to skin rash, itching or dermatitis.
◦ *Pneumonia*. In extreme cases, breathing in compressed air with oil or other substances can cause a condition known as lipoid pneumonia, which is a condition that is brought about by the presence of fats in the lungs.

5.3. Explosion Risks

The California incident shows that oil sludge and other flammable substances that may collect in the compressed air systems can cause explosions. According to other researches, applying the wrong oil type in compressors results in oil deposition in receivers and may lead to fire outbreaks. For instance, not using OEM oil when changing or adding oil to compressors, can lead to oil residue buildup.

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5.4. Noise Hazards

Besides the above mentioned risks, air compressors also increase the noise level in the workplace and may lead to hearing loss. Air compressors, especially the old ones or those that do not have noise control features, can produce noise levels that are way beyond the recommended exposure limits by OSHA and other organizations of this kind. Prolonged exposure to these high noise levels can lead to:

◦ *Hearing loss that is either temporary or permanent*. Loud noise from air compressors can lead to temporary or permanent damage of the cells in the inner ear which are responsible for hearing thus causing hearing loss.
◦ *Tinnitus*. Some of the effects of exposure to noise from air compressors include tinnitus, which is the ringing or buzzing in the ears.
◦ *Stress and fatigue*. Noise pollution from air compressors is another problem that affects workers' health and well-being, leading to stress and fatigue, which in turn decreases their efficiency and may cause accidents.

6. ERGONOMIC AND SAFETY SOLUTIONS

6.1. Pressure Regulation

It should be installed controls to prevent the pressure of compressed air from exceeding the recommended levels of 30 psi for cleaning applications [3].

6.2. Personal Protective Equipment (PPE)

It is important to use personal protective equipment (PPE) when working with compressed air. Here are some key types of PPE recommended for use with compressed air systems:

◦ *Eye protection*. It is recommended to wear safety glasses or goggles to prevent being hit by debris and particles that may be thrown around by the high pressure air. Other protective gear that may be worn include face shields, especially in operations that may involve coming into contact with chemicals or flying particles.
◦ *Hearing protection*. Compressed air systems are known to produce noise levels that are hazardous to the health of workers, including hearing loss. Earplugs or earmuffs should be used in any situation where there is loud noise.
◦ *Respiratory protection*. For cleaning purposes or where there is a possibility of exposure to hazardous dust or vapors, respirators or supplied air systems should be worn. These devices can offer clean and fresh air and prevent the intake of contaminated air and its particles.
◦ *Gloves and protective clothing*. Depending on the particular activities that are being carried out, gloves may be required to prevent cuts, scratches or coming into contact with certain substances. Also, it is recommended to wear proper attire that is not too loose in order to avoid getting caught in the machinery.
◦ *Foot protection*. It is advisable to wear steel-toed boots to prevent falling or rolling objects that may be present in the working environment especially when using pneumatic tools.
◦ *Additional safety measures*. Effective chip guarding and other protective measures should be implemented to prevent the ejection of particles when using compressed air for cleaning or other operations. This includes using nozzles designed to minimize the risk of injury from flying debris.

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6.3. Filtration Systems

It should be ensured that there are proper filters to eliminate dust, oil, and other impurities in the compressed air supply. Implementation of filtration systems for compressed air can be achieved by:

◦ Full-flow filters. These filters are intended to capture all the air flow that has been compressed and are capable of trapping large contaminants. They are crucial in preventing damage to the downstream equipment that may be in the production line from dirt and debris. This goes a long way in protecting the pneumatic tools and machinery from damage and thus they can work efficiently.
◦ Bypass filters. These systems function in parallel with full-flow filters and offer an extra level of defense by filtering a smaller volume of air continuously. They are especially useful in the regulation of air quality in the long run.

Proper filtration systems eliminate dangerous particles and oil that may be dangerous to the health of the workers and the performance of the equipment. Fresh air reduces the risks of contracting respiratory diseases and injuries resulting from flying particles. Filtration systems can therefore increase the life span of pneumatic tools and other equipment that use compressed air by minimizing contamination levels. This results in less frequent maintenance and repair hence cutting on the overall expenses.

6.4. Noise Reduction

The following are some of the key measures that can be taken in order to minimize noise from compressed air equipment:

◦ *Control turbulence*. The noise produced by compressed air systems is attributed to turbulence that occurs when air is released at high pressure. To counter this, use air nozzles instead of open pipes since they allow for the regulation of the flow of air and thus minimize turbulence. Special air nozzles can split the air into finer streams and change some of the frequencies of the sound to be less dangerous for human ears.
◦ *Install silencers*. Regarding venting valves, the use of silencers can help reduce noise levels. Silencers are used to control the noise that is made when compressed air is released through the valves, which is one of the major sources of noise in compressed air systems. Maintenance of these silencers is important since the silencers may get clogged, and thus, they also can cause noise and operational interferences.
◦ *Use acoustic enclosures*. The use of acoustic enclosures around the compressors can be used to minimize the noise levels. These enclosures should be made of sound-absorbing material and that is non-hazardous, which is non-inflammable and resistant to dust and oil. This approach not only reduces noise but also shields the equipment from damage.
◦ *Regular maintenance*. It is also important to ensure that all the components of the compressed air system such as the compressors, dryers, and pipes are well maintained so as to minimize mechanical noise. This way, problems that may cause higher noise levels, for instance, leaks or worn-out parts, can be detected during the inspection.
◦ *Personal protective equipment (PPE)*. It is also necessary to provide workers with appropriate PPE, including earplugs or earmuffs, in cases where noise levels are above the permissible level. This is especially so where the compressed air systems are running 24/7 as is the case with many industries.

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6.5. Safety Devices

It should be utilized safety devices on tool muzzles to prevent fastener ejection and other potential hazards. These are protective covers that prevent fasteners from being ejected at high speeds. They can also protect the operator from debris.

6.6. Signage and Labeling

It should be ensured that there are adequate signs and labels such as pipe markers that show the maximum working pressure. Proper labeling and signposting assist in increasing the level of awareness of the workers on the existence of the compressed air systems and the dangers that are likely to arise from them. This information can be used as a constant reminder to be careful and observe all the precaution measures when operating around these systems. Pipe markers with maximum working pressure inform the workers of the pressure that they are likely to come across in the course of their work. This information enables them to identify risks and prevent them by wearing protective gear or staying away from risky areas if needed. It also helps in the maintenance and inspection of compressed air systems by labeling pipes with maximum working pressures. Maintenance personnel can quickly identify high pressure sections that need more attention or more frequent inspection to guarantee their soundness and proper functioning. In the case of an incident occurrence or an emergency, proper signs and labels help the emergency team to easily locate the source of the danger and take necessary measures to address the situation and safeguard the employees.

6.7. Training and Education

It is important that the workers undergo extensive training to enable them to understand the right way to use compressed air systems and the risks that are associated with them. This should involve an actual focus on safety measures during the training. This includes:

◦ Adequate protection measures such as wearing of PPE when operating under compressed air.
◦ Proper identification of the equipment and its potential dangers and the recommended operating pressure.
◦ Standard operating procedures in the event of an accident or malfunction of equipment.

Comprehensive, theoretical, and practical training with emphasis on the use of compressed air equipment should be provided and the workers should be allowed to practice the use of the equipment under supervision. This can assist in consolidating theory and increase the level of confidence when working with equipment. Besides, it should be implemented assessments to test the participants' comprehension of the content taught. Issuing a certificate after the completion of the training can encourage the workers to participate in the program and appreciate the effort they are making toward the enhancement of safety.

6.8. Maintenance Protocols

The following should be put into consideration: routine inspections and maintenance schedules, lockout/tagout procedures during the servicing of the machine. The following measures should be

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taken to ensure that compressed air systems are checked on a daily basis to determine their performance and safety. Key checks include:
◦ *System parameters*. Document operational conditions including temperature, pressure, and dew point to determine when there are problems.
◦ *Air intake*. Make sure that the air intake filters are clean to avoid blockage of airflow and to prevent poor performances and high power consumption.
◦ *Oil leaks*. Check for oil leakage that may cause high temperatures and sudden system breakdowns.
◦ *Condensate management*. Ensure that the condensate management system is in good working condition and that there is no leakage since their failure can cause high moisture levels and tool damage.
◦ *Noise monitoring*. It is also advisable to listen to any changes in the noise that the machine is producing which can be an indication of a problem like leakage or mechanical failure.

In addition, it should be conducted more in-depth inspections on a weekly and monthly basis. It is important to implement lockout/tagout procedures during maintenance to ensure safety. Other maintenance protocols also should be considered.

6.9. Proper Oil Usage

It is advisable to use only the recommended (OEM) oil so as to avoid the build-up of residues and possible combustion. OEM oils are designed to offer the best protection to compressor parts through the provision of adequate lubrication. It is, therefore, catastrophic to use oils that are not recommended as this will result in the wearing out of the equipment. OEM oils are formulated to work with the materials that are used in the compressor such as seals and gaskets. Incompatible oils may lead to swelling, hardening or even degrading of these components and as a result, they may develop cracks and leaks.

6.10. Documentation

The records of all repairs and servicing for each equipment should be maintained and stored in the records section. To maintain detailed records of all repairs and servicing for each piece of compressed air equipment, consider implementing the following practices:

◦ Set up a maintenance register for each tool and implement
◦ For each maintenance task, prepare a record of the same
◦ Maintain repair records
◦ Store records securely
◦ Assess and evaluate documents.

6.11. Ergonomic Control Panel Design

In order to monitor pressure and other parameters, well-labeled controls and indicators should be used. For this purpose, it should be followed certain ergonomic recommendations:
◦ Use symbols and color codes that are easily recognizable by operators in order to aid in the identification of controls and gauges. For example, green should be used to represent normal operating conditions, red to represent critical conditions and yellow to represent conditions that are approaching the critical conditions.

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◦ Make sure that labels are printed in large fonts that can be read from a distance in case one is far from the equipment. Do not use complex terms that are hard to understand by all the operators; use simple language that can be understood by all the operators.
◦ Ensure that controls and gauges are positioned at a height and at an angle that will not cause strain to the operators. Controls should be within easy reach without having operators bend or stretch themselves too much.
◦ Make sure that the displays are placed in a way that they do not have a problem with glares and reflections in different lighting conditions. It is recommended to use anti-glare materials for screens and panels.
◦ Position the controls and displays in a way that is consistent with the operator's work process. Controls should be placed in a rational manner, with the most often-used functions being placed in the most conspicuous positions.
◦ Use lights or sounds to provide feedback about the status of the system.
◦ Ensure that pressure gauges are showing the current pressure and the safe operating pressure. Employ color-coded zones to show safe, cautious, and dangerous zones.
◦ Install thermometers and hygrometers to measure temperature and humidity since they influence the efficiency of compressed air systems. It is important to name these displays for identification purposes.
◦ Offer sessions to the operators on how to read and understand the controls and the gauges. This will improve the safety and efficiency of the equipment since the personnel will be familiar with them.
◦ Provide the users with handbooks or reference sheets that contain illustrations of the controls and gauges and their usage including problems that may arise.

7. ADVANCED PREVENTION RECOMMENDATIONS

7.1. Automated Monitoring Systems

Installation of systems that will monitor the pressure and temperature of tanks is common. In addition, these systems should be able to identify any irregularities and inform the workers of the same. It is recommended that the systems should be checked frequently to determine that they are functioning in the right manner. These systems should also be checked periodically to ascertain that they are in good condition.

7.2. Physical Barriers

Some of the important measures include ensuring the existence of barriers between the workers and the possible dangers coming from the machines. These barriers should be strong and robust so that they cannot succumb to pressure from the equipment or the process. They should also be well labeled so that the workers can be warned about the dangers that may be present in the area. These barriers should be inspected regularly so as to determine their safety.

7.3. Standard Operating Procedures

Implementing and monitoring guidelines for operating with compressed air systems can significantly enhance safety and efficiency. Some of the procedures that should be put in place are safety guidelines, maintenance check and correct use of tools and equipment. It is recommended that all personnel should be trained to know the procedures in order to avoid non-adherence to the set

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procedures. It should be done on a regular basis so as to confirm that the procedures are being followed.

7.4. Equipment Replacement Program

Organization should also involve a systematic timing to check on the state of equipment and replace those that have been in use for quite a long time. Ensure that there is regular check on the equipment in order to determine any parts that might have been worn out and need replacement. It is very important to change all the damaged or worn out parts immediately.

7.5. Redundant Safety Systems

It should be employed safety valves with redundant systems to avoid the issues of single points of failure. Safety valves are very important parts of any system since they act as a backup in the event of an occurrence of an event. Redundant systems are present in the form of two or more separate components that can be used in an emergency instead of a single component.

8. CONCLUSION

Compressed air systems are very useful in industries but they are dangerous if not well managed. The above case studies, especially the fatal incident in California, reveal that there is a need to ensure that the compressed air systems are well maintained, the right materials used and that safety measures are adhered to at all times.

If the suggested ergonomic and safety measures are adopted in the workplace, it will be possible to minimize the risks of accidents and fatalities that are related to the use of compressed air. Hence, training, equipment maintenance, safety measures, and the use of better prevention measures are some of the ways to ensure that the working environment is safe.

Certain elements of this approach regarding safety and ergonomics in connection with compressed air systems could be used as a reference for other industries that use hazardous equipment in their operations, with a view to improving safety standards and minimizing accidents and fatalities at the workplace.

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