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Maintenance and reliability: the influence of fertilizer on the service life of the pneumatic cylinder.

Maintenance and reliability: influence of fertilizer on the service life of the pneumatic cylinder

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Summary

This study analyzes wear and corrosion in pneumatic cylinders at a local port in the fertilizer sector. Given the increasing failure rate of pneumatic actuators at a particular fertilizer plant, the question arose of possible methods to mitigate the damage caused by aggressive corrosion in pneumatic cylinders, extending their lifespan and reducing operational costs at the local port. The objective is to propose corrective actions that optimize the lifespan and efficiency of the processes; for this, pneumatic cylinders need to be manufactured with corrosion-resistant materials or protective coatings. The methodology employed includes visual inspection, functional analysis of the cylinders, bench tests, and technical documentation, where the failure characteristics and analysis were based on theoretical references on preventive maintenance, reliability, pneumatic systems, wear, and corrosion. The results showed a high rate of wear and corrosion in conventional cylinders, causing failures such as jamming and leaks, compromising operational efficiency. It has been observed that choosing alternative materials and protective coatings is an effective solution for extending the service life of equipment and optimizing costs, overcoming the shortcomings of conventional cylinders in harsh environments.

Keywords: Fertilizers. Pneumatic Cylinders. Preventive Maintenance. Industrial Wear. Reliability.

Abstract

This study analyzes wear and corrosion in pneumatic cylinders at a local port in the fertilizer sector. Given the increasing breakdown of pneumatic actuators at a particular fertilizer plant, the question arises of possible methods to mitigate the damage caused by aggressive corrosion in pneumatic cylinders, extending their lifespan and reducing operational costs at the local port. The objective is to propose corrective actions that optimize the lifespan and efficiency of the processes; for this, pneumatic cylinders need to be manufactured with corrosion-resistant materials or protective coatings. The methodology employed includes visual inspection, functional analysis of the cylinders, bench tests, and technical documentation, where the failure characteristics and analysis were based on theoretical references on preventive maintenance, reliability, pneumatic systems, wear, and corrosion. The results showed a high rate of wear and corrosion in conventional cylinders, causing failures such as jamming and leaks, compromising operational efficiency. It has been observed that choosing alternative materials and protective coatings is an effective solution for extending the service life of equipment and optimizing costs, overcoming the shortcomings of conventional cylinders in harsh environments.

Keywords: Fertilizers. Pneumatic Cylinders. Preventive Maintenance. Industrial Wear, Reliability.

1. INTRODUCTION

Contemporary industrial maintenance plays a crucial and diverse role in companies, being responsible not only for the physical preservation of assets, but also for their maintenance. of the reliability, productivity, and operational safety of the processes. Among the elements that Pneumatic cylinders, which require more attention in automated environments, stand out because they are... widely used in automated systems due to their simple structure, low cost, and high

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Reliability and ease of maintenance. These linear actuators transform air energy. compressed in mechanical motion, performing fundamental tasks such as pushing, lifting, To dose, position, or transport materials in production lines.

Its use is widespread: sectors such as food, chemical, automotive, pharmaceutical and... Fertilizer manufacturers utilize pneumatic cylinders in various stages of production — from handling to from raw materials to the control of valves, gates, and packaging systems. However, despite Despite their apparent robustness, the effectiveness of these components depends heavily on environmental conditions and of the maintenance practices that are carried out.

In harsh industrial environments, such as fertilizer plants, chemical and physical factors... extremes — such as high humidity, high temperatures, frequent contact with acids and compounds Sulfur, along with abrasive solid particles, accelerates wear and corrosion of the cylinders. tires, impairing their efficiency, reliability, and longevity. According to the Association According to the Brazilian Association of Industrial Engineering (ABEMI, 2022), failures in pneumatic components can be... responsible for up to 20% of unscheduled shutdowns in chemical and fertilizer plants, which This results in significant impacts on maintenance costs, production losses, and risks. operational.

These unplanned interruptions compromise the efficiency of processes and have an impact on... It directly impacts the economic sustainability of the activities. The early replacement of components and the Indirect costs related to production line downtime highlight the urgency of implementing Advanced maintenance strategies that involve reliability, risk assessment, and prevention. of failures.

The main objective of this study is to investigate the wear mechanisms and factors. environmental factors that impact the reliability and performance of pneumatic cylinders in the sector of fertilizers, in addition to suggesting preventive and predictive maintenance approaches that can increase its durability and operational availability.

This research seeks to answer the following question:

How do the harsh environmental conditions, common in the fertilizer industry, affect the wear and reliability of pneumatic cylinders, and how the implementation of Preventive and predictive maintenance methodologies can reduce these effects, increasing the What is the availability and operational efficiency of the systems?

Based on this question, the aim is to identify, analyze, and relate the main factors that... contribute to premature cylinder wear — such as corrosion, abrasion, and fatigue resulting from repetitive cycles and chemical oxidation — and develop technical guidelines that allow for improvement. The reliability of pneumatic systems.

The relevance of this work is directly linked to the significant dependence of the systems

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pneumatic systems in automated industrial operations, especially those that operate by Continuous maintenance of pneumatic cylinders is essential in fertilizer production. to manage the flow of materials, operate discharge valves, and move critical parts. Any Failure in these devices can cause chain disruptions, impacting not only the sector in question. Not directly affected, but the entire production chain.

Furthermore, prolonged exposure to corrosive substances makes these devices... very vulnerable to degradation. Elements such as ammonia, chlorides and sulfates, which frequently They are present in fertilizers, react with the aluminum and stainless steel used in the jackets and rods, triggering oxidation processes that compromise the integrity of the materials and affect The seal fails. As a result, leaks, reduced pressure, and operational failures occur.

According to Salles (2025), in highly corrosive environments, the durability of Pneumatic cylinders can have their lifespan reduced from 10 years to just 1 or 2 years, which increases costs. Operational losses can decrease by up to 40% due to the need for frequent replacements and reduced productivity. This overview emphasizes the importance of an organized technical approach that integrates the Maintenance engineering applied to reliability.

From an asset management perspective, this study makes an important contribution to... to demonstrate that reliability analysis and predictive maintenance should be viewed as These activities are interconnected, not isolated actions. They are part of a continuous cycle of improvements. which transforms field data into valuable information for decision-making. In this way, Engineers and maintenance managers can plan data-driven interventions. concrete solutions, anticipating failures and avoiding wasted resources.

2. MAINTENANCE AND RELIABILITY IN PNEUMATIC SYSTEMS

The NBR 5462 standard (ABNT, 1994) describes maintenance as the "union of all the technical and administrative activities aimed at preserving or restoring an item in a "A condition that enables the performance of a necessary function." This description emphasizes that the Maintenance goes beyond simply fixing problems: it's a strategic action focused on ensuring... Performance, safety, and reliability of equipment throughout its entire lifecycle.

In today's industrial environment, characterized by high levels of automation, competition With fierce global competition and a growing demand for operational efficiency, maintenance management... This becomes crucial for the productivity and sustainability of companies. In this scenario, the Organizations seek methods that ensure maximum utilization of their physical assets. Reducing unexpected interruptions and optimizing costs.

Among the various methodologies available, preventive maintenance and... stand out. Predictive maintenance, which represents a natural transition from the reactive to the proactive model.

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Preventive maintenance is carried out in a planned and organized manner, with periodic interventions. based on time intervals, operating hours or usage cycles, aiming to prevent failures that Predictive maintenance could be predicted and extend the lifespan of equipment. In turn, predictive maintenance... It makes use of continuous monitoring techniques for the condition of equipment, using measurements. and analyses of physical parameters, to identify deterioration trends and predict failures before they occur. become critical.

Related to these approaches is reliability engineering, which applies analytical methods. and statistical tools to measure the performance and probability of failures in systems. Reliability, According to the same standard, it represents the chance of an item performing its required function under certain conditions. specific parameters during a given period, thus being a fundamental parameter for the evaluation of maintenance effectiveness.

In this way, preventive maintenance, predictive maintenance, and engineering approaches... Reliability forms the basis of Reliability-Centered Maintenance Management (RCM). Reliability Centered Maintenance (RCM), a model widely adopted by companies that want Increase operational safety, reduce expenses, and improve the availability of your assets. productive. This integration allows not only the early detection of failures, but also the strategic planning of interventions, optimization of human and material resources, and Continuous improvement of production processes, aligning maintenance with strategic objectives. of the organization.

Preventive maintenance involves performing scheduled checks, adjustments, and replacements. taking into account periods, number of cycles or hours of use, before a failure occurs, as exemplified in Figure 1. As established in NBR 5462 (ABNT, 1994), its The purpose is to minimize the chance of failures or deterioration in the operation of a component.

Figure 1 – The 5 steps of a Preventive Maintenance Plan

Source: Infraspeak – 5-Step Maintenance Plan

As Smith and Hinchcliffe (2004) point out, preventive maintenance aims to ensure to ensure system reliability and promote the safe operation of equipment by anticipating failures that They are known and occur in a cyclical manner.

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According to Pinto (2015), the efficiency of preventive maintenance is linked to the evaluation The importance of the equipment and the reliability of the parts. If applied without proper analysis, This can lead to unnecessary actions and high costs.

Predictive maintenance is an approach that relies on the constant monitoring of Operating characteristics of the machines, making it possible to anticipate and prevent problems before they occur. manifest themselves, as shown in Figure 2. According to Mobley (2002), it is "a system of Maintenance that uses measurements and analyses to assess the condition of a component and estimate its value. "The appropriate time for corrective action."

2.1. Performance and Reliability

Reliability engineering is the field that aims to anticipate, analyze, and improve the The functioning of systems and components in relation to the possibility of failures over time. According to According to the NBR 5462 standard (ABNT, 1994), reliability is defined as the "chance of an item performing "Its required function under specific conditions and within a defined period."

This definition demonstrates the probabilistic and statistical essence of reliability, indicating that it is not an immutable characteristic, but rather a performance measure that can vary depending on the environment, operating mode, and time.

As mentioned by Blanchard (1998), reliability should be viewed as a A crucial tool for strategic maintenance planning, as it allows for anticipating Identifying failures and establishing appropriate intervention policies, reducing risks and optimizing expenses.

In practical terms, reliability answers the question: "What is the chance that a piece of equipment will fail?" How can it function properly for a certain period of time without failing?

This perspective is fundamental in contemporary industry, especially in areas such as Mining, energy, petrochemicals, transportation, and precision manufacturing, where the lack of a single This equipment can result in significant production losses, environmental impacts, or risks to... security.

2.2. The Reliability Formula

Confidence in a component or system is often represented by the following: function:

Figure 3 – Reliability calculation formula

$$\text{CONFIABILIDADE} = R(t) = e^{-\lambda . t}$$

λ = taxa de falhas	t = tempo	e = Número de Euler
$\lambda(t) = \frac{1}{MTBF}$	Precisa seguir a unidade do **MTBF (horas, dias...)**	**2,71**

Source: Tractian - 8 essential maintenance indicators 2025

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where:

R(t) = confidence at time t;

ÿ (lambda) = failure frequency, expressed as failures per time interval;

t = duration of the operation.

This function describes an exponential probability distribution, applied when the frequency The failure rate remains constant — a premise that proves relevant for various systems in regular operation.

2.3. Main Indicators

The main performance indicators related to reliability are:

2.3.1. MTBF: Mean Time Between Failures

MTBF, or mean time between failures, is one of the most important indicators for the sector. maintenance. It is necessary to measure the average total uptime between maintenance. faults in repairable equipment, being a great way to measure the reliability of machine.

Figure 4 – MTBF Formula: Mean Time Between Failures

Source: Tractian - 8 essential maintenance indicators 2025

2.3.2. MTTR: Mean Time To Repair

This indicator is closely associated with maintainability, that is, the ease with which a team can be maintained. Maintenance involves restoring equipment to its functional state after a failure. In other words, MTTR indicates the average time to repair.

Figure 5 – MTTR Formula: Mean Time To Repair

Source: Tractian - 8 essential maintenance indicators 2025

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2.3.3. Availability

Equipment availability is the percentage of time that asset has remained operational. available within a given period. Reliability, on the other hand, is the probability that a piece of equipment will be available for a given period. to remain available at a future time.

Figure 6 – Availability calculation formula

$$\text{DISPONIBILIDADE} = \frac{\text{MBTF}}{\text{MTBF} + \text{MTTR}} \times 100$$

Source: Tractian - 8 essential maintenance indicators 2025

2.4. FMEA – (Failure Mode and Effects Analysis)

This is a proactive method that detects and categorizes possible failure modes, their origins and consequences in the system. Each failure is assigned a risk priority number (RPN). – Risk Priority Number), calculated by multiplying three elements:

$$\text{RPN} = \text{Severidade (S)} \times \text{Ocorrência (O)} \times \text{Detecção (D)}$$

The goal is to eliminate or mitigate the failure modes that have the greatest impact.

2.5. Weibull Analysis

Used to represent the behavior of failures over time, taking into account three main factors:

$$R(t) = e^{-(t/\eta)^{\beta}}$$

ÿ (beta): shape parameter – defines the type of failure;

ÿ < 1 ÿ early failures (assembly or design defects);

ÿ = 1 ÿ random failures (stable operating condition);

ÿ > 1 ÿ failures due to wear (end of useful life).

ÿ (eta): characteristic lifetime, where 63.2% of failures occur.

The Weibull distribution is quite flexible and adapts to different points in the curve. The bathtub test is frequently used in reliability research (BLOOM, 2016).

2.6. Bathtub Curve

The typical behavior of equipment failures over time is represented by the bathtub curve, which describes the variation in failure rate during the cycle of The life cycle of an asset. This curve is divided into three distinct phases, each with its own characteristics. and recommended maintenance strategies, as shown in Figure 7.

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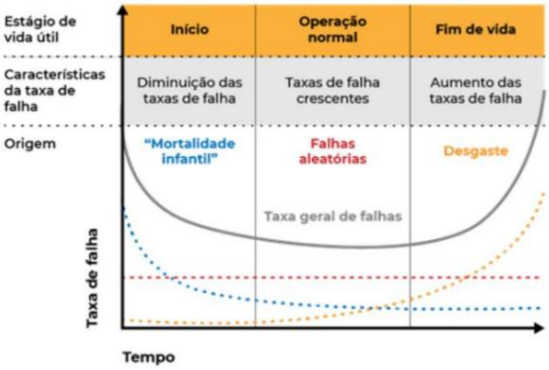
Figure 7 – Bathtub Curve



Source: Tractian – Bathtub Curve

•Early (or childhood) phase:
It is characterized by a high failure rate resulting from design, assembly, manufacturing, or calibration errors. These defects usually manifest themselves soon after the start of operation and tend to decrease as the system stabilizes.

Ideal strategy: conducting burn-in tests, acceptance inspections, and rigorous quality control.

• Useful Life Phase (or constant):
This corresponds to the period in which the equipment operates stably, with an approximately constant failure rate and a predominantly random nature. Failures observed in this phase generally result from unpredictable or external causes, such as operational variations or adverse environmental conditions.

Ideal strategy: application of predictive maintenance and continuous condition monitoring to detect anomalies before they become functional failures.

• Wear and Tear (or Aging) Phase:
In this final stage of the service life, there is a progressive increase in the failure rate due to natural wear and tear of components, mechanical fatigue, corrosion, or material degradation.
Ideal strategy: implementation of planned preventive maintenance, with replacement of critical parts and scheduled equipment overhaul.

The bathtub curve provides a conceptual model that assists in choosing the policy of

The most appropriate maintenance for each stage of the asset's life cycle. Preventive maintenance and

Predictive technologies act in a complementary way in the final stages of the curve, allowing the process to be delayed.

To reduce wear and tear, decrease the frequency of failures, and avoid unscheduled downtime.

2.7. Failure Modes and Causes

A failure occurs when a component, subsystem, or piece of equipment ceases to function.

To perform the function for which it was designed. The classification of failures according to their origin is

fundamental for the analysis and improvement of system reliability. In general, failures can

They can be grouped into the following types:

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• Random failure: caused by unpredictable events, such as overloads, impacts, or variations. environmental.

•Systematic failure: resulting from defects in design, manufacturing, assembly, or operation, which are repeated under certain conditions.

• Wear-out failure: a consequence of the natural aging of materials, loss of lubrication, or physical degradation of components over time.

• Induced failure: caused by human error, misuse, inadequate maintenance, or improper operating procedures.

A detailed understanding of failure modes and causes is of utmost importance and essential. for the application of reliability engineering tools. These tools allow Identify critical points of failure, propose corrective and preventive actions, and increase significantly improves the reliability and availability of equipment.

3. BASIC CONSTRUCTION AND MAINTENANCE OF PNEUMATIC CYLINDERS

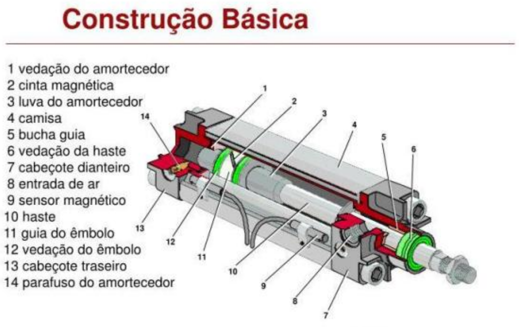
A pneumatic cylinder is a linear actuator that converts the energy of compressed air into... Mechanical movement. It is widely used in industrial automated systems for To push, pull, lift, or position parts and objects.

A typical pneumatic cylinder is composed of several integrated elements that ensure Precise linear motion and watertightness:

• Cylinder liner (cylinder tube): Main body where the piston moves;
•Front and rear heads: Structural support, guide the rod and allow air intake/exit;
• Rod: Transmits the movement of the piston to the external mechanism;
• Piston: Internal element that separates the pressure chambers and performs the movement;
• Piston guides and guide bushings: Maintain alignment and reduce lateral wear;
• Piston and rod seals: Ensure a tight seal between the chambers and prevent air leaks;

• Shock absorbers (sleeve and seal): Absorb impacts at the end of the stroke;
• Shock absorber screw: Allows adjustment of the damping intensity;
• Magnetic strap and magnetic sensor: Allow reading the piston position without mechanical contact;
• Air inlet: Connection for supplying compressed air to the system.

Figure 8 - Parts of the cylinder construction



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Source: Norgren – Pneumatic Actuators (2024)

The effectiveness and longevity of pneumatic cylinders are strongly influenced by The quality of its seals, rods, sleeves, and internal parts. The environmental conditions in which these The way devices operate has a direct impact on the level of wear and tear due to corrosion, abrasion, and fatigue. and friction, which can accelerate the deterioration process and shorten its lifespan.

3.1. Maintenance of Pneumatic Cylinders

The adoption of preventive and predictive maintenance plans, along with the choice of Materials that can withstand harsh environments are essential for extending reliable operation. of the cylinders and reduce unexpected downtime.

The durability and reliability of these devices depend not only on the design and... operating conditions, but also external factors such as temperature, humidity, dust and Compressed air contamination, which can accelerate wear and affect efficiency, requires maintenance. and productivity.

A thorough assessment of the relationship between design, operation, and environmental conditions. They allow for the creation of a more effective maintenance plan, ensuring greater reliability in Functionality, reduction of failures, and safety in industrial processes.

Pneumatic cylinders are linear actuators commonly used in systems. Automated industrial systems. Their reliability is of paramount importance, as failures in these components... They can disrupt production, affect the accuracy of movements, and compromise safety. operational.

As mentioned by Pinto (2015) and Festo (2020), pneumatic cylinders They exhibit a progressive and predictable failure pattern, which makes them especially suitable for predictive maintenance programs and for the implementation of engineering principles of reliability, allowing for the anticipation of failures, efficient intervention planning, and Increased operational availability.

4. INFLUENCE OF THE ENVIRONMENT ON THE WEAR OF PNEUMATIC CYLINDERS

Pneumatic cylinders are key components in industrial automation systems because They convert the energy of compressed air into linear motion. However, their operation is... largely affected by the conditions in which they operate. This impact is especially noticeable in sectors such as fertilizers, where the presence of chemicals, humidity and conditions Unfavorable conditions accelerate cylinder wear.

The importance of this study is highlighted by the financial and operational losses that These result from premature wear and tear. According to the Brazilian Association of Industrial Engineering (ABEMI, 2022), problems in pneumatic components can account for up to 20% of downtime.

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unexpected challenges in the chemical industry. This analysis seeks to identify the environmental factors that... They influence pneumatic cylinders, detailing the wear mechanisms and suggesting practical actions. for mitigation.

4.1. Environmental Factors Affecting Wear and Tear

The wear and tear of pneumatic cylinders is closely linked to environmental factors that vary. depending on the place of operation. In the fertilizer industry, the main factors are: exposure to corrosive chemicals, temperature changes, high humidity and contamination by particles.

4.1.1. Chemical Corrosion

Fertilizers contain aggressive substances such as phosphoric acids, sulfates, and ammonia. that react with the metals in the cylinders. Fertilizers containing nitrogen, for example, release ammonia, which, upon contact with aluminum, a material frequently used in cylinders In tires, it causes electrochemical corrosion. According to ISO 9223 (2012), these compounds They accelerate oxidation, which can result in a thickness loss of up to 0.1 mm per year. humid environments.

4.1.2. Humidity and Temperature

High humidity, common in tropical areas like Brazil, favors the formation of electrolytes. on metallic surfaces, which accelerates corrosion. Temperature variations cause expansion. and material contraction, resulting in cyclic fatigue. Research indicates that higher temperatures Temperatures of 40°C enhance chemical reactions and accelerate the wear of moving components (Jones, 2018).

4.1.3. Particle Contamination

Dust particles and fertilizer residue act as abrasives, scratching the... The internal and external surfaces of the cylinders rub together as the piston moves, increasing friction and accelerating mechanical wear.

4.1.4. Compressed Air Contamination

As stated by BLCH Pneumatic, dust, moisture, or oil vapors that are Substances present in compressed air can seep into cylinders, affecting seals and internal surfaces. and lubrication, compromising the reliability of the device.

4.1.5. Thermal Factors

Extreme thermal cycles or operation at temperatures outside the recommended ranges (such as Temperatures below -20 °C or above 80 °C cause deterioration of seals and lubricants, altering The properties of the materials and reducing the service life of the cylinders (BLCH Pneumatic).

The environmental influence on the wear of pneumatic cylinders is a result of multiple factors.

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factors including chemical corrosion, mechanical abrasion, compressed air contamination and effects Thermal factors. Integrating the analysis of these elements into reliability and maintenance assessments is... Fundamental to effective preventive and predictive maintenance planning, appropriate selection of materials and specifications for cylinders, increased cylinder durability and improved Operational reliability in harsh environments, such as those found in the fertilizer industry.

Figure 10 shows the estimated wear difference of pneumatic cylinders operating under ideal industrial conditions and in the harsh environments typical of fertilizer industries.

Figure 9 - Comparison of wear parameters of pneumatic cylinders under ideal and aggressive

PARAMETRO DE DESGASTE	CONDIÇÕES IDEAIS	CONDIÇÕES AGRESSIVAS	FONTE/REFERENCIA
Vida útil do cilindro	5 a 10 anos	6 meses a 1 ano	BLCH Pneumatic, MDPI
Perda de espessura metálica	<0,02 mm/ano	0,08 a 0,10 mm/ano	ISO 9223, Viana 2022
Frequência de manutenção corretiva	1 vez/ano	3 a 4 vezes/ano	ABEMI 2022, BLCH Pneumatic
Vazamentos de vedação	<2% dos ciclos	10-15% dos ciclos	BLCH Pneumatic
Fadiga de vedação / falhas de selos	Rara	Comum, acelera após 1-2 anos	Jones 2018
Abrasão da haste/pistão	Leve, mínima	Moderada a severa, presença de ranhuras	BLCH Pneumatic
Influência da umidade	Baixa (<60% UR)	Alta (>80% UR), aumenta corrosão	ISO 9223, Jones 2018
Contaminação por partículas	Pouca ou nula	Alta concentração de pó e partículas de fertilizantes	BLCH Pneumatic
Redução da força de atuação	<5%	15-25%	MDPI, BLCH Pneumatic

Source: Adapted from BLCH Pneumatic (2023); ISO 9223 (2012); ABEMI (2022); Jones (2018); MDPI (2021)

5. CASE STUDY: WEAR OF PNEUMATIC CYLINDERS DUE TO FERTILIZERS

This case study examines a real-life incident of corrosion deterioration observed in A pneumatic cylinder made of aluminum, which is used in an automated dosing system. of fertilizers in an industrial facility.

This equipment plays a fundamental role in the operation of valves and doors, being responsible for ensuring a controlled flow of solid and liquid materials during the production of the final item.

Failure or unavailability of the pneumatic cylinder can cause line stoppages. production, directly affecting the dosage of raw materials and causing deviations in quality. final product. Furthermore, unexpected interruptions in lines of this type result in costs. substantial maintenance costs, reduced production efficiency, and increased operational risks.

5.1. Operational Context and Environmental Conditions

The industrial environment under analysis has a high presence of corrosive particles. especially from sulfates and chlorides, which are found in the dust and vapors generated. during fertilizer handling. High air humidity levels (above 80%) and the

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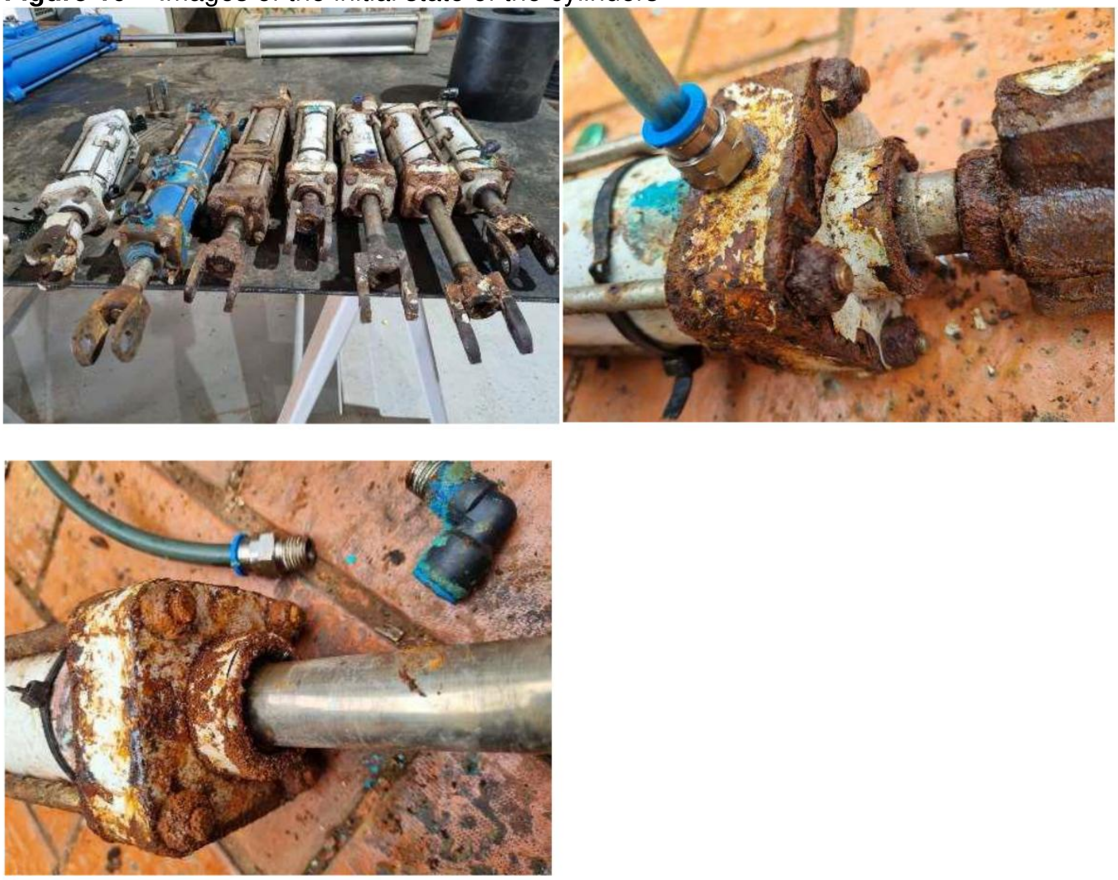
High average temperatures (ranging between 30 °C and 40 °C) exacerbate oxidation processes and galvanic corrosion in exposed metal components

The pneumatic cylinder, a crucial part of the system, operates in constant activation cycles. and rest, being continuously exposed to these hostile conditions. Despite having been designed To withstand mechanical stress and pressure changes, the equipment initially lacked a... Adequate surface protection against moisture and chemical agents.

5.2. Early Signs of Failure

During a routine check, carried out by the preventive maintenance team, the following were... No visible signs of deterioration were noted on the outside of the cylinder, such as a change in color. Paint peeling and loss of surface gloss; beginning of oxidation on the cylinder edges and in the joint area. rear; Accumulation of chemical residue on the surface; Difficulty in activating the piston due to Increased friction; Small leaks in the external seals, possibly caused by a Partial piston seizure.

Figure 10 – Images of the initial state of the cylinders



Source: Author's own work 2025

The initial assessment was carried out through direct visual inspection, supplemented with... photographs and records of the observations. Based on the severity of the damage, it was decided that... Complete disassembly of the assembly to investigate internal conditions and identify the causes.

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main factors of wear and tear.

5.3. Technical Assessment and Diagnosis

After disassembly, it was verified that the internal conditions of the cylinder were within acceptable limits. as expected. The main seals and retaining rings showed no significant wear. indicating that there was no significant internal contamination.

The problem was concentrated in the external areas and at the points of articulation, where the Contact with chemical particles and moisture occurred constantly. The outer part of the cylinder It showed significant wear at the ends, especially in the areas near the tie rods and to the rear articulation. The original protective paint was compromised, leaving the metal exposed to oxidation.

Figure 11 – Images of wear and tear shown

Source: Author's own work 2025

The bolts and tie rods became stuck due to corrosion, making it difficult to... Disassembly — an indication of ongoing chemical attack.

It has been observed that fertilizers, in both their solid and liquid forms, contain ions of Chloride and sulfate are corrosive agents that interact with aluminum, resulting in... Formation of porous oxide layers that compromise the material's strength.

A comparison with previous maintenance records indicated that the wear and tear on Cylinders operating in locations with inadequate ventilation had a 40% higher risk than cylinders installed in more open and airy areas.

5.4. Corrective Action and Preventive Measures

Based on the diagnosis, a complete cylinder recovery process was implemented, following these steps:

- Cleaning and Decontamination: A controlled chemical cleaning was performed using corrosion-neutralizing products, followed by thorough sanding of the surface to remove oxides and previous paint. This procedure ensured the removal of contaminated layers and prepared the metal for the application of a new protective layer.

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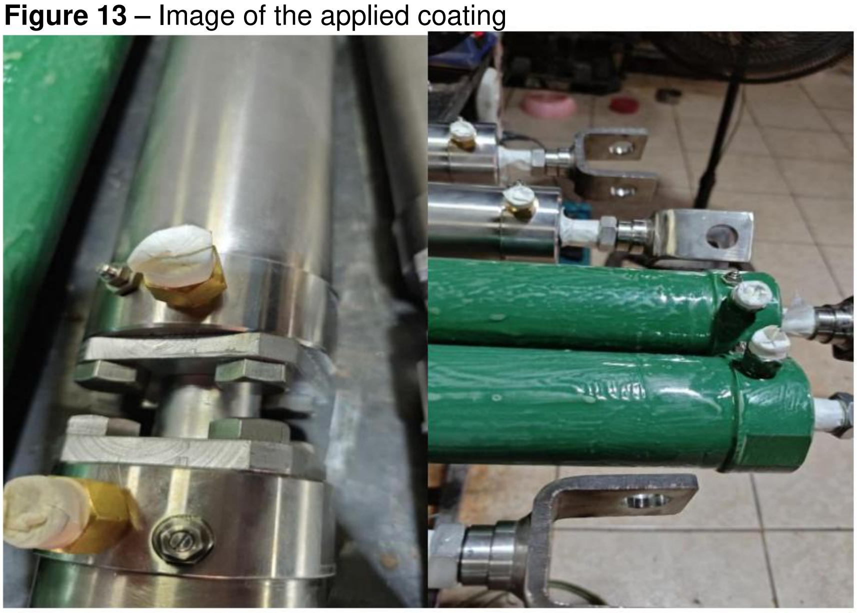
Figure 12 – Image of cleaning and decontamination

Source: Author's own work 2025

- Application of a Protective Coating: To minimize pulp accumulation and reduce exposure to corrosive agents, LOCTITE® PC 7255 coating, a two-component epoxy highly resistant to chemicals and mechanical stress, was applied. This product was selected due to its proven effectiveness in protecting against corrosion, wear, and chemical reactions, forming a dense physical barrier on the metal surface. The coating was applied in layers ranging from 0.5 mm to 1 mm thick, completely covering the sleeves and exposed areas. After the curing process, improved adhesion and a uniform finish were observed, in addition to a surface that is less prone to residue accumulation.

Figure 13 – Image of the applied coating



Source: Author's own work 2025

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•Reconditioning and Assembly: During the procedure, the scraper rings and pneumatic connections were replaced. After assembly, the cylinders underwent leak tests and functional cycles, without any leaks or anomalies in the linear movement.

Figure 14 – Assembly and reconditioning image

Source: Author's own work 2025

5.5. Results Obtained

After the intervention, the cylinder showed satisfactory performance and the

Reliability indicators have increased significantly.

The following results were observed based on comparative operational analyses:

- 60% reduction in leaks;
- 35% increase in the estimated lifespan of the cylinders after coating application;
- 15% reduction in mean time to repair (MTTR);
- Increased mean time between failures (MTBF) to 480 hours of continuous operation;
- Technical availability calculated at 99.3%.

These results demonstrate the effectiveness of predictive maintenance and preventive measures.

implemented, especially the use of the LOCTITE® PC 7255 protective coating, which

It significantly reduced the oxidation process on the surface.

5.6. Discussion and Reliability Analysis

The reliability analysis highlights the need for constant monitoring of

Performance of pneumatic cylinders through technical indicators such as MTBF and MTTR.

In addition to predictive inspections that include visual and vibration analysis.

The operating environment is undoubtedly the main factor influencing the durability of these.

equipment. In areas with poor ventilation, abrasive wear doubled due to

accumulation of solid particles and high concentration of corrosive vapors.

By using more durable materials (such as AISI 316L stainless steel) and

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High-performance polymer coatings have seen operational efficiency steadily improve.

reducing the frequency of failures due to oxidation and galvanic corrosion.

Predictive maintenance, along with regular inspections and reliability assessments,

It has proven to be the most efficient approach for anticipating failures and improving planning.

scheduled interruptions.

6. CONCLUSION

Based on the assessment carried out, it can be stated that the deterioration of pneumatic cylinders in

The hostile nature of industrial sites is essentially the result of the interaction of environmental factors and a lack of

Adequate surface protection. The maintenance and prevention actions implemented —

Especially the application of the LOCTITE® PC 7255 coating — showed positive results.

significant in reducing oxidation and extending the lifespan of components.

The case study highlights that predictive maintenance and reliability engineering should...

to work together, using field data, failure records, and technical analyses to

to provide a basis for strategic maintenance decisions.

By adopting these practices, it was possible to increase available operations and reduce...

expenses and increase the safety of the production process, demonstrating the reliability of the cylinders

The success of tires depends not only on manufacturing quality, but also on effective management.

environmental and maintenance conditions.

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"Whether you think you can or you think you can't, you're right."

To put it better: "Whether you think you're going to finish your thesis or not... well, that's up to you."

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