METHODOLOGICAL REVIEW OF HOSE TESTING MACHINE: COMPARATIVE STUDY OF DIFFERENT TESTING METHODS

Mr.Praful R.Randive[1]*, Dr. Prashant S. Kadu[2], Dr.A.R.Sontake[3], Prof. Nakul Mahalle[4], Vijay Talodhikar[5*]

[1]Research Scholar, PGTD of Computer & Electronics, Rashtrasant Tukadoji Maharaj, Nagpur University, Nagpur, and Assistant Professor in Mechanical Engineering Department, Tulsiramji Gaikwad Patil College of Engineering and Technology, Nagpur Maharashtra, India.
[2]Professor in Mechanical Engineering, Principal,Abha Gaikwad Patil College of Engineering, Nagpur, Maharashtra, India
[3]Professor,National Fire Service College, Nagpur, Ministry of Home Affairs, Government of India.
[4]Assistant Professor,National Fire Service College, Nagpur.
[5]Department of Mechanical Engineering, Tulsiramji Gaikwad Patil College of Engineering and Technology, Nagpur, Maharashtra, India.

praful.mechanical@tgpcet.com[1]
pskadu@gmail.com[2]
arsontake72@gmail.com[3]
nakul.mahalle@gmail.com[4]
v.talodhikar@gmail.com[5]

Correspondence: - praful.mechanical@tgpcet.com , v.talodhikar@gmail.com

Abstract— The efficient management of delivery hoses is important in various firefighting applications, particularly in water based systems where leakage can lead to significant operational and safety challenges. This review paper examines recent advancements in delivery hose pipe testing technologies, focusing on methodologies in different Indian and international standards for detecting and managing leaks. The research emphasizes the creation of an AI-driven leak detection system that employs acoustic listening techniques, which, although effective, tend to be labor-intensive and susceptible to human mistakes. o make leak detection better, researchers have tried using machine learning techniques like Deep Neural Networks, Convolutional Neural Networks, and Support Vector Machines to make it more accurate and efficient.. The results indicate that Thermal Imagining outperforms other models, achieving over good result in field trials, thus providing a reliable tool for operators. The paper examines the role of Internet of Things (IoT) technologies in hose integrity monitoring while addressing potential cybersecurity risks. By evaluating statistical and AI-driven failure prediction models, this study provides critical insights for selecting optimal testing methodologies for fire hose evaluation. The conclusions emphasize the significance of advanced testing technologies in enhancing the reliability and safety of firefighting operations.

Keywords—: Fire Hose, Hose testing, Structural Fire Fighting, Occupancy, Hydraulic Systems, AI-based Leak Detection

I. Introduction

Fire hoses is an important components in firefighting operations, for delivering fire extinguishing materials such as water and foam solution. Their primary function is to transport these materials from a water source to the seat of a fire, enabling firefighters to effectively combat flames and protect lives and property.

There are two kinds of fire hoses: suction and delivery

A suction fire hose is designed for drafting operations, allowing a fire engine to use a vacuum to pull water from a portable tank, pool, or other static sources. The pressure in the pipe is always lower than the atmospheric pressure. **Delivery fire hose** are used to convey water or other fire extinguishing media (such as foam) from Hydrant/Pump to the scene of fire. The pressure of water passing through is always greater than the atmospheric pressure. There are three types of delivery fire hose i.e. percolating hose (Unlined/Canvas Hose), non-percolating hose, hose reel drum.

A percolating hose is primarily used for fighting forest fires. Water seeps through the hose to protect it from glowing embers and hot ground, although this reduces water pressure. It is made from materials like flax, hemp, ramie, cotton, and vegetable fiber.

Non-percolating hoses (lined or rubber-lined) are commonly used for firefighting. They feature a reinforced jacket made of polyester or nylon with an inner layer of vulcanized rubber. This design reduces friction losses compared to percolating hoses, as they are non-porous. Non-percolating hoses are made from materials like flax, cotton, nylon, and terylene.

A hose reel drum is a cylindrical storage device made of metal, fiberglass, or plastic for hoses. It can be either permanently mounted, like wall units, or portable, attached to Fire vehicles.

During firefighting operations, a leak in the delivery hose can significantly impede the effectiveness of the response efforts. Consequently, this research initiative aims to design, develop, and evaluate a specialized testing machine for fire hoses, specifically focusing on delivery hoses, to ensure their reliability and performance under operational condition

Firefighting delivery hoses play a critical role in firefighting operations, and their performance can be a matter of life and death. The BIS of has formulated IS 636, a comprehensive standard governing the specifications and requirements for non-percolating flexible firefighting delivery hoses, with the primary objective of ensuring the quality, reliability, and performance of these critical firefighting components..

IS 636 testing involves a series of rigorous tests, including hydrostatic pressure tests, hydrostatic burst pressure tests, kink tests, change in length and diameter tests, and type tests. These tests evaluate the hose's ability to withstand internal hydraulic pressure, its burst pressure, resistance to kinking, and performance under various conditions. The results of IS 636 testing are crucial in determining whether firefighting delivery hoses meet the required standards for firefighting applications. This paper provides an overview of the IS 636 testing process and its significance in ensuring the quality and performance of firefighting delivery hoses.

"The Bureau of Indian Standards agreed to follow a new standard for India on July 10, 1988. This standard was created by a group of experts who work with rubber products and was approved by a committee that oversees petroleum and related products."

The fire hose standard has undergone revisions since its initial publication in 1958. The second revision in 1979 shifted the focus from construction-based categorization to performance-oriented classification. Recognizing advancements in fire hose quality, the Rubber Products Committee opted for a two-type classification system. Type A hoses feature rubber or rubberized fabric lining, while Type B hoses boast improved quality and elastomeric coatings.

II. Fire Hose Properties:

Pursuant to the stipulations outlined in IS 636:1988, delivery hose pipes are characterized by a distinct array of technical specifications that govern their design, construction, and performance parameters..

Physical Properties:

- Diameter: Specified sizes are 38 mm, 50 mm, 63 mm, and 70 mm.
- Length: Typically 30 meters for machine-coiled hoses.
- Coil Diameter: Type A hoses have a maximum coil diameter of 45 cm, while Type B hoses have a maximum coil diameter of 55 cm.
- Weight: Maximum weight per meter varies by hose size and type, with specified values for 38 mm and 70 mm hoses.

Material Properties:
- Inner Lining: Made of vulcanized or synthetic rubber for water, abrasion, and chemical resistance.
- Outer Cover: Made of abrasion-resistant materials like rubber or PVC.

Performance Properties:

- Hydrostatic Burst Pressure: Hoses are tested for burst pressure without failing.
- Hydrostatic Proof Pressure: Hoses must withstand 2.1 MPa (21.4 kgf/cm²) internal pressure.
- Abrasion Resistance: Tested according to Appendix C.
- Adhesion: Lining and jacket separation rate should not exceed 25 mm/min.
- Moisture Absorption: Requirements specified, with testing details not fully outlined here.

III. Actual testing procedure for defect finding in Fire Hose Pipe as per standards available in NFPA and BIS:

Hydrostatic Testing of hose is done as follows:

1. Pre-test inspection: Visually inspect the hose for any signs of damage, wear, or
2. Test setup: Couple the hose to a hydrostatic pressure testing apparatus, ensuring integration with a precision pressure gauge to facilitate accurate monitoring of pressure fluctuations.
3. Pressurization: Gradually increase the pressure to the recommended test pressure (1.5-2 times the working pressure)
4. Hold pressure: Hold the pressure for a specified time (usually 1-2 minutes) (BIS 5846:2017,
5. Inspect for leaks: Visually inspect the hose for any signs of leaks or damage.

Visual Inspection

1. External inspection: Visually inspect the hose for any signs of damage, wear, or deterioration, including cuts, abrasions, or punctures
2. Internal inspection: Use a hose inspection camera or other specialized equipment to inspect the internal surface of the hose for any signs of damage or deterioration

Pressure Testing

1. Attach the hose to a special pump that increases pressure & Connect a pressure gauge to the hose to measure the pressure..
2. Pressurization: Gradually increase the pressure to the recommended test pressure (1.5-2 times the working pressure).
3. Hold pressure: Hold the pressure for a specified time (usually 1-2 minutes).

Bend Testing
1. Bend test setup: Connect the hose to a bend test fixture or other specialized equipment.
2. Bend radius: Gradually decrease the bend radius to the recommended minimum bend radius.

Abrasion Testing
1. Abrasion test setup: Connect the hose to an abrasion test fixture or other specialized equipment
2. Abrasion cycle: Subject the hose to a specified number of abrasion cycles (usually 10,000-20,000 cycles).

Electrical Conductivity Testing (for electrically conductive hoses)
1. Electrical conductivity test setup: Connect the hose to an electrical conductivity test fixture or other specialized equipment.
2. Electrical conductivity measurement: Measure the electrical conductivity of the hose using a multimeter or other specialized equipment.

Following are some additional tests that can be performed to detect leakage in fire hoses:
1. Kelvin Test
1. Connect the hose to a Kelvin test fixture or other specialized equipment.
2. Pressurize the hose to the recommended test pressure.
3. Measure the pressure drop over a specified time period (usually 1-2 minutes).
4. Compare the pressure drop to the recommended specification.

2. Leakage Test:
1. Connect the hose to a leakage test fixture or other specialized equipment.
2. Pressurize the hose to the recommended test pressure.
3. Submerge the hose in water or use a leak detection solution.
4. Inspect the hose for any signs of leakage.

3. Ultrasonic Leak Detection Test:
1. Connect the hose to an ultrasonic leak detection test fixture or other specialized equipment.
2. Pressurize the hose to the recommended test pressure.
3. Use an ultrasonic sensor to detect any leaks or defects in the hose.

4. Acoustic Emission Test:
1. Connect the hose to an acoustic emission test fixture or other specialized equipment.
2. Pressurize the hose to the recommended test pressure.
3. Use sensors to detect any acoustic emissions or sounds that may indicate a leak or defect in the hose.

These tests can be used in conjunction with the hydrostatic test, visual inspection, and other tests mentioned earlier to detect leakage in fire hoses.

Here are some limitations of the test methods mentioned earlier for detecting leakage in fire hose pipes:
5. Hydrostatic Test
1. Limited sensitivity: Hydrostatic testing may not detect small leaks or defects in the hose.
2. Pressure limitations: Hydrostatic testing is typically limited to pressures up to 1.5-2 times the working pressure, which may not be sufficient to detect leaks at higher pressures.
3. Time-consuming: Hydrostatic testing can be time-consuming, especially for longer hoses.

6. Kelvin Test
1. Limited accuracy: The Kelvin test may not provide accurate results if the hose is not properly calibrated or if there are any variations in the test setup.
2. Sensitive to temperature changes: The Kelvin test can be affected by temperature changes, which may impact the accuracy of the results.
3.Requires specialized equipment: The Kelvin test requires specialized equipment, which may not be readily available.

7. Leakage Test
1. Limited sensitivity: The leakage test may not detect small leaks or defects in the hose.
2. Dependent on test pressure: The leakage test is dependent on the test pressure, which may not be sufficient to detect leaks at higher pressures.
3. Requires water or leak detection solution: The leakage test requires water or a leak detection solution, which may not be readily available.

8. Ultrasonic Leak Detection Test
1. Limited accuracy: The ultrasonic leak detection test may not provide accurate results if the hose is not properly calibrated or if there are any variations in the test setup.
2. Sensitive to background noise: The ultrasonic leak detection test can be affected by background noise, which may impact the accuracy of the results.
3. Requires specialized equipment: The ultrasonic leak detection test requires specialized equipment, which may not be readily available.

9. Acoustic Emission Test
1. Limited accuracy: The acoustic emission test may not provide accurate results if the hose is not properly calibrated or if there are any variations in the test setup.
2. Sensitive to background noise: The acoustic emission test can be affected by background noise, which may impact the accuracy of the results.
3. Requires specialized equipment: The acoustic emission test requires specialized equipment, which may not be readily available.

10. Common limitations
1. Human error: All test methods are subject to human error, which can impact the accuracy of the results.
2. Equipment limitations: All test methods require specialized equipment, which may have limitations in terms of accuracy, sensitivity, and reliability.
3. Test setup variations: Variations in the test setup, such as temperature, pressure, and humidity, can impact the accuracy of the results.
Incidence of Failure:-
On December 9, 2011, a calamitous conflagration of unprecedented proportions ravaged the Advanced Medicare and Research Institute (AMRI) Hospital in Dhakuria, Kolkata, precipitating disastrous repercussions. The inferno, purportedly originating in the hospital's subterranean level around 2:30 am, propagated with alarming rapidity due to the presence of highly flammable materials in the pharmacy and storage compartments. Despite being detected by local inhabitants around 3:30 am, the fire was not communicated to the Fire Control Room until approximately 4:10 am, thereby exacerbating the severity of the catastrophe. A pivotal factor that substantially contributed to the intensity of the blaze was the catastrophic failure of the building's fire suppression system, which rendered efforts to contain the inferno woefully ineffectual.

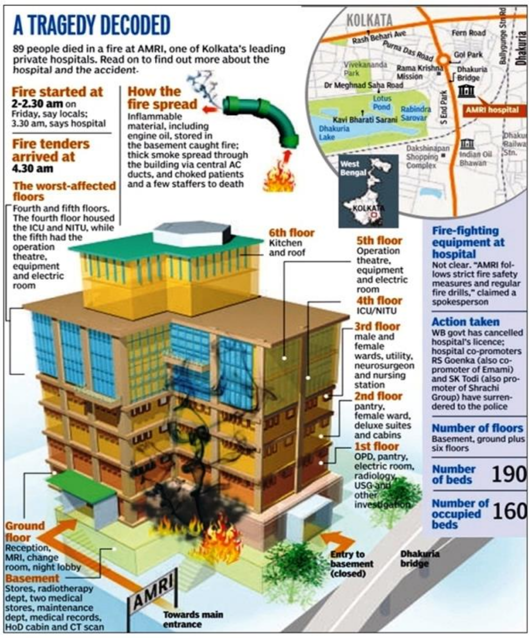

Fig.1Tragedy Decoded

Advanced Techniques to Overcome Limitations:

1. Ultrasonic testing: Ultrasonic Ultrasonic testing constitutes a sophisticated non-destructive evaluation paradigm that leverages high-frequency acoustic waveforms to discern and typify intrinsic anomalies, discontinuities, or degradations within materials, harnessing the tenets of acoustic wave dissemination to yield nuanced elucidations regarding the material's intrinsic structural cohesion and morphological stability..

2. Thermal imaging: Thermal imaging is a diagnostic technique that utilizes infrared cameras to visualize and detect temperature anomalies, leveraging the principle that damaged or leaking areas often exhibit distinct thermal signatures, allowing for the identification of potential issues through non-invasive thermal mapping.

3. Advanced materials testing: Uses techniques like scanning electron microscopy (SEM) to analyze the material structure and detect defects.

By adopting these advanced techniques, firefighters and maintenance personnel can more accurately detect fire hose failures, ensuring safer and more effective firefighting operations.

As per the guidelines outlined in IS 636: 1988 for non-percolated hose pipes, the following tests are conducted as part of the conventional test procedure:

1) Scope 2) Terminology 3) Types of test like acceptance test, routine test, types of houses 4) classification of test n the basis of workmanship, rootproffing, internal diameter, mass, coil diameter, hydrostatic burst pressure, kink test, change in length, The evaluation encompasses a range of tests, including assessments of dimensional stability, interfacial bonding durability, abrasion resistance, and resistance to environmental factors such as heat, moisture, oil, and ozone, with specific focus on Type B hoses for moisture absorption, oil resistance, and ozone resistance.

1. The sampling plan for determining acceptability a) Routine Test.

a) Determining Adhesion Strength: A Step-by-Step Guide

To evaluate the adhesive tenacity of a hose, a bespoke testing protocol is utilized. Figure 2 illustrates the paradigmatic apparatus employed for the Adhesion Test. The test entails the meticulous preparation of a cylindrical specimen, measuring 25.0 ± 0.5 mm in length, excised perpendicular to the hose's longitudinal axis. Subsequently, the specimen undergoes a deliberate inversion process, thereby exposing the innermost lining or outermost cover to facilitate a comprehensive assessment of the adhesive bond.

i. Test Apparatus

The test apparatus consists of a mandrel that fits snugly into the test piece, with a central shaft made of stainless steel. The mandrel is supported in a way that allows it to rotate freely, minimizing friction. A grip is attached to the lining or cover, and weights are applied to exert a load on the test piece.

ii. Test Procedure

To evaluate the adhesion properties of the lining/reinforcement interface, a test piece is carefully positioned onto a mandrel and subjected to a tensile force via a grip apparatus loaded with a cumulative Mass [M] of 2.5 kg, following which the extent of lining separation is quantitatively assessed after a duration of 1 minute. Conversely, the adhesion characteristics of the cover/reinforcement interface are ascertained by repeating the aforementioned procedure with a distinct test piece, albeit without reversing its orientation, and utilizing a total weight of 4.5 kg to induce the requisite stress.

iii. Test Report

The test report should encompass a comprehensive array of pertinent details, including the date on which the test was conducted, specific identification particulars of the hose subjected to testing, and a precise quantification of the extent of separation, if any, observed after a duration of 1 minute, thereby providing a thorough and definitive assessment of the hose's adhesion strength.

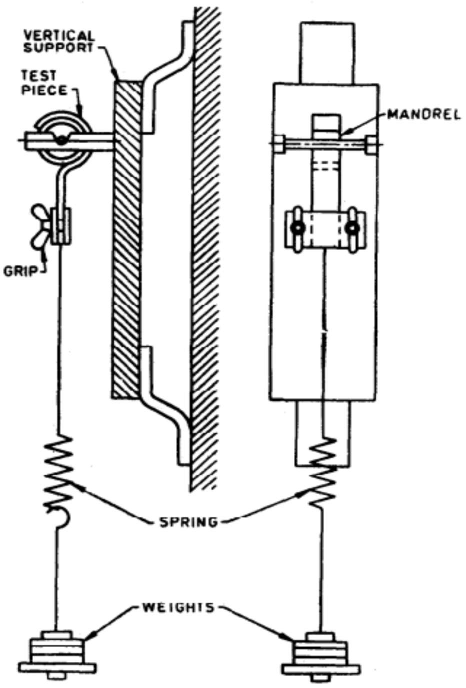

Fig. No 02 Typical Apparatus for the Adhesion Test

2. Abrasion Resistance Test:

Abrasion Resistance Test: Evaluating Hose Durability.The abrasion resistance test assesses a hose's ability to withstand rough handling and harsh environments, simulating the conditions it may encounter during fire operations. The test evaluates the hose's resistance to wear and tear, which can occur when it is dragged over rough surfaces, bent around building corners, or subjected to continuous chafing due to pump vibrations. Fig.No.03 indicates general arrangement of Abrasion Testing Machine.

i.Test Apparatus

A specialized test apparatus is used to determine the hose's abrasion resistance. The apparatus consists of:

1.. A stabilized hydrostatic pressure source is utilized to sustain a consistent pressure of 1.7 MPa (700 kPa) within the test specimen, thereby ensuring a steady-state condition.

2. A mechanical apparatus featuring a reciprocating motion is employed to subject the test piece to abrasive forces, thereby simulating wear and tear..

3. A bespoke abrasive entity, consisting of a 25 mm wide and 300 mm long strip of grade 50 'X' weight aluminum oxide abrasive paper, meticulously bonded via a high-strength adhesive matrix, is employed to intentionally induce calibrated surface degradation on the specimen, thereby facilitating a controlled wear simulation.

4. 4. An electrically powered air blower is incorporated into the system to effectively remove abraded debris and fluff from the test area, thereby maintaining a clean and controlled environment.

ii. Test Procedure

The test procedure involves:

1. Mounting the abrading strip at a 45° angle to the horizontal axis of the test piece and a 20° angle to the direction of reciprocating action.

2. Adjusting the apparatus to achieve 50-60 cycles of reciprocating movement per minute, with a stroke length of 230 mm and a downward force of 1.58 kgf (15.5 N) on the test piece.

3. Connecting the test piece to the pressure source and filling it with water to expel air.

4. The test protocol involves subjecting the specimen to a sustained hydrostatic pressure of 0.7 MPa (700 kPa) for a minimum duration of two minutes prior to initiating the abrasion test, thereby ensuring a stabilized pressure condition.

5. The test apparatus is equipped with a sophisticated metering device, such as a stroke counter, which accurately quantifies and records the cumulative number of cycles endured by the test piece until catastrophic failure occurs, as evidenced by a burst or rupture..

6. Repeating the test three times with new abrading strips and test pieces, and calculating the average value.

iii. Test Results:-

The empirical data garnered from the test yields a quantifiable assessment of the hose's resilience to abrasive forces, a parameter of paramount importance in evaluating its overall durability and operational efficacy in environments characterized by extreme conditions. The abrasion resistance of the hose is subsequently determined by calculating the mean number of cycles withstood by the test piece prior to catastrophic failure, thereby providing a definitive metric for assessing its performance capabilities.

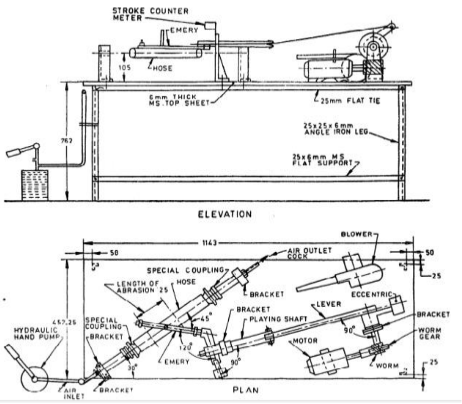

Fig. No 03.Genaral Arrangement of Abrasion Testing Machine

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3. Methods of Test for Moisture Absorption:

Methods for Testing Moisture Absorption and Heat Resistance

I.Moisture Absorption Test:-

We test a hose to see how much water it absorbs. First, we heat a 600mm piece in an oven for 3 hours. Then, we weigh it, fold it, and put it in water for 6 hours. After that, we dry it and weigh it again after 2 hours.

II. Heat Resistance Test

To test how well a hose resists heat, we take five 1-meter long samples from the hose. We connect these samples to a water source, fill them with water, and remove any air. Then, we lay the samples flat on a hard surface and apply water pressure. Next, we place a hot steel cube on top of each sample and measure how long it takes for the sample to burst. We repeat this test for all five samples and use the results to determine the hose's heat resistance..

i. Test Apparatus

The test apparatus for the heat resistance test includes a laboratory furnace, steel cubes, a pressure source, a stopwatch, steel tongs, and a guard made of steel wire mesh. The furnace is used to heat the steel cubes to 60°C, and the pressure source is used to maintain a hydrostatic pressure of 0.7 MPa in the test piece. The stopwatch is used to record the time elapsed until the test piece bursts.

ii. Test Procedure

To test heat resistance, we heat a steel cube to 60°C for 30 minutes. Then, we fill a test piece with water and put it on a hard surface. We place the hot steel cube on the test piece and wait for it to burst. We record how long it takes and do this test five times.

Conclusion:

According to IS 636, a series of standardized tests are prescribed to assess the performance characteristics of hose pipes. This standard provides a comprehensive overview of the IS 636 testing process and its significance in ensuring the quality and reliability of firefighting delivery hoses.

Findings indicate that Thermal Imaging is a highly effective method for leak detection, offering superior accuracy and cost efficiency in field trials, making it a reliable tool for operators. Additionally, the integration of IoT technologies plays a pivotal role in enhancing hose integrity monitoring. However, it also necessitates addressing potential security vulnerabilities associated with these systems.

This study concludes that hydrostatic pressure testing significantly impacts hose performance, material selection and hose design are crucial for withstanding maximum pressure limits in burst pressure testing, and leakage testing effectively detects leaks and defects. Pressure testing, burst pressure testing, leakage testing, and flow rate testing are all essential for ensuring the quality and reliability of fire hose pipes, with all four testing parameters being of high importance

A comparative analysis of various statistical and machine learning models for failure prediction underscores selecting appropriate methodologies to enhance the reliability and safety of hose systems. These advancements collectively contribute to more efficient monitoring and management practices within the industry.

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