ENHANCING FIRE HOSE MAINTENANCE EFFICIENCY WITH THE INNOVATIVE HOSE CLEANER (IHC) IN ARFF SERVICES

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ABSTRACT
This study aims to develop the Innovative Hose Cleaner (IHC) as an efficient solution for fire hose maintenance in Aircraft Rescue and Fire Fighting (ARFF) units. The manual cleaning is time-consuming and inefficient, requiring significant manpower and water usage. The IHC is designed to address these issues by providing a more effective and time-saving alternative. This research adopts the Borg & Gall development model, which typically involves ten stages. However, for efficiency, the process was condensed into six key phases: 1) Identifying potential and problems, 2) Data collection, 3) Product design, 4) Design validation, 5) Product testing, and 6) Product revision. This streamlining was necessary to facilitate faster iteration while maintaining rigorous validation standards. After design validation and product revision, the IHC was tested to evaluate its performance. Results showed that the IHC significantly reduced cleaning time, water usage, and manpower while improving the cleanliness of fire hoses. The product was deemed highly effective and suitable for implementation, offering a practical solution for enhancing fire hose maintenance in ARFF units. It is hoped that the IHC can be widely adopted, contributing to more efficient operations and improved safety in the aviation industry.

Keywords: *Aircraft Rescue and Fire Fighting (ARFF), aviation safety, efficiency, fire hose cleaning system, fire hose maintenance, Innovative Hose Cleaner.*

INTRODUCTION

In the aviation sector, safety is paramount, with strict regulations and protocols governing every aspect of airport operations. Aircraft Rescue and Firefighting (ARFF) services are at the forefront of these safety measures, tasked with responding swiftly to emergencies, particularly fire-related incidents [1], [2]. The critical nature of ARFF operations is underscored by their unique challenges, including large-scale fires involving aircraft and airport infrastructure, hazardous materials, and the need to evacuate and protect passengers, crew, and airport personnel under extreme conditions [3]. ARFF teams are required to perform under high-pressure situations where every second counts, making the reliability and functionality of their equipment essential to successful outcomes [4].

Fire hoses are indispensable among the various tools and equipment used by ARFF personnel [5], [6]. These hoses are the primary conduit for delivering water, foam, or other firefighting agents to suppress and control fires [7]. The effectiveness of fire suppression during aviation emergencies, whether in aircraft fires or fires occurring on airport grounds, largely depends on the ability of the fire hoses to perform optimally under intense conditions [8], [9]. A malfunctioning hose can significantly impair firefighting efforts, potentially leading to catastrophic consequences, including escalating fires and people losing their lives [10] .

Maintaining fire hoses in peak working conditions is therefore crucial. Proper maintenance ensures that hoses remain free of contaminants, physical damage, and degradation that could compromise their structural integrity [11], [12]. Poorly maintained hoses may develop leaks, blockages, or weakened sections, which can reduce water pressure, disrupt firefighting operations, or cause complete failure during use. Furthermore, fire hoses that are not cleaned regularly may accumulate foam residues and other firefighting agents, damaging the hose material and reducing fire suppression effectiveness during critical moments. The consequences of inadequate hose maintenance extend beyond operational inefficiency; they can result in delayed emergency response times and hinder the containment of fires, posing significant risks to human life and property. In high-risk environments such as airports, where the volume of passengers and the complexity of operations are immense, the reliability of ARFF equipment, especially fire hoses, is directly linked to the overall safety and security of the aviation ecosystem.

During the On-the-Job Training at Jenderal Ahmad Yani International Airport, Semarang, the author gained valuable ARFF operations experience, including remote attack exercises. One of the critical challenges observed was the manual cleaning of fire hoses after use, conducted outdoors. This process was labor-intensive and time-consuming and risked damaging the hoses, as they were cleaned on asphalt surfaces where sharp debris, such as gravel, could adhere to them. A similar issue was noted at Raja Haji Fisabilillah International Airport, where Yoga Pratama Hiyadat and Ika Fathin Resti Mertanti (2023) emphasized the importance of fire hose maintenance to ensure their continued functionality. This concern was also echoed in the case of KM Bukit Siguntang, where the readiness of fixed firefighting equipment was highlighted, stressing the necessity of maintaining hoses in optimal condition for emergency use [13].

Given these high stakes, there is a growing demand for more efficient, reliable, and standardized methods of maintaining firefighting equipment. While widely used, traditional manual cleaning and maintaining fire hoses are often labor-intensive, time-consuming, and susceptible to human error. As air traffic volumes increase and airports expand, the need for an advanced, automated approach to hose maintenance has become more urgent. Inadequate fire hose cleaning can compromise equipment integrity and firefighting operations, leading to significant safety hazards and operational inefficiencies. The consequences of neglecting proper cleaning protocols are far-reaching, affecting not only the lifespan of the equipment but also the effectiveness of emergency response efforts. For example, over 60% of fire hose failures can be attributed to defects such as fistulas and breaks, which are often exacerbated by improper cleaning practices that allow debris and contaminants to accumulate [14]. Moreover, corrosion of reinforcing strands within the hoses can go unnoticed, posing a significant risk of catastrophic failure during critical operations [15]. These risks highlight the urgent need for a solution that ensures thorough, consistent, and efficient fire hose maintenance.

Inadequate cleaning not only compromises equipment integrity but also impacts overall operational efficiency. One of the significant challenges is biofilm formation, which can occur in water supply systems if hoses need to be cleaned appropriately. Biofilm buildup restricts water flow, increases corrosion risks, and can ultimately hinder the effectiveness of firefighting efforts [16]. Furthermore, human error plays a critical role in poor maintenance practices. Mistakes in cleaning procedures can lead to improper hose care, reducing both the reliability and safety of essential firefighting equipment [17]. These factors underscore the need for automated solutions that eliminate inconsistencies caused by human error and ensure the consistent, thorough maintenance of fire hoses.

In response to these challenges, the development of new technologies, such as the Innovative Hose Cleaner (IHC), represents a significant leap forward in addressing the maintenance needs of ARFF services. By automating the cleaning and drying processes, the IHC offers a solution that enhances the operational efficiency of ARFF teams and ensures that fire hoses remain in optimal condition and ready for deployment in life-saving firefighting operations.

METHODS

This research adopts the Borg & Gall development model, which typically includes ten stages to ensure the developed product's feasibility [18]. For this study, the ten stages were streamlined into six key phases: 1) Identifying potential and problems, 2) Data collection, 3) Product design, 4) Design validation, 5) Product testing, and 6) Product revision. The objective is to create an innovative and efficient solution for fire hose maintenance by developing the IHC [3], [19], [20].

Identifying Potential and Problems

This phase identifies manual fire hose cleaning challenges at Jenderal Ahmad Yani International Airport, where cleaning processes are laborious and time-consuming. The study explores these issues, particularly their impact on equipment quality and firefighting efficiency.

Data collection

Observational data from firefighting units revealed that manual cleaning on rough surfaces like asphalt leads to contamination and increased hose wear. The study aimed to develop a product to address these inefficiencies by automating the cleaning and drying processes.

Product Design

Based on field data, the IHC was designed to meet the specific needs of aviation firefighting units. The device aims to streamline the hose cleaning process, reducing labor and time while improving maintenance standards.

Design Validation

Experts were consulted to evaluate the prototype based on several criteria, including effectiveness, efficiency, and ease of use. A Likert scale was employed for expert feedback, and a rating system was used to assess product feasibility.

Table 1. Validation Criteria

Score	Criteria
80% < P ≤ 100%	Highly Feasible
60% < P ≤ 80%	Feasible
40% < P ≤ 60%	Moderately Feasible
20% < P ≤ 40%	Less Feasible
0% ≤ P ≤ 20%	Not Feasible

Source: Sedarmayanti, 2002

The system feasibility analysis was conducted using a 5-point Likert scale to calculate the ideal score, which was then converted into a formula for evaluation. After obtaining the scores, the data were grouped into five intervals and translated into quantitative data, as shown in Table 1. This process followed guidelines from established references [21].

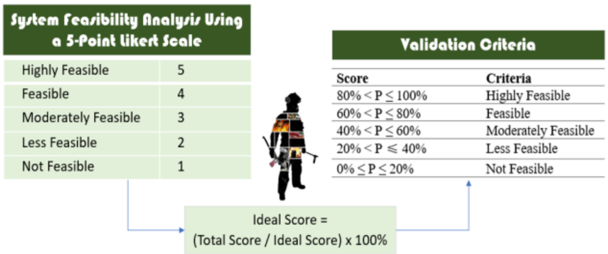

Figure 1 Data Analysis Techniques

Product Testing

Once validated, the IHC prototype underwent field testing. This phase was critical for assessing how well the IHC performed in real-world conditions, particularly regarding cleaning efficiency, time-saving, and ease of operation.

Product Revision

Based on the feedback from the testing phase, revisions were made to the prototype to enhance its performance further. The final product aimed to provide a reliable and efficient solution for fire hose maintenance, ensuring it is ready for broader use in aviation firefighting environments.

RESULTS AND DISCUSSION

1. Identifying Potential and Problems

Initial Analysis of Needs

The first stage in developing the IHC prototype involved conducting a needs analysis through preliminary observations of the ARFF services at Jenderal Ahmad Yani International Airport, Semarang, in October 2023. The research revealed that the current method of fire hose cleaning is inefficient and takes up significant time and effort. Furthermore, the cleaning process is often conducted on asphalt or concrete, which can cause dirt and debris to adhere to the hose, defeating the purpose of cleaning.

Current System

The cleaning process at the ARFF unit in Jenderal Ahmad Yani International Airport is entirely manual. This method is time-consuming and still involves using surfaces like asphalt or concrete for washing, which can lead to dirt reattaching to the hose. This inefficiency in cleaning procedures highlights the need for a more effective solution.

Desired System

The limitations of the current process inspired the researcher to develop a more efficient system, leading to the design of the Innovative Hose Cleaner prototype. This tool streamlines the cleaning process, providing a more accessible and reliable method for ARFF personnel to maintain firefighting hoses.

2. Product Design

The IHC prototype is designed to provide a more efficient and automated solution for cleaning fire hoses. The design consists of several vital components, optimizing the cleaning, drying, and rolling processes. Below is a detailed explanation of each part.

The framework of the Tool

The IHC is supported by a robust iron frame that is the foundation for mounting various components, including the electric motor, battery, cables, water drainage plates, and acrylic panels covering the machine. Iron was chosen for the frame due to its strength and stability, ensuring the structure remains steady even during operation when vibrations occur. To prevent corrosion, the frame is coated with paint, minimizing the risk of rust when water is exposed.

Figure 2 illustrates the bare frame, designed to hold all internal systems in place

Cleaning Brushes and Water Steam System

The IHC's cleaning brushes are strategically placed at the front of the machine for maximum cleaning efficiency. These brushes, operated by an electric motor, rotate in a coordinated manner, ensuring the hose's top and bottom surfaces are cleaned simultaneously as the hose passes through. The motor drives the brushes using a pulley system attached to the shaft's right side, ensuring a steady and decisive scrubbing action. The brushes are made from durable gallon brush materials, mounted on a 10mm diameter iron shaft, and measure 32cm in length.

This setup allows the fire hose to be thoroughly cleaned in one pass, significantly reducing the manual effort and time required compared to traditional methods.

Figure 3 shows the arrangement and operation of the cleaning brushes

Drying System

After the cleaning stage, the IHC utilizes a high-powered blower to ensure quick and effective fire hose drying. The blower directs airflow through holes distributed along two pipes at the machine's top and bottom. This ensures that the entire surface of the hose is evenly exposed to the drying air, speeding up the drying process. This system is particularly effective in reducing the time required for manual drying, which typically involves laying the hose out under the sun.

Figure 4 depicts the blower-based drying system integrated within the IHC.

Hose Rolling Mechanism

At the final stage of the cleaning and drying process, the IHC features an electric motor-powered hose rolling mechanism. This system allows the fire hose to be automatically rolled after it has been cleaned and dried. The mechanism includes two iron hooks designed to hold the ends of the hose (including the couplings), making it easy for the hose to be fed into the machine for rolling. Once the rolling process is complete, the hose can be easily detached from the machine, significantly reducing the effort and time required by personnel in the post-cleaning process.

Figure 5 shows the layout of the hose rolling system

Electrical and Power System

The IHC's electrical system is designed for operational efficiency and includes the following components: **a) Battery as the Main Power Supply.** The IHC is powered by a 12-volt electric bicycle battery with a 12 Ah capacity, chosen for its durability and ability to sustain long-term operations of the electric motors. Future updates to the machine will incorporate a 20 Ah battery to increase amperage capacity. The electric bicycle battery was selected over conventional motorcycle batteries due to its larger capacity, faster charging time, and enhanced operational endurance. **b) Switch Controller.** This component controls the machine's operational state, allowing users to turn it on or off as needed quickly. **c) Dimmer for Motor Speed** A dimmer is included to regulate the speed of the cleaning brushes and hose roller, giving operators control over the intensity of the cleaning and rolling process based on those conditions. **d) Brush Motor and Rolling Motor.** Separate motors power the cleaning brushes and the hose rolling mechanism. These motors ensure that both processes are automated and efficient, eliminating the need for manual labor. **e) Water Pump.** The water pump supplies pressurized water to the steam cleaning system, ensuring the hose is thoroughly washed as it passes through the machine.

3. Validation

Each process of the Innovative Hose Cleaner (IHC) was thoroughly tested to evaluate its performance, identify potential challenges, and highlight areas needing improvement. The validation process was carried out on the system to ensure that every component functioned as expected and to pinpoint any issues or parts requiring refinement. Expert validators assessed the IHC across several critical aspects.

Expert Tool Validator Assessment

The first validation was conducted by an expert tool validator who focused on the ease of maintenance, safety, structural durability, and operational performance of the IHC. The results of this assessment are shown in **Table 2** below:

Table 2. Expert Tool Validator Assessment

Aspect	Score
Ease of Maintenance	10
Safety	10
Structural Durability	10
Operational Performance	10
TOTAL	**40**

Table 2 shows the tool validator's total score of 40, resulting in an ideal score of 100%. This indicates that the tool received a high assessment from the expert tool validator.

Table 3. Expert Material Validator Assessment

Aspect	Score
Cleaning Effectiveness	10
Ease of Use	9
Prototype Reliability	9
User Comfort	8
Energy Efficiency	9
TOTAL	**45**

Table 3 shows the material validator's total score of 45, which leads to an ideal score of 90%. This reflects a high rating from the expert material validator. The average ideal score from both validators, **95%**, places the **IHC** in the "highly feasible" category. Therefore, it can be concluded that the IHC is highly suitable for use and can proceed to the trial phase.

4. Design Revisions

The IHC was validated or inspected by material and tool experts, who revealed several areas for improvement. Although the validators awarded the prototype an ideal score, placing it in the "highly feasible" category, aspects of the tool still need refinement. These adjustments aim to enhance the IHC's overall efficiency and functionality.

Feedback from Tool Experts

The expert validators suggested that the IHC could be further improved by designing it more **multifunctional**. By incorporating additional adjustments and developments, the product could become more practical and efficient for users, addressing various operational needs beyond the initial purpose. This would make the IHC more versatile, enabling it to cater to broader requirements in fire rescue operations.

Feedback from Material Experts

While the IHC was recognized for its innovation, the material experts provided critical recommendations for future developments, including **Inlet Adjustment:** The hose inlet should be adapted to accommodate different sizes of water hoses for a more universal application. **Water Disposal System:** A drainage system should be added to efficiently discharge the used water, ensuring that residual water from the cleaning process is removed through an outlet hose. **Control Buttons and User Guide:** To enhance ease of use, it was recommended that control buttons be clearly labeled, with corresponding descriptions provided in the manual. The manual should also include detailed illustrations of the tool's components for users to reference quickly.

5. Product Testing

Product testing was conducted after the validators deemed the IHC feasible and made revisions based on their feedback. This testing phase evaluated whether the IHC operates effectively and meets the researchers' expectations. The testing process focused on critical aspects such as operational performance, durability, and safety. Figure 6 shows the IHC testing process, which took place at the Aviation Fire and Rescue study program of Poltekbang Palembang. The trial compared the manual hose cleaning method with the use of the IHC. Several parameters were measured during the testing, including cleaning time, water usage, hose cleanliness, and labor requirements. The following table presents the results of the trial using a sample hose.

Table 3. Product Testing Results

Parameter	Manual	IHC
Cleaning Time	45 minutes	20 minutes
Water Usage	More	Less
Cleanliness Level	80%	85%
Labor Required	4 people	2 people

The table above demonstrates that manual cleaning takes significantly longer (45 minutes) than IHC (20 minutes). Additionally, the IHC uses less water, offers a slightly higher level of cleanliness (85%) compared to manual cleaning (80%), and requires fewer personnel (2 people for IHC versus four people for manual cleaning). From these results, it can be concluded that the IHC is more efficient and effective than traditional manual cleaning methods. The IHC reduces cleaning time, conserves water, improves hose cleanliness, and reduces labor requirements. Thus, the IHC presents a highly beneficial solution for fire hose maintenance processes.

Discussion

The IHC validation, revision, and testing results revealed several important insights into the tool's effectiveness and practicality, specifically compared to traditional, manual hose cleaning methods.

Validation and Feedback from Experts

The validation process, conducted by both tool and material experts, provides a solid basis for the IHC's viability. Tables 2 and 3 show that the validators rated the system highly, particularly on operational performance, durability, and cleaning effectiveness. The validation scores indicated that the IHC is categorized as "very suitable," with both validators offering specific recommendations for future improvements. These revisions, especially the suggestions for making the tool multifunctional and adding features like adjustable hose inlets, water drainage, and clear control instructions [22], enhance the tool's usability and safety for fire and rescue personnel. The focus on user-centered design and maintenance-friendly features supports the growing body of literature emphasizing practicality and efficiency in equipment used in firefighting operations [23].

Efficiency Gains in Hose Cleaning

The product testing results in Table 4 demonstrate the tangible benefits of using the IHC compared to manual cleaning methods. Time is a critical factor in firefighting operations, and the IHC significantly reduces the time required for hose cleaning from 45 minutes to just 20 minutes. This reduction can be attributed to the automated cleaning system, which uses rotating brushes and a high-efficiency motor to ensure thorough cleaning with minimal manual intervention. Research on automated cleaning systems shows that such efficiency improvements are expected when automation is introduced [24]. Furthermore, the IHC's water conservation ability stands out. The tool requires less water than manual methods, which is a crucial advantage given the importance of sustainable resource use in firefighting operations. The importance of water conservation in such scenarios is well-documented, particularly in areas where access to clean water may be limited (Gusti et al., 2024).

Improved Cleanliness and Labor Savings

In addition to reducing cleaning time and water usage, the IHC enhances the cleanliness level of the hoses. The 85% cleanliness level achieved by the IHC surpasses the 80% level from manual cleaning. While the difference may seem small, in firefighting, even a marginal increase in cleanliness can help maintain hose performance and extend the lifespan of equipment. As highlighted in previous studies, cleanliness and proper maintenance of firefighting hoses directly impact their durability and performance under pressure [25]. Another crucial benefit of the IHC is the significant reduction in personnel required for the cleaning process. While manual cleaning involves four individuals, the IHC allows the same task to be completed by two people, thereby cutting labor in half. This reduction in manpower requirements improves the overall efficiency of firefighting units and reduces physical strain on personnel, which is essential in maintaining their readiness for emergencies [26].

Relevance to the Broader Context of Firefighting

The development and validation of the IHC align with broader trends in firefighting technology, particularly the growing emphasis on **automation**, **resource efficiency**, and **operational performance**. Firefighting, especially in high-risk environments like airports, demands equipment that is reliable, easy to maintain, and capable of withstanding rigorous conditions. The IHC addresses these needs by automating the hose cleaning process, reducing manual labor, minimizing human error, and improving overall equipment readiness. The broader firefighting community increasingly prioritizes tools and technologies that streamline operations and reduce response times. In this context, the IHC represents a shift towards **automation in equipment maintenance**, which is becoming a key focus area as fire departments strive to enhance their operational efficiency. By automating routine but essential tasks like hose cleaning, the IHC ensures that ARFF teams can focus on core firefighting activities while keeping their equipment in top condition. This reduces the burden of labor-intensive maintenance work and ensures that firefighting hoses are always ready for emergency deployment.

In addition to reducing manual labor, the IHC contributes to **resource efficiency**, particularly in using water and cleaning agents, which are often overused in manual cleaning processes. As firefighting operations seek to optimize resource usage—both for environmental reasons and to manage costs—the IHC's ability to use less water and energy while delivering high cleanliness levels is a significant advantage. This capability aligns with broader **sustainability goals** that are becoming increasingly important in the public service sector, including firefighting departments.

Moreover, as **fire departments globally** look to adopt more advanced, reliable, and automated equipment, the IHC's proven effectiveness positions it as a valuable addition to the firefighting arsenal. Its potential to reduce **response times**, improve equipment readiness, and extend the lifespan of essential firefighting tools makes it an attractive solution for ARFF units and other firefighting organizations. Ensuring that critical firefighting equipment, such as hoses, are maintained to the highest standards, the IHC contributes to **enhanced operational safety** and **readiness**—key priorities in the firefighting profession [27]. The IHC’s relevance in this broader context suggests it has potential for wider adoption beyond airport rescue services, including municipal fire departments and industrial fire response teams. These organizations also face challenges related to the efficient maintenance of firefighting equipment, and the IHC’s proven results in reducing cleaning times, improving hose longevity, and enhancing operational efficiency can be highly beneficial across various firefighting contexts [27].

Potential for Further Development

While the IHC has demonstrated excellent performance and has been validated for its effectiveness, there is substantial potential for further enhancements based on feedback from validators and real-world testing. One key area for improvement is the **addition of multifunctionality** to the IHC. Expanding its capabilities beyond hose cleaning could transform it into a more versatile tool, addressing other critical maintenance tasks within firefighting units. For instance, incorporating features such as automated drying, pressure testing, or even minor repairs could increase its utility and reduce the need for additional equipment, streamlining operations for ARFF teams.

Moreover, enhancing the **control system** of the IHC is another avenue for development. Currently, while the system is functional, making it more intuitive could further boost user engagement and ease of use. Implementing a user-friendly interface with digital displays, clearer indicators for operational status, and automated safety checks could greatly improve the overall experience for personnel. These improvements would ensure that the tool is efficient and simple to operate, even for those with limited technical expertise. This is especially important in high-stress situations, where ease of use can significantly reduce response times and operational errors.

Incorporating **ergonomic and design features** that promote portability and durability would also expand the IHC's practicality in diverse operational environments. For example, designing a more compact, lightweight model would make it easier to transport, especially in field operations or during rapid deployment scenarios. Additionally, enhancing the robustness of materials used for the IHC could ensure its longevity in harsh environments, increasing its cost-effectiveness over time.

Finally, continued **testing and refinement** in operational settings, with feedback loops from end users, will be essential for identifying additional areas for enhancement. As firefighting technology evolves, the IHC should also remain adaptable, integrating new advancements in materials, cleaning agents, and automation technologies. By maintaining a flexible development approach, the IHC can continue to meet the growing demands of ARFF teams and support the critical mission of aviation safety. These future developments could extend the tool's lifespan and ensure that it continues to meet the evolving needs of modern firefighting operations, positioning the IHC as an indispensable tool in the firefighting equipment arsenal.

CONCLUSION

The **IHC** has proven to be an effective solution for improving the fire hose cleaning process. Expert validation shows high ratings, placing the tool in the "very suitable" category. Based on feedback, improvements were made, including adjustments to the hose inlet, drainage, and clearer control instructions. Testing results show that the IHC is more efficient than manual cleaning. It reduces cleaning time, uses less water, and requires fewer personnel. Overall, the IHC offers a practical and effective way to enhance firefighting operations, making it a valuable tool for fire hose maintenance.

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