EVALUATION OF THE EFFECTIVENESS OF SPRINKLER FIRE PROTECTION SYSTEMS

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Abstract. Along with the development of cities, increase in production facilities and production technologies today, compliance with fire safety requirements is becoming increasingly important. Effective fire safety measures help prevent tragedies and save people’s lives by quickly detecting and responding to fires, reducing material damage by protecting buildings, equipment and other values from fire damage. They help avoid major financial losses that can result from the fire and keep businesses running smoothly. Automatic fire- extinguishing systems operate continuously and without human intervention, meaning they can respond quickly to a fire at any time, even if there are no people in the room. These systems automatically detect the origin of the fire and begin to extinguish it at an early stage, thereby significantly reducing the damage caused by the fire and protecting human lives. The automatic water fire-extinguishing system is an effective fire safety means that significantly reduces the threat of fire spreading and ensures the safety of the building and its users if its operational capacity is regularly maintained and tested. A study was conducted in which the authors of the article examined and compared the experiences of other countries in the operation of sprinkler sprayers for automatic water fire extinguishing systems and conducted an experiment in how the run-off time for the spray flask of the automatic water fire sprinkler system varies, depending on the year of production. As part of this study, the authors investigated also how the timing of the spray flask of the automatic water fire sprinkler system varies depending on the year of production. The effectiveness of the automatic water fire sprinkler system was tested, and recommendations were made to improve its operational capability effectively.

Keywords: fire, firefighting, fire sprinkler system, operating time, operational efficiency.

Introduction

Nowadays, production units and cities are evolving using modern technologies and sustainable solutions. As cities become innovative, inclusive and environmentally friendly spaces, innovative approaches such as green areas, energy efficient buildings and sustainable mobility are used in their planning to reduce environmental impacts and improve the quality of life of their inhabitants. Production units are becoming increasingly automated and robotic, allowing products to be produced more efficiently and safely. In addition, fully automated plants are being introduced, where manufacturing processes take place without human involvement, using robotics. In such a situation, compliance with fire safety requirements is becoming increasingly important. Effective fire safety measures help prevent tragedies and save people’s lives by quickly detecting and responding to fires, reducing material damage by protecting buildings, equipment and other values from fire damage. Such measures help avoid major financial losses that can result from the fire, as well as ensure continuous operation of businesses.

The automatic water firefighting system is an effective fire protection measure that responds quickly to fires, provides immediate extinguishment, significantly reduces the threat of fire spread, minimizes material damage and ensures the safety of the building and its users if its operational capacity is regularly maintained and tested.

Worldwide, automatic sprinkler systems are used more than any other stationary fire protection systems, installing more than 40 million sprinkler heads each year. In buildings protected by properly designed, installed and maintained fire sprinklers, more than 99 percent of the fires were controlled by fire sprinklers alone. Studies have shown that the estimated reliability assessment for the application of automatic water sprinkler systems is 0.89 [1].

Sprinkler systems have proven themselves in use for well over 100 years. In 1812, British inventor William Congreaves patented the manual sprinkler system, where perforated pipes along the ceiling were used. When someone noticed the fire, the valve outside was opened to allow water to flow through pipes and extinguish the fire. After a while, however, given the multiple fires at factories, Hyram Stephens Maxim was invited to improve the system. The first automatic fire sprinkler system was then invented and is still in use today in an updated way [2].

Automatic water fire-extinguishing system

An automatic water fire-extinguishing system is a permanently installed fixed engineering system used in facilities with different fire loads. It shall automatically start operating as soon as a signal has been received from the fire protection systems or when one of the flasks of the sprinkler heads breaks from the fire temperature exposure to the glass flask. This system provides fire extinguishing or containment and sends signals to control other engineering systems [3].

Water is the most common extinguishing agent in the fire sprinkler system. Depending on the type of facility, other extinguishing agents may be used in the fire sprinkler system. The system is operated by two independent water inlets, and the water is fed through the pipelines onto sprinkler heads (sprayers). The total amount of water necessary for efficient functioning of the system shall be ensured both from the fire water reservoir installed in the facility with the water amount necessary for extinguishing the fire or from the urban water supply network. The main condition for the operation of the system is to ensure sufficient water flow and quantity on sprinkler heads [4].

The main task of the automatic water fire-extinguishing system is to prevent the fire from spreading in the early stages of the fire by discharging water from sprinkler heads in spaces above the fire scene. Key elements of the fire sprinkler system include sprinkler heads, or sprinklers, and sprinkler piping. Water from the pump station is fed through the pipelines to sprinkler heads and released through the opening of the sprinkler head at the scene of the fire. The opening of the sprinkler head shall work at increase of the temperature in the room between 57 °C and 77 °C or above, depending on the sprinkler heads selected. It is an active method of protection that can contribute to human safety and early fire prevention [5].

A fire sprinkler or sprinkler head is an integral part of a fire sprinkler system that drains water if a fire effect is detected, for example, if a predetermined temperature in the room is exceeded. Sprinkler heads drain a jet of water to a deflector plate that disperses water over a large area. The flow of water is blocked by a glass flask or a soldered stringe, which keeps the stopper in place. When the heat from the fire reaches the sprinkler head, the glass flask breaks as the liquid expands in it, or the soldering melts, releasing the stopper, allowing water to flow through the nozzle of the sprinkler head and extinguish the fire. Hot gases from the fire rise up and concentrate at the ceiling of the room. When the temperature at the ceiling reaches a certain level at the sprinkler head (sprinkler), it activates the system and starts spraying water to the fire site. Only the sprayers above the fire will reopen while the others remain closed. This helps to limit losses in areas where the fire has not spread and reduces the amount of water needed to extinguish the fire [4].

Overall, rapid response sprinkler heads are more effective than standard sprinkler heads. Comparing rapid response sprinkler heads to standard sprinkler heads, Jetz notes that they react faster and are more effective. It also depends, of course, on the rate at which the fire is spread, if the space is filled with combustible materials in large quantities, then the rate at which the fire is spread will also be higher, in which case standard sprinkler heads are more efficient. But if the space has a low fire load, it greatly reduces the rate of fire spread, then it is recommended to install rapid response sprinkler heads in such a space [6].

Materials and methods

Research work was carried out as part of an automatic water fire-extinguishing sprinkler system sprinkler head flask response efficiency experiment to find out how the response time varies for the sprinkler head (sprinkler) flask of the automatic water fire-extinguishing sprinkler system, depending on the year of manufacture. The aim of the experiment is to determine whether the response time of the flask of sprinkler heads of a system from a single manufacturer with the same response temperature will differ or not depending on their year of manufacture.

The experiment was divided into 7 parts. In all parts of the experiment single-manufacturer sprinkler system sprinkler head flasks at a response temperature of 68 °C were tested. In each part 5 tests were carried out on the sprinkler head flask produced in a given year with the aim of determining the response time. In two parts, quick reaction sprinkler head flasks were used for the test, in the rest of the tests – standard ones. The experiment was carried out in a 4 m2 combustion chamber with the height of 2.5 m. For each artificially formed fire, the same combustible material was used - a burner made of wood chips that had been treated with wax. Fire sprinkler spray flasks with the same response temperature of 68 °C were used for the test. The sprinkler head, in which the activation flask was installed, was placed 30 cm below the combustion chamber ceiling in the centre of the chamber. The sprinkler head of the sprinkler system was not connected to the water fire-extinguishing sprinkler system pipeline. The temperature inside the chamber was 21 °C and after each test the combustion chamber where the experiment took place was ventilated and cooled to ensure the same factors and conditions for all sprinkler head flasks. It is important to emphasise that the burning flame was not directed exactly at the sprinkler head but towards the ceiling of the combustion chamber, where the installed sprinkler head (sprinkler) with the flask was located. This means that the flame does not directly act on the head flask but raised the temperature in the combustion chamber. This technique has been chosen because the fire may not always start directly under the sprinkler spray.

Data (time) from the start of the fire to the response of the sprinkler head flask of the automatic water fire-extinguishing sprinkler system from the experimental path was recorded by a stopwatch and analysed by the method of comparing and grouping the data.

Results and discussion

The experiment was conducted to determine how the response time of sprinkler head flasks in an automatic water fire-extinguishing system varies depending on their year of manufacture. Sprinkler heads from a single manufacturer were tested at a response temperature of 68°C, with both standard and quick reaction heads included in the tests. The results, based on data collected from multiple tests in a controlled combustion chamber, are presented below.

The following table summarises the average response timings of the flask of the fire-extinguishing sprinkler system sprinkler heads (sprinklers) acquired as a result of the experiment.

Table 1

Acquired average timings for fire-extinguishing sprinkler system sprinkler head flask response

Test part	Year of manufacture of the flask	Type of sprinkler head flask	Specified activation temperature *t*, °C	Average response time
1.	2024	Standard	68	1 min. 50 sec.
2.	2018	Standard	68	5 mins. 29 sec.
3.	2004	Standard	68	2 mins. 45 sec.
4.	2003	Standard	68	3 mins. 15 sec. *
5.	2002	Standard	68	3 mins. 52 sec. *
6.	2007	Rapid response	68	1 min. 23 sec.
7.	2002	Rapid response	68	2 mins. 23 sec.

* there was one test case at a time when the sprinkler head flask did not respond in 10 min

By summarising all the above mentioned and obtained information, the authors of the paper can conclude that the average time of response of the flask of sprinkler heads varies considerably depending on the year of manufacture. From the tests in parts 1 to 5 of the experiment, where the standard flasks of the head were tested, we can see that the flask response time increases depending on the year of manufacture. The average response time for 2024 sprinkler head flasks is 1 min. and 50 sec, while the average response time for 2018 produced flasks is 3.5 times higher (5 mins 29 sec), the average response time of 2003 produced flasks from new flasks has increased 2.1 times, and 2002 produced flasks 2.35 times differently from sprinkler head flasks produced in 2004.

It should be noted that in the test parts of experiments 4 and 5 with the head flasks produced in the years 2002 and 2003 there was one case at a time that the head flask did not work during the 10 min period. Test parts 6 and 7 of the experiment tested the flask of the rapid response heads and it must be concluded that their response time is also different depending on the year of manufacture. The average response time for the 2007 sprinkler head rapid response flask was 1 min 23 sec, while for the 2002 rapid response sprinkler head average time was 1.8 times higher (2 mins 23 sec).

By summarising the results achieved as a whole, it can be seen that the year of manufacture has a significant impact on the response timings of the sprinkler head (sprayer) flask, suggesting that it is possible that the manufacturer should determine the operating period for the sprinkler head flask.

The authors emphasize that testing this type of sprinkler head flask is only preliminary to determining a more accurate response time for flasks. It would be necessary to carry out in-depth tests on sprinkler heads by attaching them to a working automatic fire extinguishing system for water pipes to determine how the flask is affected, besides the fire temperature, by the fire-extinguishing agent in the system depending on the temperature of the agent and the pressure of the fire-extinguishing liquid in the system. It would also be necessary to carry out laboratory studies on the flask expansion fluid itself and only then it would be possible to establish whether the response time of the sprinkler head flasks depends on the response temperature of the liquid, whether the surrounding factors influence the response time of the glass flask depending on the year of manufacture.

In the experiment conducted, the response time of the sprinkler head varies significantly depending on the year of manufacture and these differences may be influenced by several factors:

First, this could be due to new materials used in the production of new sprinkler heads, as well as technological improvements. New models are more likely to use components that are able to reach critical temperatures and respond from a fire source faster. The old models, on the other hand, may have used components that delay reaching critical temperatures in the sprinkler head.

Second, it is possible that in new sprinkler heads components thinner than in the old sprinkler heads are used, which also has a significant impact on their response time. As well, it is possible that old sprinkler heads have developed component wear and tear, which would also have a significant impact on the response time and, therefore, it is slowed and delayed.

Third, it is possible that over time production standards and safety requirements imposed on previously produced models have changed. It could also affect the response time for sprinkler heads. Possibly, in old models the components that suited the requirements for the year of their manufacturing were used, as well as time goes forward and in new sprinkler heads the technologies that are able to faster respond to fire exposure and reach critical temperatures are used.

Conclusions

1. The experiment showed that the response time of sprinkler head flasks in the automatic fire sprinkler system varies depending on the year of manufacture. The latest sprinkler head flasks were found to react faster than the older year product (the cases where they did not respond at all were found), indicating that improvements in technology and materials can have a significant impact and reduce the response time of sprinkler head flasks.
2. The experiment showed that rapid response sprinkler head flasks responded much faster to rising temperatures than standard sprinkler head flasks, indicating that rapid response sprinkler head flasks are more effective than standard.
3. The rate of development of a fire and the fire load may have a significant impact on the ability of the sprinkler head flask to respond to the temperature rise in the room in due time.
4. The authors emphasize the need to continue the ongoing experiment in order to more accurately determine the response time of flasks. It is necessary to carry out in-depth testing of sprinkler head flasks to determine how the flask is affected, besides the fire temperature, by the fire-extinguishing agent in the system depending on the temperature of the agent and the pressure of the fire-extinguishing liquid in the system.
5. Based on the results of the experiment, it may be necessary to determine the period of use of the sprinkler head flask of the automatic fire-extinguishing sprinkler system, thereby ensuring the efficiency of the automatic water extinguishing sprinkler system.

Author contributions:

Conceptualization, A.D.; methodology, A.D., M.Z. and V.J.; validation, A.D.; formal analysis, A.D. and V.J.; investigation, A.D. and M.Z.; data curation, A.D., V.J. and M.Z.; writing-original draft preparation, A.D.; writing-review and editing, A.D., M.Z. and V.J.; project administration, V.J.; funding acquisition, V.J. All authors have read and agreed to the published version of the manuscript.

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