Safety Engineering Series DOI 10.1515/tvsbses-2015-0009

EFFECTS OF COMPRESSED AIR FOAM APPLICATION ON HEAT CONDITIONS IN FIRE WITHIN A CLOSED SPACE

Adam THOMITZEK[1], Jan ONDRUCH[2], Dana CHUDOVÁ[3], Petr KUČERA[4]

Research article

Abstract: This article evaluates the knowledge obtained in firefighting tests using compressed air foam system (CAFS) within a confined space. Six experiments were conducted for verification during the cooling of rooms and the self-extinguishing effect. The simulation was for a fully developed fire within a room. The fuel was chosen to simulate ordinary combustible materials utilized in residential areas. Mantel thermocouples were placed in the rooms to record the temperature changes. Compressed air foam was first applied with a standard fire hose nozzle to the ceiling and then to the epicenter of fire. Fire extinguishing was initiated after reaching the desired temperature in the room. The temperature for the start of fire extinguishing matched the third phase of development of a fire. Fire extinguishing was terminated after no obvious signs of fire were shown in epicenter of fire. The outputs of the experiments were evaluated on the basis of the amount of time passed for the temperature to drop below the suggested limit. Individual experiments were also conducted with various different admixing foaming agents over different locations. In the experiments, it has been verified that the application of compressed air foam has a positive effect on room cooling. Use of a compressed air foaming agent does not allow for the development of steam that can scald firefighters and reduce visibility. Furthermore, the extinguishing agent used is more efficient utilizing less water flow out of the fire area.

Keywords: Firefighting, compressed air foam system, CAFS, extinguishing effect, temperature curve.

Introduction

Fire brigades have utilized compressed air foam in the Czech Republic since the late 1990's. The technology is not new in the world but still progressing. Compared to conventional standard air foam, compressed air foam has a higher percentage of small bubbles with the same number foaming (Laundess et al., 2012). Compressed foam better adheres to solids and is more resistant to thermal radiation (Särdqvist, 2002). In addition, the direct-fighting foam surface protects against radiant heat transferred by surrounding fires. Another positive characteristic is the reduction of the need for water to extinguish. When using a full flow of water to extinguish fire solids, only 5 - 10 % of the water is effective for heat reduction, which means that 90 % of water remains or drains from the fire area unused. The unused water can cause damage, and we can talk about the so-called extinguishing culture (Magrabi et al., 2002; The Boston Fire Department, 1994). CAFS is beneficial in areas where it is necessary to limit the amount of water used for firefighting (Kim and Crampton, 2000). Another application of CAFS is for use in firefighting in aircraft hangars, which achieves better results than conventional systems based on basic water extinguishing (Cheng and Xu, 2014; Kim and Crampton, 2001).

The unique aspect of fire hoses with compressed air foam is that the hoses are significantly lighter; some sources suggest that up to 61 % less weight over the hose with pressurized water only. The disadvantage is the greater tendency of fracturing and the possibility of limiting the flow of a burning hose (Grant, 2012). The greater reaction force acting on the operator at the nozzle cannot be overlooked in the event of prolonged closure of the

[1] VŠB - Technical University of Ostrava, Faculty of Safety Engineering, Ostrava, Czech Republic, adam.thomitzek@vsb.cz
[2] VŠB - Technical University of Ostrava, Faculty of Safety Engineering, Ostrava, Czech Republic, jan.ondruch@vsb.cz
[3] VŠB - Technical University of Ostrava, Faculty of Safety Engineering, Ostrava, Czech Republic, dana.chudova@vsb.cz
[4] VŠB - Technical University of Ostrava, Faculty of Safety Engineering, Ostrava, Czech Republic, petr.kucera@vsb.cz

nozzle and pressurizing the hose (Dicus at el., 2013). Due to the different specific gravity of compressed air foam versus water, a lower hydrostatic pressure is produced by the foam allowing the foam to be displaced through the hoses at considerably greater heights than the fire-fighting water or a solution of water with a foaming agent. Compressed air foam is utilized primarily for firefighting of solids, difficult to wet combustible materials and flammable liquids. Up to 87 % savings on extinguishing agents over conventional extinguishing methods using water and class B foaming agents when using CAFS on flammable liquid fires. The CAFS system is able to extinguish flammable liquid fires using foaming class A (Crampton and Kim, 2004; Su et al., 2012; Wang et al., 2009). CAFS use in confined spaces can have the advantages of an improved extinguishing effect versus extinguishing water. When fighting a fully developed room fire, the use of CAFS can extinguish the fire faster than water alone or conventional foam (Kim and Crampton, 2012). The next and most important benefit is the reduction of peripheral damage caused by the extinguishing water and the creation of an environment in the area with better visibility (Lyckebäck and Öhrn, 2012). Verification tests were performed using simulated fires in actual building rooms to verify the possibility to use different types of foaming agents on newly acquired fire fighting vehicles CAS 30/9000/540-S3VH-CAFS.

Materials and methods

Test equipment and place

The FRB MSR used an existing building that was prepared for demolition for training. The building was a three-story, full basement building, with a structural system based on a combination of reinforced concrete columns and full brick peripheral walls. The ceilings are monolithic reinforced concrete or concrete inserts into the steel girders. The flat roof of the building is covered with asphalt waterproofing. The building itself will be demolished following the intensive training. The architectural and structural condition of the building is preserved, with no leaking rainwater and statically sound. The objective was to perform the tests chosen in three rooms on the same ground area, ground plan dimensions of 2.79 x 5.6 m and a ceiling height of 3.2 m. To limit the ventilation sheet metal lockers were placed in the windows of the rooms so that the vent area of the window (400 mm x 1800 mm) was approximately the same in all cases. The temperatures were recorded using sheath type K thermocouples, which were distributed as follows:

T1 - 100 mm below the lintel ventilation areas of the window opening;

T2 - 100 mm below the ceiling in the middle of the room;

T3 - 1000 mm below the ceiling in the middle of the room;

T4 - 100 mm below the lintel of the front door to the room.

Deployment of the thermocouples is shown in Fig. 1.

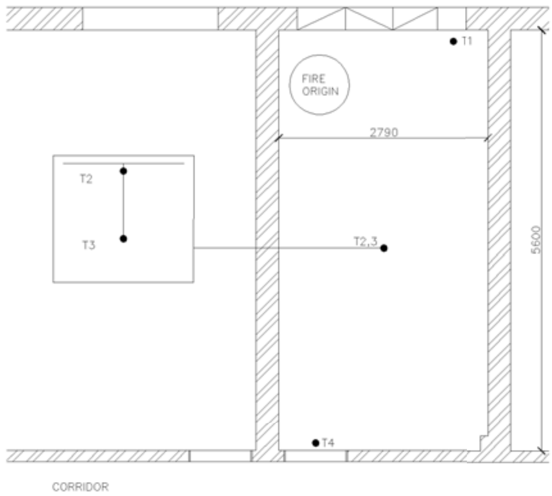

Fig. 1 Floor plan layout and thermocouples

Sheath thermocouples were used because of easy preparation for further use even after heat exposure to fire. For continuous monitoring and recording of temperature OMEGA HH309 data loggers were used. For visual recording, a water-cooled camera was placed near the floor of the room. Thermographic imaging was also conducted through the window of the room from an outside FLIR T640 thermal camera.

Fig. 2 Disposition of combustible material in the test room

To simulate the fire in the room the following combustible materials were used: sofa, chair, wardrobe, 8 pieces of wooden pallets, and two rubber tires. This equipment represents a fire load of approximately 38 kg.m^{-2}. The disposition of the flammable materials is shown in Fig. 2.

The fire load in the room was chosen such that a fire with excess and fuel limited ventilation was created. The maximum heat output during fire, directed by the ventilation is to be determined from the formula 1.1 (Kawaoge, 1958):

$$\dot{Q} = 0{,}10 \cdot \chi_A \Delta H_C \left(A_O \cdot \sqrt{H_O} \right) \qquad 1.1$$

where $\dot{Q}$ max. heat output [MW]; χ_A combustion efficiency [–]; ΔH_C calorific value [MJ.kg^{-1}]; A_O area of all openings [m^2]; H_O opening height [m].

According to the above formula, the ventilation conditions for the heat output fire in a model room will be at max. 7.14 MW.

The vehicle CAS 30/9000/540-S3VH-CAFS fit with a device for producing compressed air foam type; One Seven OS-C0-100-MR was used Fig. 3. The foam was applied with a streamline AWG CAFS Turbo-Twist nozzle with a diameter of 25 mm.

Fig. 3 Vehicle with single hose line and streamline - left, compressor and proportioned One Seven OS-C0-100-MR - right

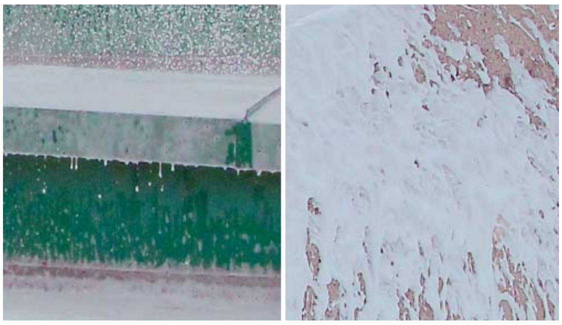

Fig. 4 Wet extinguishing foam - left, dry foam - right

This system produces a wet and dry foam according to the degree of foaming. The difference between the wet and dry foam is illustrated in Fig. 4.

Test procedure

Test procedure was as follows:

1. The flammable material in the room was ignited and left to heat up freely.
2. The hallway was prepared with a pressurized stream of compressed air foam.
3. After reaching 700 °C in one of the thermocouples, instruction was given to start fire extinguishing.
4. Before starting the extinguishing, foam was released from the nozzles to achieve a consistent flow of foam.
5. The foam was applied gradually to the room from side to side along the ceiling of the room and into the epicenter when located.
6. Extinguishing was terminated when the temperature dropped significantly below 150 °C as measured at the thermocouple.
7. The behavior of the fire in the room was observed.

The building is constructed of a non-flammable construction system; the spreading of the fire is possible only on the surface of the flammable materials or through hot pyrolysis gases and smoke. Localization of the fire is possible in terms of thermodynamics and considers no room flashover. The temperatures of the hot gases must be substantially lower than 600 °C. For a safe threshold, the temperature of the hot gases of 200 °C was considered when the majority of flammable substances has not reached ignition temperature. Thus extinguishing time was considered as the time between the start of application the foam stream to the room temperature drops to thermocouples below 200 °C.

Fig. 5 Application of compressed air foam into the examination room

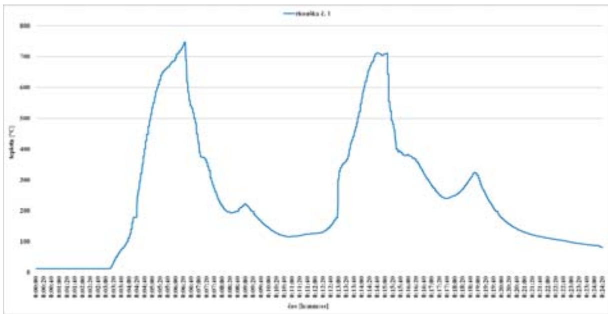

Fig. 6 The temperature of the thermocouple T2 (the ceiling) test no. 1

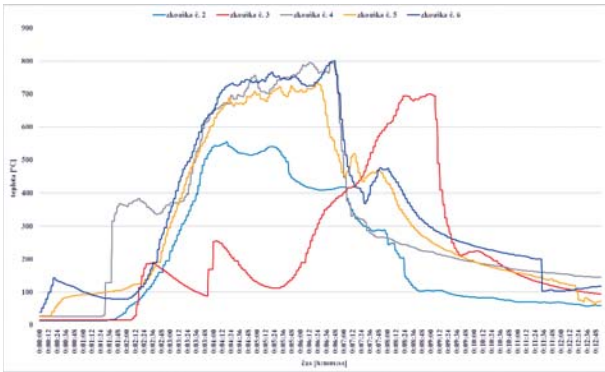

Fig. 7 Temperatures at the thermocouple T2 (the ceiling) in the tests no. 2 - 6

Results and discussion

A total of 6 tests were performed each in three rooms and over two days as listed in Tab. 1 below. Different types of foaming agents intended for producing compressed air foam with different admixing foaming agent in water were used.

Tab. 1 Overview of tests and extinguishing agents used

Test no.	Date and time	Extinguishing agents	Incorporating [%]	Foam type
1a	28. 5. 2015 9:28	foamer class AR	0.6	dry foam
1b	28. 5. 2015 9:37	foamer class AR	0.6	wet foam
2	28. 5. 2015 11:45	foamer class B	0.5	wet foam
3	28. 5. 2015 13:25	foamer class A	0.3	wet foam
4	21. 7. 2015 10:48	foamer class B	0.5	wet foam
5	21. 7. 2015 12:18	foamer class B	1.0	wet foam
6	21. 7. 2015 14:01	foamer class A	0.5	wet foam

Course temperature were recording by every measurement.

Fig. 6 is a temperature curve for test no. 1 one can observe a re-ignition and the re-burning temperature after the application of the dry foam. After re-ignition, the fire was liquidated with wet foam. In other tests already on the basis of this experience is used only wet foam.

The course of the temperature at thermocouple installed below the ceiling in the tests no. 2 - 6 is in Fig. 7. The output temperature from test no. 2 is distorted, and the disappearance of the ceiling mounted thermocouple. Measured values and temperatures are significantly lower than the reality, but the course of application of the extinguishing agent as well as the video evidence can be used to ascertain the actual temperatures reached.

For illustrative purposes, in Fig. 8 the given temperature curve for all thermocouples recorded during the test no. 4 is shown.

Tab. 2 Results of the tests carried out

Test no.	Extinguishing period [s]	Result
1a	178	not extinguished
1b	302	extinguished
2	108*	extinguished
3	84	extinguished
4	189	extinguished
5	224	extinguished
6	274	extinguished
* ascertained from the video		

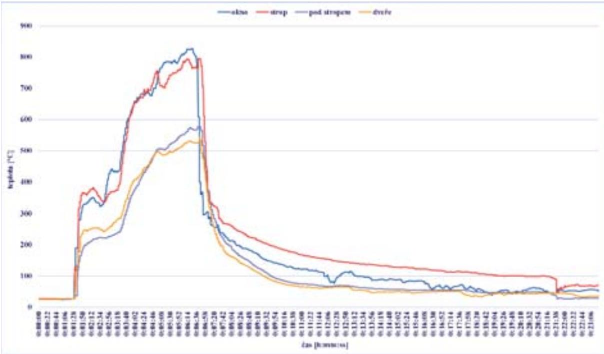

Fig. 8 The temperature for all thermocouples during the test no. 4

Tab. 2 shows the extinguishing times determined according to the above conditions and the state after the application of the extinguishing agent. From the results it is apparent that the maximum time between the longest is more than three times the shortest time to extinguish. In this case (test no. 3) was applied a foaming agent designed to extinguish flammable substances in Class A in the right admixture according to the manufacturer's documentation. It can therefore be concluded that the variations in the blending of foam and the use of foam designed for extinguishing polar or non-polar flammable liquids for extinguishing solids can reduce compressed air foam extinguishing effect. However, for this hypothesis to be confirmed, it is necessary to carry out more repetitions of tests under the same conditions. Given the complex nature, it is complicated to test the extinguishing effect of different firefighting foams. The most important influence that might skew the test results is the manual application of foam. This manual application is largely random and can vary by applicant. It is for this reason the conditions were chosen for a confined space fire where, because of limited ventilation, thermodynamic conditions in different parts of the room without significant deviations exist. Individuals conducting extinguishing are not able to influence the foams effect on the cooling of hot gases by directional application. It is different in the case of tests in the open environment, where the experience of the fireman and the routing method to significantly affect the amount of time to extinguish the fire can be impacted.

Fig. 9 displays the thermographic image of the window before and after 15 seconds after the start of application of the extinguishing agent. The obvious is the rapid drop in temperature in the area caused by the cooling hot gases and foam covering hot surfaces.

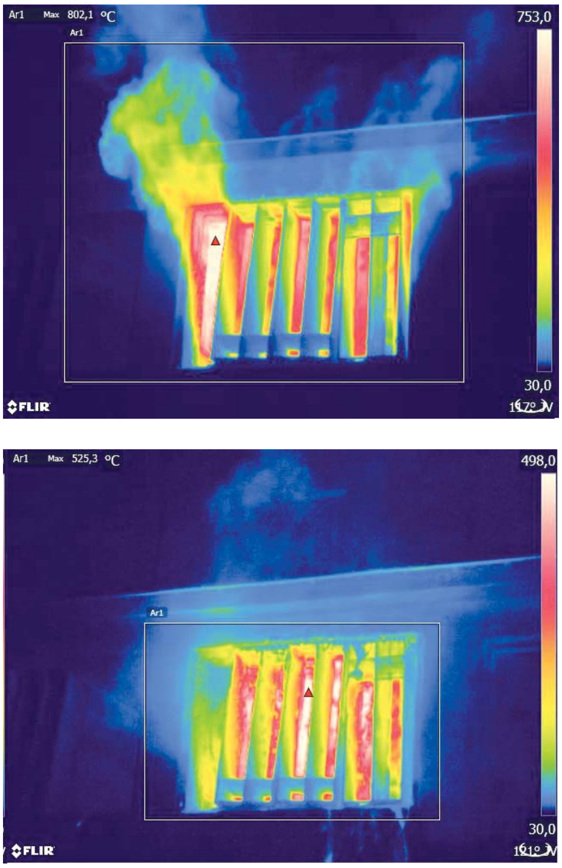

Fig. 9 Visualization during the extinguishing time of 15 seconds after launch on the thermographic image taken during the test no. 3

The output of the tests is also affected by these technical restrictions. Tests 1 - 3 included contact thermocouple shells, thereby affecting the accuracy of measurement, when the measured temperature is slightly lower than actual. A Sheath Thermocouple of 2 mm in diameter exhibits a time constant of about 5 - 10 seconds with such conditions, which could affect the measured values in scenes with rapid movement.

Conclusion

From the practical tests performed, one can conclude that compressed air foam can be successfully applied to extinguish a fire in a confined space and in conditions just after the flashover during the third stage of fire development. Compressed air foam applied to the ceiling layer of hot gas has a cooling effect and the application of compact foam stream. Nevertheless, the foam application was continuous; there was significantly less development of steam as compared to the application of the same using extinguishing water (which agrees with training in these cases routinely performed). On the scene of the fire and was exhibited significantly better visibility, which made it easier to find the source of fire. After extinguishing with compressed air foam on the floor, a minimal amount of unused extinguishing agent remains. It can be concluded that the use of compressed air foam in rooms can positively reduce secondary damage caused by the fire extinguishing water. Standardized tactics for routine use in these types of fires is lacking. Additional tests carried out in larger areas would be appropriate. At a minimum, the footprint of a conventional flat panel apartment building should be further tested.

References

CHENG, J.Y.; XU, M. (2014).: Experimental Research of Integrated Compressed Air Foam System of Fixed (ICAF) for Liquid Fuel. *Procedia Engineering*. 2014, 71: 44-56. DOI: 10.1016/j.proeng.2014.04.007. ISSN 18777058. Available at: http://linkinghub.elsevier.com/retrieve/pii/S1877705814004251.

CRAMPTON, G.; KIM, A. (2004).: *Comparison of the Fire Suppression Performance of Compressed-Air Foam with Air Aspirated and Unexpanded Foam Water Solution.* Ottawa: National Research Council Canada, 2004, 25 p.

DICUS, Ch.A.; KORMAN, T.; GRANT, C.; LOHR, S.; MADRZYKOWSKI, D.; MOWRER, F.; PASCUAL, Ch.; TURNER, D. (2013).: Compressed Air Foam and Structural Firefighting Research. *Fire Engineering*. 2013: 65-69.

GRANT, C.C. (2012).: *Capabilities and Limitations of Compressed Air Foam Systems (Cafs) for Structural Firefighting.* Rockville: The Fire Protection Research Foundation, 2012, 58 p.

KAWAGOE, K. (1958).: *Fire Behaviour in Room*, Report No. 27, Building Research Institute, Tokyo, 1958.

KIM, A.; CRAMPTON, G. (2000).: A New Compressed-Air-Foam Technology. In: *Halon Options Technical Working Conference.* Sheraton Old Town, Albuquerque, New Mexico: Center for Global Environmental Technologies, New Mexico Engineering Research Institute, 2000, p. 343-348.

KIM, A.; CRAMPTON, G. (2001).: Compressed-Air-Foam (CAF) Fire Suppression System for Aircraft Hangar Protection. *Fire Research Program*. 2001.

KIM, A.; CRAMPTON, G. (2012).: Evaluation of the Fire Suppression Effectiveness of Manually Applied Compressed-Air-Foam (CAF) System. *Fire Technology*. 2012, 48(3): 549-564. DOI: 10.1007/s10694-009-0119-3. ISSN 0015-2684. Available at: http://link.springer.com/10.1007/s10694-009-0119-3.

LAUNDESS, A.J.; RAYSON, M.S.; DLUGOGORSKI, B.Z.; KENNEDY, E.M. (2012).: Suppression Performance Comparison for Aspirated, Compressed-Air and in Situ Chemically Generated Class B Foams. *Fire Technology*. 2012, 48(3): 625-640. DOI: 10.1007/s10694-010-0155-z. ISSN 0015-2684. Available at: http://link.springer.com/10.1007/s10694-010-0155-z.

LYCKEBÄCK, E.; ÖHRN, J. (2012).: *Investigation on the gas-cooling effect of CAFS.* Lund: Department of Fire Safety Engineering and System Safety, 2012.

MAGRABI, S.A.; DLUGOGORSKI, B.Z.; JAMESON, G.J. (2002).: A comparative study of drainage characteristics in AFFF and FFFP compressed-air fire-fighting foams. *Fire Safety Journal*. 2002, 37(1): 21-52. DOI: 10.1016/S0379-7112(01)00024-8. ISSN 03797112. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0379711201000248.

SÄRDQVIST, S. (2002).: *Water and other extinguishing agents*. Karlstad, Sweden: Swedish Rescue Services Agency, 2002. ISBN 91-725-3265-3.

SU, L.; WANG, L.; WANG, Z.; ZHANG, J.; TIAN, Y.; YAN, Y. (2012).: Investigation on Compressed Air Foams Fire-extinguishing Model for Oil Pan Fire. *Procedia Engineering*. 2012, 45: 663-668. DOI: 10.1016/j.proeng.2012.08.219. ISSN 18777058. Available at: http://linkinghub.elsevier.com/retrieve/pii/S1877705812032316.

THE BOSTON FIRE DEPARTMEN (1994).: *Compressed Air Foam for Structural Fire Fighting: A Field Test*. Boston: Federal Emergency Management Agency, 1994.

WANG, X.S.; LIAO, Y.J.; LIN, L. (2009).: Experimental study on fire extinguishing with a newly prepared multi-component compressed air foam. *Chinese Science Bulletin*. 2009, 54(3): 492-496. DOI: 10.1007/s11434-008-0571-3. ISSN 1001-6538. Available at: http://link.springer.com/10.1007/s11434-008-0571-3.