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Water mist – an emerging fire suppression system to control coal mine fire

'Water mist' refers to fine water sprays in which 99% of the volume of the spray is in droplets with diameter less than 1000 µm. The paper deals with the use of 'water mist' as fire suppressant in coal mines. Water mist could have better suppressant in comparison with other existing fire suppressant like Halon 1211, Halon 1301 as the latter have environmentally unsuitable, being ozone depletion properties. Water mist considerably reduces heat and subsequently temperature of fire as well as radiation attenuation, which resists the spreading of fire to virgin fuel. Higher latent heat of evaporation and specific heat of water mist make it better than other suppressant. Large scale model based study done by Central Institute of Mining and Fuel Research (CIMFR), Dhanbad on water mist establishes its suitability to suppress coal mine fires. Water mist infusion has been proved to be safe and very effective technique for not only controlling open fire in underground mines but also reducing toxic gases, minimizing rollback and improving visibility in the fire affected areas. However further research should be carried out to determine the optimum water droplet size, air velocity, water droplet velocity according to fire size and category on field based study.

Introduction

Water mist refers to fine water sprays in which 99% of the volume of the spray is in droplets with diameter less than 1000 μm. Water mist fire suppression systems have been around for about a century. The first models were steam-flooding systems used for the protection of lumber drying kilns. However, since the advent of chemical fire suppressants Halon 1211 ($CBrClF_2$) and 1301 ($CBrF_3$) in 1960s the popularity and use of water mist went down as Halons were much more effective at putting out fires. But later, with the discovery of ozone-depletion power of Halons due to their ability to transport bromine into the stratosphere, their use have been gradually phased out as the consciousness against ozone-depleting substances (ODSs) grew over years [Montreal Protocol, 1987; London Amendments, 1990; Copenhagen Amendments, 1992; Montreal Protocol, 1995]. It led to a search for alternative fire suppressants and water mist appeared as the most potential candidate for some of its unique advantages. Presently, water mist system is in use in spacecrafts, aircrafts, ships, electronically equipped sites, gas turbines, several industries, tunnels, and ventilated and domestic areas. However, few trials have so far been carried out to find out the suitability of water mist in coal mine fires.

No standard definition for water mist fire suppression system has yet been established [Notarianni, 1994]. However, in a water mist system, water flow rate is usually less than that in a conventional water sprinkler. It has been reported that the water consumption is 6-10 times less compared to sprinkler system [www.danfoss.com].

How water mist works

The study and description of the fundamental principles of extinguishment of liquid and solid fuel fires by water mist can be traced back to the mid-1950s. The early studies [Braidech et al, 1955; Rasbash et al, 1960] focused on the extinguishing mechanisms of water mist and the optimum droplet parameters for efficient fire suppression.

Fire suppression by water mist is primarily a physical mechanism and no significant chemical effects are involved. When a water mist is applied into the fire, it evaporates and turns into steam, absorbing a great deal of heat and reducing the temperature of fire drastically. In the process, water mist vapourizes and expands to displace air from the fire thus creating an environment short of oxygen, O_2. Thus water mist helps to eliminate two of the three sides of the fire triangle. In addition, radiation attenuation provided by water mist stops the fire from spreading to un-ignited fuel surface and reduces the pyrolysis rate at the fuel surface. Tests conducted at National Research Council of Canada revealed that the radiant heat flux to the walls of the test chamber reduced by more than 70% by water mist [Mawhinney et al, 1994]. Other extinguishing mechanisms, considered as secondary, include dilution of flammable vapors, and direct impingement wetting and cooling of the combustibles [Wighus, 1995; Mawhinney, 1996].

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Compared to other fire suppressants commonly used in mines, water has the highest specific heat capacity and latent heat of evaporation as illustrated in Table 1. Owing to the high latent heat of evaporation, water absorbs much larger quantity of heat compared to the other two fire suppressants leading to more rapid cooling of fire. Thus water mist suppresses deep-seated fires more effectively than gaseous flooding agents because of its better cooling and penetration potential.

TABLE 1: PROPERTIES OF DIFFERENT FIRE SUPPRESSANT

Fire suppressant	Boiling point, °C	Latent heat of vaporization, KJ/Kg	Specific heat, KJ/Kg °C
Carbon dioxide	-78.5	571.3	0.850
Liquid nitrogen	-196	199.1	2.042
Water	100	2250.0	4.180

Recent R&D on water mist technology

Water mist system are readily available, simple in design and construction, easy to maintain, effectual in suppressing various fires, non-toxic, and cheaper than other familiar fire suppressing systems with no harmful environmental impact. While applied in fire areas, it cleans the air by dissolving soluble toxic gases produced during combustion, washing down smoke and suppressing dust, and thus improves visibility as well. Unlike many other firefighting systems, water mist can be safely used in manned areas and found to be effective in open condition. Furthermore, water consumption in this system is far less than that in water flushing, spraying or sprinkling systems. On account of these advantages, much study has been carried out in recent years to develop appropriate water mist systems to control various types and sizes of fires.

Water mist in fire suppression does not behave like true gases, and is substantially affected by the fire size, the degree of obstruction, ceiling height and the ventilation condition in the compartment. Selection of the optimum size of droplets for fire suppression is dependent on the potential size of fire, properties of the combustibles, and the degree of obstruction and ventilation in the compartment. Water mist characteristics, such as drop size distribution, flux density and spray momentum, have a direct effect on its fire suppression effectiveness. There is no single drop size distribution to fit all fire scenarios.

A survey carried out in 1996 indicated that nearly 50 agencies around the world were involved in the research and development of water mist fire suppression systems, ranging from theoretical investigations into extinguishing mechanisms and computer modelling to the development, patenting and manufacturing of water mist generating equipment [Mawhinney and Richardson, 1997]. Meticulous reviews of recent R&D and applications of water mist fire suppression system have been presented in different papers [Liu and Kim, 2001; Kim 2002]. Nonetheless, they do not cover the limited R&D investigations conducted so far on the suitability of water mist to suppress coal mine fire.

A preliminary study to determine the feasibility of using a water mist system to suppress in-cabinet Class C electronic fires showed that the fine water mist was effective in extinguishing fires without causing short circuits or other damage to electrical and electronic components [Kim, 2002]. National Research Council, Canada carried out a study that established that the traditional total-flooding approach (used for Halon 1301), was unreliable when applied to water mist. On the other hand, reliable fire suppression was achieved with water mist by exercising rigorous control over spray direction to the hazard. The study showed that coarser sprays [$200\ \mu < D_{V0.9} < 400\ \mu$], which produced wetting of surfaces and water dripping down into recessed places, performed better than very fine sprays [$D_{V0.9} < 90\ \mu$] against fires in electronic equipment. The investigation also proved that water mist can be used to suppress fires in electrical and electronic equipment with minimum water damage [Mawhinney, 1996].

An advantage of water mist is that the damage to the electronic equipment could be far less than the damage caused by thermal decomposition products of gaseous Halon replacement agents [Kim and Su, 1999]. Furthermore, the performance of water mist can be further improved by using a cyclic discharge. The cyclic discharge involves continuous alternation of "on" and "off" cycle of the water mist discharge. The effectiveness of water mist system substantially increased when a cyclic discharge was used instead of a continuous discharge. Cyclic discharge further cuts down water consumption in the system [Kim et al, 1999].

National Research Council, Canada and several other research agencies conducted a series of investigations that proved water mist technology to be effective in dousing Class B spray and pool fires in machinery spaces, gas turbine enclosures, combat vehicles, and flammable liquid storage rooms with encouraging results [Kim and Su, 1999; Liu and Kim, 2001].

Studies over decades reveal that water mist can extinguish large fires in unventilated machinery spaces, diesel and hydraulic fluid in ships and submarines quite effectively consuming limited quantity of water with performance comparable to those of gaseous Halon replacements [Lungar, 1979; Mawhinney, (1993,1994); Darwin et al, 1995; Buckley and Rush, 1996]. Studies on the capabilities and limitations of total flooding water mist system in machinery space (100 to 1000 m^3 in volume) applications as a replacement of Halon 1301 total flooding systems are in progress [Back et al, 2000]. Water mist is being evaluated for the suppression of fires in diesel fuel storage areas in underground mines at National Institute for Occupational Safety and Health (NIOSH), Pittsburgh [Yuan and Lazzara, 2004].

The Center for the Commercial Applications of Combustion in Space (CCACS) at the Colorado School of Mines, in conjunction with NASA Glenn, is investigating the properties of water mist fire suppression in microgravity (mist). These experiments consist of varying water droplet sizes (20 and 30 μ) and water mist concentrations applied to flame fronts of different propane/air mixtures. The mist experiment flew on the ill-fated Space Shuttle Columbia (STS-107 mission) in January, 2003. The experiment was flown as an experiment mounting structure (EMS) insert into the updated combustion module (CM-2). Water mist experiments continue at CCACS using the invaluable data down-linked from Columbia. Analysis of the data is going on, but preliminary observations have already uncovered important and unexpected results. A new experimental insert will be built to go inside the Combustion Integrated Rack (CIR) onboard the International Space Station (Mckinnon et. al, 2001)

Research is in progress to appraise the aptness and develop proper designs of water mist system to combat Class A fires in residential occupancies, marine accommodations and public spaces, heritage buildings and libraries [Kim and Su, 2001; Kim and Ryou, 2003]. Applications of water mist have been proved successful in suppressing Class K fires in commercial cooking areas [Liu and Kim, 2001]. Water mist has been found effective to put out cooking oil fires of Class F are difficult to extinguish as they are easy to re-ignite [Qin et. al, 2004].

Simultaneously several research projects are underway on mechanisms of propagation of diverse types of fires under different surrounding conditions and their interaction with water mist systems of various designs by theoretical analyses, computer simulation and laboratory scale and full scale trials [Mawhinney et. al, 1994; Carvel et. al, 2001].

As an outcome of these extensive R&D investigations and trials, and their optimistic results, in recent years, several water mist systems are commercially available. Some are using high or intermediate pressures of water through small orifices of nozzle to produce water mist while others are using twin fluid nozzles (water and air). Some of the commercial water mist systems are listed in Table 2.

TABLE 2: LIST OF COMMERCIALLY AVAILABLE WATER MIST SYSTEM (KIM, 2002)

Manufacturers	System name	Nozzle type	Discharge pressure, kPa
Securiplex		Twin fluid	600
Marioff	Hi-Fog	Single fluid	10,000
Baumac	Micromist	Single fluid	7000
Reliable	Mistafire	Single fluid	7000
Spraying system	FogJet	Single fluid	700 to 7000
Lechler		Single fluid (cluster)	Low discharge pressure
BETE		Single fluid (impingement)	1200 to 3200
Fike	Micromist	Single fluid	1200
Chemetron	Chemetron fire systems	Single fluid	2400
Grinnell	AquaMist	Single fluid	1200
Ultra fog	ULTRA FOG® AB	Single fluid	12500
Kidde/Fenwal	Aquasafe	Single fluid	1200
Fogtec fire protection	Fogtec	Single fluid	12000

Water mist technology in coal mine fire

Experiments have been conducted in USA and India in their experimental tunnel or model gallery with a view to develop water mist technology for fighting mine fire. Water mist has shown a positive impact to control a fuel-rich duct fire [Loomis and McPherson, 1995]. A 30 cm square wind tunnel with a total length of 9 meters has been constructed in the Department of Mining and Minerals Engineering, Virginia Polytechnic Institute and State University to carry out a series of experiments on water mist. A fire is called a fuel-rich one when the oxygen concentration falls to below 15% in products of combustion [Roberts and Blackwell, 1969].

A range of studies have been conducted to explore the use of water sprays and mists to inert/dilute gas-air mixtures and to reduce flame speeds and associated pressures in gas-air deflagrations. Two specific applications were pointed out; one is the use of water spray curtains to dilute flammable vapour clouds and the other one to control methane-air deflagrations and coal dust explosions in mines. The main function of the system is to trigger of the system by the pressure/shock wave propagating ahead of the flame front in a long mine gallery [Notarianni, 1994].

To determine the efficacy of water mist as a fire-fighting agent to control open fire in coal mine a set of experiment was conducted in Central Institute of Mining and Fuel Research (CIMFR) mine fire model gallery. The model gallery is 65.5m long, arch in section with a base of 2.4 m and crown height of 2.7 m. The cross section of the gallery is 5.86 m^2. The gallery is equipped with a state-of-the-art, computer-aided, on-line telemonitoring system for the continuous monitoring of various fire parameters such as gas concentration (O_2,CO_2, CO, CH_4 and H_2), air velocity, pressure across fire zone and fan, temperature, heat flux, dust and particulate matter concentration inside the gallery during experimentation. An axial flow fan, Model AF-50 with 30 HP motor having a capacity to deal with 25 m^3/s of air quantity at 500 Pa pressure was also deployed. Details of construction of gallery and its instrumentation system have been described elsewhere (Singh et. al, 2004).

The water mist generation system essentially consists of a high-pressure pump, motor and two sets of fog-jet nozzles. The two sets of fog-jet nozzles were operating at a discharge pressure of 800 kPa to produce a shower-like full cone spray pattern of very fine drops up to 50 μm. The nozzle assembly consists of a nozzle body and seven removable atomizing spray caps (1" NPT or BSPT). Each cap has an internal core, which is easily removed for cleaning or replacements. The nozzles are mounted on a GI pipe of 4.87 cm diameter, placed on a height adjustable stand of maximum height 1.4 m. In the GI pipe two sets of nozzles are fitted at 45° angle with the length of the pipe. The distance between two sets of nozzles is 2.65 m. A water pressure gauge and a water flow meter are also provided with the system. The GI pipe is connected with a high-pressure pump through a flexible hose of 4.03 cm diameter. Coupling arrangements are provided to join the flexible hose with GI pipe. The system is also provided with a safety valve to release the excess pressure beyond 10 kg/cm^2. Fig. 1 represents the schematic diagram of the water mist generation system [CMRI Report, 2004].

The water mist was infused in the gallery at a rate of 33 l/min. The air velocity maintained in the gallery was about 1.5 m/sec. From the study the following points are emerged.

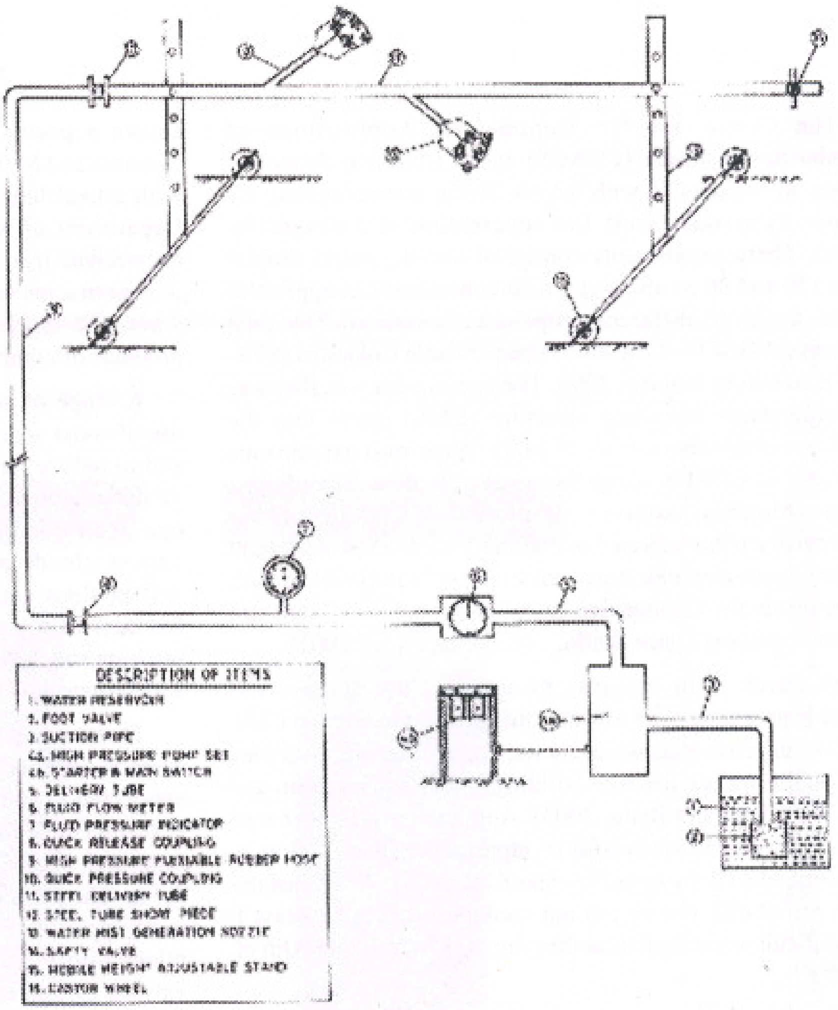

Fig. 1 Water mist generation system

- The potential significance of water mist technology is that sealing of the fire zone is not required. Further, it is capable of reducing the rollback to a large extent.
- On infusion of water mist on the full-fledged fire the temperature along the length of the gallery was reduced to a great extent. The average reduction of temperature was found to be 294°C per hour.
- It has been found that after application of water mist the oxygen concentration had increased whereas the product of combustion gases have decreased indicating retardation of combustion process.
- On application of water mist, reduction of generation rate of CO_2 and CO was estimated as 89% and 93% respectively.
- In the experiment with water mist no substantial increase in hydrogen percentage was observed. The maximum value of hydrogen concentration was recorded as 0.26% which is well below the explosive limit. Therefore, there was no formation of water gas discounting the possibility of explosion.
- On application of water mist the opacity was decreased by 84%. Therefore, it can be inferred that the water mist has the potential to improve the visibility in the mines during open fire condition.

The findings were encouraging indicating high prospect of the applicability of water mist to suppress coal mine fires. In addition, with very fine water mist there is the possibility that the drops will float with the airflow and may act as a full flooding agent, as in case of underground mine ventilation network is already there. To achieve the droplets to float with the air they must be up to 50 μ size because the evaporation of larger drops is influenced by the gravity and a float process becomes unrealistic.

Conclusions: need for further research

Evidently, there is an urgent need to make the water mist technology compatible to Indian mining condition. Only one set of experiment has been conducted in the mine fire model gallery utilizing water mist as fire suppressant agent. Although the experiment gave encouraging result further research is required to make the technology perfect.

It is essential to carry out future research to:

1. determine optimum water flow rate and water droplet size distribution to suppress fires of known size;
2. find out the optimum air flow rate to carryout generated water mist in fire area;
3. quantify the effect of water mist on combustion gases particularly hydrogen and SPM concentration with various sizes of fire;
4. ascertain the optimum distance from the source of the fire or fire area at which the mist set up to be kept; and finally
5. develop a portable water mist system readily useable in mines.

Extensive R&D work should be carried out in the following areas:

- Scope of application of water mist in combating fires in opencast mines vis-à-vis facility required; and
- Application area of water mist to control fire in underground coal mines vis-à-vis infrastructure requirement.

CIMFR is already planning for R&D in this front and processing for getting fund from coal industry and other funding agencies.

References

1. Back, G. G., Beyler, C. L. and Hansen, R. (2000): "The Capabilities and Limitations of Total Flooding, Water Mist Fire Suppression Systems in Machinery Space Applications", *Fire Technology*, Vol. 36, No. 1, p. 8.
2. Braidech, M. M., Neale, J. A., Matson, A. F. and Dufor, R. E. (1995): "The Mechanisms of Extinguishment of Fire by Finely Divided Water", Underwriters Laboratories Inc. for the national Board of Fire Underwriters, NY, 73p.
3. Buckley, C. and Rush, D. (1996): "Water Mist Developments for the Royal Navy", Proceedings of Halon Options Technical Working Conference, Albuquerque, NM, p. 37.
4. Carvel, R. O., Beard, A. N, Jowitt, P. W. and Drysdale, D. D. (2004): "The Influence of Tunnel Geometry and Ventilation on the Heat Release Rate of a Fire", *Fire Technology*, Vol. 40, No. 1, p. 5.
5. CMRI Report (2004): "Studies on Simulation of Open Fires in a Mine Gallery under Varied Airflow for Suppression of Fire and Explosions in Underground Coal Mines" 116p.
6. Darwin, R. L., Leonard, J. T and Back, G. G. (1995): "Development of Water Mist Systems for US Navy Shipboard Machinery Spaces", Proceedings of Halon Options Technical Working Conference, Albuquerque, NM, p. 411.
7. Kim, A. K. (2002): "Overview of Recent Progress in Fire Suppression Technology", Proceedings of 2nd NRIFD Symposium, Tokyo, Japan, p. 1.
8. Kim, A. K and Su, J. Z. (1999): "Full-Scale Evaluation of Halon Replacement Agents", *SEPE Journal of Fire Protection Engineering*, Vol. 10, No. 2, p. 1.
9. Kim, A. K., Liu, Z. and Su, J. Z. (1999): "Water Mist Fire Suppression using Cycling Discharges", Proceedings of Interflam '99,Edinburgh, UK, p.1349.
10. Kim, S. C., and Ryou, H. S. (2003): "An Experimental and Numerical Study on Fire Suppression using a Water Mist in an Enclosure", *Building and Environment*, p 1309.
11. Liu, Z. and Kim, A. K. (2001): "A Review of Water Mist Fire Suppression Technology: Part II – Application Studies", *Journal of Fire Protection engineering*, Vol. 11, No. 1, p. 16.
12. Loomis, M. and McPherson, M. J. (1995): "Application of Water Mist for the Control of Fuel-Rich Fires in Model Coal Mine Entries" Proceedings of the 7th US Mine Ventilation Symposium, p. 225.
13. Lungar, J. R. (1979): Water Mist Fire Protection, David W. Taylor Naval Ship, R&D Center, Bethesda, MD.
14. Mawhinney, J. R. (1993): "Design of Water Mist Fire Suppressions Systems for Shipboard Enclosures", In: Water Mist Instead of Halon? International Conference on Water Mist Fire Suppression Systems in Boras, Sweden.
15. Mawhinney, J. R. (1994): "Water Mist Fire Suppressions Systems for Marine Applications: A case study", Inst. of Marine Eng., IMAS 94: Fire Safety on Ships, London, UK.
16. Mawhinney, J. R., Dlugoggorski, B. Z. and Kim, A. K (1994): "A Closer Look at the Fire Extinguishing Properties of Water Mist", Fire Safety Science – Proceedings of Fourth International Symposium, Ottawa, p.47.
17. Mawhinney, J. R. (1996): "Findings of Experiments Using Water Mist for Fire Suppression in an Electronic Equipment Room", Proceedings of Halon Options Technical Working Conference, Albuquerque, NM, p. 15.
18. Mawhinney, J. R. and Richardson, J. K. (1997): "Review of Water Mist Fire Suppression Research and Development", *Fire Technology*, Vol. 33, No. 1, p.54.
19. McKinnon, J. T., Abbud-Madrid, A., Riedel, E. P., Gokoglu, S., Yang, W. and Kee, R. J. (2001): "The Water-Mist Fire Suppression Experiment: Project Objectives and Hardware Development for the STS-107 Mission", Sixth International Microgravity Combustion Wokshop, NASA Glen Research Center, Cleveland, OH, p. 105.
20. Notarianni, K. A. (1994): "Water Mist Fire Suppression Systems", Proceedings of Technical Symposium on Halon Alternatives, Knoxville, TN, p. 57.

21. Qin, J., Yao, B. and Chow, W. K. (2004): "Experimental Study of Suppressing Cooking Oil Fire with Water Mist Using a Cone Calorimeter", *International Journal of Hospitality Management*, Vol. 23, p. 545.
22. Singh, R. P., Ray, S. K., Sahay, N. and Bhowmick, B. C. (2004): "Study on application of fire suppression techniques under dynamic condition of fire" *The Journal of the South African Institute of Mining & Metallurgy*, Vol. 104, No. 11, December, p. 607.
23. Roberts, F. and Blackwell, J. R. (1969): "The Possibility of the Occurrence of Fuel-Rich Mine Fires", *The Mining Engineer,* September, p. 699
24. Wighus, R. (1995), "Engineering Relations for Water Mist Fire Suppression Systems", Proceedings of Halon Options Technical Working Conference, Albuquerque, NM, p. 453
25. Yuan, L. and Lazzara, C. P. (2004): "The effects of Ventilation and Preburn Time on Water mist Extinguishing of Diesel Fuel Pool Fires", *Journal of Fire Sciences*, Vol. 22, No. 5, p. 379.

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Special issue on

FUTURE OF UNDERGROUND COAL MINING IN INDIA – MECHANIZED BORD & PILLAR OR LONGWALL?

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