High rate spray technique – a new way for effective aerial wildfire suppression

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Abstract

Aerial fire-fighting techniques rely on firebombing by water or retardant from fixed wing aircrafts and helicopters. Extinguishing agent is dropped directly on the flaming fuels to blanket fire-line and to cool burning area. In the vicinity of ground firemen, equipment or buildings at urban interfaces, firebombing can cause very serious injuries or damage. Because of safety reasons the firebombing operations are particular concern for the firefighting management. Moreover, such application has an unavoidable disadvantage- very low degree of extinguishing agent utilization due to highly unequal concentration of liquid agent along the drop pattern. The effectiveness of a firebombing drop is related to the pattern of the drop on the ground and whether this meets the coverage required to extinguish the fire or coat fuel to form an effective firebreak. A different coverage level distribution within the drop pattern footprint makes drop to be ineffective with broken spots having small areas and high concentration of liquid.

To provide a maximum efficiency of water, as a most common and most available fire-extinguishing agent when applied from a helicopter, it is important to be achieved maximal cooling efficiency. Helicopter fire-fighting effectiveness could be significantly improved if water is applied as high rate spray with optimal dimensions and as much as possible uniform droplets structure. High rate water spray considerable increases cooling rate of a fire. Moreover, uniform cover of the fireline reduces water waste and increases accuracy, which makes suppression operation more cost-effective. All these features decrease total operational costs of aerial suppression tasks.

Thanks to performances of High rate water spray technology, helicopter equipped with water tank suspended beneath helicopter, capable to create high performance water spray with a necessary droplets range, momentum and flux density, needs less amount of water to suppress the wildfire more effective than any current aerial tool.

As a conclusion, in order to obtain more effective way to suppress wildfires, instead of firebombing, the aerial high rate water spraying is a promising option as future cost-effective aerial firefighting tool against wildfires.

Moreover, use of such new aerial suppression technique would be compatible with Minimum Suppression Tactics (MIST), which prefers use of water instead of retardant and recommends selection of tactics, aerial tool and equipment that least impact the environment.

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Introduction

Wildfires are the real threat in many areas of the world. They are often characterized by inaccessible terrain, where firefighting with ground resources is quite difficult. In such situations, the only realistic access to burning zones is by air. Therefore, wildland firefighting operations include application of water, foam or retardant from fixed wing aircrafts and helicopters.

Most of the current aerial firefighting means, including airtankers or properly equipped helicopters, are based on firefighting tactics relying on “liters per hour” concept, which their operational effectiveness determine by quantity of extinguishing material dropped onto a fireline in unit of time. Such a concept consists of delivering of large volumes of water or retardants in as short a time period as possible.

Helicopters are generally used for fire fighting operations because they are more versatile than fixed wing aircrafts. Since a helicopter does not require a landing strip, the firefighting equipment (slung bucket or belly tank) can be filled, without landing the helicopter, at a water source or at a temporary supplement point set up to maintain a supply of water or fire retardant material close to the fire. This reduces the amount of time required between aerial drops, which likewise reduces the time required to extinguish the fire.

Many fire retarding or suppressing chemicals are also applied to increase suppression efficiency. However, they are often difficult to use against wildfires. One problem with such chemicals is that they are environmentally toxic. They are also difficult to transport to remote locations in large quantities. In many cases, fire retardant chemicals require specialized and bulky application equipment. Moreover, both the chemicals and the application equipment are expensive.

Safety, efficiency and cost-effectiveness are essential requirements for a successful aerial firefighting operation. Reducing fire suppression costs has long been a priority for all agencies and companies involved in wildfire fighting operations. Therefore significant efforts are currently directed to develop and improve wildland firefighting techniques in order to gain more cost-effective aerial tool against wildfires.

Main disadvantages of the firebombing technique

The most common delivery tools for aerial suppression operations rely on gravity drop systems. Helicopters are equipped with belly tanks or suspended buckets (Fig.1) with doors or valves that open and discharge extinguishing agents (plain water, water soluble retardant or foam). Known buckets and belly tanks, as aerial firefighting tools, come in a variety of configurations, depending on helicopter carrying capacity, but their common feature is that all of them use gravity drop delivery system.

Buckets may be made of a rigid material or fabric mounted on a metal frame. They are slung several meters under the helicopter, which hovers as the bucket is filled from either a nearby body of water. When the bucket is full, the helicopter proceeds to the drop zone where the fire retardant is emptied through an opening in the bucket bottom, usually as the helicopter flies along a drop line. The most basic manner of emptying the bucket carrying water or retardant simply opens a valve as quickly as possible when helicopter approaches the drop line,

thus allowing the material to flow uncontrolled out of the bucket. There are many different types of valves, both electrically and hydraulically driven, known to be suitable to this purpose.

The rigid tanks attached to the belly of the helicopter are more complex but less reliable and more expensive aerial tools than helibuckets. They use a snorkel pump to fill their tank. Belly tank's delivery system has the drop doors driven by hydraulic actuators in order to dump "water bombs" onto the fireline.

However, described firebombing technique has limited effectiveness because of improper dispersion of extinguishing material, which is reflected through unequal concentration over the fireline. It is known that flow rate of the liquid from the bucket or belly tank affects the actual coverage level on the ground and suppression effectiveness more than any other factor. Effectiveness of the firebombing technique is related to the drop pattern on the ground and whether this meets the coverage required to extinguish the fire or coat fuel to form an effective firebreak. Drop pattern footprint can be influenced by the aircraft's speed, height above the ground, wind speed and canopy interception. An effective drop should either extinguish or curtail the fire along the length of the drop.

Figure 1 - *Representatives of common gravity delivery systems*

Although firebombing is a highly effective manner of delivering large quantities of extinguishing agent, implementation this technique has certain disadvantages, which relates mainly to suppression effectiveness and safety.

In order to be effective, the fire extinguishing material should be delivered onto the ground at a specific minimum concentration depending on the type of fire. Any concentration of extinguishing material (defined as coverage level) other than the optimum, wastes valuable agents. Coverage level (CL) is expressed as the volume of extinguishing material per unit area. A concentration that is too high obviously wastes firefighting medium, as does a concentration that is too low. Fig. 2 shows an example of typical drop pattern concentration distribution ([4], [8]). This example illustrates how varied concentrations over the drop pattern footprint can strongly affect aerial suppression effectiveness. Highly concentrated zones within the drop pattern footprint with coverage levels higher than 0.5 liters per m2, which comprise approximately 80 percent of the delivered material, cover only 28 percent of the total drop footprint area. This indicates how low suppression effectiveness is achieved by firebombing technique. When the

water firebombing is applied in fighting wildfires, water alone can be especially inefficient. Some parts of the delivered water, which are broken into too small droplets, evaporate before reaching the fuel bed on the ground. Water, which does reach the ground in high concentration, runs off over the sloped terrain or penetrates through the thin fuel bed and then it is being absorbed by soil. So, great part of the delivered water is being wasted before using up its full heat absorbing capacity. In many firebombing operations, it has been estimated that water is only 5 percent to 15 percent efficient, which means that most of the dropped water is being wasted as an ineffective material.

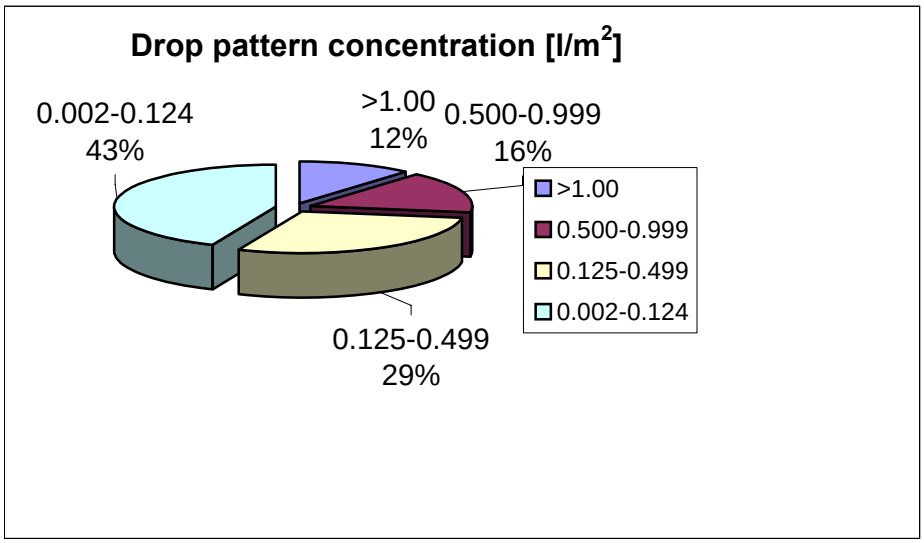

Figure 2 – *A typical drop pattern concentration distribution*

However, a more severe consequence is that an excessive extinguishing material concentration reduces the area that can be covered by the fixed amount of material in the bucket or belly tank. An insufficient concentration over some of the drop pattern area has the same effect because additional deliveries will have to be done at fireline locations that did not receive enough water. Not only does increasing the time to extinguish the fire cause additional loss of property, it also requires additional aircrafts operating flights. This makes entire firefighting operation less cost-effective. Taking into consideration that the flight-hour of fire fighting aircrafts (airtanker or helicopter) costs thousands of EURO-s, and when the firefighting operation requires the use of additional aircrafts due to low suppression efficiency, then the total cost will be increased proportionally.

Aerial firebombing technique has, except low degree of suppression effectiveness because of uncontrolled and drastically different coverage level zones within the drop pattern footprint, moreover safety disadvantage. During firebombing, drop must not deliver directly on firemen, supporting equipment or buildings (at urban interfaces). The impact of the liquid load could cause serious injury or death to personnel and heavy damage to equipment or buildings.

An alternative to firebombing – high rate spray technique

Despite described disadvantages that are resulted from firebombing technique, using water as extinguishing agent offers an efficient fire suppression capability. Water, as it is converted into steam, has tremendous capacity to absorb and carry away heat. It has the further advantage of being completely environmentally safe, which is very important when Minimum Suppression Tactics (MIST) is recommended. MIST guidelines [6] include selection tactics and suppression tools that least impact the environment.

When water spray droplets enter a flame they vaporize removing heat from the surroundings. As droplet size decreases, the total contact surface and heat transfer increases and the evaporation rate increases, enhancing homogenous vapor-phase inhibition mechanisms. Heat absorption is considerable increased due to spending of latent heat of water during evaporation. The steam occupies a thousand times as much space as water and it pushes the air away as it forms, reducing the local concentration of oxygen feeding the flames. Ideally, for maximum heat absorption, droplets should be smaller as much as possible. However, small droplets are not able to reach sufficient distance. The light droplets, although preferable for heat absorption, easily flow out of the fire zone, blown out by the fire heat and turbulence. Too small droplets also evaporate too early, so their vaporization is not available to cool the flame. Larger droplets are able to reach the flame, pass through the flame without fully evaporating and hit burning surfaces in their path. Therefore, proper applied droplets size is a key factor for suppressant effectiveness

In order to determine an optimal aerially applied droplets size range, a theoretical comparative analysis was carried out. Heat absorption effectiveness of the equal quantities of water, applied as uniform sprays with different droplets size, discharged from height of 30 m, were analyzed and compared with referential spray consisting of droplets with 10 mm diameter. A criterion for suppression capability evaluation was the ratio of the total heat absorbed by the uniform spray, passing through a hot flame surrounding with an assumed temperature profile, to the referential spray heat absorption capacity. Results presented in Fig. 3 indicate that a uniform spray, containing droplets of 1.5 mm diameter, absorbs even 24 times more heat quantity when compared to the referential uniform spray of equal water amount and with 10 mm diameter droplets. Sprays with droplets smaller then 1mm diameter are less effective because they evaporate before reaching the ground. As a general conclusion of this brief analysis, due to high heat absorption and penetration capabilities, an aerial spray with droplets size distribution ranged between diameters of 1 to 4 mm would be the most suitable for aerial application against most of common wildfires.

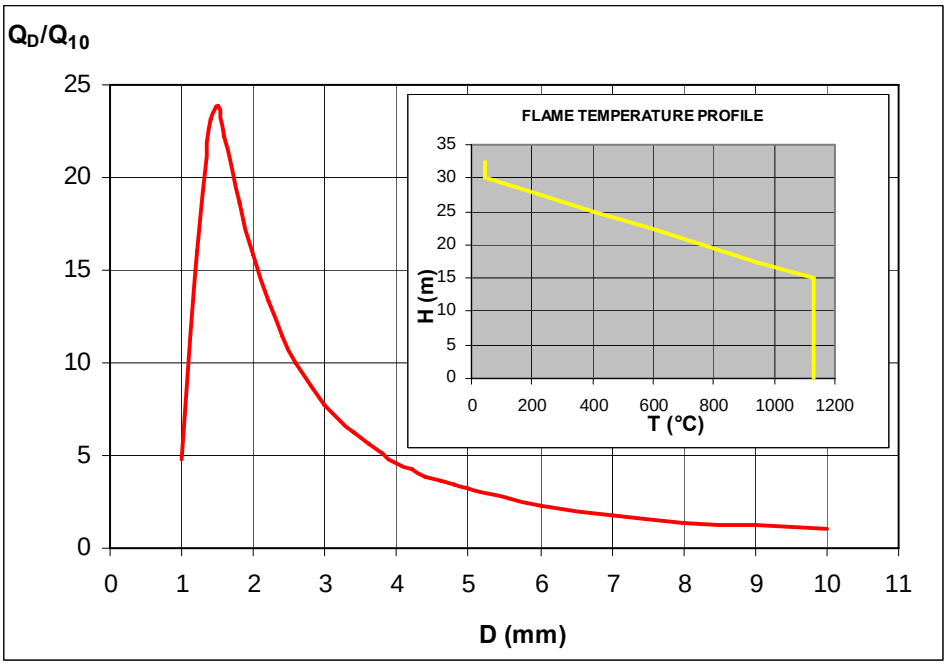

Figure 3 - *Ratio of the heat absorbed by uniform spray while passed through a hot flame surrounding with an assumed temperature profile to the referential spray heat absorption capacity*

Besides the droplet size distribution, another three important characteristics of the water spray strongly affect the suppression effectiveness. These are water flux density, spray coverage and spray momentum.

Spray flux density refers to the amount of water spray applied in a unit time onto a unit area (l/s m^2) and directly relates to the discharge rate. The fire cannot be extinguished unless the water quantity discharged from an aerial system is sufficient enough to extinguish the flame by removing sufficient heat from the flame, or to cool the organic fuel below its fire point. Generally, higher flux density means better effectiveness although for optimal application it should not be overstepped.

Since a certain amount of water is required to suppress a fire, water spray coverage must be large enough to cover the fire front along fireline with sufficient width, which enables water spray to attack effectively the flames and cool the fuel over the fuel covered surface.

Water spray momentum is the third characteristic required in suppression a wildfire. Spray momentum refers to the droplets mass and velocity. It must be sufficient enough to allow water droplets to penetrate the fire plume and reach the fuel bed surface. Water spray with low momentum will be carried away by the fire plume or wind. To overcome the fire plume, the water spray momentum must be at least equal in magnitude, and opposite in direction, to the fire plume momentum.

The suppressing effectiveness of the applied water spray is proportional to removed heat, as a part of the maximum heat absorption capacity. The heat absorption rate depends on water spray performances. To ensure high suppression effectiveness, due mainly to environmental conditions during discharging (wind, turbulence, high temperatures) water spray must reach the heart of a flame. Such a directional wide spray, containing a high concentration of dispersed water

droplets, when discharged onto the combustion zone of the burning material, practically “cuts off” the flame from the fire source, thus eliminating one of the fire pyramid parameters (fuel, heat, oxygen) [1]. Other mechanical and physical mechanisms include: large surface area heat absorption and dispersion, destruction of flame front, cooling of fuel surface, forced mixing of droplets with fuel vapors, and separation between oxygen/air and fuel.

Therefore, aerial wildfire suppression effectiveness can be significantly increased if high-rate water spray, at application rates approaching those from conventional slung buckets, is applied. Such a high rate spray technique, applied aerially should provide the following common features:

- to produce high rate spray, which maximizes the effective use of water for wildfires fighting;
- to absorbs heat rapidly and enhances the rate at which water is converted to steam, removing more heat from the surrounding fire;
- to spend less amount of water with better suppression effects;
- to cover wider and larger fire surface area with a uniform spray pattern;
- to enable good spray penetration through canopy;
- to eliminate damage on environment and buildings at urban interface from drop impact;
- to provide a complete safe aerial application for ground crew.

For practical purpose, these features should be converted to product design specifications of an advanced aerial firefighting appliance. To this date, however, there exists no practical aerial high-rate water spray appliance, which would be able to achieve these performances. Recently, certain efforts have been done to develop and apply aerial spray systems, as MAFFS (U.S.A.), SHAEP (France) or IFEX Technology (Germany) but with limited results. The flow from a standard firehose nozzle, as for example proposed in SHAEP project, is simply not adequate. The most significant obstacle to be created a high rate spray from aerial applicators is the extremely high volume of water which should be applied by means of practical and low cost pressurization mode.

The main goal of the high rate spray technique proposal is to introduce a new cost-effective method for aerial wildfire fighting and thereby achieve better suppression effectiveness with less water

The helicopter’s high rate spray system - HELSY

The effectiveness of water spray is well established and explained previously but the only limitation so far has been a high rate effective delivery mode onto the fireline in order to be obtained a practical solution for aerial application of the high rate spray technique. Delivering large quantities of water from helicopters onto a fire zone and dispersing them in homogeneous spray that penetrate the fire flame front to cause quick fire suppression, is a challenging task.

A new approach to solve this task, suggested in this paper, is based on solid propellant gas generator technology. In principle, the generated gas propels water accommodated within the suspended tank through plurality of stream nozzles, whereby dispersing water onto the fire area and increasing the original water’s volume and droplets surface area to obtain fast and reliable fire suppression.

A helicopter aerial firefighting system, which is developing in accordance with this approach, is also presented in the paper. The system called HELSY,

based on the patented technology, enables that the proposed high rate spray technique can be applied for aerial wildfire suppression.

The high rate spray system HELSY is a slung transportable helicopter fire suppression system. It is able to provide all specified features when the high rate spray technique is applied, discharging a high rate spray with proper sized droplets. This unique system is in advanced development stage.

In general, HELSY system contains two main functional components:

1. Suspended appliance comprising refillable tank for water accommodation, gas generator combustion chamber compartment, spray nozzles plurality, electrical ignition device and appropriate attachment accessories (Fig. 4);
2. Consumable solid propellant gas generator cartridge (Fig. 5), which is the component for pressurization.

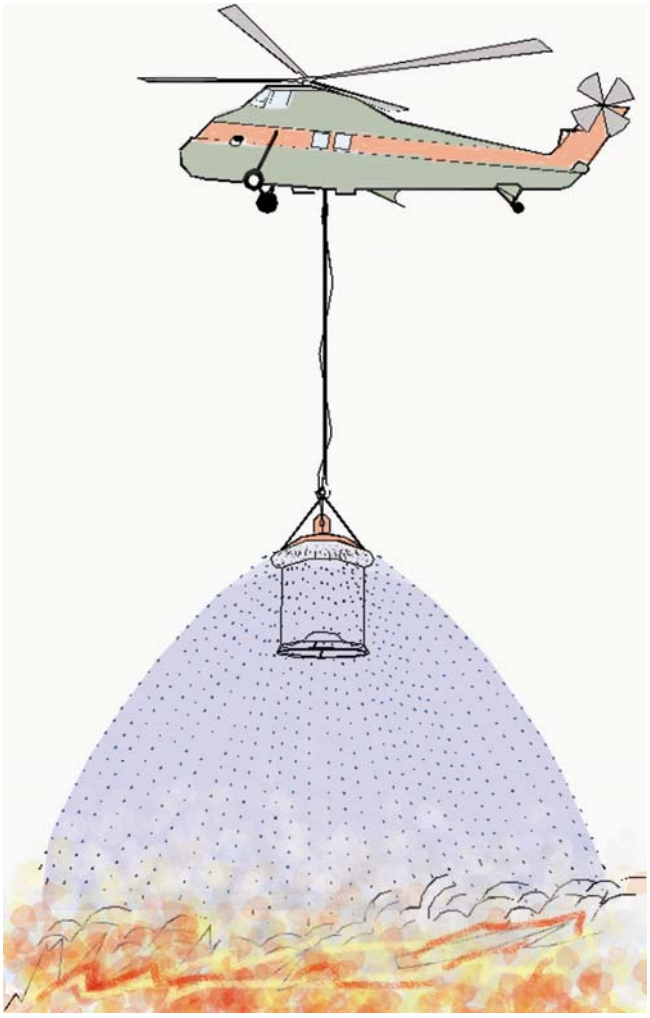

Figure 4 – *HELSY-high rate spray system in action*

The HELSY - high rate spray delivery system combined with helicopter flying speed and its performance characteristics make this equipment as an especially productive one. HELSY is able to produce a variety of coverage levels. Its advanced high rate spray delivery system provides fire managers with the ability to place more line down with less water than they can with conventional helibucket or belly tank delivery systems. Its high rate spray delivery system

makes it one of the most effective delivery tools. Highly uniform coverage is delivered in blankets that have no gaps in its ground coverage pattern.

The consumable solid propellant gas generator cartridge (Fig.5) produces sufficient gas pressure to discharge the tank in form of directional spray. The cartridge is safe to handle and operate. They are consumed for each appliance's tank discharge. Moreover, the combustion gases generated by the gas generator cartridge are environmental friendly with zero Ozone Depletion Potential (ODP) and do not contribute to the Global Warming Effect (GWP).

The HELSY appliance is attached to the helicopter's cargo sling-hook. It can be attached to different types of helicopters. When emptied, it can be fast replaced with prepared full one at an established refilling point in very short time without landing. Replacement is carried out easily by the ground crew while helicopter hovers above refilling point. This procedure improves refilling management reducing turnaround time. Refilling points should be located at natural water sources close to the fire. Besides, adequate and convenient reservoirs of water can often be found near burning fires. Helicopters equipped with HELSY system and supported by the ground crew can be also supplied from such reservoirs. Anyhow, the proximity of a refilling point minimizes turnaround flying time.

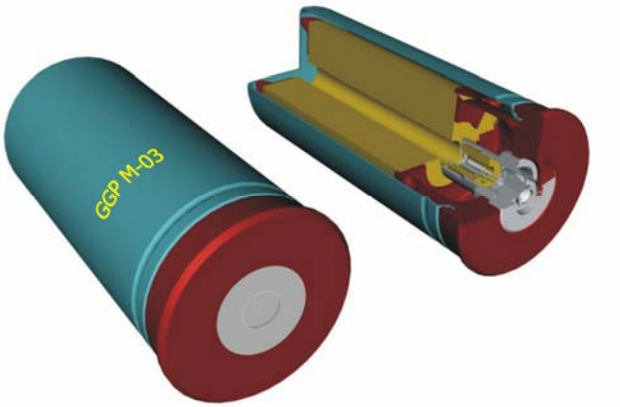

Figure 5 - *Consumable gas generator cartridge of the HELSY system*

As an innovative solution the HELSY system gives a significant contribution to aerial fire fighting technology. Employing such an aerial system provides unprecedented fire extinguishing capability against wildfires. HELSY- helicopter high rate water spray system offers the following advantages:

- Increased suppression effectiveness, achieved by smaller quantity of sprayed water as environmentally friendly fire extinguishing agent;
- Rapid spray discharge that enables high spray flux density, large area coverage with optimal volume and short suppression time;
- Increased spray pattern accuracy;
- Uniform spray pattern;
- Minimized recoil during discharging;
- Minimized influence of wind and rotor downwash;
- Short appliance set-up time;
- Slung appliance can be jettisoned;
- Safe for ground crews while it is applied;

- By means of mobile fire pumps the appliance tank can be refilled from most of water natural sources (rivers, creeks, lakes or sea) or from fire hydrants, reservoirs or tanker trucks;
- Cost effective (low purchase price and life cost cycle);
- Simple appliance installation and minimal maintenance required;
- Faster turnaround provided by two replaceable tanks;
- High reliability – system does not contain functional moving parts, pressurized vessels, pumps or hydraulic devices.

In order to evaluate the proposed new aerial firefighting technology, methodology and criteria in [3] are accepted and used in the following analysis, which is presented in Table 1.

Table 1 – *Evaluation of the HELSY system*

Criterion	Comment
Integration	Helicopter equipped with a HELSY system can be easily integrated into the existing firefighting system
Response	Helicopter equipped with a HELSY system is able to carry out rapid wildfire suppression within existing firefighting operations
Effectiveness	Thanks to its superior performances, HELSY is capable to deliver high concentrated water spray more accurate onto the fireline under different conditions (determined by fire behavior, fuel type, terrain and weather) providing a high heat absorption capability
Capability	Thanks to its operational characteristics, proper organization at a closest refilling point and by using two HELSY appliance, which are sequentially filled, prepared and replaced, the turnaround time is reduced
Efficiency	With high rate spray and varied helicopter speed, different spray flux and spray coverage can be simply achieved
Accuracy/Ground Crew Support and Safety	Thanks to dense and wide spray coverage, accurate deposition of the water spray onto the fireline can be easily carried out. Ground crews are completely safe against impact injury
Damage evaluation	Faster and more effective wildfire suppression and thus saving more endangered wildland area and property from damage is enabled by using HELSY system

Nevertheless, there are two minor disadvantages of the HELSY system. They are:

- It is dependant on the ground crew at the refilling point, whose task is preparation of the system, which includes refilling the appliance tank, insertion of the gas generator cartridge and attachment the apparatus to the suspended sling. Since this supporting operation requires only one or two men, importance of this disadvantage is not so significant, because each firefighting operation employs much more personnel than needed for such a ground-supporting task.
- System is not designed to be used in multi-discharge option. This option is used mainly by airtankers or belly tank systems with larger capacities. Even when those systems have multi-drop mode of delivery, they use this mode very rarely. According to statistic data in U.S.A., single engine airtankers (SEAT) spent only 29 percent of total firefighting operations

using multi-drop delivery mode. So, this disadvantage is not also important for practical application.

However, these disadvantages have been considerable overcome with more significant advantages offered by the HELSY system. Its features make it as a cost effective alternative to current gravity dropping systems. Application the high rate spray technique with HELSY system becomes reality.

HELSY systems can be designed and manufactured to be used by light (Type3), medium (Type 2) or heavy (Type 1) helicopters, although they are most suitable for Type 2 and Type 3 helicopters.

Conclusion

Plain water used for suppressing wildfires when combined with the high rate spray technology, allow water to be used more efficiently, covering more fire line area and leaving less liquid as a wasted matter. Delivering water onto a fire zone, dispersing it in homogeneous sprays that penetrate the fire flame front and stop it, thus causing immediate fire suppression is much more effective method than traditional firebombing.

The application of aerial high rate water spray technique offers a cost-effective alternative to replace the current helicopter gravity drop delivery systems (slung buckets and belly tanks). It mainly aims to provide an effective and safe aerial firefighting equipment to improve aerial firefighting operations and reduce operational costs.

Compared to traditional firebombing techniques, analytical results show that proper use of the high rate water spray technique can achieve a better cooling effectiveness, with less spent water by using optimal droplets structure and wide spray coverage. Optimum performances of the high rate water spray technique are determined by characteristics of the water spray (e.g., droplet size distribution and velocity, spray coverage, flow rate, etc.), discharge conditions (e.g., helicopter speed, discharge height) and wildfire conditions (e.g., fire intensity, canopy and fuel type, atmospheric conditions, wind speed and direction).

Presented new HELSY helicopter aerial system offers a promising practical solution for high rate spray application.

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