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Regular Article

Fast surface disinfection with COUNTERFOG® SDR-F05A+

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Abstract COUNTERFOG® has been proposed as a rapid decontamination and disinfection
technology that uses dynamic submicrometric-disinfecting fog cones. When projected onto 1
surfaces, they create a micrometre-thick film of disinfectant minimizing the use of liquids and
the impact on environment. The extremely thin film is intended to be enough to cover and kill
microorganisms and simultaneously thin enough to evaporate in a few minutes—depending
on the environmental conditions. In the present work, experimental tests were carried out
to verify this hypothesis. These include a physical characterization of the fog in the cone, a 2
measurement of the liquid flow projected on surfaces as well as disinfection tests with a series
of microorganisms. In addition to these results, operational recommendations are derived to
ensure disinfection reliability.

1 Introduction

Fomites and aerosols are two main transmission channels for many pathogens. Particularly, they are currently accepted as the main transmission mechanisms for COVID19. This virus has been proved to remain active for hours both on surfaces and in aerosols [1].

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Fig. 1 COUNTERFOG® dynamic fog cone

Therefore, a key for success when fighting against transmission of the pandemic is to effectively disinfect both surfaces and air wherever people can be exposed to—including buildings, vehicles, facilities, etc. [2].

COUNTERFOG® technology was recently developed[1] within the 7th Framework Program for research and technological development (FP7) aiming to be a fast and universal technology for decontamination of both surfaces and air from Chemical, Biological, Radiological and Nuclear agents on a large scale [3].

This decontamination technology is based on dynamic fog cones composed of submicron-sized liquid droplets that, when projected into the air, collapse air-borne CBRN agents posing them down onto surfaces.

It was previously demonstrated that COUNTERFOG® cones made of biocidal liquid projected on surfaces, covering them with a thin layer of biocide (a few microns thick) disinfect *Bacillus Turinghiensis*. Biological agents are rapidly eliminated, saving significantly in the use of biocide and in the recovery time of the operation of the place, whether the agents are stuck or adhered to a surface, as if they are floating in the air or are easily resuspendable [4] (Fig. 1).

COUNTERFOG® technology uses a specially designed nozzle fed by liquid—generally water and solutions—and low-pressure compressed air. The portable device COUNTERFOG® SDR-F05A+ for rapid disinfection uses this technology to make a practical device able to be operated just by a single person in a very simple way.

Suspended particles collapse with the fog nano-sized liquid droplets and are dragged by the cone, posing on the ground or onto surfaces. This prevents the agents from continuing to disperse, thus facilitating decontamination and generating minimal liquid waste and consequent damage to the environment [5] (Fig. 2).

The physical principle that governs the operation of COUNTERFOG® technology is the droplet and micro–nano-CBRN particles dynamics. When these substances are floating in air, they are absolutely dragged by airflow. The smaller they are the fitter they behave. This implies that they can only collapse or coalesce with droplets of liquid of a similar size—they

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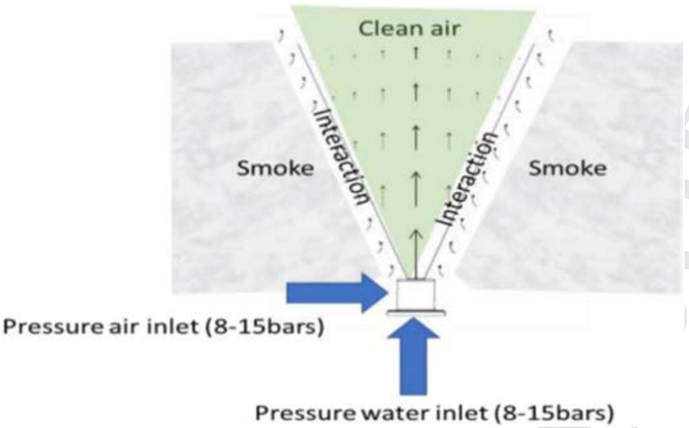

Fig. 2 Schematic representation of a COUNTERFOG® cone absorbing the air—in this case with smoke—around it

cannot collapse to droplets of a larger size, such as those produced by conventional sprinklers or sprayers [6–8].

In this way, airborne matter—or particles adhered to a surface—collapse with the COUNTERFOG® cone, making them to fall or detach. If the projected liquid is a biocide, the biological particles are neutralized as they collapse with the fog droplets. The layer of liquid formed after the application of the fog should be extremely thin, allowing its evaporation in a few minutes depending on the environmental conditions, guaranteeing the necessary time to disinfect said surfaces [9].

In this work, different tests have been carried out to physically characterize and verify the operation of the COUNTERFOG SDR-F05A+ device, as well as a set of biological tests for the neutralization of different pathogenic microorganisms with commercial disinfectants as shown below. These tests include the following: (1) COUNTERFOG® cone characterization, (2) projected micrometre film distribution and thickness, (3) liquid flow variation, (4) droplet distribution, and (5) biological tests (Fig. 3).

2 COUNTERFOG® SDR-F05A+ characterization

This section describes the tests and procedures to characterize the portable fast surface disinfection device COUNTERFOG® SDR-F05A+.

2.1 SDR-F05A+ physical characterization

The fog cone and operability of the COUNTERFOG® SDR-F05A+ device have been characterized through a series of physical tests and experimental measurements:

2.1.1 COUNTERFOG® cone geometrical and dynamic characterization

The objective of this test is measuring the absorbed airflow by the COUNTERFOG® cone; analyzing the velocity distribution of the air entering said cone; calculating the variation of the diameter and velocity of the fog cone along its horizontal axis.

Fig. 3 Operator using disinfection COUNTERFOG® SDR-F05A+ device

An SDR-F05A+ nozzle was horizontally fixed on a tripod. The very end of the nozzle was taken as origin of coordinates. A digital anemometer *Kestrel 3000* was used to measure fog velocity along its horizontal axis as well as at different peripheral points around the axis of the fog cone. The criteria to define the border of the cone was based on the axial component of the velocity. Points with axial velocity under 0.1 m/s are considered out of the cone.

The total flow of external air dragged by the cone was calculated by integration all over the border of the cone.

2.1.2 Projected micrometre film distribution and thickness

The objective of this experimental test is to measure the aggregated liquid fog distribution projected on a flat surface—ml/min cm^2—and its film thickness (μm) generated by a COUNTERFOG® nozzle.

Small cups were provided onto a vertical surface in order to collect the liquid projected onto 100 mm × 100 mm patches. Total weight of liquid collected at those patches were measured. This test was repeated for different distances ranging from 1 to 3 m, the projected fluid flow was variated by opening the water stopcock valve in proportional angles to 45°.

2.1.3 Liquid flow variation

The third physical test was realized with the objective of analyzing the quantity of liquid projected by the cone as a function of the opening of its corresponding liquid stopcock valve.

It was evaluated the time it took to empty the 12-L tank—pressurized with the 11 bar—-varying in each projection the opening of the water stopcock valve in proportional angles to 45°. As the previous tests, it was repeated a statistical number of times.

Table 1 Biological tests results

Test	Microorganism	Disinfectant	Application velocity (m/s)	Application time (min)	Film thickness (μm)	Reduction (Log_{10})	Reduction (%)
E1	*Escherichia coli*	0.6% NaClO	0.45	1	21.8	2	99.00
E2	*Candida albicans*	1% NaClO	0.36	1	27.3	3	99.90
E3	*Proteus hauseri*	1% NaClO	0.16	6	61.53	3	99.90
E4	*Enterococcus hirae*	1% NaClO	0.15	1	65.64	5	99.99
E5	*Pseudomonas aerugi-nosa*	1% NaClO	0.37	6	26.60	3	99.90
E6	*Staphylococcus aureus*	1% NaClO	0.21	1	46.88	0.99	93.00
E7	*fago phi29*	1% NaClO	0.57	1	17.27	3	99.90

2.1.4 Droplet distribution

The verification of the previously calculated—nanometric—size of the COUNTERFOG® cone droplets, were carried out by experimental measurements using an optical emission spectrometer at Instituto Nacional de Técnica Aeroespacial (INTA).

2.2 SDR-F0A+ biological characterization

2.2.1 Biological tests

Biological tests to verify the effectiveness of the COUNTERFOG® SDR-F05A+ device against different pathogenic microorganisms have been carried out. Bacteria—*Escherichia coli, Proteus hauseri, Enterococcus hirae, Pseudomonas aeruginosa, Staphylococcus aureus*—, fungi—*Candida albicans*—, and viruses—*fago phi29*—were disinfected.

The objective of the biological tests consisted in assessing the minimum quantity of different commercial disinfectants necessary to apply, defining for each microorganism the application velocity—sweep—of the projected cone by an operator to neutralize each type of microorganism—obtaining the corresponding film thickness (μm).

Biological tests were realized using solutions of the different pathogenic microorganisms on stainless steel coupons, in accordance with ISO-UNE standards. There were performed in a closed room, projecting the cone at a distance of 2 m—from the nozzle to the impact area where the coupons were located—by means of a horizontal sweep, at the velocities specified in Table 1. *Biological tests results.*

Colony-forming units—cfu—in the control coupons without any disinfection were compared in a laboratory with the disinfected samples, thus obtaining logarithmic and percentage reductions of the cfu.

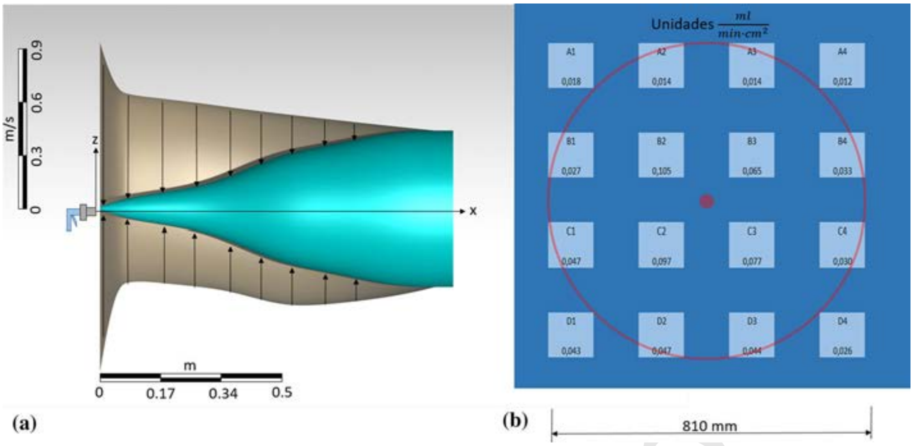

Fig. 4 **a** Distribution of the airflow drawn in by the fog cone (m/s). **b** Distribution of the projected droplets by the fog cone at 2 m (ml/(min·cm^2))

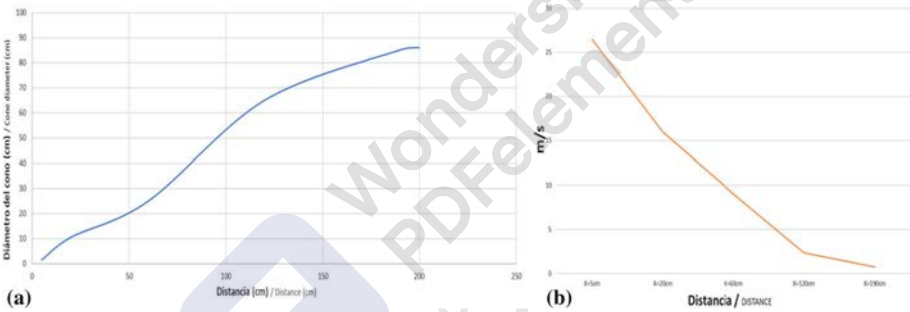

Fig. 5 **a** Cone diameter with respect to the distance from the end of the nozzle. **b** Velocity in the axis of the cone with respect to the distance from the end of the nozzle

3 Results

This section includes the results of the aforementioned tests.

3.1 SDR-F05A+ physical characterization results

3.1.1 COUNTERFOG® cone characterization results

The airflow COUNTERFOG® cone absorbs 0.3 m^3/s air from around with an average velocity of the air drawn into the cone of 0.3 m/s and –with a maximum airflow of 0.9 m/s. Figure 4a shows the velocity distribution of the absorbed airflow in the *x*–*z* plane.

Figure 5a shows the evolution of the cone diameter—cm—with respect to the distance from the end of the nozzle—as the origin of coordinates. Figure 5b the velocity along the horizontal axis of the cone with respect to the previously mentioned distance—m/s.

D_{10} particles (µm)	D_{90} particles (µm)	% emission
0,02	0,03	47,86
0,03	0,04	85,57
0,05	0,07	76,46
0,10	0,15	47,53
0,22	0,26	23,50
0,32	0,43	12,77
0,59	0,73	4,91
0,91	1,17	1,37
1,52	1,86	0,23
2,28	2,95	0,07
3,81	4,92	0,03
6,37	7,76	0,02

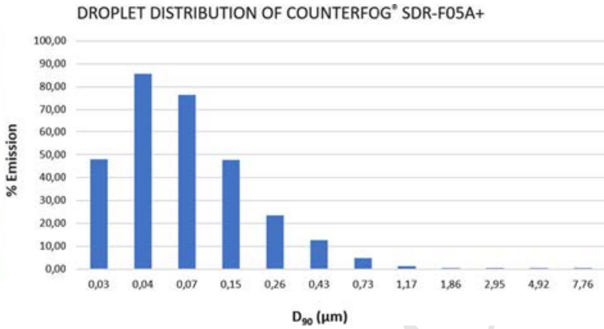

Fig. 6 Droplet distribution of COUNTERFOG® SDR-F05A+

3.1.2 Projected micrometre film distribution and thickness results

The projected fog distribution—ml/ min cm^2—in a flat surface has been assessed by a series of fluid projections, variating the opening of the water stopcock valve and the distance from the impact surface to the nozzle. Figure 4b shows the results of a projection carried at 2.0 m from the end of the COUNTERFOG® nozzle to the impact area, with the water stopcock valve opened 3/8 turn.

The flow ranges from 0.1 to 0.01 ml/(min cm^2). If for instance the user moves the nozzle horizontally at 0.45 m/s, an average of 21.8 µm can be easily calculated.

3.1.3 Liquid flow variation results

The liquid mass flow projected by the cone as a function of the opening of its corresponding liquid stopcock valve has been evaluated.

It was observed a constant maximum projected liquid flow of 0.65 l/min when there was a valve opening greater than or equal to 3/8 turn.

3.1.4 Droplet distribution results

Droplet size distribution of COUNTERFOG® SDR-F05A+ nozzle was analyzed by experimental measurements in Instituto Nacional de Técnica Aeroespacial (INTA). The results are shown in Fig. 6, thus verifying the previously calculated nanometric size.

3.2 SDR-F0A+ biological characterization results

3.2.1 Biological tests results

Biological disinfection results show an average reduction of three orders of magnitude for the different pathogenic microorganisms assessed.

The following Table 1 shows the disinfectant applied for killing each pathogenic microorganism with the correspondent solution, application velocity, and time, film thickness—µm—of the projected fluid layer and the total reduction of the biological microorganisms—logarithmic and percentage.

4 Conclusions

COUNTERFOG® SDR-F05A+ portable device has been demonstrated to provide a fog cone made of nanometric to micrometric droplets. This cone absorbs 0.3 m^3/s of air from the environment and projects a few micron thick liquid film over a 1 m^2 surface in a typical time of 1–3 s. Last, with these rates of application the equipment has shown 2–3 log reduction disinfection of a number of microorganisms including fungi, bacteria and virus.

Data Availability Statement Experimental test and previous researches.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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