EFA air disinfection using Kronos^{TM} based air purifiers

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***Abstract* — Electrostatic Air Filtration and Purification systems developed by Kronos Air Technologies use positive corona discharge to simultaneously and silently move air and perform air filtration (e.g. particulate removal) and air purification (e.g. microorganism destruction). This paper presents recent experimental results demonstrating high efficacy of Kronos based air purifiers in capturing and destruction of various types of microorganisms in different environmental settings.**

I. INTRODUCTION

Airborne infectious diseases have become prominent public health concerns with heightened focus after the anthrax attacks of 2001, the spread of severe acute respiratory syndrome (SARS), and increased avian influenza mutations that have caused morbidity, mortality, and very significant economic damage to affected countries. The goal of this paper is to demonstrate that the advanced electrostatic and corona discharge technology systems developed by Kronos Air Technologies, Inc. can be successfully used in different occupational settings to destroy and arrest airborne infectious diseases.

Kronos Air Filtration and Purification system uses the same principle of operation as Electrostatic Fluid Accelerators (EFA). The operation principle is illustrated for the case of an electrostatic air purifier which consists of an array of identical patterns, a schematic representation of one of which is shown in Fig. 1. Each pattern consists of a thin wire, flat collecting electrodes with a rounded bar attached to the end facing the wire, and a repelling electrode. High voltage difference is applied between the corona wire and collecting electrodes. The voltage of the repelling electrode is set between the voltage of the wire and voltage of collecting electrodes. The small radius of the wire and high voltage difference provide the nonuniform electric field necessary for corona discharge. For positive corona, i.e. when electric potential of coronating wire is higher than that of the collecting electrodes, positive ions born in the small ionization zone surrounding the wire and are dragged by coulombic force in the drifting zone along electric field lines toward collecting and repelling electrodes, colliding with neutral air molecules. During these collisions, momentum is transferred from the ionized gas into the neutral air molecules, resulting in bulk gas movement towards the collector electrode. After the ions settle on the collecting electrodes, they are deionized and become neutral molecules. The governing equations describing the interaction of electric charges with moving media in an electrostatic fluid accelerator are well known and have been studied extensively [1-7]. The operating voltage range for corona discharge lies between the corona onset and air gap breakdown voltage [5]. Corona induced airflow is possible with both a positive and negative voltage. However, higher efficiency along with silent operation and lower ozone generation can be achieved by using positive polarity [8].

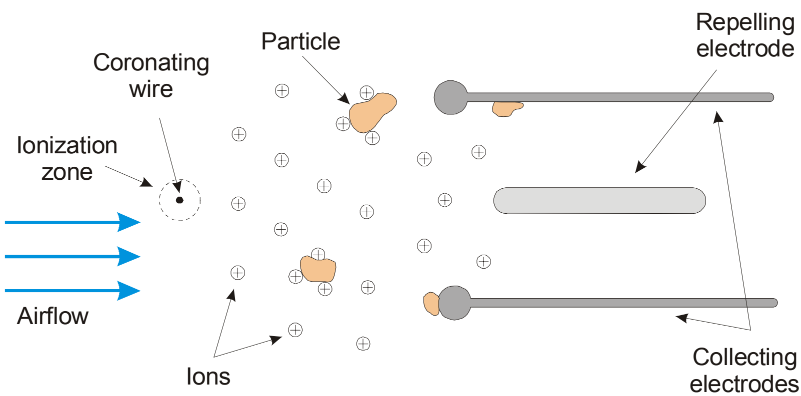

Fig. 1. *Schematic representation of Kronos electrostatic air purifier.*

The cleaning process in Kronos filtration and purification systems occurs through several mechanisms. First, free charged ions discharged by the corona electrodes attach to particles such as suspended particulate matter, dust, smoke, microorganism *etc.* In the electric field these newly charged particles then move together with air in the gap between collecting and repelling electrodes. The electric field created by the electric potential difference between repelling and collecting electrodes forces charged particles to move toward the collecting electrodes and attach on its surface. Second, the ions being discharged by the corona electrode collide with pathogens, bacteria, and other foreign particles in the electric field. These collisions and charge differentials created by the ion shower cause damage to the surfaces of microorganisms and potentially render microorganisms inert.

In order to effectively eliminate and kill various types of airborne infectious agents in different occupational settings, the following aspects have to be addressed:

- **Air movement:** air flow produced by the system should be sufficient for a particular application.
- **Filtration:** filtration effectiveness should be close to 100% to make sure that airborne infectious agents do not penetrate through the system.
- **Disinfection:** disinfection effectiveness should be close to 100%.
- **Safety:** operation of the system should meet safety requirements.

Kronos filtration and purification systems have reached considerable performance in all aspects mentioned above through its patented technology [9-18].

Existing Kronos devices can silently deliver up to 850 cubic feet per minute (CFM) of air movement and reach air velocity up to 1,700 feet per minute without the use of any moving parts. Kronos systems have been certified by third party testing agencies to perform at HEPA (99.97%) and ULPA (99.999%) level particulate filtration for 0.3 micron and larger particles and have been shown to remove greater than 99% of particulates down to 20 nanometers in size.

One of the main concerns regarding devices that use corona discharge phenomenon is ozone generation created as a byproduct of the discharge process. Although ozone can potentially assist in killing microorganisms and disinfection of air, in high concentration it can be harmful for people. Therefore, it is desirable to control ozone levels generated by air purifiers. Kronos filtration and purification systems generate only small amounts of ozone and comply with section 37 of the most recent version of UL 867 standard.

Kronos systems have been tested for particle cleaning efficiency, air flow rate, and ozone generation by recognized third party testing organizations including LMS Technologies, Intertek, and University of Washington, St Louis. Recent bacteriological destruction testing was completed in the United States, Russia, and Ukraine to determine the effectiveness of Kronos air systems in the destruction of bacteria and microflora. All studies conclude either complete or very effective destruction of tested bacteria and microflora by the Kronos air purifiers. The purpose of this paper is to present experimental results demonstrating the efficacy of Kronos air systems in capturing and destruction of various types of microorganisms.

II. AIR PURIFIERS BASED ON KRONOS TECHNOLOGY

Several air purification systems developed by Kronos Air Technologies have been tested for microorganism destruction. Experimental results obtained for two of them, shown in Fig. 2, are considered in this section.

A. Kronos K-75 air purifier

Kronos K-75 air purifier, Fig. 2 (a), has dimensions of 10” by 12” by 16” and produces 75 CFM of airflow while consuming not more than 25 W. Its single pass cleaning efficiency exceeds 99% for particles with size of 0.3 micron and greater. Ozone concentration produced by K-75 is well below the UL 867 standard requirement.

(a) (b)

Fig. 2. *Air purifiers based on Kronos technology: (a) K-75 and (b) "TREE".*

The Kronos K-75 air purifier has been tested at the Intertek microbiology lab in Columbus, OH, for its ability to reduce the number of microorganisms aspirated into a 411 cubic foot test room. In two experiments the test room was contaminated with *Escherichia coli* bacteria and the MS2 virus. Air samples were collected in the center of the test room every 5 minutes during the first hour and every 10 minutes during the second hour of the experiment. The experimental results, Fig. 3, demonstrated that the Kronos K-75 air purifier successfully reduces *Escherichia coli* 87.9% and MS2 99.9% in a two hour period compared to the control natural decay.

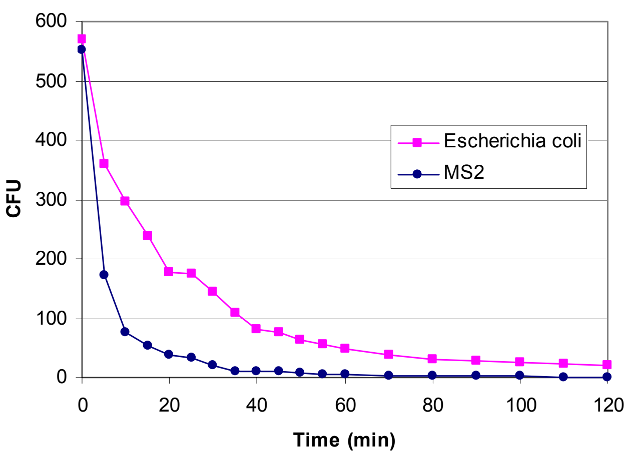

Fig. 3. *Number of colonies of microorganisms as a function of time with working Kronos K-75 unit: Escherichia coli bacteria (purple squares) and MS2 virus (blue circles).*

In a study designed by Environmental Health and Engineering, Inc. (EH&E), two Kronos K-75 air purifiers were installed in the waiting room of a working pediatric office. The goal of the study, conducted over two weeks during the cold and influenza season, was to determine if the use of Kronos air purifiers reduce levels of airborne particulate matter (PM) and whether they capture respiratory viruses.

Airborne PM samples were collected continuously in both the waiting room and outdoors over the typical 9AM to 5PM workday with TSI Aerodynamic Particle Sizer™ (Shoreview, MN). After controlling for outdoor PM levels, the average levels of PM less than 3 microns in aerodynamic diameter was 50% less on days when the air purifiers were operating compared to control days. PM trapped by the Kronos air purifiers was collected and analyzed using a polymerase chain reaction (PCR) assay for a panel of respiratory viruses. EH&E was able to detect at least one type of respiratory virus on each test day (see Table 1). By demonstrating the ability of the Kronos K-75 air purifiers to reduce airborne PM levels and capture respiratory viruses, it indicates that the levels of airborne respiratory viruses in the air are being reduced, leading to reduced exposure to airborne respiratory viruses for the waiting room occupants.

Table 1. Viruses detected on Kronos K-75 air purifiers: HRV – Human Rhinoviruses; EV – Enteroviruses; hCVOC43 – Human Coronavirus OC 43; hCVNL63 – Human Coronavirus NL 63; RSVB – Respiratory Syncytial Virus; AdVC – Adenovirus; Boca – Bocavirus; FluA – Influenza A; FluB – Influenza B.

Test Day	HRV	EV	hCVOC43	hCVNL63	RSVB	AdVC	Boca	FluA	FluB
1	X		X	X		X	X	X	X
2									X
3								X	X
4		X							X
5					X				X

B. "TREE" air purifier

The "TREE" air purifier, Fig. 2 (b), was developed together by Kronos Air Technologies and Russian company EOL (Moscow) [19]. Its dimensions are 6" by 12" by 16". The "TREE" air purifier produces 55 CFM of airflow while consuming not more than 30 W. Its cleaning efficiency exceeds 99% for particles in size of 0.3 micron and greater. Ozone concentration produced by the "TREE" air purifier does not exceed 10 ppb in a 30 cubic meter room. The proposed areas of application for the "TREE" air purifier are clinical facilities, manufacturing facilities that require a high level of air disinfection, and various other facilities.

In the study conducted by Disinfection Research Institute Sterilization Laboratory in Moscow, Russia, the effectiveness of air disinfection with the "TREE" air purifier was studied in different settings. The purpose of that study was to investigate the possibility to use the "TREE" air purifier in clinical facilities. In this paper several representative results are reported while complete and detailed information can be found in [19-21].

The first set of experiments was performed in hermetically sealed rooms of two sizes:

30 and 70 cubic meters. There were no people present in the rooms during the test. The air was artificially infected with the microorganisms - *Staphylococcus aureus* strain 906[1] and *Bacillus cereus* strain 96, both vegetative and spore forms. The level of microbial air contamination in the room was measured by taking air samples every 15 minutes in the center of the test room while the air was being treated with the "TREE" air purifier. In addition, in order to evaluate how effectively the microorganisms are captured by the "TREE" air purifier, the air that passed through the purifier was sampled immediately after it left the device.

The changes in the quality of air artificially inoculated with model organism *Staphylococcus aureus* and *Bacillus cereus* in 30 and 70 cubic meter test rooms while being treated with the "TREE" air purifier are provided in Table 2 and Table 3.

Table 2. Disinfection effectiveness of a "TREE" air purifier in a 30 cubic meter hermetically sealed test room artificially contaminated with *Staphylococcus aureus* and *Bacillus cereus*.

Time, min	*Staphylococcus aureus*		*Bacillus cereus*			
			Vegetative Form		Spore-forming Form	
	CFU/m^3	Disinfection Effectiveness, %	CFU/m^3	Disinfection Effectiveness, %	CFU/m^3	Disinfection Effectiveness, %
Air samples taken in the center of the room						
0	$2.9\cdot10^4$	–	$3.4\cdot10^4$	–	$2.1\cdot10^4$	–
15	$1.4\cdot10^4$	51.7	$5.2\cdot10^3$	84.7	850	95.9
30	$4.4\cdot10^3$	84.8	290	99.2	110	99.5
45	16	99.9	17	99.9	20	99.9
60	0	100.0	6	99.9	0	100.0
Air samples taken at the outlet of the "TREE" air purifier						
	0	100.0	8	99.9	6	100.0

Table 3. Disinfection effectiveness of "TREE" air purifier in a 70 cubic meter hermetically sealed test room artificially contaminated with *Staphylococcus aureus* and *Bacillus cereus*.

Time, min	*Staphylococcus aureus*		*Bacillus cereus*			
			Vegetative Form		Spore-forming Form	
	CFU/m^3	Disinfection Effectiveness, %	CFU/m^3	Disinfection Effectiveness, %	CFU/m^3	Disinfection Effectiveness, %
Air samples taken in the center of the room						
0	$3.1\cdot10^4$	–	$3.4\cdot10^4$	–	$2.1\cdot10^4$	–
15	$8.7\cdot10^3$	72.1	$5.2\cdot10^3$	84.7	$1.5\cdot10^3$	92.8
30	$2.4\cdot10^3$	92.2	790	97.7	910	95.7
45	64	99.8	320	99.0	410	98.1
60	2	99.9	9	99.9	6	99.9
75	0	100.0	0	100.0		100.0
Air samples taken at the outlet of the "TREE" air purifier						
	0	100.0	8	99.9	6	100.0

Experimental results showed that despite the high level of artificial room air inoculation ranging from $2.1\cdot10^4$ to $3.4\cdot10^4$ Colony Forming Unit/m^3 (CFU/m^3), viable cells were observed only in one case in air samples taken immediately at the outlet of the device. The high single pass decontamination efficiency agrees well with measured particle collection efficiency. The effectiveness of air purification in the room was also found to be high. The air in both 30 and 70 cubic meter rooms was virtually free of the artificially introduced microorganisms within 60 minutes, regardless of the air inoculation level. This is well illustrated in Fig. 4. The study did not show any differences in the effectiveness of capture capacity for microorganisms based on the type of microflora.

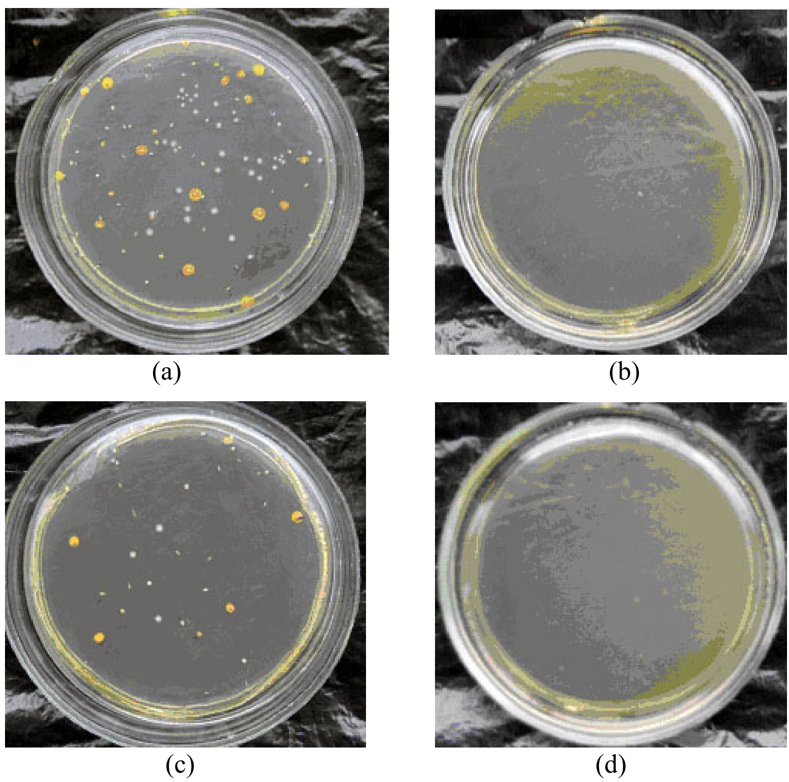

Fig. 4. *"TREE" air purifier test results with Culture S. aureus performed at Disinfection Research Institute Sterilization Laboratory (Russia) in a 30 cubic meter test room: (a) room air inoculation after spraying S. aureus suspension (control); (b) air sample taken from the air stream immediately after passing through the device, after spraying the suspension into the test room; (c) room air inoculation after 30 minutes of the device operation; (d) room air inoculation after 45 minutes of the device operation.*

When the surfaces of the collecting electrode plates were rinsed, considerable microbial growth was observed on the surface of the electrodes, especially on the fronts of the plates. This supports the fact that the majority of the microorganisms remain viable and adhere firmly to the plates. The attachment density of microorganisms on the filter surface was confirmed with an air sample study in which the device was turned on an hour and 24 hours after atomizer spray testing was completed. Air was blown through the device filtering elements on which microbial contamination remained after the previously-conducted experiment. The test results indicated that the microbe contamination particles were firmly attached to the surfaces of the collecting electrodes, and were not dislodged by the air stream after the device was activated an hour and 24 hours after the completion of the spray atomizer tests in the test room.

The “TREE” air purifier has also been tested for the ability to disinfect air contaminated with viruses. For this purpose the MS2 virus was used in a 30 cubic meter test room. As with bacteria, the experimental results shown in Table 4 also demonstrated high efficacy of air sterilization by the “TREE” air purifier. The air in the test room was completely free of the MS2 virus after 45 minutes of operation of the “TREE” unit.

Table 4. Disinfection effectiveness of the “TREE” air purifier in a 30 cubic meter test room contaminated with the MS2 virus.

Time air probe taken, min	MS2 virus	
	CFU/m^3	Disinfection Effectiveness, %
0	$1.8 \cdot 10^4$	–
15	$5.6 \cdot 10^3$	69.0
30	187	99.9
45	0	100.0
60	0	100.0

The effectiveness of air purification by the “TREE” unit was also studied in real hospital rooms with and without the presence of people and with natural air contamination. For example, Fig. 5 – Fig. 7 show experimental results obtained in three rooms of a municipal hospital in the town of Korolyev, Moscow region.

Room 1, Fig. 5, had size of 83 m^3. Door and windows were closed, one person was present during the entire experiment, and two “TREE” units were operating. Room 2, Fig. 6, had size of 113 m^3. Door and windows were closed, no people were present during the entire experiment, and one “TREE” unit was employed. Room 3, Fig. 7, had size of 66 m^3. Door and windows were open, four people were present during the entire experiment, and two “TREE” units were engaged. As the reported results show, considerable reduction in concentration of microorganisms was observed in all cases. Thus, disinfection efficacy provided by “TREE” air purifier is shown to be high in real hospital rooms with and without presence of people and with natural contamination of the air.

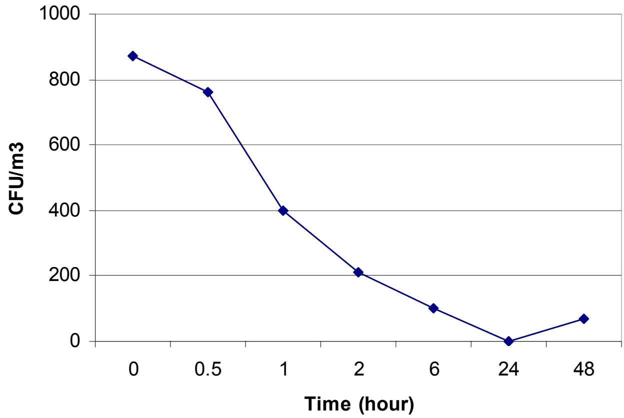

Fig. 5. *Reduction in concentration of microorganisms in naturally contaminated air by two "TREE" air purifiers in an 83 m^3 hospital room with door and windows closed and presence of one person.*

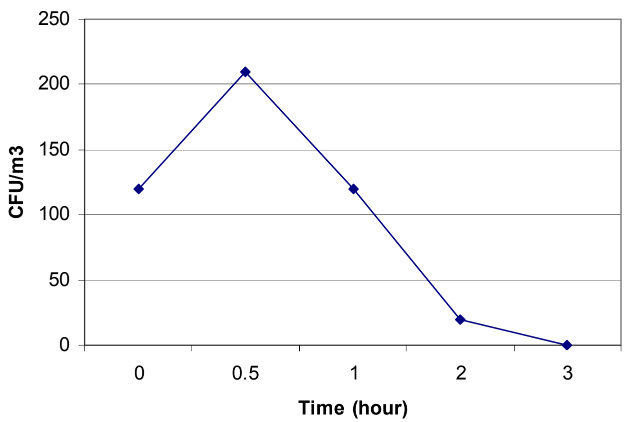

Fig. 6. *Reduction in concentration of microorganisms in naturally contaminated air by one "TREE" air purifier in a 113 m^3 hospital room with door and windows closed.*

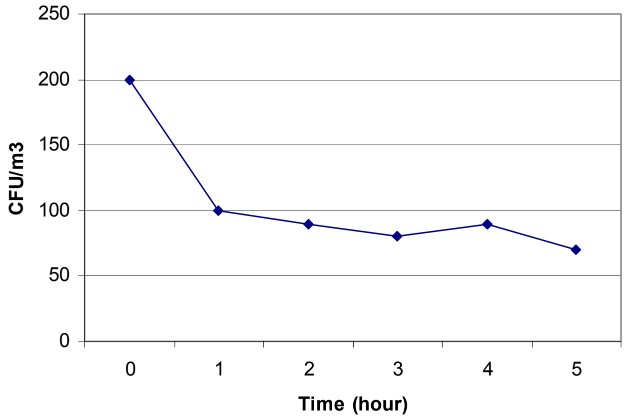

Fig. 7. *Reduction in concentration of microorganisms in naturally contaminated air by two "TREE" air purifiers in a 66 m^3 hospital room with door and windows open and presence of four people.*

In the study conducted by Institute for Veterinary Medicine in the Ukraine, the "TREE" air purifier was able to destroy and sterilize air which had been inseminated with *Anthrax*, *Anthrax* spores and *E.coli* spores in a contained testing area [22]. The study concluded in their findings, that "TREE" air purifier is capable of sterilizing air that may be contaminated with other microflora which both does and does not produce spores. Such other microflora can include avian (bird) flu and Severe Acute Respiratory Syndrome associated corona virus (SARS-CoV).

Based on all collected experimental results, "TREE" air purification device has passed its final clinical trial and has been approved by the Russian Research Institute of Medical Equipment for use in hospitals and other healthcare facilities [19]. The "TREE" air purifier received Category I approval, which means the product has met the strictest regulations required for a device to be used in operating rooms and other areas that require a sterile environment.

III. CONCLUSION

Experimental results presented in this paper showed that Electrostatic Air Filtration and Purification systems based on Kronos technology demonstrated high capturing and destruction efficiency for different types of microorganisms, bacteria and viruses, and can be successfully used for disinfection of air in real word environmental settings, including hospital facilities both with and without the presence of people.

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