Application of Ultraviolet Light for the Control of Airborne Pathogens & Spoilage Organisms

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Abstract

Ultraviolet light has been demonstrated to effectively de-activate pathogens and all other airborne bacteria, virus and mould species.

The technology is already widely used within process users of air, GMP manufacturers and by those with an interest in a high quality indoor air supplies, such as call centres, banks and other high employee density locations. The technology is now being applied to reduce the incidence of nosocomial infection at healthcare providers worldwide.

Key Words

Ultraviolet disinfection, nosocomial, MRSA, mycobacterium tuberculosis.

Technology

Ultraviolet light is generated by the excitement of electrons in orbit around a mercury nucleus. The mercury is contained within a quartz tube, and varying voltages are applied to electrodes situated at either end of the quartz body. Lamp types are separated by gas pressure into 2 principal types; low pressure and medium pressure.

Low pressure UV lamps are generally 1 meter in length and have an input power of up to 200 watts. The lamps are up to 30% efficient, so can emit up to 60 watts of germicidal light per lamp. These type of lamp have a life of about 10,000 hours and should be left switched on, as frequent cycling (switching on/off) will damage the filament and shorten the lamp life. This type of lamp is best suited to upper air space disinfection, tank headspace disinfection, or for the disinfection of poor transmittance fluids. Low pressure lamps have a single line output at 254nm, and are often called monochromatic lamps. High output lamps are now being used that have an amalgam of mercury and bismuth or indium. These lamps do not show variation in output caused by air temperature and have been measured to have an efficiency of 32-35%.

Medium pressure lamps are typically 30cm in length and have an input power of up to 3500 watts. This type of lamp is hot running, with a surface temperature of 600-900°C. The lamp needs to have a nominal flow of air across it to keep it cool. Lamp life is between 6000-8000 hours and the lamps have an efficiency of up to 23%. Typically a 3½kW lamp will output up to 800 watts of germicidal UV light, so typically one medium pressure lamp has an equivalent output of up to 10-12 low pressure lamps. Medium pressure lamps are used to treat high flows of dynamic air contained with an air duct, or high fluid volumes. Medium pressure lamps have a broad spectral output, from 170nm up to 450nm.

Kill Mechanism

UV light between 240nm and 280nm is germicidal. The principal kill mechanism is absorption of UV at 265nm by the DNA, contained in the nucleus of bacteria yeast and moulds. RNA is found within the nucleus of a virus and the mechanism is similar.

UV light centred at 265nm will dimerize the thymine base and effectively prevents replication.

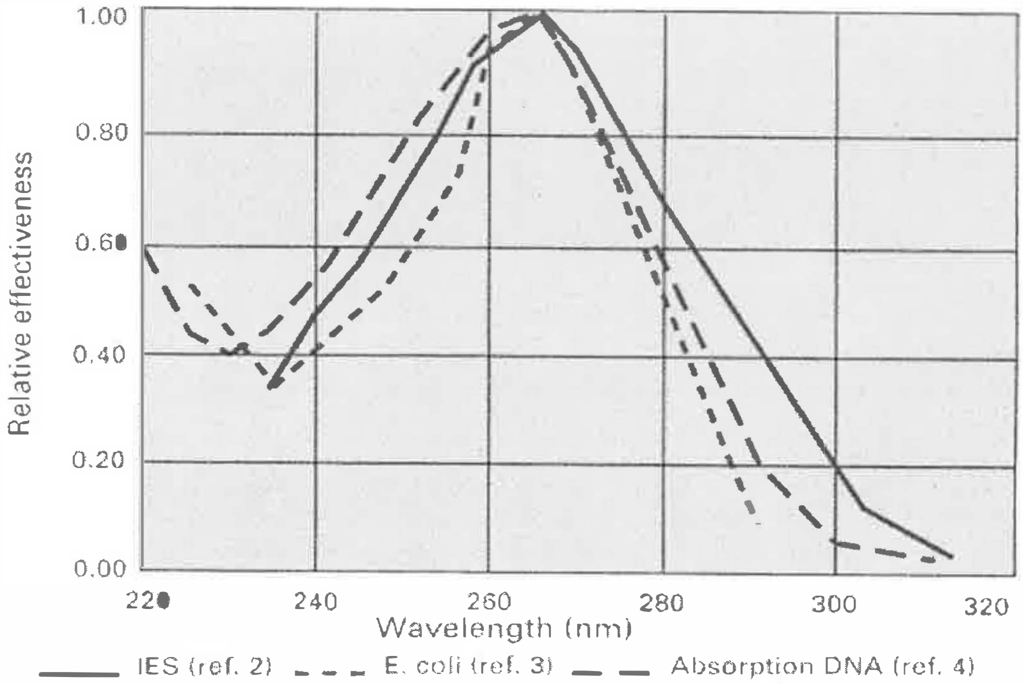

Figure 1 Action Spectrum of DNA and E Coli.

The damage is permanent and irreversible. The action of this portion of the spectrum has been documented by Meuleman, who has compared the effect that low pressure lamps (with the single output at 254nm) have with the polychromatic medium pressure lamp.

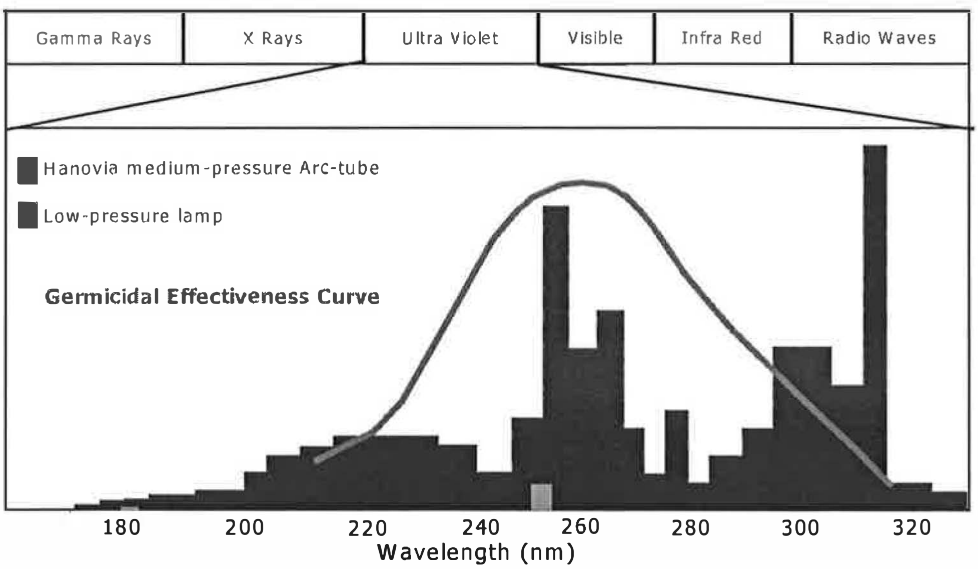

Figure 2. Arc Tube Technology.

UV light centred on 240nm causes a lethal insult to the outer cell membrane of airborne species. As the wavelength decreases, so the frequency of the radiation increases, so lower wavelength UV is far more energetic than long wave UV. Energy (E) = hν h = plancks constant, ν = frequency of radiation. UV centred on 240nm behaves in a similar fashion to other oxidants, i.e. chlorine or ozone. The damage to the outer cell membrane is permanent and occurs instantaneously.

The organism is more prone to mechanical damage and in water is unable to regulate osmotic pressure, and quickly becomes soluble.

UV light centred on 280nm causes damage to protein in the cytoplasm. The three effects are outlined below:

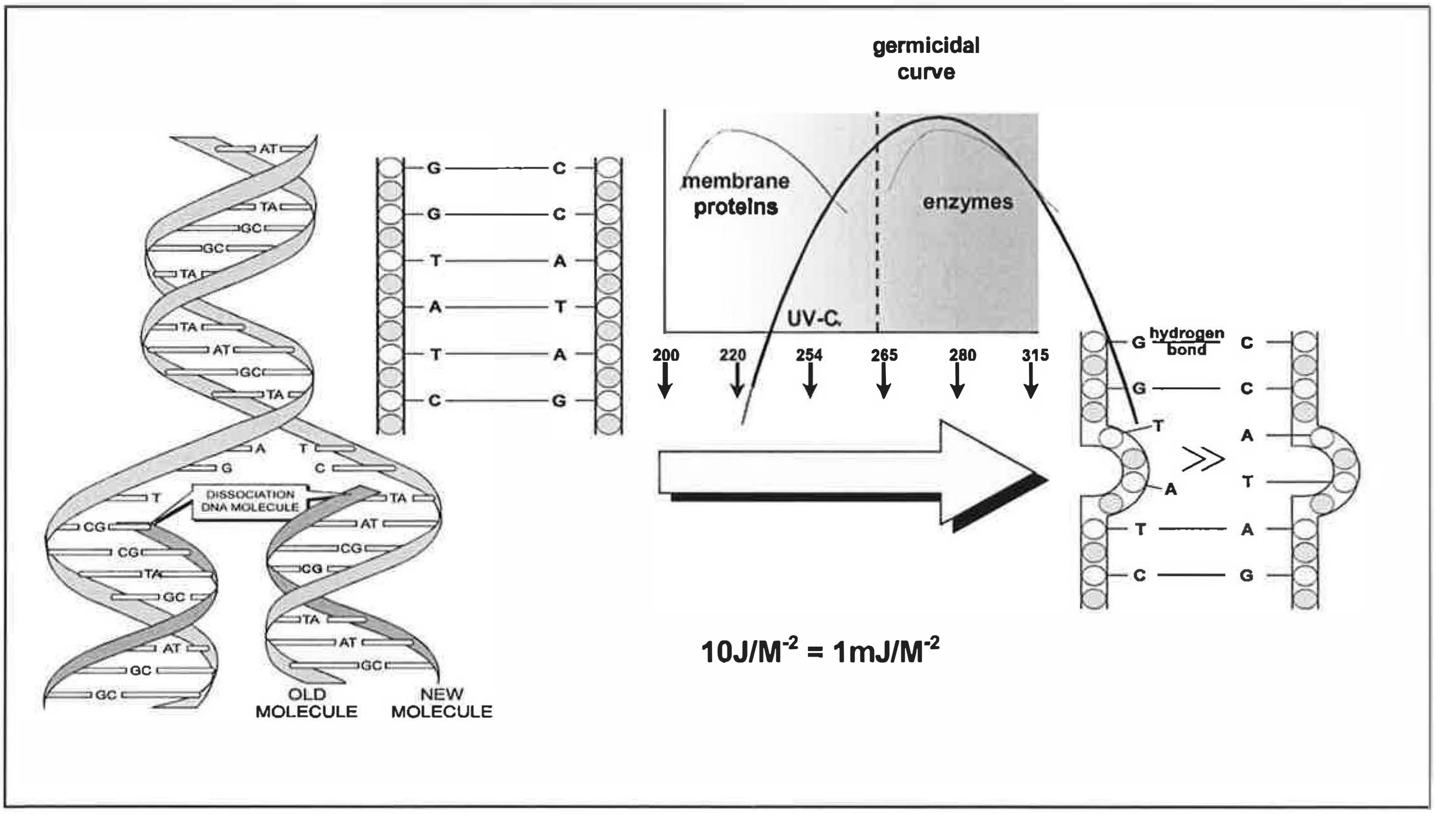

Figure 3. UV damage to protein in the cytoplasm at 280nm

Each organism has a different susceptibility to UV, and the amount of UV (expressed in J/M^{-2} (i.e. $10mJ/cm^{-2}$) is outlined below in Figure 4:-

Bacteria	Dose
Bacillus anthracis	45.2
B. enteritidis	40.0
B. megatherium sp. (veg.)	13.0
B. megatherium sp. (spores)	27.3
B. paratyphosus	32.0
B. subtilis	71.0
B. subtilis spores	120.0
Corynebacterium diphtheriae	33.7
Eberthella typhosa	21.4
Escherichia coli	30.0
Micrococcus candidus	60.5
Micrococcus sphaeroides	100
Neisseria catarrhalis	44.0
Phytomonas tumefaciens	44.0
Proteus vulgaris	26.4
Pseudomonas aeruginosa	55.0
Pseudomonas fluorescens	35.0
S. typhimurium	80.0
Sarcina lutea	197.0
Seratia marcescens	24.2
Dysentery bacilli	22.0
Shigellia paradysenteriae	16.3
Spirillum rubrum	44.0
Staphylococcus albus	18.4
Staphylococcus aureus	26.0
Streptococcus haemolyticus	21.6
Streptococcus lactis	61.5
Streptococcus viridans	20.0

Yeasts	Dose
Saccharomyces ellipsoideus	60.0
Saccharomyces sp.	80.0
Saccharomyces cerevisiae	60.0
Brewers'yeast	33.0
Bakers' yeast	39.0
Common yeast cake	60.0

Mold spores	
Penicillium roqueforti	130.0
Penicillium expansum	130.0
Penicillium digitatum	440.0
Aspergillus glaucus	440.0
Aspergillus flavus	600.0
Aspergillus niger	1320.0
Rhizopus nigricans	1110.0
Mucor racemosus A/B	170.0
Oospora lactis	50.0

Figure 4. Target organisms (D_{10} Values)

The amount of UV required to achieve a 90% kill is known as a D_{10} dose. Double the D_{10} dose achieves a 99% kill, and three times the D_{10} achieves a 99.9% kill. Note that yeasts and mould species are proportionally harder to kill and systems do need to be sized to accommodate the highest D_{10} species.

The D_{10} rating of the organism is also a key determinant of kill, and the D_{10} valves do vary considerably across species MRSA and TB are relativity easy to achieve high log kill, however A.Niger and other mould species are far more difficult to de-activate and do require a higher UV dose. The influenza virus has a low D_{10} rating and UV is highly effective at destroying it.

System Sizing

The principal factors that effect system sizing are as follows:

- Air flow rate
- Relative humidity of air
- D_{10} of target species
- Duct dimensions and materials of construction

The relative humidity (RH) of the air has a pronounced effect on its ability to transmit UV light, and as the correction factor is outlined below; high RH leads to a marked reduction in the transmittance of the air.

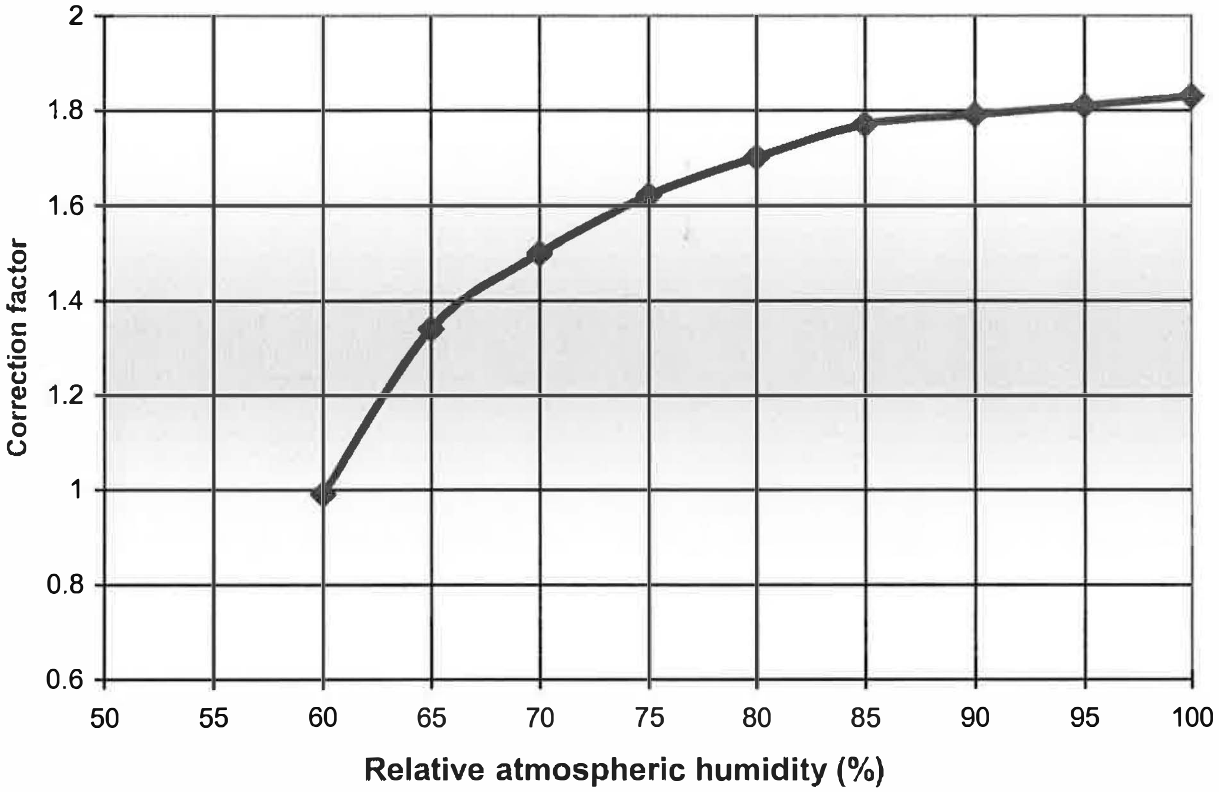

Figure 5. Humidity correction factors

` The duct dimension and material of construction is important; the ideal profile for duct is rectangular with the UV lamp inserted as per the photograph below:

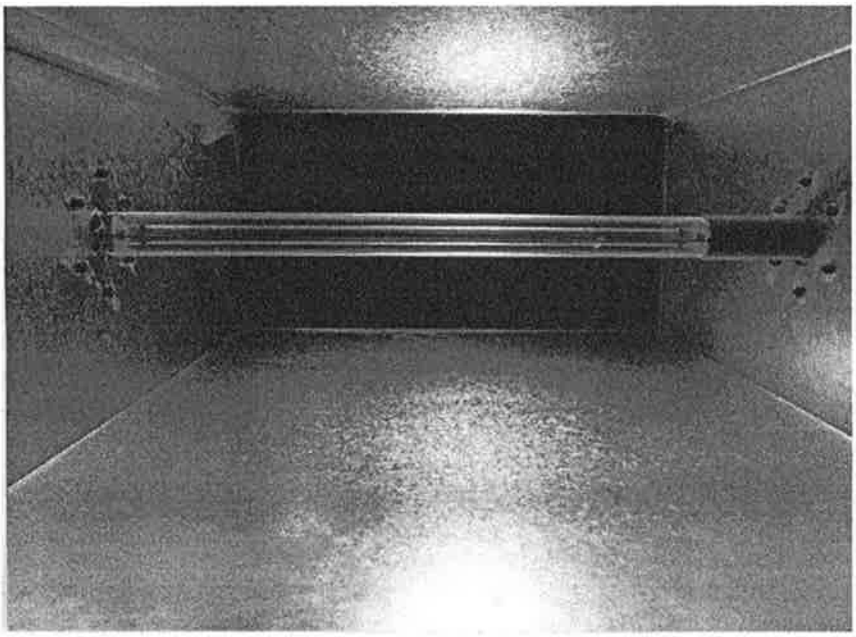

Figure 6. Rectangular duct installation

The material of construction of the duct plays an important role and the correct choice is vital. Most plastics or PVC ducts will fail when exposed to germicidal UV light, as UV at 240-280nm is absorbed by the PVC and the resultant damage is known as "chalking", which is irreversible and leads to catastrophic failure. As can be seen from the table below, certain metals have a reasonable reflectance of germicidal UV light and duct work should be fabricated from these materials.

Material		Reflectance %
Aluminium :	untreated surface	40-60
	treated surface	60-89
	sputtered on glass	75-85
`ALZAK'-treated aluminium		65-75
`DURALUMIN'		16
Stainless Steel/Tin Plate		25-30
Chromium Plating		39
Various white oil paints		3-10
Various white water paints		10-35
Aluminium paint		40-75
Zinc oxide paint		4-5
Black enamel		5
White baked enamel		5-10
White plastering		40-60
New plaster		55-60
Magnesium oxide		75-88
Calcium carbonate		70-80
Linen		17
Bleached wool		4
Wallpapers :	ivory	31
	white	21-31
	red printed	31
	ivory printed	26
	brown printed	18

Figure 7.
Duct material reflectance ratings

It is important that operators are shielded from UV light as short term exposure can cause erythema (reddening of the skin) and conjunctivitis (inflammation of the mucous membranes around the eye). Electrical interlocks are fitted to the control panel and mechanical key retentive interlocks are fitted to the duct. Maintenance is limited to a lamp change every 6000-8000 hours, a sleeve change every 2-3 years and in addition the sleeve should be wiped periodically with a soft clean cloth to remove any dust or other airborne deposits.

Applications for Medium Pressure UV lamps

Medium Pressure (MP) UV is now widely accepted by a large number of process users of air in the UK and overseas. Below are several examples of application. Dynamic air environments generally adopt a single medium pressure lamp due to economic considerations.

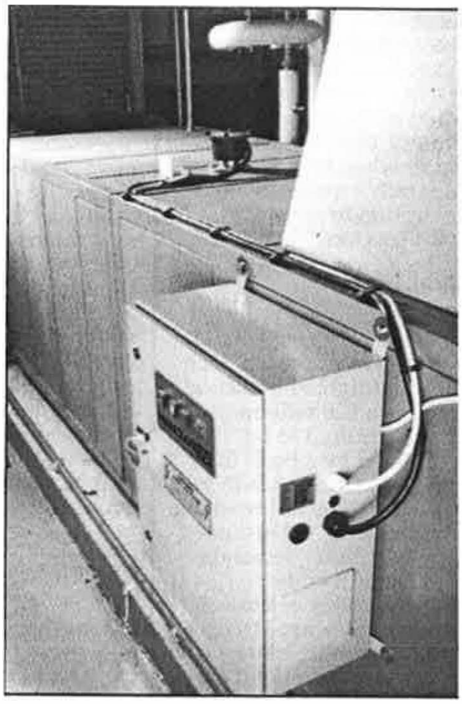

Figure 8. Call centre Indoor Air Quality improvement

A call centre operator in Surrey (UK) has observed a 40% reduction in absence due to sickness following installation of a Hanovia UV system in the recirculating air duct at one of their offices.

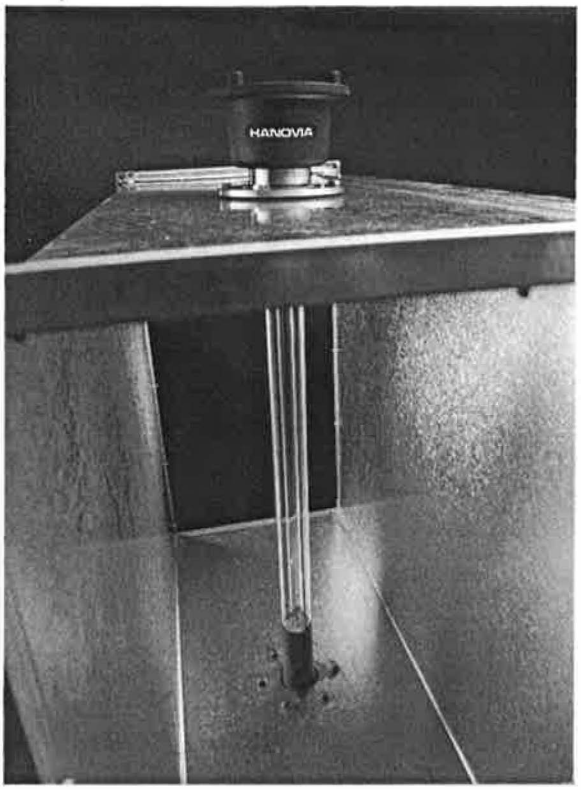

Figure 9. UV-V System with 2.5kW lamp capable of treating 3m^3/second air flow at 55% RH

Mushroom growers the world over have benefited from yield improvements of up to 60% following installation of 2.5kW systems in the chilled air ducts. Low pressure technology is generally unsuitable due to the low operating temperature, and resultant output reduction

Figure 10. Hanovia UV system for a mushroom farming application

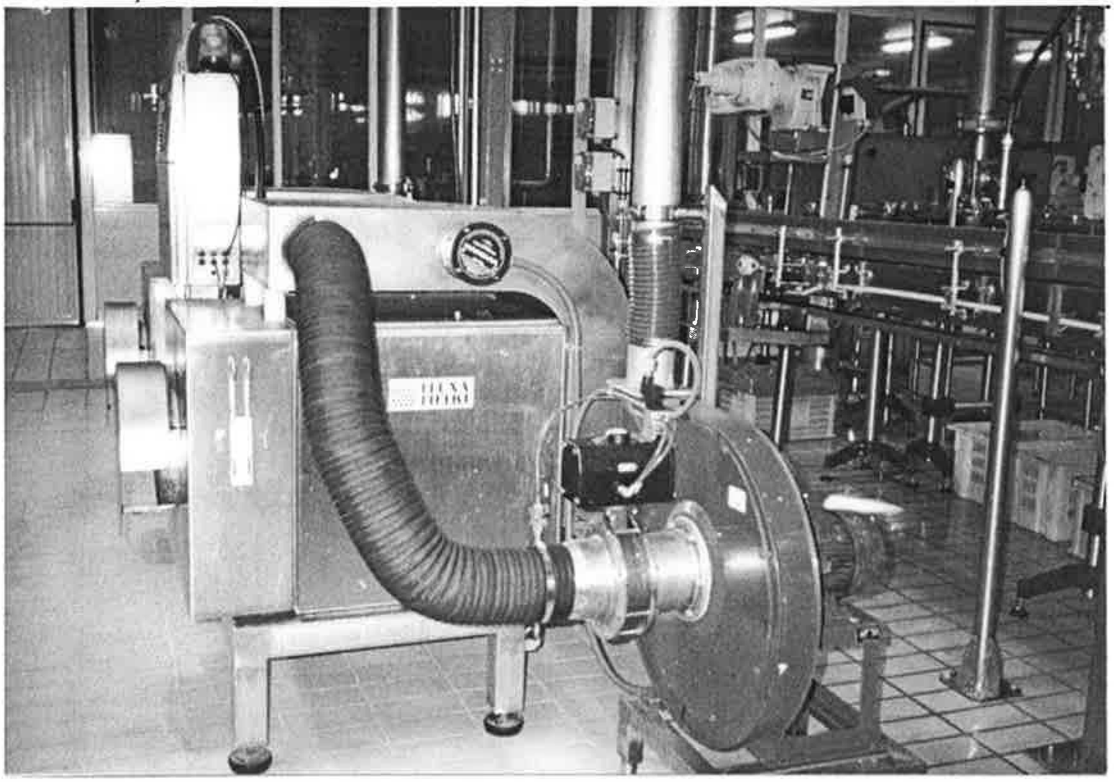

Figure 11. UV-V installation for bottling plant of international brewer

Work undertaken by Campden Food & Drink Research Association on Hanovia's behalf has demonstrated the effectiveness of UV on a wide range of spoilage organisms.

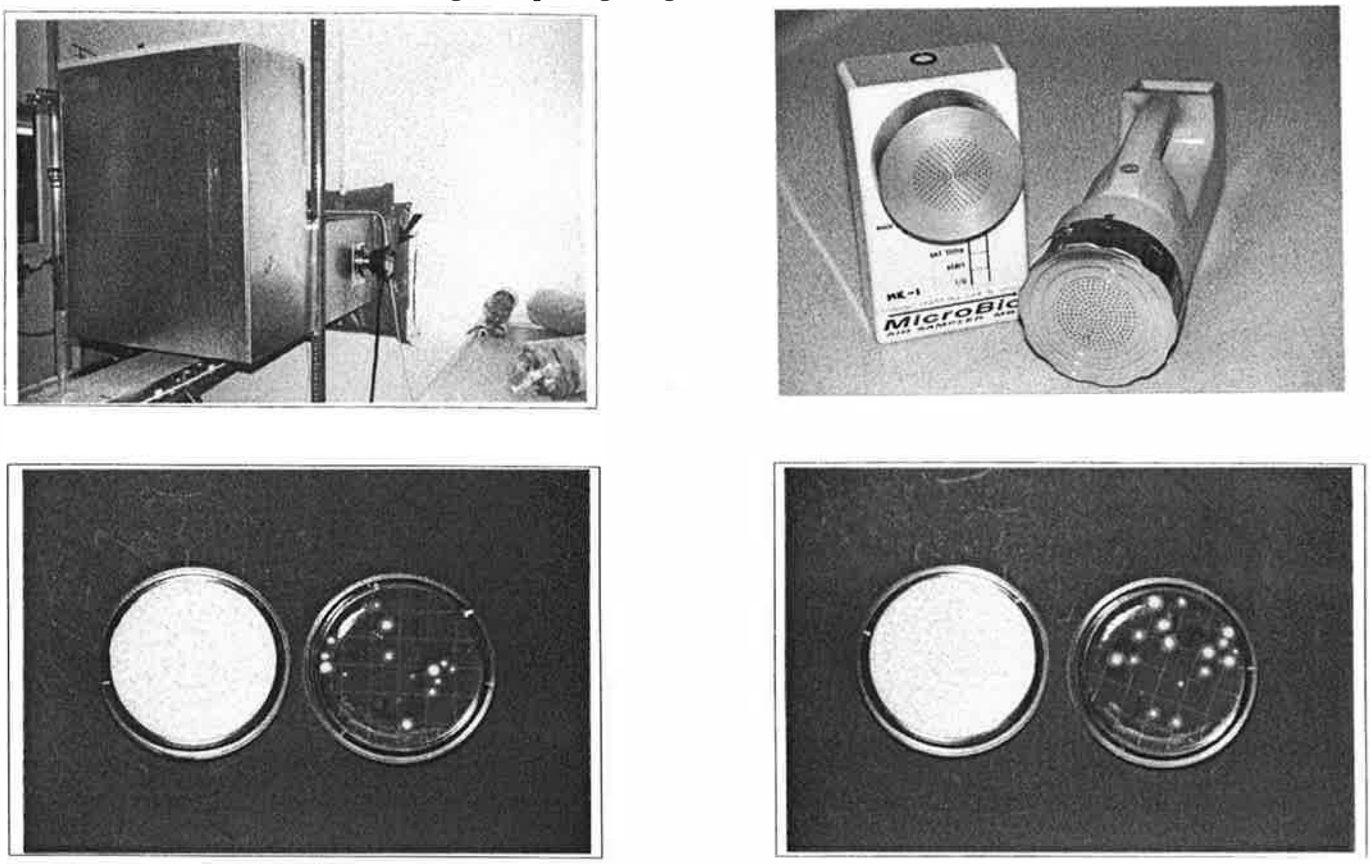

Figure 12. Plates showing the effects of UV on Penicillium chrysogenum. The plate on the left was inoculated with a sampler installed before UV-V lamp, while the right hand plate was inoculated with a sampler installed after the lamp

Low pressure UV equipment and low pressure systems are used in most bulk sugar syrup storage tanks to control airborne yeasts and mould that would effect the integrity of the syrup and is inserted into the headspace. Usually medium pressure UV is used to treat the syrup in line.

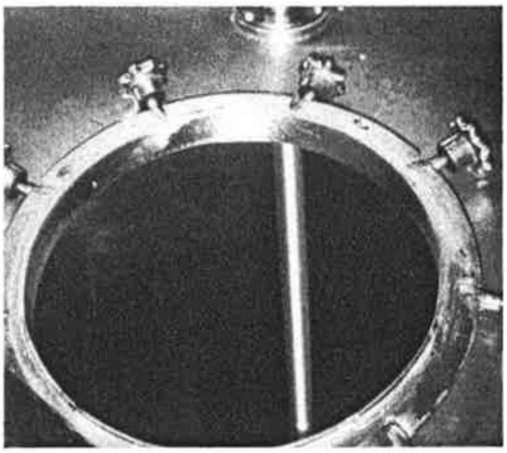

Figure 13. UV-I system installed in the head space of a sugar syrup tank at a major soft drinks manufacturer

Summary

Medium pressure UV lamps are a demonstrated means of controlling airborne bacteria, yeast, virus and mould. Their application is now widespread throughout the process industries, health care providers and those with an interest in Indoor Air Quality.

Low pressure lamps are well suited to upper or lower airspace disinfection.