Purificación ultravioleta

Perfection preserved by the purest of light

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SLS Sound Light Spain

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Contents

Introducción

La contaminación del macro y micro ambiente ha causado preocupación durante décadas y en los últimos tiempos las macro consecuencias han sido sometidas a protocolos internacionales acordados, destinados a reducir la contaminación. Además, ahora existen leyes nacionales e internacionales para limitar la existencia de microorganismos, particularmente aquellos que afectan la salud humana, animal y de aves en el medio ambiente y la cadena alimentaria. Una consecuencia de esta preocupación ha sido que la reducción de la contaminación es ahora una industria que cubre áreas tales como las tecnologías cambiantes para reducir la contaminación primaria y consecuente y la limpieza química, biológica y física. En estas técnicas se incluye la purificación con ultravioleta (UV) C luz (UVC), que tiene el beneficio de ser eficiente y posiblemente la tecnología más efectiva en energía.

La purificación UVC tiene una larga y honorable historia en la limpieza del aire de la sala. Sin embargo, el crecimiento en otras aplicaciones, como el tratamiento de líquidos de alta tecnología y los estanques domésticos, se ha expandido, mientras que para el tratamiento de la superficie de los alimentos se ha utilizado para extender la vida útil en los supermercados, lo que resulta en menos desperdicio de alimentos y menores existencias.

Si bien UVC se puede usar como la solución exclusiva en algunas aplicaciones, a menudo se usa en conjunto con otras técnicas.

Se deduce que es poco probable que un enfoque único sea ideal. También se deduce que, dado que la UVC es tan simple y eficaz en términos energéticos, quizás sea conveniente considerar esta opción primero.

Philips se ha asociado con el progreso en este campo desarrollando, fabricando y comercializando lámparas que generan UVC y continúa investigando nuevas configuraciones de lámparas. Este folleto es la cuarta encuesta de información dirigida al personal técnico y de producción en organizaciones donde los microorganismos presentan problemas.

Los microorganismos como bacterias, mohos, levaduras y protozoos pueden destruirse o eliminarse mediante métodos físicos, biológicos y químicos. La UVC funciona usando un efecto fotolítico por el cual la radiación destruye o desactiva el microorganismo para que ya no pueda multiplicarse.

Para el ADN, esto hace que las bases de timina adyacentes formen un enlace químico, creando así un atenuador y, si se crean suficientes, el ADN no puede replicarse. Algunos microorganismos pueden repararse a sí mismos al absorber los rayos UVA. En otros casos, los rayos UVC (y de hecho los rayos UVA o UVB) pueden causar la división de enlaces en una molécula, lo que resulta en la creación de radicales libres, que a menudo son altamente lábiles y pueden reaccionar juntos para producir un producto final inerte. Para la purificación, estos efectos son producidos por longitudes de onda inferiores a 320 nm, con el efecto óptimo ocurre a alrededor de 260 nm. El fenómeno por el cual los microorganismos pueden desfigurarse o destruirse es independiente del estado del huésped (fluido o sólido). De hecho, con pH o temperatura, la característica importante de la acción es que la radiación puede alcanzar el organismo; Esto significa que una bacteria sombreada por otra o por una partícula escapará del ataque. A diferencia de otras técnicas, la fotólisis UVC rara vez produce subproductos potencialmente peligrosos.

1. Micro-organismos

General

Los microorganismos son formas primitivas de vida. Sus pequeñas dimensiones no solo constituyeron la razón original para clasificarlos por separado de los animales y las plantas, sino que también son relevantes para su morfología, la actividad y flexibilidad de su metabolismo y su distribución ecológica. Incluyen protozoos, bacterias y mohos.

La muerte celular en el caso de los microorganismos se refiere a la pérdida de la capacidad de crecer y multiplicarse, o en términos prácticos, a la pérdida de la capacidad de división celular.

La esterilización significa que se matan todos los microorganismos. La pasteurización o el uso de conservantes conducen a la reducción de la cantidad total de microorganismos. La purificación se puede lograr mediante calor húmedo, calor seco, filtración, agentes químicos y radiación ultravioleta (UV).

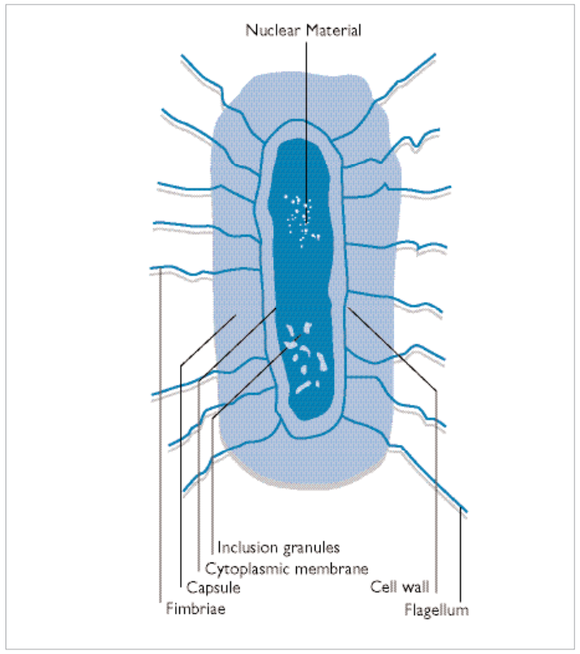


Figura 1. Los componentes principales de una célula bacteriana típica.

1.1 Bacteria and bacterial spores

1.1.1 Bacteria

Bacteria is the name given to a large group of organisms, which can be both uni and multicellular; they have a simple nuclear mass, and multiply rapidly by simple fission. The structure of typical bacterial cell is shown in figure 1 and examples of their shapes are given in figure 2.

Bacteria occur in air, water, soil, rotting organic material, animals and plants. Saprophytic forms (those living on decaying organic matter) are more numerous than parasitic forms; the latter include both animal and plant pathogens. A few species of bacteria are autotrophic, i.e. able to build up food materials from simple substances.

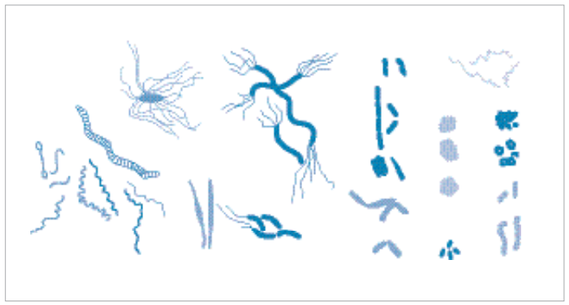


Figure 2. Some examples of bacteria varieties.

1.1.2 Bacterial spores

Bacterial spores are resistant to extreme conditions, such as high temperatures and dryness; for instance some bacterial spores, can stand a temperature of 120°C without losing their capability for germination. Viable spores of bacillus subtilis have been found in earth that has been dry for hundreds of years, thus demonstrating their ability to survive under extremely unfavourable conditions.

1.2 Moulds and yeasts

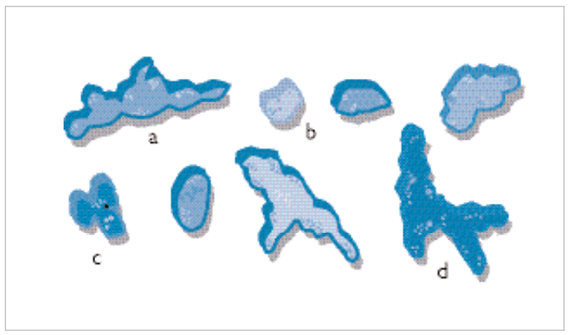


Figure 3. Brewer's yeast (Saccharomyces cerevisiae) in various stages of development: a. Various forms b. Yeast cell with spores c. Yeast spores d. Yeast spores after germination.

1.2.1 Moulds

The variety of moulds is immense and they are found everywhere. Many are saprophytic, causing food spoilage resulting in enormous damage; some are pathogenic (parasitic).

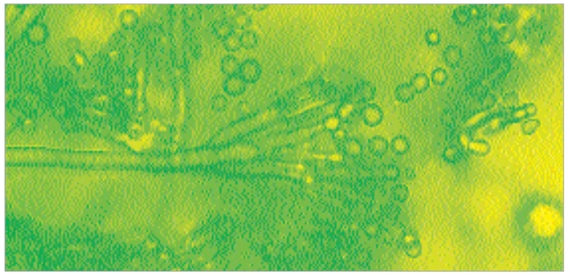


Figure 4. Mould culture, as seen through the microscope, showing the fungus mycelium with spores forming as beads at the extremities. These spores detach as the result of the formation of further spores pushing from behind. In the photograph many spores have already become detached and begun to move away freely.

Amongst the diseases caused by moulds, the most frequent are fungal infections of the skin and diseases of the mucous membranes.

Certain kinds of mould form antibiotic substances; these have given rise to the highly important antibiotics industry. Penicillin and streptomycin are early examples. A mould (see figures 4 and 5) consists of a mycelium and special structures, (sprorangia and conidiophores, for example), which result in the formation of spores. In a favourable environment, a mould spore germinates and a mesh of fine filaments (hyphae) is formed. The filaments together form the mycelium, which takes up food and water from the surface on which the spore has germinated. Spores, and the manner, in which they are formed, play a considerable part in the classification of moulds.

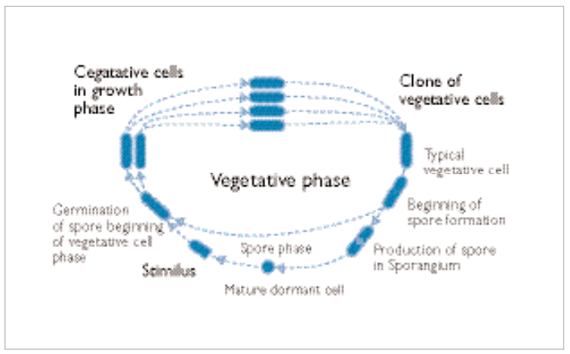


Figure 5. 'Life cycle' of spore formers.

1.2.2 Yeasts

Yeasts are unicellular moulds. They differ from the other moulds in the way that they propagate. Yeasts (figure 3) multiply by means of budding or sprouting. A selection of yeasts are used in various industries, the most important of these being those where fermentation produces wine, beer, vinegar and bread. The action of fermentation is the enzymatic transformation of the particular organic substrate, for instance the alcoholic fermentation of carbohydrates. Some yeasts are pathogenic.

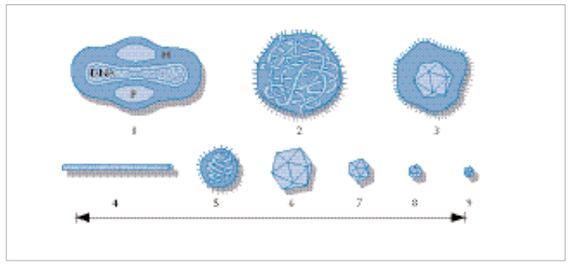


Figure 6. Relative shapes and sizes of some types of viruses.

1. Smallpox virus
   Abbreviations:
   DNA = virus DNA
   P = elliptical protein body
   H = enveloping layers
2. Mumps virus
3. Herpes virus
4. Tobacco mosaic virus
5. Influenza virus
6. Insect polyhedral virus
7. Adeno virus
8. Polyema virus
9. Poliomyelitis virus

1.3 Viruses

Viruses are a group of biological structures with extremely small dimensions (figure 8) which are obligatory parasitic. Viruses are so small that bacterial filters do not retain them, neither do they precipitate in normal centrifuges. They can be observed by using an electron microscope (figure 7). Viruses are unable to grow and multiply by division, they can only grow in living cells, so by their multiplication they kill the host cell.

The same process can take place in adjacent cells and eventually whole cellular complexes can be destroyed. Tissue damage is a way of recognising the presence of a virus.

Viruses have been identified as the causative agent of disease in humans, animals, plants and bacteria themselves (bacteriophage). In human beings they are the cause of diseases such as chickenpox, mumps, measles, warts, poliomyelitis, the common cold and influenza (figure 6).

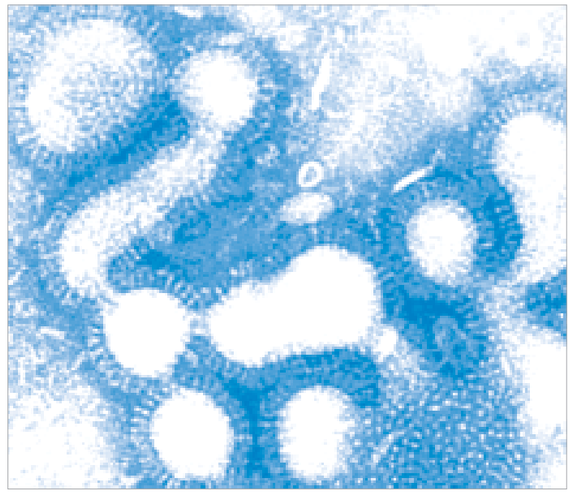


Figure 7. One of the types of influenza virus as seen enlarged 3600 times by means of an electron microscope. This virus occurs in the form of filaments and globules having a diameter of approximately 0.1 mm.

In animals; foot-and-mouth disease, Newcastle disease and bird flu are amongst the diseases caused by viruses.

Plants are also subject to many mosaic diseases caused by viruses. An interesting case is that of 'parrot' tulips. Formerly these were regarded as a separate variety, because of their feathery looking petals and their combinations and patterns of color. It has now been shown that the color pattern and shape of the petals results from a virus, which has no destructive effect on the tulip itself, or its reproductive powers. The attractive colors and patterns of the petals are the symptoms of the 'disease'.

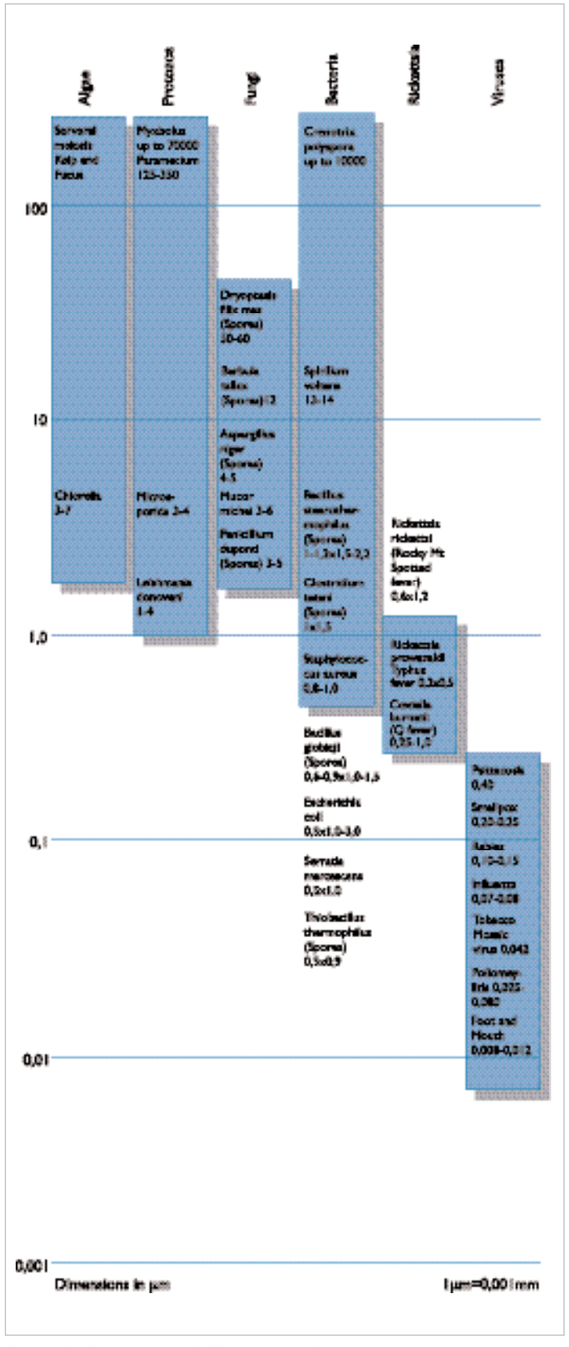


Figure 8. Relative sizes of different types of micro-organisms.

2. Ultraviolet light

General

Ultraviolet (UV) is that part of electromagnetic light bounded by the lower wavelength extreme of the visible spectrum and the X-ray radiation band. The spectral range of UV light is, by definition between 100 and 400 nm (1 nm=10-9m) and is invisible to human eyes. Using the CIE classification the UV spectrum is subdivided into three bands:

UVA (long-wave) from 315 to 400 nm
UVB (medium-wave) from 280 to 315 nm
UVC (short-wave) from 100 to 280 nm

In reality many photobiologists often speak of skin effects from the weighted effect of wavelength above and below 320 nm, hence offering an alternative definition.

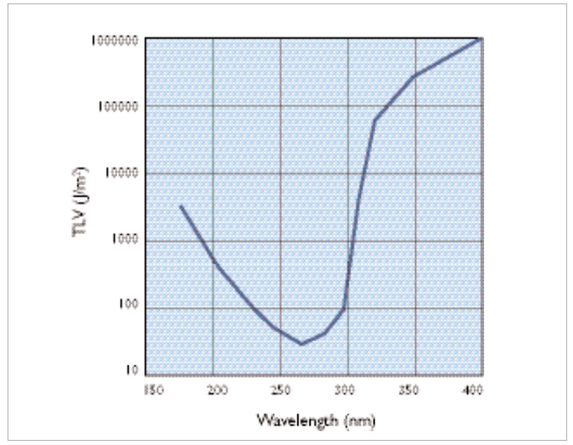


Figure 9. UV Light Threshold Limited Values (TLV) according to ACGIH 1999-2000 (Ref 1).

A strong germicidal effect is provided by the Light in the short-wave UVC band. In addition erythema (reddening of the skin) and conjunctivitis (inflammation of the mucous membranes of the eye) can, also be caused by this form of Light. Because of this, when germicidal UV-Light lamps are used, it is important to design systems to exclude UVC leakage and so avoid these effects.

Self evidently people should avoid exposure to UVC. Fortunately this is relatively simple, because it is absorbed by most products, and even standard flat glass absorbs all UVC. Exceptions are quartz and PTFE. Again fortuitously, UVC is mostly absorbed by dead skin, so erythema can be limited. In addition UVC does not penetrate to the eye's lens; nevertheless, conjunctivitis can occur and though temporary, it is extremely painful; the same is true of erythemal effects.

Permissible UVC Exposures	
Duration of exposure per day	**Irradiance (µW/cm²)**
8 hours	0.2
4 hours	0.4
2 hours	0.8
1 hour	1.7
30 minutes	3.3
15 minutes	6.6
10 minutes	10
5 minutes	20
1 minute	100

Table 1. Permissible 254 nm UV exposures, according to ACGIH.

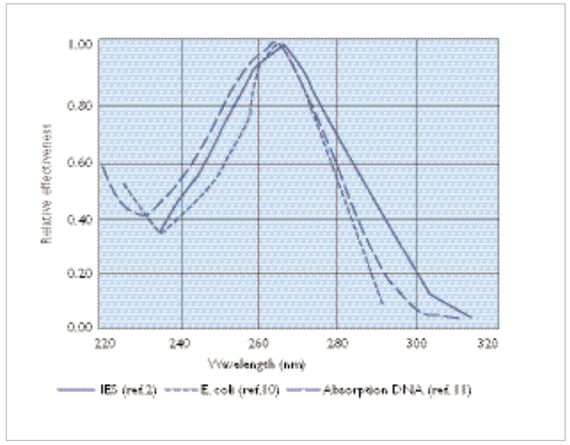


Figure 10. Germicidal action spectrum.

Where exposure to UVC Light occurs, care should be taken not to exceed the threshold level norm. Figure 9 shows these values for most of the CIE UV spectrum. In practical terms, table 1 gives the American Congress of Governmental and Industrial Hygienist's (ACGIH) UV Threshold Limit Effective Irradiance Values for human exposure related to time. At this time it is worth noting that radiation wavelengths below 240 nm forms ozone, O_3 from oxygen in air. Ozone is toxic and highly reactive; hence precautions have to be taken to avoid exposure to humans and certain materials.

2.1 Generation and characteristics of short-wave UV light

The most efficient source for generating UVC is the low-pressure mercury discharge lamp, where on average 35% of input watts is converted to UVC watts. The radiation is generated almost exclusively at 254 nm viz. at 85% of the maximum germicidal effect (figure 10). Philips' low pressure tubular flourescent ultraviolet (TUV) lamps have an envelope of special glass that filters out ozone-forming radiation, in this case the 185 nm mercury line. The spectral transmission of this glass is shown in figure 11 and the spectral power distribution of these TUV lamps is given in figure 12.

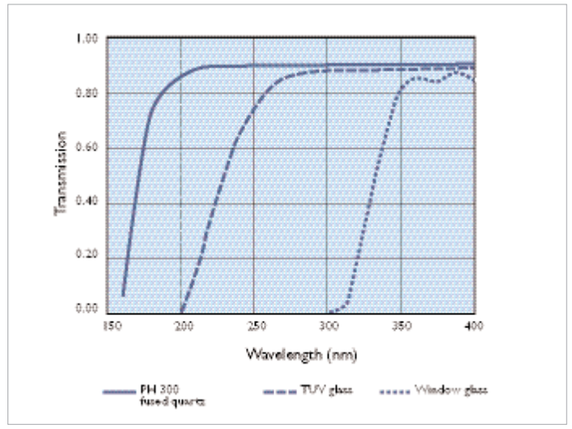


Figure 11. Special transmission of glasses (1mm).

For various Philips germicidal TUV lamps the electrical and mechanical properties are identical to their lighting equivalents.

This allows them to be operated in the same way i.e. using an electronic or magnetic ballast/starter circuit. As with all low pressure lamps, there is a relationship between lamp operating temperature and output. In low pressure lamps the resonance line at 254 nm is strongest at a certain mercury vapour pressure in the discharge tube. This pressure is determined by the operating temperature and optimises at a tube wall temperature of 40°C, corresponding with an ambient temperature of about 25°C. (See page 28, figure 28). It should also be recognised that lamp output is affected by air currents (forced or natural) across the lamp, the so called chill factor. The reader should note that, for some lamps, increasing the air flow and/or decreasing the temperature can increase the germicidal output. This is met in high output (HO) lamps viz. lamps with higher wattage than normal for their linear dimension. (See page 28, figure 29).

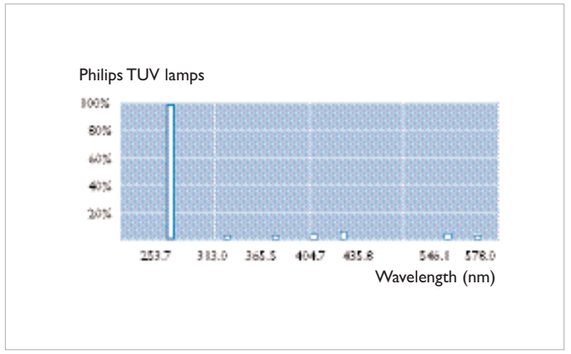


Figure 12. Relative spectral power distribution of Philips TUV lamps.

A second type of UV source is the medium pressure mercury lamp, here the higher pressure excites more energy levels producing more spectral lines and a continuum (recombined radiation) (figure 13). It should be noted that the quartz envelope transmits below 240 nm so ozone can be formed from air.
The advantages of medium pressure sources are:

- High power density
- High power, resulting in fewer lamps than low pressure types being used in the same application
- Less sensitivity to environment temperature. The lamps should be operated so that the wall temperature lies between 600 and 900°C and the pinch does not exceed 350°C. These lamps can be dimmed, as can low pressure lamps

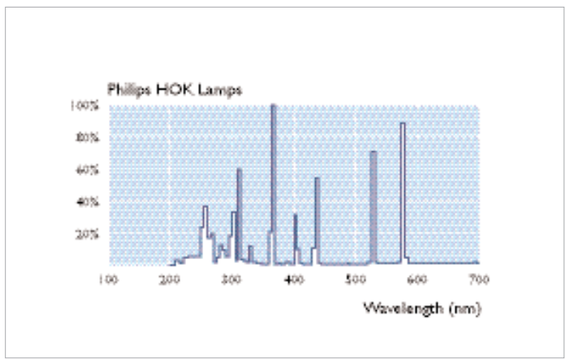


Figure 13. Relative spectral power distribution of Philips HOK and HTK lamps.

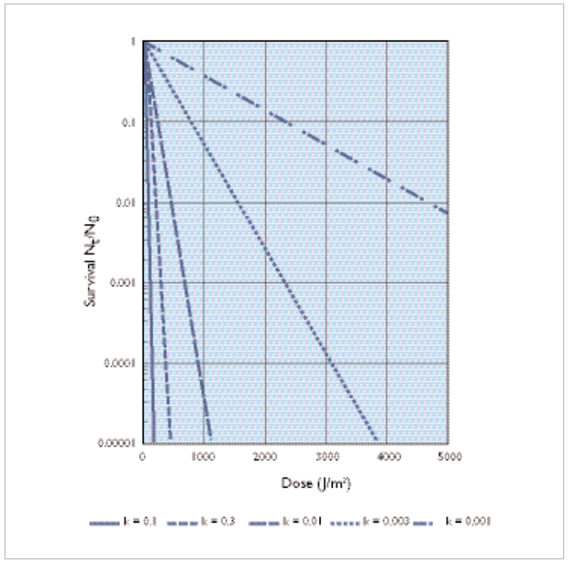


Figure 14. Survival of micro-organisms depending on dose and rate constant k.

2.2 Germicidal action

The UV light emitted by a source is expressed in watts (W) and the irradiation density is expressed in watts per square meter (W/m^2). For germicidal action dose is important. The dose is the irradiation density multiplied by the time (t) in seconds and expressed in joules per square meter (J/m^2). (1 joule is 1W.second).

From figure 10 it can be seen that germicidal action is maximised at 265 nm with reductions on either side. Low pressure lamps have their main emission at 254 nm where the action on DNA is 85% of the peak value and 80% on the IES curve. For wavelengths below 235 nm the germicidal action is not specified, but it is reasonable to assume that it follows the DNA absorption curve.

Micro-organisms effective resistance to UV light varies considerably. Moreover, the environment of the particular micro-organism greatly influences the radiation dose needed for its destruction.
Water, for instance, may absorb a part of the effective radiation depending on the concentration of contaminants in it. Iron salts in solution ware well known inhibitors. Iron ions absorb the UV light.
The survival of micro-organisms when exposed to UV light is given by the approximation:

$$N_t/N_0 = \exp.(-kE_{eff}t) \quad \text{.....1}$$

$$\text{Hence } \ln N_t/N_0 = -kE_{eff}t \quad \text{.....2}$$

- N_t is the number of germs at time t
- N_0 is the number of germs before exposure
- k is a rate constant depending on the species
- E_{eff} is the effective irradiance in W/m^2

The product $E_{eff}t$ is called the effective dose H_{eff} and is expressed in $W.s/m^2$ of J/m^2

It follows that for 90% kill equation 2 becomes

$$2.303 = kH_{eff}$$

Some k value indications are given in table 2, where they can be seen to vary from 0.2 m^2/J viruses and bacteria, to 2.10^{-3} for mould spores and 8.10^{-4} for algae. Using the equations above, figure 14 showing survivals or kill % versus dose, can be generated.

UV dose to obtain 90% killing rate		
Bacteria	**Dose**	**k**
Bacillus anthracis	45.2	0.051
B. megatherium sp. (spores)	27.3	0.084
B. megatherium sp. (veg.)	13.0	0.178
B. parathyphosus	32.0	0.072
B. suptilis	71.0	0.032
B. suptilis spores	120.0	0.019
Campylobacter jejuni	11.0	0.209
Clostridium tetani	120.0	0.019
Corynebacterium diphteriae	33.7	0.069
Dysentery bacilli	22.0	0.105
Eberthella typhosa	21.4	0.108
Escherichia coli	30.0	0.077
Klebsiella terrifani	26.0	0.089
Legionella pneumophila	9.0	0.256
Micrococcus candidus	60.5	0.038
Micrococcus sphaeroides	100.0	0.023
Mycobacterium tuberculosis	60.0	0.038
Neisseria catarrhalis	44.0	0.053
Phytomonas tumefaciens	44.0	0.053
Pseudomonas aeruginosa	55.0	0.042
Pseudomonas fluorescens	35.0	0.065
Proteus vulgaris	26.4	0.086
Salmonella enteritidis	40.0	0.058
Salmonella paratyphi	32.0	0.072
Salmonella typhimurium	80.0	0.029
Sarcina lutea	197.0	0.012
Seratia marcescens	24.2	0.095
Shigella paradysenteriae	16.3	0.141
Shigella sonnei	30.0	0.077
Spirillum rubrum	44.0	0.053
Staphylococcus albus	18.4	0.126
Staphylococcus aureus	26.0	0.086
Streptococcus faecalis	44.0	0.052
Streptococcus hemoluticus	21.6	0.106
Streptococcus lactus	61.5	0.037
Streptococcus viridans	20.0	0.115
Sentertidis	40.0	0.057
Vibrio chlolerae (V.comma)	35.0	0.066
Yersinia enterocolitica	11.0	0.209

UV dose to obtain 90% killing rate		
Yeasts	**Dose**	**k**
Bakers' yeast	39	0.060
Brewers' yeast	33	0.070
Common yeast cake	60	0.038
Saccharomyces cerevisiae	60	0.038
Saccharomyces ellipsoideus	60	0.038
Saccharomyces sp.	80	0.029

Mould spores		
Aspergillus flavus	600	0.003
Aspergillus glaucus	440	0.004
Aspergillus niger	1320	0.0014
Mucor racemosus A	170	0.013
Mucor racemosus B	170	0.013
Oospora lactis	50	0.046
Penicillium digitatum	440	0.004
Penicillium expansum	130	0.018
Penicillium roqueforti	130	0.018
Rhizopus nigricans	1110	0.002

Virus		
Hepatitis A	73	0.032
Influenza virus	36	0.064
MS-2 Coliphase	186	0.012
Polio virus	58	0.040
Rotavirus	81	0.028

Protozoa		
Cryptosporidium parvum	25	0.092
Giardia lamblia	11	0.209

Algae		
Blue Green	3000	0.0008
Chlorella vulgaris	120	0.019

Table 2. Doses for 10% survival under 254 nm radiation (J/m^2) and rate constant k (m^2/J), Ref 2, 3, 4, 5, 6 and 7

3. Purification by means of ultraviolet lamps

General

In practice, germicidal applications and design factors are governed by three main factors:

A. The effective dose (Heff)

Effective dose is the product of time and effective irradiance (the irradiance that makes a germicidal contribution). However, dose is severely limited by its ability to penetrate a medium. Penetration is controlled by the absorption co-efficient; for solids total absorption takes place in the surface; for water, depending on the purity, several 10s of cm or as little as a few microns can be penetrated before 90% absorption takes place.

B. The possible hazardous effects of such radiation

Germicidal radiation can produce conjunctivitis and erythema, therefore people should not be exposed to it at levels more than the maximum exposure given in figure 9. It follows that this needs to be taken into consideration when designing purification equipments. Germicidal applications can be and are used for all three states of matter, viz. gases (air), liquids (mainly water) and solids (surfaces) with greatest technical success in those applications where the absorption coefficient is smallest.

However, some notable success has been achieved in applications where, despite a disadvantageous absorption, "thin film" or closed circuit (recycling the product) design techniques have provided effective solutions.

C. Lamps

Five Philips ranges of lamps are available for purification purposes:

- Classic Philips T5 and T8 TUV lamps
- High output Philips TUV lamps
- Philips PL-S and PL-L twin-tube compact TUV lamps
- And the newest addition: Philips extreme power technology (XPT) amalgam germicidal lamps in various diameters

All of these are based on low pressure mercury technology. Increasing the lamp current of low pressure lamps produces higher outputs for lamps of the same length; but at the cost of UV efficiency (UV watts/input watts); this is due to higher self-absorption levels, and temperature influences. The application of mercury amalgams, rather than pure mercury, in the lamps corrects for the latter.

- Philips HOK lamps, which are of the medium pressure mercury type, mainly characterized by a much higher UVC output than low pressure options, but at much lower efficacies

The choice of the lamp type depends on the specific application. (See chapter 4.4). In most cases the low pressure types are the most attractive. This is because germicidal lamps are highly efficient in destroying micro-organisms, hence there is limited need for high wattage lamps. For water purification, low and medium pressure are both used, although the choice is not necessarily based on UVC efficacy. Initial total systems costs, including metalwork and space limitations, can be the driving factor rather than efficacy.

D. Systems

Near lamps Philips provides also inhouse manufactured ballasts and sleeves to offer a complete system solution for ultimate performance.

3.1 Air purification (Ref.12,13)

Good results are obtained with this form of purification because air has a low absorption coefficient and hence allows UVC to attack micro-organisms present. In addition, two other beneficial conditions are generally present, viz. random movements allowing bacteria etc. to provide favorable molecular orientations for attack and high chances of "closed circuit" conditions, that is second, third and more recycle opportunities. From this, it is evident that air purification is an important application for UV light.

Even in the simplest system (natural circulation) there is an appreciable reduction in the number of airborne organisms in a room. Thus the danger of airborne infection, a factor in many illnesses, is considerably reduced.

However, it should be remembered that purified air is not, in itself, a purifying agent.

Presently, there are five basic methods of air purification using UV lamps viz:

a. Ceiling or wall mounted Philips TUV lamps
b. Philips TUV lamps (in upwards-facing reflectors) for upper-air irradiation.
c. Philips TUV lamps (in downwards-facing reflectors) for irradiation of the floor zone (often in combination with b.).
d. Philips TUV lamps in air ducts sometimes in combination with special dust filters.
e. Philips TUV lamps, incorporated in stand-alone air cleaners with a simple filter.

3.1.1 Ceiling-mounted Philips TUV lamps

This method is used in those cases where either the interior is unoccupied or where it is possible for the occupants to take protective measures against light. These protective measures entail covering the:

Face	
	glass spectacles, closefitting goggles or plastic face visors
Hands	
	gloves (for long exposure, special plastic is preferable to rubber)
Head and neck	
	head cover

Note: Normal glasses and plastics can be used to give protection, because they transmit little or no UVC; some exceptions are special UV glasses, quartz and certain PTFEs

3.1.2 Philips TUV lamps for upper-air irradiation using upward facing reflectors

This method of purification can be used to combat bacteria and moulds; it also has the advantage that it can be used occupied interiors without the occupants using protective clothing.
The lamps should be mounted in suitable reflectors and aimed to emit no radiation below the horizontal.

The reflectors should be mounted more than 2.10m above the floor, the lower air thus entirely free of any direct UV light. Air above the 2.10m level maintains a low germ level, because it subject to direct UVC light.

Free convection of air without forced ventilation causes air movements of about 1.5 - 8 m^3 per minute, thus producing exchanges between the upper treated and lower untreated parts of the room. The process reduces air contamination to fractions of that before the TUV lamps were activated. As an indication for general applications in a simple room, or enclosure, it is advisable to install an effective UVC level of: **0.15 W/m^3**

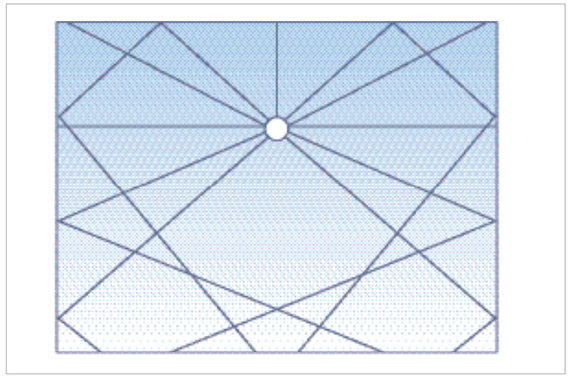
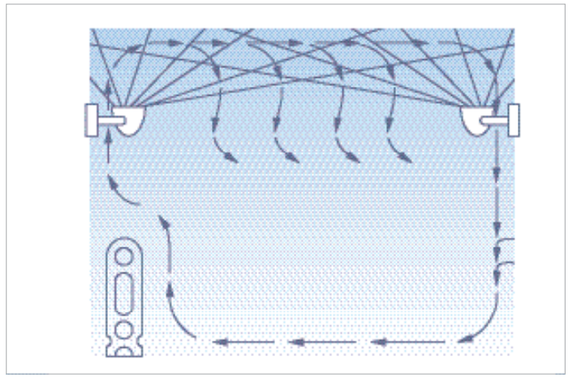
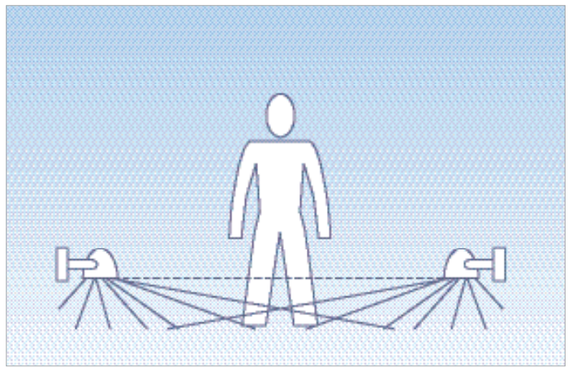


Figure 15. Various principles of air purifications
a. Ceiling mounted lamps.



b. Upwards facing reflectors.



c. Downwards facing reflectors.

3.1.3 Philips TUV lamps for irradiation of the floor zone using downward facing reflectors

This method is for use in those cases where it is important that the entire room air, even at floor level is rendered as sanitary as possible. In this case, lamps supplementing those irradiating the upper air should be fitted in downward-aimed reflectors at about 60cm above the floor.

In methods 3.1.1, 3.1.2 and 3.1.3 person detectors/systems can be used to deactivate TUV lamps, if necessary.

3.1.4 Philips TUV lamps in air ducts

In this method, all the conditioned air is subjected to radiation prior to entry. The injected air can be purified to a specified killing level, depending upon the number of lamps installed and the dwell time, that is the time spent in the effective killing region of the lamp(s); by definition this takes the dimensions of the air duct into consideration. Such systems have a controlled flow rate and their performance can be predicted theoretically. Certain aspects should be borne in mind, however

- These installations are only suitable for bacteria; most moulds have higher resistances to UV, so the air flow rate is not likely to allow a sufficient dwell time to produce a high enough effective dose
- Dust filters should be installed to prevent the lamps from becoming soiled and hence seriously reducing their effective emission
- The number of lamps required in an air purifying chamber in an air duct system is dependent on the required degree of purification, the airflow rate, the ambient temperature, the humidity of the air and the UV-reflecting properties of the chamber walls.

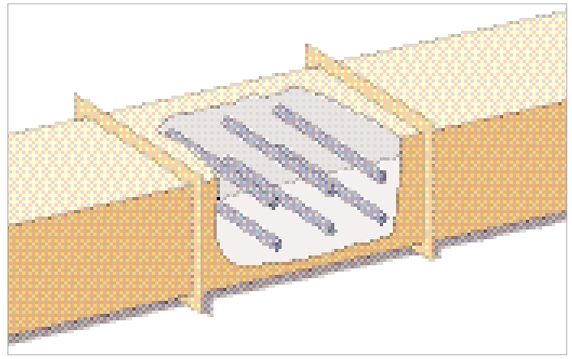


Figure16. Basic arrangement of Philips TUV lamps in an air duct for room purification.

The advantage of purifying air prior to it entering a room is that there is then no limit to the maximum permitted radiation dose, since humans are totally shielded.

Designing duct systems needs to account for practical issues, such as large temperature and humidity variations caused by exterior weather variations, if only because air is often drawn from outside, then released into a room after a single pass over the lamps. Recycling part of the air will allow multiple passes, hence improving system efficiency.

Lining the UV lamps section with aluminum, also increases efficiency. The lamps and the wall of the duct should be easily accessible to permit regular cleaning and easy maintenance, another reason for a modular design. Micro-organisms exposed to UV, experience a normal exponential decrease in population, as already expressed on page 10:

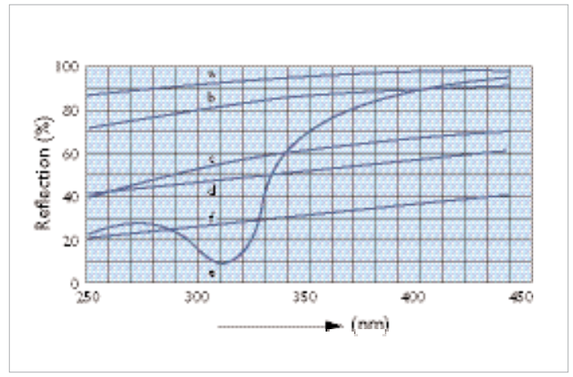


Figure 17. Metal surfaces.
a. Aluminum foil
b. Chromium
c. Evaporated aluminum
e. Silver
f. Stainless steel
d. Nickel

$$N_t/N_0 = \exp.(-kE_{eff}t)$$

The rate constant defines the sensitivity of a micro-organism to UV light and is unique to each microbial species. Few airborne rate constants are known with absolute certainty. In water based systems, Escherichia coli are often used as test organism. It is however not an airborne pathogen. For aerosolization tests, often the innocuous Serratia marcescens is used.

Points to remember when constructing Philips TUV lamp installations in air ducts:

- The surface of the chamber walls should have a high reflectance to UV 254 nm, for example by using anodised aluminum sheet (reflectance 60-90 per cent)
- The lamps should be so arranged that there are no 'shadow' areas
- Lamps should be mounted perpendicular to the direction of the airflow

- Lamps and the inner (reflecting) walls of the chamber should be cleaned frequently using a soft cloth
- Lamps should be changed after the nominal lifetime; an elapsed time meter will help
- An external pilot light should be used to indicate that the lamps are functioning

Reflectance of various materials to UV 254 nm

The graphs shown give the spectral reflectance of various metals (figure 17) and organic substances (figure 18) to radiation of different wavelengths. These graphs demonstrate the importance of determining a material's 254 nm reflectance. As can be seen, high reflectance to visible radiation is not consistent with high reflectance to short-wave UV light.

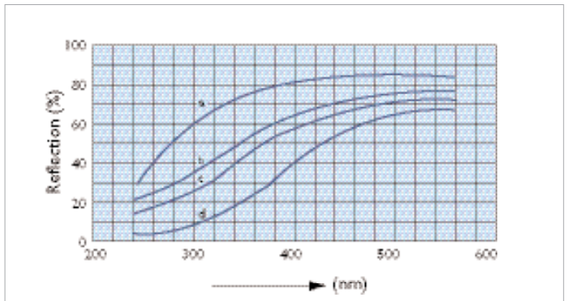


Figure 18. Organic substances

a. Bleached cotton
b. White paper
c. Linen
d. White wool

Materials with a high reflectance to 254 nm are used to construct reflectors for both direct and upper-air irradiation. Material with a low reflectance to 254 nm are used where UV light has to be absorbed after performing its function. This latter is necessary to avoid the consequences resulting from the unwanted 254 nm reflections, so ceilings and walls should be treated with a low reflectance material people comfort and safety factors.

3.1.5 Philips TUV lamps in stand-alone units

Recently this method has gained commercial favor by meeting a growing need for a better Indoor Air Quality, (IAQ). Closed stand-alone devices are safe, simple and flexible. In essence the units consist of Philips TUV lamps, mostly PL-L types driven by high frequency ballasts, mounted inside a "light trap" container. The unit incorporates a fan that firstly draws air across a filter, then across the lamp(s). Single and multiple lamp options can be built into a small outer using either single or double-ended lamp options.

For maximum design flexibility, PL-L and PL-S lamps offer the best solutions, because their dimensions are compact, so reducing unit size and because their single ended configuration allows more mounting options.

The units have the benefits of portability and hence more mounting positions viz. wall, floor or ceiling mounted in either permanent or temporary options. A feature of their design is that cleaning and lamp and filter replacement is easy. Additionally their portability can be used to produce immediate results. Variation in UVC dose can be achieved both by varying the number of lamps and their wattage (see also dimming below). As an example, it is possible to use the same physical design dimensions for PL-L lamps with a nominal wattage range between 18 and 95W HO, in single and multi lamp variants. Commercial products are known for as few as 1 x PL-L 18W and as many as 4 x PL-L 95W HO lamps inside the same container, giving a unit capable of producing a 25-fold difference in effective dose. PL-L lamps are more flexible; they have readily available and competitively priced electronic regulating (dimming) ballasts to vary UV output in a simple reliable fashion. Ballasts can be single, double and in the case of 18W, four lamp versions. This adds to the flexibility of portable units.

Reflectance of UVC radiation	
Material	**Reflectance %**
Aluminum: untreated surface	40-60
treated surface	60-89
sputtered on glass	75-85
'ALZAK' - treated aluminum	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
Aluminum 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
Bleached cotton	30
Wallpapers: ivory	31
white	21-31
red printed	31
ivory printed	26
brown printed	18
White notepaper	25

Table 3. Reflectance of various materials to UV-254 nm radiation.

3.2 Surface purification

Surface purification generally requires high-intensity short-wave UV light. Mostly this means TUV lamps are mounted close to the surface requiring to be kept free from infection or to be purified.

The success of surface purification depends largely on the surface irregularity of the material to be purified, because UV light can only inactivate those micro-organisms that it hits with a sufficient dose. Thus purification can only be successful if the entire surface is exposed to UV light. Micro-organisms sitting in "holes" in a surface are not likely be overcome by reflections from the hole walls, as can be deduced from the reflectances shown in table 3.

In practice, solid surfaces, granular material and packaging (whether plastic, glass, metal, cardboard, foil, etc.) are purified or maintained germ-free by means of intensive, direct irradiation. Additionally, purified material can be kept largely germ-free throughout its further processing by irradiating the air along its path.

3.3 Liquid purification

Germicidal energy radiation is capable of penetrating liquids with varying degrees of efficiency. From a treatment view, liquids can be regarded as similar to air so the further the UV light is able to penetrate the liquid, the more efficient is its action. The degree of efficiency thus greatly depends on the liquid and more particularly its absorption coefficient at 254 nm (table 4). As an example, natural water's transparency to 254 nm may vary by as much as a factor of 10 or more from place to place. Polluted industrial water often needs purification followed by disinfection; here UVC is growing with many thousands of systems in use in North America and Europe, each with a multitude of lamps. Often UV light may supplement or replace conventional chlorination measures (see later). UVC has advantages over chlorinating techniques, because it produces far fewer noxious

Figure 19. UV "cascade" surface purification of spicies.

by-products and is it unaffected by the pH of the water or its temperature. The reader should note that the latter comment refers to the radiation, not to the lamp, or its environment as described earlier. Micro-organisms are far more difficult to kill in humid air, or in a liquid environment, than in dry air. This is because they limit transmission of 254 nm radiation. In more quantitative terms liquids decrease the germicidal intensity exponentially according to the formula

$$E_x = E_0 \cdot e^{-\alpha(x)}$$

E_x intensity at depth x
E_0 incident intensity
α absorption coefficient

Liquids with a high α can only be purified when they are exposed as thin films. A rough indication to estimate penetration depth is $1/\alpha$, at this depth the irradiation level will have fallen to 1/e or to 37%. To overcome wall effects where liquids are notoriously static, turbulence or rigorous stirring is necessary for better purification, agitation helps orientate micro-organisms hidden behind particles.

Iron salts (as well as other inorganic salts) and suspended matter in liquids will decrease the effectiveness of germicidal radiation.

Additionally, it is feasible that organic compounds, in particular, those susceptible to bond fissure under UV light, can change the texture and taste of the liquid being treated.

Hence experimentation is needed. In round terms the effective depth of penetration for a 90% kill may thus vary from 3m for distilled water, down to 12cm for normal drinking water and even less in wines and syrups (2.5mm), see table 4.

The penetration depths cause more special techniques to be applied to allow 254 nm radiation to penetrate sufficiently, these include generating "thin films" and or slow speed presentation to the radiation, so that a sufficient dose can be applied.

If an UV lamp has to be immersed in a liquid, it should be enclosed in a quartz or UVC transparent PTFE sleeve. Installations for purifying liquids may have the following forms:

1. One or more lamps enclosed in a quartz container or one of similar material (with a high transmittance at 254 nm), which is surrounded by the liquid to be purifieded. A multiple of such configurations can be used inside one outer container.

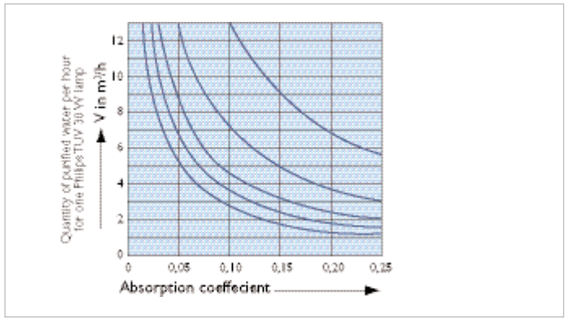


Figure 20. Volume of purified water V as a function of the absorption coefficient α (for distilled water α = 0.007-0.01/cm, for drinking water α = 0.02-0.1/cm) with respect to different degrees of purification (in terms of Escherichia coli).

2. A quartz tube (with high transmittance at 254 nm) transporting liquid surrounded by a cluster of lamps in reflectors or by an integral reflector Philips TUV lamp e.g. Philips TUV115W VHO-R.

3. Irradiation by means of lamps installed in reflectors or integral reflector Philips TUV lamps e.g. Philips TUV115W VHO-R mounted above the surface of the liquid.

Example of absorbtion coefficients	
Liquid	**α**
Wine, red	30
Wine, white	10
Beer	10-20
Syrup, clear	2-5
Syrup, dark	20-50
Milk	300
Distilled water	0.007-0.01
Drinking water	0.02-0.1

Table 4. Absorption coefficient (α) of various liquids to UV-254 nm per cm depth.

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