UV Light Disinfection of Air and Water

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OLTP seminar
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WAYS of INFECTIONS: AIR, WATER AND SURFACE

Infections are mainly transmitted through air, water, and surfaces.

Infections are most quickly transmitted through the air from sick people.

Reasons:

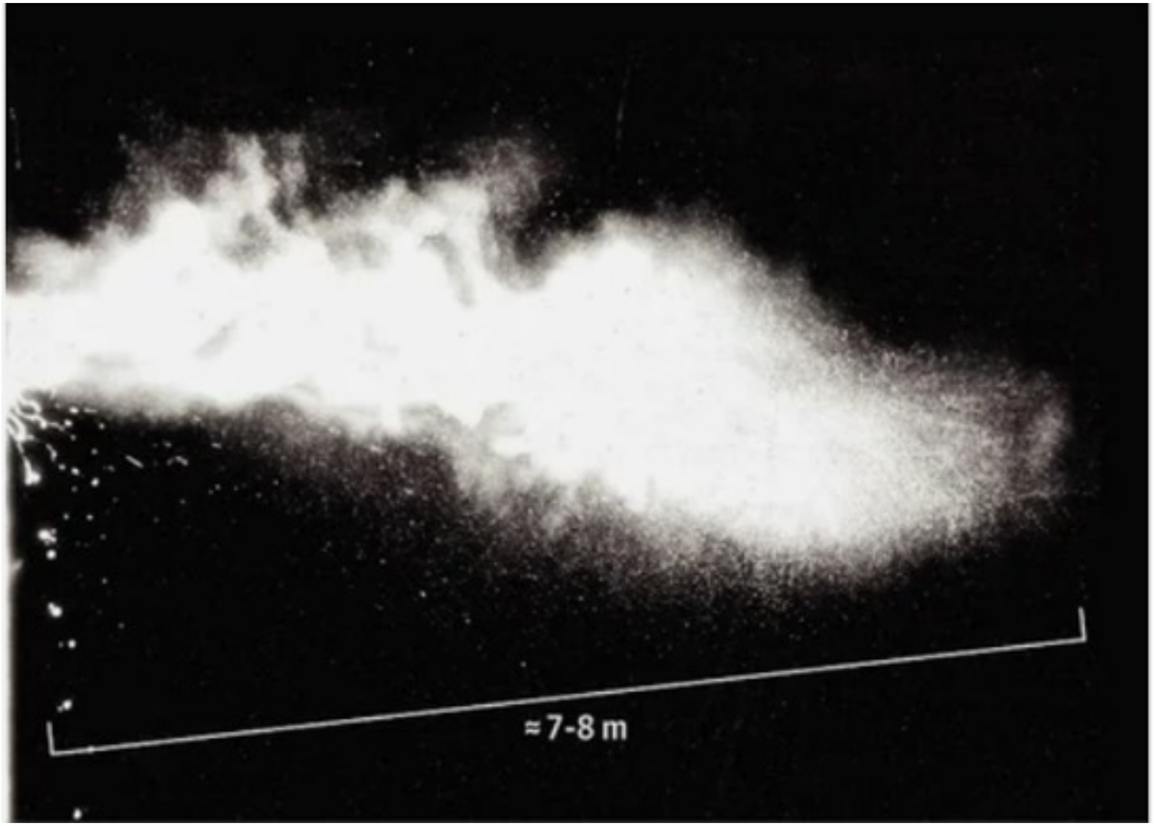
- a lot of crowded places, crowded transport and long-term stay of people in offices.
- high mobility of air.

The air cannot be chemically disinfected in the presence of people.

Physical methods of disinfection should be used.

INFECTION in AIR

Microbes and viruses in the air are located in water droplets or on dust particles (0.5-100 micron).



The spread of sputum secretions when sneezing is 7-8 m

[L. Bourouiba, E. Dehandschoewercker and J. W. M. Bush // Journal of Fluid Mechanics, 2014. Vol. 745, pp. 537-563]

COVID -19 usually causes a cough. When coughing, infected drops with a diameter of 30 micron can fly to a length of up to 2 m.

HEALTH-CARE ASSOCIATED INFECTION (HCAI)

Hospitalized patients caused by pathogens that are resistant to most modern antibiotics (MRSA) and highly resistant to chemical disinfectants. (HCAI)

- The US Center for Disease Control and Prevention reports:

that nearly 1.7 million hospitalized patients annually acquire HCAI is while being treated for other health issues and that more than 98,000 patients (one in 17) died.

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6245375/#b8-idr-11-2321

-The European Centre for Disease Prevention and Control reports:

4 131 000 patients are affected by HCAI every year in Europe.

https://www.who.int/gpsc/country_work/gpsc_ccisc_fact_sheet_en.pd)

- Annual financial losses due to health care-associated infections are estimated €7 billion in Europe, and at about US$ 6.5 billion in the USA.

https://www.who.int/gpsc/country_work/gpsc_ccisc_fact_sheet_en.pdf

WAYS of INFECTIONS: WATER

A century ago, water was the main source of infection.

Chlorination of water solved the problem.

Disadvantages:

1. Formation of dangerous organochlorine compounds in water.

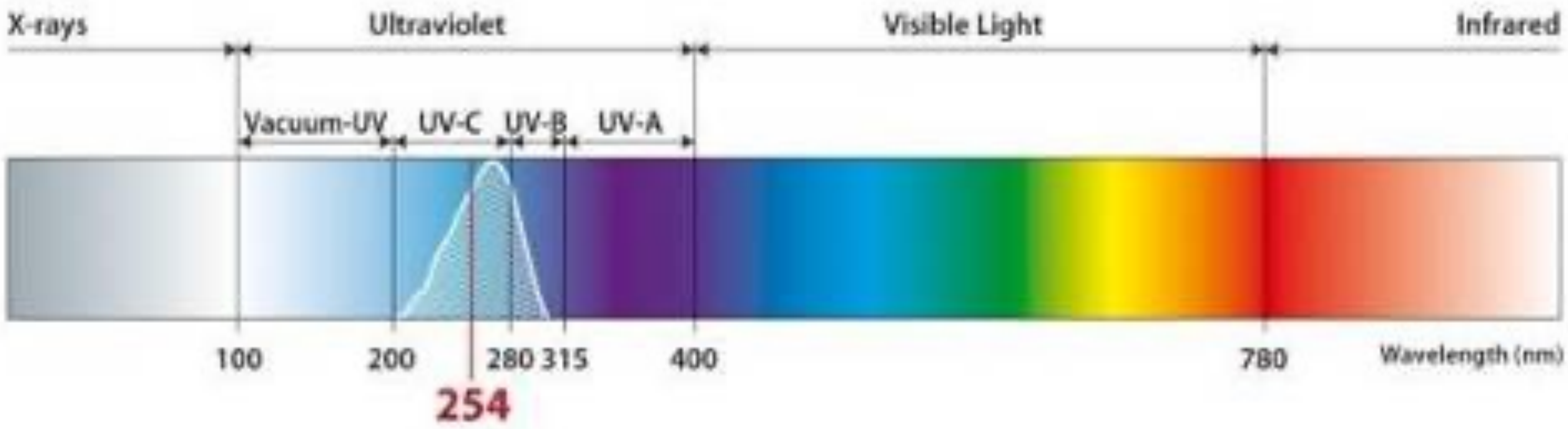
2. Chlorine is a dangerous poison.

Physical methods of disinfection should be used – UV Light.

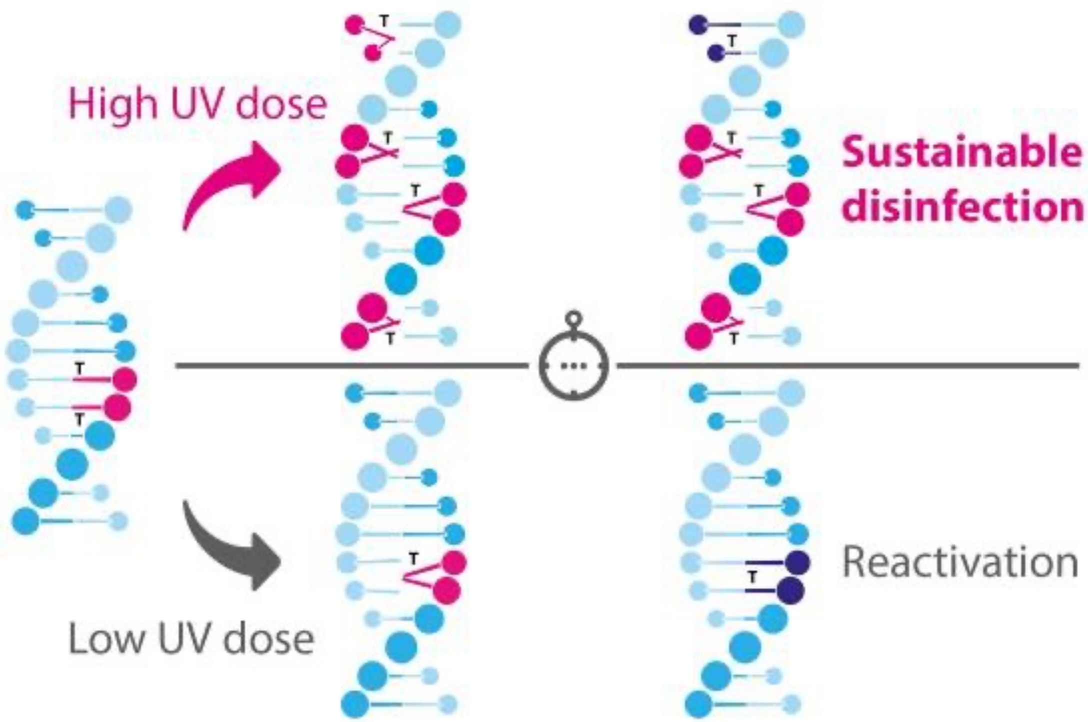
For industrial UV disinfection of drinking water, powerful UV lamps are needed.

This problem was the main reason for the development of powerful UV lamps.

ACTION of UV IRRADIATION at DNA

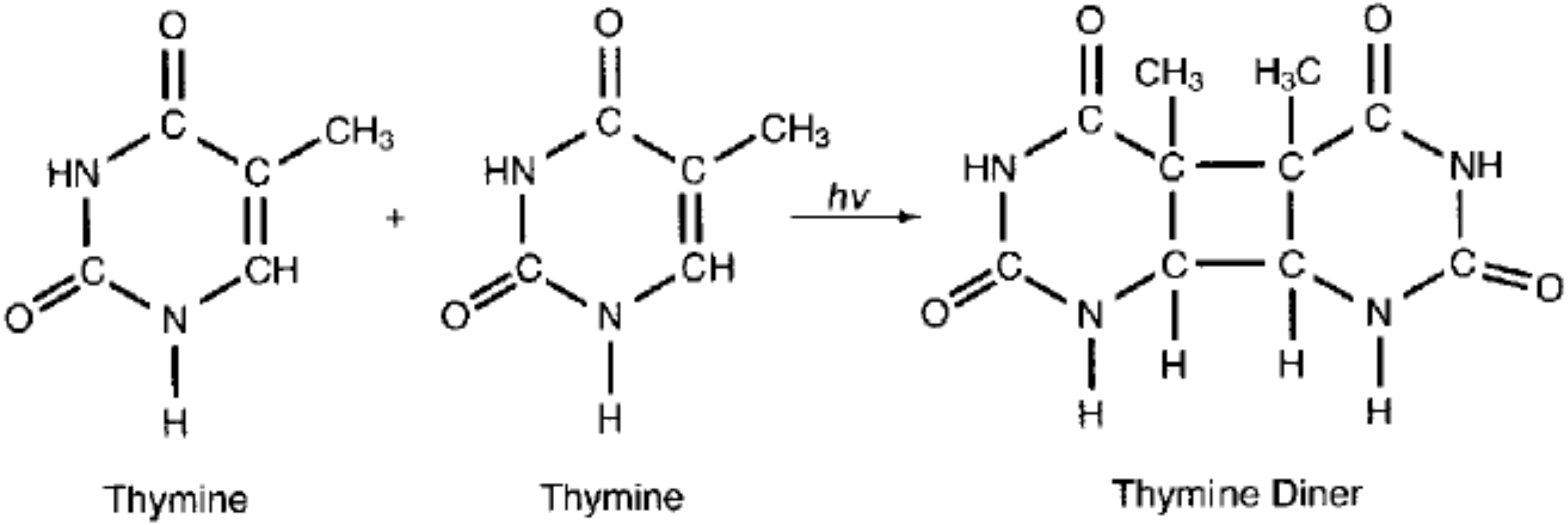


High UV dose is necessary.

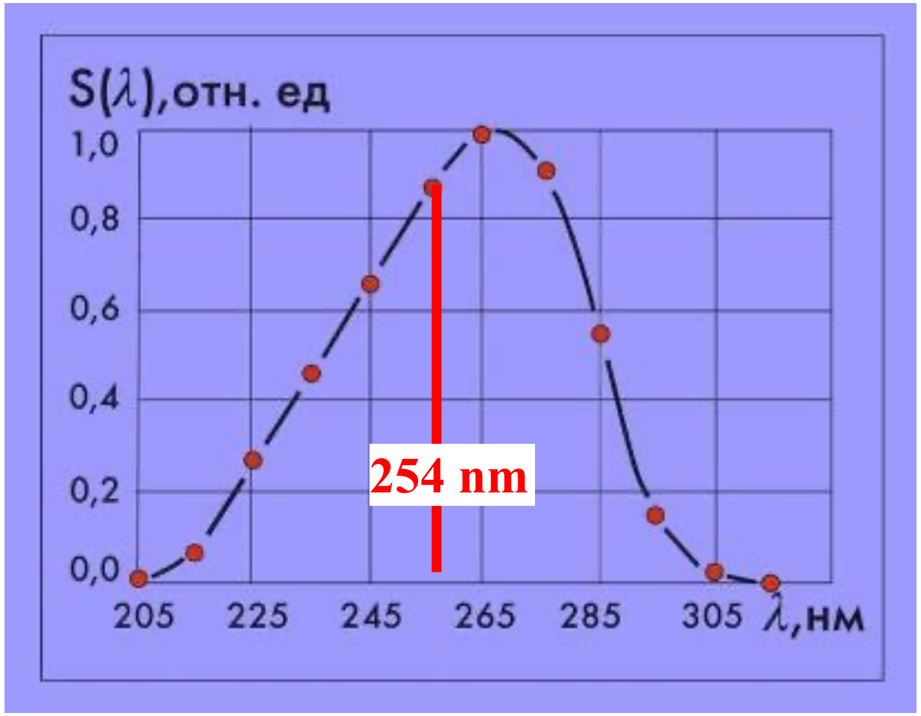


UV LIGHT ACTION at DNA

Photochemical dimerization of two thymine bases in DNA (or uracil in RNA).



GERMICIDAL UV RADIATION 205-315 nm



GERMICIDAL EFFICIENCY

Reduction (survival) law

$$N = N_0 10^{-kD},$$

D – UV dose (fluence), K – gems sensitivity

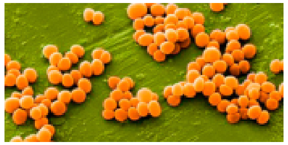
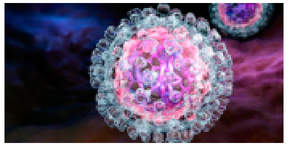
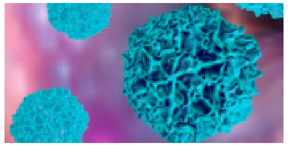
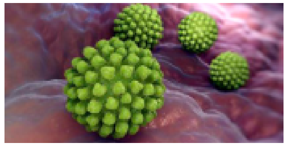
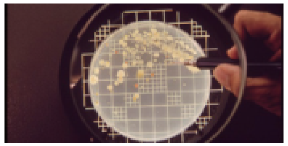
Low pressure mercury lamps emit UV light with wave length of 254 nm

UV 254 nm doses for reduction efficiency of 99.9%

Conventional air and surface disinfection systems are sized against *Staphylococcus aureus*. D=7 mJ/cm^2

Does this really show the effectiveness of disinfection?

It does not, because efficacy against *Staphylococcus aureus* <u>does not reflect efficacy</u> against other important pathogens (reduction efficiency of 99.9%):

Staphylococcus aureus		7	mJ/cm^2
Hepatitis virus		8	mJ/cm^2
Mycobacterium tuberculosis		10	mJ/cm^2
Pseudomonas aeruginosa		10,5	mJ/cm^2
Klebsiella pneumoniae		12,6	mJ/cm^2
Poliovirus		21	mJ/cm^2
Rotavirus		24	mJ/cm^2
TBC		25+	mJ/cm^2

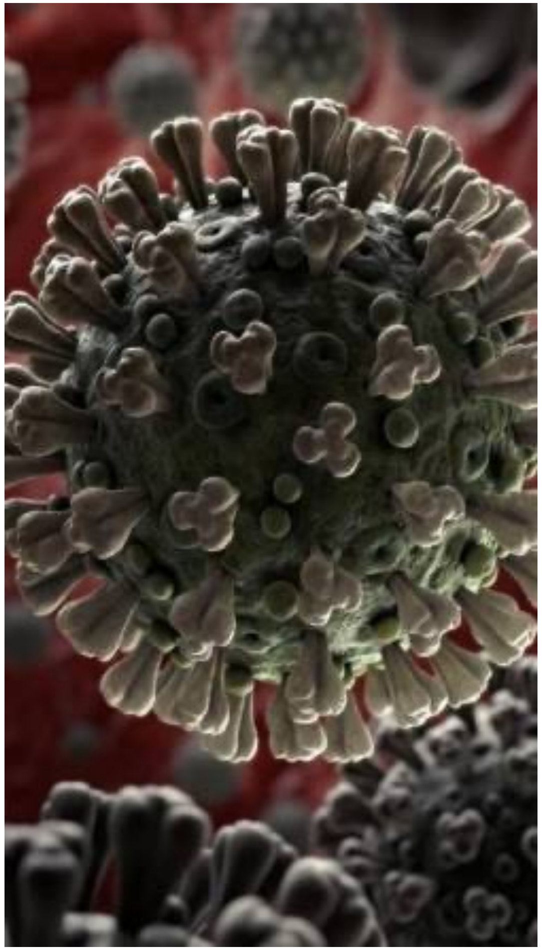
ASSOCIATED INFECTION (HCAI)

S.aureus (resistant) MRSA: D=20 mJ/cm^2

On the contrary, the total microbial count (TBC) is a general indicator of UV disinfection.

HIGH UV DOSES are NECESSARY for SARS-CoV 2 (COVID-19)

The virus SARS-CoV 2 that causes COVID-19 belongs to a group of coronaviruses. Coronaviruses are RNA-containing viruses with a viral envelope and a specific shape, from which their name derives. Another group of RNA-containing viruses with a similar structure but without a viral envelope are rotaviruses.



According to International Ultraviolet Association a UV dose of 10-20 mJ/cm^2 is required for 99.9% reduction of SARS-CoV 2.

Russia: UV 254 nm dose of 25 mJ/cm^2

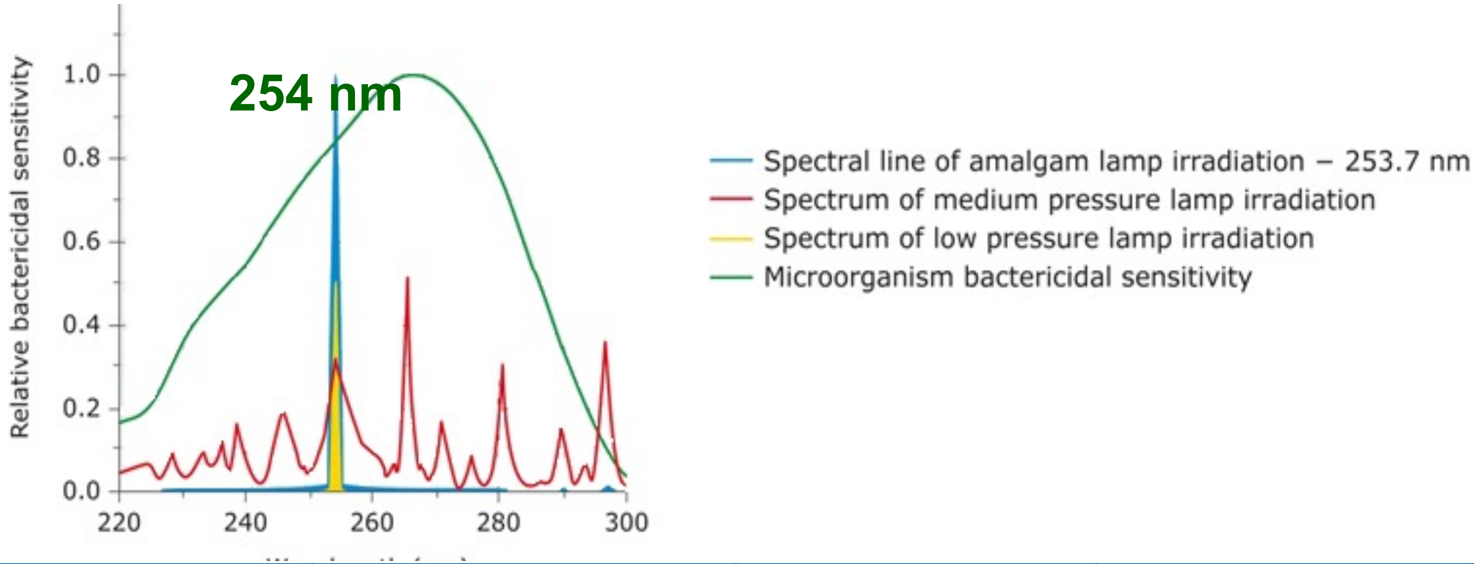
Advantages of UV disinfection technology

- High disinfection efficiency against a wide range of microorganisms, including bacteria, viruses and protozoa;
- Does not form by-products;
- Does not change the physical and chemical properties of the medium;
- Simple technology, compact equipment, low operating costs.

UV Lamp requirements:

UV radiation efficiency	- 35-40%
Electrical power	- 200-400 W/m
Service life	- 8000-16000 h,
UV flux drop	- less than 15%

UV LAMPS CHALLENGE



PARAMETER	Medium pressure lamp	Mercury low pressure lamp	Amalgam low pressure lamp	Xe pulse lamp
LAMP POWER, W	2,000 – 20,000	15 – 100	100 – 800	Average 200-1000
UV EFFICIENCY	10 – 12%	35-40%	35-40%	12-15%
LIFITIME, hours	8,000	16,000	16,000	1,000
BY-PRODUCT FORMATION	O3 POSSIBLE	None	None	O3 possible
SPECTRUM	continuous	Line 254 nm	Line 254 nm	continuous

“LIT” AMALGAM LOW PRESSURE LAMPS

Investigations and solutions, fundamental and technical.

Solutions for producing high-power UV lamps with high efficiency:

1. reducing the pressure of the buffer gas;
2. changing the composition of the buffer gas, instead of pure argon, use a mixture of Ar-Ne

The result: an increase in electron temperature, an increase in power, an increase in UV efficiency

3-ozone-free lamps, special quartz: line 254 nm, no 185 nm, no ozone O_3

4. Solving the problem of oxide evaporation from the electrode.
5. Increasing the frequency of the discharge current from 50 Hz to 30-50 kHz
6. Replace metallic mercury with amalgam: an increase in power

7. Increasing the service life to 16,000 h:
   - protective coating for quartz;
   - The problem of destruction of cathodes of high-power lamps

8 - Design and production of special lamp power supplies

OXIDE ELECTRODE

before the test

after the test

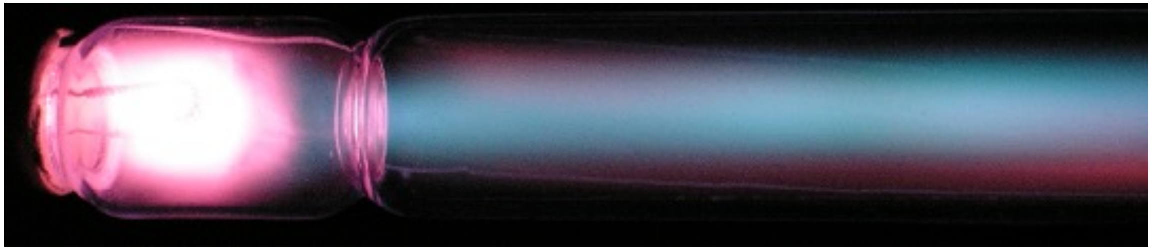
Lamp after the test

OXIDE ELECTRODE.
“on-of’ test

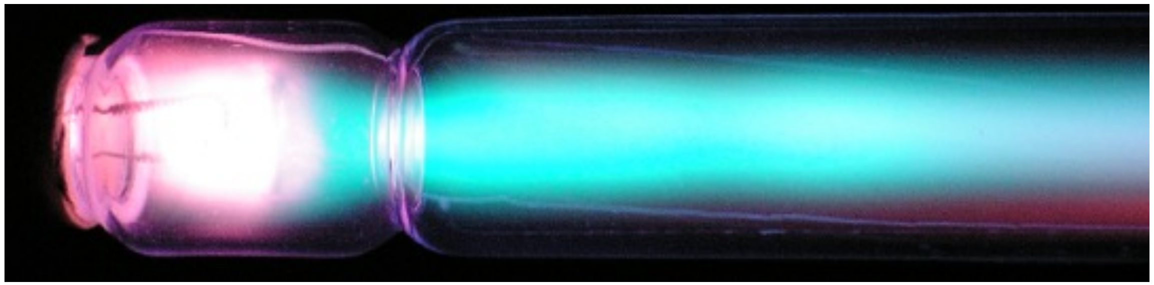
There is **no oxide** on the electrode after **500 “on-off” cycles** when working with a **standard power source**

Ignition of a lamp with a standard power source

The initial stage of ignition of a glow discharge near a cold electrode



Glow discharge with cold electrode



Stage of transition from glow to arc discharge

Arc discharge

OXIDE ELECTRODE. “on-of’ test

500 “on-off” cycles
with a **standard power source.**
No oxide on the electrode

200,000 “on-off” cycles
with a **special power source**

The reasons of electrode destruction during the ignition period :

- ion sputtering in a glow discharge
- and thermal destruction from heat stroke during arc discharge ignition.

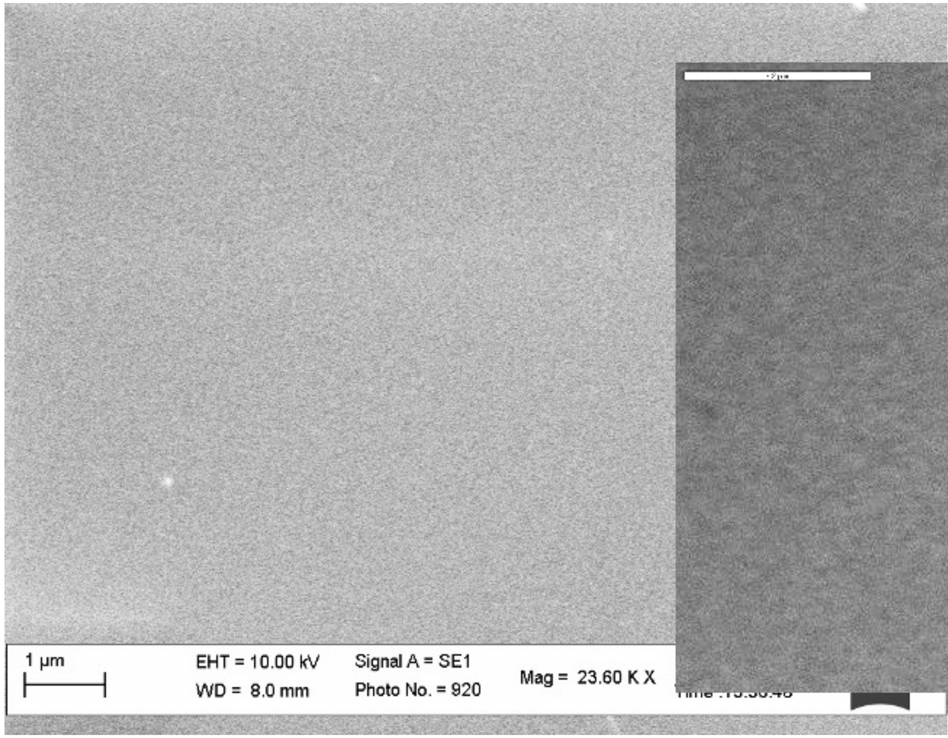
The surface of pure quartz before and after LP mercury discharge exposure of 12 000 h

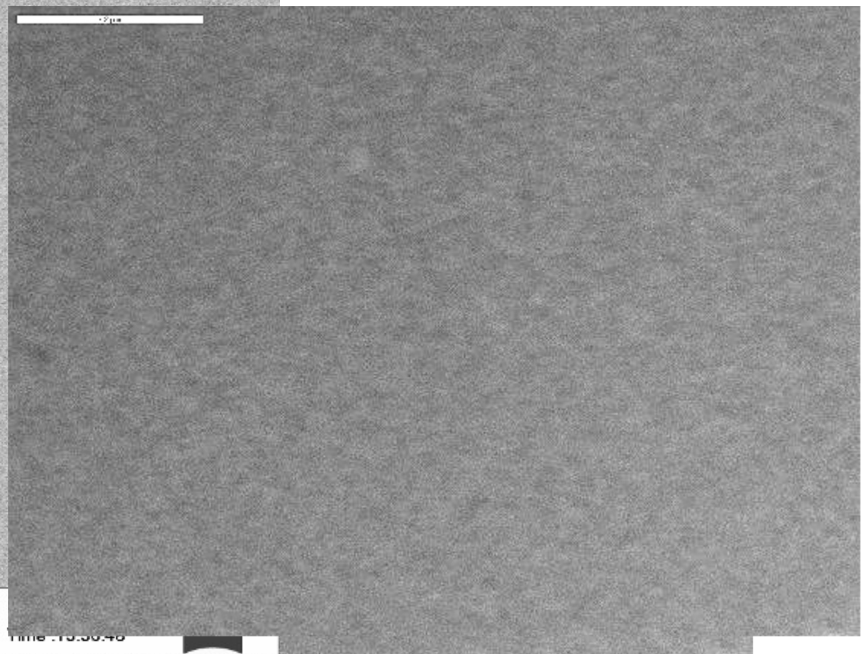
before

after

after

before

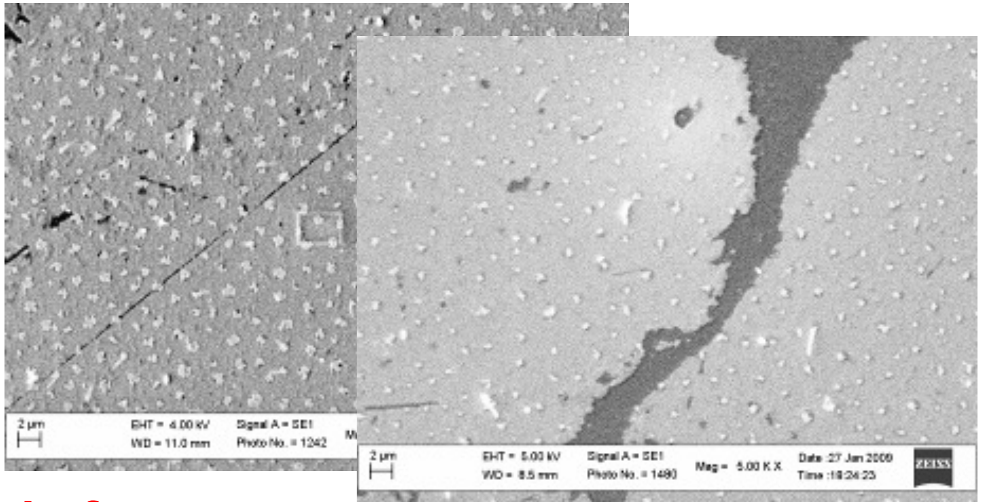




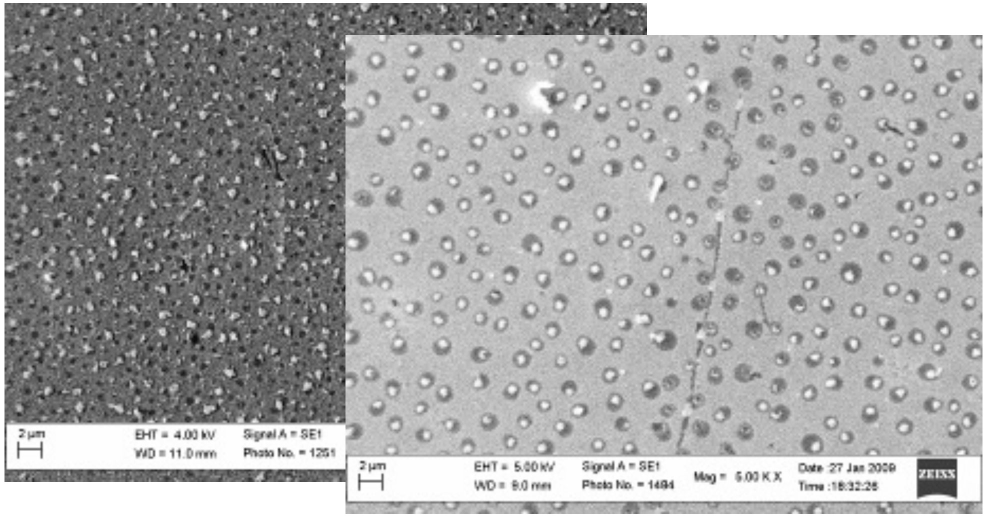
Effect of discharge in inert gases on coated quartz

We were the first to protect the quartz wall from discharge with a protective coating

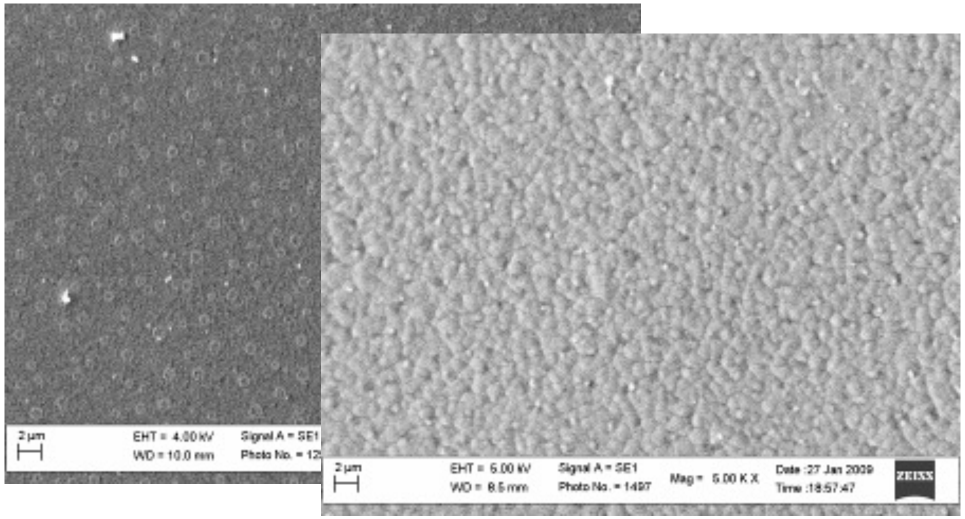
before 1 layer After 6h



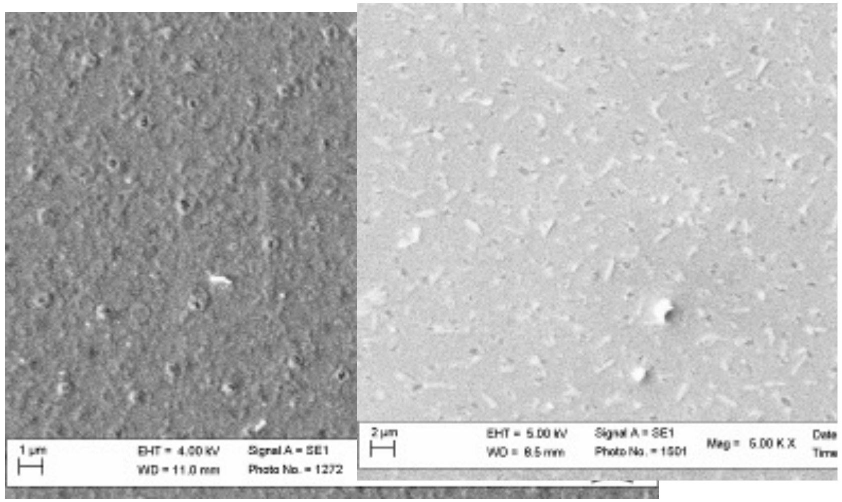
before 2 layers After 24 h



before 3 layers After 170 h



before 4 layer After 500 h

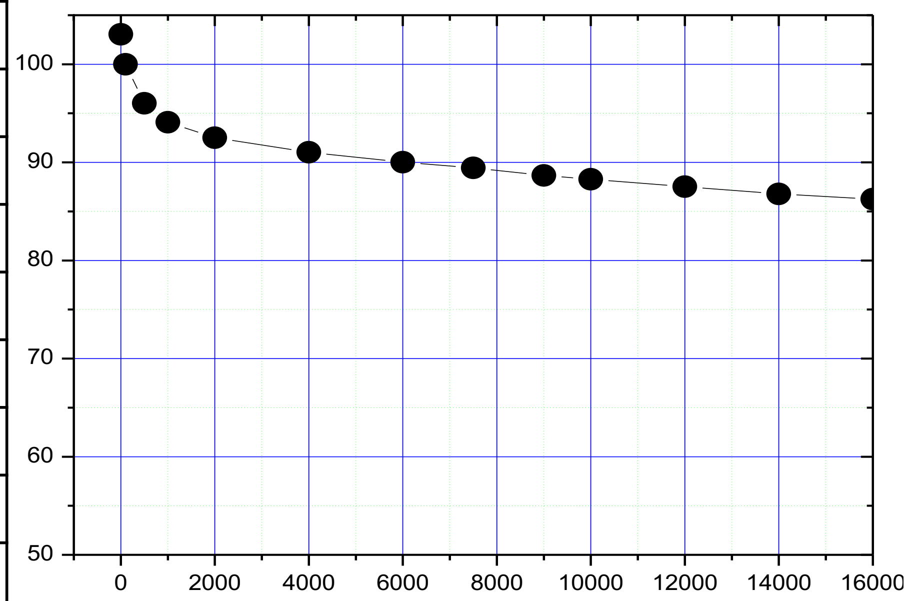


UV LAMPS. LIT design and production

LIT

Lamp	Power, W	UV-Power, W	LIFITIME, hr
DB 95	95±5	30±3	12000-16000*
DB 145	145±5	50±3	12000-16000*
DB 200	170±7	58±3	12000-16000*
DB 240	200±10	65±3	12000-16000*
DB 300 H	250±10	90±3	12000-16000*
DB 300	235±10	87±3	12000-16000*
DB 350	325±10	125±5	12000-16000*
DB 500	440±12	150±5	12000-16000*
DB 600 B	510±15	200±10	12000-16000*
DB 800 B	710±15	240±12	12000-16000*
ANC 100/32	75±5	23±2	12000-16000*
ANC 120/45	95±5	30±3	12000-16000*
ANC 170/70	145±5	50±3	12000-16000*
ANC 215/95	190±10	65±3	12000-16000*
ANC 240/107	215±10	75±3	12000-16000*
DB 75-2	70±5	26±3	12000-16000*

UV Power, a.u. **UV lamp DB 350**



Time, hr

UV DISINFECTION OF AIR AND SURFACE

VENTILATION AND AIR CONDITIONING SZYSTEMS

HOSPITAL HEALTH CARE

PUBLIC BUILDINGS

FOOD PROCESSING

DISINFECTION OF AIR

The best way to decontaminate indoor air is an open window or ventilation.

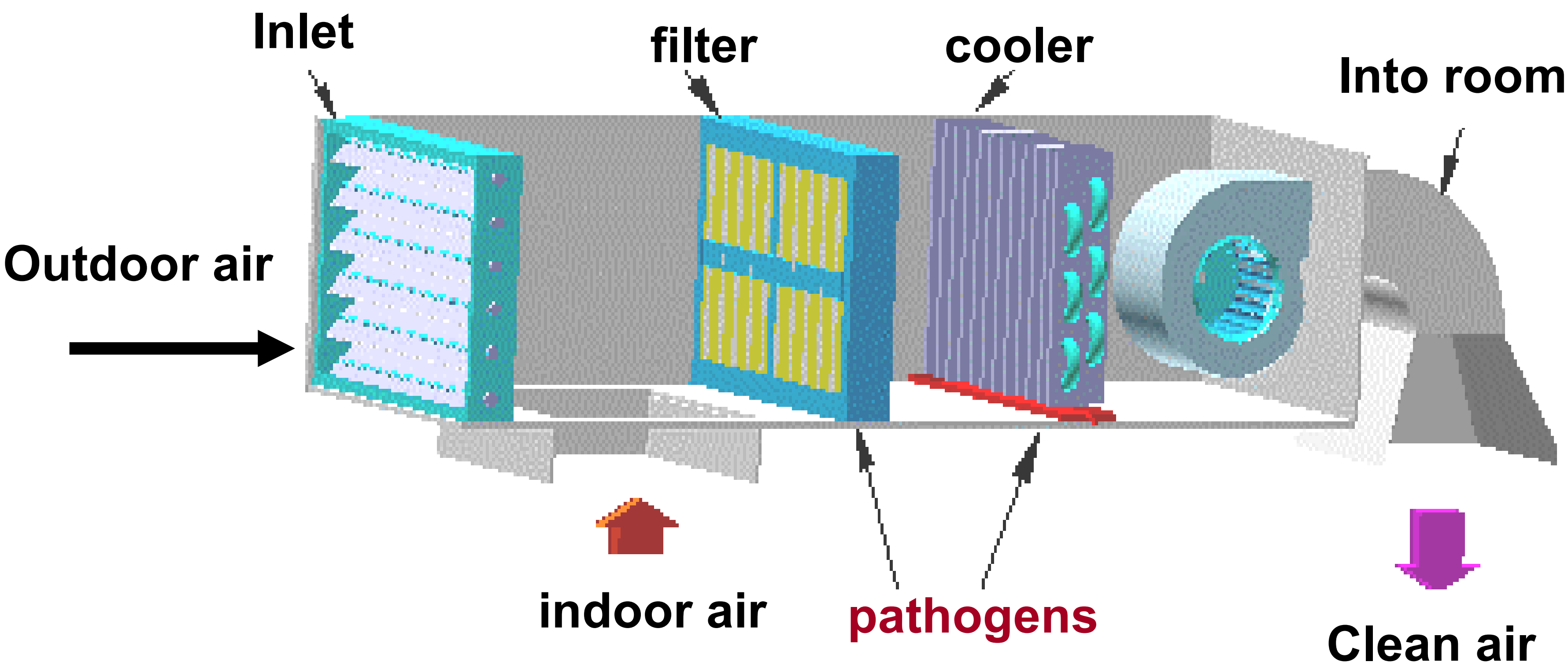
Filtration and air conditioning remove sputum and dust particles with pathogens.

Air recirculation rate of at least 4-5 times per hour is required

Disadvantages:

1. **pathogens can live in filters and coolers.**
2. **when stop and starting, dust with pathogens can fly into the room.**
3. **Fine filters are expensive**

AIR CONDITIONING SYSTEM



Pathogens can live in filters and coolers.

UV light does not remove pathogens, but inactivates them in the air and on surfaces.

UV systems for ventilation and air conditioning systems

OPEEN UV DISINFECTION SYSTEMS FOR AIR & SURFACE

UV system should be able to provide:
a high UV dose (25 mJ/cm^2).
Short exposure time – 5-10 minutes.

We recommend to use powerful mobile UV irradiators (with a total UV power of at least 200-300 W and an electric power of at least 600 W)

UV irradiator "*SVETOLIT 600* "
«LIT».
4 lamps DB500,
Total electric power - 2000 W,
254 nm UV power - 600 W

OPEEN UV DISINFECTION SYSTEMS FOR AIR & SURFACE

UV irradiators SVETOLIT exposure time for **UV dose of 30 mJ/cm^2**

SVETOLIT-50			SVETOLIT -100		
Room volume	Radius of treated area	Exposure time	Room volume	Radius of treated area	Exposure time
up to 25 m^3	up to 1.2 m	16 minutes	up to 25 m^3	up to 1.2 m	9 minutes
25-30 m^3	up to 1.5 m	18 minutes	25-50 m^3	up to 2 m	16 minutes
30-50 m^3	up to 2 m	29 minutes	50-75 m^3	up to 2.5 m	22 minutes

SVETOLIT-300		SVETOLIT -600	
Room volume	Exposure time	Room volume	Exposure time
up to 50 m^3	7 minutes	up to 75 m^3	5 minutes
50-100 m^3	11 minutes	75-150 m^3	9 minutes
100-200 m^3	20 minutes	150-250 m^3	13 minutes

Large UV systems MEGALIT for ventilation and air conditioning

- **A high UV dose of 30 mJ/cm^2**
- **Capacity 1000 – 37 000 m^3/h**
- **Low pressure loss – not more than 100 Pa**

UV AIR RECIRCULATOR AEROLIT 550 m^3/h, high UV dose of 30 mJ/cm^2

For the effective disinfection of indoor air in the presence of people (who are seen as sources of continuous additional air contamination)

Air recirculation rate of at least 5 times per hour is required.

UV DISINFECTION IN THE VENTILATION AND AIR CONDITIONING SYSTEM OF THE UNDERGROUND CAR

UV DISINFECTION OF THE CARS in MOSCOW UNDERGROUND

Remarks on other sources of UV radiation

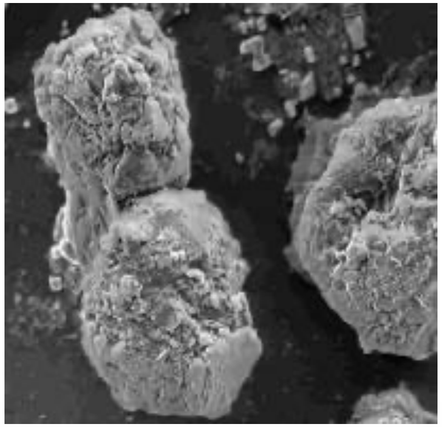
1. Pulsed xenon lamps.

2. λ= 222 nm. Excimer lamps.

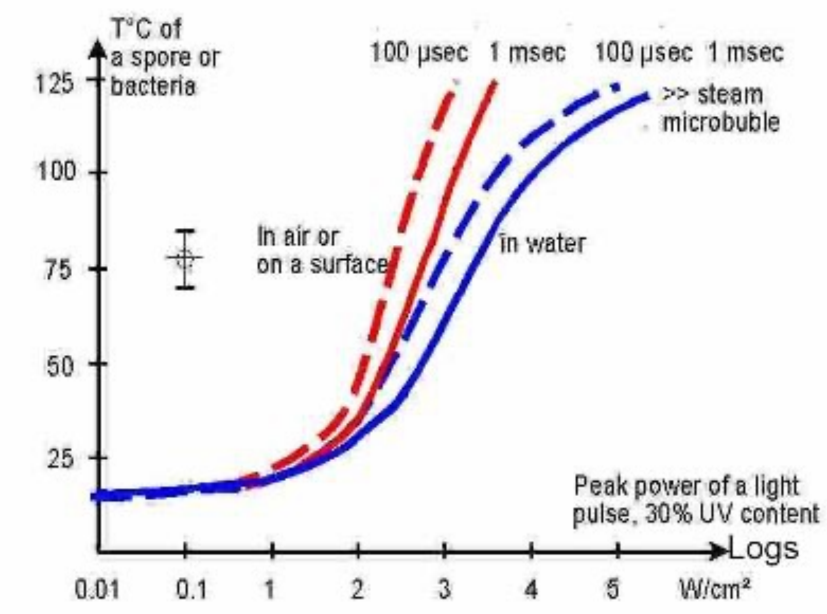
3. UV diodes.

PULSED UV RADIATION - OVERHEATING of MICROORGANISMS

Visible radiation does not significantly contribute to the heating of microorganisms.
When the total power density of UV radiation in the spectral ranges A, B, C is higher than the threshold, the rate of radiant energy supply exceeds the rate of discharge of thermal energy by the microorganism into the environment, and the microorganism overheats to a temperature of more than 130C, leading to its disintegration. Overheating depends on the properties of the environment. In water, the radiation power is higher than in air.



Aspergilus.Niger spores before and after irradiation with two pulses with a peak UV power of 33 kW/cm^2.



Calculated heating temperatures for the e-coli bacterium depending on the peak power density of UV radiation in air (red lines) and in water (blue lines) for a pulse of 100 microseconds and 1 ms.

To overheat e-coli bacteria, a peak radiation power density of 1 kW/cm^2 in air and 10 kW/cm^2 in water is required on the treated surface.

It is possible to sterilize food products, biological solutions, medical materials with UV radiation from the A and B range, if harsh radiation from the C range is not applicable. Sterilization of samples inside the package.

Capability of pulsed UV

For a pulse power of 1 MW, the overheating disinfection mechanism is ineffective at distances of more than 20 cm.

At a distance of more than 1 m, peak power is not significant, only UV dose is needed to destroy DNA.

It is possible to sterilize food products, biological solutions, medical materials with UV radiation from the A and B range, if harsh radiation from the C range is not applicable.

Special conditions when mercury is prohibited.

Pulsed Xenon Lamp vs. UV amalgam Lamp sanitation of glass cups

Alex Wekhof, SteriBeam Systems

99,99% sanitation B. Subtilis moving glass cups
(3000/h, diameter 8 cm, height 8 cm, speed 7,5 cm/s).
UV dose 250 mJ/cm² (bottom), 1900 – cup entry


	1 Pulsed Xenon Lamp, Length - 40 cm, 500 J/pulse, 2 pps, UV - 12% (total - 11 pulses)	2 amalgam Lamps, UV 30+30 W, Length 70 cm	Advantages by amalgam Lamp to Pulsed Xenon Lamp
Capital costs	€19,000	€750	1 to 25
El. power	1,5 kW (1 kW - lamp, 0,5 kW - cooling)	0,34 kW	1 to 5
El. Cost per h (0,2 €/kWh)	0.3 €/h	0.068 €/h	1 to 5
Lamp cost	€690	€440	1 to 1,6
Lamp life	1000 h	9000 h	1 to 9
Lamp cost/h	0.69 €/h	0.049 €/h	1 to 9
Operating costs/h	0.99 €/h	0.117 €/h	1 to 8,5
Operating price per sterilized cup	0,033 cent/cup	0,004 cent/cup	1 to 8
Depreciation of hardware (5y, 16000 wh)	1,25 €/h	0.019 €/h	1 to 65
Depreciation per cup	0,042 cent/cup	0,00063 cent/cup	1 to 67
Full price for a cup sanitation	0,0075 cent/cup	0,00048 cent/cup	1 to 16

Remarks on other sources of UV radiation

λ= 222 nm. KrCl Excimer lamps.

Very low efficiency 3%
High power

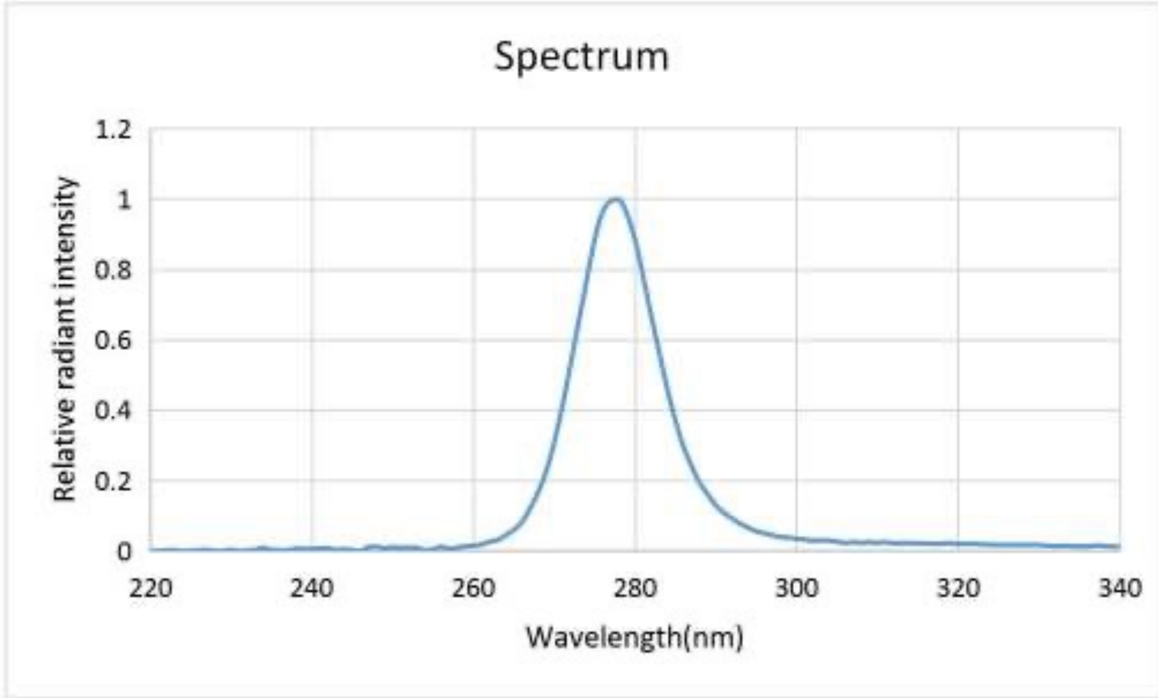
An increase in the temperature of the lamp bulb leads to a decrease in both efficiency and resource. This causes the need for forced cooling of the lamp/

Statement:

222 nm is completely absorbed by the upper layer of dead skin cells.
222 nm does not reach living cells in the epidermis layer.
222 nm does not cause skin cancer/
Conclusion based on what?
What can happen to the eyes or skin in 5 or 10 years?

A very dangerous path!

UV diodes :
InGaN, 265-275 nm, 2.5 mW



Very low efficiency 3%
Low UV power
Can be used for laboratory tests
High heat dissipation and high temperature gradients reduce UV efficiency

WATER UV DISINFECTION

DRINKING WATER

WASTEWATER

WATER REUSE

WATER UV DISINFECTION

SWIMMING POOLS

PHARMACEUTICAL INDUSTRY

FISH FARMS

FOOD INDUSTRY

MICROELECTRONICS

OIL&GAS INDUSTRY

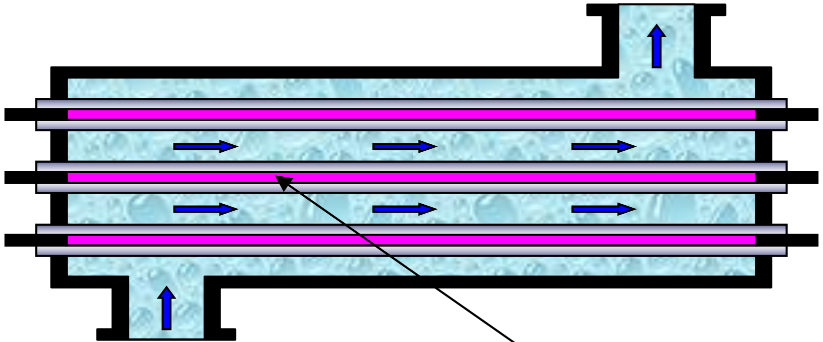
DRINKING WATER: DISINFECTION METHOD COMPARISON

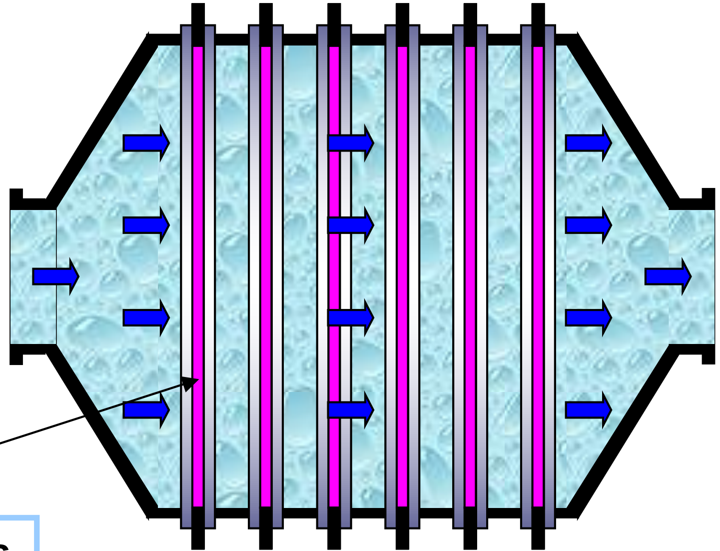
Disinfection method	Advantages	Disadvantages
Chlorine gas Cl_2	• Effective against bacteria • Medium long term effect • Low operation cost	• Ineffective against protozoa • By-product formation (THM) • Environment and explosion hazard
Hypochlorite NaClO	• Effective against bacteria • Medium long term effect • Low operation cost	• Ineffective against protozoa • By-product formation (THM) • Water quality dependence
Chloramines NH_2Cl, $NHCl_2$, NCl_3	•No by-product formation • Effective against biofilms • Relative low operation cost	• Ineffective against bacteria and protozoa • Water quality dependence
Ozone O3	• Effective against bacteria and protozoa • Increase water quality	• High capital and operation costs • No long term effect • By-product formation • Poison
UV	• Effective against bacteria and protozoa • No by-product formation • Medium operation cost • Environment friendly	• No long term effect

LOCATION OF UV LAMPS RELATIVE TO THE FLOW

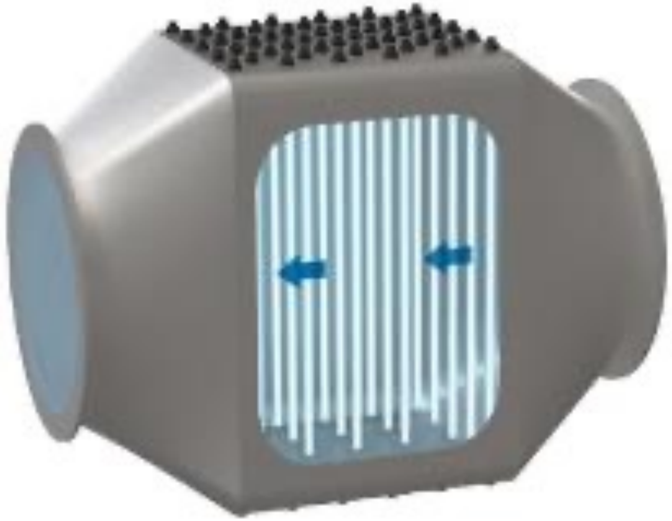
Lamps along the (air or water) stream. Longitudinal flow.

Lamps across the (air or water) stream. Cross-flow.





UV lams in quartz sleaves



FROM SMALL CAPACITY UV UNITS TO LARGE TREATMENT PLANTS

BASIC | **ADVANCED** | **MASTER**

Power Consumption: 340 W | **730 W** | **3700 W**

DRINKING WATER: ST. PETERSBURG, RUSSIA.

North WTP 1,584,000 m^3/day

UV unit.

216 amalgam lamps DB 350

North WTP.
18 units

Hepatitis A rate drastically reduced from 124 to 3.3 per 100,000 persons (according to Ministry of Health Report)

DRINKING WATER:
EU'S LARGEST UV DISINFECTION SYSTEM
BUDAPEST, HUNGARY 600,000 m^3/day
5 UV units LIT

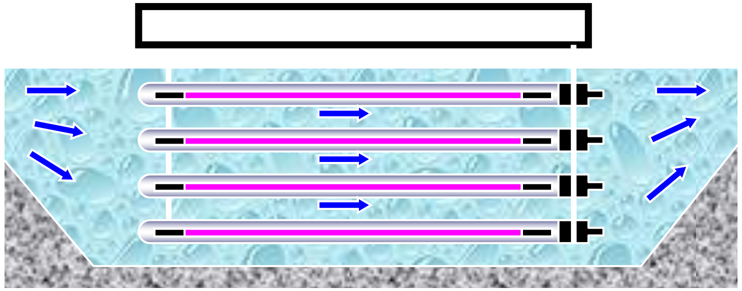
WASTE WATER: CLOSED UV UNITS

UFA city, Russia. 3 UV units UDV-216A.

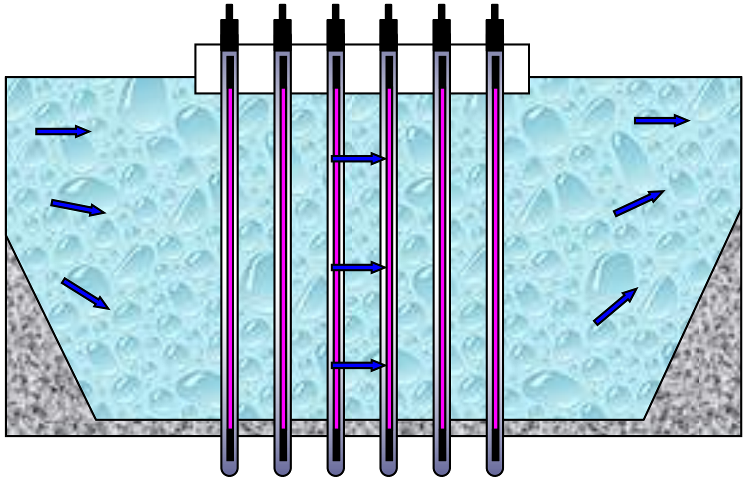
UV units UDV-216A: Capacity 3600 m^3/hr. 216 UV lamps DB 300

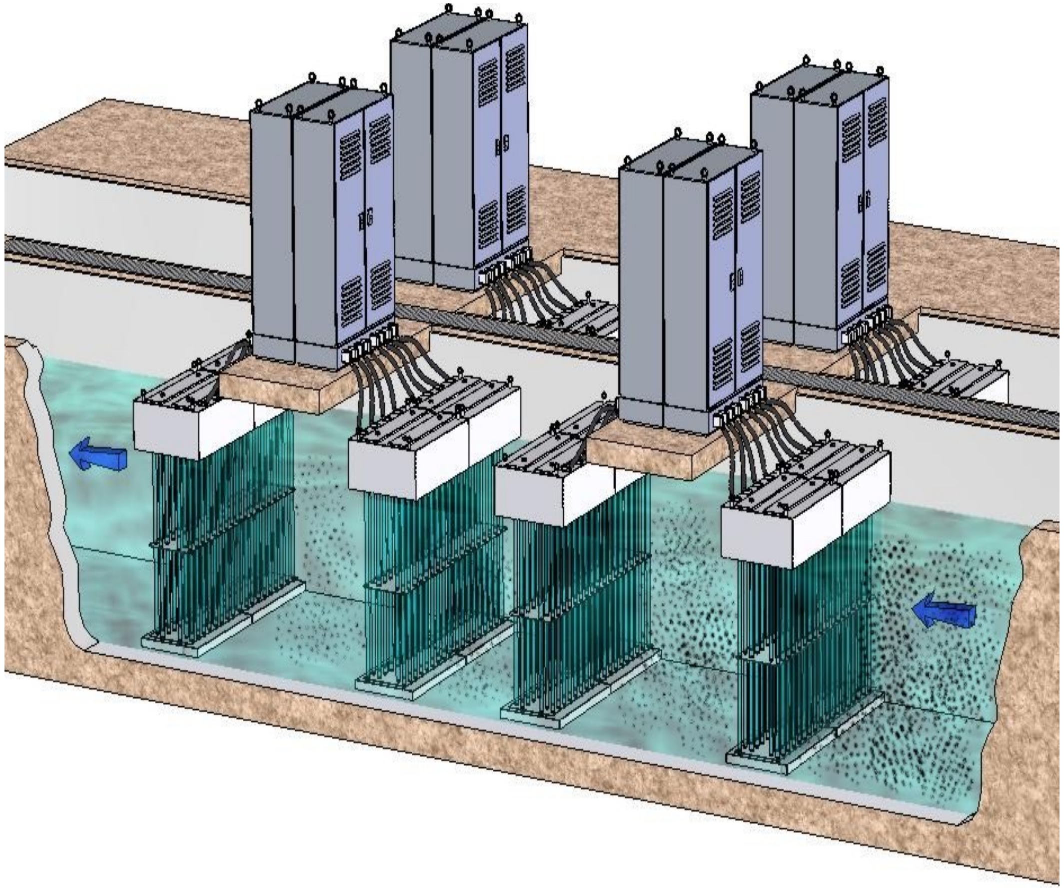
WASTE WATER: OPEN CHANNEL UV SYSTEMS

Lamps along the stream.
Longitudinal flow.



Lamps across the stream.
Cross-flow.

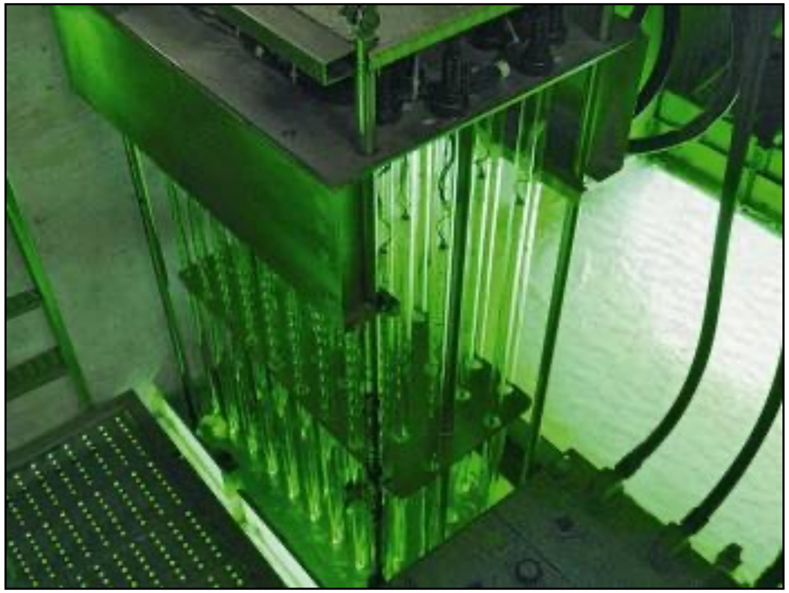




WASTE WATER: MOSCOW WWTP.

ASIA AND EUROPE'S LARGEST UV SYSTEM.

3,125,000 m^3/day (180,000 m^3/hr)



17 channels,
170 UV units,
6,120 lamps
DB600

ODOR REMOVAL UV SYSTEMS

WASTE WATER TREATMENT PLANTS

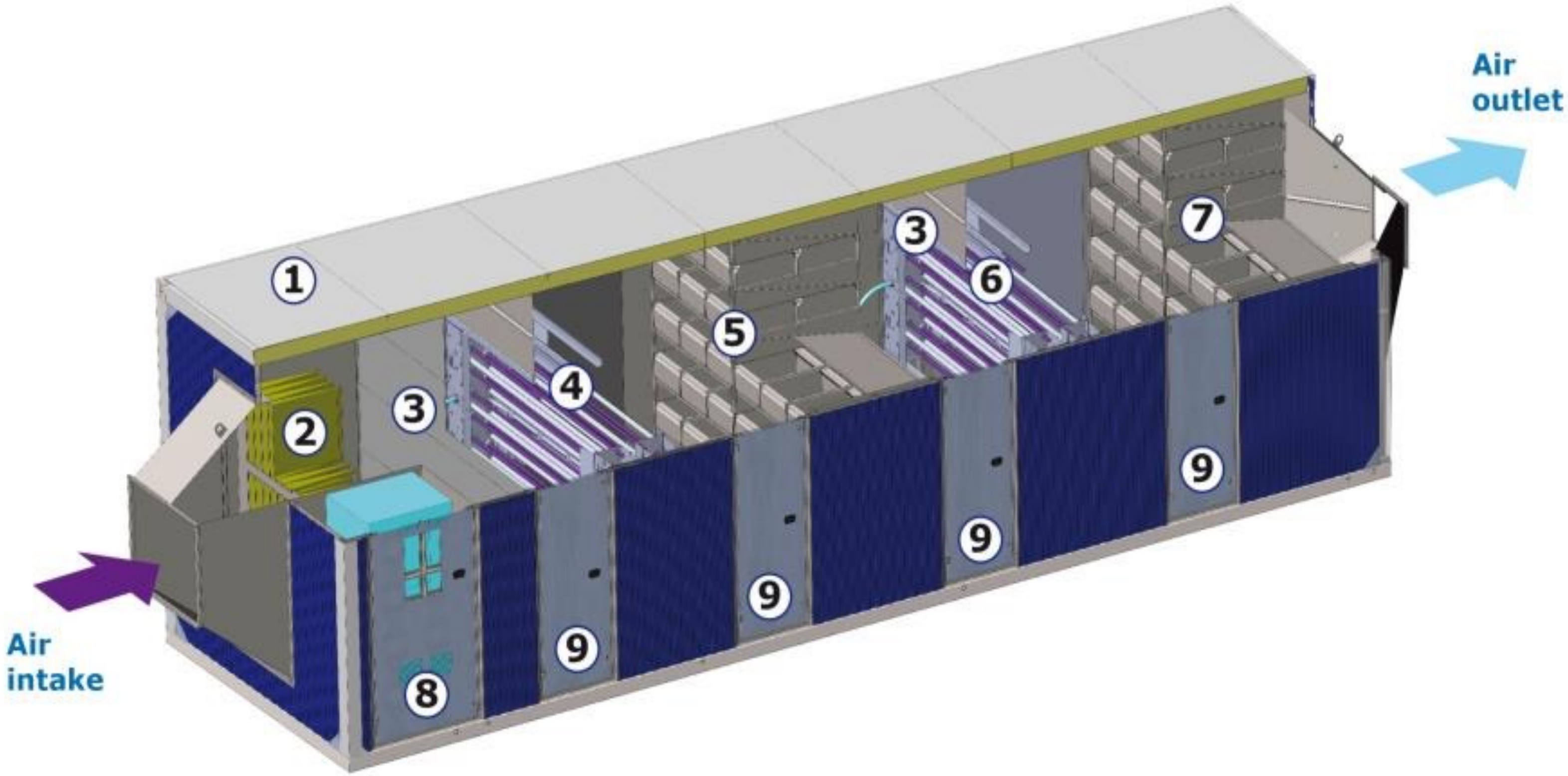
FOOD INDUSTRY

PAINT MANUFACTURING

The main odor causing substances:

- **Hydrogen sulfide**
- **Mercaptans**
- **Ammonia**
- **Formaldehyde**

ODOR REMOVAL EQUIPMENT. LIT



① Container
② Aerosols and suspended solids pretreatment system
③ Baffle plate
④ 1st UV section
⑤ 1st section of catalytic medium
⑥ 2nd UV section
⑦ 2nd section of catalytic medium
⑧ Service door of control cabinet
⑨ Service door

Oxidation of hydrogen sulfide H_2S by UV light (special lamps 185 nm + 254 nm)

Model:

73 Reactions:

$O_2 + 185\ \text{nm} \rightarrow O + O$ $\quad\quad$ $O + O_2 \rightarrow O_3$

$O_3 + 254\ \text{nm} \rightarrow O_2 + O$

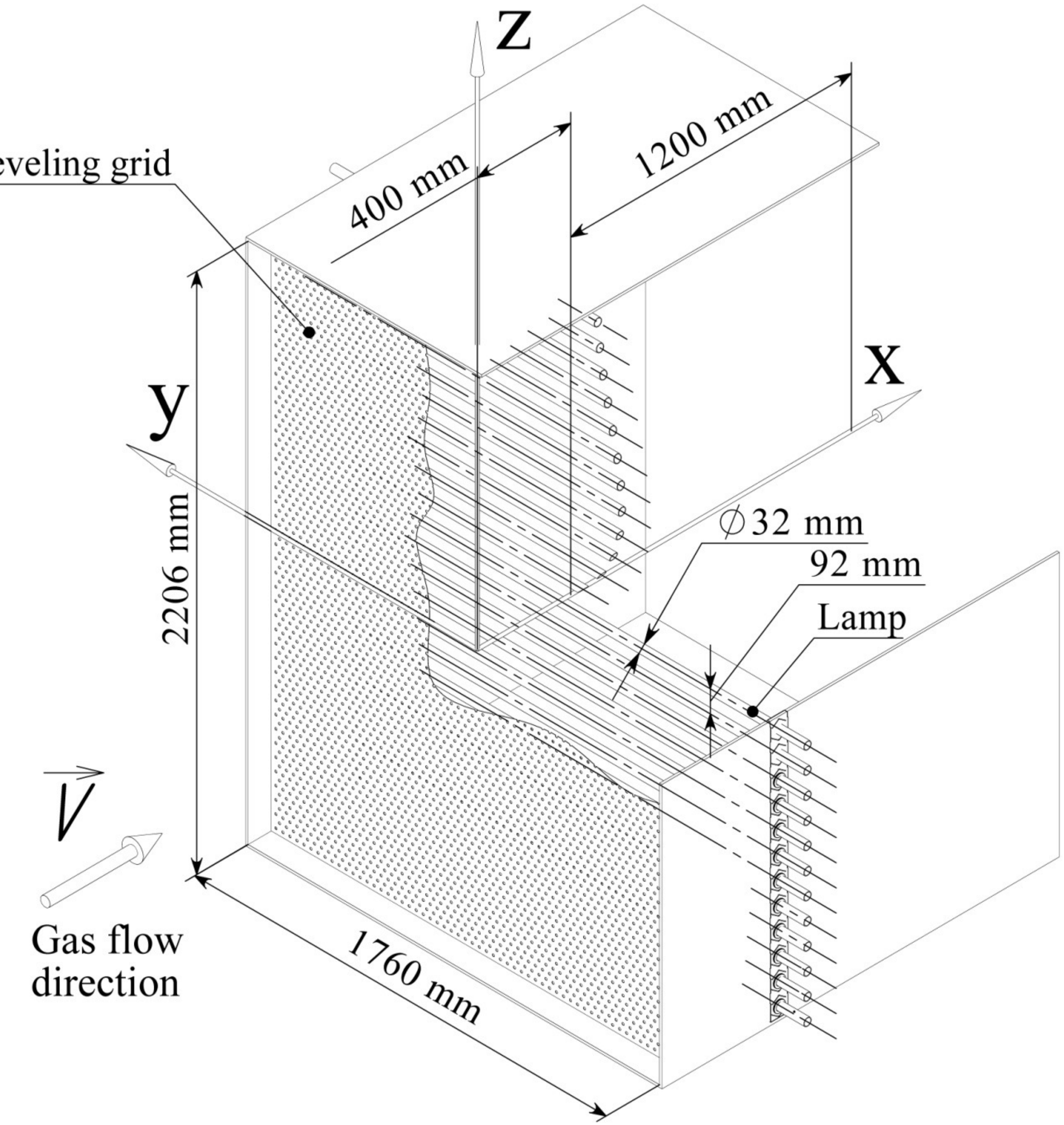
$H_2O + 185\ \text{nm} \rightarrow H + OH$

$H + H_2O \rightarrow H_2O_2$

$H_2O_2 + (254\ \text{nm}) \rightarrow OH + OH$

The free path length λ185 nm in humid air is 10 cm .
The numerical simulation “Chemical Workbench 4.2”

Oxidation of H_2S by UV light 185 + 254 nm



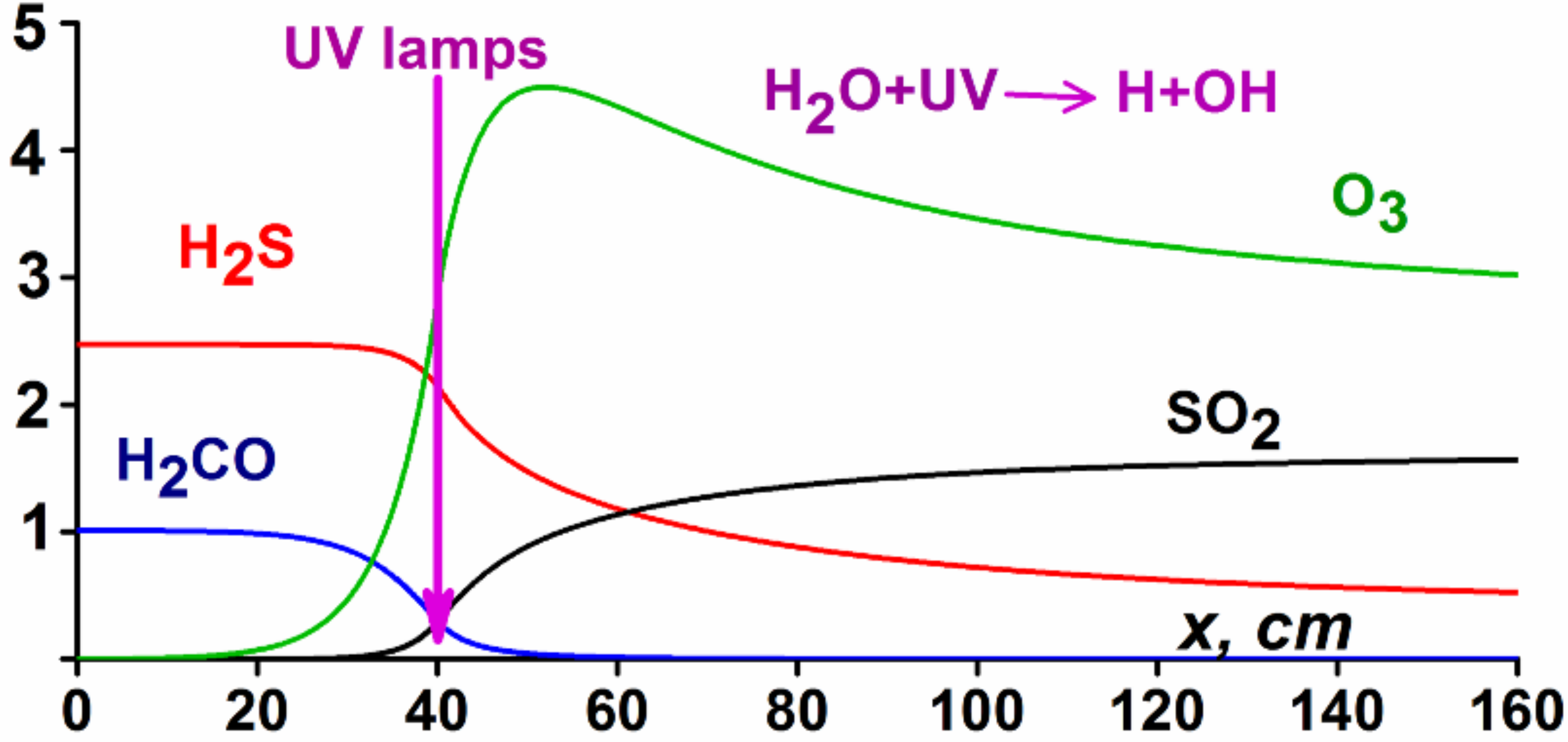
Oxidation of H_2S by UV light 185 + 254 nm. Model and Experiment.

Amalgam lamps 620 W – 24 units.
Lamp UV output was 32 W for 185 nm and 200 W for 254 nm
The total UV output of all lamps was 768 W for 185 nm and 4800 W for 254 nm.
Air flow 5000 m^3/hour, pressure of 1 atm.

M.G. Bryukov, L.M. Vasilyak et al. //J PHYS CHEM A, 2020. V. 124. P.7935

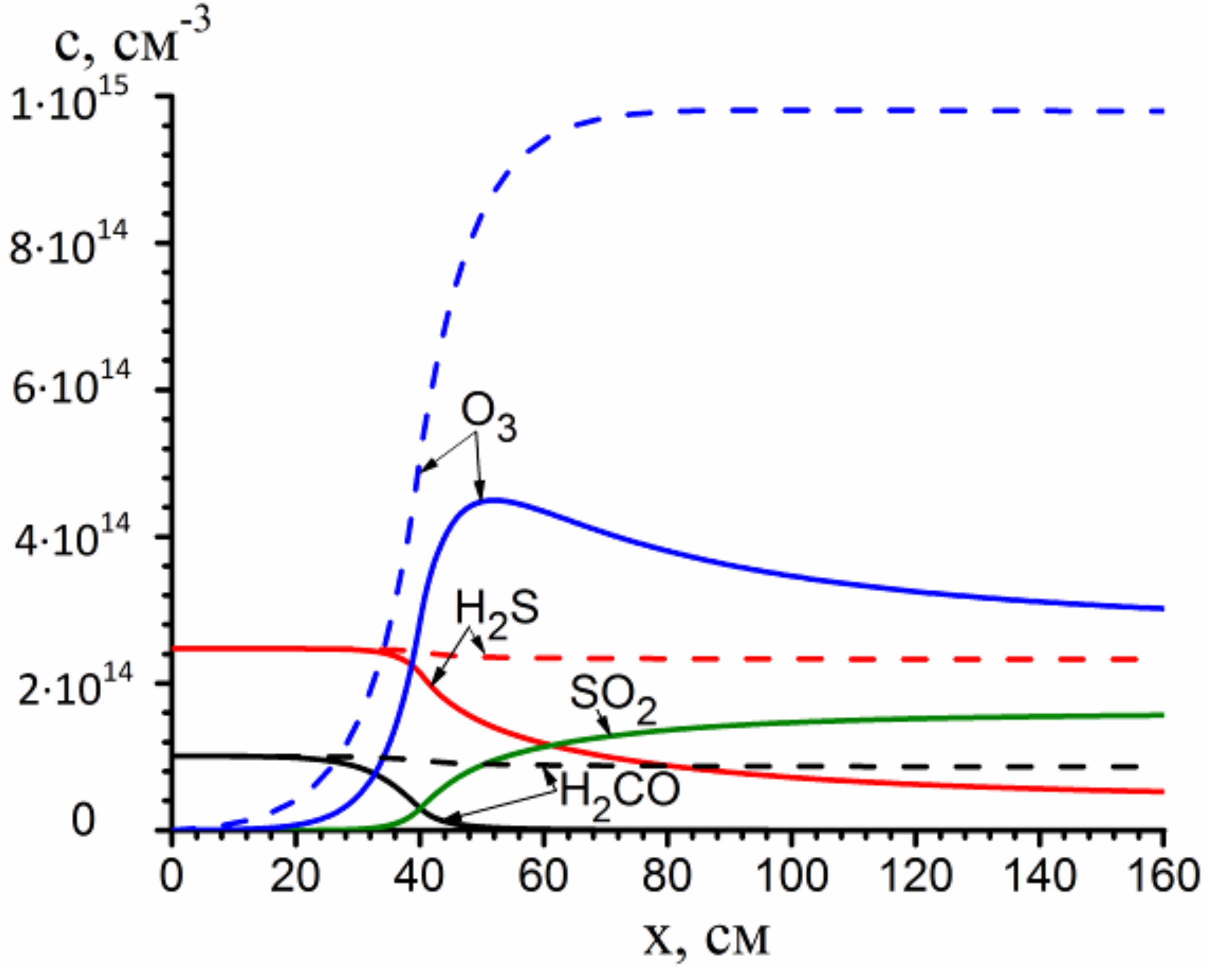
24 tubular low pressure amalgam lamps ANO 680/189 produced by LIT were placed in the cross section of the reactor at a distance of 40 cm from its entrance. The length of the lamp radiating column was 176 cm and diameter was 3.2 cm. The lamp axes were located at a distance of 9.2 cm apart.
The lamp power consumption was 620 W, the UV output was 32 W for a wavelength of 185 nm and 200 W for a wavelength of 254 nm. The total UV output of all lamps was 768 W for 184.95 nm and 4800 W for 254 nm.
Simulation at the flow rate of 4920 m^3/hour, pressure of 1 atm, temperature of 20 °C, and relative humidity of 90 and 0 %.

Oxidation of H_2S by UV light 185 nm + 254 nm. Calculation with H_2O. Humidity of 90%

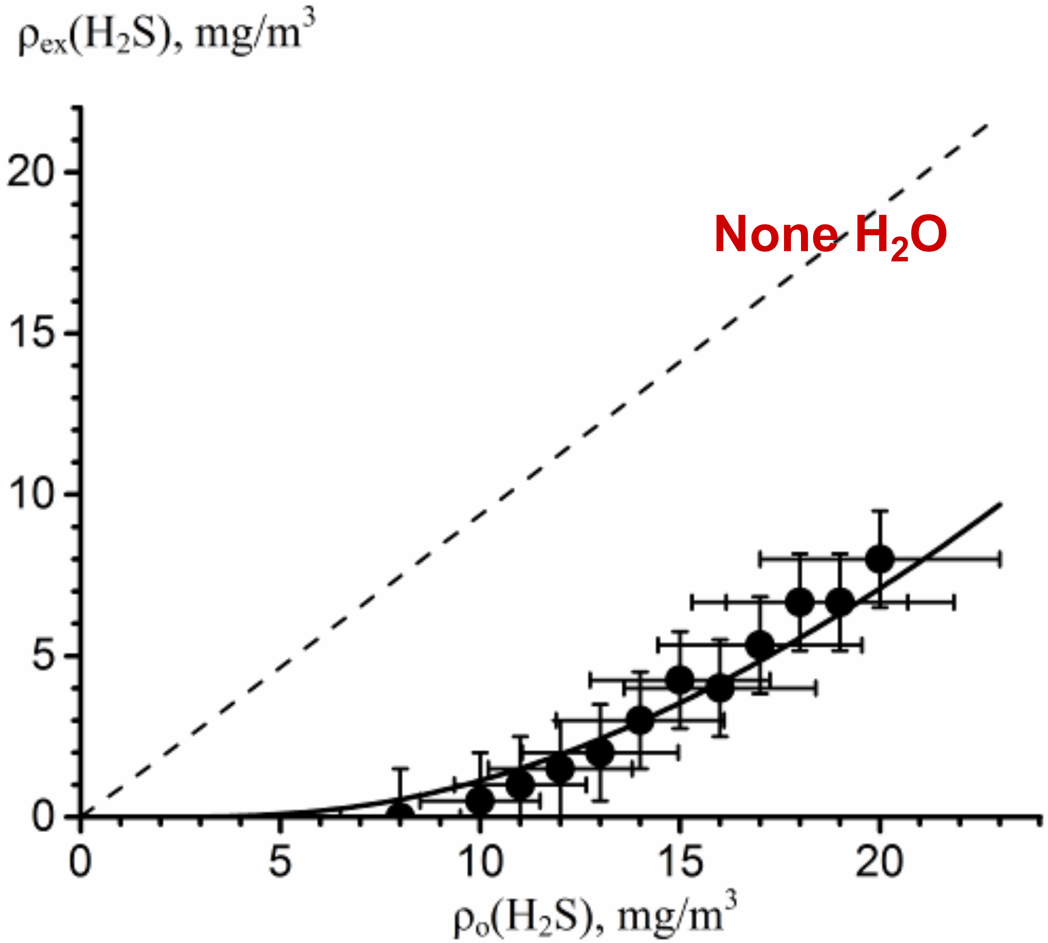


M.G. Bryukov, L.M. Vasilyak et al. // J PHYS CHEM A, 2020. V. 124. P.7935

Oxidation of H_2S by UV light 185 nm + 254 nm. Calculation. None H_2O.



Oxidation of H_2S by UV light 185 nm + 254 nm. Calculation and experiment.



Dependence of the H2S concentration at the reactor outlet ρex(H2S) on its concentration at the reactor inlet ρo(H2S). Circles - experiment; solid and dashed lines - numerical simulation at the relative humidity of air 90% and 0%, respectively.

VENTLIT INDUSTRIAL UNITS.

MOSCOW WASTE WATER TREATMENT PLANT

55 units, total 500,000 m^3/h of air $+H_2S$ 30-60 mg/m^3

LIT

Thank you for attention