

PAPER ID: 11A10J



PHOTOCATALYTIC METHOD OF DISINFECTION OF INDOR AREAS WITH INCREASED MICROBIAL CONTENT

V.S. Shkrabak¹, E.I. Gavrikova², R.V. Shkrabak¹, Yu.N. Braginec¹,
V.F. Bogatirev¹, A.P. Savelyev³, O.A. Bykova⁴

¹ Department of Safety of Technological Processes and Production, St.Petersburg State Agrarian University, RUSSIA.

² Department of Feeding, Orel State Agrarian University named after N.V. Parakhin, RUSSIA.

³ Department of Feeding, National research Mordovian State University. N. P. Ogareva, RUSSIA.

⁴ Department of Feeding, Ural State Agrarian University, RUSSIA.

ARTICLE INFO

Received 06 January 2020
Received in revised form 23
February 2020
Accepted 01 April 2020
Available online 16 April
2020

Keywords:

Agro-industrial complex;
Microbial content; Indoor
area disinfection;
Photocatalytic
disinfection;
Piezoelectric ceramic
element; Ultra-violet
radiation.

ABSTRACT

The great attention is paid to health protection of agricultural laborers specified with peculiarities of the social-economic level; the labor losses degree as well as determined with morbidity with a temporary disability, technical capacities availability, financial soundness, and some other factors. Sustained employment of agricultural laborers workplaces is with the increased microbial content induces the disease growth. It requires some measures on their health protection and promotion. In the capacity of the active substance for pathogenic microorganisms inactivation, we examined reactive oxygen species which generate photosensitizers at the photodynamic effect. Antimicrobial photodynamic disinfection is a relatively new direction in workplace air sanitation of the agro-industrial complex, but on its background, considering the research load devoted to this problem the effective disinfection methods can be developed. As a germicide, we used the composition based on furocoumarin and the exposure was carried out with near-UV radiation (UV radiation with wavelength 320-400 nm). The spraying and radiation were performed for 5-10 minutes per day within 15 days using the developed photocatalytic air cleaner. Before disinfection, we determined common microbial air impurity according to the original method, using the empirical graph dependence of electric conductivity of the thermostate solution of the nutrient medium with microorganisms from microorganisms number. From the experiment results, the decrease of general microbial content at the average of by four times was observed.

Disciplinary: Microbiological Environmental Hygiene, Health Sciences.

©2020 INT TRANS J ENG MANAG SCI TECH.

1. INTRODUCTION

The potential development of common and professional diseases of the agro-industrial complex laborers resulting in temporal as well as sustainable losses of their work capacity is in direct relationship to harmful labor conditions, particularly, to negative parameters of workplaces microclimate [1].

The hot topic in the sphere of labor protection is the application of innovations of modern science and technology specially directed search for active compounds and substances to struggle with microbial content [2], provided with the increase of pathogen strains resistibility to antibiotics of different action spectrum and formation, reluctant to eliminations of biofilms from bacterial colonies [3]. One of the solutions to this problem is the possibility to use single oxygen obtained in the photocatalysis process, as bactericide agents, and in correspondence with it, search and synthesis of new compounds –photosensitizers and study of their antibacterial properties.

The result of microorganisms' adaptation to the ambient conditions is the absence of facilities use effect for their disinfection. The bacteria resistance to antimicrobial agents led to the indication of the fundamental up to date problem – the search for the alternative means and methods of protection from bacterial infection, in relation to which bacteria during the long period will not be able to acquire resistance.

Everywhere applied for the last hundred years often without obvious necessity, antibiotics practically lost their efficiency. In this regard, the necessity in the combined approaches application the pathogenic microorganisms elimination increases.

Photocatalytic air disinfection is an application of photosensitizers, excited with the light of the definite wavelength. During the excitement the waves transfer the energy to molecular oxygen, after this the formation of active oxygen intermediates takes place, in particular single oxygen, which is able to abolish bacteria, oxidizing their intracellular structures, necessary for their life activity support [4-5].

Antimicrobial photocatalysis is one of the comparatively new trends of protection from bacterial contamination; however, it has already demonstrated the variety of advantages in comparison with other methods of deactivation of pathogen microorganisms: considerable activity relatively gram-positive and gram-negative bacteria [6]; capacity to influence locally with radiation on the necessary area or object.

Photosensitizers are not toxic substances by themselves. When getting into the organism to start photochemical reactions with a cell-target they need light, herewith all substances have their own «absorption peak» - a short range of wavelength, where the performance of photoreactions considerably increases.

The variety of advantages of antimicrobial photocatalytic air disinfection in comparison with the conventional disinfection methods is determined:

- the minimum time for disinfection;
- the detected efficiency is not in the direct relationship to resistance to the well-known antibiotics;
- the unmarked resistance to photosensitizers after the repeated processing;
- the target-microorganisms variety [7].

At the end of the last century as a result, of the numerous investigations, it was stressed that susceptibility to photo influence of gram-positive and gram-negative bacteria is different.

Gram-positive bacteria form connections with neutral, anionic and cationic photosensitizer molecules and gram-negative bacteria – with neutral or cationic ones in combination with the substances damaging cell membranes [8].

According to some scientists' opinion, the usage of special devices helps to increase the outer membrane penetration of gram-negative bacteria for photosensitizers inside bacteria [9].

The heterogeneous sensitivity of bacteria to photosensitizers is determined with some difference in their structure. Since peptidoglycan and lipoteichoic acid form the sponge structure of the cell wall of the cytoplasmic membrane of gram-positive bacteria, photosensitizers easily establish the connection with it. Gram-negative bacteria possess doubled shells out of outer cytoplasmic membranes, which provides them with an increased penetration barrier.

The outer membrane is the main barrier for penetration of the variety of substances into a cell. Chitin and beta-glucan form a considerable layer in the cell walls of pathogen fungi. Within this context, their penetration value is intermediate between the penetration of gram-positive and gram-negative bacteria.

The negative charge of outer membranes of pathogen bacteria and fungi explains the fact that positively charged molecules will be for antimicrobial treatment with the general photosensitizers of the multifaceted action spectrum.

In this regard, many papers devoted to the investigation of the germicidal efficiency of the substances of different nature in relation to gram-positive and gram-negative bacteria for the purpose of their usage for antimicrobial photocatalytic treatment are published [8].

2. RESULTS AND DISCUSSION

We took air samples to determine its bacterial contamination before and after photocatalytic air disinfection, herewith we determined general microbial contamination by the original method [11].

We used as the nutrient medium for inoculation 1% sterile solution of glucose based on 0.9% saline. The nutrient medium was introduced into the Zaytsev absorbent with aspirator «Briz-1».

The aspirator was switched on for 15 min in the working range of the indoor area. Penetrating through glucose solution the air bacterial flora stuck in the solution, which was placed into the vial and was maintained at the temperature of 37°C for two hours.

At the preset temperature mode, bacteria digested glucose and evolved acid metabolic byproducts, resulting in solution conductivity change. Then, we measured the solution conductivity by sensor KDS-1038. The number of microorganisms in the working range is determined according to the graph of the empirical dependence of the solution conductivity from bacteria number, plotted by the values, available from experiments.

The duration of the suggested method of the air microorganisms determination is 4 hours 20 min, which is significantly less the time spent as a result of the application of the standard method.

For disinfecting treatment of the air working range in the indoor areas at the potential presence of people, we suggested the method of the photocatalytic air disinfection.

The following methods of air sanitation were examined as analogs at the suggested method development.

The solution of the extract of steroidal saponins, sodium benzoate, and zedoary oil was sprayed in the air of the working range of the stock building [12]. However, this method disadvantage is the

usage of sodium benzoate (E 211), applied in the aerosol form. The results of the carried out experiments proved that systematic breathing in of sodium benzoate (E 211) in the aerosol form leads to anemia development, blood abnormality, at which point, to acute exacerbation of chronic disease [13]. It is known from the literature about such property of sodium benzoate as producing the cumulative effect with the delayed negative effect of the influence on the tested person organism as a whole.

It is known, that coumarine is used for growth inhibition of microbiocenosis – biofilms [14]. The notorious method disadvantage is its underperformance at indoor area disinfection.

Also, the method of disinfection and air cleaning, which includes the spraying of the bactericide 20-30% freshly prepared water extract of coniferous trees was studied, herewith the sprayed preparation was exposed to UV-irradiation (the RF patent №2068706) [15]. The notorious method disadvantage is the necessity to use freshly prepared water extract of coniferous trees.

For simplicity and intensification of the process of disinfecting air treatment of indoor areas, it was necessary to increase the antimicrobial activity of the reactant during light exposure, in which spectral range corresponds to the electronic absorption spectrum of the reactant, at the treatment time reduction.

As the bactericide, we used the composition containing by weight from 0.0001 to 100% of the photosensitizer – furocoumarine or its derivatives, the rest were the neutral components or other substances, intensifying activity of the given composition. The exposure was performed with UV-irradiation with the wavelength of 320-400 nm; the spraying and irradiation were carried out for 5-10 min. per day for 15 days.

Furocoumarines (furanocoumarines = coumarone- α -pyrone) are natural organic oxygen-containing compounds, in which the furan ring is condensed with coumarine (benzol and pyrone rings). These structural class representatives are substances with high reactivity: angelicine, psoralen, etc.

As the main reactant, furanocoumarines are typical for the representatives of the umbellifer family plants and the citrus subfamily, at that according to the phytochemical testing, roots, fruit and seeds contain a considerably greater number of phenolic group compounds, than leaves and stems. The peucedanum derivatives – vegetative furocoumarine, extracted from Peucedanum Morisoni (perennial herbaceous plant of the umbellifer family), possess antimicrobial activity. As a result of the investigations [16], it was proved, that the inhibitive influence of the furocoumarines, extracted from grapefruit juice, on the process of formation of biofilms *Escherichia coli*, *Salmonella typhimurium*, and *Pseudomonas aeruginosa*.

The method was realized in the following way. Furocoumarine water mixture (preparation «Ammifurin») at a concentration of 0,00226 M was sprayed in the air of the indoor area using the photocatalytic air cleaner developed by us.

Figure 1 presents the scheme of the device developed by us; Figure 2 presents the electric scheme of power source; Figure 3 -- the electric scheme of the working fluid level warning device with the UV-source.

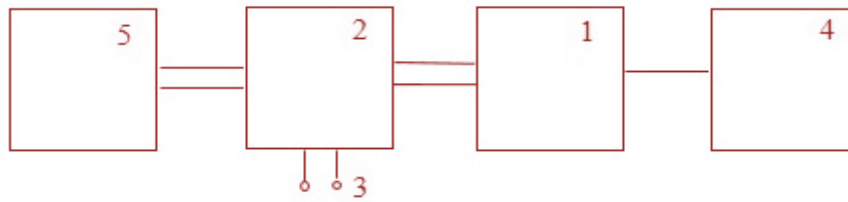


Figure 1: device scheme.

1 – electric oscillation generator, 2 – power source, 3 - clips,
4 – sonic transmitter (piezoelectric element), 5 – working fluid level warning device.

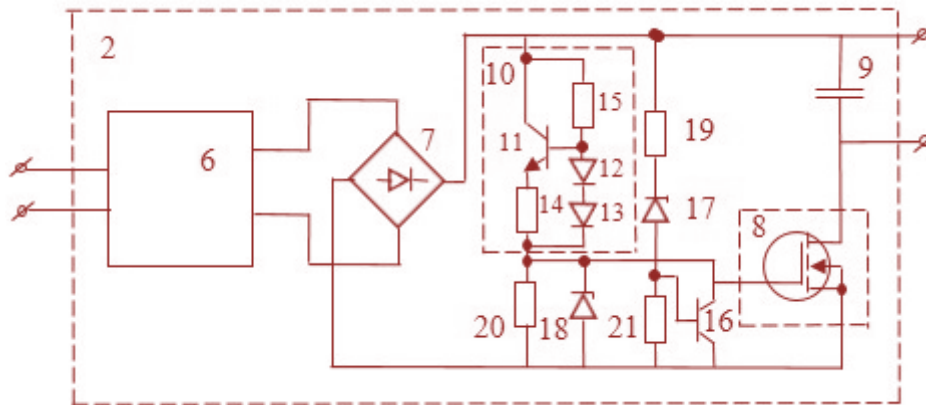


Figure 2: Electric scheme of power source.

2 - power source, 6 – inductive-capacitive power supply filter, 7 – rectifier bridge, 8 – power key, 9 – storage capacitor, 10 – current stabilizer, 11, 16 transistors, 12, 13 - diodes, 14,15, 19, 20, 21 - resistors, 17, 18 – stabilitrons.

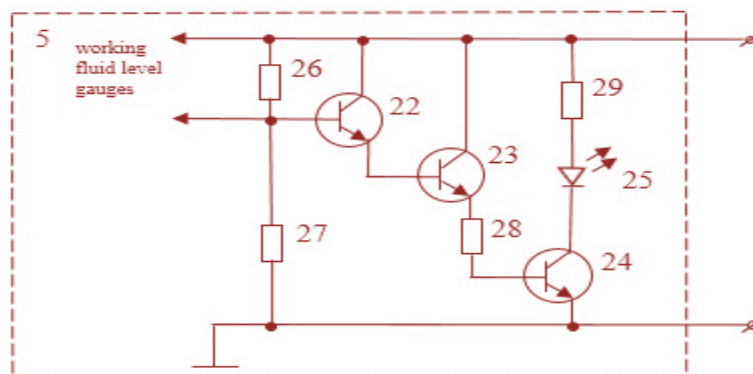


Figure 3: Electric scheme of the working fluid level warning device with the UV-source.

5 - working fluid level warning device, 22, 23, 24 - transistor,
25 – UV-light emitting diode, 26, 27, 28, 29 - resistors.

Photocatalytic air cleaner (Figure 2) contains generator 1 of electric oscillations, power supply source 2, clips 3, hermetically sealed sonic transmitter 4 (piezoceramic element), working fluid level warning device 5, connected according to the composite transistor scheme.

Power supply source 2 (Figure 3) contains inductive-capacitive power supply filter 6, rectifier bridge 7, power key 8, storage capacitor 9, current stabilizer 10 (connected on transistor 11, diodes 12, 13, resistors 14, 15), transistor 16, stabilitrons 17, 18, resistors 19, 20, 21. Stabilitron 18 is intended for voltage limitation on the lock-source junction of transistor 8.

Working fluid level warning device 5 (Figure 4) contains working fluid level gauges (not presented in Figure 4), transistors 22, 23, 24, UV-light emitting diode 25, resistors 26, 27, 28, 29. Resistors 26, 27 are intended to generate the bias voltage based on transistor 22, necessary to provide steady operation of warning device. Resistor 28 is necessary to limit the current flowing via transistors 23, 24; resistor 29 is necessary to limit the current flowing via light-emitting diode 25.

The photocatalytic air cleaner operates in a flowing way. Sonic transmitter 4 is plunged into the with working fluid container, connected with an electric power supply source 2, which clips 3 are connected to any current source.

Piezoelement deformation is performed under the influence of high-frequency signals and results in aerosol formation.

When the sensors are plunged into working fluid, the resistance on base-collector of transistor 22 is low, the potential on its base is high, and this results in its opening. Correspondingly transistors 23 and 24, therefor switching on UV-light emitting diode 25. At a decrease of the working fluid level, resistance on the transition base-collector of transistor 22 increases, effectively the positive potential on its base increases, resulting in the closing of transistor 22 and correspondingly transistors 23 and 24. UV-light emitting diode 25 switches off.

Therefore, in the presence of the working fluid, it is subjected to the UV-radiation, and in the absence of it, the UV-light emitting diode switching off indicates the necessity to replenish the container with the solution.

Air bacterial content is recorded before and after disinfection. During the process of photocatalytic treatment, the decrease of common microbial content was registered (Table 1).

Table 1: Air bacterial content at using the photocatalytic disinfection (Total Microbial Count, CFU/m³)

Case	Sampling interval			
	Before treatment	in 1 day	on the 8th day	on the 15th day
Control	380	382	385	370
Test	380	320	210	135

According to the test results, the decrease of common microbial content at the average of by 4 times is registered.

3. CONCLUSION

Optimized conventional stages and methods of the microbial practice, such as the aspirating air sampling method, thermostatic control with the observance of optimal conditions and selection of nutrient media, recording of the obtained colonies, provided the basis for the developed methodology of determination of microorganisms number in the working range of the indoor area. It permitted to reduce considerably the time of obtaining results. The suggested model of the photocatalytic air cleaner gives the opportunity for simultaneous UV-treatment and expenditure control of working fluid and preparations. The investigation results testified that after the application of the suggested method of photocatalytic air disinfection the level of the microbial content of the treated indoor areas decreased considerably. Thus, successively carried out experiment stages to provide well-timed control of microorganisms concentration in the working range air and fulfill the necessary disinfection efficiently.

4. AVAILABILITY OF DATA AND MATERIAL

Information can be made available by contacting the corresponding author.

5. REFERENCES

- Shkrabak R.V., Shkrabak V.S., Frolova N.N., Davlyatshin R.Kh., Shkrabak A.V. Socio-economic aspects of safety problems of life activity and the effective ways of their solution / R.V. Shkrabak, V.S. Shkrabak, N.N. Frolova, R.Kh. Davlyatshin, A.V. Shkrabak // Protection and labor economics. 2017. 3(28), 12-19.
- Gavrikova E.I. Development of the disinfection devices, intended for washing and sanitation of protective over garment / E.I. Gavrikova. Bulletin of Saratov State Agro University named after N.I. Vavilov. 2013. 4, 59-62.
- Romanova Yu.M., Smirnova T.A., Andreev A.L., Ilyina T.S., Didenko L.V., Gintsburg A.L. Biofilms formation – an example of «social» bacteria behavior / Yu.M. Romanova, T.A. Smirnova, A.L. Andreev, T.S. Ilyina, L.V. Didenko, A.L. Gintsburg // Microbiology. 2006, 75(4), 1-6.
- Mroz, P., Hamblin, MR. Advances in photodynamic therapy: basic, translational and clinical. Artech House; Norwood: 2008.
- Liyi H., Yi X., Yuichiro K., Zhiyentayev T., Masamitsu T., Hamblin M.R. Type I and Type II Mechanisms of Antimicrobial Photodynamic Therapy: An In Vitro Study on Gram-Negative and Gram-Positive Bacteria // Lasers in Surgery and Medicine, 2012, 44, 490–499.
- Xavier R.D., Ruiz-Gonzalez R.S., Dai T. Cationic Porphycenes as Potential Photosensitizers for Antimicrobial Photodynamic Therapy. J. Med. Chem. 2010, 53, 7796–7803
- Musetti C., Spagnul C., Mion G., Ros S., Gianferrara T., Sissi C. DNA Targeting by Cationic Porphyrin–Ruthenium(II) Conjugates. ChemPlusChem, Jan. 2015, 80, 158–168.
- Lauro FM., Pretto P., Covolo L., Jori G., Bertoloni G., Photoinactivation of bacterial strains involved in periodontal diseases sensitized by porphycene-polylysine conjugates. Photochem Photobiol Sci 2002, 1, 468–470.
- Bertoloni G., Rossi F., Valduga G., Jori G., van Lier J., Photosensitizing activity of water-and lipidsoluble phthalocyanines on Escherichia coli. FEMS Microbiol Lett 1990, 59, 149–155.
- Patent № 2493258 the Russian Federation, IPC C12Q 1/02, G01N 27/06 Determination method of air microorganisms number / Laktionov K.S., Gavrikova E.I.; patent applicant and patent holder Federal State Budgetary Educational Institution of Higher Professional Training Orel State Agrarian University. № 2012111034, published 2013, Bull. № 26.
- Patent № 2407547 the Russian Federation, IPC A61L 9/013, A61L 9/14 A means of disinfection and air sanitation / Reznik I. R., Ishchenko P. S., Spektr M. I.; patent holder Reznik I. R. - № 2008143151; 2010, Bull. № 36.
- Concise International Chemical Assessment Document 26, Benzoic acid and sodium benzoate, World Health Organization, Geneva, 2000, 18.
- Patent № 2616237 the Russian Federation, IPC A61K 31/37, A61P 31/04 Application of coumarine and its derivatives as an inhibitor of the system "quorum of sensing" LuxI/LuxR type in bacteria / Deryabin D. G., Tolmacheva A. A., Inchagova K. S.; patent applicant and patent holder Federal State Budgetary Educational Institution of Higher Education, Orel State University. № 2015151822, published 2017, Bull. № 11.
- Patent № 2068706 the Russian Federation, IPC A61L 9/014 Method of disinfection and air cleaning /

Priyman R. E., Visnapuu L. Yu., Pyarnaste E. E., Zakomyrdin A. A. patent applicant and patent holder All-Union Scientific Research Institute of veterinary sanitation, hygiene and ecology. № 914923913, published 1991

Girenavar B., Cepeda M.L., Soni K.A., Vikram A., Jesudhasan P., Jayaprakasha G.K., Pillai S.D., Patil B.S. Grapefruit juice and its furocoumarins inhibits autoinducer signaling and biofilm formation in bacteria. *Int. J. Food Microbiol.* 2008, 125, 204-208.



Professor Dr.V.S Shkrabak is Professor, Department of Safety of Technological Processes and Production, Faculty of Technical Systems, Service and Energy, Saint Petersburg State Agrarian University, Russia. He had a Doctor of Technical Sciences degree. His scientific interests are Dynamic Strategy to Reduce and Eliminate Injuries, Engineering and Technical Methods for the Prevention of Injuries and Accidents in the Agricultural Sector.



E.I. Gavrikova, is a Candidate of Biological Sciences. Her scientific interests are Investigation the Causes of Temporary Disability of Workers of Agro-industrial Complex; Monitor Conditions and Safety; Microbial Contamination and Disinfection of Premises; Environmental Safety.



R.V. Shkrabak, an Assistant Professor, is Head Department of Safety of Technological Processes and Production. He is a Candidate of Technical Sciences. His scientific interests are Innovative Methods and Means of Preventing Injuries and Diseases of Agricultural Workers, Forecasting the Situation and Proactive Preventive Measures.



Yu.N. Braginec is a Candidate of Agricultural Sciences. His Scientific interests: Labor Conditions and Labor Protection in Dairy Farming of Complexes and Farms of Agricultural Enterprises.



V.F. Bogatirev is Chairman of the cooperative "Shushary". Scientific interests: provision of standardized working conditions for workers in workshops for Post-Harvest Refinement of Table Root Crops.



Professor Dr.Savelyev is Professor. He had a Doctor of Technical Sciences,. His scientific interests are ensuring Technical and Fire Safety at the Agricultural Facilities.



Bykova O.A. holds a Doctor of Agricultural Sciences. Her Scientific interests: sound-absorbing constructions at Food Industry Enterprises, Vehicle Control, Microflora of Food Production, Active Compounds for Fighting Microorganisms.

Note: The original version of this article has been reviewed, accepted, and presented at the International Scientific and Practical Conference "From Inertia to Development: Scientific and Innovative Support for Agriculture" (IDSISA2020) at the Ural State Agrarian University, Ural, Russia, during 19-20 February 2020.