THEORETICAL MODEL FOR THE UV DISINFECTION SYSTEM IN THE OPERATING WARD OF PZU "FILIP VTORI"

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***Abstract* – Here we investigate the theoretical modeling of an UV disinfection system for the operating ward in PZU "FILIP VTORI". As nocosomial infections pose a serious threat to patients everywhere in the world, here the disinfection of the air and the surfaces is modeled and discussed. The surfaces are disinfected with direct illumination of open UV after hours system, UV curtains, overhead disinfection, floor disinfection and disinfection of the incoming air through the ventilation/air-condition system. From the results it can be seen that the concentrations of bacteria, fungi and viruses drop significantly which in turn should give a significant drop in a number of hospital acquired infections.**

***Keywords* – UVGI, infections, disinfection, operating room**

1. INTRODUCTION

UV disinfection has been a method for disinfecting air, surfaces and water for quite a while. Lately disinfection methods for disinfection of raw foods have been developed. Primarily for the disinfection of raw meat and clear juices through irradiation from xenon pulsing light lamps [1]. The disinfection of microorganisms is conveyed through the dimerisation of thymine in the DNA [2]. The DNA has a very narrow band of resonance frequencies which coincides with one of the highest spectral lines of excited mercury under low pressure. The spectral line of mercury is at 253.7nm. The lamps that produce this spectral line are called low pressure mercury lamps. There are also medium pressure lamps and xenon pulse lamps. All three have different applications and properties.

2. MATERIALS AND METHODS

In this project we use modeling software and also the general mathematical package Mathematica™ 7.0 by Wolfram Research. The modeling software is DIALux™ 4.8.0.1 by DIAL, GmbH, Lüdenscheid. DIALux™ is primarely used for lighting picture rendering and the primary unit of measurement there is lux. But since lux is a unit of measurement which is tied to the human sense of sight it is of no purpose in the world of UV light where the used unit of measurement is W/m^2 . Because of this, DIALux™ is used only for qualitative investigation. Namely, when a simulation is done it is used so that no shadows are created, nor large discrepancies in the irradiation field strength.

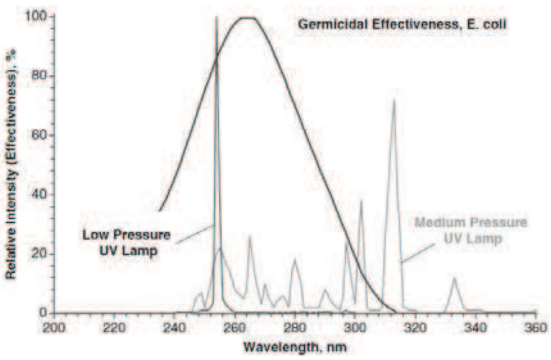

Fig.1 Germicidal efficiency of UV wavelengths, comparing High (or medium) and Low pressure. UV lamps with germicidal effectiveness for E. coli. Based on data from Luckiesh (1946) and IESNA (2000)

In the course of this research a small Mathematica™ 7.0 notebook was created which was used to calculate the irradiances at arbitrary spots on the surfaces and in the air when needed. The code is given below together with the explanation of the formulas used.

```
(*the numbers given here are
 the dimensions of a
 standard PHILIPS(TM) TUV
 light bulb with 36W power from the
 Xtra T8 Range for which
  the pure UVC power is 15W*)
Clear[x];
dol := 113.5;
r := 1.4;
H := x / r;
L := dol / r;
Y := (1 - H)^2 + L^2;
Z := (1 + H)^2 + L^2;
M := Sqrt[(H - 1)/(H + 1)];
F = L/(Pi * H) * (1/L * ArcTan[L/Sqrt[H^2 - 1]] +
     (Z - 2 * H)/Sqrt[Z * Y] * ArcTan[M Sqrt[Z/Y]] - ArcTan[M]);
Euv = 15;
Iuv = Euv/(2 * π * r * dol) * F;
x = 3;
Iuv = Euv/(2 * π * r * dol) * F
```

The constant dol is the lenght of the arc inside the tube; x is the distance from the middle of the tube; r is the radius of the tube; Euv is the power of the tube given in pure UVC watts; Iuv is the irradiance of the UVC on a perpendicular element at some distance x from the middle of the tube. This is the most important number used when calculating the survival rate of a particular microorganism.

To calculate the survival rate of a particular microorganism a constant for that microorganism must be known. For most of them these numbers can be found in reference tables. This constant is called UV rate constant, k, and its unit of measurement is m^2/J. The survival rate, S, is given by the formula

$$S = e^{-kD} \tag{1}$$

where D is the integrated UVC dose over some time. Considering that variations in the UVC output are very slow, instead of integrating we simply multiply the irradiance with the time to obtain the dose, as such

$$D=t*Iuv \tag{2}$$

The extinction rate, R, is simply

$$R=1-S \tag{3}$$

These are all the methods and formulas that we need to model the UV disinfection system for almost any space.

3. RESULTS

3.1 Direct UV irradiation of rooms

The results given here will be for the spot that is in the middle of each room respectively. There is an extensive list of measured UV rate constants for almost all known or important microorganism from which averages have been drawn [2]. From these average values we determine the extinction rates for each room and each microorganism group separately. If any extinction value falls under log10 it is automatically equaled to 100%. This method gave extinction rates for each room that were greater than log10. Since all of the numbers were 100% in consideration we put representatives from each microorganism group that are the most resistant to UV for that group. It must be noted that the method used is the one for the worst case scenario. By this it is meant that the reflectivity of the surfaces are taken to be the ones for UV, not visible light. If a reflectivity constant for some surface is unknown then it is taken to be 0%. Using this method we get numbers that are the worst that can happen. The extinction percentages are the lowest theoretically possible. In practice this means that the numbers can only be higher than these given here, thus ensuring at least the lowest known rate of extinction. The numbers were calculated for 6 hours of irradiation and are given in Table 1. The layout plan of the operating ward is given in Figure 2. On the layout plan the relative irradiances are given together with the distribution of the lamps.

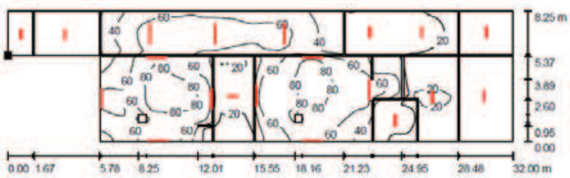

Fig. 2 - Layout plan of the operating ward

3.2 Disinfection of in-duct air

The air that enters the operating ward is supplied by a ventilation system. This system gives a positive pressure of the air inside versus the air inside, so no air from outside can contaminate the premises. In turn the air that is supplied through the ventilation system is only treated with HEPA filters which have very good results in removing micro particles. To ensure a better disinfection of the air UV disinfection system is modeled for the intake air. The lamps in this case are medium pressure mercury lamps.

Table 1. Extinction rates after 6 hours of irradiation

	Microorganism→				
Room↓	Bacteria-vegetative	Viruses-all	Bacterial spores	Fungal cells and yeast	Fungal spores
	Francisella tularensis	Bacteriophage MS2	Bacillus Subtillis	Aspergillus Niger	Aspergillus Niger
OR1	100	100	100	99.997	99.997
OR2	100	100	100	99.997	99.997
Anesthesia 1	100	100	100	98.16	98.16
Anesthesia 2	100	100	100	99.97	99.97
Hall 1	100	100	100	86.41	86.41
Hall 2	100	100	100	95.88	95.88
Hand washing	100	100	100	99.24	99.24
Storage	100	100	100	99.91	99.91
Sterilisation storage	100	100	100	99.40	99.40
Sterilisation-clean	100	100	100	97.38	97.38
Sterilisation-unclean	100	100	100	97.38	97.38
Lobby	100	100	100	97.95	97.95

There are three intake ducts. The first one supplies air at a rate of 5200 m^3/h, the second and the third one supply 7300 m^3/h. Their lengths are 1.7 m, 1.3 m and 1 m respectively. Their perpendicular dimensions are 0.35 m x 0.7 m, 0.4 m x 0.7 m and 0.4 m x 0.7 m respectively. A calculation is needed to ensure that the UV rating of these ducts is at least 20.

The exposure time of the air in each duct can be calculated through the following formula:

$$t=WHL/Q \tag{4}$$

where
W is the width
H is the height
L is the length
Q is the rate of air supply
The exposure times for the three ducts are
$t_1=0.29s$, $t_2=0.18s$ and $t_3=0.14s$.
The total irradiance is calculated with reflectivity of the internal walls of 50%.

The total irradiance is

$$I_{rtot}=I_{R1}+I_{R2}+I_{R3}+(I_{R3})^2/(I_{R2}-I_{R3}) \tag{5}$$

Using formula (6) to calculate the view factor for each reflection separately, for 1000W PHILIPS HOK 10/120L lamp it yields:

$$F = \frac{L}{\pi H}\left(\begin{array}{l} \frac{1}{L}\arctan\left(\frac{L}{\sqrt{H^2-1}}\right)+\frac{Z-2H}{\sqrt{ZY}}\arctan* \\ *\left(M\sqrt{\frac{Z}{Y}}\right)-\arctan(M) \end{array} \right) \tag{6}$$

$I_{rtot1}=3329.68\ W/m^2$

$I_{rtot2}=6659.36\ W/m^2$

$I_{rtot3}=6659.36\ W/m^2$

for each duct separately. It should be noted that the first duct has one lamp and the second and third have two lamps. The lamps are positioned perpendicular to the air flow.

Considering the exposure times for each duct the dose can be calculated.

$D_1=965.6\ J/m^2$

$D_2=1198.68\ J/m^2$

$D_3=932.31\ J/m^2$

These dose rates easily put this system in the highest possible UV rating of UVR=24

3.3 Upper room air disinfection

Upper room air disinfection is utilized in ultra high clean rooms like operating rooms which are the subject of our investigation. Due to the fact that the light is parallel to the ceiling and the systems are mounted above 2.7meters there is no harm to the personnel working in the room. They are used to continuously disinfect the air for the whole time while personnel is present. The air circulates due to convection so even if new contaminants are introduced to the room they will pass through the disinfection sector of the room.

Presently there are no guidelines for calculation of extinction rates of these systems and they are installed one in each room. The lamp inside is the standard 36W low pressure mercury lamp.

3.4 UV Curtains

UV curtains are installed above doors to create a wall of UV light that will ensure extinction of microorganisms that enter the room when the door is opened. Due to the fact that people passing the doors never stay in the UV light more than 0.5 seconds there is no need for extra protective measures for the eyes and the skin. Additionally, this means that nobody should stay under the doorframe for no particular reason. If one intends to do so, the curtain should be turned off.

Similarly to upper room systems, presently there are no guidelines for calculation of extinction rates of these systems and they are installed one in each room. The lamp inside is the standard 36W low pressure mercury lamp.

4. CONCLUSION

From the given investigation it can be seen that with the installation of properly designed UV disinfection systems concentrations of bacteria, viruses and fungi can be severely reduced. Parallel to this reduction of bacterial counts goes the reduction of hospital acquired infections which pose a serious problem not just for hospitals in third world countries but also for those in well developed countries.

Another benefit of these systems is the fact that usage of disinfection chemicals is greatly reduced and the power consumption is minimal.

5. REFERENCES

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