Fluid disinfection system based on UV radiation

A. Bazylińska[1], A. Jenei[2], J. Walczak[3], S. Küttis[4]
1 Wroclaw Univeristy of Technology
2 Obuda University in Budapest
3 Technical University of Lodz
4 Tallin University of Applied Sciences

***Abstract*—These days water treatment is a very important topic, because the world's fresh water resources are becoming limited. Every year millions of people die from a water related disease and others due to lack of access to clean water. Therefore, our project intends to be a contribution for finding methods for different approaches that will make it possible for already used water to be prepared for a new use. In this report we describe the development process of a system which is going to be applied in contaminated water so that it is disinfected for a specific use: growing algae in an artificial environment. In order to do that, we based our system in UV technology. The whole system is controlled by PLC, and the water in it is filtered and driven by a small diaphragm pump. The mechanical and control parts of the system were tested and the chemical tests performed afterwords came out with positive results.**

***Keywords*—modular system, PLC, UV radiation.**

I. INTRODUCTION

The objective of our project is to build and develop a fluid disinfection system which will remove bacteria, viruses and seaweeds using UV radiation. There are several applications and approaches for cleaning the water, like using chemicals (chlorine, ozone), UV lamps, reverse osmosis and filtering. We decided to use UV radiation for removing microorganism, because it is the most advantageous method and fully satisfies our target. Before final disinfection with UV lamp we are using also pre-filtration. The system is controlled by PLC. Our client, who is going to use the system in future research, is the Chemical Engineering Department. We are supposed to design such a system taking into consideration all specifications provided by the client:

1.The system must work for 72 liters per hour with continuous flow-rate
2.In the water should not be any viable cells of pathogenic (in particular bacteria, viruses, seaweeds).The cleanness of water should be that sun light can pass through the water and reach about 15cm depth of water with microalgae
3.The system should be controlled by PLC and possess apart from mechanical valve, electrical valve as well
4.The budget is 400€.

To conclude our client`s needs, our goal is to build a system which will be as inexpensive as possible and the most applicable in the future. We intend to use equipment offered by the Chemical Engineering Department and also buy some of them in local stores. The final product will be used in greenhouse at Insitituto Politécnico do Porto, but it will be universal and can be modified to be adaptable to every laboratory with similar needs.

Apart from some difficulties which our team encountered on the way to reach the final result, we eventually managed to build a well-working system which fulfills all the requirements. The biggest obstacle was to find appropriate materials in local stores and sometimes to understand each other within the team. However, thanks to our motivation to work, supervisors' help and positive attitude we obtained full success.

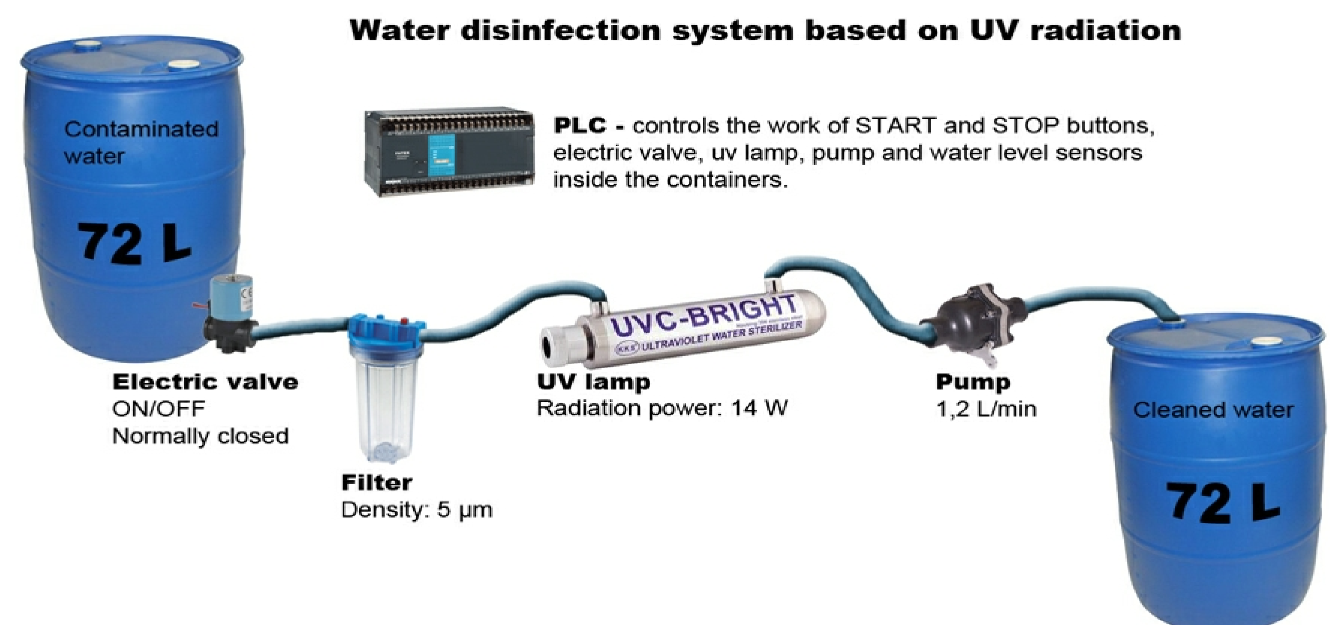

Fig. 1 Structure of the built system

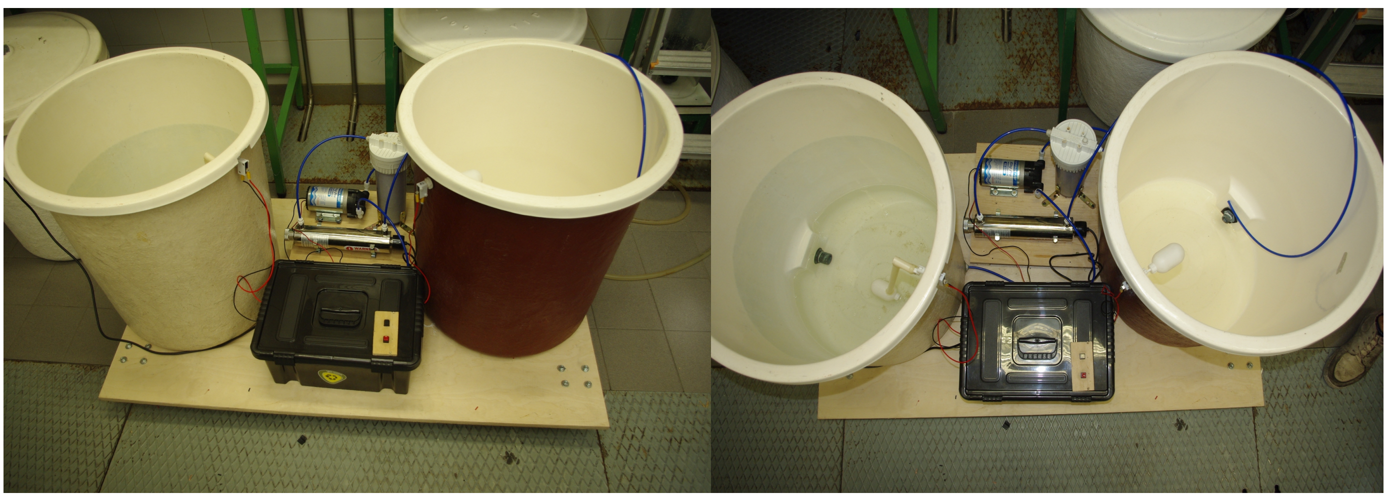

Fig. 2 and 3 Final product

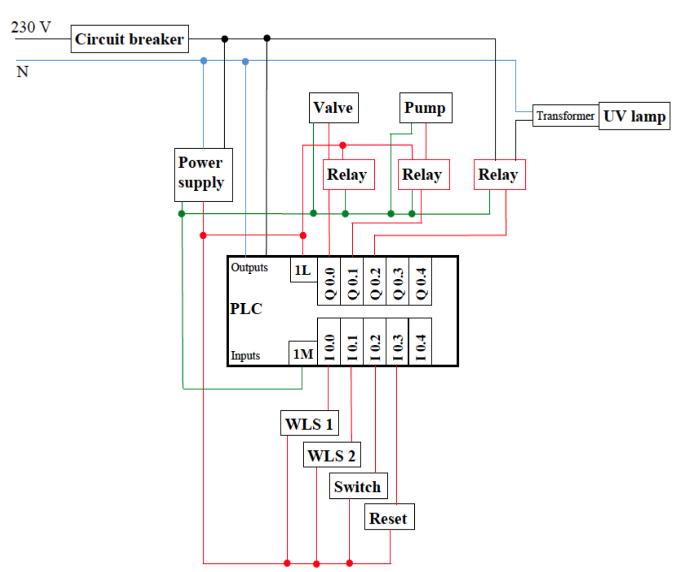

Fig. 4 Electric circuit of the system

Fig. 5 UV Sterilizer. Model No. A-140-6

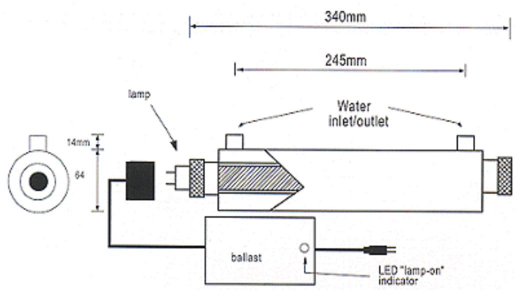

Fig. 6 UV Sterilizer, mechanical scheme.

Fig. 7 Model No. Ro-6088, King Pro

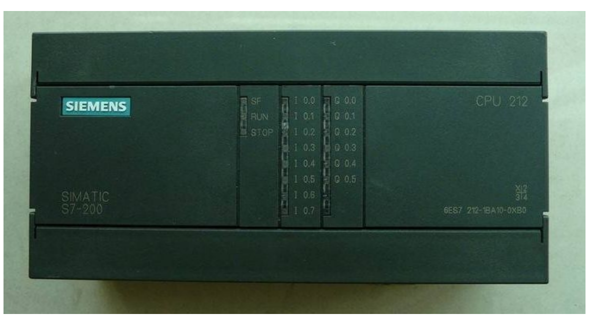

Fig. 8 Model No. 6ES7212-1BA10-0XB0, SIMATIC S7-200, CPU 212

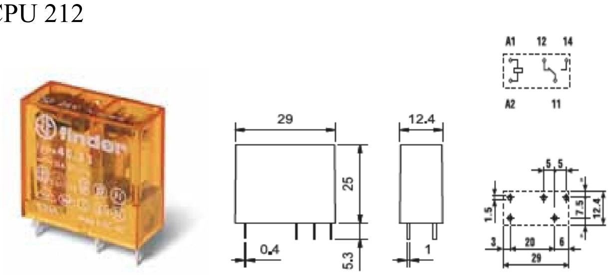

Fig. 9, 10 and 11 Relay and mechanical sketch of relay 40.51

Fig. 12 Socket 95.05 for relay 40.51

Fig. 13 Model No. S82K-05024, Omron

Fig. 14 Mechanical filter

Fig. 15 Solenoid Valve YCWS1

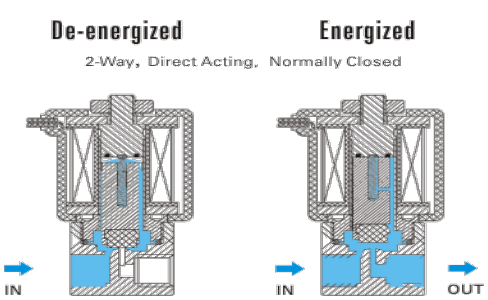

Fig. 16 Valve diagram

II. System design and specifications

Structure of the system

Figure 1 presents our idea how the structure of cleaning system should look like and Figures 2 and 3 illustrate its final result. In order to exaplain how the electrical part of the system works we created scheme of electrical circuit (Figure 4). The Fluid Disinfection System Based on UV Radiation system consists of different kind of mechanical and electrical parts and modules:

A. UV water sterilizer

The UV water sterilizer, which illustrates figure 5 and 6, is the most important part of the system. Our team chose this one because of exact specifications which are suitable for our project.

Specifications:

1. Flow rate: Clean water: 6 l/min, R.O.water:8 l/min
2. Voltage: 220~240 V, 50/60 Hz
3. UV germicidal lamp: 14 W x 1 (Model:UVC-D287T5)
4. Ballast: 14 W x 1(Option: Traditional or Electronic type)
5. Dimension: 64 x 340 mm
6. Inlet / outlet size: 6.35 mm
7. Max. working pressure: 0.86 MPa
8. Chamber/housing: 304 stainless steel
9. Quartz sleeve: Model No. SQ230330
10. Lamp failure warning system: LED + Alarm (option)
11. Lamp, average life: 9 000 h (1)

This UV water sterilizer was chosen taking into consideration the water flow rate of this system. The capacity of the pump is 1,2 L/min, so the capacity of the water sterilizer should be a bit higher to give certainty, that the water is sterilized. On the market, there is also available cheaper UV systems, but this specific sterilizer is more reliable and sustainable because of its stainless steel housing. The Figure 5 explains how UV lamp is built, inside outlet is situated fragile, quarz lamp and the lamp is powered directly to current.

B. Mini diaphragm pump

Pump's task is to pump the water from the first container (contaminated water) through mechanical filter and UV sterilizer to the second container. This pump (Figure 7) was selected because of its low throughput so it matches nominal capacity of the filter and UV sterilizer. Higher throughput would have meant higher capacity of other parts and therefore higher price.

Mini diaphragm pumps operate using two opposing floating discs with seats that respond to the diaphragm motion. This process results in a quiet and reliable pumping action. Higher efficiency of the pump is evident in the longer life of the motor pump unit. These DC motor diaphragm pumps have excellent self-priming capability and can be run dry without damage, rated to 343.15 K. No metal parts come in contact with materials being pumped. So these mini diaphragm pumps are great chemically resistant. Mini diaphragm pumps prime within seconds of turning the pump on; prime is maintained by two check valves (one on either side). Separated from the motor, the pump body contains no machinery parts, so pump can be in dry running condition for a short while. A built-in pressure switch insides the pump can automatically stop the pump, when the pressure reaches a setting data (2).

Specifications:

1. Open flow: 1.2 l/min
2. Pressure: 0.55 Mpa
3. Booster: 24 V DC

C. PLC

A Programmable Logic Controller (PLC) is an industrial digital computer used for control of electromechanical devices such as control of industrial machinery, pumps, lighting etc. A PLC will be connected to inputs. The PLC processes the inputs in real time based on the logic stored in it and switches the outputs on or off. (3)

Specifications:

1.Size: 160 mm x 80 mm x 62 mm

2.Memory: 512 words

3.Local inputs/outputs: 8 DI / 6 DQ

In this system PLC (Figure 8) is used to control the work of ON/OFF and START buttons (inputs), two water level sensors (inputs), and 3 relays (outputs) behind which the main modules are connected (pump, UV lamp, electric valve). The PLC is programmed like this: first the system is turned on by ON/OFF button which gives the right to the START button to start the system. It means, if pushed, the electric valve is opened and pump and UV light are turned on. The system can be shut down two ways, by the ON/OFF button or by each of the water level sensors. If the system is shut down by the water level sensors, it can be started by pressing again the START button, but only if it's allowed by the water level sensors.

D. Relays and socket

Figure 9, 10 and 11 present used in our system electrical valve, which is normally closed.The valve is open only if system works.

Specifications:

1.Rated current/max peak current (A): 10/20

2.Rated voltage/max switching voltage (V AC): 250/400

A relay is an electrically operated switch. Many relays use an electromagnet to operate a switching mechanism mechanically, but other operating principles are also used. Relays are used where it is necessary to control a circuit by a low-power signal

(with complete electrical isolation between control and controlled circuits), or where several circuits must be controlled by one signal. (4)

In our system relays are used for protecting the outputs of the PLC. If something happens with the UV lamp, pump or electrical valve it breaks down the relay, which is cheap and very easy to replace.

To protect relay we used also socket, which model illustrates figure 12.

E. Power supply

Power supply is needed to give 24 V DC to PLC outputs, because relays and electric valve and pump are working with 24 V DC.

Power supply used in our system, which presents Figure 13, has folllowing specifications:

Specifications:

1. Voltage input: 100 to 240 V AC
2. Frequency: 60 Hz
3. Voltage output: 24 V DC
4. Electric current: 2.1 A.

G. Mechanical filter

In this system, filter is placed before the UV lamp to clean the water from any particles which are bigger than 5 µm. It's important for the UV sterilizer so it can work with the highest efficiency.

Specifications:

1. Pore size: 5 µm
2. Height: 25.4 cm

The figure 14 shows schematically the filter which we used in our system.

H. Electrical valve

In this system is used normally closed electrical valve, it is opened only if system works. The chosen model of the system is presented on Figure 15 and walve diagram illustrates Figure 16.

III. System Evaluation

A. Chemical tests

Aim of the first exercise:

The aim of this exercise is to get acquainted with method of bacterial water test and laboratory equipment. Another goal was to check how much tested water is contaminated by bacteria and in result determine amount of this substrate which should be taken to final experience.

Procedure:

1. Prepare mixture of agar to solidify mixture and nutrient to grow bacteria. I used 1.5 g of agar and 0.8 g of nutrient for 100 ml of water.

2. After mixing all together and warming up in microwave to completely dissolve powders in water, I put the mixture into autoclave. There, in condition of high temperature (394.15 K) and high pressure (0.2 MPa), our mixture and piped tips were sterilized.

3. After sterilization, the next step was to prepare our samples in also sterile environment. We decided to prepare four Petri dishes with: Samples were prepared by incorporation technique. 0.25 ml of testing, contaminated water ± 20 ml of mixture 0.50 ml of testing, contaminated water ± 20 ml of mixture 0.75 ml of testing, contaminated water ± 20 ml of mixture 1 ml of testing, contaminated water ± 20 ml of mixture

4. After all I put samples into chamber with temperature of 298,15 K to solidify the samples and grow microorganisms.

Results and observations:

Results after 24 hours:

There were easily visible bacterial colonies on each Petri dish. I decided to calculate colonies from: 0.25 ml of tested water and there were 37 colonies and 0.75 ml of tested water where I calculated 211 colonies. I could also easily read out that there were different kinds of bacteria. For example, those who like oxygen (close to cover of Petri dish) and those who don`t like oxygen.

Results after 3 days:

Number of bacterial colonies increased to the amount which is highly difficult to calculate.

Conclusions:

Conclusion from that exercise is that water, which is going to be sterilized in our UV system, is highly contaminated by microorganisms and for the next research is recommended to use 0.5 ml of contaminated water and 1 ml of disinfected water for the best results and calculations. I can draw also conclusion that in the final examination I should observe my samples after 24 hours and 48 hours, because after longer time calculating of bacterial colonies is highly difficult and not recommended.

Aim of the second exercise:

The aim of this exercise is to check if our system disinfect the water from all pathogenic cells.

Procedure:

1. Prepare mixture of agar to solidify mixture and nutrient to grow bacteria. I used 1.2 g of agar and 0.6 g of nutrient for 75 ml of water.

2. After mixing all together and warming up in microwave to completely dissolve powders in water, I put the mixture into sterilization machine like during the first exercise.

3. After sterilization, the next step was to prepare our samples and we decided to prepare two Petri dishes with:

- 0.5 ml of testing, disinfected water ± 20 ml of mixture
- 1 ml of testing, disinfected water ± 20 ml of mixture

Results after 24 hours:

In the below figures there are no visible of bacterial colonies in 1ml and 0.5 ml samples.

Figure19. 1 ml sample

Figure 20. 0.5 ml sample

After 48 hours results were the same: no visible pathogenic cells.

Conclusions:

To conclude, our system disinfected water from all pathogenic cells. Lack of bacterial colonies proves that UV system is proper method to clean delivered by client water.

B. Electrical simulation:

In order to check of our electrical system works we used two useful software: Simulador_S7_200_V2 Esp and MFC PC_Simu version 1.0. Thanks to those software we were able to predict if our programmed logic works properly with PLC and system.

IV. Functionalities

A. Water disinfection using ultraviolet

Bactericidal activity is based on the absorption of UV-C light through the structure of the DNA of microorganisms. By using a properly selected time and intensity of UV radiation can completely destroy microorganisms through the destruction of their DNA. Different organisms have different resistance to ultraviolet light. In order to destroy certain microorganisms are given UV dose in mJ/cm^2 (5).

The effectiveness of disinfection depends on the microbial contamination of water intended for disinfection. Usually it is defined for indicator bacteria, namely Escherichia coli. For the purpose of drinking water disinfection in waterworks usually taken to be effective for E. coli at the level of 99.9%.This performance provides a UV dose of 40 mJ/cm^2. The dose is adjusted depending on the application.

UV sterilization lamps are widely used in the world to disinfect water without using heat and chemicals. Disinfection of water in the local scenes, factories, hospitals and laboratories.UV lamps can replace pasteurizers in breweries, mineral water bottling plants, processing plants food, at a fraction of operating costs. These devices provide a sterilizing, disinfecting water in conventional greenhouses and closed loop with drainage. Ultraviolet sterilization in the swimming pools provides chlorination or the abandonment of several dosing reduces the amount of chlorine. Use in ponds and fountains protected from rotting. UV lamps are also used for the destruction of ozone in ozone water.

The main advantages of UV sterilization lamps:

- Devices using UV radiation of wavelength 254 nm damage DNA. This is lethal to microorganisms. The use of proper wavelength protects protein against decay.
- Do not cause any changes in the chemical composition of water,
- You cannot overdose,
- Low operating costs,
- No hassles with chlorine and corrosion,
- Some pathogens such as Cryptosporidium are resistant to chlorination.

B. Other methods of water treatment

1. Mechanical filtration
2. Carbon filtration
3. The softening
4. Iron and manganese removal
5. Chlorination of water
6. Disinfection of water by ozonation
7. Dosing of chemicals
8. Decarbonisation
9. Correction of pH
10. Removal of nitrates from water
    - Biological denitrification
    - Nitrate removal by ion exchange
11. Demineralisation
    - Demineralization by reverse osmosis
    - Demineralization by ion exchange

Demineralization process involves the removal of water of all cations and anions derived from dissolved salts. This can be done using:

- Reverse osmosis - Ion exchange – Distillation.

C. *Water treatment methods depending on the impurities present*

1) Organoleptic:

Color	Active carbon filtration / Flocculation + Filtration
The pH	Correction of pH
Turbidity	Flocculation + Filtration
Hardness	Ion exchange / Reverse osmosis
Odor	Active carbon filtration / Oxidation / Ozone

2) Physico-chemical properties:

Ammonia	The oxidation / Ion exchange / Reverse osmosis
Nitrite	Ozonation / Chlorination
Nitrate	Ion exchange / Reverse osmosis
Free chlorine	Filtration on active carbon
Chlorides	Ion exchange / Reverse osmosis
Phosphorus	Reverse osmosis
Monophosphates	Reverse osmosis
Silica general	Reverse osmosis
Manganese	Removal of manganese
Magnesium	Ion exchange / Reverse osmosis
Potassium	Ion exchange / Reverse osmosis
The electrical conductivity	Ion exchange / Reverse osmosis
Sodium	Ion exchange / Reverse osmosis
Sulfates	Ion exchange / Reverse osmosis
Oxidation	Ion exchange / Reverse osmosis
Calcium	Ion exchange / Reverse osmosis
Organic carbon	Carbon filtration / Ozone + Carbon filtration
General iron	Iron removal

3) Bacteriological:

Bacteria, viruses, etc.	Disinfection (Ozone / Chlorination / UV)

(6)

V. Future developments

Current researches are focused on improving water technology for different applications. Many worldwide companies patented their own UV technology and they are using also other methods like ozone systems or reverse osmosis. In our project, we presented and built one main system which is adjusted to our client needs, but also we gave some different possibilities of fluid disinfection using different methods. We can provide service for different individual clients taking into consideration low cost, good quality and sustainability. In the future we can think about building systems for different water treatment applications, like: softening, iron and manganese removal, pH moderation, chlorination of water etc. After getting acquainted with all impose by client parameters and requirements we can modify our UniVersal system.

VI. Conclusions

Water technology for disinfection, is currently rapid developing field of science. Researches around the world try to find the most efficient way to clean the water for different purposes. Regarding our client requirements our team decided to focus on UV radiation method. UV technology can be used for different applications in science, in laboratories (e.g.: bacterial Identification, medical diagnosis), in industry (e.g.: UV curing), in criminology (e.g.: forensic applications), in electronics (e.g.: quality control) but it is also a big promise to design many innovative systems to clean the water.

In our project we proved that UV radiation can be successfully applied to water disinfection and removes pathogenic cells like bacteria and viruses. To sum up our work, we built fully and properly working system and we believe that fulfills all client requirements.That proved that method, which we chose and built system, is sufficient in this particular case of water disinfection. The most significant factor that shows value of our project is efficiency of proposed method, and its future application will tell us if proposed idea defend themselves.

During these four months of work we have learnt many different aspects connected with not only mechanical, electrical and chemical knowledge but also teamwork. We improved our cooperation in international team and communication in team. Moreover, we dealt with conflicts and other restrictions and limitations which we encountered on our way. For example: time limitation, budget and knowledge limitation. As we are not specialists in the field of chemistry, electronics and UV disinfection, we had to firstly get knowledge to start thinking how our system should look like. According to electrical part of the system, we were supposed to learn how PLC controller works, how to program PLC and make an electrical stimulation. Regards chemical test, we get acquainted to the method of bacterial water test and laboratory equipment. To sum up, thanks to this project we improved our teamwork skills and get new knowledge which can be useful in our future career.

Acknowledgment

Special thanks to Ana Barata for her boundless positive energy and a lot of work. She put much effort into teaching us and helping to resolve our problems .

We also would like to thank all the supervisors and teachers: António Ferreira da Silva, Manuel Santos Silva, Maria Benedita Malheiro, Maria Cristina Ribeiro, Nídia Sá Caetano, Paulo Ferreira, Pedro Barbosa Guedes, Francisco Marques Vieira, Alexandra Ribeiro da Costa, Luis Filipe Caeiro Castanheira and Roger Nylund for their valuable guidance.

To Victor Fernando Ferreira Moreira, Carlos Miguel Silva and António Ferreira da Silva we give our sincere regards for their help in creating our system; their time and patience.

We also thank to Maria Aurora Soares da Silva for helping carrying out chemical tests.

We owe a big gratitude to João Francisco Silva for his assistance in solving difficult problems.

Thank You all very much.

References

(1) Aqua-Win Watertec Co., *2G UV Water Sterilizer,* Available at: http://www.aquawin.com.tw/products/uvc-lighting-2G220V.htm, [Accessed from 2008].

(2) Wikipedia, Available at: http://en.wikipedia.org/wiki/Diaphragm_pump , [Last uptade: June 2012].

(3) Lakshmi Anand K, *Unit 4: Programmable Logic Controller*, Available at: [Accessed from 2008]

(4) Wikipedia, Available at: http://en.wikipedia.org/wiki/Relay , [Last uptade: June 2012].

(5) Wyczarska-Kokot Joanna - System dezynfekcji wody basenowej wspomagany naświetlaniem promieniami UV, *Rynek Instalacyjny 12/2009,* Available at: http://www.rynekinstalacyjny.pl/artykul/id1237,system-dezynfekcji-wody-basenowej-wspomagany-naswietlaniem-promieniami-uv.

(6) Kowal A.L, Maćkiewicz J, Świderska-Bróż M, *Podstawy projektowe systemów oczyszczania wód,* 3d ed. Wroclaw: 1998.