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Intelligent Photonic Sensors for Application in Decentralized Wastewater Systems

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1. Introduction

The generation and treatment of wastewater is considered a serious ecological, economical and technical problem (Bourgois et al., 2001); (Richardson, 2003); (Richardson, 2004); (Savage & Diallo, 2005); (Bartrand et al., 2007). There have been several reviews published concerning the instruments and methods of monitoring the contamination of water and detection of contaminants in water samples (Moorcroft et al., 2001); (Nakamura & Karube, 2003); (Dabek-Zlotorzynska & Cello, 2006); (Dabek-Zlotorzynska et al. 2008).
Recent publications on detection of nitrate and nitric oxides in water include (Cho et al., 2001); (Ensafi & Kazemzadeh, 2002); (Sun et al., 2003); (Wen & Kang, 2004); (Bates & Hansell, 2004); (Biswas et al., 2004); (Palaniappan et al., 2008); (Sivret et al., 2008). A method of detecting sulphide in water was presented (Ferrer et al., 2004), as well as one for chlorite (Praus, 2004), other inorganics (Hua & Reckhow, 2006); (Masar et al., 2009) and acidic drugs (Basheer et al., 2007). The sensors of metallic contaminants in water and their performance have been reported for the case of iron (Pons et al., 2005), arsenic (Toda & Ohba, 2005), chromium (Tao & Sarma, 2006) and other metals (Masàr et al. 2009).
New organic contamination detection methods and instruments have been widely reported in recent literature (Lucklum et al., 1996); (Bürck et al., 1998); (Rössler et al., 1998); (Yang et al., 1999); (Scharring, 2002); (Yang & Chen, 2002); (Yang & Lee, 2002); (De Melas et al.,2003); (Fernàndez-Sànchez et al., 2004); (Kamikawachi et al., 2004); (Sluszny et al., 2004); (Falate et al., 2005); (Pons et al., 2005); (Mauriz et al., 2006); (Rodriguez et al., 2006); (Tao & Sarma, 2006); (Jeon et al., 2009). Optical sensors for bacteria detection and quantification in water have been reported (Ji et al., 2004); (Zourob et al., 2005); (Nakamura et al. 2008).

1.1 The configuration of wastewater treatment systems

The major sources of wastewater can be classified as municipal, industrial and agricultural. Wastewater can be treated in wastewater treatment plants (WATP) or in decentralized

wastewater treatment systems (DEWATS) (Jo & Mok, 2009). Wastewater can be described using physical properties and by a list of chemical and biological constituents which should be precisely specified (Muttamara, 1996). The physical properties of wastewater are commonly listed as color, odor, turbidity, solids content and temperature. The wastewater treatment and disposal commonly depends on water contamination with suspended solids, biodegradable organics, pathogens, nutrients, refractory organics, dissolved inorganic solids and heavy metals. The heavy metals are particularly present in industrial wastes. The typical examples of refractory organics are surfactants, phenols and pesticides. While phenols are present in industrial wastes, pesticides in agricultural wastes, surfactants are common in households' wastes. The surfactants (Abdel-Shafy et al., 1988) and oils tend to resist conventional methods of wastewater treatment.

The properties of wastewater in the treatment process have to be monitored, particularly before the effluent water is discharged to the environment. The commonly examined parameters of wastewater before, during and after treatment in WATP are: pH, electric conductivity (EC in μS), chemical oxygen demand (COD), biochemical oxygen demand (BOD), total kjeldahl nitrogen (TKN mg/l), total organic carbon (TOC), total suspended solids (TSS), and also bacteria presence (E. Coli- number/100ml) (Thomas et al., 1997). Users of WATP run regular tests for those parameters.

DEWATS are intended for recycling domestic wastewater from individual households, community plants and small industrial type systems producing effluent with similar characteristics to domestic wastewater (Qadir et al., 2010). The objective of their operation is efficient removal or conversion of the various types of pollutants that are present in wastewater (Shirish et al., 2009). A typical DEWATS configuration is presented in Table 1.

Treatment	Device	Function
Primary	Settling tank	Initial separation solids and liquid. Solid matter or sewage disintegration by bacteria.
	Septic tank	
	Anaerobic baffled reactor	
Secondary	Mechanical filter for example: sand or membrane.	Filtration of wastewater to the acceptable discharge standard.
	Horizontal planted filter: • filter media: pebbles with top layer of sand, • plant cover: Canna Indica and Arundo Donax.	
Finish	UV electrically powered filter	Reduction of bacteria and virus count.
	Open collection tank	In the regions with high solarization the collected water is naturally UV-filtered.
	Open polishing tank	

Table 1. Example of typical configuration of DEWATS

Domestic wastewater can be divided into grey and black wastewater. The grey wastewater may be used directly for undersurface irrigation, when the irrigation does not cause formation of ponds. It is recommended however that grey water should be treated before use and that its contamination by surfactants should be tested. When the level of surfactants in grey wastewater is high the discharge should be directed to sewage. The oil presented in grey wastewater can block up the filters, so their condition also should be tested. The

common way of treatment of grey and in some cases black wastewater is sedimentation with microbiological disintegration in compact devices and mechanical filtration. Planted vegetation is used sometimes for additional filtration. The UV light disintegration of pathogens is also recommended as finishing treatment.

1.2 Sensors of parameters of liquids

There are many types of sensors that can be used for water and liquid monitoring, including a wide range of fiber optic sensors with chemical or biological sensitive layers, and electrochemical sensors that use fuel cells (Cusano et al., 2008). Under development are sensor devices that could be used for wastewater monitoring: pH meters, conductivity meters (EC), sensors for selected metal ion concentration, turbidity, liquid and sludge level meters, flow meters, sensors of particle presence in flowing liquid and biosensors of aerobic activated sludge organisms (Fazalul Rahiman & Abdul Rahim 2010) (Holtmann & Sell, 2002). The suspended solids concentrations and size distribution and particle weight can be determined from turbidity measurements. The metal ion concentrations of dissolved oxygen and carbon dioxide can be measured by using sensitive layers deposited on fiber tips or inside of capillaries where they are optically monitored. The wastewater contamination with toxic colony of micro organisms and BOD can be detected using fluorescence methods that include adding a sensitive fluorescent liquid to the examined sample or by the immobilization of a microbial layer on an amperometric oxygen electrode. The composition of wastewater can be also monitored using near-infra-red (NIR) spectroscopy, but this technique requires a laboratory setup and the set of reagents. Water contamination can be also analyzed indirectly in the form of gas with the use of a chemical nose which is a matrix sensor with integrated signal processing. There are sensors array systems intended for monitoring volatile components of wastewater. In more advanced chemical noses the wastewater sample is turned into vapor phase before the measurement is performed (Bourgeois et al., 2003). In such systems the detector of the principal contaminating component is used as the classifier of wastewater pollutants. The problem of implementation of sensors in wastewater monitoring is mainly the cost of keeping the sensor running or the time needed for examination and calibration.

1.3 The design objectives of DEWATS

Apart from technical aspects, the efficiency and the costs of the purification of wastewater, which include the cost of wastewater examination, require serious consideration (Rulkens, 2008). The simple DEWATS configuration does not include sensors for discharge monitoring, but as mentioned, the surfactants contamination and oil disintegration should be tested. The operation of DEWATS should not require constant samples examination in a laboratory. Therefore, DEWATS users need simple in use, low cost and fast sensing methods for in-situ initial qualification of water treatment and discharge (Vanrolleghem & Lee, 2003). Such methods would use sensors operating in a continuous mode without use of reagents, and would feature simple or automatic head cleaning and regeneration. The sensors for DEWATS have to be low cost in construction and operation and they have to enable monitoring of surfactants presence and give a clear answer if the discharged water is acceptable from environmental control point of view. Such requirements can be met by physical methods of measurement using light or the electric current.

2. Intelligent photonic sensors for wastewater treatment monitoring

In this work we present intelligent photonic sensors that can be used for monitoring of wastewater treatment. These sensors work on the principle of optical intensity changes that take place in dynamically forced measurement cycles. The sensors examine simultaneously many liquid parameters which are processed in artificial neural networks (Borecki et al., 2008a). The first type of sensors monitors signals from a drop forming during emerging and after emergence of an optical fiber from the examined medium (Borecki, 2007). The second type of sensors uses a fiber optical capillary in which the phase change from liquid to gas and again to liquid is forced by local heating while the propagation of light across the capillary where the liquid changes phase is monitored (Borecki et al., 2008b).

2.1 The examined liquids

To evaluate the proposed systems we used several liquids: still water, sparkling water, fresh edible oil, spoiled edible oil and grey wastewater including in its composition commonly present domestic discharge contaminants. We examined the still and sparkling waters coming from this same source and producers. The sparkling water was saturated with carbon dioxide. The detection of dissolved CO_2 is based on the measurements of differences of the solubility of gases in water. Values of gas solubility in water are presented in Table 2.

Gas	Solubility (ml/L)
Nitrogen	16.9
Oxygen	34.1
Methane CH_4	35
Carbon Dioxide CO_2	1019

Table 2. Examples of gas solubility in the water at 20°C

To simulate domestic grey wastewater with controllable composition we used water with suspended solids (carbon powder), biodegradable organics (rapeseed oil, milk, fats), nutrients (sugar, starch), and refractory organics (surfactants) and also dissolved inorganic solids (some components of powder milk). We did not include in the composition heavy metals and pathogens, but the pathogens can arise in the presence of milk, yogurt and sugar, Table 3.

Type of contaminants	Concentration of contaminant
Carbon powder	75 mg/l
Biodegradable surfactant	5ml/l
Rapeseed oil	10ml/l
Proteins with milk acid bacteria (Actimel)	1.25 ml/l
Proteins with fat (Powder milk 3.2% of fat)	1g/l
Starch (Flour)	1g/l
Sugar	1g/l

Table 3. Composition of the examined grey wastewater

The composition was treated for a few days in a still tank with a biological activator. We used as activator a 1ml/l solution of 0.5 tablet which includes 4*108cfu of nonpathogenic bacteria and enzymes that can disintegrate proteins, starch, oils, fats, papers and surfactants.

After dissolving, the tablet works like a mixture of soda and vinegar. Our still tank was kept at 26°C and had a volume of 5 liters and a height of 30cm. The sample for examination was probed from the middle part of tank using a pipette. The changes in the liquid in 4 days of probing in terms of pH and capillary action, which was measured in a glass capillary with a diameter of 536μm, are presented in Table 4. The visualization of bacteria growth during the treatment is presented in Fig. 1.

Treatment [day]	pH	Capillary action in [mm]
0	6.908	25.6
1	7.925	25.3
2	7.912	27.0
3	8.168	26.6

Table 4. pH and capillary action of grey wastewater in the function of treatment holding time

The measured pH of the sample 1 day after preparation was about 8 and remained stable during the following days, while initially the pH of the water was 7.0. The capillary action remained stable at the average level of 26mm, while the capillary action of clear water was about 39mm

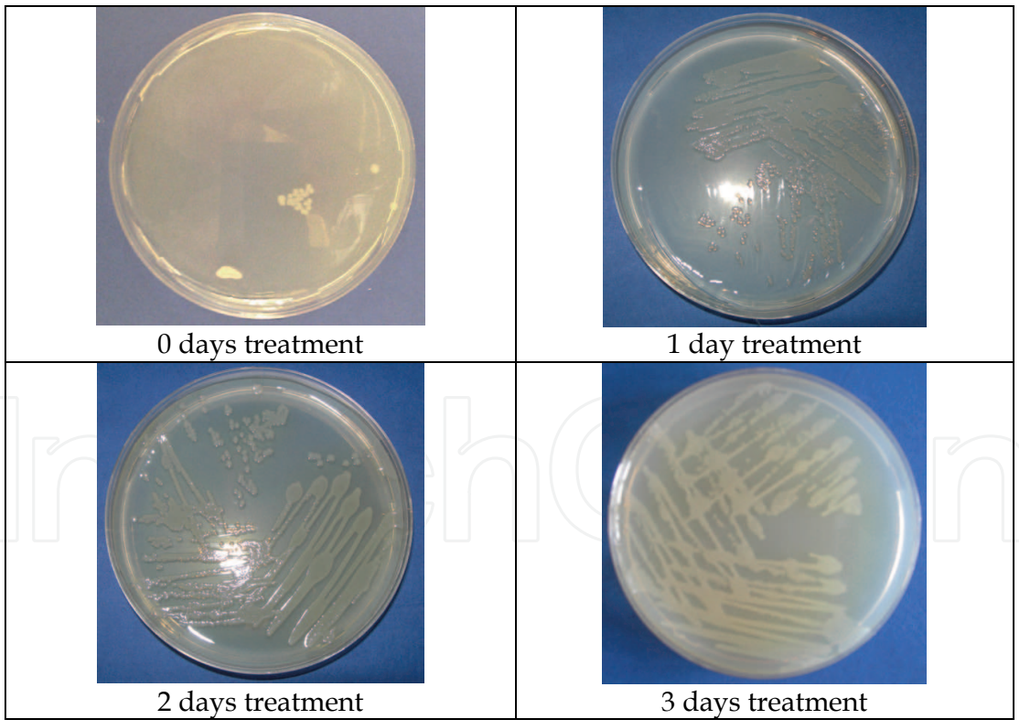

Fig. 1. Visualization of bacteria growth as function of treatment holding time

The microscopic examination in the following days showed that our gray wastewater has slightly increased number of bacteria. Therefore, we see that after 3 days of treatment our gray wastewater which sediments in tank quite effectively, was not fresh drinkable water.

2.2 Experimental setup
2.2.1 General description

We used two experimental setups, both with intelligent optoelectronic multi-parametric signal detection (Borecki et al., 2008a). Both examined sensors used light intensity measurements in forced measuring cycles and they used electrically controlled actuation to generate time-dependant information (Borecki et al., 2010). In their construction we used to the extent possible commercially available components.

The light source, and detection hardware were the same in both constructions. The heads were optically connected using large core SMA optical connectors. As light source we used a fiber coupled laser source S1FC635 from THORLABS that was coupled to the sensing head with a multi-mode optical path-cord finished with FC connectors and FC to SMA mating sleeves. The S1FC635 enabled light power stabilization and adjustments of power in the range from 0.01mW to 2mW. We eliminated the effect of the ambient light by modulating the probing light with 1kHz by connecting electrically a DG2021A function generator to the modulation input of S1FC635. The scheme of the light source is presented in Fig. 2.

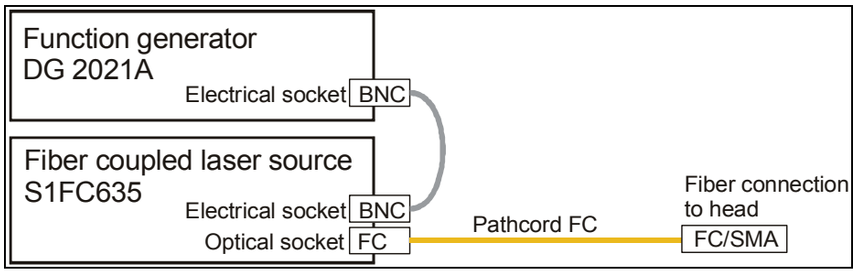

Fig. 2. The light source used in experiments

In our experiments we used the optical signal from a S1FC635 LD at a level from 0.01 to 0.2mW. The signal was transmitted almost without losses to the head by a SMA socket. The presented light power coupled into large core fibers could be also realized using properly selected LED diodes powered from an electric driver which consisted of a laboratory power supply that had precise output current settings and a transistor switch connected to the generator.

The detection hardware consisted of an optoelectronic interface, a data acquisition system, an electric actuation system and a PC with software, as shown on Fig. 3.

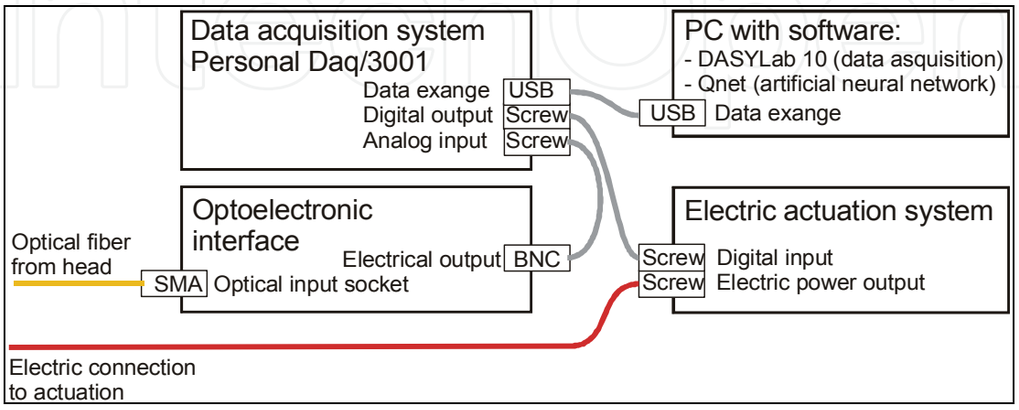

Fig. 3. Scheme of the detection hardware

The optoelectronic interface converted the intensity of amplitude modulated light into an electric signal. First the light was converted to the electric signal by a photodiode that was integrated in a trans-impedance circuit OP301. Then, all the components of the electric spectrum that were not in the modulated band were filtered with the UAF42 circuit. Next, the sensed changes of the modulated light intensity were demodulated with an AD536 true RMS detector. The interface was sensitive for the changes of the modulated signal slower that 5V/0.01s. The most expensive elements of the optoelectronic interface were the SMA socket (about 16EUR distributor's price) that was positioned mechanically directly above the OP301 (50EUR).
The signal from the optoelectronic interface was fed to the data acquisition system that read analog signals and converted them to the digital form proper for processing in the data acquisition software. We used DASYLab software with two scripts. The first DASYLab script was developed for data acquisition and the second was aimed for data classification. The data were analyzed with 0.1second time base and were observed and converted to the form required in the artificial neural network (ANN) Qnet microcontroller with embedded software. We used ANN that was in the form of multilayer perceptron, because this configuration showed its high usability in signal classification in sensors technique, (Borecki & Korwin-Pawlowski, 2010).

2.2.2 Fiber optic setup for fiber drop analysis (FDA)

The first sensing setup consisted of a mini-lift holding an optical fiber optic with a bare tip as a measuring head. This setup is presented in Fig. 4 and we used it for intelligent fiber drop analysis.

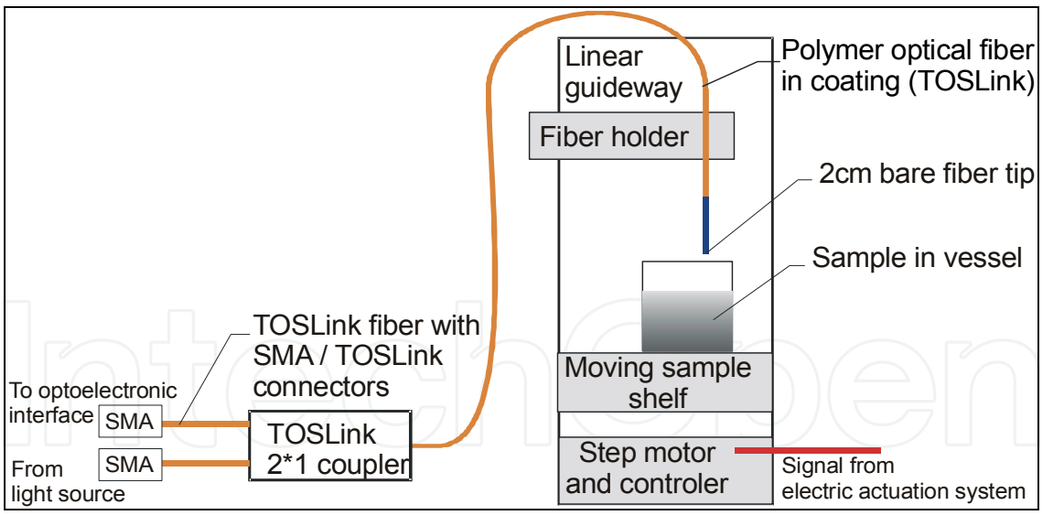

Fig. 4. Scheme of mini-lift sensing setup used for fiber drop analysis

In this setup we used a linear guideway type MLA0373-5HK1SKK from Wobit with a length of 50cm powered by a 10W step motor 57BYGH804. The guideway and optical fiber of the head were mounted on the wall for stability. On the guideway we fixed a vessel with a sample of a volume of 100ml. We controlled the movement of the liquid sample in the directions up and down with a tolerance of 0.1mm by using a data acquisition system and software. This construction provided a stable optical path that resulted in a more repeatable signal than the configuration with a moving fiber and a fixed vessel. We configured the

optical path using slightly modified TOSLink standard elements. We found that present polymer optical fibers can have their coating stripped easily from the fiber without damage being inflicted to the cladding or to the core. The sensing arm was one half of TOSLink pathcord type T-T from Vitalco PRC cut in half with stripped coating tip on 2cm length. The connections from light source and to the optoelectronic interface were made from HC302-200 Clicktronic pathcord cut in a half with mounted SMA connectors on the cut tips.
We have also considered using pathcords from different producers and found them working not as well with TOSLink coupler, but we found only one type of TOSLink coupler available on the market. Inside the coupler there were four fibers with slightly smaller diameter than ½ of the TOSLink fiber which we put together on our head arm and each two fibers were connected with the input and output arms as is presented in Fig. 5. Therefore, the coupler was in fact a divider and gave us the coefficient of light coupling from the source to the detection lower than 25%. We also evaluated the SMA BFL48-600 pathcord from Thorlab which had a core diameter 600μm, cladding diameter 630μm, coating diameter 1040μm and numerical aperture (NA): 0.48 ± 0.02 and a multimode FC pathcord with core 62.5mm for making the asymmetrical coupler presented in Fig. 5.

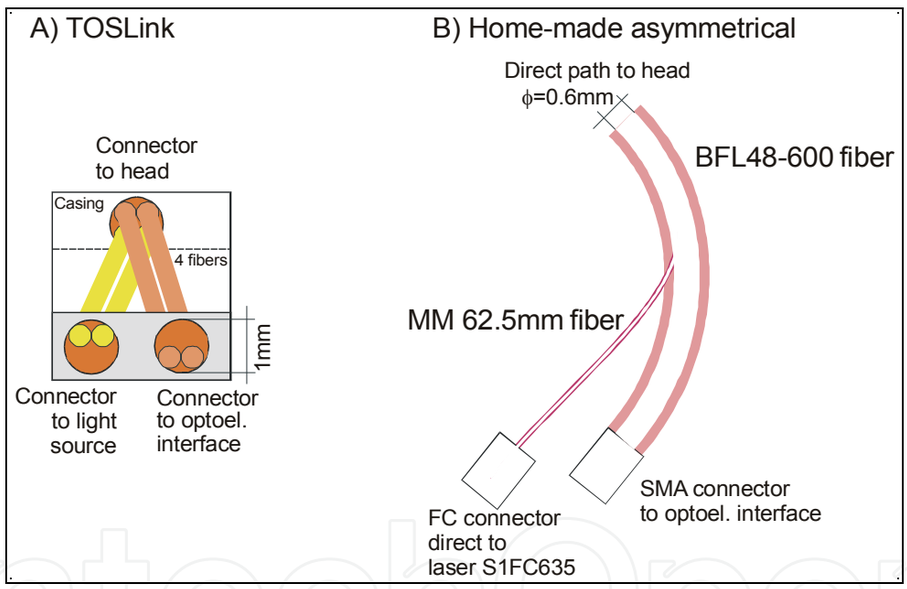

Fig. 5. The two variants of couplers: A) – TOSLink, B) – Asymmetrical

The asymmetrical coupler had a coefficient of light coupling from the source to the detection equal 43%, which was much higher than in the TOSLink construction, but the construction with only TOSLink elements had still sufficient light power output and, moreover, the light power balance in TOSLink did not decrease unacceptably when the LED light source was tested. With the LED light source the asymmetrical coupler made from polymer fiber presented in (Borecki, 2007) is recommended.

2.2.3 The setup for liquid-gas phase change measurements

The second sensing setup consisted of a head base, optical fibers, a miniature heater and a disposable capillary. This setup is presented in Fig. 6 and we used it for intelligent liquid-gas phase change capillary measurements.

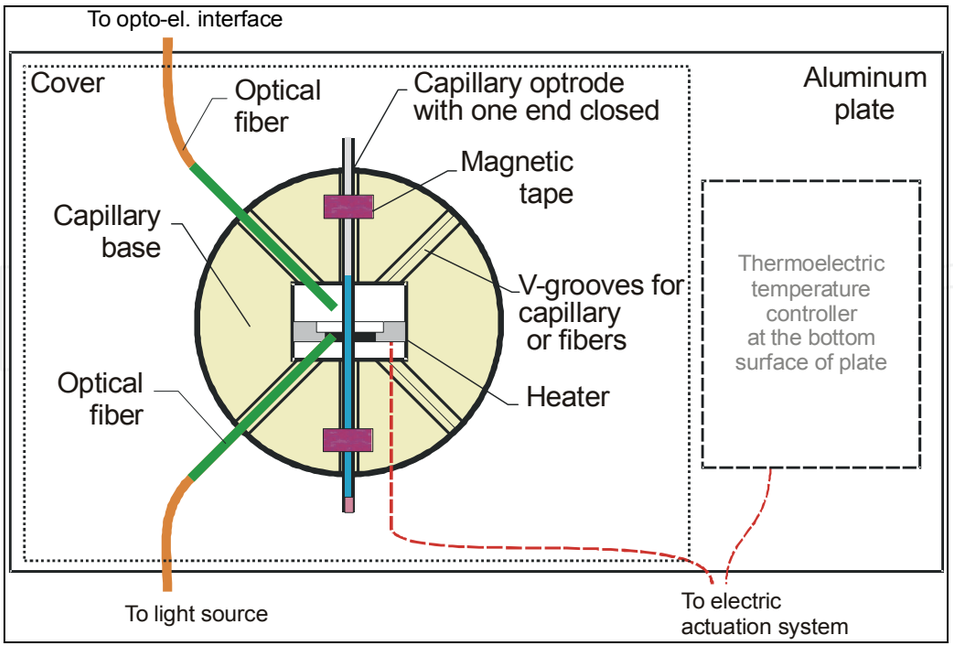

Fig. 6. Scheme of capillary liquid-gas phase change sensing setup

In this setup we used capillaries TSP700850 from Polymicro Inc. and BFL48-600 optical fibers with outer diameters of cladding similar. An important feature of the capillary probe was that the top end of the capillary was blocked with the operator's finger after the sample was drawn and the bottom end contacted with liquid was blocked with modeling clay. This prevented any sample spilling and ensured a safe transfer from the place of sample drawing to the point of examination. The capillary had the length of 6cm and after introducing the sampled liquid by capillary force to the length of about 20mm, modeling clay was inserted to a length of a few millimeters to act as a stopper.

We used a SMA BFL48-600 fiber-tipped pathcord cut in a half. The stripped ends of the fibers were mounted with mechanical clamps on the capillary base that was made from steel with the tolerance of 2μm. The base was mounted on top of an aluminum plate. A replaceable cover was put over the plate to prevent changes of heat transfer due to uncontrolled air movement. On the bottom of the plate a thermoelectric temperature controller was mounted to stabilize the temperature of the plate with an accuracy of 0.5°C.

The heater was made in thick film technology. The heating area was 1mm×3mm and the heater could dissipate 10W in 60 second without degradation, with 6 minutes of stabilization time required between temperature steps. The heater could generate a bubble in the liquid filling the capillary above the middle or the edges of the heating area with the bubble always moving towards the open end of capillary. Therefore, to avoid false measurement results the observations were done above the edge of the heater closer to the open tip of capillary.

2.3 Experimental results of fiber drop analysis (FDA)

The scheme with a mini-lift and a head with a bare POF fiber generated repeatable time-domain signal waveforms. For example, during the examination of still water repeated 10 times it gave signals presented in Fig. 7. The signal can be analyzed considering two

dynamic phases of the sensing head moving down (submerging) and up (emerging). When the head during submerging crosses the liquid level the reflected signal decreases. The signal drop depends on the indexes of refraction of the liquid and the fiber and on the turbidity of the liquid. The signal decreases during first part of head emerging cycle. When the head comes out of the liquid it takes with it a drop of the liquid. The signal behavior next depends on the liquid's parameters as: density, viscosity and surface tension related to the fiber material which in this case should be not wetting. Probing of still water results in formation of a drop that increases in volume and lasts for about 3 minutes when it comes off. After that the signal returns to its initial level.

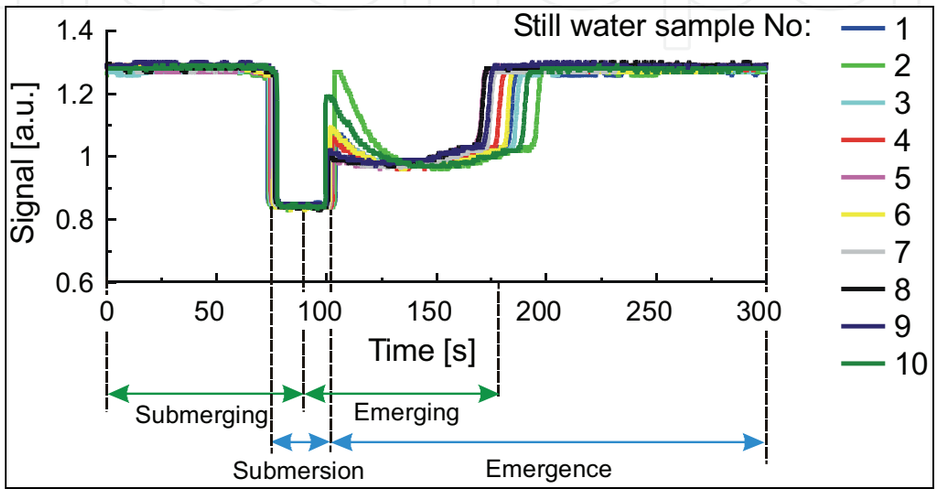

Fig. 7. Signal collected in FDA for still water samples

In Fig. 8 is presented the signal collected from the solution of milk power in water at the concentration of 500mg/l.

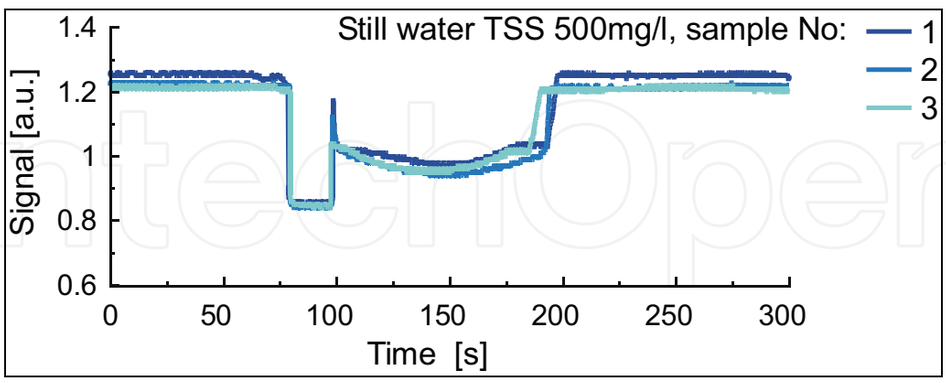

Fig. 8. Signals collected in FDA for samples of milk powder in still water at the concentration of TSS = 500mg/l

Clearly, the signals presented in Fig. 7. and in Fig. 8. do not differ significantly. To simulate closer the grey wastewater we added out-of-date edible refined rapeseed oil (without chemical modifications) to the examined solution. We observed a 1mm thick coat of oil forming on the water surface. The collected signals are presented in Fig. 9.

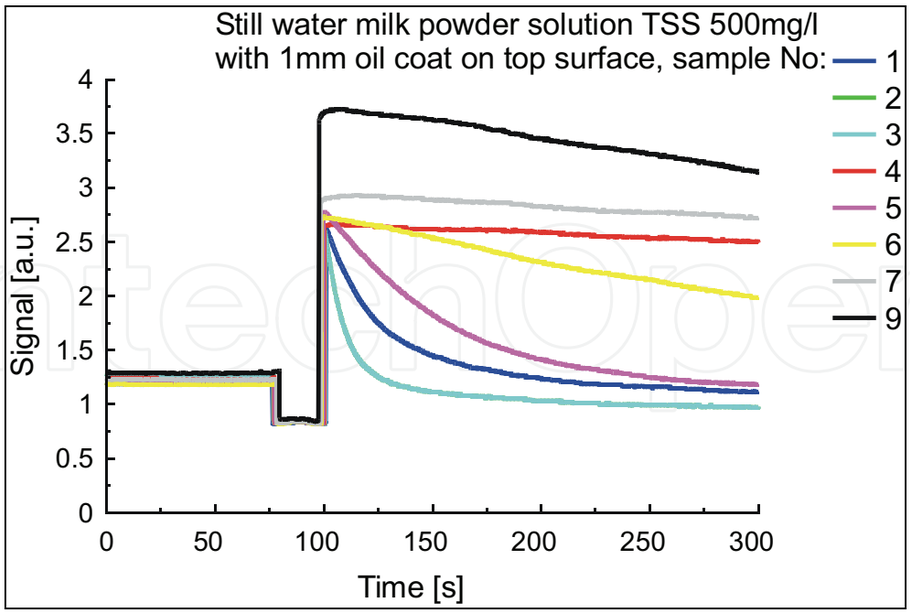

Fig. 9. Signal collected in FDA for samples prepared of still water with milk powder in concentration of TSS = 500mg/l and covered with 1mm out of date oil coat

The modification of the liquid sample with out of date oil introduces big differences between the collected signals. The signals collected for liquid covered with 1mm thick coat of fresh refined rapeseed oil are presented in Fig. 10.

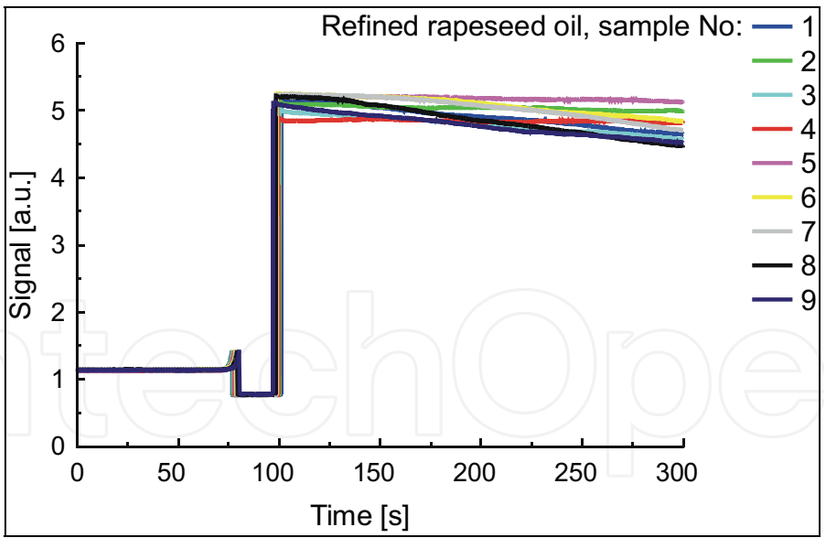

Fig. 10. Signal collected in FDA for samples prepared of fresh refined rapeseed oil

The comparison of the characteristics from Fig. 9 and Fig. 10 leads us to the conclusion that the signals from FDA for the samples of liquid with layer of fresh refined rapeseed oil are repeatable, contrary to the signals collected from the layer of out-of-date oil on the surface of water. We evaluated also the influence of a surfactant as water pollution agent. The characteristics collected for a 5ml/l solution of biodegradable kitchen surfactant are presented in Fig. 11.

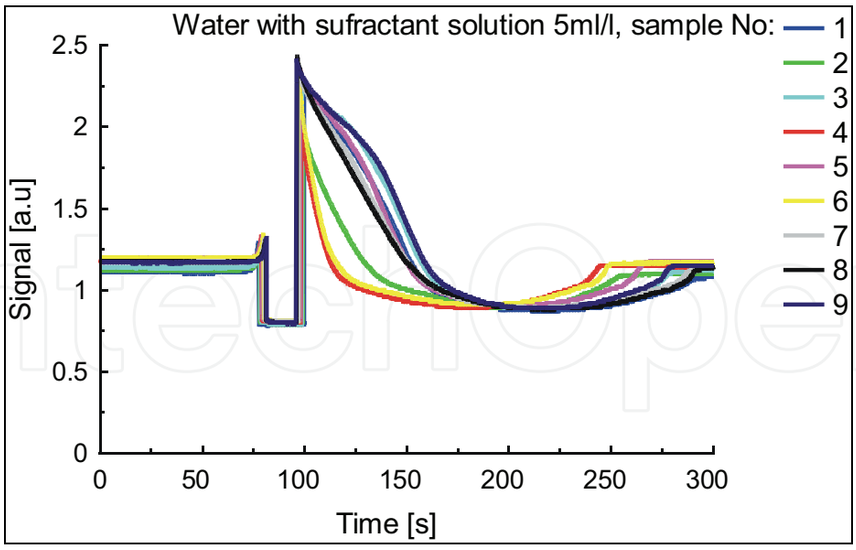

Fig. 11. Signal collected in FDA for water with biodegradable kitchen surfactant 5ml/l solution

The last individual agent we examined that could be normally present in the wastewater was carbon dioxide in the form of gas saturating bottled sparkling water. The following samples were taken from the bottle in specified time in a period of about 6 minutes with the time of opening the bottle was labeled 0min, as shown on Fig. 12.

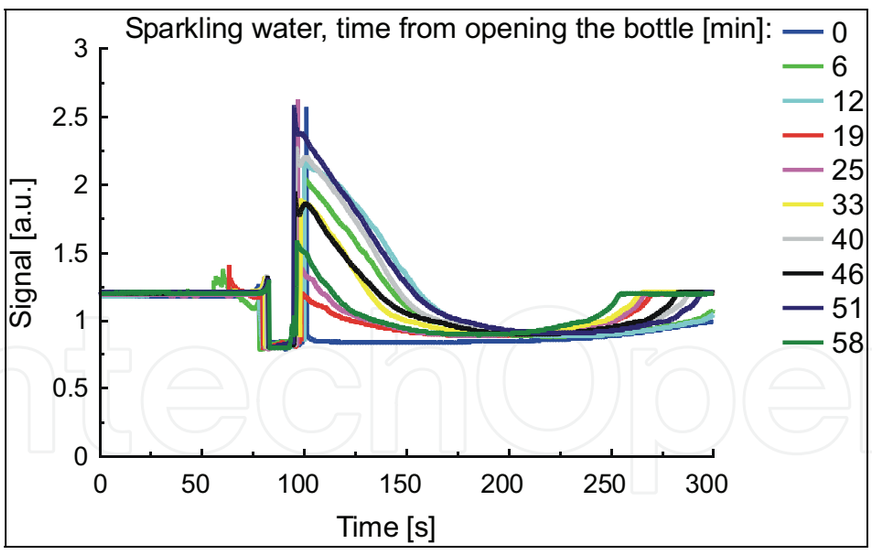

Fig. 12. Signal collected in FDA for sparkling water

An observation can be made that in the presented method the water surfactant solution with a concentration of 5ml/l and the sparkling water results in similar signals versus time dependences. Similarly, washing objects is more efficient when using water with surfactant or sparking water than still water.

Finally, we did tests with grey wastewater that was stored in a still tank for a few days. The collected data are presented in Figs. 13-15.

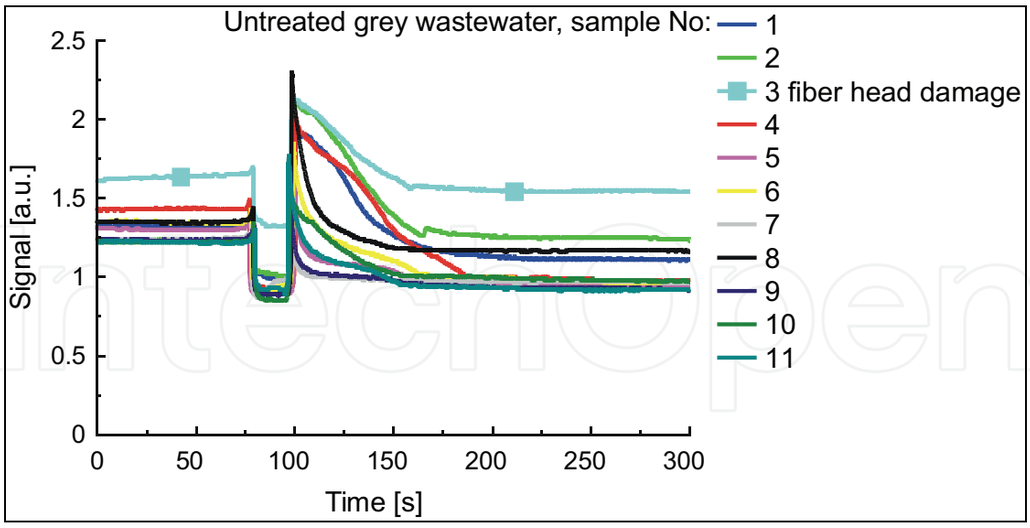

Fig. 13. Signal collected in FDA for grey wastewater just after preparation

The data collected from raw grey wastewater just after preparation is presented in Fig. 13. During that experiment we damaged the fiber head while cleaning it with a piece of tissue. The damage was visible in the fiber cladding. The signal collected for next sample has lover dynamics and increased level, which can be explained with changes in optical path parameters due to fiber damage. The way to restore the head was simply to cut off the damaged section, strip another fiber section and re-position the fiber tip. After this procedure we collected the signals from the next samples. The signals collected for grey wastewater that was treated in still tank for 1 day are presented in Fig. 14.

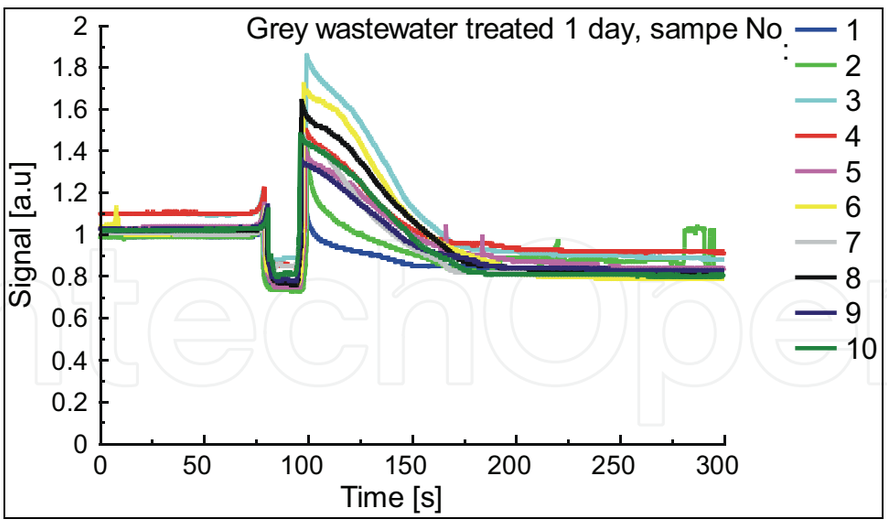

Fig. 14. Signal collected in FDA for grey wastewater that was treated in still tank for 1 day

The result of two days sample treatments is evident from comparison of data from Fig. 13 to Fig. 15. Firstly, the examined wastewater just after preparation is not a homogeneous mixture. This mixture stabilizes its parameters, but comparing Fig. 15, Fig. 7 and Fig. 11 gives us information that the presented treatment does not produce clear water which is in accordance in biological examination shown on Fig. 1 and in Table 2. It is probable that the

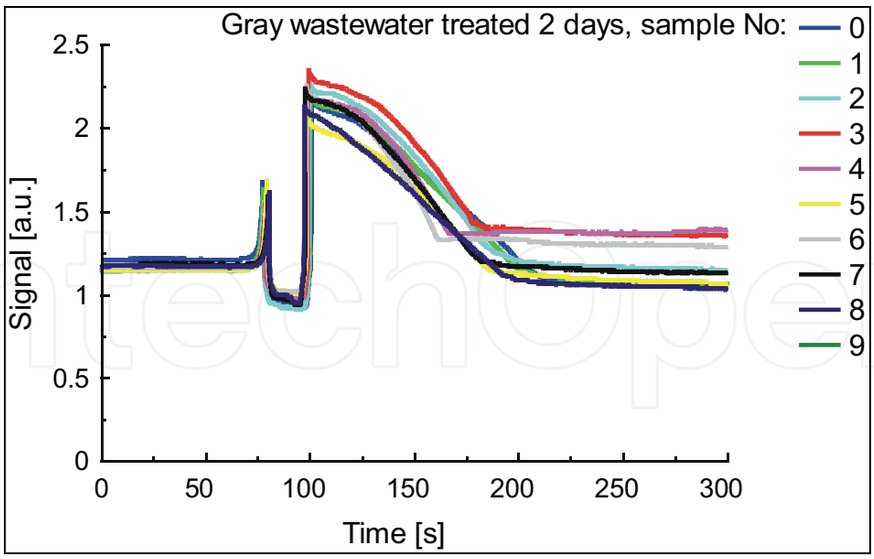

Fig. 15. Signal collected in FDA for grey wastewater that was treated in still tank for 2 days

biodegradable surfactant as suggested by its producer is not as quickly biodegradable as we may wish. After four days we observed a layer of coat on the surface of the grey water, the signals collected during this examination are presented in Fig. 16.

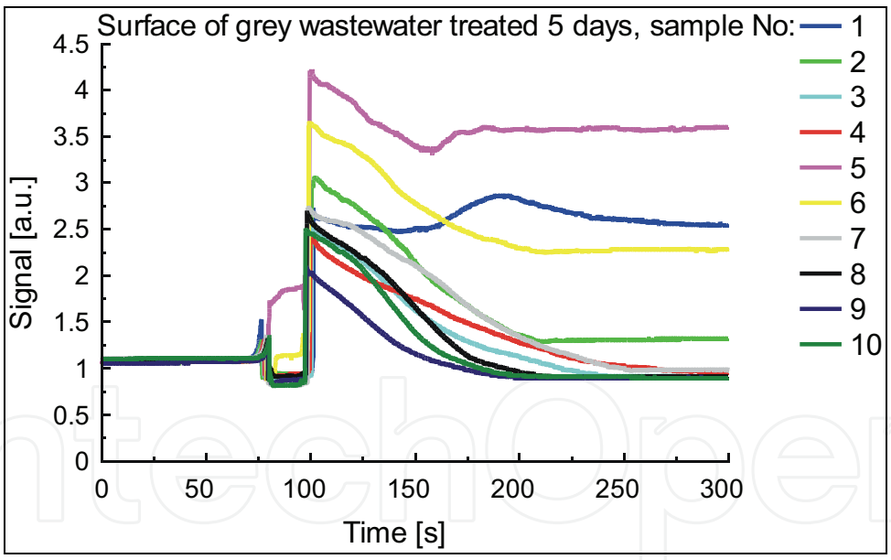

Fig. 16. Signal collected in FDA of grey wastewater surface that was treated in still tank for 4 days

The coat looked like thin ice surface with slightly yellow color. The exact observing of the coat resulted in conclusion that its structure was not uniform and it could be easily break into parts. The signals in measurement cycles were not repeatable in the presence of the coat. Sometimes the measurement cycle broke the coat and during the following measurements we effectively examined wastewater without coat (samples No. 2, 3, 4, 7, 8, 9, 10). Interestingly, the signal for sample with coat looked somewhat similar to the signal for samples with an oil layer on the water surface (Fig. 9).

2.4 Experimental results of capillary liquid-gas phase-change analysis

The sensing setup enabled the measurement of the reflected and scattered signals, but we present and use only the reflected signals. The signals were collected for 120s for liquid locally heated with 10W until the gas bubble was created. The signals collected for still water are presented in Fig. 17

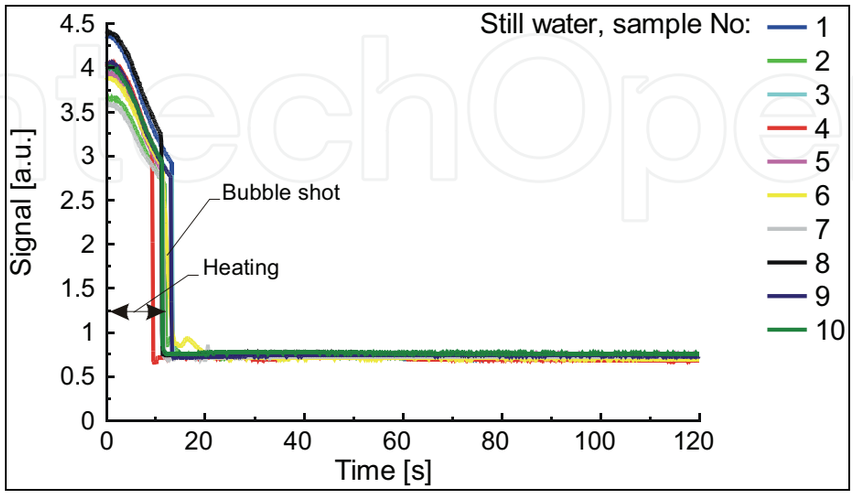

Fig. 17. Signal collected in capillary system for still fresh water sample

The signal during local heating first decreased slowly, which can be explained by the lowering of the refraction index of liquid. Next, we examined the water with the surfactant solution in volume concentration of 5ml/l, as shown on Fig. 18.

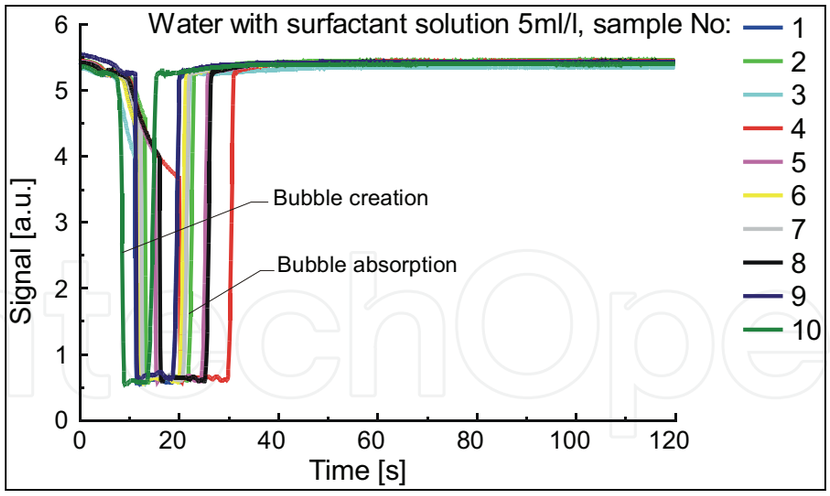

Fig. 18. Signal collected in capillary system for water with surfactant solution of 5ml/l

The created bubble in the capillary filled with water caused a shot of a drop of water out of the capillary; the added surfactant modified the situation significantly causing liquid motion slower and vapor phase absorption in the liquid. Also, the time of creation of the bubble varied when the surfactant was added to water and the initial signal level changed.

The last examination we did with the capillary system was of the grey wastewater that had been stored in a still tank. The data collected are presented in Figs. 19-21.

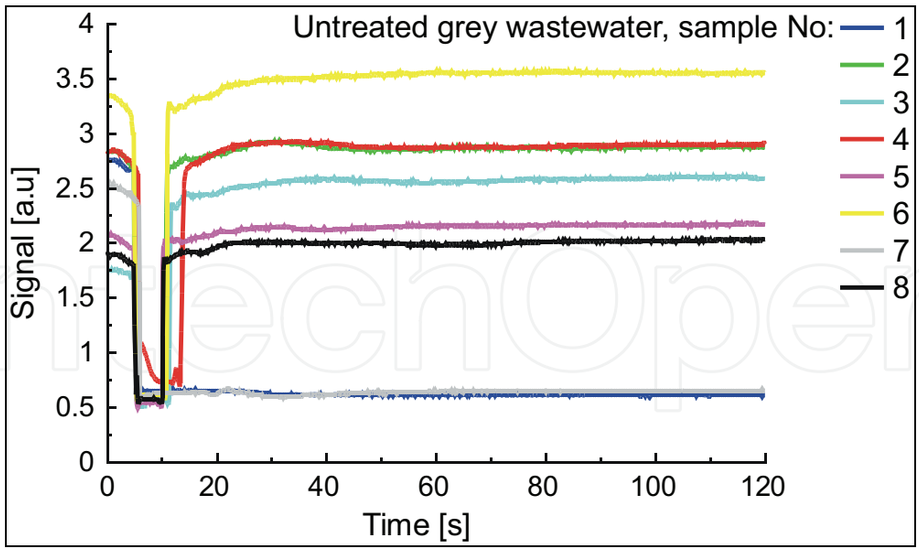

Fig. 19. Signal collected in capillary system for untreated grey wastewater

The time when the bubble formed and when a drop of water shot out of the capillary in the case of unprocessed grey wastewater was very repeatable and was one half of the time of bubble formation and drop shot-out for the clear water previously examined.

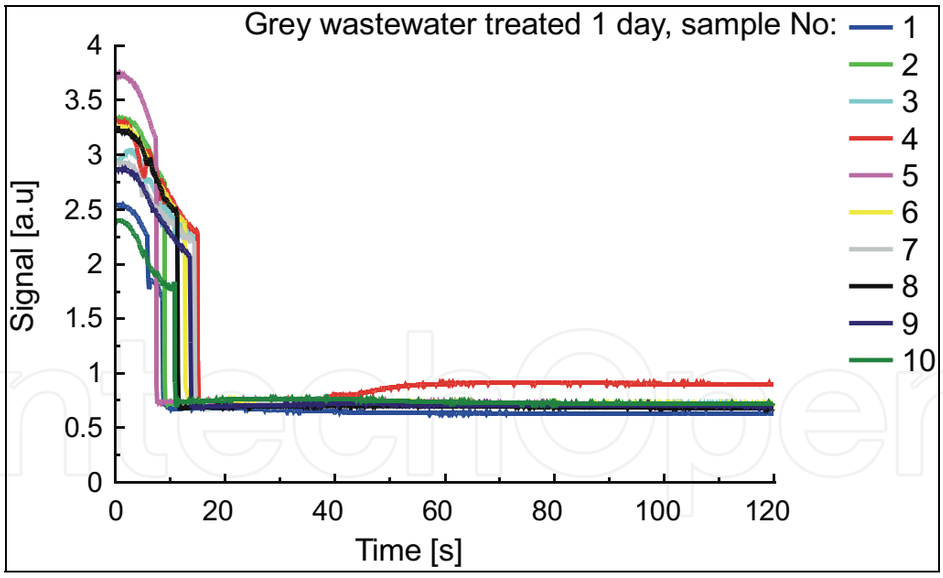

Fig. 20. Signal collected in capillary system for grey wastewater treated 1 day

The signals after one day of treatment, presented in Fig. 20, had lower initial levels than for clear water (Fig. 17), but no bubble shoot out was observed.

The signal from the sample No 10 presented in Fig. 21 has a sudden peak at 270s, the effect of local impurities of wastewater. In all other samples on Fig 21 the shape of signals versus time is similar to that measured for clear water Fig. 17.

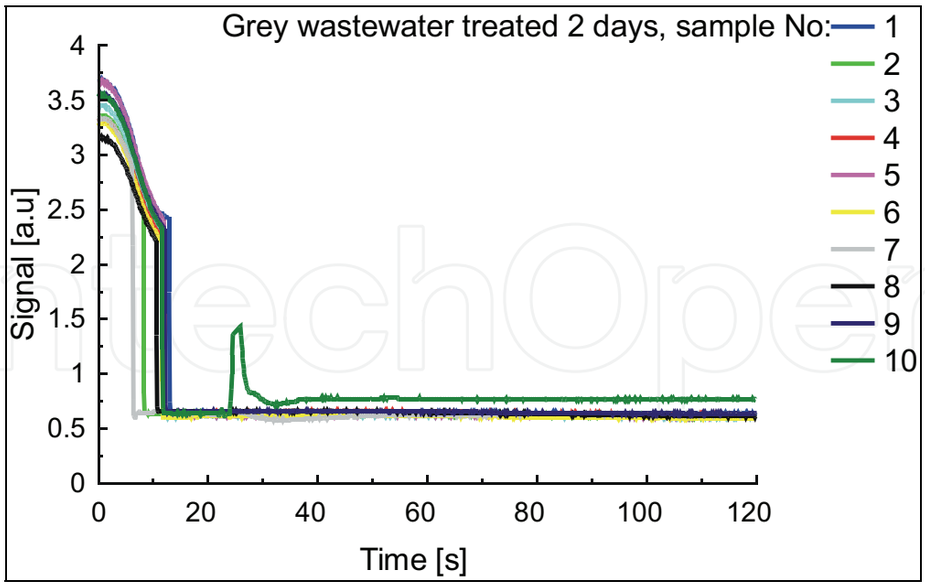

Fig. 21. Signal collected in capillary system for grey wastewater treated 2 days

2.5 Water classification with ANN in photonic systems

We examined sequentially samples of liquids of the same composition with the fiber optic FDA and the capillary system. For both types of the measurement systems our intention was to classify the water according to 5 classification states: clear water, water with surfactant solution of concentration 5ml/l, grey wastewater without treatment and after 1 and 2 days of treatment. The corresponding outputs of the ANN are given in Table 5.

Water state	No. of ANN output				
	1	2	3	4	5
Clear water	1	0	0	0	0
Water with surfactant	0	1	0	0	0
Grey wastewater – raw	0	0	1	0	0
Grey wastewater - 1 day treated	0	0	0	1	0
Grey wastewater - 2 day treated	0	0	0	0	1

Table 5. The outputs of ANN for FDA water classification

The inputs of ANN are different for each of the two systems. The data classification in FDA system can be correlated with:

a. initial level (10s),
b. level during submersion (75s),
c. peak level of 100s - correlated with drop appearance,
d. three levels for 125, 150, 200s of measuring cycle time - correlated with drop forming,
e. final signal level.

We used a 4 layers perceptron network, with 6 and 5 nodes in hidden layers and sigmoid transfer function. This network giving with training the RMS error of 0.017 and the correlation coefficient of 0.998. These values and the ANN output results were satisfactory, Table 6.

No. of ANN output	Std	Correlation
1	0.01770	0.99906
2	0.02971	0.99713
3	0.02990	0.99730
4	0.02087	0.99871
5	0.02413	0.99811

Table 6. The outputs parameters of trained ANN for FDA water classification

The data classification in the capillary system can be correlated with:

a. initial level,
b. slope before bubble creation, (5s),
c. time of bubble creation,
d. time of bubble absorption, or 0 when bubble shoot the liquid,
e. final signal level.

In this case we also used a 4 layers perceptron network giving with training the RMS error of 0.12 and the correlation coefficient of 0.89. The ANN output test data are presented in Table 7.

No. of ANN output	Std	Correlation
1	0.17347	0.90426
2	0.06646	0.98702
3	0.05557	0.98936
4	0.22671	0.83018
5	0.27209	0.74438

Table 7. The outputs parameters of trained ANN for capillary water classification

3. Conclusion

We have shown that intelligent photonic sensors are capable of classifying wastewater parameters and can be easy in operation. The proposed sensors work in contact with the examined liquid. The proposed construction is based on new sensing ideas. The classification of grey wastewater treatment, water with surfactant 5ml/l solution and clear water was performed satisfactorily in both systems. The FDA system was superior to the capillary system in terms of classification parameters of wastewater, but the capillary system is simpler in construction and does not require moving parts. The capillary system does not require head cleaning; the capillary optrode is disposable, which is an advantage. The cost of the examination is relatively small. Before the systems can be used for practical applications further system integration and automation of the measurement process are required.

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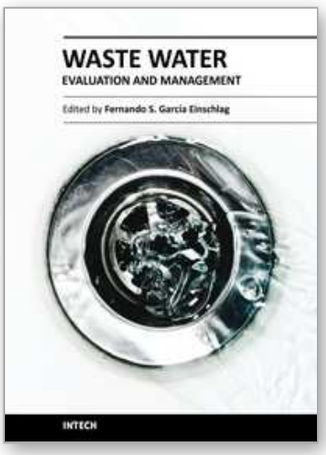

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