ACADEMIA ROMÂNĂ
Revue Roumaine de Chimie
http://web.icf.ro/rrch/

Rev. Roum. Chim.,
2016, *61*(11-12), 903-912

INFLUENCE OF THE POLYPROPYLENE [PPR] PIPES CHARACTERISTICS ON THE DRINKING WATER QUALITY

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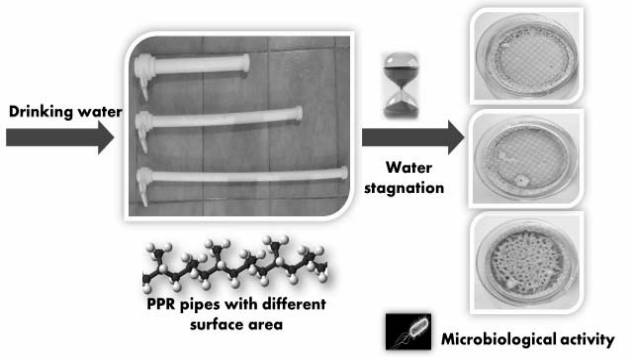
Received May 4, 2016

Polypropylene random [PPR] has been tested as pipe material in contact with drinking water. The influence of the pipe's dimensions, surface and volume in contact with water, of the temperature and of the stagnation period of water in pipes on the germs and bacteria growth has been studied, using un-chlorinated drinking water and drinking water, from the same source, chlorinated into the laboratory, at a minimum level and at the maximum level allowed by the law. After 9 hours of contact with PPR, water has been submitted to a microbiological and physical-chemical analysis. The total number of germs [NTG] developed at 22°C and respectively 37°C, Coliform bacteria [CB] and *E. coli* numbers of colonies, as well as water turbidity [T], have been determined.



INTRODUCTION

Although water represents a resource of great importance to both humans and animals, its storage mode and effects of its transit through household drinking water networks is little studied for a perishable product. The temperature of storage and the material from which the pipes are made, represent important factors in water quality deterioration, with serious consequences on human health.[1] Consequently, the hazard analysis and critical control point (HACCP) system and SR EN ISO 22000: 2005 Food Safety standards must be continuously and responsible applied to drinking water, as well as with other food products.

Degradation of water quality in the distribution network is due to both chemical contaminants (a) as well as microbiological contaminants (b).

(a) Contaminants of chemical nature coming from distribution pipes can seriously damage human health through their accumulation in the body over time. Recent studies on water that has passed through metal pipes in the network of 17 families have indicated that overnight stagnant water presented in some cases concentrations of metals (Cu, Pb, Ni or Al) over the maximum threshold allowed by legislation.[1] Besides metals, other dangerous chemical compounds from the pipes can migrate into drinking water, with serious consequences on human health. For example, in England, a study performed on pregnant women draws attention to the fact that contamination with tetrachloroethylene, coming from the pipes, increases the risk of congenital anomalies.[2] It also draws attention to the fact that one of the causes of endocrine disorder is the consumption of water

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from PVC networks and cancer may be due to chemical compounds leached from plastics used for storing drinking water.[3] Unlike biological contaminants, the toxic compounds accumulate over time and do not cause immediate clinical manifestations, and thus health measures are usually taken very late.

(b) Microbiological contaminants are equally dangerous to human health and in some cases can lead to death. It is well known in this regard, the epidemic of dysentery in Detroit (USA), which included over 50,000 cases of disease. Unlike chemical contaminants, microbiological ones produce immediate symptoms, health degradation being made very rapidly. Microbiological risk can be induced by external factors in the distribution network, but little is known about the fact that the distribution network itself may constitute a risk in microbiologically altering the quality of drinking water.

Moreover, it has been demonstrated that PPR pipes manufacturers take into consideration only the physical-chemical aspects, as evidenced by the certificate of quality of the product, where chemical resistance is an exhaustive chapter treated in accordance with ISO / TR 1035: 1993, making reference to chemical resistance to 140 different substances, while microbiological resistance remains an untreated issue. The present work aims to monitor the microbiological activity evolution of water distributed through PPR pipes, depending both on the volume of the pipe, and on the pipe surface in contact with water for 9 h at 22°C.

In this study, microbial activity monitoring of stagnant water in random polypropylene pipes (PPR) with different diameters has been achieved, depending on the volume of the water and the surface in contact with the water. The study takes into account that not all consumers use chlorinated water sources, so the water quality monitoring has been performed for both chlorinated and non-chlorinated water, using the same source. The study takes into account the chlorination level of water, as it is known that the consumers from the beginning of the distribution network have a higher concentration of free chlorine than the end consumers of the network. For these reasons the study was performed on water with free chlorine concentration close to the minimum and maximum allowed values, ie. 0.1 mg/L Cl_2 and 0.5 mg /L Cl_2 according to Law no. 458/2002 on drinking water quality (republished) - completed by Law no. 311/2004, so the experimental data involves all the categories of consumers.

The PPR material was not randomly chosen, but in accordance to the current state of art in the field of hydro constructions. So far, for both financial and technical reasons (pressure and corrosion resistance, lower weight, low expansion coefficient, easy maneuverability), only polymer pipes are used, among which PPR is the most frequently used.

MATERIALS and METHODS

1. Materials

Drinking water (non-chlorinated) was sampled from Ciucaş source, Zone II of the Water Distribution Company Brasov, Roumania. The initial quality of the water used for the experiments was determined in accordance with the requirements of Law 458/2002, Annex 2 on the quality of drinking water supplied to the city mains. Because this source of drinking water is a natural one, the characteristic parameters varied at different sampling time due to amount of rains and temperature. As example, we reported in this paper the behavior of three initial samples with the following particular characteristics:

a) **Sample 1** with turbidity [T] 0.15 NTU; coliform Bacteria [CB] 1 cfu /100 mL, *E. coli* 0 cfu/100 mL, Intestinal enterococci 0 cfu/100 mL; *Clostridium Perfringens* 0 cfu /100 mL ; total number of germs [NTG]: 37˚C 15 cfu/1 mL; NTG 22˚C 10 cfu/1 mL

b) **Sample 2** with T 0.25 NTU; CB 3 cfu / 100 mL, *E. coli* 0 cfu /100 mL, Intestinal enterococci 0 cfu /100 mL; *Clostridium Perfringens* 0 cfu /100 mL; NTG 37˚C 18 cfu/ 1 mL; NTG 22˚C 22 cfu/ 1 mL

c) **Sample 3** with T 0.09 NTU; CB 0 cfu / 100 mL, *E. coli* 0 cfu /100 mL, Intestinal enterococci 0 cfu / 100 mL; *Clostridium Perfringens* 0 cfu /100 mL; NTG 37˚C 17 cfu/ 1 mL; NTG 22˚C 17 cfu/ 1 mL

and commune characteristics:

pH: 7.89- 7.96; conductivity: 226-227 µS/cm; $[Al^{3+}]$< 0.009 mg / L; $[NH_4^+]$< 0.007 mg / L; $[NO_3^-]$: 6.07-6.35 mg / L; $[NO_2^-]$< 0.007 mg /L; $[O_2]$< 0.6 mg / L; 6.67 °d; $[Cl^-]$: 6.00-6.15 mg / L;

Sodium hypochlorite for chlorination of water to ~0.1 mg /L Cl_2 (minimum concentration of free chlorine under the laws in force) and ~ 0.5 mg /L Cl_2 (maximum concentration of free chlorine under the laws in force). This solution has been used to check the effect of chlorination on the microbial activity developing in stored water.

Fig. 1 – PPR pipes having the same volume but exhibiting different surfaces for contact with water.

Table 1

Dimensional characteristics of PPR pipes used in the study

V_{ct} = 150.000 cm^3			S_{ct} = 430.000 cm^2		
Ø (cm)	**L (cm)**	**S (cm^2)**	**Ø (cm)**	**L (cm)**	**V (cm^3)**
1.400	97.500	428.610	1.400	97.800	150.475
1.800	59.000	333.468	1.800	76.000	193.298
2.000	47.800	300.184	2.000	68.500	215.090

where: Ø is the pipe diameter, L is the length of pipe, S is the interior surface of the pipe, V is the interior pipe volume.

12 PPR pipes, from Valrom-Industrie srl., Bucharest-Roumania, cut according to the dimensions shown in Tab.1, so as to contain either an equal volume of water (one set for chlorinated water and another set for non-chlorinated water) at different surfaces contact with water, or to contain different volumes of water in contact with the same pipe surface. The pipes with three diameters have been sealed at one end with a plastic cover and at the other end with valves from the same material (Fig. 1).

The pipes have been repeatedly washed with water and then disinfected with a 70% ethanol solution. Aiming a high level of disinfection, the pipes have been subjected to UV irradiation (λ = 253.7 nm) for 48h.

PPR, pipes material, is a mixture of polypropylene $(-C_3H_6-)_n$ with different molar mass, which confers the material a better impact resistance. As a function of chain arrangement and size, polypropylene materials can be classified as short-chain polypropylene (PPS), long-chain polypropylene (PPH) and polypropylene with randomly-sized and displaced macromolecular chains (PPR).

In contrast with other plastic materials, PPR is more rough and rigid[4] (TC003, 2006 technical bulletin, www.valrom.ro). The roughness of the materials represents one of the factors that facilitate bacterial adhesion, as proven by Katsikogianni.[5]

The PPR pipes, filled with water in a micro-biologically controlled environment have been submitted to stagnation for a 9 hours period (the same period of time the water stagnates in household distribution networks overnight) at 22˚C (average room temperature). The experiments have been performed in triplicate.

2. Methods of analysis

2.1. Coliform and Escherichia coli bacteria counting and detection

For the determination of lactose-positive bacteria, the filtering membranes method has been used. The principle of this method consists in filtration of determined volumes of water through membranes with 0.2-0.45μm porosity. The bacteria from the water sample remain on the surface of the membrane, and then the membranes containing the bacteria are placed on a selective culture medium (Tergitol TTC), which contains lactose, triphenyltetrazolium chloride (TTC) and sodium heptadecylsulphate (Tergitol). The culture media have been purchased in a ready to use form (Nutri Disks Tergitol TTC from Dr. M□LLER & SCHMETZ), which includes sterile Petri dishes with the culture medium and the corresponding filtering membrane, for each Petri dish. The testing has been performed in accordance with SR EN ISO 9308-1/2004 *AC:2009*.

From each storage recipient, 100 mL of water has been sampled and filtered through the membranes. The membranes have been placed in the Petri dishes containing the hydrated culture media and incubated for 24 h on 36±2˚C. After the incubation period, the membranes have been examined and all the yellow-orange lactose-positive bacteria and red lactose-negative bacteria colonies developed have been counted (Fig. 2).

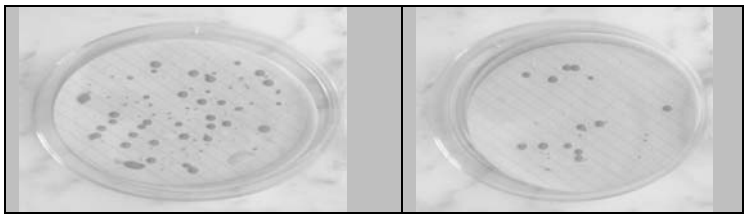

Fig. 2 – Example of Coliform Bacteria test.

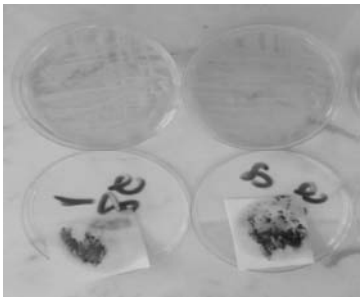

Fig. 3 – Positive oxidase test.

Fig. 4 – Negative oxidase test.

From the culture media obtained as described above, several strains have been further inoculated on specific culture media such as Tryptone Soy Agar plates (a), Tryptophan Broth tubes (b) and TBXG plates (c) for oxidase, indole and β-glucuronidase tests:

a) The oxidase test has been performed in order to confirm the presence of above-presumed coliform bacteria. For the culture media preparation, 40 g dry Tryptone Soy Agar (Sharlau), has been dissolved under heating in 1000 mL distilled water and the pH has been adjusted to 7.2±0.1 at 25˚C. The prepared culture media has been further sterilized in an autoclave at 121˚C for 15 minutes and placed in the Petri dishes. Samples from the presumed coliform bacteria have been thus inoculated on the Petri dishes with Tryptone Soy Agar and incubated at 36˚± 2˚C for 21± 2 hours. After the incubation period, on a filter paper (sterile), 2-3 drops of freshly prepared Oxidase Reagent (VWR PROLABO) have been placed. With a glass rod, samples from bacterial colonies developed on the Tryptone Soy Agar culture medium have been placed on the filter paper. In 30 seconds, either an intense blue-violet colouring appears which infirms the presence of coliform bacteria (positive test – Fig. 3), either no blue colouring appears, which confirms the presence of coliform bacteria-negative oxidase test (Fig. 4).

b) For the indole test, lactose-positive bacteria have been inoculated in Tryptophan Broth tubes, prepared as following: 16 g dry Tryptophan Broth culture (Sharlau), has been dissolved in 1000 mL of sterilised distilled water under heating, cooled to room temperature, adjusted to pH 7.5±0.1 at 25˚, and then placed in tubes sterilised in the autoclave at 121˚C for 15 minutes and cooled to room temperature. After inoculation, they have been incubated at 44.0˚±0.5˚C for 21± 3 hours. After incubation, indole presence has been verified by the addition of 0.2-0.3 mL of Kovacs reagent (Sharlau). Development of a rosewood-red colour on the surface of the culture medium indicates the presence of *E.coli* (Fig. 5).

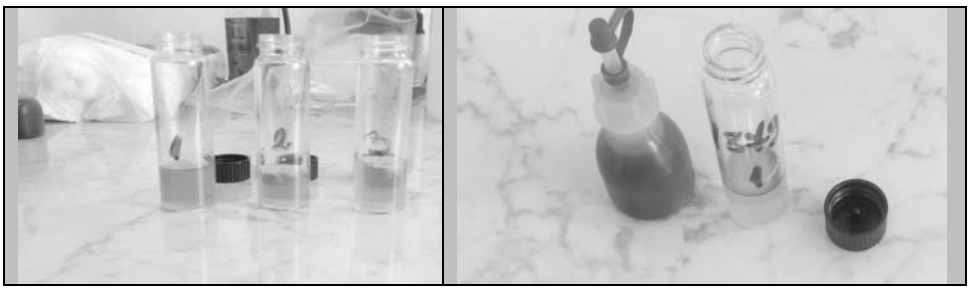

Fig. 5 – Indole test.

Fig. 6 – *E. coli* confirmation test.

c) Because some *Klebsiella oxytoca* strains also give positive indole results, β-glucuronidase test has also been performed. In this way, *E.coli* will give positive results (development of green-blue colonies), and *Klebsiella* will give negative results. For the confirmation test, Tryptone Bile X-Glucuronide (TBXG) has been prepared by weighing 31.6 g dry TBXG culture medium (Institut für Immupräparate und Nähr medien GmbH Berlin) and dissolving it under stirring in 1000 mL sterilised distilled water. After this step, the obtained dispersion has been sterilised in an autoclave at 121˚C for 15 minutes, cooled to room temperature and the pH has been adjusted at 7.2±0.2 at 25˚C. *E. coli* bacteria existence has been confirmed when the oxidase test is negative, indole test positive and green-blue colouring of the growth medium (fig. 6).

The obtained results have been expressed as colonies forming units (cfu).

2.2. NTG 37˚C and NTG 22˚C determination

The NTG parameter has been determined according to SR EN ISO 6222/2004, and offers a general view on the water contamination level because it quantifies a large number of microorganisms, such as all the aerobic bacteria, yeasts and moulds capable of forming colonies on agar-yeast extract culture media. The culture media has been prepared as following: 24g of dried Tryptone Yeast Extract Agar (Sharlau) has been dissolved in 1L of sterilised distilled water. The obtained dispersion has been autoclaved at 121˚C for 15 minutes, cooled to 25˚C and adjusted to pH 7.2±0.2. On each Petri dish, 1 mL of analysed water has been added, following the addition of 15-20 mL sterile culture media. The Petri dishes have been incubated at 37˚C for 48 hours (NTG 37˚C) and respectively at 22˚C for 72 hours (NTG 22˚C).

After the incubation period the results have been expressed as "cfu" (Fig. 7).

2.3. Turbidity determination

It is generally known that a high increase in turbidity of the drinking water indicates possible microbial activity, due to which the concentration of the microorganisms suspension prepared in the laboratory have as equivalents established levels of turbidity.[6-8] The turbidity of the stored water has been determined with a WTW 430 IR turbidimeter, according to SR EN ISO 7027 / 01.

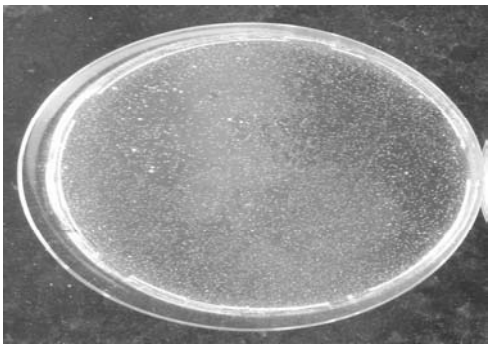

Fig. 7 – NTG 37˚C sampling.

2.4. Determination of the free and total chlorine

The determination of the free and total amount of chlorine has been performed according to SR EN ISO 7393-2 /2002 with DPD (*N*, *N*-diethyl-*p*-phenylenediamine) using a UV-VIS T60 spectrophotometer. The calibration curve has been performed according to SR ISO 8466-1 /1999.

RESULTS AND DISCUSSION

Aiming to determine the influence of stagnation period of drinking water in pipes, of pipe material quality and dimensions, of level of water chlorination on the microbial activity in stored drinking water, the following experiments have been performed:

1-firstly, the initial characteristics of the water used in the microbiological and physico-chemical experiments (turbidity, pH, conductivity, free chlorine, aluminum, nitrates, nitrites, ammonium, oxidability, sum of Ca^{2+} and Mg^{2+}, chlorides) have been determined.

2-The evolution of the microbial activity has been followed from different perspectives: a) the influence of different dimensional characteristics of PPR pipes- constant volume/constant surface; b) influence of the initial chlorination of water; c) turbidity variation during stagnation.

We have to mention that all the water quality parameters have been performed in triplicate, realizing a total number of 48 analysis for each parameter described at chapter 2, which means a cumulated amount of 240 results for the stagnant water.

a) The influence of different dimensional characteristics of PPR pipes on microbial activity of drinking water

a.1- Influence of different contact surface areas at constant pipes volume

When a constant water volume (150 mL) was stored for 9 hours in the three pipes with different diameters, an increase in the microbiological load has been registered with the contact surface increasing, as it could be seen in Table 2. At an increase of the contact surface with 30%, an increase with approximately 6% of NTG 37°C and with 26.6% of NTG 22°C have been noted. This aspect could be correlated to the biofilm formation on the pipe's interior surface. Increasing of biofilm amount led to bacteria growing.

a.*2*. *Influence of different pipes volumes at constant contact surface areas*

In the case of water stagnation in pipes with a constant value of the surface in contact with the water, the lack of any tendency in the micro-organisms development indicates that the volume variations affect in a lesser extent the microbial activity (Tab. 3). All the other parameters remained approximately constant. This result is in concordance with the former observation concerning the higher influence of the surface contact on the bacteria development.

Table 2

Variation in the water quality parameters for the non-chlorinated and chlorinated water (Sample 1), stagnated 9 hours at 22 ˚C in PPR pipes with constant volume and variation of surface contact

Level of chlorination	Surface cm^2	NTG 37°C cfu/mL	NTG 22°C cfu/mL	Coliform bacteria cfu/ 100 mL	*E. coli* cfu/ 100 mL	Turbidity NTU
non-chlorinated	428.610	53	39	2	absent	0.19
	333.468	51	34	4	absent	0.17
	300.184	50	29	2	absent	0.15
0.125 mg/L Cl_2	428.610	45	59	absent	absent	0.45
	333.468	20	38	absent	absent	0.39
	300.184	11	33	absent	absent	0.34
0.480 mg/L Cl_2	428.610	1	2	absent	absent	0.22
	333.468	absent	1	absent	absent	0.16
	300.184	absent	1	absent	absent	0.16

Table 3

Variation in the water quality parameters for the non-chlorinated and chlorinated water (Sample 2), stagnated 9 hours at 22 ˚C in PPR pipes with different volumes and constant surface contact

Level of chlorination	Volume cm^3	NTG 37°C cfu/ mL	NTG 22°C cfu/ mL	Coliform bacteria cfu/100 mL	*E. coli* cfu/100 mL	Turbidity NTU
Non-chlorinated	150.475	310	247	36	absent	0.39
	193.298	312	250	39	absent	0.39
	215.09	312	248	36	absent	0.36
0.128 mg/ L Cl_2	150.475	29	25	absent	absent	0.37
	193.298	29	23	absent	absent	0.37
	215.09	27	23	absent	absent	0.35
0.488 mg/ L Cl_2	150.475	absent	2	absent	absent	0.28
	193.298	absent	2	absent	absent	0.21
	215.09	absent	2	absent	absent	0.25

b) Influence of the initial level of water chlorination

The concentration of chlorine used for the water disinfection represents an important factor in the evolution of the microbial activity, so as at high concentrations of chlorine the water is protected from microorganisms. Still, even at this level, after 9 hours of stagnation, a low microbiological activity could be noted: low values for NTG 37°C and for NTG 22°C, only in case of the highest pipe surface exposed, and only low values for NTG 22°C for all tested volumes.

In contrast with the highly chlorinated water, the mild chlorinated water registered a noticeable increase in microbial activity and in the case of the non-chlorinated water, the increase has been considerable, as suggested from the examples presented in Table 4.

Table 4

Influence of chlorination level on the microbial development from the 9 hours stagnant water (Sample 2) at 22 ˚C in PPR pipes with variable diameters

Diameter cm	NTG 37°C cfu/mL	NTG 22°C cfu/mL	BC cfu/ 100mL	*E. coli* cfu/ 100mL	NTG 37°C cfu/ mL	NTG 22°C cfu/ mL	BC cfu/ 100mL	*E. coli* cfu/ 100mL
	V_{ct}				S_{ct}			
Un-Chlorinated water								
$Ø_{1.400}$	320	285	12	absent	310	247	11	absent
$Ø_{1.800}$	303	283	7	absent	312	239	11	absent
$Ø_{2.000}$	300	270	6	absent	311	212	12	absent
Chlorinated water 0.128 mg/L Cl_2								
$Ø_{1.400}$	30	28	1	absent	29	30	1	absent
$Ø_{1.800}$	27	25	1	absent	29	31	1	absent
$Ø_{2.000}$	26	24	1	absent	24	31	absent	absent

Table 4 (continued)

Chlorinated water 0.488 mg/L Cl_2								
$Ø_{1.400}$	3	1	absent	absent	3	2	absent	absent
$Ø_{1.800}$	2	2	absent	absent	2	2	absent	absent
$Ø_{2.000}$	0	2	absent	absent	3	2	absent	absent

The initial quality of the water subjected to stagnation is a key factor in the development of microbial activity. Thus, in the case of the highest quality water, at the highest level of chlorination, 9h of stagnation proved to be insufficient to establish an increase in the microbial activity with the variation of the surface or volume (approximately constant microbial activity) (Tab. 5). Still, after this stagnation period, it could be considered that the concentration of active chlorine is starting to decrease and the efficiency of the disinfection diminishes. The demand for chlorine is time dependent and represents the amount of chlorine used or consumed by the bacteria, algae, organic compounds and some inorganic cations, such as iron and manganese. Thus it is explained why the consumers from the beginning of the distribution network are supplied with a higher chlorine-content water than those from the end of the network. The time dependence is due to the fact that many of the reactions are not instantaneous, necessitating a certain amount of time for finalizing. Thus, the minimal microbial increase registered in the 9 hours of stagnation indicates the fact that in the interior of the pipe, oxidation of organic pollutants leached from the material of the pipe took place. The other pollutants coming from water oxidation is ruled out due to the low initial oxidabillity of water (< 0.6 mg O_2/L) and the amount of ammonium, nitrites, and nitrates under the detection limit. The phenomenon of minimal initial microbial activity is explained by the fact that the active chlorine, once entered in an oxidation reaction with other pollutants is reduced to the chloride anion (Cl^-) thus losing its activity. It is understood that a higher contact surface of water with the polymer material generates a higher amount of leached organic compounds from the pipe, involved in the reaction with chlorine.

It was also determined that for the non-chlorinated water with the lowest quality allowable by law (18 cfu for NTG at 37° C, 22 cfu for NTG at 22°C, 3 cfu for coliforms), the 9h stagnation represents a real risk of disease, given the final results which confirm coliforms and establish values of hundreds magnitude for NTG 37° C and 22° C. In these circumstances, an assessment of microbial activity according to the variation of the surface or volume could not be established, given the large uncertainty of the microbiological determintions and the relatively small variations of the contact surface or volume.

Table 5

Quality parameters (Sample 3) after 9hours stagnation at 22°C at a maximum level of chlorination

Pipe characteristics	**NTG 37°C (cfu)**	**NTG 22°C (cfu)**	**Coliform bacteria (cfu)**	***E.coli* (cfu)**	**Turbidity (NTU)**
Initial values	**0**	**0**	**0**	**0**	**0.09**
Constant volume 0.476 mg/L Cl_2					
Ø = 1.400 cm L = 97.500 cm S = 428.610 cm^2	1	1	0	0	0.15
Ø = 1.800 cm L = 59.000 cm S = 333.468 cm^2	1	0	0	0	0.12
Ø = 2.000 cm L = 47.800 cm S = 300.184 cm^2	1	0	0	0	0.15

Table 5 (continued)

Constant surface 0.476 mg/L Cl_2					
Ø = 1,400 cm L = 97,800 cm V = 150.475cm^3	1	0	0	0	0.12
Ø = 1,800 cm L = 76.000 cm V = 193.298cm^3	1	1	0	0	0.16
Ø = 2.000 cm L = 68.500 cm V = 215.09 cm^3	0	1	0	0	0.15

c) Correlation of microbial activity with water turbidity

The initial turbidity of water can be of chemical nature (colloids, undissolved matter) or of bacterial nature (bacteria in suspension or their metabolism byproducts). Both types of turbidity are undesirable in drinking water. Turbidity of chemical nature favors bacterial activity by the particles in suspension that become support for bacterial adhesion, offering a higher contact surface with water. The turbidity of biological nature is undesirable because bacterial proliferation is inavoidable, and also due to the eliminated toxins. In this case, neither boiling water, devoided of viable bacteria, is not safe in terms of health. In this study, it is noted that after the 9 hours stagnation, in all samples, the increase in turbidity was evident. In a statistical approach, the increase in turbidity was 100%, by comparing to the initial samples. Also, the intensity of microbial activity is dependent on the initial content of particles suspended in the water, expressed in terms of water turbidity (Fig. 8).

The advantage of the corelation with turbidity is represented by the opportunity to obtain quick information about the intensification of the microbial activity in water, since microbiological testing has a very long duration (3-4 days).

Given the results obtained in this study it could be assumed that morning water consumption without prior cleaning of the pipe is a real risk of disease. Moreover, stagnant water can lead to biofilm formation known as a good substrate for microbial activity. Under these conditions, a contamination-safe water can be obtained only after emptying the pipe network where water stagnates overnight, implying a very high water consumption. Moreover, for a more efficient washing, a higher-pressure water jet is required for removing the bacteria adhering to the walls of the pipe. In this way biofilm development time is greatly reduced.

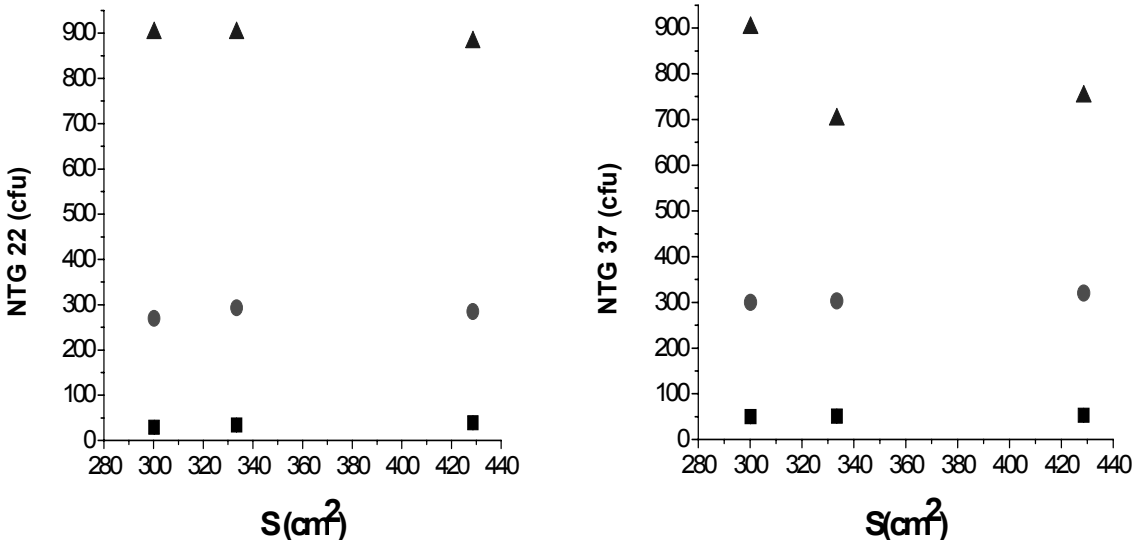

Fig. 8 –NTG 22 °C and NTG 37 °C evolution as a function of PPR surface contact after 9 h storing at 22 °C for non-chlorinated water, with different values of the initial turbidity: 0.09 NTU (■); 0.15 NTU (●); 0.25 NTU (▲).

CONCLUSIONS

PPR pipes allow the growth of microorganisms during water stagnation in the distribution network. The development of microorganisms is favored by the increase of the surface area of water contact with the pipe's material, by the PPR roughness, by the decrease in the concentration of free chlorine, and also by the presence of inorganic suspensions into the water. The 9 hours stagnation is enough to turn water into an unfit product for consumption. This study found that the simplest design of the home's water network distribution characterized by short liner PPR pipes having the smalest diameters could diminish the probability of bacteria growth. Increasing of water pressure into the pipes, due to the decrease of the pipe's diameter, will contribute to the biofilm destruction too, but this parameter is limited due to the limitation of mechanical resistance of the pipes and armatures. Taking into account the antagonism between the need of minimizing the PPR pipe's surface in contact with water and the water pressure increase due to the pipe's diameter decrease, a possible solution to diminish the microbial activity in stagnated water is the treatment of PPR surface material with an antimicrobial agent. This aspect is not being taken into consideration by the drinking water distributers because the state of the domestic network is the exclusive responsibility of its owners. Therefore, both the education of the population concerning the impact of different materials as well as of the drinking water network design on the water quality, combined with new materials research and development are necessary to ensure the sustainable development of society.

Acknowledgement: This work was partially supported by the strategic grant POSDRU/159/1.5/S/137070 (2014) of the Ministry of National Education, Roumania, co-financed by the European Social Fund –Investing in People, within the Sectoral Operational Programme Human Resources Development 2007-2013.

REFERENCES

1. G. Vasile, A. Catrangiu, G. Matau and L. N. Damian, *IWA-METAL 2013*, **2013**, November 6-9, Shanghai, China.
2. A. Aschengrau, J. M. Weinberg, P. A. Janulewicz, L. G. Gallagher, M. R.Winter, V. M. Vieira, T. F. Webster and D. M. Ozonoff, *Environ Health*, **2009**, *8*, 44.
3. J. G. Brody, A. Aschengrau, W. McKelvey, C. H. Swartz, T. Kennedy and R. A. Ruthann, *Environ Health: A Global Access Science Source*, **2006**, *5*, 28.
4. Buletin tehnic TCOO3 – Rezistența chimică a polipropilenei, **2006**, V1.1, copyright (c)VALROM Industrie srl (www.valrom.ro).
5. M. Katsikogianni and Y. F. Missirlis, *eCM Journal*, **2004**, *8*, 37.
6. J. J. Rojas, V. J. Ochoa, S. A. Ocampo and J. F. Munoz, *BMC Complement and Altern. Med.*, **2006**, *6*, 6:2 doi 10.1186/1472-6882-6-2.
7. J. A. K. Noumedem, J. D. Tamokou, G. N. Teke, R. C. D. Momo, V. Kuete and J. R. Kuiate, *SpringerPlus*, **2013**, *2*, 503.
8. J. D. Tamokou, D. J. Mpetga Simo, P. K. Lunga, M. Tene, P. Tane and J. R. Kuiate, *BMC Complement and Altern. Med.*, **2012**, *12*, 99.