Research Journal of Applied Sciences, Engineering and Technology 5(14): 3783-3790, 2013
ISSN: 2040-7459; e-ISSN: 2040-7467

Submitted: September 22, 2012 Accepted: October 09, 2012 Published: April 20, 2013

Effects Velocity Changes on the Water Quality in Water Distribution Systems

Hossein Shamsaei, Ir. Othman Jaafar and Noor Ezlin Ahmad Basri
Civil and Structural Engineering Department, Faculty of Engineering and Built Environment,
University Kebangsaan Malaysia, 43600 UKM, Bangi Selangor, Malaysia

Abstract: One of the parameter that could reason to decrease water quality in distribution system is velocity change in networks. This study is to analyze the effects velocity changes on the water quality in water distribution systems. We need to choose different locations that will be water quality and quantity relative too much. Location of the study has been in Ahwaz of Iran. There are two instances for the conduct of this analysis, local environment and Laboratory condition and this analysis had been done independently as far as the plants are concerned. The results showed that the distance travelled and residence time have been causing to increase bacterial growth (HPC), hydraulic change in water distribution system in Ahwaz so, velocity has a reversed relationship with bacterial growth (HPC). Velocity change has been causing to increase bacterial growth (HPC) so change Velocity has a direct relationship with residual chlorine. Velocity change has been causing to increase chlorine consumption more. Also, Kw hasn't any relationship with change velocity and bacterial growth (HPC) and change Velocity has a direct relationship with turbidity with the aid of the diagrams and Figures, the results of station sampling in the water distribution systems of Ahwaz have shown that the systems have large transmission line and have extensive networks.

Keywords: Bacterial growth (HPC), residual chlorine, velocity changes, water age and water distribution system, water quality

INTRODUCTION

One of the parameter that could reason to decrease water quality in distribution system is velocity change in network. Many researchers have been carried out about affects velocity change in the water quality in distribution systems, high residence time could cause decay of water quality as it had been responsible for increment in the rate of bacteria growth". In addition, he declared that "laminar flow causes deposits and hence corrosion". Codonya *et al*. (2005) the systems with vast transmission lines, high water residence time and long distance travelled that high velocity changes have increased DBPs. EPA (1992) the control of biofilm growth in drinking water in distribution systems. The bacteria growth is influenced by flow velocity, changes of velocity. Licia *et al*. (2006) also investigated bacteria growth. They concluded that changes in hydraulic, (velocity) could increase bacteria growth in distribution systems. Also, Delahayea *et al*. (2003) large transmission lines (distance travelled and residence time) high changes velocity there is an increase in HPC and chlorine decay, which causes microorganism's growth and Cohen (2002) further observed that changes of velocity cause turbidity, so the part of systems that has back flow or high velocity could increase turbidity in distribution systems, it is one of the important parameters for delivering water to customer. Piriou *et al*. (1997) conducted a pilot study on bacteria growth in the distribution systems. They used model of SAFEGE, changes velocity. The results demonstrated that hydraulic (velocity) and disinfection materials contribute to the increase of bacteria growth. Hallama *et al*. (2002) studied decay of chlorine (K_w, K_b), velocity and pipe material. In the booklet, Cerrato *et al*. (2006) carried if we wish to have higher water columns in distribution systems, it is necessary for the pressure in the distribution systems to be high. Ideally, pumps are required for this but will shackle the distribution systems, also the quality of water in the distribution systems decays over time. In addition, those components of distribution systems with laminar flow will develop deposits that increase corrosion, leakage and breakage. Volk (1999), the level of decay for chloramines is less than for chlorine. One of The important parameter related to bacteria re-growth is hydraulic agents. Guzzella *et al*. (2006) did a registered study in Italy on the detection of mutagens in water distribution systems after disinfection. They assessed water quality before and after the water treatment plant

Corresponding Author: Hossein Shamsaei, Civil and Structural Engineering Department, Faculty of Engineering and Built Environment, University Kebangsaan Malaysia, 43600 UKM, Bangi Selangor, Malaysia, Tel.: 0060122847323

from three sampling stations. One of these was in a water treatment plant and the other two in the water distribution system. Their results suggest that changes in bacteria growth patterns in the distribution system depend on changes in hydraulics (velocity), pH, temperature, water age, piping materials and chlorine residuals. Soini *et al*. (2002) did a study on bacteria growth (HPC) with various changes of velocity within the distribution system reporting that velocity rates do not cause bacteria growth in distribution systems. Also, Janis *et al*. (2007) causes for bacteria growth are velocity, disinfection materials, temperature, nutrient material and deposits and systems with distance traveled and higher flows with lower chlorine levels have increased bacteria re-growth. EPA (1992) increased bacteria growth in the water distribution systems have been product height volume of water in the water treatment plan**.** It refers to, high velocity flow rates, velocity changes in the distribution systems, that reasons for changes in velocity in the system has been about the lack of careful designing, also the height level of the flow in the system, the opening and closing the valves had effects on cross-connections, so that the hydraulics in water distribution systems have given cause for increased bacteria growth. They went further to say that the effects of hydraulics and bacteria growth on biofilm haven't been easily related and that many parameters involve pipe design, high velocity flow rates and conditions of terminal demands. Cohen (2002) wrote a book about various problems with water distribution systems. He reports that turbidity is a reason for taste, odor and clouded potable water. He suggests that changes in velocity cause turbidity. Petr *et al*. (2006), that population growth and greater consumption equals the demand for a greater product so that the loss of water can be avoided utilizing the model EPAENT; reminding us that water supply will be limited for customers. They offered a formula for relation between hydraulics changes and demand. Mustonena *et al*. (2008) carried out a study on changes of Hydraulic (flow, pressures and velocity) and their effects on water quality. They considered various flows and pressure and showed that changing the velocity could increase turbidity and corrosion in distribution systems. However, with due attention to problems of water quality and quantity in distribution, This study is to analyze the effects velocity changes on the water quality in water distribution systems.

MATERIALS AND METHODS

This study is to analyze the effects velocity changes on the water quality in water distribution systems. Choosing location and sampling time is very important because we need to choose different locations that will be water quality and quantity relative too much. Location of the study has been in Ahwaz of Iran and we have done on 2009.

Ahwaz city is at the center of the province of Keaston, as shown Fig. 1 It is located in south west of Iran. Ahwaz is situated on a wide expanse of land of about 17000 hectares and with population of about 1,300,000. Ahwaz has five water treatment plants. Two of the plants are major ones while the rest are just minors and it has about 186 km of water transmission line and about 2260 km of water distribution line (Fig. 1). In Ahwaz, two methods will be utilized. In the first method, samples will be taken from different locations in other to examine the quality of water in the distribution systems and the other method involves the use of simulation of models EPANET. Five (5) different locations will be considered in Ahwaz as follows: A1 (water treatment plant), A2 (middle line), A3 (middle line), A4 (finish line) and A5 (end deadline). In addition, the time of taking samples to be considered are during maximum consumption peak, this means, between to 8 am, 11 am to 15 and 19 pm to 22 pm. Also, the minimum consumption time; this means, at 8 to 11 am, between 15 to 19 and 22 pm to 5am. Samples were taken over a period of 60 days (8 weeks) and 450 samples were taken over this period in Ahwaz i.e., 6 (six) times at five locations, 360 samples were taken i.e., 6 (six) times at four locations. There are four reservoirs in Ahwaz and they are in the north eastern part. Three of them are of 50, 000 m^3 in capacity while the fourth one's capacity is 10,000 m^3. The reservoirs are useful during the period of maximum consumption and they guarantee supply of water to all parts of the town and the adjacent township. The total output of water in Ahwaz is about 637, 000 m^3/day, and the chlorine concentration of water before leaving the plants is between 1.2-1.5 mg/L.

Analysis and comparison experiment: This study also presents experiments based on impact changes on water quality as it affects distribution systems. The parameters to be examined are pressures, velocity, (heterotrophic plate count (HPC), Turbidity, Total coli form Bulk Coefficient (Kb),Wall Coefficient (Kw) and chlorine residual.

Effect of area under analysis: There are two instances for the conduct of this analysis.

- Local environment
- Laboratory Condition

Effect of parameters such as velocity, Turbidity, residual chlorine and Temperature on a local area will be considered the while the effects of HPC, THMs, K_b and K_w under laboratory conditions will also be examined. Some qualitative and quantitative parameters

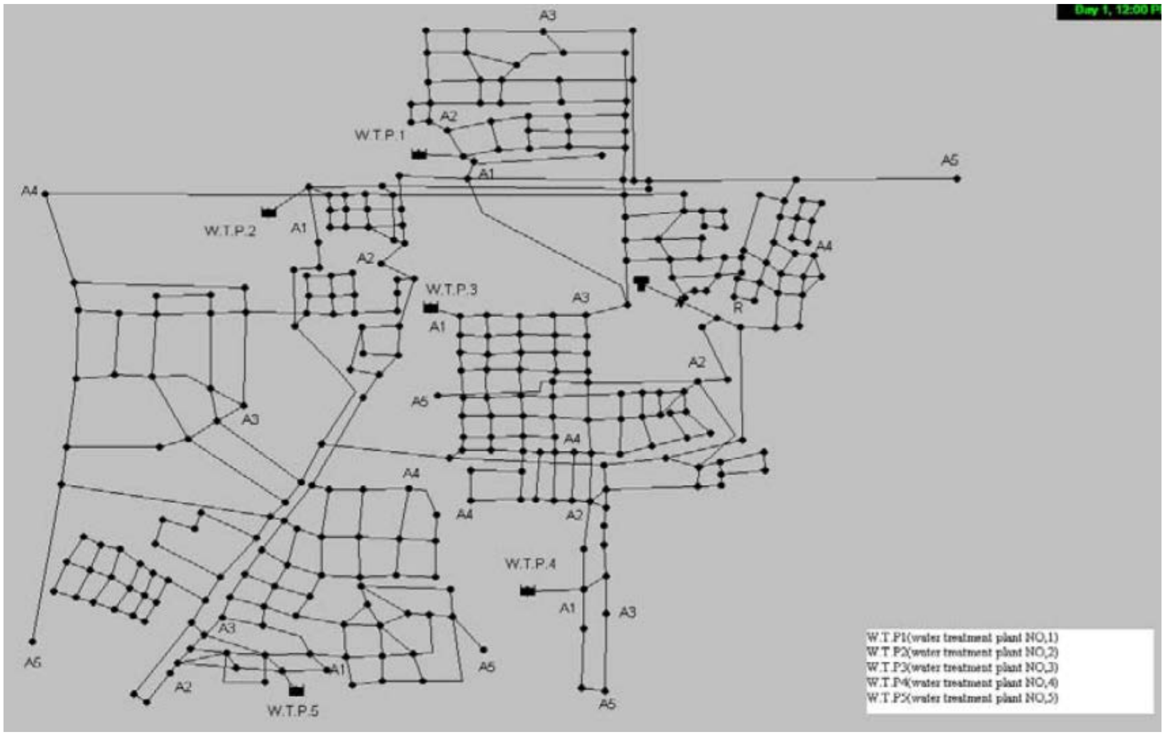

Fig. 1: The map of the water distribution in Ahwaz

Table 1: Information of in the water distribution system with due attention to locations in Ahwaz

Part	HPC (cfu/mL)	Turbidity (NTU)	CL(mg/L)	P m	Vm/s^2	THMSMg/L	Tol-Coli MPN/100 mL	T°C	Kb l/day	Kw l/day	Q m^3/s
A1 (AVG)	15.7	5.48	1.2	58	2.65	120	0	21	0.3	0.3	1.06
A2 (AVG)	57	5.38	1	45	1.45	169	3	23	0.33	0.4	0.44
A3 (AVG)	390.5	3.95	0.6	20	1.2	142	2	26	0.33	0.46	0.29
A4(AVG)	2552	1.8	0.4	10	0.6	121	1	25	0.38	0.6	0.20
A5 (AVG)	2820	2.37	0.6	0	0.3	131	2	26	0.34	0.4	0.09

Table 2: Information of peak maximum and peak minimum with due attention to locations in Ahwaz

	Peak flow (5-8, 11-15, 19-22)					Peak off (8-11, 15-19, 22-5)				
	A1	A2	A3	A4	A5	A1	A2	A3	A4	A5
CL (mg/L)	1.2	1	0.6	0.6	0.4	1.1	1	0.7	0.6	0.5
NTU (ppm)	5.38	5.48	3.95	1.8	2.37	5	5.1	3.1	1.2	2.5
pH	6.73	6.76	6.86	7.2	7.3	6.94	6.98	7.1	6.9	7.42
HPC(cfu/mL)	19.6	55	261	1721	2560	23.4	89	650	3250	3970
Pressure (m)	58	30	15	15	10	58	35	20	20	10
Conductivity (Ec)	1765	2350	2330	3140	3420	2100	2650	2460	2530	2347
T °C	20	21	25	24	28	22.5	24	27	25	26

will be considered and a comparative study will be undertaken, this will include local sampling and some laboratory activities and the results will be obtained with the help of analysis involving the use of EPANET model. Comparative qualitative and quantitative study has been selected for Ahwaz region.

RESULTS

The result of velocity changes among others can be water aging Table1 and 2, decrease in chlorine content and hydraulic factors, because the systems may be extensive and thus possess complex networks. Changes in quantity cause velocity of flow. As earlier said, area considered in this study, this will include local sampling and some laboratory activities and the results will be obtained with the help of analysis involving the use of EPANET model. According to Fig. 2 which shows the velocity in the water distribution network of Ahwaz, the velocity had been on the decline in the distribution system large the way, changes level have been between 0.3 to 2.65 m/s in Ahwaz. Minimum velocity was at the finale of the network and maximum velocity was at the beginning of distribution system. Maximum velocity was at A1, 2.65 m/s at the beginning of the network and minimum velocity was at A5 0.3 m/s at t he dead end of the distribution system.

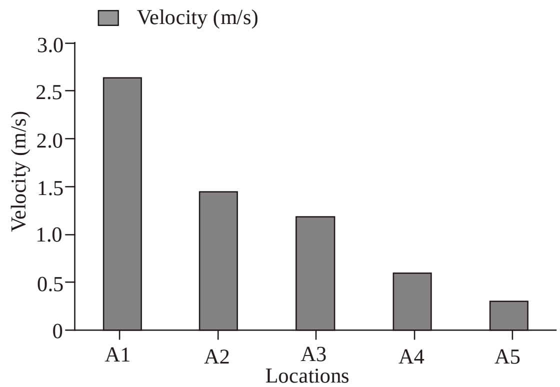

Fig. 2: Flow velocity at various locations in Ahwaz

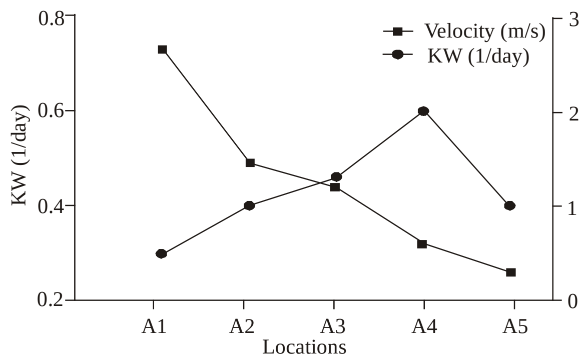

Fig. 3: The realationship between KW and velocity in Ahwaz

V	Kw
2.65	0.3
1.45	0.4
1.2	0.46
0.6	0.6
0.3	0.4

	Kw	V
Kw	1	
V	-0.675775025	1

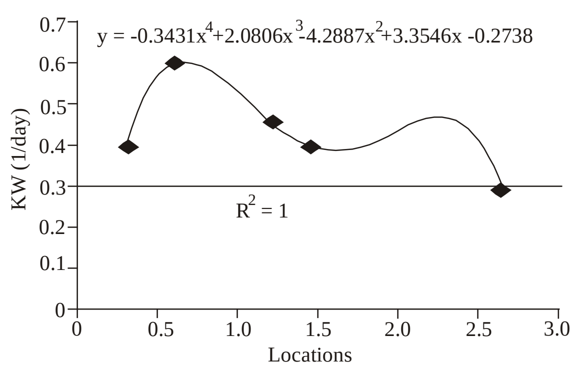

Fig. 4: The correlation and regression between KW and velocity in Ahwaz

Maximum velocity was at A1, 2.65 m/s at the beginning of the network and minimum velocity was at A5 0.3 m/s at the dead end of the distribution system.

The relationship between K_w (wall coefficient) and velocity: Figure 3 shows the relationship between Kw and velocity in the water distribution network of Ahwaz. The value of Kw increases as velocity decreases in distribution system. This is an inverse proportional relationship. However, if the value of Kw were to increase, the parameters that will be taken into considerations are Hydraulics, water age, pipe age and pipe material. And according to Fig. 4 shows relationship between Kw and velocity. The Figure showed Kw has a reversed relationship with velocity. Decreasing velocity was effecting to increase Kw in Ahwaz system. One of the reason, was low velocity (zero) and the Kf haven't been using chlorine, or maybe Decreasing the Kw have been using PVC of the pipe in the A5 (end dead) and the Kw haven't been using chlorine in the area, another of the factor, chlorine couldn't penetrate to bio film of layers. Because the rate of HPC was high in the parts (A5) and rate of the residual chlorine was high, so the chlorine consumption was low in A5 (end dead). According to the results in Fig. 5 which shows the relationship between velocity, Kw and residual chlorine in the distribution system in Ahwaz, residual chlorine has a reversed relationship with Kw in the distribution system nearly. This indicates that increased velocity leads to reduction in residual chlorine value. The maximum level of Kw was found as 0.6/day at A4, while the minimum level of Kw was 0.4/day at A5 (end dead). Residual chlorine value was found to be very high when the velocity was at maximum.

Relationship between velocity, NTU and pressure: The results in Fig. 6 which shows the relationship between NTU, velocity and pressure in water distribution system in Ahwaz, rate of velocity, pressure and NTU level was decreasing to with distance travelled of water in the system. Pressure was almost zero in distribution system at point A5. The maximum level of velocity is 2.65 m/s in A1 and minimum velocity was0.3 m/s at A5 (dead end). Many times, velocity has a much lower rate. Also, NTU according to with distance travelled of water in the system have decreased but between points A4and A5 (end dead), NTU have increased. The result shown in Fig. 7 gives the relationship between velocity, K_w and residual chlorine in the distribution system in Ahwaz.

Hydraulic changes were causing others for chlorine consumption effectively. Figure 8 show relationship between hydraulic changes and residual chlorine. The Figures showed Hydraulic changes (velocity) have a direct relationship with rate of the residual chlorine, but the pressure was effect more than velocity to decrease residual chlorine. The results of this regression that decreasing the residual chlorine when velocity was

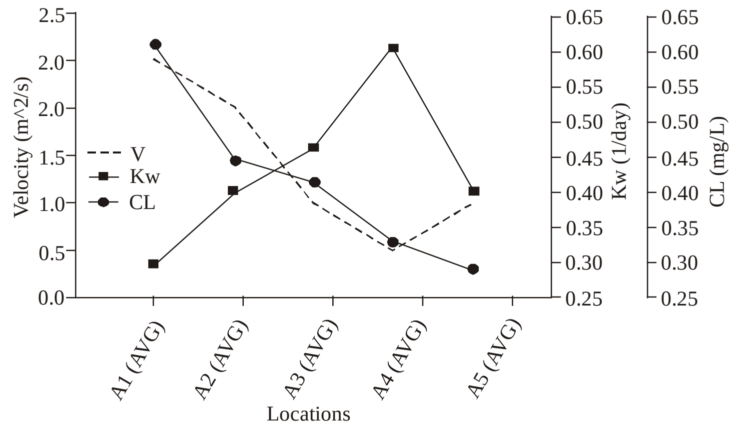

Fig. 5: The relationship between KW and velocity and residual chlorine in Ahwaz

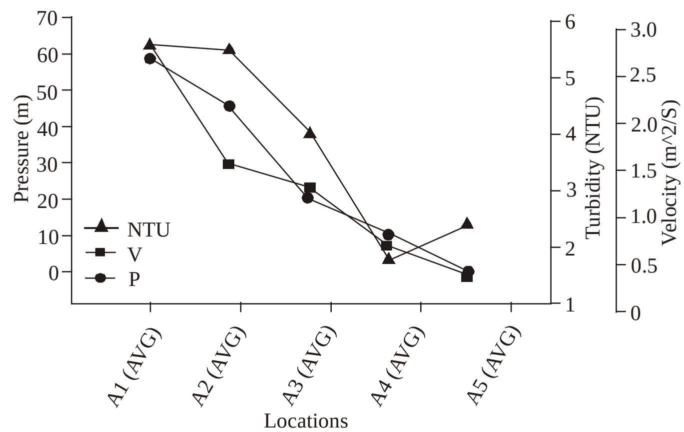

Fig. 6: The relationship between velocity and NTU and pressure in Ahwaz

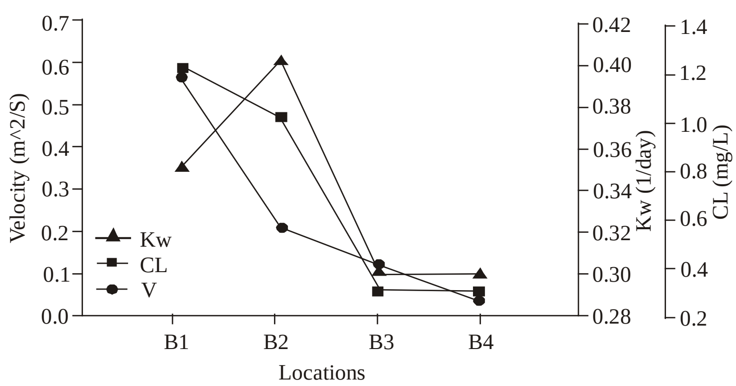

Fig. 7: The relationship between KW and velocity and residual chlorine in Ahwaz

between 2.65 to 0.6 m/s and after that increasing the residual chlorine when velocity was between 0.6 to 0.3 m/s. Maybe one of the reason that increasing the residual chlorine was low velocity in the end dead and decreasing Kf in the area. Another of the factor that could cause increasing HPC in Ahwaz system was high hydraulic changes. Figure 8 and 9 shows relationship between HPC and velocity and pressure. The Figures showed bacterial growth (HPC) has a reverse relationship with velocity and pressure nearly. Decreasing pressure in Ahwaz system were cause increasing HPC.

V	CL
2.65	1.2
1.45	1
1.2	0.6
0.6	0.4
0.3	0.6

	V	CL
V	1	
CL	0.882505445	1

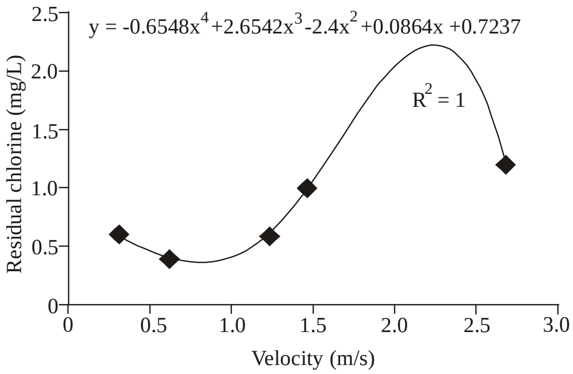

Fig. 8: The correlation and regression between velocity and residual chlorine in Ahwaz system

V	HPC
2.65	15.7
1.45	57
1.2	391
0.6	2552
0.3	2820

	HPC	V
HPC	1	
V	-0.836793636	1

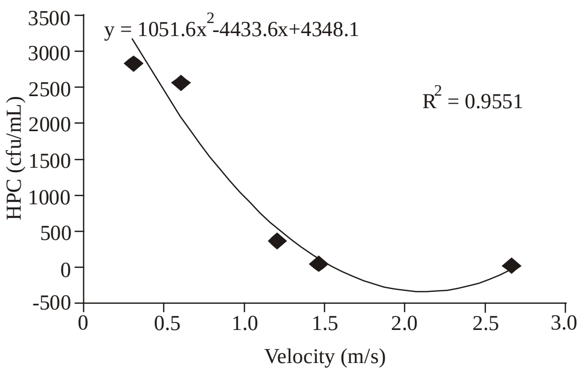

Fig. 9: The correlation and regression between hpc and velocity in Ahwaz system

DISCUSSION

Hydraulic changes (velocity) will be too much in the big network and long transmission lines. High velocity could cause increased turbidity and corrosion rate in the water distribution system and could lead to decline in water quality in the distribution systems. The high turbidity makes chlorine lose its efficiency even if residual chlorine is high. This happens because when turbidity is high, coli forms will be attached to the particles and chlorine would not be able to reach and kill the bacteria. EPA (1992) opined that high velocity has been responsible for increased bacterial growth in

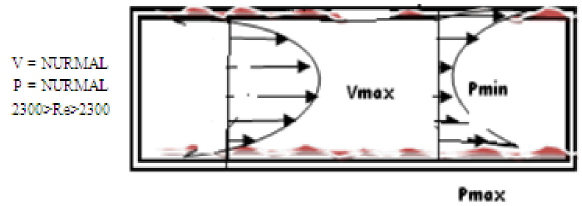

Fig. 10: Normal flow [2300 ≤ RE≤ 2300]

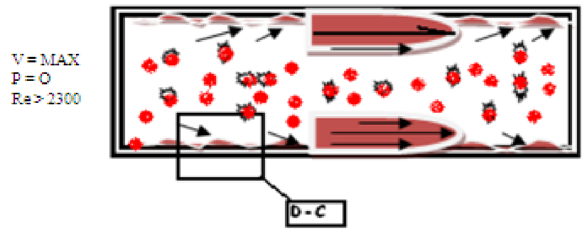

Fig. 11: Turbulent flow [RE> 2300]

the distribution system, but in itself cannot be correct, because high velocity alone cannot cause bacterial growth. However velocity could increase turbidity. High velocity has been responsible for the separation of bacteria from the pipe wall, the volume of bacteria will increase in those parts and once this happens, chlorine consumption will be high and may not be enough to be effective over the required area. Alternatively, high turbidity could cause the chlorine content couldn't decrease the bacterial in the distribution systems. Janis *et al*. (2007) argued that high velocity may not prevent the bacterial growth, or even restrict them, but it could keep biofilm layers to certain thickness. According to the results of this study, high velocity had been responsible for bacterial count in the water distribution system. High velocity is an important factor for flushing pipes in systems and distribution networks. When system washing is successful, the velocity can separate bacteria (bio film) and particles from pipe walls. High velocity supplies shear force between the pipe wall and water flow. At any velocity, if the sheer force increases, the volume of the flow will be lower, Washing of pipes has improved the water distribution systems. Castorina and Jegatheesan (2002) observed that low velocity will cause deposition in the systems and distribution network.

In the distribution system of Ahwaz, there are two forms of energy; Kinetic and Potential energy. Potential energy has been responsible for the increased deposition in the water distribution system in Ahvaz. And due to the high kinetic energy, there has been increased turbidity in the distribution system caused by the presence of shear force between the flow of water and pipe walls. The high potential energy has been the cause of increased corrosion and growth of bio film and deposits in pipe wall, though these could also be traced

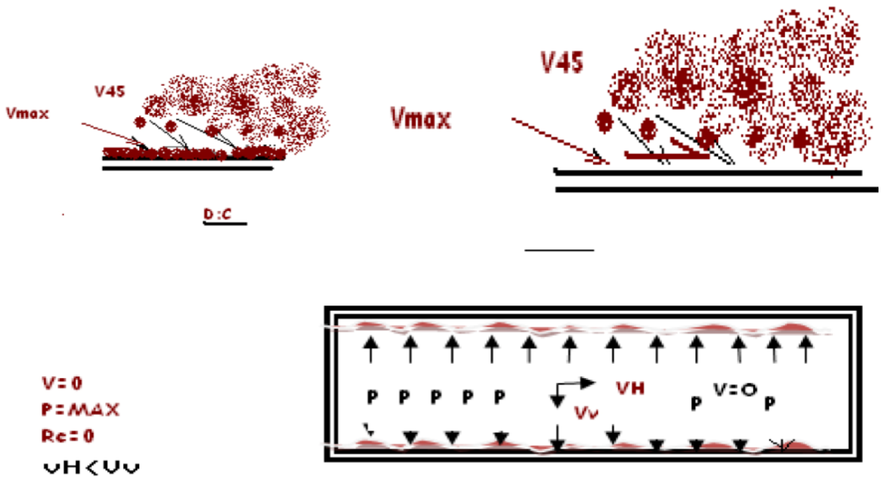

Fig. 12: Laminar flow [RE< 2300]

to material and age of pipes. The corrosion rate of steel and cast iron pipes is more than that of polyethylene pipes. And also, if the potential energy is high, velocity will be zero in the water distribution system and this brings about deposits which eventually cause corrosion in the system. Both instances of high and low velocity i.e., kinetic and potential energy respectively can initiate corrosion in the distribution system. Chlorine consumption needs to have normal velocity in the water distribution systems. In water distribution systems and networks. According to the results of Ahvaz during 12 to 6 am which show a off flow rate, At this time, according to the results rate of residual chlorine was low(chlorine consumption have been very much the same), whereas bacterial growth was increasing in the water distribution in Ahwaz. It means, the chlorine couldn't cause to decreasing bacterial growth (Bulk coefficient (Kb)). At this time level the velocity will be low and more chlorine will be spent in the pipe wall (wall coefficient (Kw)). According to the results of Ahvaz during peak flow rate, chlorine consumption has been lower than off flow rate. So, the chlorine has decreased bacterial growth much than at off flow rate and at this time the chlorine was using for decreasing bacterial growth (Bulk coefficient (Kb)).

Velocity and pressure could be through three forms: Normal flow (Fig. 10), turbulent flow (Fig. 11) and laminar flow (Fig. 12). Alternatively, with due attention to Fig. 10, velocity and pressure profiles have been in the normal state. The maximum velocity profile was in the center pipe and the maximum pressure profile is at the wall. The relationship is reversed between pressure and velocity which is the best situation for the network systems and water distribution system. Throughout the system and with regard to Fig. 11 the level of the velocity has been high. At low Pressure, the flow is turbulent. Figure10 shows Normal flow ($2300 \leq Re \leq 2300$) and maximum speed profiles were found from the center of the pipe wall. The amount of chlorine consumption and turbidity are at the maximum level. This might be one of the best circumstances for washing purposes in a water distribution systems and network. According to Fig. 11, the velocity rate has been zero. The water is in a static state. And pressure in the situation is in form of potential energy. In this case, due to the effects of forces of gravity, the particles will attach the pipe to the wall and the amount biofilm sediment grows remarkably. High amount of chlorine could help increasing the speed of deposit in pipes. Decay of chlorine will require more biofilms in the system. Most of the times, there have been situation of high residence time and a reduced velocity in the water distribution system of Ahwaz. And the best method is shown in Fig. 10. Using Sherwood formula and given that Reynolds number i.e., $Re < 2300$, only decay of Chlorine will be expended in relation to K_w (wall coefficient) more than in Kb (bulk coefficient) and K_f and while chlorine consumption for K_w. because at this time velocity is low. However, If Reynolds number is $Re > 2300$, only decay of the Chlorine will be more reflected in Kb (bulk coefficient) and K_f than K_w (wall coefficient) also chlorine consumption K_w (wall coefficient) will be low. And the best velocity for chlorine consumption is when the Reynolds number is between $2300 \leq Re \leq 2300$ in the water distribution network system.

CONCLUSION

Hence low and high velocity could affect of water quality in the water distribution system. The system in Ahwaz have quite a few hydraulic changes, thus many points have negative pressure in the distribution system there. High velocity could cause high turbidity and increase corrosion rate in the water distribution system while low velocity will increase bacterial growth, depositions and corrosion rate.

The system was partitioned to five separate entities (plants) and each entity had been analyzed on the basis of qualitative and quantitative parameters vis-a-vis velocity and pressure and volume of consumption. This analysis had been done independently as far as the plants are concerned. The results showed that changes have occurred regarding the status of quantitative and qualitative attributes within the system. Some of the changes are:

- The distance travelled and residence time have been causing to increase bacterial growth (HPC), chlorine consumption and hydraulic change in water distribution system in Ahwaz
- Velocity has a reversed relationship with bacterial growth (HPC). Hydraulic change has been causing to increase bacterial growth (HPC)
- Change Velocity has a direct relationship with residual chlorine. Hydraulic change has been causing to increase chlorine consumption more
- Kw hasn't any relationship with change velocity, pressure and bacterial growth (HPC)
- Change Velocity has a direct relationship with turbidity

ACKNOWLEDGMENT

First and foremost I am very grateful to my supervisor Ir. Dr. Othman Jaafar who supported me all the time during the project. I would also to thank Dr, Noor Ezlin Ahmad Basri for endless support and encouragement during my study.

REFERENCES

Castorina, J. and V. Jegatheesan, 2002. Corrosion Impact on Drinking Water Distribution Systems a Review and Future Research Direction. School of Engineering Janes Cook University Townsville, QLD4811, Australia.

Cerrato, J.M., L.P. Reyes, C.N. Alvarado and A.M. Dietrich, 2006. Effect of PVC and iron materials on Mn (II) deposition in drinking water distribution systems. Water Res., 40(14): 2720-2726.

Codonya, F., J. Morato and J. Mas, 2005. Role of discontinuous chlorination on microbial production by drinking water biofilms. Water Res.,39(9): 1896-1906.

Cohen, Y.C., 2002. Problems in Water Distribution: Solved, Explained and Applied. C.RC. Press, LLC, New York, London, pp: 133-143.

Delahayea, E., B. Welteb, Y. Levic, G. Montielb and A. Leblond, 2003. An ATP-based method for monitoring the microbiological drinking water quality in a distribution network. Water Res., 37(15): 3689-3696.

EPA, 1992. Control of Biofilm Growth in Drinking Water Distribution Systems. EPA/625/R-92/001June, pp: 1-33.

Guzzella, L., F. Di Caterino, S. Monarca, C. Zani, D. Feretti, I. Zerbini, G. Nardi, A. Buschini, P. Poli and C. Rossi, 2006. Detection of mutagens in water-distribution systems after disinfection. Mutat. Res., 608(1): 72-81.

Hallama, N.B., J.R. West, C.F. Forstera, J.C. Powell and I. Spencer, 2002. The decay of chlorine associated with the pipe wall in water distribution systems. Water Res., 36: 3479-3488.

Janis, R., J. Talis, H. Lars and K. Andreas, 2007. Methodology of modeling bacterial growth in drinking water systems. TECHNEAU, D5.5.4 (March 2007), pp: 11-28.

Licia, M.P., M.R. Cintia, D.B. Mario and R.C. Guillermo, 2006. Catalytic properties of lipase extracts from *Aspergillus niger*. Food Technol. Biotechnol., 44(2): 247-252.

Mustonena, S.M., S. Tissaria, L. Huikkoa, M. Kolehmainena, M.J. Lehtolab and A. Hirvonena, 2008. Evaluating online data of water quality changes in a pilot drinking water distribution system with multivariate data exploration methods. Water Res., 42: 2421-243.

Petr, I., S. Zdenek, P. Ajay and T. Ashok, 2006. Modelling Intermitten water supply systems with EPANET. 8th Annual WD Symposium EPA Cincinnati, August, pp: 27-30.

Piriou, P., S. Dukan, Y. Levi and P.A. Jarrige, 1997. Prevention of bacterial growth in drinking water distribution systems. Water Sci. Technol., 35(11-12): 283-287.

Soini, S.M., K.T. Koskinenb, M.J. Vilenius and J.A. Puhakkaa, 2002. Effects of fluid-flow velocity and water quality on plank tonic and sessile microbial growth in water hydraulic system. Water Res., 36: 3812-3820.

Volk, C.J., W.M. Mark and W.A. Lechevallier, 1999. Impacts of the Reduction of Nutrient Levels on Bacterial Water Quality in Distribution Systems. American Water Works Service Co. Inc., Belleville, Illinois 62220,1 and American Water Works Service Co. Inc., Voorhees, New Jersey 080432, pp: 4957-4966.