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New Methodology for Losses Determination in Water Distribution Networks

By:

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Abstract:

The problems associated with water loss are numerous. High real losses indirectly require water suppliers to extract, treat, and transport greater volumes of water than their customer demand requires. The additional energy needed for treatment and transport taxes energy-generating capabilities which often rely upon large quantities of water in their process. Leaks, bursts, and overflows often cause considerable damage and inflate liability for the supplier.The main objective of the current research is to find the direct relationship between the losses in water distribution networks and the residual chlorine. The experimental program is designed to monitor the losses in water distribution networks and how it can be related to the residual chlorine in a certain part of an existing network. For this purpose, a certain measurements on a part of a water network in Nasr-City, Cairo, Egypt have been made to find residual chlorine relationship with time and pipelines lengths and amount of leakage. The field measurements of both the rate of flow and the value of the residual chlorine at different locations and at consecutive intervals of time were carried out through three steps (runs). The first run for a single pipeline, the second step for three pipelines while the third run for the whole part of the network (nine pipelines).Two main equations are concluded from this field measurements and analysis. Equation (1) represents the relationship between residual chlorine, time and pipeline length, and equation (2) represents the relationship between residual chlorine and leakage with pipeline lengths. The results from these equations verification showed that, deviation percent between field measurements and the application of the equations is minor and within allowable rate.

Keywords:

Water losses, residual chlorine

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1. Introduction:

Water loss occurs in all distribution systems, only the volume of loss varies. This depends on the characteristics of the pipe network, the water provider's operational practice, and the level of technology and expertise applied to control it and other local factors. The volume of the losses varies widely from country to country, and between different regions within a country. One of the keystones of a water loss strategy is to understand the relative significance of each of the components, ensuring that each is measured or estimated as accurately as possible, so that priorities can be set via a series of action plans. Old or poorly constructed pipelines, inadequate corrosion protection, poorly maintained valves and mechanical damage are some of the factors contributing to leakage. Leak detection has historically assumed that all, if not most, leaks rise to the surface and are visible. In fact, many leaks continue below the surface for long periods of time and remain undetected. With an aggressive leak detection program, water systems can search for and reduce previously undetected leaks. Water lost after treatment and pressurization, but before delivered for the intended use, is water, money and energy wasted. Accurate location and repair of leaking water pipes in a supply system greatly reduces these losses. Once a leak is detected, the water utility must take corrective action to minimize water losses in the water distribution system. In drinking water utilities, a strict control of residual chlorine levels is required during the treatment process and within the distribution system. Chlorine doses applied during water treatment are in many cases adjusted manually according to the information on residual chlorine measured downstream from field sampling or on-line monitors .The control of water quality, is important to estimate the evolution of water quality from the treatment plan to the consumers tap. During the water transportation through the distribution network, the residual chlorine concentration should ensure microbiologically safe water quality. The residual chlorine concentration diminishes due to the reactions within the pipeline and outwardness from leakage in the pipe line. Every water system in the world has a certain volume of real losses, and it is well known among leakage practitioners that water losses cannot be eliminated completely, and even in newly commissioned distribution networks there is a minimum volume of real losses. However, it is also well known and proven that real losses can be managed so that they are within economic limits. The problems associated with water loss are numerous. High real losses indirectly require water suppliers to extract, treat, and transport greater volumes of water than their customer demand requires. In order to find an easy and quick way to determine leakage in water supply networks and if any a little rate of keying error, the present study has been setup and conducted.

2. Materials and methods:

2.1 Study Concept

The objective of this research is to predict and evaluate the water losses in water distribution networks by measuring the residual chlorine, then establishing a direct relationship between the water losses and the measured residual chlorine. Field investigations have been carried out in a selected part of on existing water distribution network lines in Nasr City, Cairo, Egypt which serves a small group of residential buildings. This part is connected to the main network via two control valves as shown in figure (1). The selection of this part of the network was based on the facility of field measurement without disturbing the habitants in this area. The part of the network chosen for investigation composed of nine pipelines of different length as show in figure (1). The field measurements of both the rate of flow and the value of the residual chlorine at different locations and at consequetice intervals of time were carried out through three steps (runs).The first run for a single pipeline, the second run for three pipelines while the third run for the whole part of the network (nine pipelines).figures (1, 2, 3, 4).

2.2 Program Steps

Each run was performed in two consecutive days where the measurements started in the midnight. The whole work was conducted in three weeks, one for each individual run. The steps of work for any pipeline were scheduled as follows:
(a) First the domestic and fire hydrants were completely closed.
(b) The flow rate and the residual chlorine were measured in the inlet and outlet of each individual pipeline, three times every ten minutes.
(c) One of the fire hydrants was partly opened to illustrate the leakage conditions, where the measurements were carried out three times every 20 minutes at the same locations.

2.3 Methods of measurement

The two parameters of this research namely, the rate of flow and the residual chlorine were measured using:
(1) Magnetic flow meter (PT878) for measuring the rate of flow in litre/second
(2) Chlorine detector meter (RC-24P) for measuring value of the residual chlorine in mg/litre

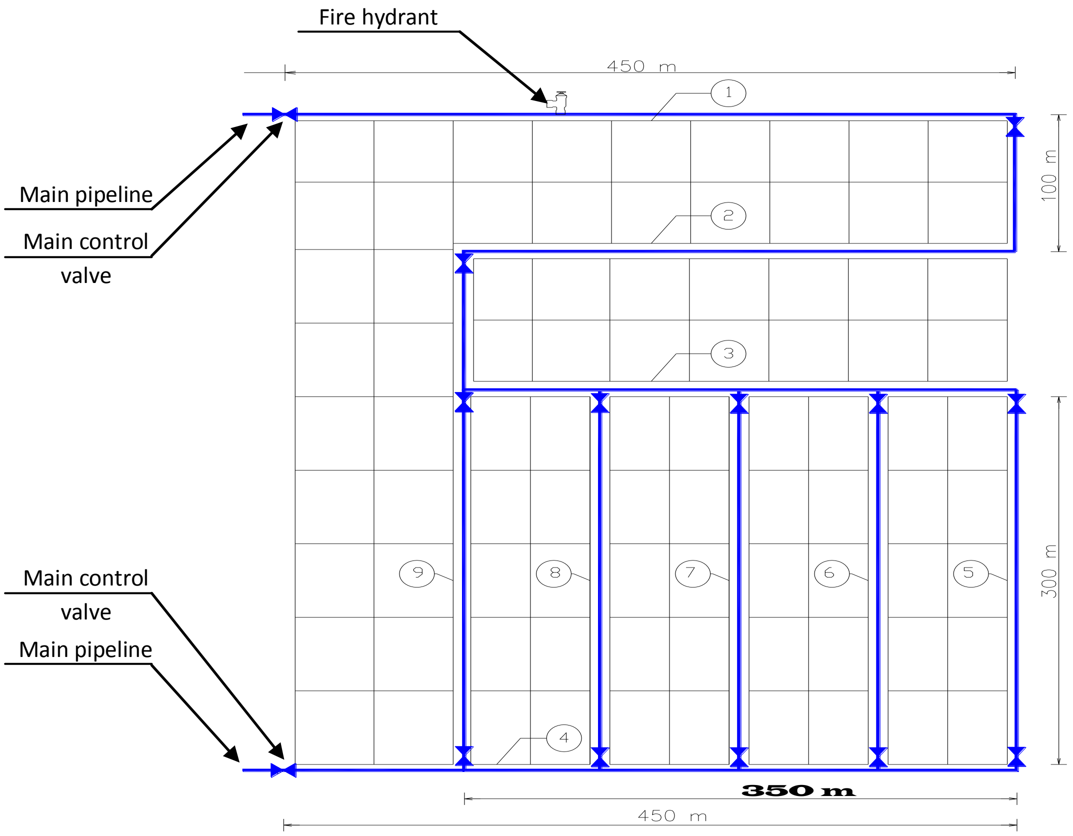


Figure (1): *Study network in Nasr-City water distribution network*

3. Results:

3.1 Results of run I

This run was made on only one 200 mm diameter pipeline of length 450m as shown in figure (2) by measuring the inlet and the outlet discharges, where all the house connections and the fire hydrants are closed. The measuring of residual chlorine was also made at the inlet and outlet of the pipeline. After three readings at time interval 10 minutes, one of the hydrants was partially opened to leak water from the pipe line during measuring of both discharge and residual chlorine at time interval 20 minutes. Table (1) illustrates the results of measurements.

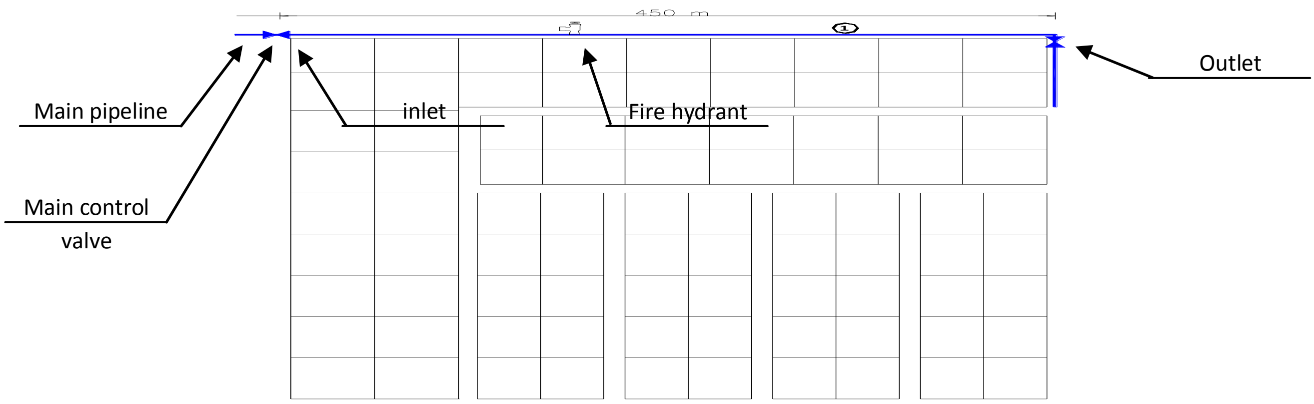


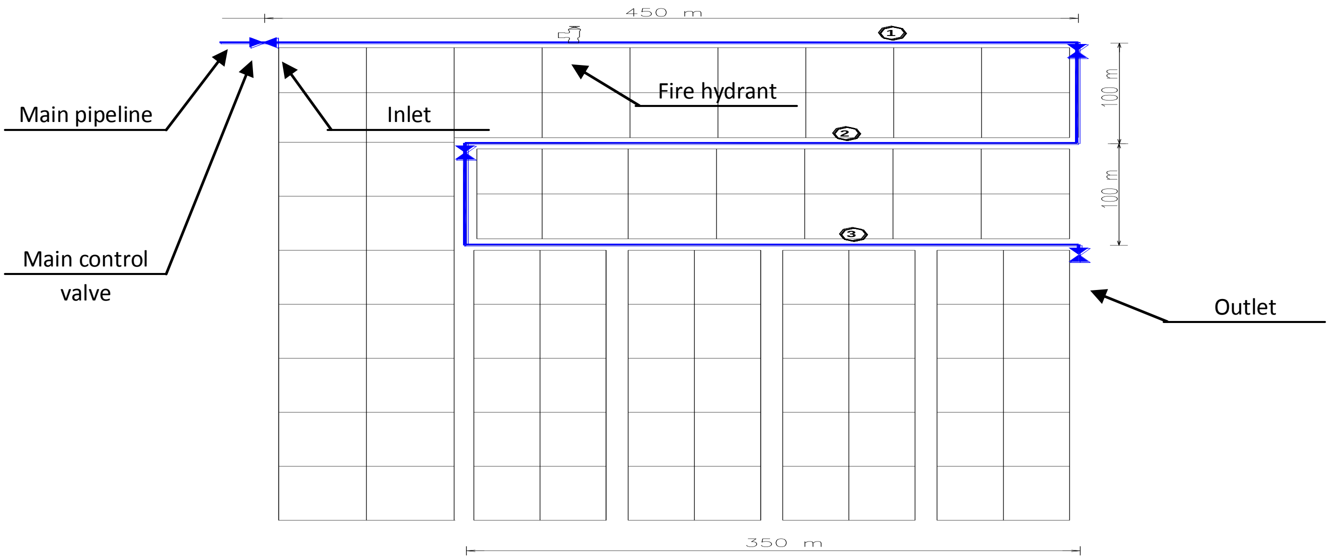
Figure (2): *One pipeline in district of Nasr-City water distribution network (Run I)*

Table (1): *The results of measurements for one pipeline at inlet and outlet*

Sample No.	discharge at inlet (l/s)	residual chlorine at inlet (mg/l)	discharge at outlet (l/s)	residual chlorine at outlet (mg/l)	time of measure (minutes)
1	22	0.16	22	0.158	0
2	22	0.16	22	0.158	10
3	22	0.16	22	0.158	20
4	22	0.16	21.6	0.148	35
5	22	0.16	21.6	0.147	55
6	22	0.16	21.6	0.146	75

3.2 Results of run II

This run was made on Three 200 mm diameter pipelines each of length 450 m as shown in figure (3) by measuring the inlet and the outlet discharges, where all the house connections and the fire hydrants are closed. The measuring of residual chlorine was also made at the inlet and outlet of the pipe lines. After three readings at time interval 10 minutes, one of the hydrants was partially opened to leak water from the pipe lines during the measuring of both discharge and residual chlorine. This run was conducted in two consecutive days. Table (2) illustrates the *results of measurements*.



Figure(3): *Three pipelines in district of Nasr-City water distribution network (RunII)*

Table (2): *The results of measurements for three pipelines at inlet and outlet*

pipe line No.	sample No.	discharge at inlet (l/s)	residual chlorine at inlet (mg/l)	discharge at outlet (l/s)	residual chlorine at outlet (mg/l)	time of measure (minutes)
	1	22	0.16	22	0.158	0
	2	22	0.16	22	0.158	10
	3	22	0.16	22	0.158	20
	4	22	0.16	21.8	0.146	35
	5	22	0.16	21.8	0.145	55
1	6	22	0.16	21.8	0.144	75
	1	21	0.16	21	0.158	0
	2	21	0.16	21	0.158	10
	3	21	0.16	21	0.158	20
	4	21	0.16	20.8	0.146	35
	5	21	0.16	20.8	0.145	55
2	6	21	0.16	20.8	0.144	75
	1	22	0.16	22	0.158	0
	2	22	0.16	22	0.158	10
	3	22	0.16	22	0.158	20
	4	22	0.16	21.8	0.146	35
	5	22	0.16	21.8	0.145	55
3	6	22	0.16	21.8	0.144	75

3.3 Results of run III

This run was made on Nine 200 mm diameter pipelines four of them each of length 450 m and five of them each of length 300m as shown in figure(4) by measuring the inlet and the outlet discharges, and the residual chlorine at both inlet and outlet of each pipe closing all the house connections and the fire hydrants. After three readings at time interval 10 minutes, one of the hydrants was partially opened to leak water from the pipelines during the measuring for both discharge and residual chlorine. The measures were repeated 5 times in first day and 4 times in second day. Table (3) illustrates the results of measurements.

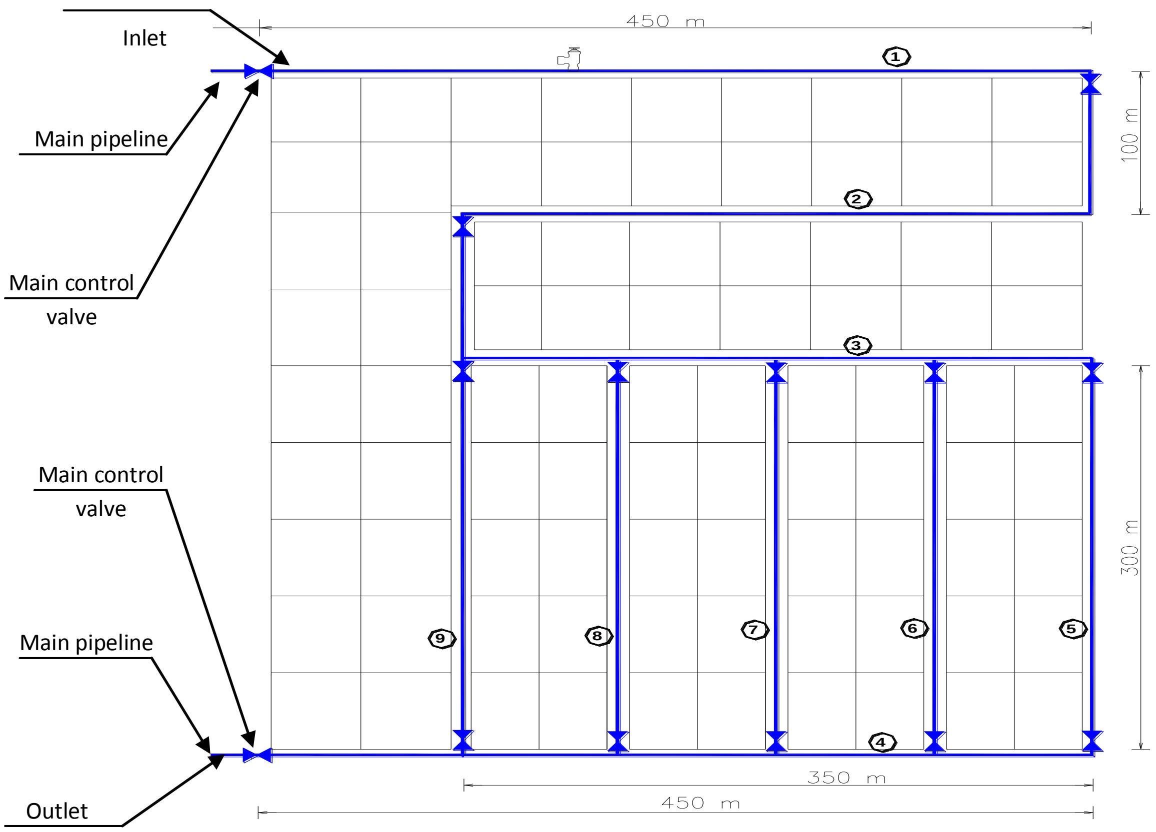


Figure (4): *Nine lines in district of Nasr-City water distribution network (Run III)*

Table (3): *The results of measurements for nine pipelines at inlet and outlet*

pipe line No.	sample No.	discharge at inlet (l/s)	residual chlorine at inlet (mg/l)	discharge at outlet (l/s)	residual chlorine at outlet (mg/l)	time of measure (minutes)
	1	22	0.16	22	0.158	0
	2	22	0.16	22	0.158	10
	3	22	0.16	22	0.158	20
	4	22	0.16	21.9	0.146	35
	5	22	0.16	21.9	0.145	55
1	6	22	0.16	21.9	0.1436	75
	1	21	0.16	21	0.158	0
	2	21	0.16	21	0.158	10
	3	21	0.16	21	0.158	20
	4	21	0.16	20.9	0.145	35
	5	21	0.16	20.9	0.143	55
2	6	21	0.16	20.9	0.1426	75

3	1	22	0.16	22	0.158	0
	2	22	0.16	22	0.158	10
	3	22	0.16	22	0.158	20
	4	22	0.16	21.9	0.146	35
	5	22	0.16	21.9	0.145	55
	6	22	0.16	21.9	0.1436	75
4	1	22	0.16	22	0.158	0
	2	22	0.16	22	0.158	10
	3	22	0.16	22	0.158	20
	4	22	0.16	21.9	0.144	35
	5	22	0.16	21.9	0.1434	55
	6	22	0.16	21.9	0.1426	75
5	1	21	0.16	21	0.158	0
	2	21	0.16	21	0.158	10
	3	21	0.16	21	0.158	20
	4	21	0.16	20.9	0.144	35
	5	21	0.16	20.9	0.1434	55
	6	21	0.16	20.9	0.1426	75
6	1	22	0.16	22	0.158	0
	2	22	0.16	22	0.158	10
	3	22	0.16	22	0.158	20
	4	22	0.16	21.9	0.145	35
	5	22	0.16	21.9	0.1434	55
	6	22	0.16	21.9	0.1426	75
7	1	22	0.16	22	0.158	0
	2	22	0.16	22	0.158	10
	3	22	0.16	22	0.158	20
	4	22	0.16	21.9	0.145	35
	5	22	0.16	21.9	0.1434	55
	6	22	0.16	21.9	0.1426	75
8	1	21	0.16	21	0.158	0
	2	21	0.16	21	0.158	10
	3	21	0.16	21	0.158	20
	4	21	0.16	20.9	0.144	35
	5	21	0.16	20.9	0.1434	55
	6	21	0.16	20.9	0.1426	75
` 9	1	22	0.16	22	0.158	0
	2	22	0.16	22	0.158	10
	3	22	0.16	22	0.158	20
	4	22	0.16	21.9	0.144	35
	5	22	0.16	21.9	0.1434	55
	6	22	0.16	21.9	0.1426	75

4. Discussion of results:

The analysis of the results includes the study of the variation of residual chlorine in the water within the studied network for several time intervals. This relationship is expected to be a reasonable estimation or prediction for the water losses in the network (leakage). The results are tabulated as numbers and plotted on curves. Finally, the direct relationship between the water leakage in the network and the residual chlorine is formulated. This derived formula is expected to be used by having records for the residual chlorine in any network in time intervals.

4.1 Residual chlorine and time relationship

As previously mentioned, the field measurements are divided into three phases. The field results of phase I (one street) are tabulated in table (4) and plotted in figure (5),the results of phase II (three streets) are tabulated in table (5) and plotted in figure(6) and finally the results of phase III(nine streets) are tabulated in table (6) and plotted in figure (7).

Table (4): *Variation of residual chlorine and losses with time (case I)*

Time (minutes)	Average of residual chlorine (mg/l)	ΔQ(Losses) (l/s)
35	0.148	0.4
55	0.147	0.4
75	0.146	0.4

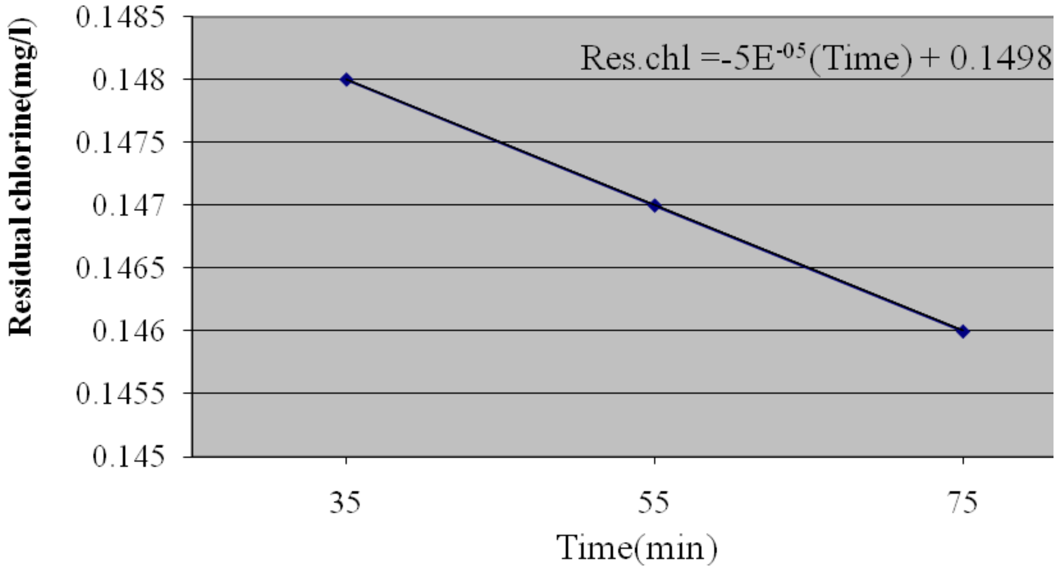


Figure (5): *Variation of residual chlorine with time at constant leakage (1.8%)*

Table (5): *Variation of residual chlorine and losses with time (case II)*

Time (minutes)	Average of residual chlorine (mg/l)	ΔQ(Losses) (l/s)
35	0.146	0.2
55	0.145	0.2
75	0.144	0.2

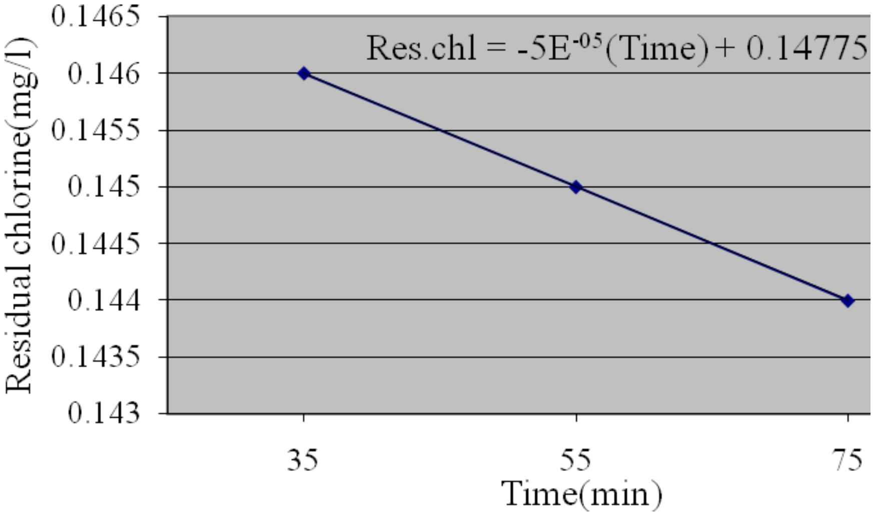


Figure (6): *Variation of residual chlorine with time at constant leakage (0.9%)*

Table (6): *Variation of residual chlorine and losses with time (case III)*

Time (minutes)	Average of residual chlorine (mg/l)	ΔQ(Losses) (l/s)
35	0.14477	0.1
55	0.14382	0.1
75	0.14282	0.1

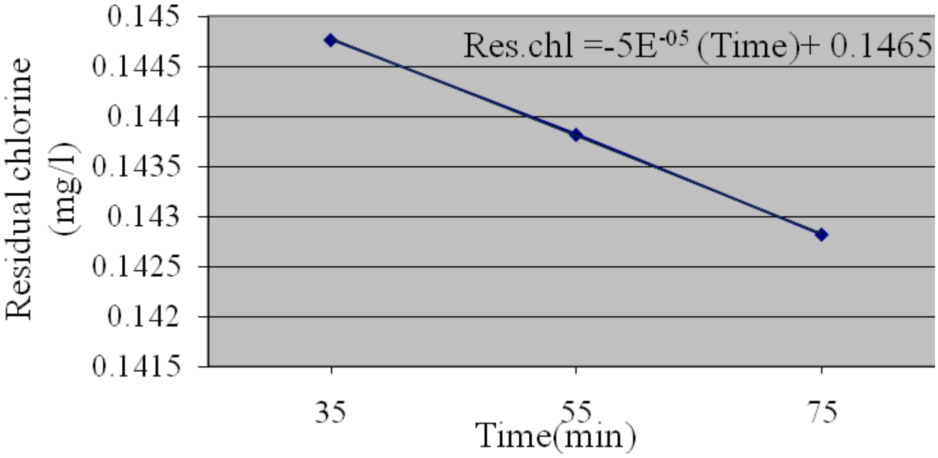


Figure (7): *Variation of residual chlorine with time at constant leakage (0.46%)*

4.2 Equations govern residual chlorine-time relationship

The main target of this step is focused on the derivation of an equation to illustrate the relationship between the water leakage of the networks and the residual chlorine. To start this analysis, presented herein a the equations that illustrate the relationship between the change of residual chlorine and the elapsed time as formulated from figures (5),(6),(7):

- For case I(one street):

$$\text{Residual chlorine} = -5E^{-05}(\text{Time}) + 0.1498 \quad (1)$$

- For case II(three streets):

$$\text{Residual chlorine} = -5E^{-05}(\text{Time}) + 0.14775 \quad (2)$$

- For case III(nine streets):

$$\text{Residual chlorine} = -5E^{-05}(\text{Time}) + 0.1465 \quad (3)$$

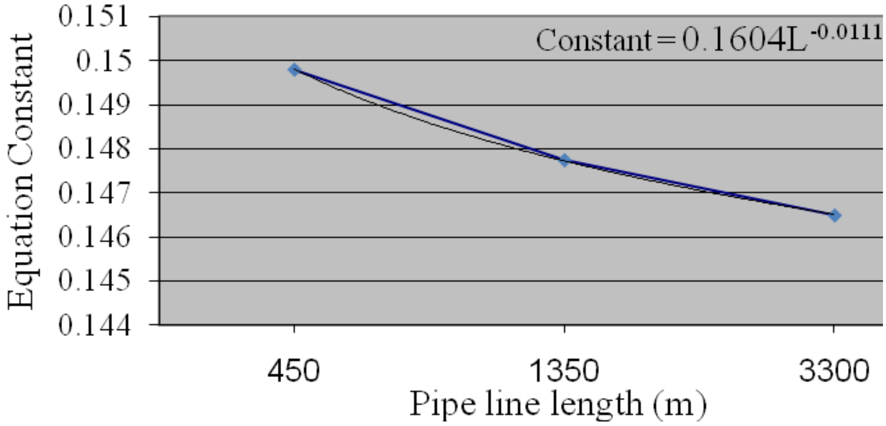
The equations formulated, indicate that they are all have the same form and parameters except for the constant part which was found to decrease with the increase of the network length. The general form of equation:

$$\text{Residual chlorine} = -5E^{-05}(\text{Time}) + \text{Constant} \quad (4)$$

4.3 Relation between equation constant and network size (length of pipes)

Table (7): *Variation of equation constant and pipe network size (length of pipes)*

Constant	Line length (m)
0.1498	450
0.14775	1350
0.1465	3300



Figure(8): *The relation between equation constant and experimented pipeline length*

The results indicate a clear decrease in the equation constant with total length of pipelines. The equation that simulates the relationship between the equation constant and the length of pipelines can be written as follows:

$$\text{Equation constant}=0.1604L^{-0.0111} \quad (5)$$

Replacing the equation of constant from equation (5) into equation (4), this release the following equation for the direct relationship between residual chlorine, time and network size (length of pipes):

$$\text{Residual chlorine}= -5E^{-05}(\text{Time}) +0.1604L^{-0.0111} \quad (6)$$

4.4Relation between residual chlorine and pipeline length considering the time

Table (8): *Variation of residual chlorine with time and network pipeline length (L)*

Length of line (m)	Residual chlorine(mg/l)		
	After 35min	After 55min	After 75min
450	0.148	0.147	0.146
1350	0.146	0.145	0.144
3300	0.14477	0.14382	0.14282

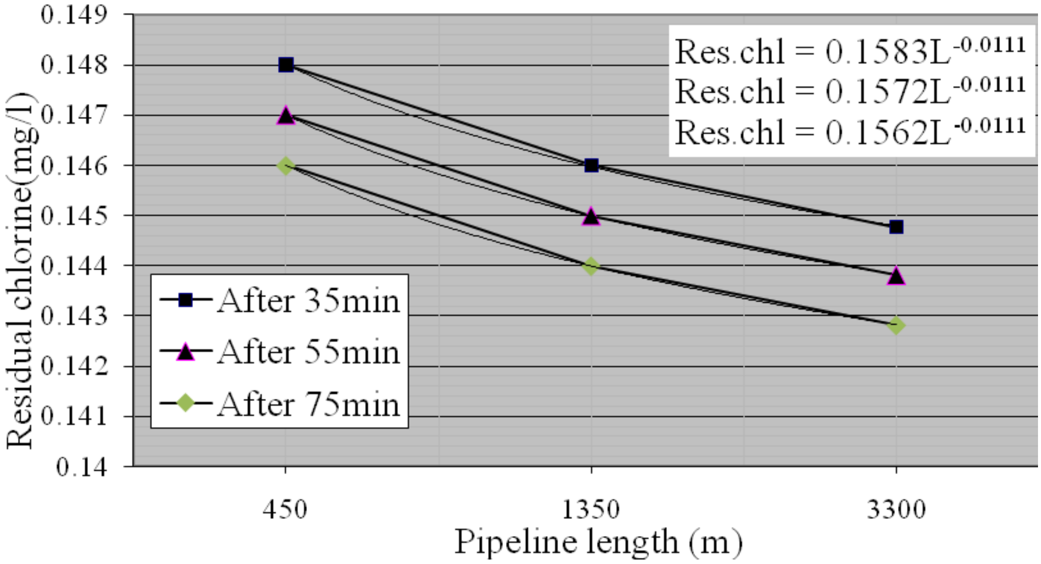


Figure (9): *Variation of residual chlorine with pipeline length and time*

The residual chlorine was found to be sensitive to both length of pipe lines and time. Three different times and three different networks (different in length) were studied in this research. The residual chlorine decreases by almost a constant rate as time increased or size of network increases. This can be attributed to: that, the increase the length of the pipeline means an increase in the amount of water passing through pipeline, this means that the volume of water which is polluted by bacteria has increased. This leads to a decrease in the residual chlorine quantity whenever the length of the pipe line increased.

Three equations (7, 8, 9) were found to govern the variation of residual chlorine with length of pipes for different three times.

At time=35 min, Residual chlorine=0.1583L$^{-0.0111}$ (7)

At time=55 min, Residual chlorine=0.1572L$^{-0.0111}$ (8)

At time=75 min, Residual chlorine=0.1562L$^{-0.0111}$ (9)

The general relationship can be summarized in equation (10):

Residual chlorine=Constant L$^{-0.0111}$ (10)

The equation constant was found to change slightly as length of pipes, and elapsed time increased

4.5 Relation between leakage percent in constant equation (10)

Table (9): *Leakage and constant in equation (10)*

Leakage (%)	Constant
1.8	0.1583
0.9	0.1572
0.46	0.1562

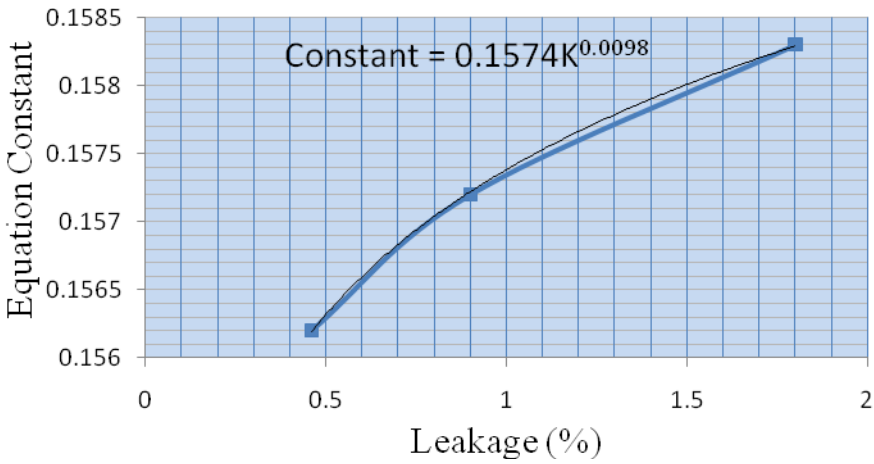


Figure (10): *Relationship between leakage and constant in equation (4)*

The equations that govern the relationship between the equation constant and the leakage in pipelines are found to be as follows:

$$\text{Constant} = 0.1574\ K^{0.0098} \quad (11)$$

Where:

K: % of leakage from water pipe network

Replacing the equation of constant from equation (11) into equation (10), this release the following equation for the direct relationship between residual chlorine, leakage and network size (length of pipelines):

$$\text{Residual chlorine} = 0.1574\ K^{0.0098}\ L^{-0.0111} \quad (12)$$

4.6 Equations verification

In all figures, the value of least squares (R^2) to verify the accuracy of the trend line R^2=1.

4.6.1 Equation (6) verification

Table (10): *Variation of residual chlorine from run (1) and Equation (6) with time*

Time (minutes)	Residual chlorine(mg/l)		Deviation percent (%)
	From run results	From equation	
35	0.148	0.1481	-0.067
55	0.147	0.1471	-0.068
75	0.146	0.1461	-0.068

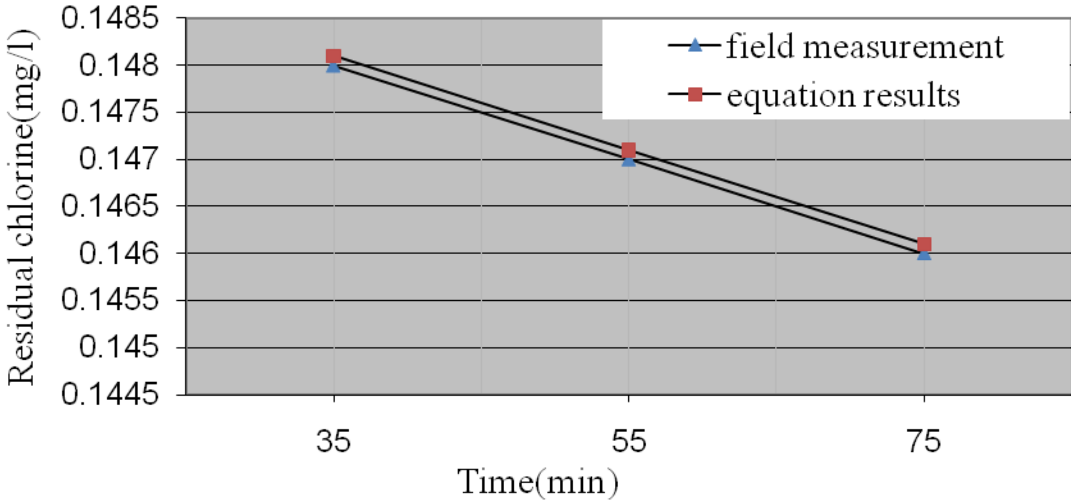


Figure (11): *Comparison of the residual chlorine from first run results and from equation (6) with time*

***Table (11):** Variation of residual chlorine from run (2) and equation (6) with time*

Time (minutes)	Residual chlorine(mg/l)		Deviation percent (%)
	From run results	From equation	
35	0.146	0.1463	-0.205
55	0.145	0.1453	-0.206
75	0.144	0.1443	-0.208

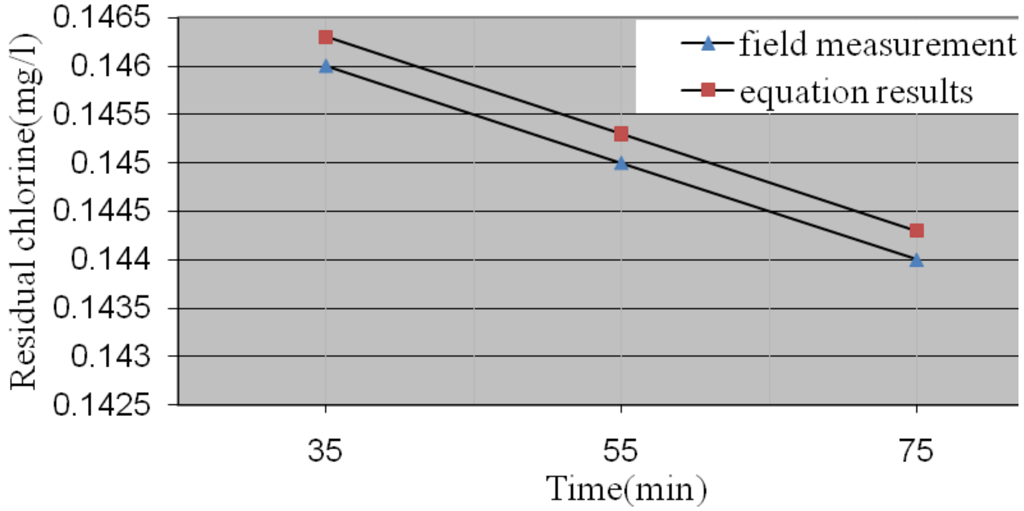


***Figure (12):** Comparison of the residual chlorine from second run results and from equation (6) with time*

***Table (12):** Residual chlorine from run (3) and equation (6) with time*

Time (minutes)	Residual chlorine(mg/l)		Deviation percent (%)
	From run results	From equation	
35	0.14477	0.14485	-0.055
55	0.14382	0.14385	-0.020
75	0.14282	0.14285	-0.021

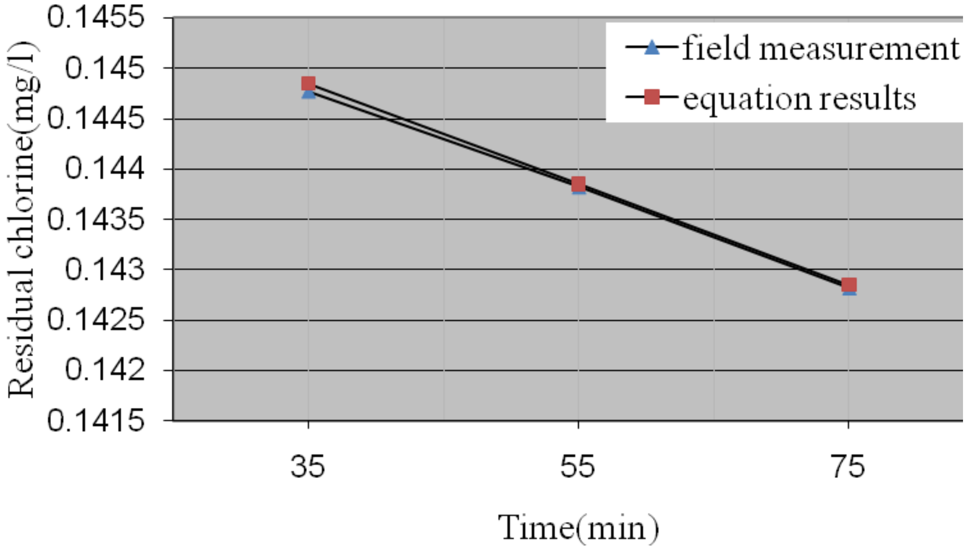


Figure (13): *Comparison of the residual chlorine from third run results and from equation (6) with time*

The results showed that, deviation percent between field measurements and the application of the equation (6), is minor and ranging from (-0.02) to (-0.208).

4.6.2 Equation (12) verification

Table (13): *Residual chlorine from runs (after 35 minutes) and from equation (12) with pipeline length.*

Line length (m)	Residual chlorine(mg/l)		Deviation percent (%)
	From run results	From equation	
450	0.148	0.1479	0.067
1350	0.146	0.1451	0.616
3300	0.14477	0.1427	1.429

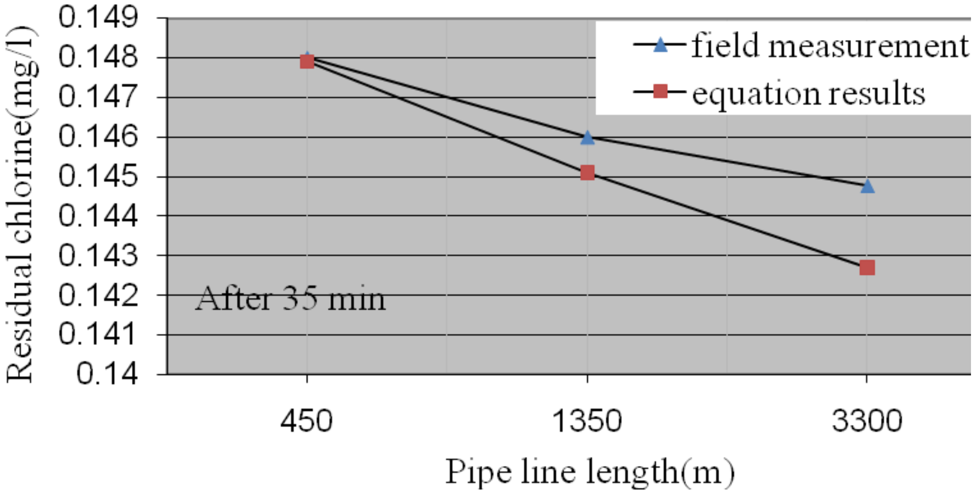


Figure (14): *Comparison of the residual chlorine from run results (after 35 minutes) and from equation (12) with pipeline length.*

Table (14): *Residual chlorine from runs (after 55 minutes) and from equation (12) with pipeline length.*

Line length (m)	Residual chlorine(mg/l)		Deviation percent (%)
	From run results	From equation	
450	0.147	0.1479	-0.612
1350	0.145	0.1451	-0.068
3300	0.14382	0.1427	0.778

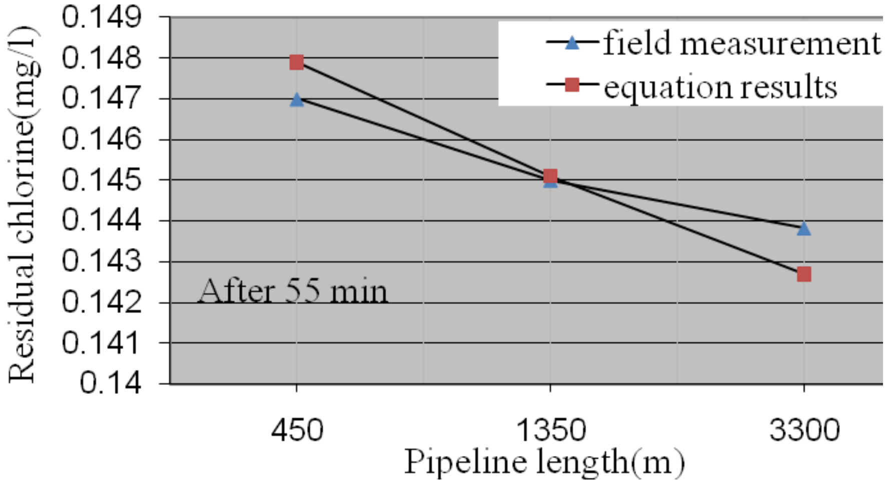


Figure (15): *Comparison of the residual chlorine from run results (after 55 minutes) and from equation (12) with pipeline length*

Table (15): *Residual chlorine from runs (after 75 minutes) and from equation (12) with pipeline length.*

Line length (m)	Residual chlorine(mg/l)		Deviation percent (%)
	From run results	From equation	
450	0.146	0.1479	-1.301
1350	0.144	0.1451	-0.763
3300	0.14282	0.1427	0.084

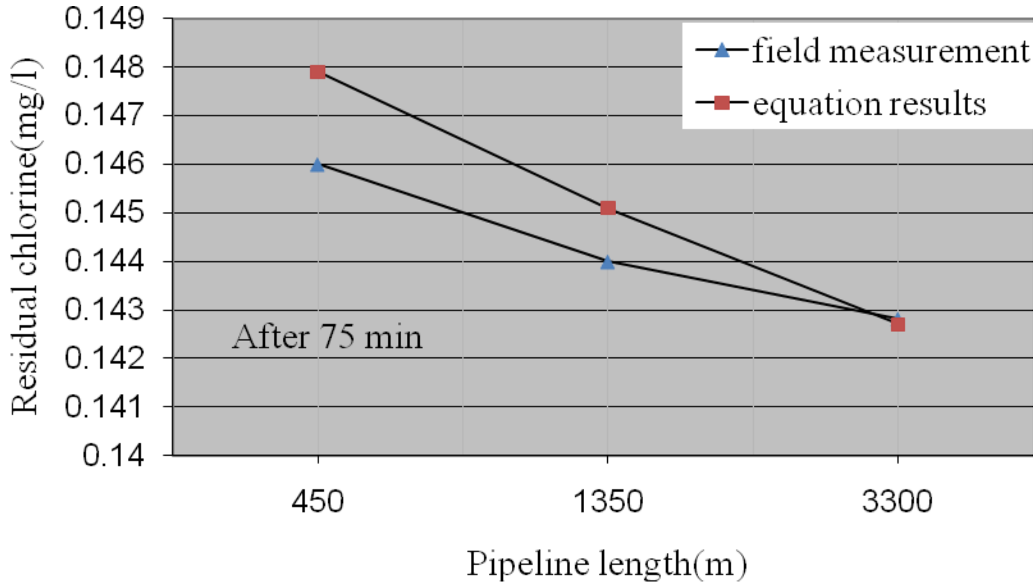


Figure (16): *Comparison of the residual chlorine from run results (after 75 minutes) and from equation (12) with pipeline length*

The results showed that, deviation percent between field measurements and the application of the equation (12), is minor and ranging from (0.067) to (1.429).

5. Conclusions

The prevailing study has been set up for the prediction of some practical formulae as a new methodology for water losses (leakage) determination in water distribution networks. According to the experimental work as well as according to the measured parameters, the amount of leakage and the residual chlorine along time increments, the following conclusions can be started up:

1. The effect of elapsed time after leakage start on the residual chlorine was very sensible.

The relation could be simulated by the following equation:

$$Res.chl = -5E^{-05}\ (Time) + Constant \ldots\ldots \text{(Equation (4))}$$

2. The pipe length also affected the values of residual chlorine with the elapsed time that converted the equation (1) to be as follows:

$$Res.chl = -5E^{-05}\ (Time) + 0.1604L^{-0.0111} \ldots\ldots \text{(Equation (6))}$$

3. In another point of view the relation between pipe length and the residual chlorine values was observed to be as follows:

$$Res.chl = Constant\ .L^{-0.0111} \ldots\ldots \text{(Equation (10))}$$

4- The leakage percentage has an effect on the relation between the residual chlorine and pipe length that modified equation (3) to be as follows:

$$\text{Res. Chl.} = 0.1574(\text{Leakage \%})^{0.0098}\ L^{-0.0111}$$ ………………...(Equation (12))

5- The percentage of leakage can be estimated by inversing the items of equation (12) to form the following equation:

$$\text{Leakage \%} = (5000L^{0.0111}\ \text{Res.chl.}/787)^{5000/49}$$ ……………. (Equation (13))

6. According, the a/m equations can be used to control the performance of any water distribution system via providing the necessary measurements. This could be used to estimate the leakage amount or the residual chlorine content to take up the necessary quick action to overcome the inherent problems due to the unforeseen cracking of pipes particularity the small ones.

6. References

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