LEAKAGE IN PIPELINE FLOWNET

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ABSTRACT

In this paper a mathematical model is proposed to study the effect of leakage in the networks, instead of the long leak detection study before the rehabilitation work. The mathematical model simulates the flow characteristic in an existing network. The model input data was collected from field, these data are entry flow, pressure, consumption flow; and the pipeline length and diameter. Leakage effect is considered in the model. The leakage affects the flow rate and pressure for any network. The output results of the model give very good agreement with the field data. The model output data are the correct flow, pressure, head losses, leakage flow, consumption and head at any node at the network. The proposed model is solved using the Newton Raphson method for N-linear equation. N-linear equations are equal to the number of the node of network. The verification emphasis the availability of this model. Results show that leakage should be considered in the studying and planing of network.

Keywords: Flownet, pipeline and leakage.

INTRODUCTION

The supplement with treated water needs treatment water-works (plants and networks). The construction of a treatment plant depends on the required increasing of consumption and its demands for domestic. The planning and construction of a new pipeline or modification for existing nets and their extension is costly, moreover it wastes time and faces many difficulties. The increasing of potable water can be achieved by minimize losses. The best solution to minimize losses is the maintenance program by repairing cracks and damage in pipeline. Repairing network should be done through a rehabilitation program which needs leak detection procedures.

Rehabilitation work is also costly, however, it costs less than the construction of a new network. It is well known that predicting the correct flow characteristic of the existing network before starting any rehabilitation work or extension of network, will save time and money.

In this paper a model is proposed to study leakage effect which can be successfully applied to predict the actual conditions of existing network.

Data collected from the field during two years were used to verify the proposed model. These data were collected through leak detection work which consists of a large number of measurements feeding sources (1).

BACKGROUND

The main categories of losses are the friction losses and reaction of leakage. A literature review revealed that little attention has been given to study leakage in network. Boulos, and D Wood (2) studied the design of a network and its function. They did not include the leakage factor. The development for their design, operation, and calibration parameters for pipe network assisted in reaching an evaluation and specification of pressure and flow constraints.

Leak detection work is one of the most important tools for evaluation analysis of data for an existing network. A study was done by Ranko *et al.* (3), to the find the answer for the following question: can a leak be located by pressure measurements in a pipe network by using little data? The answer depends on the configuration of the system, the accuracy of pressure measurements, pipe friction and the accuracy of the required demands. In the forward problems the demands are known and the characteristics of the system are known and they try to find to the pressure and how the demands will be divided?

In the inverse problem the characteristics of the system and demands are known but there is an unaccounted for nodal flow and certain leaks, in case of design the characteristics will be needed to meet the demands and target pressure. The constraint condition will be added to obtain one solution only.

The solution continuously depends on the data and is unique for all admissible data. The pipe flow equation for the criteria of design with this method is as follows:

$$Q_{kij} = D_i + q_i^{\,L} \qquad (1)$$

The difference of pressure from node i to j is

$$P_i - P_j = K_{ij}[Q_{kij}]\ Q_{kij} - 6\,(E_i - E_j) \qquad (2)$$

The leak (qi) at the nodes is usually unknown but can expressed in terms of pressure by an orifice formula:

$$q_l = Co_i A 1_{ij} \sqrt[L]{2\,gp_i\,/\,6} \qquad (3)$$

Where:

Kij = the number of the pipe that lies between nodes i,j,

D_i = the demand(known out flow at the node(which may be negative) m^3/s

q_i = the leak at the node, m^3/s

Q_{kij} = the flow at the pipe kij and the positive from node i toj. m^3/s

P = pressure, m

6 = The specific weight of the fluid,

K = Coefficient of resistance and include the pipe diameter,

n = The exponent to be applied to the velocity in the friction equation,

E = Elevation.m

Co_l = an orifice coefficient, A_l= an equivalent orifice area. m^2 .

The Proposed Model

The model input data are the entry flow, entry pressure, pipeline length, diameter, total flow and consumption flow. The output results are obtained for every node. Leakage is the main subject considered in this model. Leakage affects the flow rate and pressure for any net work. This model can be applied to study the conditions of existing or predicting networks instead of the field studies of leak detection work. Using the model saves time and money. The proposed model uses the continuity and energy equation and their applications. Newton Raphson method is used as a method of iteration correction for obtaining the results which included the correct pressure, head losses, the pipeline length with sufficient supply, dry lengths and the percentage of leakage. Newton Raphson Method is used to solve N-linear equations N-linear equation. N-linear equation are equal to the number of the nodes of network. The solution of Newton Raphson iteration used LU Decomposition subroutines from Cambridge University Press (8).

In this study the results obtained from the computer model were compared with the field data.. The verifications were done by drawing relationships between the results of the model and the field data. The collected field data and model output results describe flow characteristics (diameter, length of pipeline, flow pressure).

The districts studied here are from rural area at Abo Hummos Markaze. The districts were chosen from different locations at high pressure and low pressure areas. The districts selected were near water works and far from them, at zones with sufficient and insufficient flow rates. The conclusion will show the availability of this model and its limits and applications. The results will give the chance to decide that if network needs any rehabilitation work or extension of network or other additional feeding source. The proposed model shows that the leakage effect can be applied successfully to predict the actual conditions of existing network.

Model Assumptions

The assumptions of this mathematical model are; a steady state condition, a one dimensional flow, the application of continuity and energy equations, the leakage flow is calculated using the orifice flow equation, the calculations of flow pass and consumption depend on a number of consumers and coefficient of consumption. The coefficient of consumption of a certain area is fixed according to the type of consumer. The types of consumer are varied from house connection, mosques, stand pipe, big consumers. The coefficient of consumption is defined as the quotient of the avenge consumption and the number of consumers. The Friction factor (fr) is .005. The minor losses (losses at bends, tees and valves) are very small and can be neglected.

The Model Formulation

The model consists of three parts, the continuity equation, energy equation, and the leakage reaction. The model formulation will be considered in the following section:

The continuity equation

The situation of flow in the network of N_j junction is achieved by the continuity equation, as shown in Figure 1, as follows:

-The summation of total flow in - the total consumption =0

$$\sum_{i=1}^{NJ} Q_{ij} - Qcons_i = 0 \quad ,i=1,NJ \tag{4}$$

The net flow at any node= the flow in-consumption

$$f_i = Q_{ij} - Qcons_i \tag{5}$$

The leakage equation

In the existing network, the leakage affects on the value of flow, pressure and head losses. In the mathematical model the value of leakage considered using the orifice flow equation Pudar and Liggett (3). The hole of leakage assumed as an equivalent area of orifice. The head is the pressure for flow passed at the point of leakage.

$$C_{ij} = A1_{ij} * \sqrt{2 g H_i} \tag{6}$$

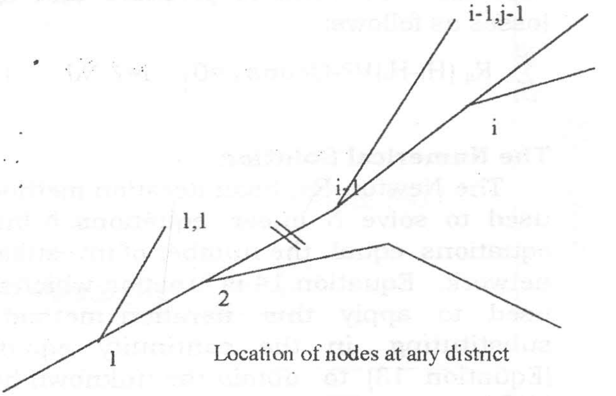

Figure 1 Flow and pressure/head losses relationships

The equivalent diameter of leakage orifice (Dl_{ij}) can be obtained from Equation 4. It should be used to obtain the leakage value. The leakage value C_{ij} by Equation 3 is used to obtain the corrected discharge, pressure, head losses, at every node.

The energy equation

The head losses at the nodes are calculated using the energy equation and the flow conditions at these nodes as:

$$flow = (C_{ij})^2 / 2 g (A_{ij})^2 \tag{7}$$

The leakage losses Equation 4, will be added to friction head losses to be the total head losses, neglecting the minor losses.

The head losses $H_j - H_i = fr\, L_{ij}\, Q_i^{\,2} / 2g\, A_{ij}^2\, D_{ij} + C_{ij}^{\,2} / 2g\, A_{ij}^2$ (8)

Kl' is coefficient of leakage, which can be used in Equation 6 as follows:

$$H_j - H_i = Q_{ij}^2 \left(fr\, L / 2\, g\, A_{ij}^2\, D_{ij} + Kl^2 / 2\, g\, A_{ij}^2\right) \tag{9}$$

$$H_j - H_i = Q_{ij}^2\ Pr_{ij}^2 \tag{10}$$

$PR_{ij}^2 = fr\ L / 2\ g\ A_{ij}^2\ D_{ij} + K1^2 / 2\ g\ A_{ij}^2$ (11)

$R_{ij}^2 = 1/PR_{ij}^2$ (12)

$Q_{ij} = Hl_{ij}^{1/2} / Pr_{ij} = R_{ij}\ Hl_{ij}^{1/2} = R_{ij}\ (H_j - H_i)^{1/2}$ (13)

The continuity Equation 2 can be expressed in term of pressure and head losses as follows:

$$\sum_{i=1}^{NJ} R_{ij}\ (H_j - H_i)^{1/2} - Qcons_i = 0 \quad , i=1,NJ \qquad (14)$$

The Numerical Solution

The Newton-Raphson iteration method is used to solve N linear equations. N linear equations equal the number of investigated network. Equation 14 is function which was used to apply this iteration method by substituting in the continuity equation (Equation 13) to obtain the unknown head losses as given by Equation 15.

$$f_i(h_1.....h_N) = \sum_{i=1}^{NJ} R_{ij}\ (H_j - H_i)\ (H_j - H_i)^{-1/2} - Qcons._i = 0 \qquad (15)$$

The correct value of head losses were obtained by adding correction element (δH_i H_i). The correction element (δH_i) was obtained by evaluating the function of continuity Equation 13 and the derivatives-ordinary deferential equations of df/dh at every node as follows:

$$f_i(h_1...h_n) + \sum_{i=1}^{NJ} df_i / dh_i\ \delta H_i = 0,\ i=1,N \qquad (16)$$

These may be expressed in the form: df_i/dh_j array and the f_i vector are known, the element δH_i will be found by the iterative Newton Raphson method. Where dfi/dhi array and fi vector are known, the elements of δHi vector can be calculated through the Newton Raphson method.

Where

δH_i= the correction of the head losses at node i,

$df_i/dh_j = R_{ij}/2\ (H_j - H_i)^{-1/2}$ (17)

$df_i/dh_i = -\Sigma\ df_i / dh_j$ (18)

$[df_i/dh_j]\quad [\delta H_i] = [-f_i]$ (19)

The model at this stage can calculate the corrected flow, pressure, head losses and leakage. A flowchart for the proposed model is given in the Appendix. The following section will discuss the flow chart in full details.

MODEL VERIFICATION

The Pressure-Flow Relationships

In what follows we show the pressure-flow relationships required to make the appropriate verifications. They are calculated for the district numbers 3 and 5 of Abo Hummos Markaz. The symbols used are AH/D3, AH/D5 for the mentioned districts as follows:

1- The total flow and the pressure

In this case, the relationship between total flow and pressure was studied. Comparisons of the field data and the model output result are shown in Figures 2 and 3. For the districts AH/D3, AH/D5 there is a very good agreement between the model output and field, both have the same trend.

2- The pressure and the consumption flow

In this case, The relationship of consumption and pressure was studied. Comparison of the field data collected for district AH/D3, AH/D5 compared with results are shown in Figures 4 and 5, which show that very good agreement at the beginning. On the other hand there are small difference at some points, but fortunately they have the same trend.

3- The pressure and the leakage flow

In this case, The relationship between pressure and leakage was studied. Comparisons of the field data collected for district AH/D3, AH/D5 and model output results are shown in Figures 6 and 7. The model output results are close to the field data in these Figures. The simulations show that both model results and field data have the same trend.

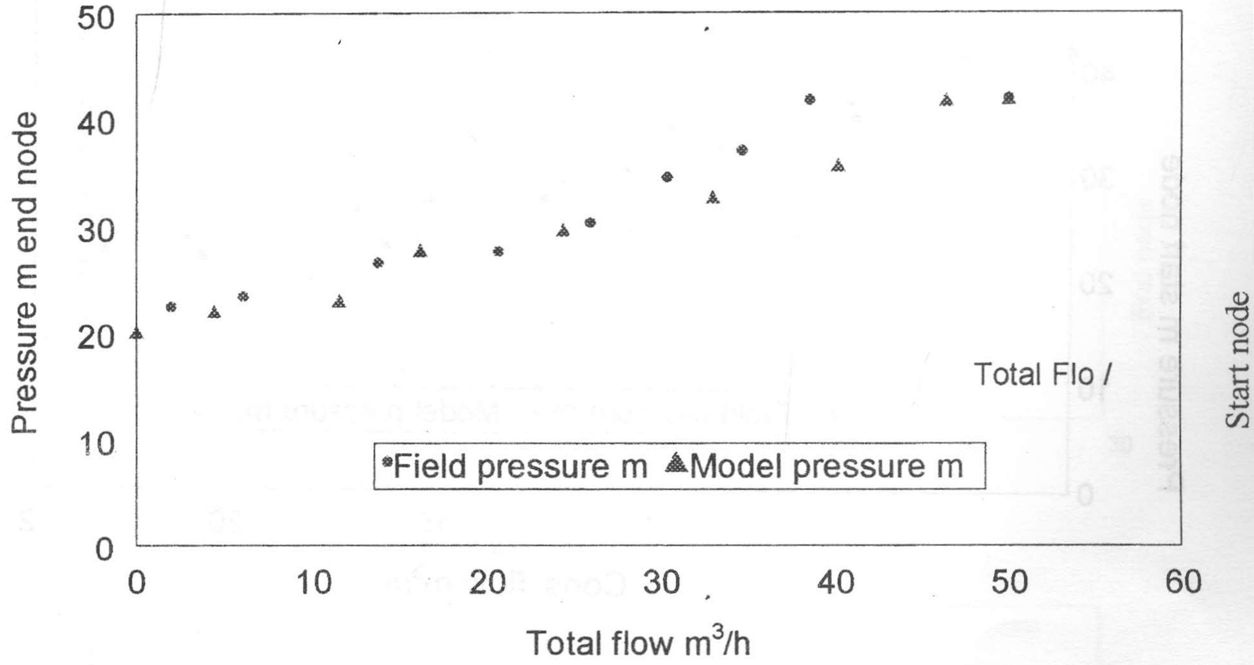

Figure 2 Comparison between field and model :AH/D3

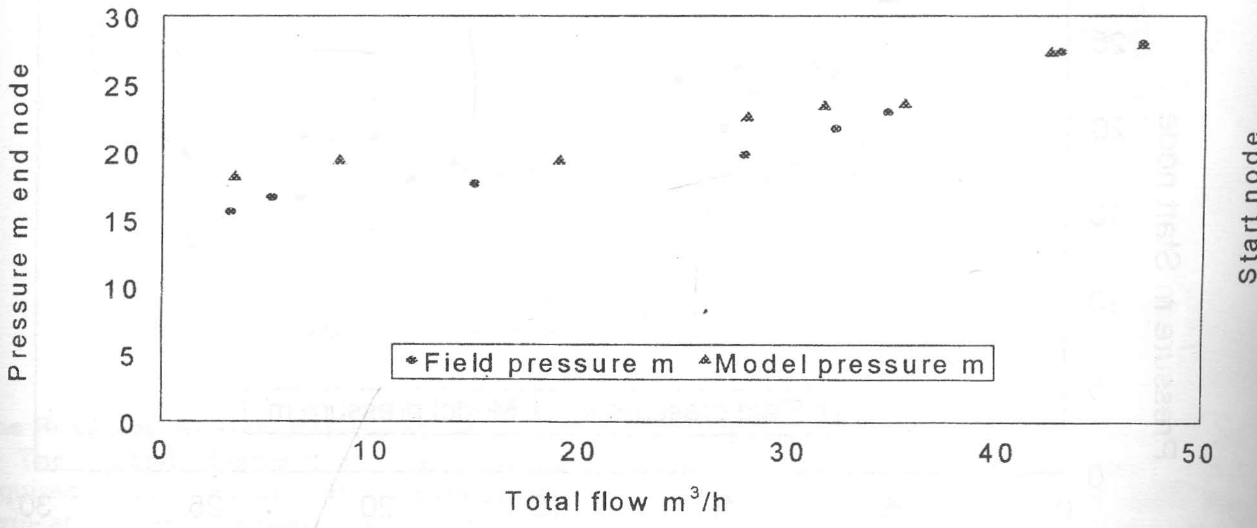

Figure 3 Comparison between field and model: AH/D 5

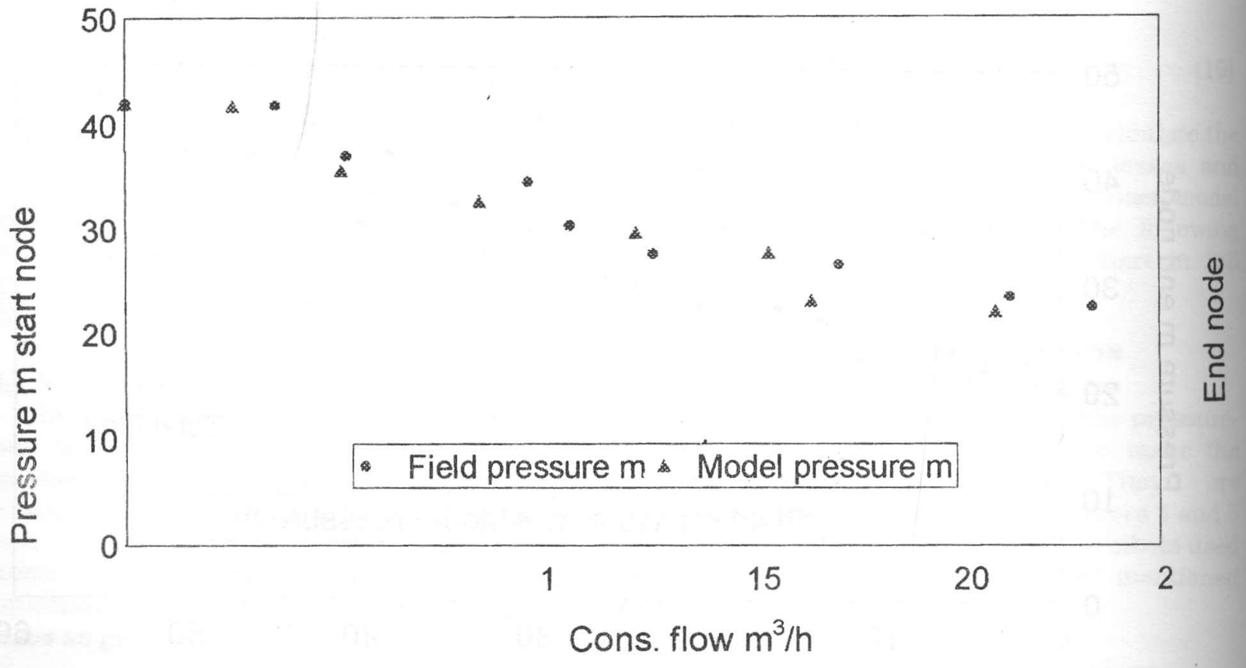

Figure 4 Comparison between field and model: AH/D3

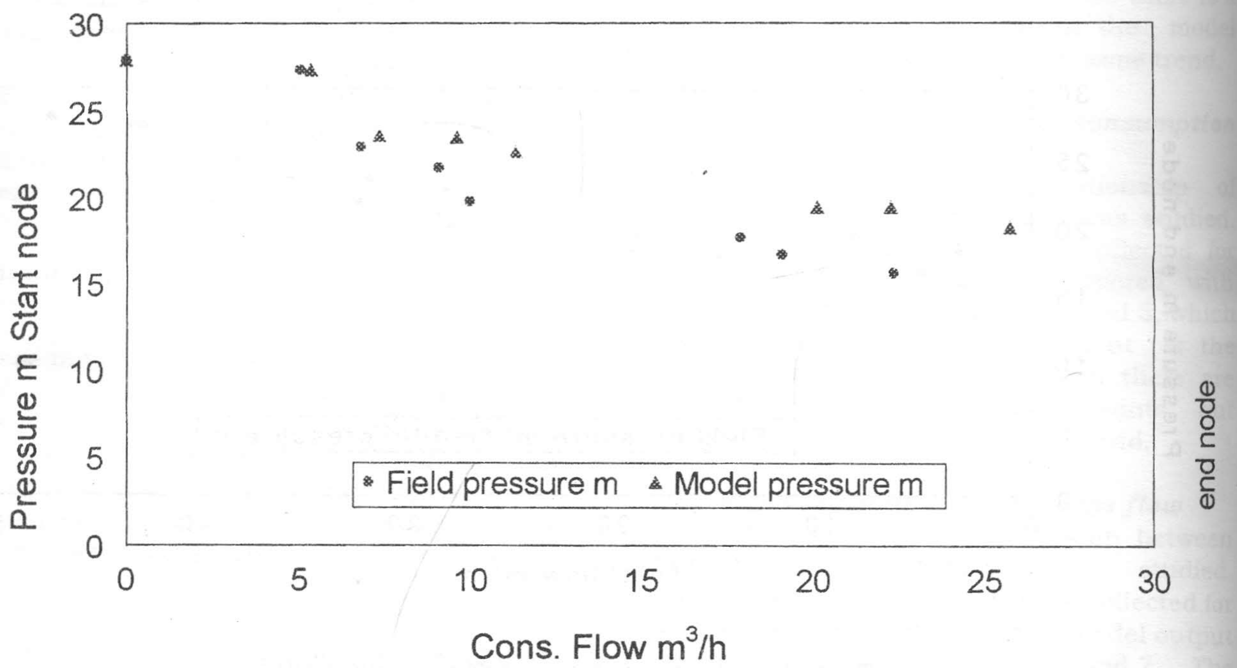

Figure 5 Comparison between field and model: AH/D5

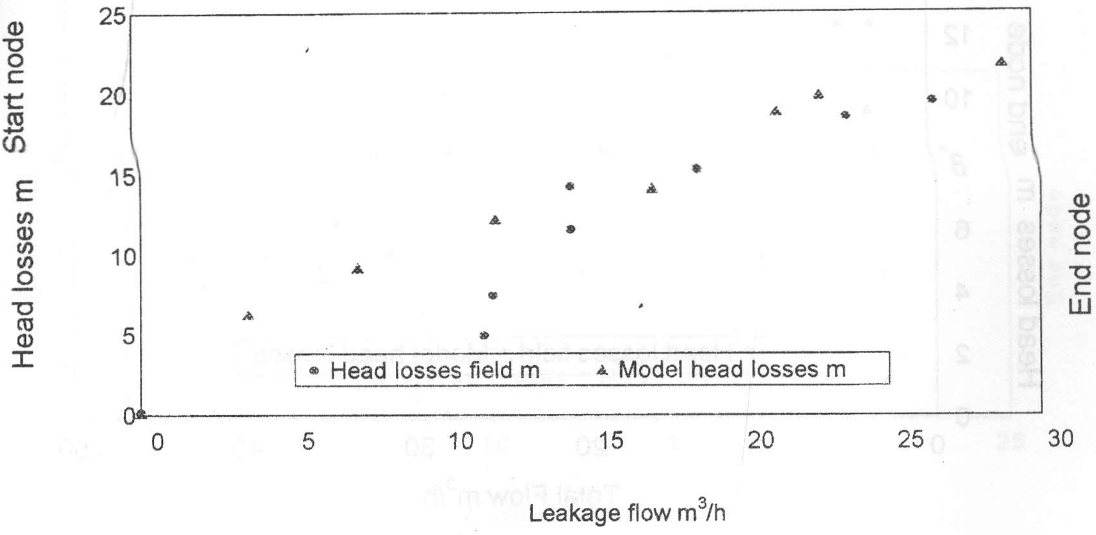

Figure 6 Comparison between field and model: AH/D3

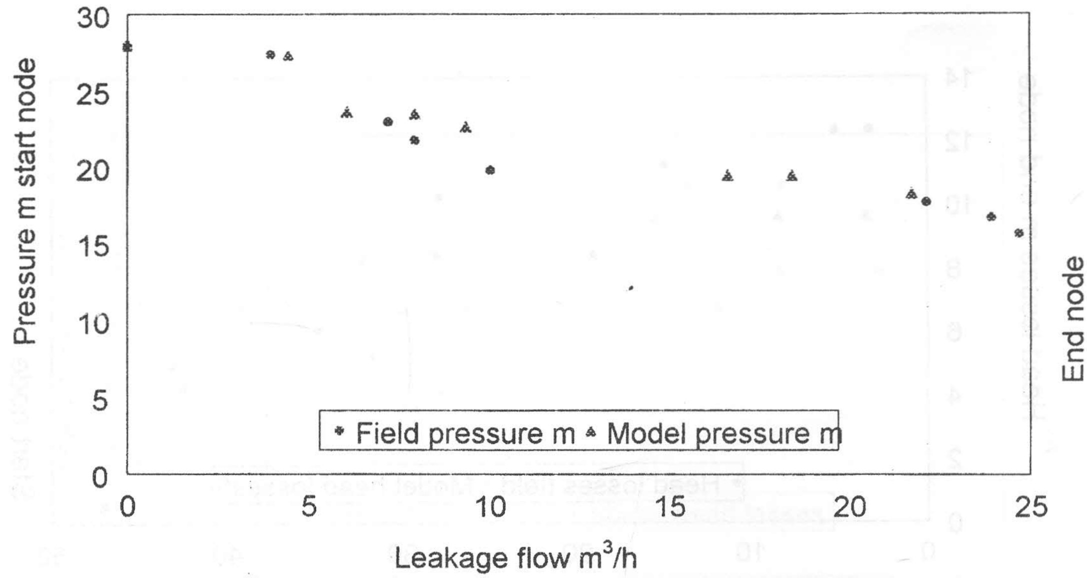

Figure 7 Comparison between field and model: AH/D5

The Head Losses-Flow Relationships

The head losses-flow relationships required to make the appropriate verifications are calculated for the districts AH/D3, AH/D5 are as follows:

1- The head losses and the total flow

In this case, the relationship between total flow and the head losses was studied. Comparison of the field data collected for districts AH/D3, AH/D5 and model output results are shown in Figures 8 and 9. The cumulative figures show that the head losses of the field data have a good agreement with the model results, both. have the same trend. The model results gave good simulation with field data.

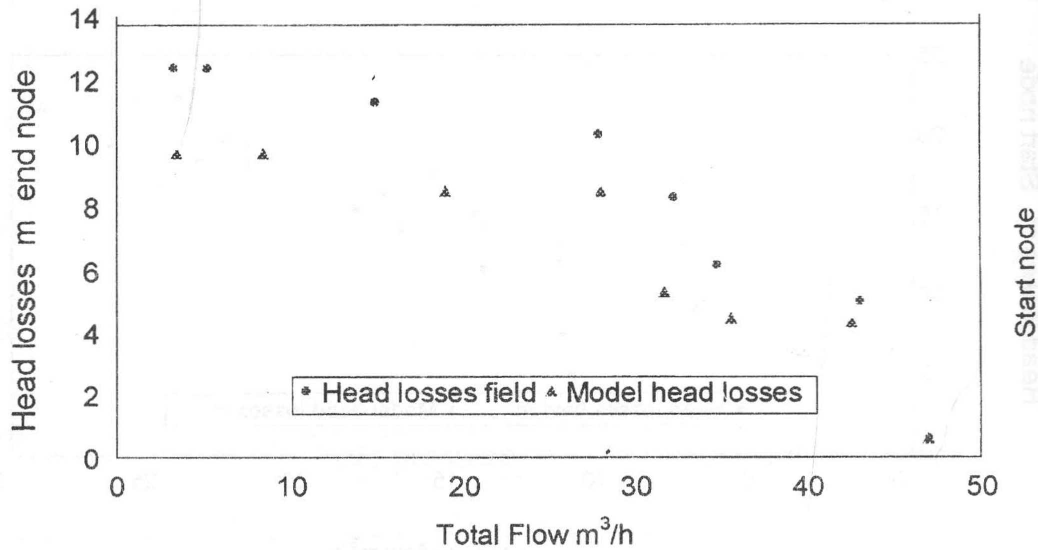

Figure 8 Comparison between field and model: AH/D3

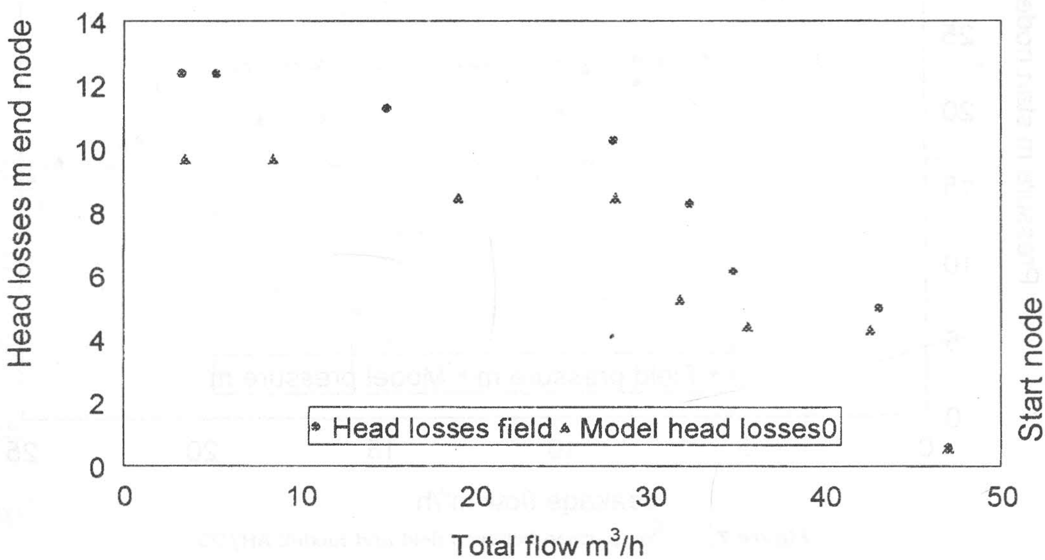

Figure 9 Comparison between field and model: AH/D5

2- The head losses and the consumption flow

In this case, the relationship between consumption flow and the head losses was studied. Comparisons of the field data collected for district AH/D3, AH/D5 and model output results are shown in Figures 10 and 11. At the beginning the model results have very good agreement with field data. At the middle, the head losses of field data has small difference than the model result for the same consumption, both have the same trend. The results agreed succeed for the simulation between the model and field.

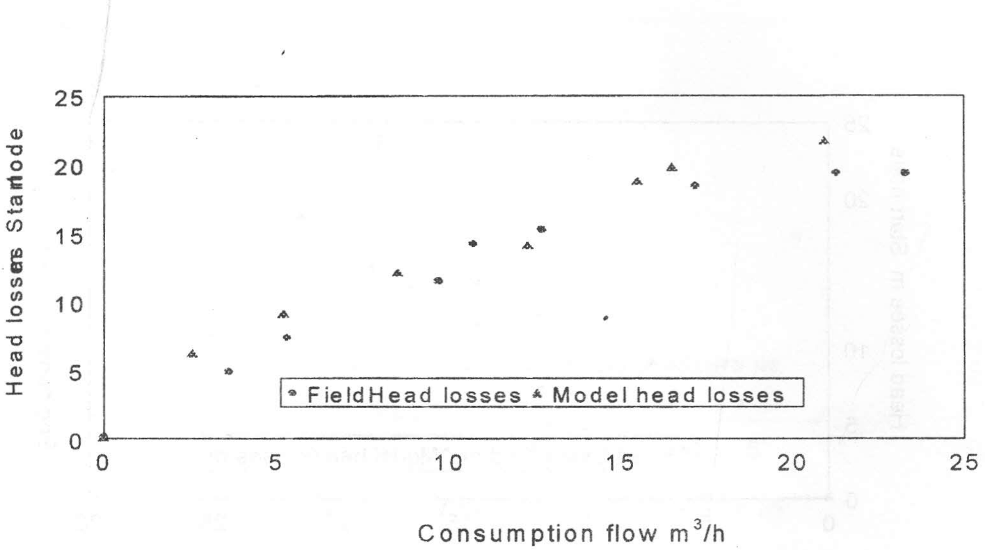

Figure 10 Comparison between field and model AH/D3

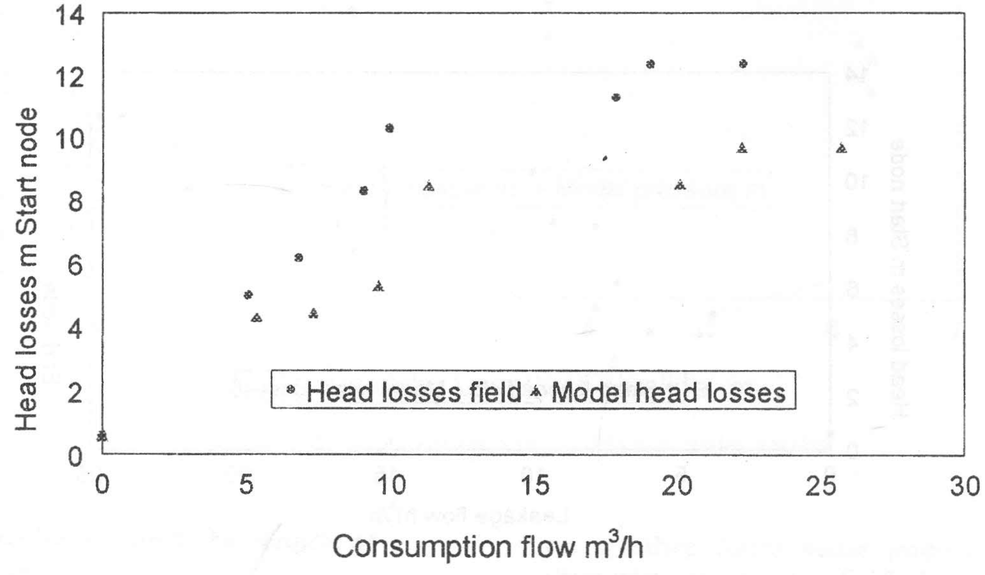

Figure 11 Comparison between field and model: AH/D5

3- The head losses and leakage flow

In this case, for the districts AH/D3, AH/D5 the analysis shown Figures 12 and 13.

At the beginning, the model results and the field data have small difference between chart cords. At the second part of chart they have the same difference but the location of cofds were reversed, both have the same trend. Comparison results gave very good agreement between model and field for these districts.

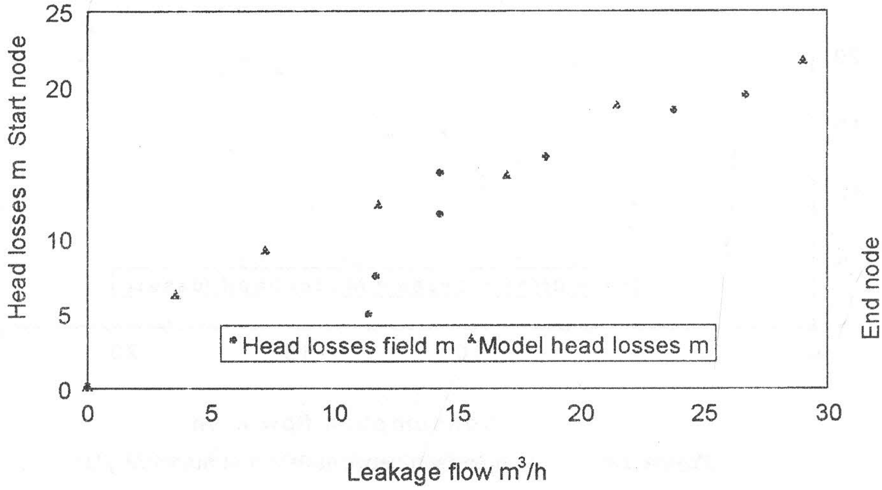

Figure 12 Comparison between field and model: AH/D3

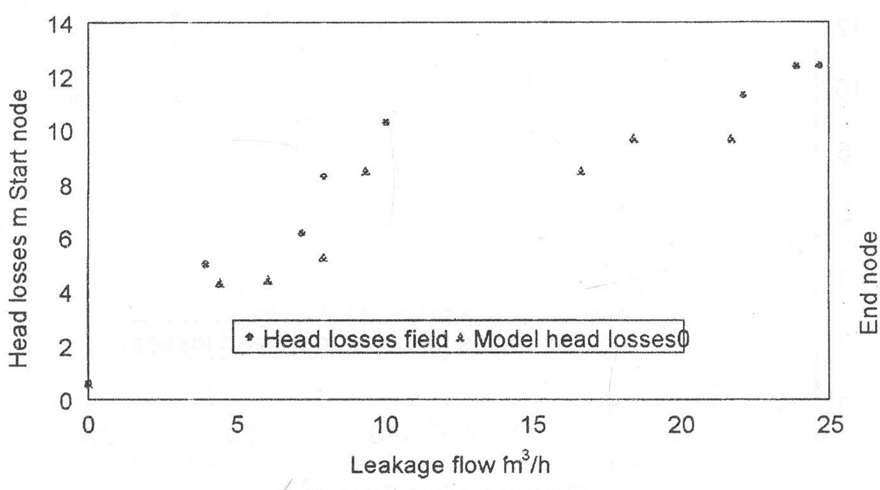

Figure 13 Comparison between field and model: AH/D35

The Pressure/Head Losses-Length of Pipeline Relationships

The pressure/head losses-length of pipeline relationships required to make the appropriate verifications are calculated for AH/D3 , AH/D5 as follows:

1- The pressure and length of pipeline

In this case, the comparison of the results and model data agreed successfully for districts AH/D3, AH/D5 as shown in Figures 14 and 15. The comparison gave excellent agreement between model results and field data.

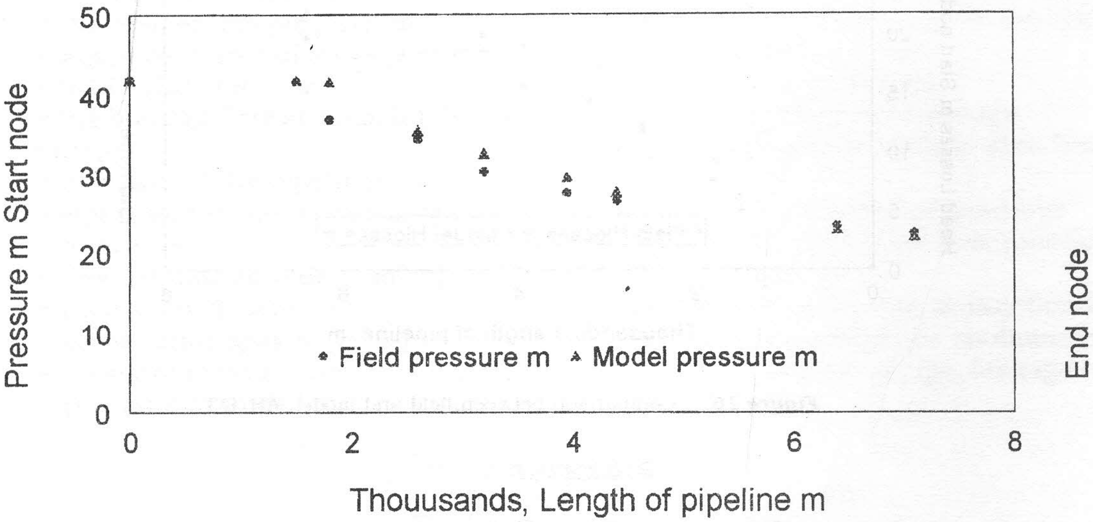

Figure 14 Comparison between field and model: AH/D3

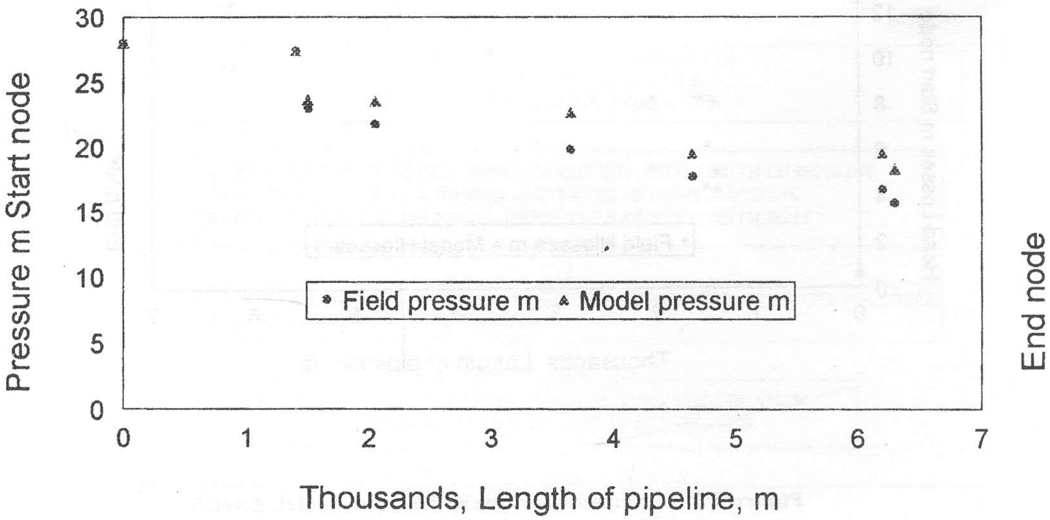

Figure 15 Comparison between field and model: AH/D5

2- The head losses and the length of pipeline

In this case, the relationship of pressure and the pipeline length was studied. Comparison of the data collected for district AH/D3, AH/D5 and model output results are shown in Figures 16 and 17. In the model results some points are higher, and on other hand some points in opposite direction than the field data. The model output results are close to field ones for the same length of pipeline. The model output chart has the same trend of the field data chart. The model succeeds to simulate the field conditions

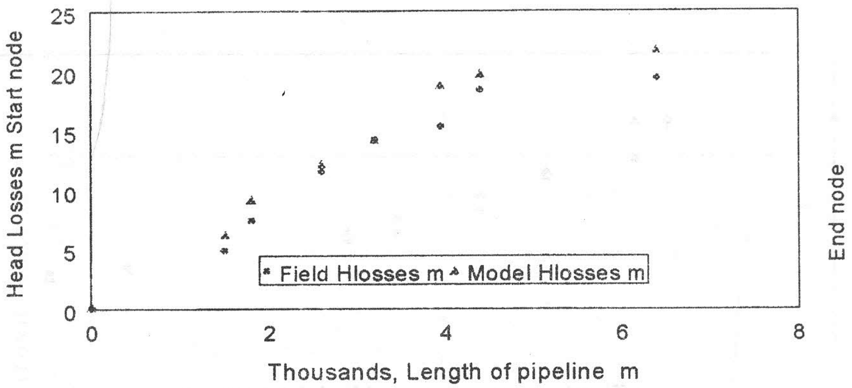

Figure 16 Comparison between field and model: AH/D3

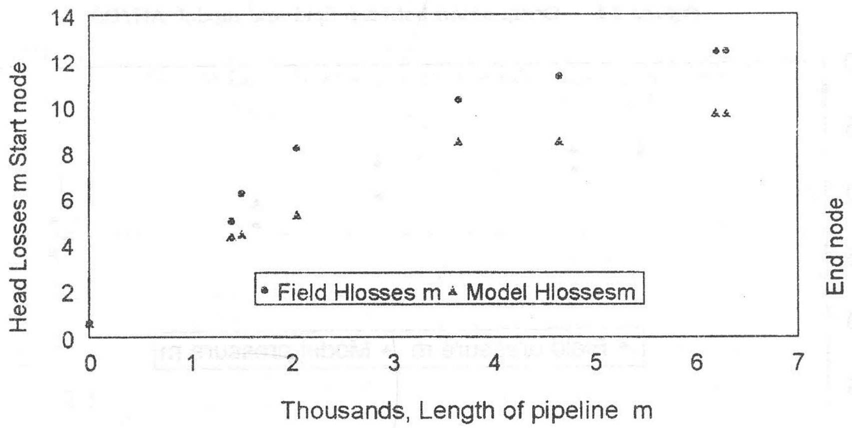

Figure 17 Comparison between field and model: AH/D5

CONCLUSIONS

The comparison between the model results and field data established the following points:

1. The model results have good agreement with the field data.
2. The effect of leakage is very important in explaining the reason for deviation occurring between the field data and the model due to the leakage. Many factors in the field affected the leakage reaction.
3. There is no relation between the leakage flow and the length of pipeline. This is logic because the leakage can happen at the beginning of the districts.
4. The increases in flow rates increase the rate of leakage, and the same for pressure.
5. This model has a wide range of applications as the leakage percentage is (.0 to 70%) of flow-in. The minimum pressure required to run this computer program equal 0.9 bar.

NOMENCLATURE

A_{ij} = the area of this pipeline (m^2)
Al_{ij} = Equivalent area of leakage orifice;
Al_{ij} = $3.14\ (Dl_{ij})^2 / 4$, (m^2)
C_{ij} = the leakage flow at branch ij (m^3/s)
C_{ij} = $Kl\ Q1_{ij}$
D_{ij} = diameter of the pipeline(ms),
Dl_{ij} = equivalent diameter of leakage orifice (m)
f_I = The net flow at node i. (m^3/s)
fr = friction coefficient
g = acceleration gravity (m/s^2)
H_I = pressure at node i.(m)
H_j = pressure at node j(m) ,
$H_j - H_I$ = head loses between nodes j,i (m).
Hl_{ij} = The head losses at the node of ij(m)
I = node number,
J = branch number
Kl = coefficient of leakage
L_{ij} = length of pipeline of th branch ij (m)
N = the number of junctions
Q_{ij} = The flow pass from junction i to j(m^3/s)
Qconsi = consumption at junction i(m^3/s)
R_{ij} = factor depends on diameter, length and flow of pipe, leakage coefficient.

APPENDIX

Flow Chart of Computer Program
(Mathematical Model Program)

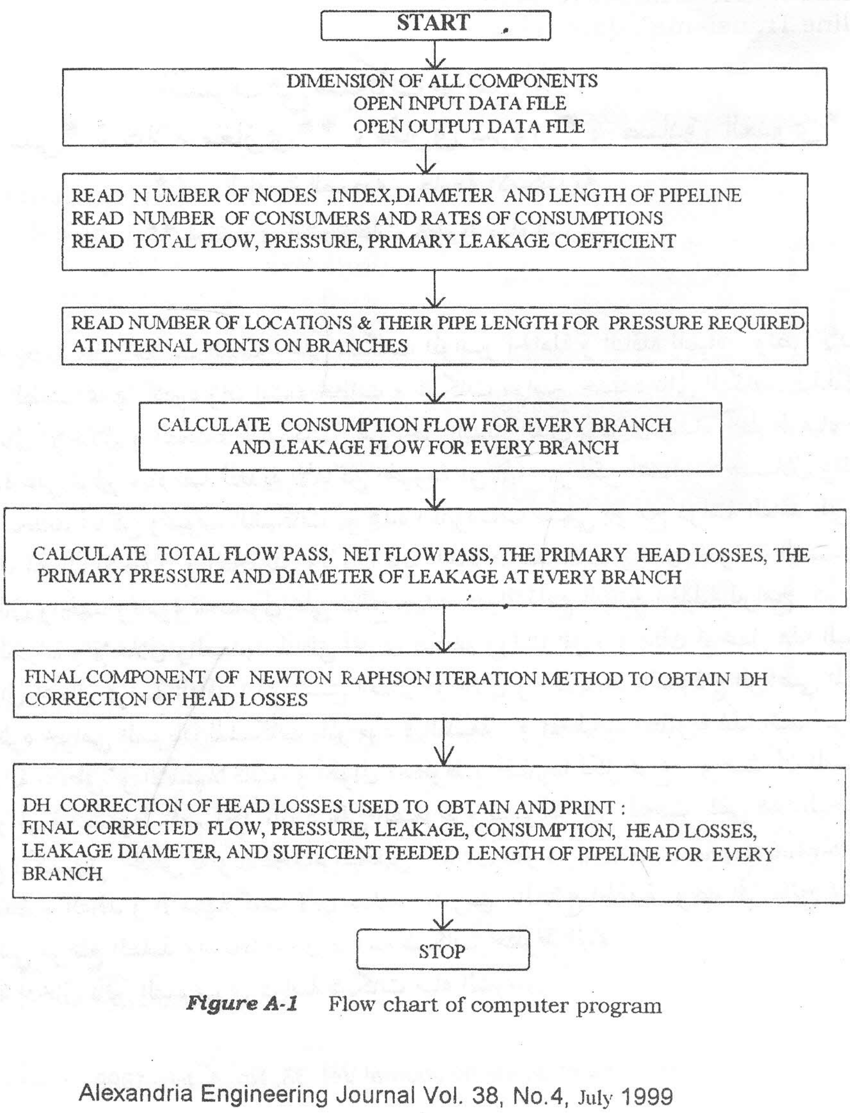

Figure A-1 Flow chart of computer program

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التسرب في شبكات مواسير المياه

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ملخص للبحث

إن الإمداد بالمياه النقية يعتمد على محطات التنقية وعلى شبكات المواسير الحاملة و الناقلة للمياه . ونظرا لان العوامل المؤثرة على استهلاك المياه وازدياد الطلب عليها كثيره وان إنشاء محطات و شبكات مواسير جديده عالي التكلفه. فبذلك تكون اعمال تقليل ا لفاقد عن طريق أعمال الإحلال و التجديد للشبكات هى الحل البديل الذى يوفر فى إنشاء خطوط مياه جديده . وهذه الأعمال تؤدى إلى المساعدة على توفير مياه نقيه لتغذية الأماكن المحرومة من المياه ,و لكن أعمال الإحلال والتجديد تحتاج لدراسات ميدانيه ومكتبيه لتحديد أماكن وعيوب الشبكات ,و هذه ا لدراسات تسمى ببرامج دراسة الفاقد التى تكلف كثير من النفقات و الجهود قبل وأثناء أعمال الإحلال و التجديد. ولذلك فان إيجاد طريقه علميه وعمليه لدراسة الفاقد فى الشبكات بحيث تكون سريعة لتوفر المال والجهد وقادرة للحصول على نتائج جيده متوافقة مع النتائج الحقلية لبرامج دراسة الفاقد سوف يسمح بالتوسع في أعمال الصيانة والإحلال والتجديد لمناطق أخرى بتكلفه ووقت اقل. ولذلك تم عمل هذا البحث.

فى هذا البحث تم باستبدال أعمال دراسة الفاقد ا لتي تسبق أعمال الإحلال و ا لتجديد بالنموذج الرياضي المقترح. حيث يقوم هذا النموذج الرياضي بمناظره خواص السريان للشبكات بالموجود فىالطبيعة . و المعطيات المطلوبة لهذا النموذج عبارة عن التصرف و الضغط عند بداية المناطق و الاستهلاكات و أطوال الخطوط و أقطارها لكل فرع . وحيث أن التسرب في الشبكات يؤثر على قيمة السريان و قيمة الضغوط فتم آخذ تأثيره على الضغوط والتصرف في البحث. ففى هذا البحث يقوم النموذج الرياضي والممثل في برنامج الكمبيوتر الخاص به وباستخدام التحليل العددي بطريقة **Newton Raphson Method** للحصول على نتائج تمثل التصرف و الضغط و الفاقد و الاستهلاكات لأي منطقه ومقارنتها بالنتائج الحقلية ,وجد أنها نتائج ممتازة تعطى الثقة لوضع هذا النموذج الرياضي موضع التنفيذ واستخدامه في دراسة شبكات خطوط المياه.

أظهرت النتائج مدى أهمية إدخال تأثير التسرب فى دراسة شبكات مياه الشرب.