Comparision of Pipeline Hydraulic Analysis between EPANET And HAMMER Softwares

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Comparision of Pipeline Hydraulic Analysis between EPANET And HAMMER Softwares

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Abstract

This paper presents a comparative study about the hydraulic analysis outputs of pipeline network between softwares EPANET and HAMMER. The main objective is to model a pipeline of water distribution network and accordingly putting the inputs as required in both the softwares. The outputs mainly at junctions (i.e. hydraulic grade line and pressure), pipes (i.e. flow, unit headloss) and velocity are considered for representing the above study. The comparative study has been carried out with the help of statistical regression analysis by finding out correlation coefficient and probable error coefficient. A relation is found out between the outputs of EPANET and HAMMER by the properties of Linear Regression, so that in unavailability of any one of the software, the results of the other software could be found out. Any network analysis software gives the same result for a fixed input, when statistical analysis of results are considered a significant difference though difference is too low but still an important one where precision becomes first criteria of designing a pipeline network. For a particular distribution network it is seen that during hydraulic analysis the output obtained from the two softwares are moreover the same but a very slight difference could be found among them while undergoing statistical analysis by the process shown in this paper. Graphical representation is also seen between the outputs of pipes and junctions of the above network and discusses the probable amount of correlation between the outputs of the two softwares.

***Keywords**: EPANET, HAMMER, water distribution network, correlation coefficient, probable error coefficient, linear regression.*

1. Introduction

This is a comparative study which addresses about the changes that are identified in two pipeline networking softwares namely EPANET and HAMMER while going through hydraulic analysis of a pipeline network. In addition, by methods of statistical analysis the correlation coefficient, the probable error coefficient can be found out by which the accuracy of comparison of the results obtained from the two softwares. Moreover a relation can be found out between the outputs of EPANET and HAMMER by the properties of Linear Regression, so that in unavailability of any one of the software, the results of the other software can be found out. For this purpose a detailed pipeline network along with its accessories such as valves, reservoirs, pipes, pumps and junctions are considered. Any network analysis software gives the same results for a fixed input, when statistical analysis of results are considered a significant difference though difference is too low but still an important one where precision becomes first criteria of designing a pipeline network. In order to find a low cost design in practice, experienced engineers have traditionally used trial-and-error methods based on their intuitive 'engineering sense'. However, their approaches have not guaranteed 'optimal' or 'near-optimal' designs, which is why researchers have been interested in optimization methods [2, 5].

EPANET (Version 2.0) computer software, developed by Rossman (1994) based on gradient algorithm, has been used in this study. After modeling the network the software calculated the optimum head losses in pipes and valves, pressures and hydraulic head in junctions [3].

EPANET tracks the flow of water in each pipe, the pressure at each node, the height of water in each tank, and the concentration of a chemical species throughout the network during a simulation period comprised of multiple time steps. In addition to chemical species, water age and source tracing can also be simulated. EPANET is designed to be a research tool for improving our understanding of the movement and fate of drinking water constituents within distribution systems. It can be used for many different kinds of applications in distribution systems analysis.

Bentley HAMMER (version 8i) is based on technology originally created by GENIVAR (formerly Environmental Hydraulics Group Inc.), the water Bentley HAMMER specialists, and backed by a long-term collaboration between GENIVAR and Bentley [5].

HAMMER is a powerful yet easy-to-use program that helps engineers analyze complex pumping systems and piping networks as they transition from one steady state to another. Hydraulic transients only last from seconds to a few minutes, but they can damage a system or cause significant operational difficulties. For example, Bentley HAMMER's name is due to the loud "water hammer" knocking sound that can be heard when sudden hydraulic transients occur. Bentley HAMMER helps engineers understand their pumping and piping networks better, enabling them to design safe and economical surge-control systems. This software can be used for both purpose like firstly, steady state analysis as like as above software and secondly transient analysis that happened due to water hammer.

2. Similarities and dissimilarities between EPANET 2.0 and HAMMER v 8i

For undergoing the pipeline network analysis various input and output parameters are considered in both the software as found in EPANET 2 user manual,2000; Bentley HAMMER version 8i edition user guide) [3,5]:

	EPANET 2.0 (Parameters)	**HAMMER V8i (Parameters)**
Junctions: Junctions are points in the network where links join together and where water enters or leaves the network. The basic input and output data required for junctions are:		
Input	Elevation(m)	Elevation (m)
Outputs	Hydraulic head (m)	Hydraulic Grade (m)
	Pressure (N/m^2)	Pressure (N/m^2)
		Transient head [max] (m)
		Transient head [min] (m)
		Transient pressure [max] (m)
		Transient pressure [min] (m)

Reservoirs: Reservoirs are nodes that represent an infinite external source or sink of water to the network. They are used to model such things as lakes, rivers, groundwater aquifers, and tie-ins to other systems. The basic input and output data required for reservoirs are:		
Input	Elevation (m)	Elevation (m)
Outputs	Hydraulic Head (m)	Hydraulic Grade (m)
	Pressure (N/m^2)	Pressure (N/m^2)

Tanks: Tanks are nodes with storage capacity, where the volume of stored water can vary with time during a simulation. The basic input & output data required for tanks are:		
Inputs	Bottom elevation [where water level is zero] (m)	Base Elevation (m)
	Diameter [or shape if non-cylindrical] (m)	Diameter (m)
	Initial water levels (m)	Initial Elevation (m)
	Minimum water levels (m)	Minimum water levels (m)

	Maximum water levels (m)	Maximum water levels (m)
Output	Hydraulic Head (m)	Hydraulic Head (m)

Pipes: Pipes are links that convey water from one point in the network to another. EPANET assumes that all pipes are full at all times. Flow direction is from the end at higher hydraulic head (internal energy per weight of water) to that at lower head. The head loss is calculated by the use of Hazen-William Formula. The basic input & output data required for pipes are:		
Inputs	Start and End nodes	Start and End nodes
	Diameter (mm)	Diameter (mm)
	Length (m)	Length (m)
	Roughness coefficient (for determining head loss)	Roughness coefficient (for determining head loss)
	Status (open, closed, or contains a check valve).	Status (open, closed, or contains a check valve).
Outputs	Flow rate (m^3/h)	Flow rate (m^3/h)
	Velocity (m/s)	Velocity (m/s)
	Head loss (m/km)	Head loss Gradient (m/km)
	Friction factor (unit less)	Friction factor (unit less)
		Transient initial head (m)
		Transient head [max] (m)
		Transient head [min] (m)
		Transient Pressure [max] (m)
		Transient Pressure [min] (m)
		Transient Velocity [initial] (m/s)
		Transient Velocity [max] (m/s)

Valves: Valves are links that limit the pressure or flow at a specific point in the network.		
Inputs	Diameter (mm)	Diameter (mm)
	Setting(Pressure (N/m^2), minor loss coefficient and Flow (m^3/h))	Setting(Pressure (N/m^2), minor loss coefficient and Flow (m^3/h))
	Status (open/closed)	Status (open/closed)
Outputs	Flow (m^3/h)	Flow (m^3/h)
	Velocity (m/s)	Velocity (m/s)
	Head loss (m/km)	Head loss (m/km)

Pumps: Pumps are links that impart energy to a fluid thereby raising its hydraulic head.		
Inputs (Pump & Efficiency curve)	Head(m)	Design head (m)
		Shut off Head (m)
	Flow(m^3/h)	Design flow (m^3/h)
	Efficiency (%)	Pump constant efficiency (%)
		Motor efficiency (%)
Inputs (Transient)		Inertia Pump Motor (N-m^2)
		Brake Horse Power (kW)
		Speed [full] (rpm)
		Pump type (Shut down after time delay)
		Diameter [Pump Valve] (mm)
		Time Delay [until shut down] (seconds)
		Pump valve type (check/control)
Inputs (other parameters)	Power (kW)	Power (kW)
	Status (open/closed)	Status (open/closed)
		Elevation (m)

Outputs	Flow (m^3/h)	Flow [Total] (m^3/h)
	Head loss (m/km)	Head loss Gradient (m/km)
		Hydraulic head [suction] (m)
		Hydraulic head [discharge] (m)
Outputs (Transient)		Flow [max] (m^3/h)
		Head [max] (m)
		Head [min] (m)
		Pressure [max] (N/m^2)
		Pressure [min] (N/m^2)
		Velocity [Initial] (m/s)
		Velocity [maximum] (m/s)
Wave speed calculator: The wave speed calculator allows determining the wave speed for a pipe or set of pipes. The basic inputs required for the wave speed calculator only in HAMMER V8i.		
Inputs		Bulk modulus of elasticity (N/m^2)
		Specific gravity
		Young's Modulus (N/m^2)
		Poisson's Ratio
		Wall thickness (mm)
		Pipeline support (Anchored, Expansion joints throughout and supported at one end.

3. Methodology

For comparative study between the above two software the following **methodology** is undertaken:

1. Firstly an optimized water distribution network is modeled in the two software keeping all the input parameters same in both the software.
2. The input data for junctions, reservoirs, tanks, pumps, valves and pipes are entered according to the similarities and dissimilarities of the two softwares from the above discussion.
3. The outputs from two softwares are recorded. This paper considers the outputs of the junctions and pipes i.e. for junctions - pressure and hydraulic grade line (HGL); for pipes - flow, unit headloss and velocity are considered.
4. The outputs are statistically analyzed and correlation coefficient (r), Probable Error (P.E.) of correlation coefficient is found out. The regression equation of y on x is also found out. x denotes the output values of EPANET and y denotes the values for HAMMER. These all are done by following the theory of correlation and regression (Das,1991 [2]):
   a. **Calculation of r :** Correlation coefficient (r) is unaffected by the choice of origin and scale of one or both the variables.Therefore, it can be calculated from a given set of n pairs of observations $(X_1,Y_1),(X_2,Y_2)\ldots\ldots(X_n,Y_n)$ as follows:

   If $x = X - c$ and $y = Y - c'$ (here, c and c' are constants), then

$$r_{XY} = r_{xy} = \frac{\text{cov}(x,y)}{\sigma_x \sigma_y} = r \tag{1}$$

where $$\sigma_x^2 = \frac{\Sigma x^2}{n} - \left(\frac{\Sigma x}{n}\right)^2, \sigma_y^2 = \frac{\Sigma y^2}{n} - \left(\frac{\Sigma y}{n}\right)^2$$

$$\text{cov}(x,y) = \frac{\Sigma xy}{n} - \left(\frac{\Sigma x}{n}\right)\left(\frac{\Sigma y}{n}\right) \tag{2}$$

Thus the given values of x on y on subtracting convenient numbers c and c', obtain deviations, $x = X - c$ and $y = Y - c'$. From these reduced values x and y, the two standard deviations and covariance, σ_x, σ_y and $\mathrm{cov}(x, y)$ respectively are calculated, and finally the correlation coefficient r or r_{xy} between them. σ_x^2 and σ_y^2 are the variance of x and y.

b. **Calculation of Probability Error (P.E)** : Calculation of Probability Error (P.E) of correlation coefficient found out by following equation taking the parameters from above:

$$\text{P.E.} = 0.6745\left(\frac{1-r^2}{\sqrt{n}}\right) \tag{3}$$

c. **Regression equation of y on x**: The regression equation of y on x is found out as

$$y - \bar{y} = b_{xy}\left(x - \bar{x}\right) \tag{4}$$

where, $b_{xy} = \dfrac{\mathrm{cov}(x, y)}{\sigma_x^2}$, $\bar{y} = \dfrac{\Sigma y}{n}$ and $\bar{x} = \dfrac{\Sigma x}{n}$ = average or mean of y on x respectively. Equation (4) is used to estimate y when the values of x is known.

5. Graphical representation is also seen between the outputs of pipes and junctions of the above network and discusses the probable amount of correlation between the outputs of the two softwares.

4. Input requirements of the network for analysis purpose for both the softwares

The inputs of the elements required for the given network are as follows:

Table 1. Reservoir details

Reservoir ID	Elevation (m)
WTP	96.16

Table 2. Tanks details

Tank ID	Elevation (m)	Initial level (m)	Minimum level (m)	Maximum level (m)	Diameter (m)	Minimum volume (m3)
T1	99.90	2.25	1.65	6.75	24.84	2664.2
T2	95.38	2.25	1.65	6.75	21.65	2023.8
T3	95.75	2.25	1.65	6.75	20.47	1809.2

Table 3. Pump specification

Head (m)	Discharge (m^3/hr)	Power (kW)	Pump efficiency (%)	Quantity
55	3408.75	561.07	91	3 Working

Table 4. Junction details

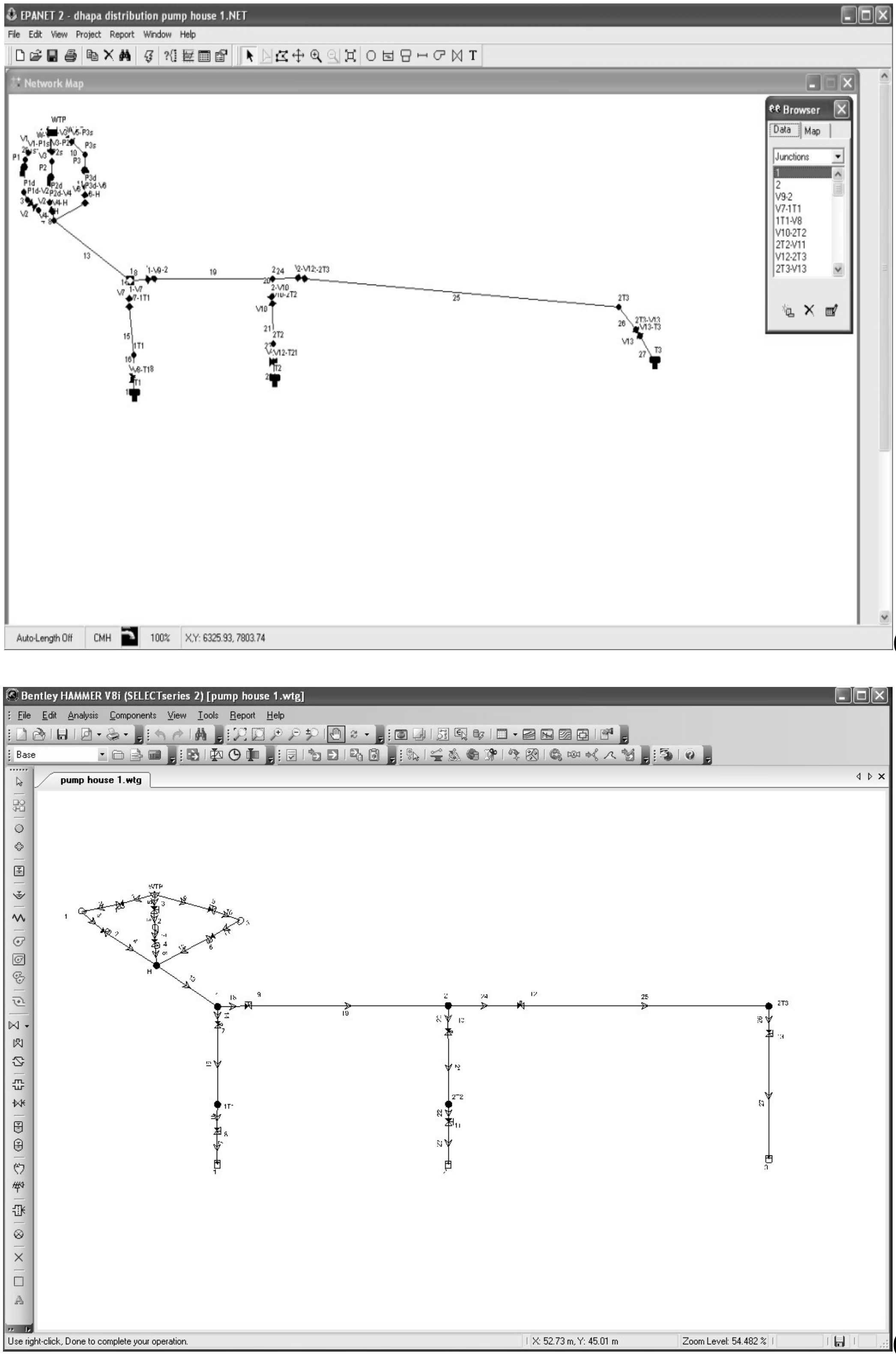
Nodes	Elevation (m)
H	98.10
1	98.25
1T1	100.35
2	98.57
2T2	102.33
2T3	99.20

Table 5. Pipes details

Pipe ID	Length (m)	Diameter (mm)	Roughness	Status
1	5	800	130	Open
2	3	800	130	Open
3	5	700	130	Open
4	7	700	130	Open
5	5	800	130	Open
6	3	800	130	Open
7	5	700	130	Open
8	7	700	130	Open
9	5	800	130	Open
10	3	800	130	Open
11	5	700	130	Open
12	7	700	130	Open
13	575	1400	130	Open
14	5	900	130	Open
15	2563	900	130	Open
16	10	700	130	Open
17	5	700	130	Open
18	6	1100	130	Open
19	3666	1100	130	Open
20	5	900	130	Open
21	1858	900	130	Open
22	10	700	130	Open
23	5	700	130	Open
24	4	750	130	Open
25	4883	750	130	Open
26	10	700	130	Open
27	5	700	130	Open

Table 6. Pipes details

Valve ID	Diameter (mm)	Type	Setting	Status
V1	800	TCV	0 (unit less)	Open
V2	500	PRV	0.44 MPa	Active
V3	800	TCV	0 (unit less)	Open
V4	500	PRV	0.44 MPa	Active
V5	800	TCV	0 (unit less)	Open
V6	500	PRV	0.44 MPa	Active
V7	900	FCV	2660 m^3/hr	Active
V8	700	TCV	0.2 (unit less)	Active
V9	1100	TCV	10(unit less)	Active
V10	900	FCV	2020 m^3/hr	Active
V11	700	TCV	0.2 (unit less)	Active
V12	750	FCV	1810 m^3/hr	Active
V13	700	TCV	0.2 (unit less)	Active



(a)
(b)

Figure 1. Software interface (a) EPANET and (b) HAMMER

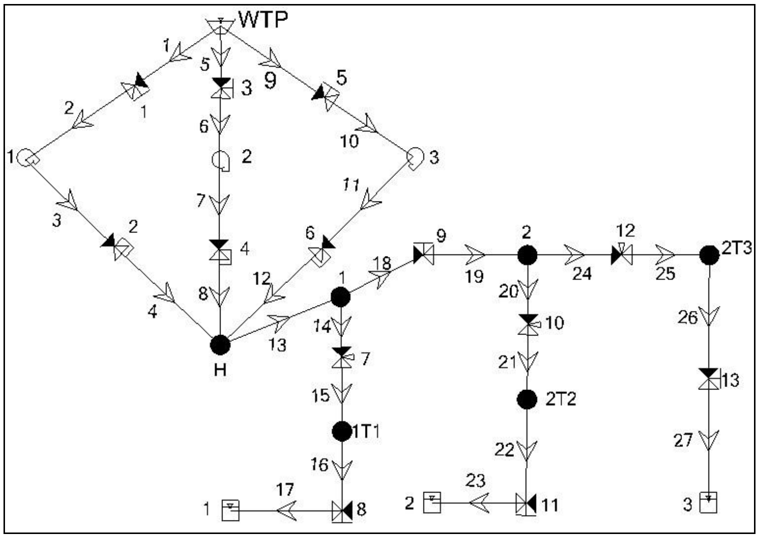


Figure 2. A pipeline distribution network

5. Results and discussion

By following the network in the Figure 2 and following the statistical analysis as per and graphical representation which discusses probable amount of correlation of the output from the pipes and junctions are found out.

Table 7. Junctions

Nodes	Elevation (m)	HGL (m) H_x	HGL (m) H_y	Pressure ($10^6 \times$ N/m^2) P_x	Pressure ($10^6 \times$ N/m^2) P_y
H	98.10	143.08	143.19	0.44	0.44
1	98.25	142.65	142.81	0.44	0.44
1T1	100.35	102.25	102.25	0.02	0.02
2	98.57	138.65	139.24	0.39	0.40
2T2	102.33	97.69	97.69	-0.01	-0.05
2T3	99.20	98.05	98.05	-0.01	-0.01
		r = 0.9999 **P.E.** = 1.59×10^{-5} $H_y = 1.006\, H_x - 0.6106$		r = 0.9987 **P.E.** = 0.000741 $P_y = 1.0321 P_x - 1.1733$	

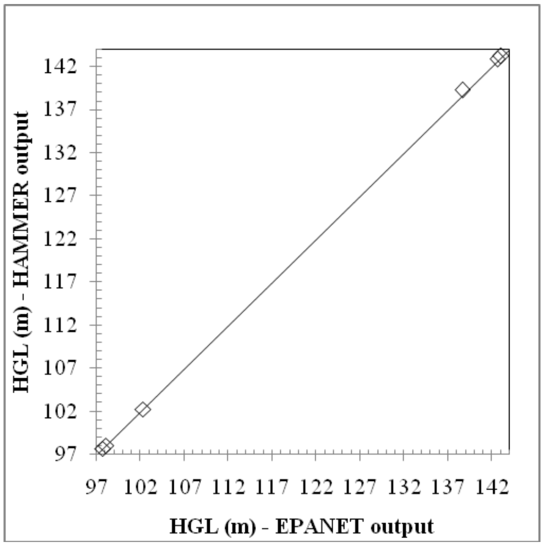


Figure 3. HGL output HAMMER vs EPANET

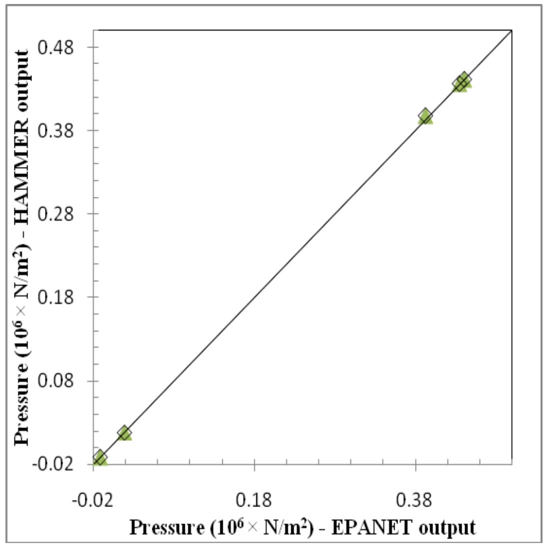


Figure 4. Pressure output HAMMER vs EPANET

From the above Figures 3 and 4 it is seen that all the points at different instant lies on the same best fit line drawn between the output parameters of junctions for the two software s in both the cases the percentage of difference between the two software output are in the order of 0.01%.

Table 8. Pipes

Pipe ID	Flow (m^3/h) Q_x	Flow (m^3/h) Q_y	Unit Headloss (m/km) h_x	Unit headloss (m/km) h_y	Velocity (m/s) V_x	Velocity (m/s) V_y
1	2163.33	2163.33	1.50	1.498	1.20	1.20
2	2163.33	2163.33	1.50	1.499	1.20	1.20
3	2163.33	2163.33	2.87	2.872	1.56	1.57
4	2163.33	2163.33	2.87	2.870	1.56	1.57
5	2163.33	2163.33	1.50	1.498	1.20	1.20
6	2163.33	2163.33	1.50	1.499	1.20	1.20
7	2163.33	2163.33	2.87	2.872	1.56	1.57
8	2163.33	2163.33	2.87	2.87	1.56	1.57
9	2163.33	2163.33	1.50	1.498	1.20	1.20
10	2163.33	2163.33	1.50	1.499	1.20	1.20
11	2163.33	2163.33	2.87	2.872	1.56	1.57
12	2163.33	2163.33	2.87	2.870	1.56	1.57
13	6490.00	6490.00	0.75	0.654	1.17	1.18
14	2660.00	2660.00	1.24	1.237	1.16	1.16
15	2660.00	2660.00	1.24	1.237	1.16	1.16
16	2660.00	2660.00	4.21	4.209	1.92	1.92
17	2660.00	2660.00	4.21	4.209	1.92	1.92
18	3830.00	3830.00	0.91	0.798	1.12	1.13
19	3830.00	3830.00	0.91	0.797	1.12	1.13
20	2020.00	2020.00	0.74	0.743	0.88	0.89

21	2020.00	2020.00	0.74	0.743	0.88	0.89
22	2020.00	2020.00	2.53	2.528	1.46	1.47
23	2020.00	2020.00	2.53	2.528	1.46	1.47
24	1810.00	1810.00	1.47	1.474	1.14	1.15
25	1810.00	1810.00	1.47	1.474	1.14	1.15
26	1810.00	1810.00	2.06	2.063	1.31	1.32
27	1810.00	1810.00	2.06	2.063	1.31	1.32
	r **= 1** **P.E.** = 5.4173×10^{-13} $Q_y = 0.9999Q_x + 0.0032$		***r*** = 0.9995 **P.E.**=0.00013 $h_y = 1.0140h_x - 0.0394$		***r*** = 0.999 **P.E**= 4.54×10^{5} $V_y = 0.9992V_x + 0.0073$	

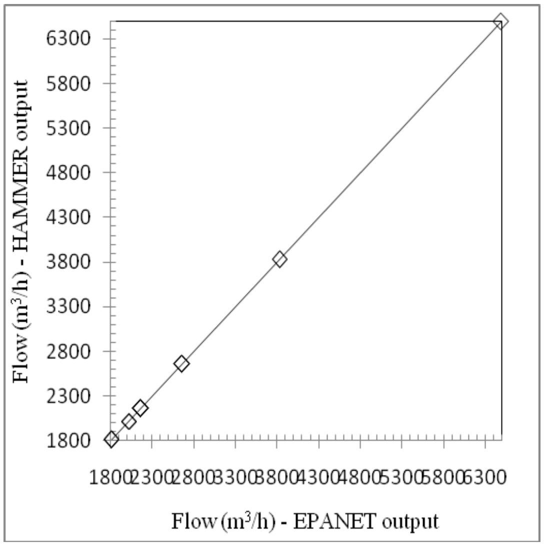


Figure 5. Flow output HAMMER vs EPANET

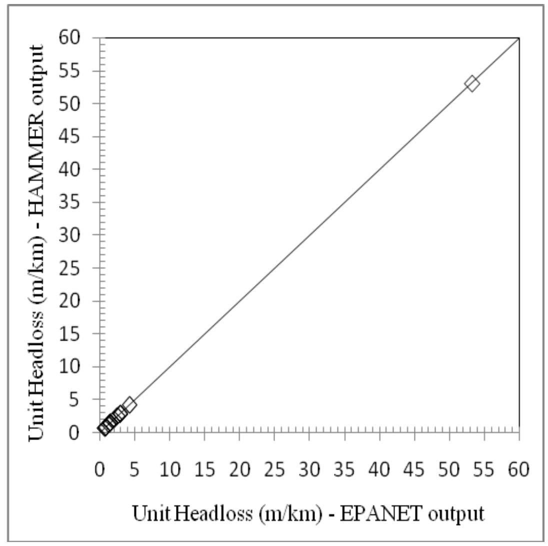


Figure 6. Unit headloss output HAMMER vs EPANET

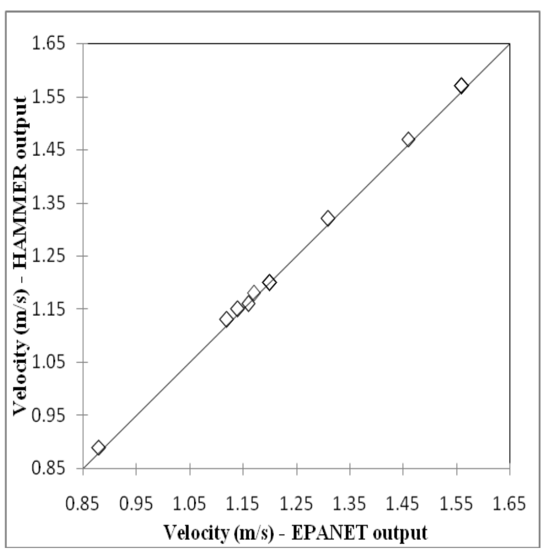


Figure 7. Velocity output HAMMER vs EPANET

From the above Figure 5 it can be easily said that the flow output remains more about same for both the softwares as ***r* =** 1. For Figures 6 and 7 the percentage of difference remains same as for the junction output between two softwares i.e. 0.01%.

6. Conclusions

For a particular distribution network it is seen that during hydraulic analysis the output obtained from the two softwares are moreover same but a very slight difference could be found among them while undergoing statistical analysis by the process shown in the paper. A relation in terms of x and y are found such that on unavailability of one software for the above network one can easily find out the output of the other software from the relations found out in this papers for various parameters. The change in the output data that is seen is most probable due to the change in the input values of pumps i.e. by the formula of pump curve we get $H = A - (B \times Q^{C})$, where H is the pump head developed by the pump, Q is the design flow of the pump, A, B, C are the pump curve coefficients and their units as (m), (m/m^3/h) and constant = 2.00 respectively. For both the software s a difference in order 0.001 is seen for coefficient B which in turn can change the values of developed head of the pump and likewise have an impact on the outputs of the junctions and pipes though the difference between the outputs of the softwares are in order 0.01% as shown in Tables 7 and 8.

7. Notation

r	=	correlation coefficient [–];
x	=	output values of EPANET;
y	=	output values of HAMMER;
σ_x	=	standard deviation of x [–];
σ_y	=	standard deviation of y [–];
σ_x^2	=	variance of x [–];
σ_y^2	=	variance of y [–];
n	=	number of data points [–];
P.E.	=	Probable error coefficient [–];
$\overline{y}$	=	mean or average value of y;
$\overline{x}$	=	mean or average value of x;
H_x	=	hydraulic grade lines values of x [L];
H_y	=	hydraulic grade lines values of y [L];
P_x	=	pressure values of x [$ML^{-1}T^{-2}$];
P_y	=	pressure values of y [$ML^{-1}T^{-2}$];
Q_x	=	flow values of x [L^3T^{-1}];
Q_y	=	flow values of y [L^3T^{-1}];
h_x	=	unit headloss values of x [–];
h_y	=	unit headloss values of y [–];
V_x	=	velocity values of x [L^1T^{-1}];
V_y	=	velocity values of y [L^1T^{-1}];
H	=	developed pump head [L];
Q	=	designed pump flow [L^3T^{-1}];
A	=	pump curve coefficients [L];
B	=	pump curve coefficients [$L^{-2}T$];
C	=	pump curve coefficients [–]; and
HGL	=	hydraulic grade line [L];

8. References

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Authors Profile

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