ECONOMICAL VELOCITY THROUGH PIPELINE NETWORKS "CASE STUDY OF WATER SUPPLY PIPELINE NETWORK IN LEBANON"

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ABSTRACT

A new concept for the economic design of pipeline is presented. The concept was applied on a single pipeline to show that this economic velocity leads to least total annual cost. The new methodology is based on selecting a constant design velocity through the entire pipeline network; main line and branch lines. At a least total annual cost, the velocity is called an economic velocity. Three different markets were considered; Lebanese, United States, and Indian. Two pipeline materials were studied: ductile iron and high density polyethylene. In this paper, the new methodology of economic velocity is applied on an actual case study of a water supply pipeline network in North Lebanon. The components of pipeline network were designed based on selecting several design velocities. For each design velocity, the total annual cost of pipeline network components, was estimated. The least total annual cost was related to the design velocity. At the least total annual cost, the design velocity was estimated to be defined as the economic velocity. Results of economic velocity for the pipeline network for ductile iron pipes were 1.0 m/s, 1.50 m/s, and 0.75 m/s for Lebanon, United States of America, and India, respectively. Moreover, economical velocities for high density polyethylene were 1.50 m/s, 1.25 m/s, and 1.50 m/s for Lebanon, United States of America, and India, respectively. The identified economical velocities for India and Lebanon for the two different pipeline materials were almost alike. However, the economical velocity for USA market was different. WaterCAD, computer software for hydraulic modeling confirmed the calculation results for the case study.

Keywords: Constant Velocity, Annual Cost, Economic Velocity

1 INTRODUCTION

Design of pipeline network is based on satisfying several criteria. The most important one is the design velocity. Design velocity through pipeline is so important. It may be responsible for not only erosion and sedimentation but also for raising the total annual and capital cost of the project. Economical velocity through a pipeline was not often considered by researchers. Most of the studies considered a single pipeline and estimated the cost of the water supply project using economical diameter. (Akintola & Giwa, 2009; Bedjaoui & Bouziane, 2005; Hu & Yu, 2013; Merkleym & Allen, 2004; Nervers, 2005; Peters et al., 2003; Robaina & Peiter, 2004; Towler & Sinnotti, 2008; Zocoler & Hernandez, 2006).

Considering a single pipeline, a new concept was presented by Sakr & Gooda (2018). They presented a mathematical model to relate different types of annual costs to the design velocity of pipeline. At least annual cost, they presented and solved the flowing equation:

$$b.C_{PL}.V^{-b-1} - 2.4325C_7.C_{PS}.V^{2.4325C_7-1} - 2.4325C_{AE}.V^{1.4325} = 0 \qquad (1)$$

Where; V is the design velocity for a single pipeline while b, C_{PL} ,C_7 ,C_{PS} ,and C_{AE} were coefficients related to the type of pipes and characteristics of pump as well as unit costs of different three markets. Relationships between design velocity and different parameters related to the pipeline were presented to show the effect of pipeline length, static head, capital recovery factor, flow discharge, pipeline accessories, as well as excavation and backfill on the economic design velocity .

The main objective of this paper presented herein, is to apply the new concept of economic velocity on an actual case study of pipeline network instead of a single pipeline. Three different markets were considered to estimate the annual cost of different components of pipelines. These markets were: Lebanese, United States, and Indian. Two different types of pipe materials were considered: ductile iron (DI) and high density polyethylene (HDPE) pipes. In order to achieve a long term economic water supply project, the economic velocity should be identified in the entire network. Therefore, the economical velocity is crucial for identifying the most economic water supply project.

2 PREVIOUS CONCEPTS OF DIFFERENT RESEARCHERS

1- Akintola & Giwa (2009) identified the economical diameter for a case study taking into consideration: annual pumping cost, cost of electrical energy, operational hours per year, efficiency of motor and pump, and cost per unit length of pipe (see table 1).

Table 1. Research Parameters

S /N	Parameters	Value
1	Compressibility	1.136363 x 10^{-3} m^3kg^{-1}
2	Operating time	8000 $hrs.yr^{-1}$
3	Mass flow rate	10 kgs^{-1}
4	Viscosity	1.1 x 10^{-3} Nsm^{-2}
5	Elect. Energy cost	N 2.50$kwhr^{-1}$
6	Cost / mm length of pipe	N 5.0mm^{-1}
7	Capital Charge	10%
8	Maintenance charge	5%
9	Ratio of total costs for fittings and installation to new pipe purchase cost	2.25
10	Efficiency	0.6
11	Initial guess for internal pipe diameter	31.9mm
12	Increment in pipe diameter	0.05mm

Note that N=Nigerian Naira

The authors took an increment of 0.05 mm in diameter to show the effect of diameter on the total annual cost of the project. No economical velocity is identified. A single market is shown with only 1 type of material for a single pipeline and not a pipeline network (see table 2 and fig. 1).

Table 2. Total Annual Costs for Each Diameter

Inside Diameter of Pipe (mm)	Total Annual Cost (N)	Inside Diameter of Pipe (mm)	Total Annual Cost (N)	Inside Diameter of Pipe (mm)	Total Annual Cost (N)
31.95	65700.9	33.35	64534.6	34.25	64303.5
32.00	65639.7	33.60	64433.9	34.30	64300.9
32.05	65580.0	33.80	64374.2	34.35	64299.3
32.25	65357.0	33.95	64341.0	34.40	64298.6
32.50	65111.7	34.00	64332.1	34.45	64299.0
32.65	64981.8	34.05	64324.3	34.50	64300.3
32.80	64864.4	34.10	64317.6	34.55	64302.7
32.90	64792.8	34.15	64311.8	34.60	64305.9
33.15	64636.8	35.20	64307.2	34.65	64310.2

Note that N=Nigerian Naira

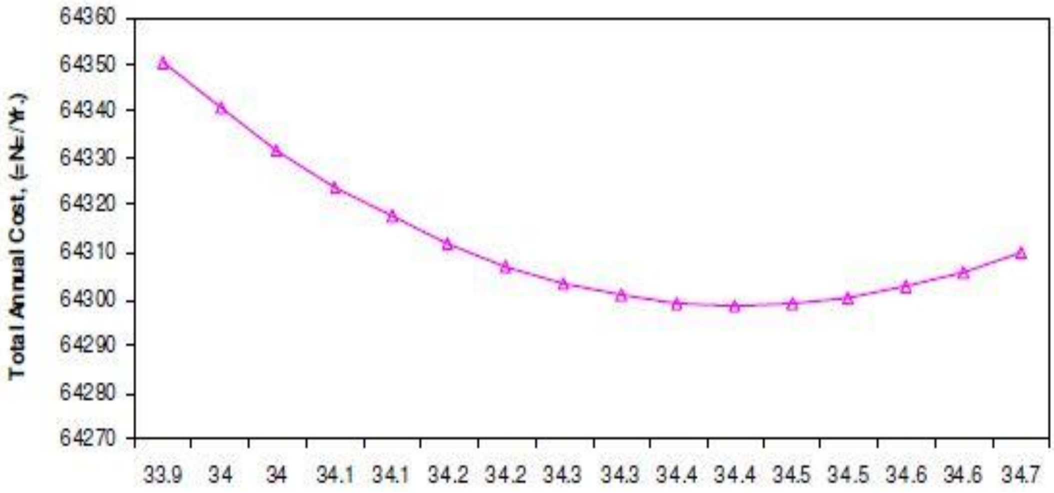


Figure 1. Economical Diameter Timothy A. Akintola, and Solomon O. Giwa (2009)

The total annual cost is plotted as a function of diameter. The economic diameter for a single pipeline is identified having the least annual cost.

2- - Peters, et al. (2003) designed the water supply pipes for turbulent flow in steel pipes with an inside diameter ≥ 1 inch (2.54 cm) according to the following equation:

$$di, opt \approx 0.363 m_v^{0.45} \rho^{0.13} \qquad (2)$$

Where di is the internal diameter in m, m_v is the flow rate in m^3/s and ρ is the density in kg/m^3.

3- Towler & Sinnotti (2008) calculated the economic diameter of the pipeline for turbulent flow in steel pipe using the following equations for diameters, di, ranging between 25 and 200 mm;

$$di, opt = 0.664\, G^{0.51} \rho^{-0.36} \qquad (3)$$

Where di is the internal diameter in m.

For diameters, di, ranging between 250 and 600 mm, $di, opt = 0.534\, G^{0.43} \rho^{-0.30}$ (4)

Where di is the internal diameter in m and G is the flow rate in kg/s.

In both researches the economic diameter was calculated for steel pipelines rather than other materials such as HDPE pipeline which is also commonly used. In addition, equations 2, 3, and 4 were used to calculate the optimum diameter for a single pipeline but not for a water supply network. The economic diameter should also differ from a country to another. Applying equation 2, 3, or 4, the economic diameter was identified for a certain unique market. No mentioned factor representing the cost of the pipeline for the market.

2.1 Comparison of Economic Diameter among Previous Researchers

Equation (4) presented by Towler & Sinnotti, 2008 is limited to a max diameter of 600 mm. Therefore, a comparison between Peters et al., 2003 and Towler & Sinnotti, 2008 can be done for diameters up to 600 mm. Volumetric flow values were considered in m^3/s and kg/s according to the units for equations 2 and 4. The comparison is shown in table 3 below.

Table 3. Economic diameter calculation using equation (2 and 4) as mentioned by Towler & Sinnotti, 2008 and Peters et al., 2003

Peters et al., 2003 (Eq. 2)			Towler & Sinnotti, 2008 (Eq. 4)		
ρ (kg/m3)	Q (m3/s)	di (m)	ρ (kg/m3)	Q (kg/s)	di (m)
1000	0.05	0.23	1000	50	0.36
1000	0.08	0.29	1000	80	0.44
1000	0.1	0.32	1000	100	0.49
1000	0.125	0.35	1000	125	0.54
1000	0.15	0.38	1000	150	0.58
1000	0.2	0.43	1000	200	0.66

After the application of equations 2 and 4 as shown in table 3, economic diameter for the same volumetric flow is calculated which resulted in different optimum diameter between both methods. For example, at a flow rate of 0.1 m^3/s which is equivalent to 100 kg/s, the economic diameter was 0.32 m using Peters et al., 2003 method while it was 0.49 m using Towler & Sinnotti, 2008 method. This comparison indicated that the concept of economic diameter was not consistent and can be only used for a single pipeline not a network.

2.2 Summary of Old Researches

Most of the researchers defined the economic pipeline as an economic diameter for a single pipeline. However, rarely of the researchers mentioned the concept of design velocity. Also, none of them related the economic pipeline to different markets. In addition, no one defined the economical velocity of pipelines and its relation with the market. Sakr & Gooda, 2018 did both. However, they did not consider a pipeline network.

2.3 Economic Velocity Concept

Sakr & Gooda, 2018 presented a new concept in the design of pipelines network. According to this concept, the designer can select a design velocity, called the economic velocity which can be maintained through all network such as the main and branches. The paper applied the new concept on a Lebanese case study. In a previous paper, Sakr & Gooda (2018) applied the concept on a single pipeline in which a pump was used to deliver water to either a populated area or agriculture area. A mathematical model was presented to formulate a relationship to estimate total annual cost as a function of the economical velocity. At least annual cost, the design velocity was called an economic velocity. In this paper, the concept will be applied on a network not only a single pipeline.

3 CASE STUDY OF PIPELINE NETWORK IN NORTH - LEBANON

The case study is represented by a small residential area in North-Lebanon in the governorate of Akkar called Massoudiyeh. Massoudiyeh is a small village and it would have a population of an approximately 8200 persons by 2040. A pump station is used to supply the pipeline network with water. The number of pumps is four (three working in parallel + one standby). The total length of the whole network (A-B-C-D-E-F-G-H-I-J-K) is 5945 meter, as shown in figure 3. Two types of pipelines were considered; Ductile iron (D. I.) and High Density Polyethylene Pipe (HDPE)

The following data are available:

- Annual cost pump station and pipelines are assumed to be 10% of capital costs.
- The ground level for each junction is shown in figure 3.
- Minimum required design pressure at the junction equal to 20 meters of water.
- Demand required at each junction is shown on the figure.
- Hazen-Williams coefficient for D.I. and HDPE pipes are (C_{HW}) = 120, and 150 respectively.
- Difference in ground level between highest level of and lowest level of a junction is 5 meters.
- Overall efficiency of the pumping station is 80%.

Water will be pumped 12 hours per day and 340 days per year

Figure 2. Massoudiyeh Village Site Plan

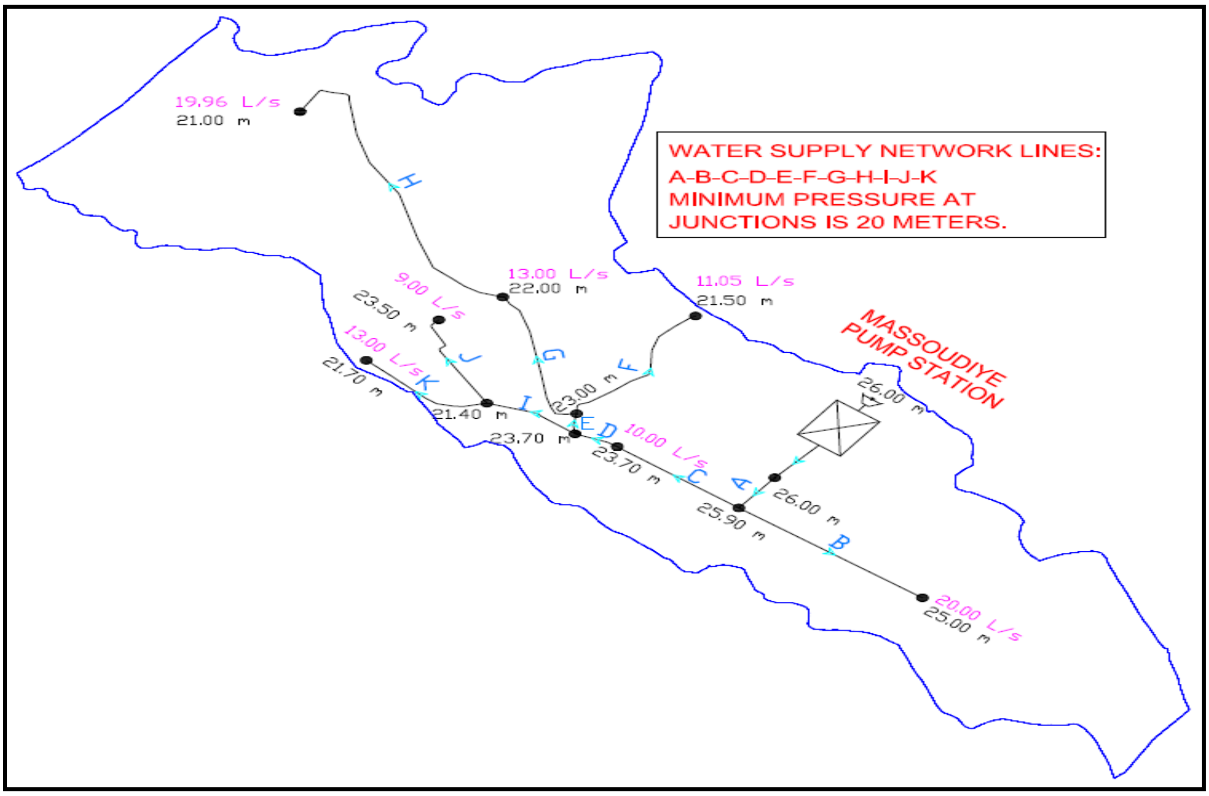


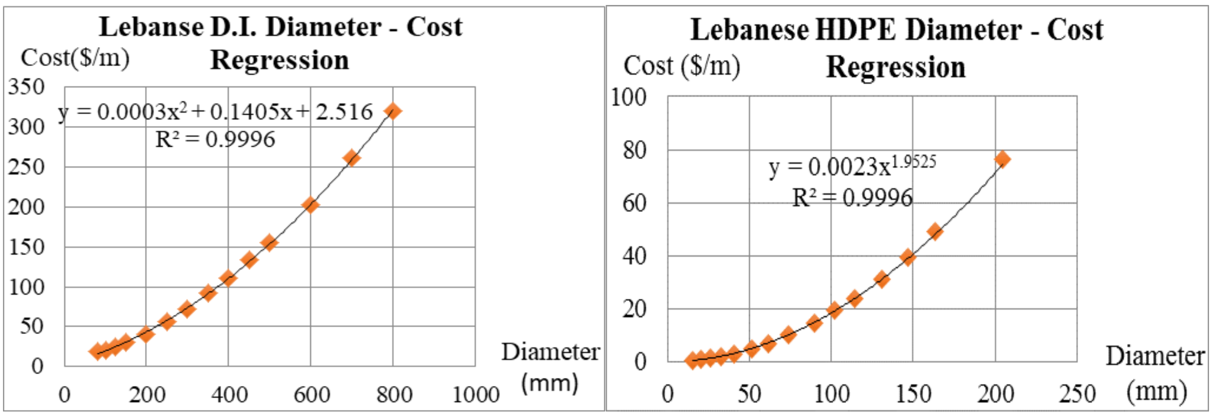
Figure 3. Scheme of the Residential Area Water Supply Network for the Case Study

4 COST ANALYSIS FOR THE CASE STUDY CONSIDERING THREE MARKETS

A cost analysis was done for the three different markets. For each market, several constant design velocities were assumed. For each constant design velocity, diameters of main and branched lines were estimated. Both the total and annual costs were estimated. The relationship between the total annual costs with the assumed design velocity was plotted. The least total annual cost tangent to plotted curve, gives the value of economical velocity.

4.1 Regression Analysis for Lebanese, USA, and Indian Markets

Pipeline cost for D.I. and HDPE pipes is plotted as a function of diameter for the three markets. In addition, pump cost is plotted as a function of power. Regression analysis for pipeline diameter and pump power is done to obtain a mathematical formula to calculate the cost of the pipeline and the cost of energy in the three markets for the case study (see figs. 4 and 5).



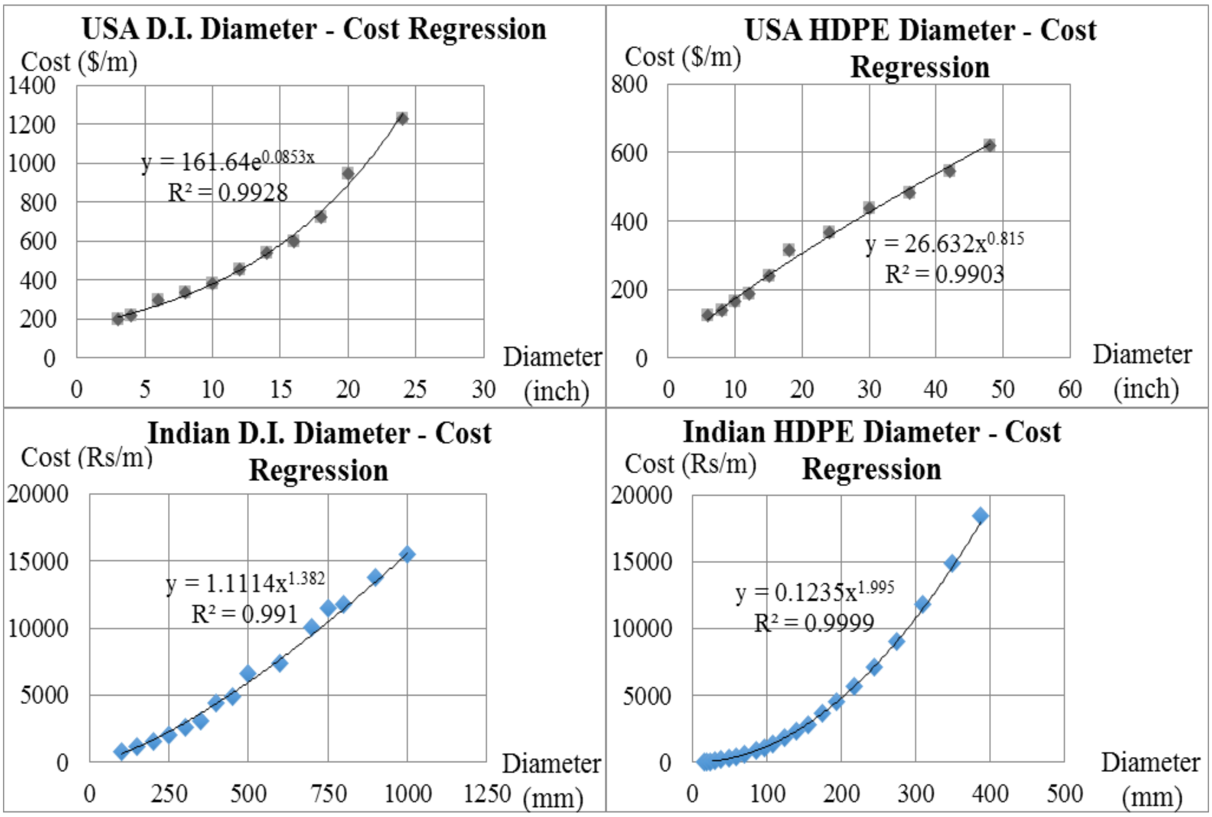


Figure 4. Diameter Cost Regression for Lebanese, USA, & Indian Markets (D.I. & HDPE)

Cost data has been obtained using personal communication, (year 2016).

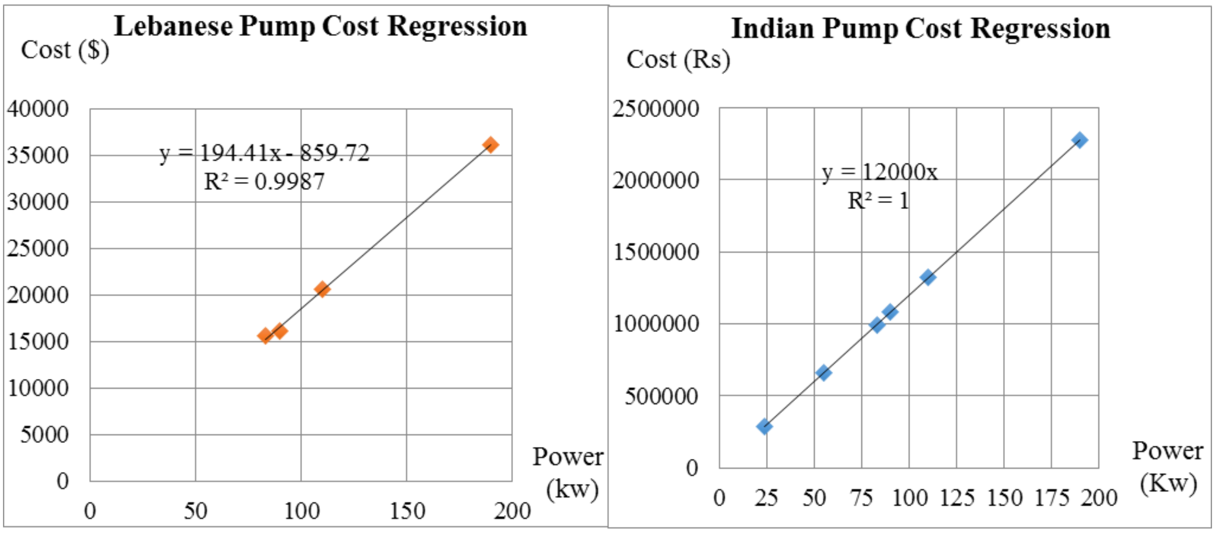


Figure 5. Pump Cost Regression (Lebanese & Indian Markets)

USA PUMP COST ESTIMATION; 1 HP = 440 $

Cost data has been obtained using personal communication, (year 2016)

4.2 Application of the New Concept Methodology

A cost analysis is prepared for the three different markets. For each market, several design velocities are assumed constant in all the pipeline network; main line and branched lines. The actual velocity is calculated to match the assumed velocity. For each assumed design velocity, annual cost of pipeline network is calculated. At least annual cost, the design velocity is called economic velocity.

The capital cost of the pipelines and the pumps is calculated using the regression analysis shown in figures 4 and 5. The annual cost is calculated by multiplying the capital costs for the pipelines, and pumps by an assumed capital recovery factor of 10%. The total annual cost includes the annual cost of pipelines, pumps, and the energy consumed annually by the pumps. The following tables show the application of the new concept.

4.3 Cost Analysis for Lebanese Market (Case Study of Ductile Iron Pipeline Network)

Table 4. Cost Analysis for Lebanese Market at a Velocity of 1.00 m/s for the Case Study (D.I.)

Scenario Number	Section Number	Discharge Q(m3/s)	Length (m)	Chosen Diameter (mm)	Cross Section Area (m2)	Unit Cost of Pipe ($/m)	Assumed Velocity (m/s)	Actual Velocity (m/s)	Capital Cost($)	Annual Cost($)	C	Head loss (m)
3	A	0.096	196	350	0.10	97	1	1.00	19012	1901.2	120	0.64
3	B	0.02	774	150	0.02	33	1	1.13	25542	2554.2	120	8.55
3	C	0.076	518	300	0.07	79.5	1	1.08	41181	4118.1	120	2.32
3	D	0.066	158	300	0.07	79.5	1	0.93	12561	1256.1	120	0.54
3	E	0.044	104	250	0.05	63	1	0.90	6552	655.2	120	0.41
3	F	0.011	695	120	0.01	24.5	1	0.97	17027.5	1702.75	120	7.52
3	G	0.033	708	200	0.03	47	1	1.05	33276	3327.6	120	4.87
3	H	0.02	1447	160	0.02	35.5	1	1.00	51368.5	5136.85	120	11.68
3	I	0.022	345	160	0.02	35	1	1.09	12075	1207.5	120	3.32
3	J	0.009	500	110	0.01	22	1	0.95	11000	1100	120	5.70
3	K	0.013	500	130	0.01	27.2	1	0.98	13600	1360	120	4.99
								Total	243195	24319.5		

Continue Table 4. Cost Analysis for Lebanese Market at a Velocity of 1.00 m/s for the Case Study (D.I.)

Gamma Water Kg/m3	Max Static head(m)	Other Losses(m)	Sum of All Hf(m)	Power of Pumps (KW)	Capital Cost of Pump Station Using Regression	Annual Cost of Pump Station ($)	Annual Cost of Energy 0.077$/KW.hr.	Total Capital Cost($)	Total Annual Cost($)
1000	5	20	20.46	57.09	13940.35	1394.03	17937.31	257135.35	43650.85

Table 5. Summary of Cost Analysis for Lebanese Market (Case Study of D.I.) at different design velocities Used in Analysis

Assumed Velocity(m/s)	Capital Cost of Pipes ($)	Annual Cost of Pipes ($)	Capital Cost of Pump Station Using Regression	Annual Cost of Pump Station($)	Annual Cost of Energy 0.077$/KW.hr.	Total Capital Cost($)	Total Annual Cost($)
0.5	386521	38652.1	8056.40	805.64	10806.11	394577.40	50263.85
0.75	298076	29807.6	10224.83	1022.48	13434.20	308300.83	44264.28
1	243195	24319.5	13940.36	1394.04	17937.32	257135.36	43650.85
1.25	214069	21406.9	18495.43	1849.54	23457.96	232564.43	46714.40
1.5	189924.5	18992.45	25306.16	2530.62	31712.38	215230.66	53235.45
1.75	171610.5	17161.05	34418.04	3441.80	42755.75	206028.54	63358.60
2	158862.5	15886.25	42663.16	4266.32	52748.63	201525.66	72901.20

Table 5 shows that 1.00 m/s is the identified economic velocity for the Lebanese market for the case study for ductile iron pipes. Other annual and capital costs for different velocities are also shown.

4.4 Cost Analysis for USA Market (Case Study of Ductile Iron Pipeline Network)

The same application of the new method is prepared to the USA market. The following table will show the final results and the identified economic velocity for ductile iron pipes.

Table 6. Summary of Cost Analysis for USA Market (Case Study of D.I.) at different velocities

Assumed Velocity(m/s)	Capital Cost pipes($)	Annual Cost pipes($)	Capital Cost of Pump Station(440$/HP)	Annual Cost of Pump Station($)	Annual Cost of Energy 0.054$/KW.hr.	Total Capital Cost($)	Total Annual Cost($)
0.75	1992756	199275.6	32369.95	3237.00	9117.29	2025125.95	211629.89
1	1762270.9	176227.09	47947.84	4794.78	13504.94	1810218.74	194526.82
1.25	1668962	166896.2	60484.18	6048.42	17035.92	1729446.18	189980.54
1.5	1595488	159548.8	77822.02	7782.20	21919.28	1673310.02	189250.28
1.75	1530622.3	153062.23	103286.55	10328.66	29091.60	1633908.85	192482.48
2	1481036.5	148103.65	136737.56	13673.76	38513.38	1617774.06	200290.78

Table 6 shows that 1.5 m/s is the identified economic velocity for the USA market for the case study for ductile iron pipes. Other annual and capital costs for different velocities are also shown.

4.5 Cost Analysis for Indian Market (Case Study of Ductile Iron Pipeline Network)

The same application of the new method is prepared to the Indian market. The following table will show the final results and the identified economic velocity for ductile iron pipes.

Table 7. Summary of Cost Analysis for Indian Market (Case Study of D.I.) at different velocities

Assumed Velocity (m/s)	Capital Cost of Pipes (Rs)	Annual Cost of Pipes (Rs)	Capital Cost of Pump Station Using Regression	Annual Cost of Pump Station(Rs)	Annual Cost of Energy 4.1Rs/KW.hr.	Total Capital Cost(Rs)	Total Annual Cost(Rs)
0.5	14231014	1423101.4	550349.31	55034.93	575390.20	147813633.1	2053526.53
0.75	10696563.5	1069656.3	684196.35	68419.63	715327.28	11380759.8	1853403.27
1	8633412	863341.2	913537.99	91353.80	955103.97	9546949.99	1909798.96
1.25	7588324	758832.4	1194701.09	119470.1	1249059.99	8783025.09	2127362.50
1.5	6582336.5	658233.65	1615094.51	161509.45	1688581.31	8197431.01	2508324.41
1.75	5940008.5	594000.85	2177527.24	217752.7	2276604.73	8117535.74	3088358.30
2	5482713.5	548271.35	2686459.54	268645.9	2808693.45	8169173.04	3625610.76

Table 7 shows that 0.75 m/s is the identified economic velocity for the Indian market for the case study for ductile iron pipes. Other annual and capital costs for different velocities are also shown.

4.6 Annual Cost Relations for Three Markets (Case study of D.I. Pipeline Network)

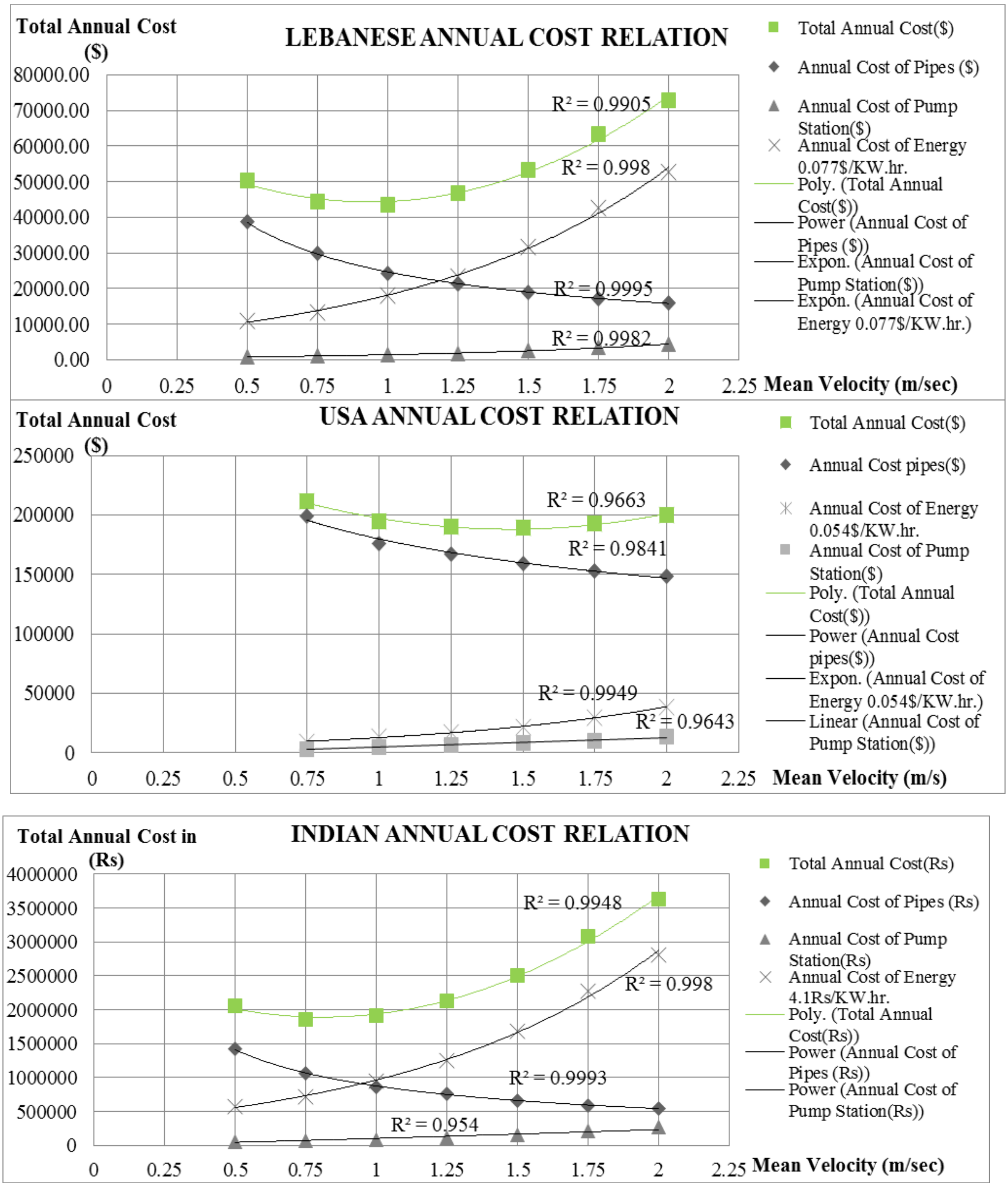


Figure 6. All Markets Annual Cost Relations versus Mean Velocity for D.I. Pipes

Cost analysis for Lebanon, USA, and India for ductile iron and pipes are calculated. In addition, economic velocity for Lebanon, USA, and India is identified for ductile iron. The economical velocities for ductile iron are 1.0m/s, 1.5m/s, and 0.75m/s for Lebanon, United States of America, and India, respectively (see fig. 6).

4.7 Cost Analysis for Lebanese Market (Case study of HDPE Pipeline Network)

Constant economic velocity method is also applied for Massoudiyeh case study for HDPE pipelines material for the three markets. The following tables will demonstrate the results. After different number of scenarios, scenario number 4 is selected to demonstrate the results for the application of the new constant design velocity in the main lines and branches method.

Table 8. Cost Analysis for Lebanese Market at a Velocity of 1.5 m/s for the Case Study (HDPE)

Scenario Number	Section Number	Discharge Q(m3/s)	Length (m)	Chosen Diameter(mm)	Cross Section Area (m2)	Unit Cost of Pipe ($/m)	Assumed Velocity (m/s)	Actual Velocity (m/s)	Capital Cost($)	Annual Cost($)	C	Head loss (m)
4	A	0.096	196	290	0.07	148	1.5	1.45	29008	2900.8	150	1.06
4	B	0.02	774	130	0.01	31	1.5	1.51	23994	2399.4	150	11.36
4	C	0.076	518	260	0.05	119	1.5	1.43	61642	6164.2	150	3.08
4	D	0.066	158	240	0.05	102	1.5	1.46	16116	1611.6	150	1.07
4	E	0.044	104	200	0.03	71	1.5	1.40	7384	738.4	150	0.81
4	F	0.011	695	100	0.01	18	1.5	1.40	12510	1251	150	12.09
4	G	0.033	708	170	0.02	52	1.5	1.45	36816	3681.6	150	7.11
4	H	0.02	1447	130	0.01	31	1.5	1.51	44857	4485.7	150	21.23
4	I	0.022	345	140	0.02	36	1.5	1.43	12420	1242	150	4.21
4	J	0.009	500	90	0.01	15	1.5	1.42	7500	750	150	10.02
4	K	0.013	500	105	0.01	20	1.5	1.50	10000	1000	150	9.35
								Total	262247	26224.7		

Continue Table 8. Cost Analysis for Lebanese Market at a Velocity of 1.75 m/s for the Case Study (HDPE)

Gamma Water Kg/m3	Max Static head(m)	Other Losses(m)	Sum of All Hf(m)	Power of Pumps (KW)	Capital Cost of Pump Station Using Regression	Annual Cost of Pump Station($)	Annual Cost of Energy 0.077$/KW.hr.	Total Capital Cost($)	Total Annual Cost($)
1000	5	20	34.35	75.89	18812.07	1881.21	23841.71	281059.07	51947.62

Table 9. Summary of Cost Analysis for Lebanese Market for the Case Study (HDPE) Used in Regression Analysis

Assumed Velocity (m/s)	Capital Cost of Pipes ($)	Annual Cost of Pipes ($)	Capital Cost of Pump Station Using Regression	Annual Cost of Pump Station($)	Annual Cost of Energy 0.077$/KW.hr.	Total Capital Cost($)	Total Annual Cost($)
0.75	501259.5	50125.95	9053.37	905.33	12014.41	510312.87	63045.70
1	369406	36940.6	11511.14	1151.11	14993.18	380917.14	53084.90
1.25	298917	29891.7	16414.33	1641.43	20935.71	315331.33	52468.85
1.5	262247	26224.7	18812.07	1881.20	23841.71	281059.07	51947.62
1.75	217768.7	21776.87	25056.90	2505.69	31410.29	242825.61	55692.86
2	193580.5	19358.05	30510.97	3051.09	38020.48	224091.47	60429.63

Table 9 shows that 1.50 m/s is the identified economic velocity for the Lebanese market for the case study for HDPE pipes. Other annual and capital costs for different velocities are also shown.

4.8 Cost Analysis for USA Market (Case Study of HDPE Pipeline Network)

The same application of the new method is prepared to the USA market. The following table will show the final results and the identified economic velocity for HDPE pipes.

Table 10. Summary of Regression Analysis for Cost Analysis of USA Market (Case Study of HDPE)

Assumed Velocity(m/s)	Capital Cost pipes($)	Annual Cost pipes($)	Capital Cost of Pump Station(440$/HP)	Annual Cost of Pump Station($)	Annual Cost of Energy 0.054$/KW.hr.	Total Capital Cost($)	Total Annual Cost($)
0.75	869296	86929.60	29200.33	2920.03	8224.54	898496.33	98074.17
1	753801.5	75380.15	38175.33	3817.53	10752.43	791976.83	89950.11
1.25	695929.1	69592.91	50713.02	5071.30	14283.78	746642.12	88948.00
1.5	647117	64711.70	65628.82	6562.88	18484.96	712745.82	89759.54
1.75	610543.5	61054.35	80091.15	8009.11	22558.40	690634.65	91621.87
2	576820.5	57682.05	98238.36	9823.84	27669.73	675058.86	95175.61

Table 10 shows that 1.25 m/s is the identified economic velocity for the USA market for the case study for HDPE pipes. Other annual and capital costs for different velocities are also shown.

4.9 Cost Analysis for Indian Market (Case Study of HDPE Pipeline Network)

The same application of the new method is prepared to the Indian market. The following table will show the final results and the identified economic velocity for HDPE pipes.

Table 11. Summary of Regression Analysis for Cost Analysis of Indian Market (Case Study of HDPE)

Assumed Velocity(m/s)	Capital Cost of Pipes (Rs)	Annual Cost of Pipes (Rs)	Capital Cost of Pump Station Using Regression	Annual Cost of Pump Station(Rs)	Annual Cost of Energy 4.1Rs/KW.hr.	Total Capital Cost(Rs)	Total Annual Cost(Rs)
0.75	34013233	3401323.3	611887.7	61188.8	639728.6	34625120.7	4102240.6
1	24944750	2494475.0	763594.6	76359.5	798338.2	25708344.6	3369172.7
1.25	19766740	1976674.0	1066244.7	106624.5	1114758.8	20832984.7	3198057.3
1.5	17578402	1757840.2	1214245.7	121424.6	1269493.9	18792647.7	3148758.6
1.75	14580351	1458035.1	1599709.7	159971.0	1672496.5	16180060.7	3290502.5
2	12937182	1293718.2	1936362.8	193636.3	2024467.3	14873544.8	3511821.8

Table 11 shows that 1.50 m/s is the identified economic velocity for the Indian market for the case study for HDPE pipes. Other annual and capital costs for different velocities are also shown.

4.10 Annual Cost Relations for the Three Markets (Case of HDPE Pipeline Network)

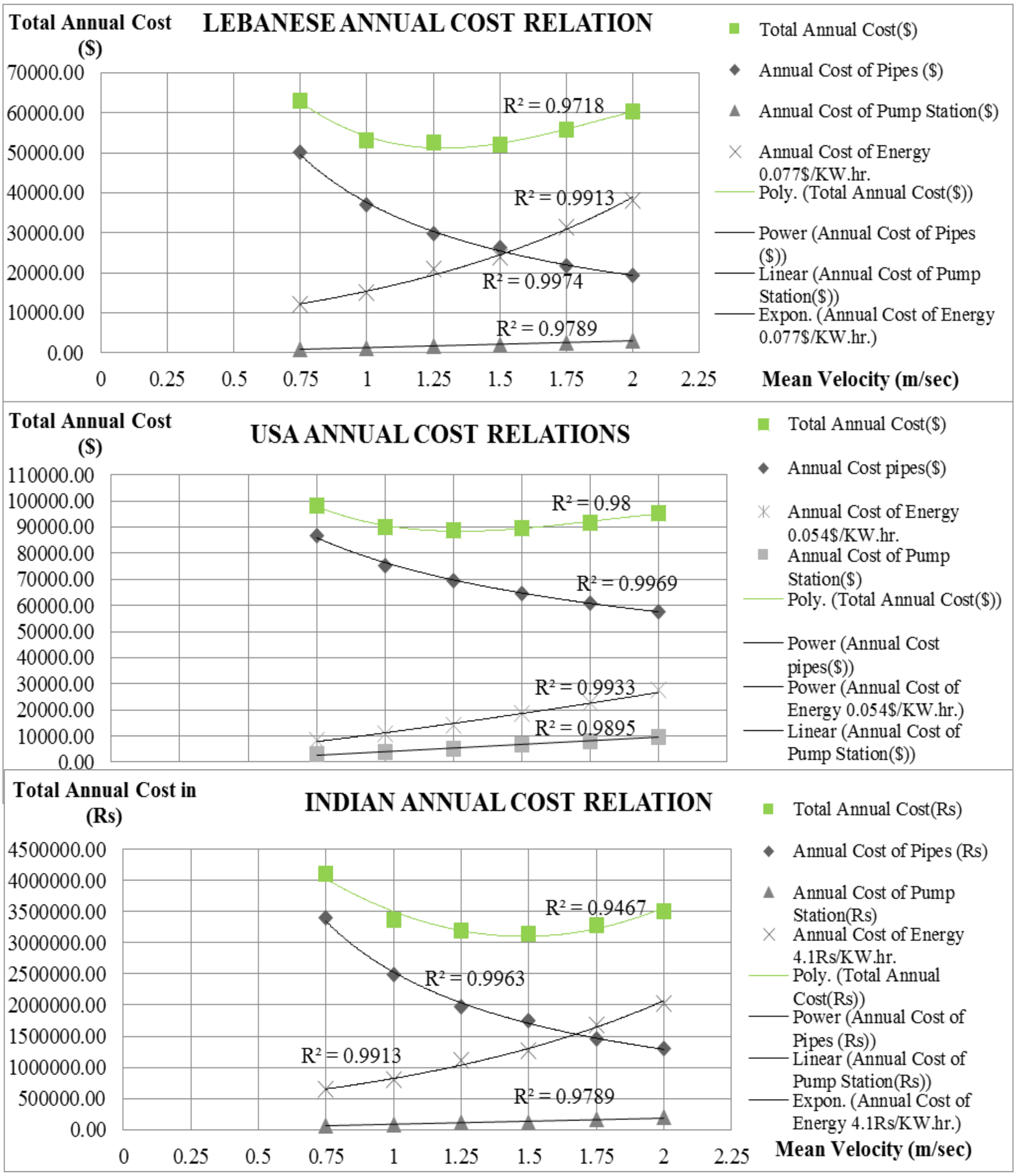


Figure 7. All Markets Annual Cost Relations versus Mean Velocity for HDPE Pipes

Cost analysis for Lebanon, USA, and India for high density polyethylene pipes are calculated. In addition, economic velocity for Lebanon, USA, and India is identified for high density polyethylene pipes. The economical velocities for high density polyethylene are 1.50 m/s, 1.25 m/s, and 1.50 m/s for Lebanon, United States of America, and India, respectively (see fig. 7).

5 MODELING OF PIPELINE NETWORK CASE STUDY USING WATERCAD

WaterCAD a computer software used for hydraulic modeling. The model is shown in fig. 8. The results shown in tables 12&13 were used to check the hydraulic calculations done by Excel.

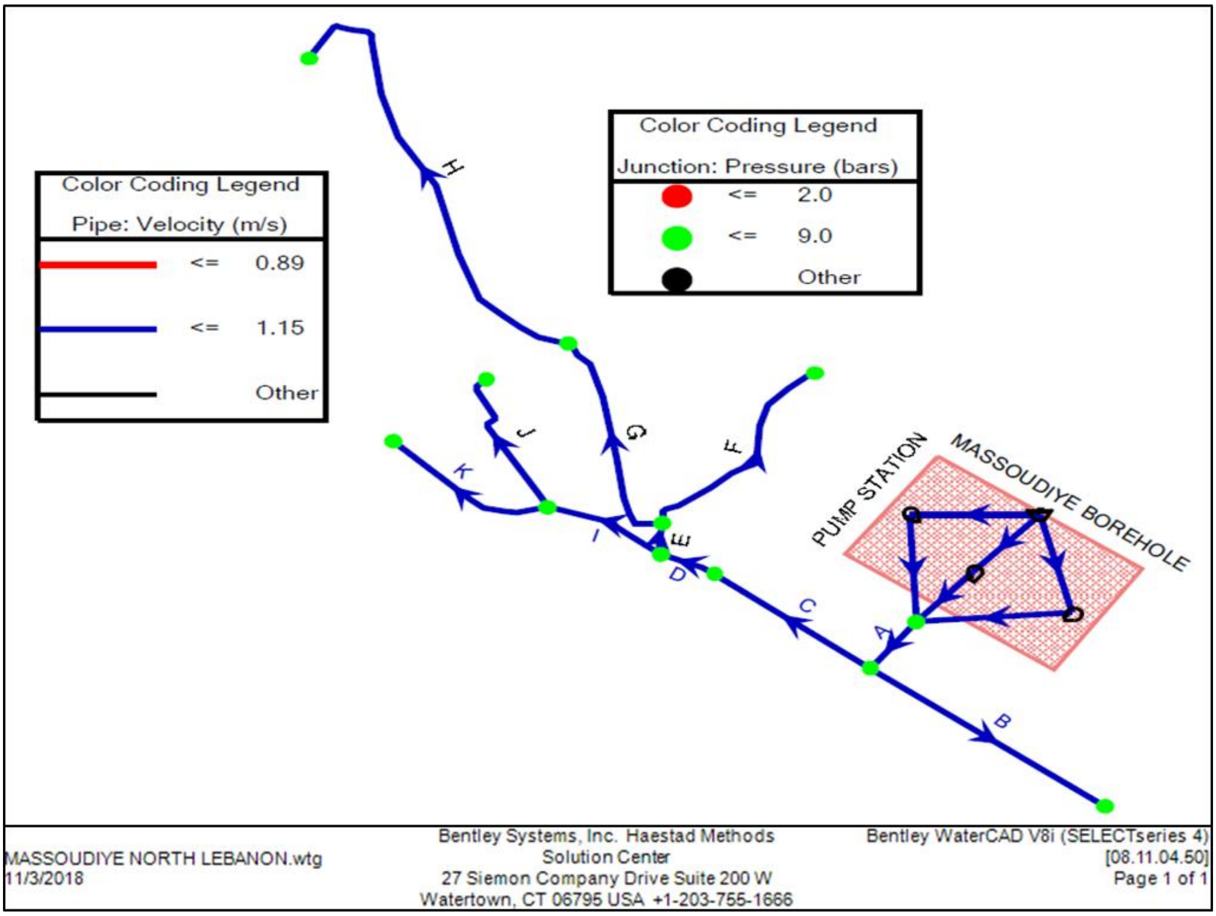


Figure 8. WaterCAD Case Study Water Supply Network Layout

Table 12. WaterCAD Simulation Reults for the Case Study at Velocity of 1.0 m/s (Lebanese Market - D.I.)

FlexTable: Pipe Table

Current Time: 0.000 hours

Label	Length (User Defined) (m)	Diameter (mm)	Material	Hazen-Williams C	Flow (L/s)	Velocity (m/s)	Headloss (Friction) (m)
A	196	350.0	Ductile Iron	120.0	96.01	1.00	0.64
B	774	150.0	Ductile Iron	120.0	20.00	1.13	8.57
C	518	300.0	Ductile Iron	120.0	76.01	1.08	2.32
D	158	300.0	Ductile Iron	120.0	66.01	0.93	0.55
E	104	250.0	Ductile Iron	120.0	44.01	0.90	0.41
F	695	120.0	Ductile Iron	120.0	11.05	0.98	7.60
G	708	200.0	Ductile Iron	120.0	32.96	1.05	4.87
H	1,447	160.0	Ductile Iron	120.0	19.96	0.99	11.65
I	345	160.0	Ductile Iron	120.0	22.00	1.09	3.33
J	500	110.0	Ductile Iron	120.0	9.00	0.95	5.71
K	500	130.0	Ductile Iron	120.0	13.00	0.98	5.00
P-1	1	200.0	Ductile Iron	120.0	32.00	1.02	0.01
P-1'	1	200.0	Ductile Iron	120.0	32.00	1.02	0.01
P-2	1	200.0	Ductile Iron	120.0	32.00	1.02	0.01
P-2'	1	200.0	Ductile Iron	120.0	32.00	1.02	0.01
P-3	1	200.0	Ductile Iron	120.0	32.00	1.02	0.01
P-3'	1	200.0	Ductile Iron	120.0	32.00	1.02	0.01

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Table 13. WaterCAD Pump Table

FlexTable: Pump Table

Current Time: 0.000 hours

ID	Label	Elevation (m)	Pump Definition	Status (Initial)	Hydraulic Grade (Suction) (m)	Hydraulic Grade (Discharge) (m)	Flow (Total) (L/s)	Pump Head (m)
256	PMP-1	26.00	Pump Definition - 1	On	25.99	70.99	32.00	45.00
266	PMP-2	26.00	Pump Definition - 1	On	25.99	70.99	32.00	45.00
261	PMP-3	26.00	Pump Definition - 1	On	25.99	70.99	32.00	45.00

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The WaterCAD model calculations shown in table 12 was consistent with the calculations done using Excel as shown in table 4 for characteristics such as pipeline friction head losses, flow rates, and the economic velocities in the pipeline network.

6 COMPARISON BETWEEN ECONOMIC VELOCITY VERSUS ECONOMIC DIAMETER

The new concept of economic velocity study, presented in this study, can be applied in a water supply network rather than the old concept of economic diameter which can only be applied for a single pipeline. Moreover, this new methodology is applicable by all certified hydraulic design programs. Designers and engineers according to the existing market can apply the new concept in the range of the presented three markets. Two different materials of pipelines such as: Ductile Iron and High Density Polyethylene were presented as guideline.

7 CONCLUSIONS

In this research, a case study of water supply pipeline network in North Lebanon was presented. The new concept of economic constant design velocity was applied for the case study. Cost analysis for different three markets and two materials showed that the economical velocities for ductile iron (D.I.) were 1.0 m/s, 1.50 m/s, and 0.75 m/s for Lebanon, United States of America, and India, respectively. The value of the calculated economic velocity of 0.75 m/s for India is close to the value of the calculated economic velocity of 1.00 m/s for Lebanon compared to 1.50 m/s for the USA market. This confirms the similarity between the Lebanese and Indian Markets. While, the economical velocities for high density polyethylene (HDPE) were 1.50 m/s, 1.25 m/s, and 1.50 m/s for Lebanon, United States of America, and India, respectively.

The USA market had an economic velocity higher than the Lebanese and the Indian markets for ductile iron pipes. Whereas in HDPE pipes the USA market had an economic velocity lower than the Lebanese and the Indian markets. Those results are due to the effect of the costs of the pipeline compared to the cost of energy for every market. In ductile iron pipes, the USA had high economic velocities. This means that the cost of ductile iron pipe in the USA is high compared to the cost of energy. In order to compensate the costs, smaller diameters are needed to result in an economic velocity in the USA. Small diameters result in high velocities. On the contrary, using HDPE pipes the USA had low economic velocities. This means that the cost of HDPE pipes in the USA is low compared to the cost of energy. In other words, in order to have an economic velocity in the USA for HDPE, larger diameters are needed to decrease the cost of energy in the USA market, since large diameters result in low velocity in the pipeline; whereas, smaller diameters are needed in Lebanon and India in order to have an economic velocity for HDPE pipes. Moreover, large diameters are needed in Lebanon and India in order to achieve economic velocity for ductile iron pipes.

Economic velocity is determined at the least total annual cost of the whole water supply network. It is a new methodology based on selecting a constant design velocity through the entire pipeline network; main line and branch lines. It can be used not only for a single pipeline but also for the whole water supply network. The whole water supply network would have a unified value of economic velocity. This concept is more applicable than the concept of optimum diameter. The latter is limited to a single pipeline; however, the former is applied for the whole water supply network.

The economic design velocity was identified for three different markets representing samples of countries all over the world. The economic velocity may be affected by the market. However, the range is not so large. In the future, more markets should be applied. Economic design velocity concept is considered a new methodology applicable for the hydraulic design of pipeline network.

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