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A Gasoline Pipeline Network for Trinidad

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ABSTRACT

The twin island Republic of Trinidad and Tobago (10^0 N, 61^0 W), the most southerly Caribbean Islands (Area 5,128 km^2 and an estimated year 2005 population of approximately 1.3 million), has a vibrant petroleum based economy and has approximately 600,000 motor vehicles. Consequently, there is a large demand for gasoline in the island. However, there are frequent shortages of this commodity at the gasoline filling stations due to a slow, inadequate and unreliable response from gasoline delivery trucks. Further, the movement of these trucks, in and out of the gasoline filling stations, causes traffic congestions and poses a safety hazard. Furthermore, the provision of a mass transit system, which is currently being proposed, is not likely to materialize in the foreseeable future. Under such circumstances, this paper proposes an island wide gasoline pipeline network which can supply, from a petroleum refinery at its Southwest Coast, gasoline filling stations on a round the clock basis. Moreover, this paper highlights the relative advantages of such a pipeline network and outlines a schematic design of the same.

Keywords: Large demand for gasoline, frequent shortages, unreliable response

INTRODUCTION

The twin island Republic of Trinidad and Tobago (10^0 N, 61^0 W) is known internationally for its natural resources of oil and gas, its vibrant petrochemical and other heavy industry and for its diverse and rich music and culture. The larger island of Trinidad (Area 4,828 km^2), hereafter referred to as the island, has 95 % of the population and is the economic powerhouse of the Commonwealth Caribbean Region. This paper relates only to the island, whose economic prosperity has led to a large motor vehicle population of approximately 600,000, and severe traffic congestion in its urban areas. Nevertheless, proposals for a rapid mass transit system in the island are still on the drawing board and are not likely to materialize in less than 10 – 15 years. Thus, a large demand for gasoline is likely to exist in the foreseeable future. At present, gasoline is distributed to retail suppliers via tanker trucks, and this mode of supply has proven to be slow, inadequate and unreliable. Specifically, storage tanks at gas stations rapidly empty causing disruption in socio-economic activities, and inconvenience to the public. Further, the large tanker trucks cause traffic congestion on the roadways and also pose a health and safety risk as can be seen in Photograph 1. It has been studied and concluded that constant exposure to traffic congestions in fact creates numerous health problems apart from the most obvious, mental stress. Exhaust fumes are pervasive and contains dangerous gases, namely, carbon monoxide, oxides of nitrogen, hydrocarbon gases, just to name a few.

The present government of the island has made statements referring to a vision into the future, one which would foresee the island's transformation from that of third world status to one of first. Research has shown that many nations globally have long made the switch from tanker trucks being the sole means of transportation of gasoline to that of transportation pipelines. This transformation can be seen as a step in the right direction for the continued development of the island and its occupants. Against such a background, this paper proposes the construction of an island wide gasoline pipeline network for a more reliable and cost effective means of supplying gasoline to 48 gasoline filling stations (Figure 1 and Table 1) spread throughout the island, and outlines a schematic design of the same (Villafana 2006).

Photograph 1 – A typical scene of traffic congestion caused by a gasoline truck

Photograph 1 above depicts a typical scene of what takes place when a storage tank at a gas station is in need of being refilled. This photo was taken in one the island's major towns. Commuters are stuck in traffic due to the tanker truck trying to make its way down the already busy streets to get to the gas station that is still almost a quarter of a mile away. Usually, motorists would line up at the gas stations and wait until the tanker trucks arrive so that it can refuel the storage tanks at the gas stations and in turn the motorists can refuel their vehicles. Apart from the traffic congestions commuters that depend on taxi services are left without transportation since taxi cabs also run low on fuel.

PROBLEM STATEMENT

In hydraulic engineering terms, the problem of supplying gasoline stations on a round the clock basis reduces to a pipe network problem. Specifically, it relates to the estimation of the diameter of pipeline in various network components and more importantly to the estimation of pressures at supply nodes. In precise terms, the problem is to ascertain suitable pipeline diameters in various segments to ensure adequate delivery pressures at the supply nodes.

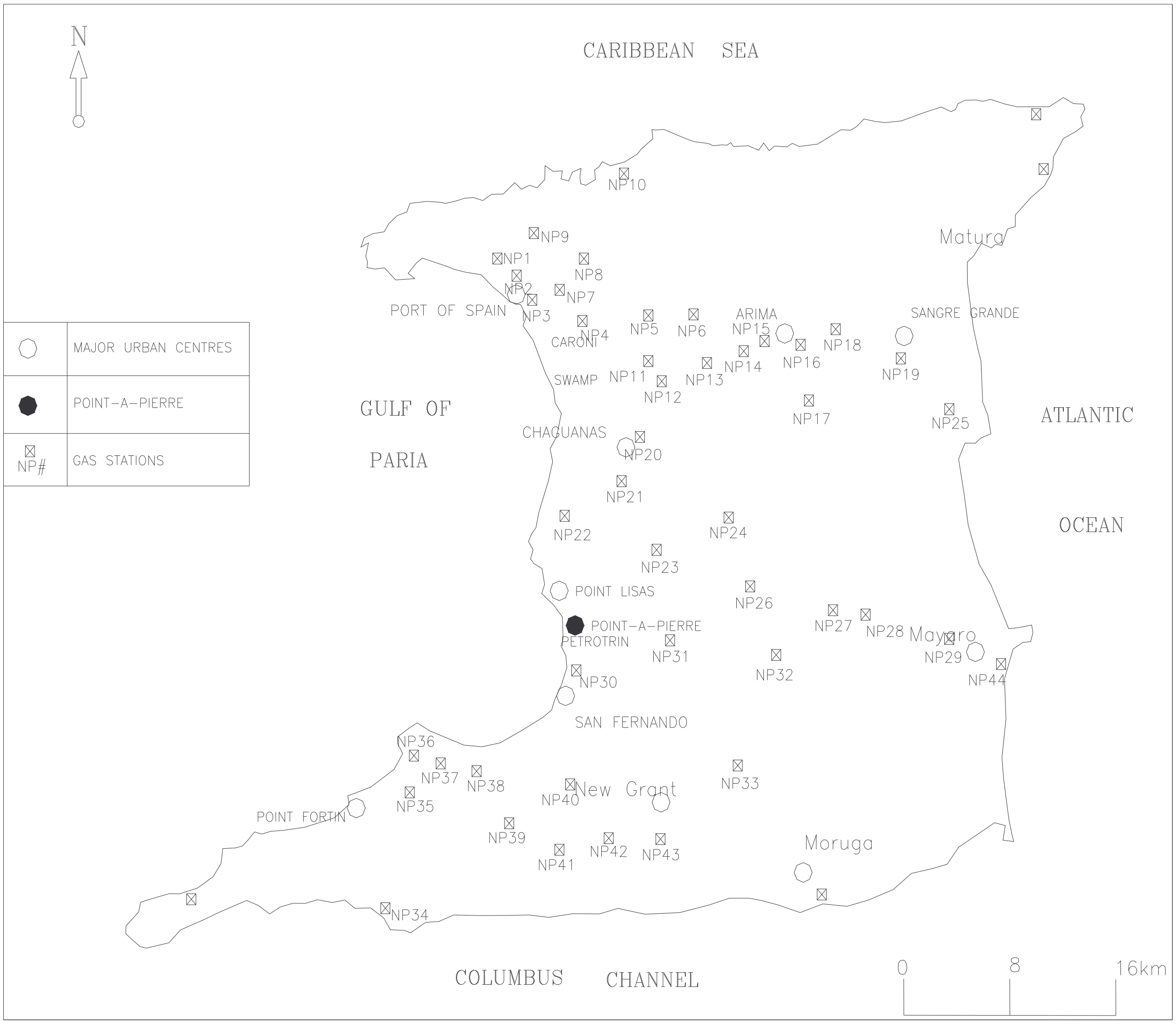

Figure 1: A schematic diagram of the 44 gas stations to benefit from the island wide gasoline pipeline

Figure 1 above, a map of Trinidad depicts the location of forty four (44) gas stations on the island that would benefit from the island wide gasoline pipeline network. This network, illustrated in figure 2 and 3 is designed so all gas stations would receive the required volume of gasoline per day so that costumer consumption is met (Table 1).

Each of the five (5) loops (Figure 2) houses a number of gas stations with fifteen pipelines meeting at points forming nodes which serve as entry and exit points for the volume of gasoline being delivered. The process of supply begins at the Petrotrin refinery at Point-A-Pierre (Figure 1) and continues throughout the network with an initial pressure and volume of 2MPa and 966m^3 respectively (Figure 3).

Table 1: A List of the Gas Stations and their Average Daily Sale of Gasoline

Gas Station	Volume of Gasoline Sold per day (m^3)	Gas Station	Volume of Gasoline Sold per day (m^3)
	Unleaded		**Unleaded**
NP 1	31	NP 23	24
NP 2	30	NP 24	11
NP 3	31	NP 25	21
NP 4	26	NP 26	20
NP 5	18	NP 27	20
NP 6	26	NP 28	25
NP 7	14	NP 29	12
NP 8	23	NP 30	24
NP 9	30	NP 31	27
NP 10	27	NP 32	29
NP 11	22	NP 33	22
NP 12	28	NP 34	16
NP 13	24	NP 35	19
NP 14	26	NP 36	10
NP 15	24	NP 37	14
NP 16	26	NP 38	16
NP 17	28	NP 39	17
NP 18	16	NP 40	14
NP 19	31	NP 41	12
NP 20	34	NP 42	14
NP 21	27	NP 43	10
NP 22	29	NP 44	21

Remarks: Approximately 966 m^3 of gasoline is consumed per day, and each of the five (5) loops would require approximately 256, 245, 223, 102 and 140 m^3 of gasoline per day.

Table 1 above represents the volume of gasoline required on a daily basis by each gas station shown in order to meet the island's demands. Each gas station falls within one of the five (5) loops (figure 2) which together makes up the total volume of gasoline required in the network. These volumes would later be used to obtain the required flow through each pipeline making up the network.

METHODOLOGY

A loop system was used to determine the required flow, Q (m^3s^{-1}) in all of the fifteen (15) pipelines making up the network (Figure 2). The network comprises five (5) loops each of which encloses a number of gas stations. The required daily consumption for each gas station is known hence this volume is used for the flow design. The nodes in the network represent entry and exit points of gasoline.

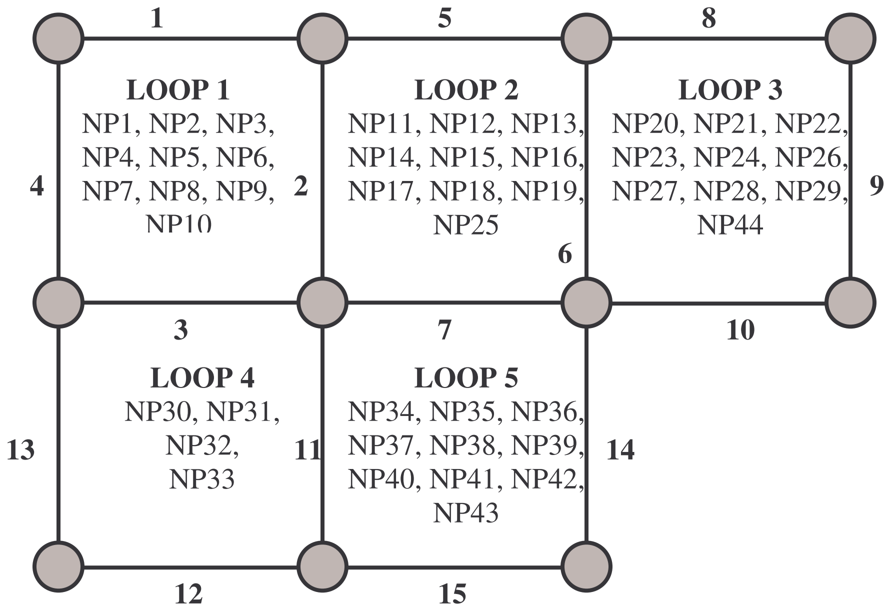

Figure 2: The proposed gasoline pipeline network

The flow in each of the fifteen (15) gasoline pipelines forming the loops was estimated through an EXCEL Spreadsheet by an algorithm, which can be sequentially described as follows:

1. Loops were established throughout the country (Figure 2). These loops are to service all forty four (44) gas stations in the island, and volume of gasoline required by each gas station each day was obtained from Table 1.
2. After the loops were set up, flows through each node in the loop were estimated.
3. The length of each pipe was obtained from the loops shown in Figure 2, and a diameter was then intuitively selected for each pipeline.
4. An initial flow Q (m^3s^{-1}) was assumed for each pipe.
5. The Resistance Factor *f*, was determined for each pipe using an equation given by Jain (1976), [equation 1].

$$\frac{1}{f^{0.5}} = 1.14 - 2\log\left(\frac{\varepsilon}{D} + \frac{21.25}{R^{0.9}}\right)$$; Where R is the Reynolds Number --------------- (1)

6. The Reynolds Number *R* was obtained as follows:

$$R = \frac{VD}{\nu}$$ ------------------- (2)

Where: V = Fluid velocity (m/s)
ν = Kinematic viscosity (m^2s^{-1}) = 4.1 x 10^{-6}
D = Pipe Diameter (m)
A = Cross sectional area of pipe (m^2)

7. Values for friction factors, f_1 to f_{15} would now be calculated for each of the Reynolds Number obtained.
8. Governing equations were set up utilizing the laws of conservation of mass (Kirchoff's First Law) and energy (Kirchoff's Second Law).
9. A network matrix was then set up from these equations.
10. The values of flows, Q_1 to Q_{15} were obtained by solving this matrix and by trial and error. These values represent the actual flow required in each pipeline in order to supply the required volume of gasoline on a daily basis to each gas station.

A Sample Calculation is now shown so as to outline the procedures carried out in determining the flows in each of the pipeline. Note a pipe diameter of 0.3m was used as well as an initial trial flow, Q (m^3s^{-1}) of 0.03.

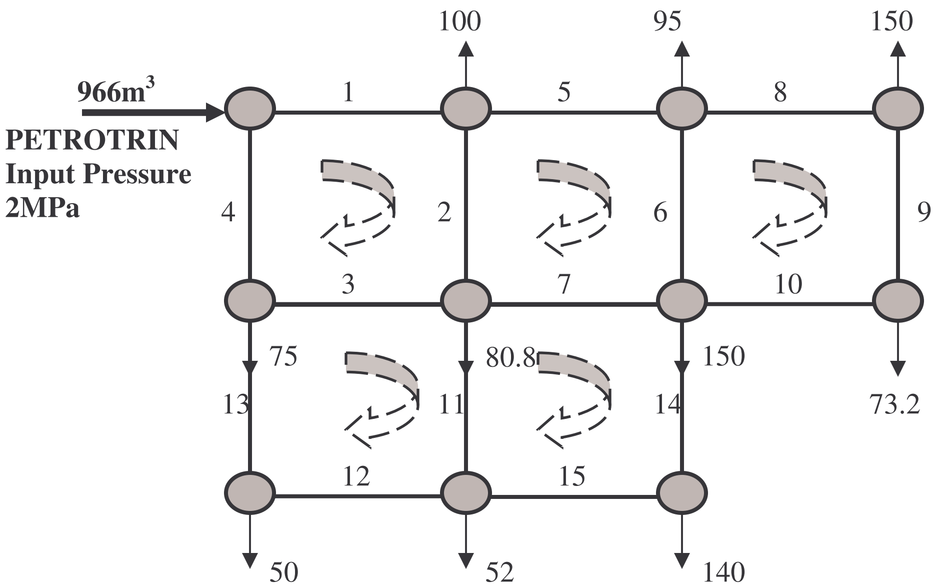

Figure 3: Schematic of Pipeline Network (Note: The capacities at the nodes are in m^3/day). This capacity is the quantity of gasoline needed by the gas stations in each loop in order to satisfy their daily demand.

ESTIMATING THE FLOWS IN THE PIPES

Take the roughness height of all pipes, ε(m) = 0.00006
First Trial: Assuming Flow, Q (m^3s^{-1}) = 0.03

TABLE

Table 2 below gives the pipeline network parameters all of which are required to carry out the design for the determination of the flow in each pipeline. These parameters represent the values in relation to an estimated pipe diameter of 300mm and an initial flow of 0.3 m^3s^{-1}.

Table 2: Pipeline Network Parameters

Pipe	1	2	3	4	5	6	7	8	9
Length (m)	9994	28404	29982	6838	20514	12098	18410	8942	10783
Dia. (m)	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Q (m^3s^{-1})	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Area(m^2)	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
V (ms^{-1})	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42
R	31001	31001	31001	31001	31001	31001	31001	31001	31001
ε/D	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
$21.25/R^{0.9}$	0.0019	0.0019	0.0019	0.0019	0.0019	0.0019	0.0019	0.0019	0.0019
A	6.48	6.48	6.48	6.48	6.48	6.48	6.48	6.48	6.48
f	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024

Table 2 Con't: Pipeline Network Parameters

Pipe	10	11	12	13	14	15
Length (m)	9731	9205	11046	25511	10520	22355
Dia. (m)	0.3	0.3	0.3	0.3	0.3	0.3
Q (m^3s^{-1})	0.3	0.3	0.3	0.3	0.3	0.3
Area(m^2)	0.07	0.07	0.07	0.07	0.07	0.07
V (ms^{-1})	0.42	0.42	0.42	0.42	0.42	0.42
R	31001	31001	31001	31001	31001	31001
ε/D	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
$21.25/R^{0.9}$	0.0019	0.0019	0.0019	0.0019	0.0019	0.0019
A	6.48	6.48	6.48	6.48	6.48	6.48
f	0.024	0.024	0.024	0.024	0.024	0.024

Determination of the pipe Friction Factor, λ was based on equation (1).
Before λ was obtained the Reynolds number, R, for each of the pipe had to be determined from equation (1).
The kinematic viscosity of Unleaded Gasoline, $\upsilon = 4.1 \times 10^{-6}$ (ms^{-2})

Governing Equations

$\Sigma Q_i = 0$ at each node -- (3)

$$h_f = \frac{fLV^2}{2gD} = \frac{fLQ^2}{2gD\left(\frac{\pi D^2}{4}\right)^2} = KQ^2 = K|Q|Q = \Gamma Q \text{ ------------------------ (4)}$$

From all of the above, the governing equations, based on the laws of conservation of mass (Kirchoff's First Law) and Energy (Kirchoff's Second Law) are represented in matrix form shown subsequently in this paper.

RESULTS

The disadvantages of relying on gas trucks to refuel gas stations and the advantages of having a cross-island gasoline pipeline refueling the same stations were studied. A design was carried out so as to determine the lengths and flows in all the pipes that would be required to meet the demands of the country's daily fuel consumption.

The pipes were designed to form five (5) loops (Fig. *2*) throughout the country with a total of fifteen lines making up the network. A multi-purpose pipeline would be used to transport all three (3) fuel types, namely diesel, leaded and unleaded. After all calculations were carried out the flows in each of the fifteen pipes were determined for each of the three (3) fuel types. Table 3 shows the results for gasoline.

Table 3: Results showing flows in each pipeline

Pipe	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Flow, Q (m^3d^{-1})	836	123	3	130	814	285	205	448	523	597	67	15	34	666	0.3

One of the major factors in the design was the determination of the friction factor. Initially the "Colebrook – White equation" was acknowledged, but because of the trails and errors involved with this method it was decided to use Jain (1976), equation (1).

$$
\begin{bmatrix}
-1 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
-1 & -1 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & -1 & -1 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & -1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 \\
0 & 1 & 1 & 0 & 0 & 0 & -1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & -1 & 0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 1 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & -1 \\
\Gamma_1 & \Gamma_2 & -\Gamma_3 & -\Gamma_4 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & -\Gamma_2 & 0 & 0 & \Gamma_5 & \Gamma_6 & \Gamma_7 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & -\Gamma_6 & 0 & \Gamma_8 & \Gamma_9 & \Gamma_{10} & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & \Gamma_3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \Gamma_{11} & -\Gamma_{12} & -\Gamma_{13} & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & \Gamma_7 & 0 & 0 & 0 & -\Gamma_{11} & 0 & 0 & \Gamma_{14} & -\Gamma_{15}
\end{bmatrix}
\begin{bmatrix} Q_1 \\ Q_2 \\ Q_3 \\ Q_4 \\ Q_5 \\ Q_6 \\ Q_7 \\ Q_8 \\ Q_9 \\ Q_{10} \\ Q_{11} \\ Q_{12} \\ Q_{13} \\ Q_{14} \\ Q_{15} \end{bmatrix}
=
\begin{bmatrix} 966 \\ -100 \\ -80.8 \\ -75 \\ -95 \\ -150 \\ -150 \\ -73.2 \\ -50 \\ -52 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}
$$

Values for Q_1 to Q_{15} and Γ_1 to Γ_{15} were obtained from the solution of this network matrix. By use of iterations or trial and error the values for all the flows in the pipes were obtained.

CONCLUSION

In Conclusion it can be said that the equation by Jain (1976) is an explicit equation for friction factor based on implicit relationship of Colebrook and White. The explicit equation was very accurate, easy to handle and is applicable to the entire turbulent zone of pipe flow. Its use eliminated the trials involved with the Colebrook-White equation and permitted direct and accurate computation of the friction factor. The friction factor for each pipe was found to range from 0.02 to 0.03.

From Table 3 it can be seen that the flows obtained in each pipe would meet the daily needs of fuel consumption in the country, henceforth eliminating all negative impacts caused by delivery trucks.

ACKNOWLEDGEMENT

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APPENDIX 1: REFERENCES

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APPENDIX 11: NOTATION

D = Pipe Diameter (m)

K = Minor Loss coefficient

Q = Flow rate through pipe or into or out of node (m^3s^{-1})

R = Reynolds Number of flow

V = Average velocity (ms^{-1})

Γ = Linearization Factor = K |Q|

ε = Relative roughness height of pipe wall (m)

ε/D = Relative roughness

f = Pipe resistance or friction factor

ν = Kinematic viscosity of fluid (ms^{-2})

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