SCIENCE FORUM (JOURNAL OF PURE AND APPLIED SCIENCES) 23 (2023) 735 - 772

Science Forum (Journal of Pure and Applied Sciences)

Journal Homepage: https://atbu.edu.ng/science-forum/

Performance Evaluation of Microsoft Excel Solver in The Pipe Network of An Open Loops

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ABSTRACT

In this paper, pipe network analysis was conducted on an open loop system utilising Microsoft Excel Solver (MiES) as a way to evaluate the performance of MiES and attain a sustainable potable water supply scheme. The pipe network, a non-closed loop, was analysed using MiES. Selected hydraulic variables (discharge rate, velocity of water flow, friction factor in the pipe, Reynold's number of the flow and headloss due to friction loss) were determined. Models that relate the friction factor of the pipe to the selected hydraulic parameter and diameter of the pipe selected were developed using Microsoft Excel Solver and evaluated statistically (using correlation coefficient and coefficient of determination). These equations to establish the flows were solved using the Microsoft Excel Solver method to calculate, pump characteristics parameters, headloss and flows. These calculated flows and headloss were evaluated statistically using root squared error, total error, mean squared error, average error, analysis of variances (ANOVA), sum of error, and model of selection criterion (MSC), using results of hydraulic parameters from EPANET as standard. The study revealed that the flow rate computed for the pipes was comparable for the two equations (EPANET and MiES) and there are no significant differences between the expected flow rates and computed flow rates in the pipes using continuity equations using the two techniques (statistical $F_{41,41}$ was 0.785774; probability was 0.7782333) at 95 % confidence level. The best model was a model that relates the friction factor of the pipe to the hydraulic parameter and diameter with an MSC of 3.094. It was concluded that determining flow rate and conducting pipe network analysis with MiES is among the best techniques for pipe network analysis. The calculated flow rates using MiES were similar to the computed flow rate using the EPANET technique and there was no significant difference between these calculated flow rates using the two techniques

ARTICLE INFO
Received 12 July 2023
Received in Revised Form 11 August 2023
Accepted 11 August 2023
Published 20 November 2023
Available online 20 November 2023

KEYWORDS
EPANET,
Pipe network analysis,
Microsoft Excel Solver,
Headloss,
Statistical evaluation

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One of the major setbacks and impediments to sustainable development and long-term progress is a deficiency of safe and potable drinking water. Drinking water is an essential ingredient that is even being sourced in the desert, where water is not available or access to it is limited (Figure 1). Steady population progression and growth rates have put pressure on the adequate production of the required quantities (Abdulsamad and Abdulrazzaq, 2023). In addition, the effects and impacts of climate change and man's activities have become a concrete reality, which contributes to cumulative pressure on the inadequate quality of groundwater and surface resources available (Figure 2). Water is a rudimentary human necessity, essential for drinking, supportive of hygiene and sanitation, and sustaining health and life (JMP, 2023). Water is established as a human right, clean drinking and potable water are crucial to the comprehension of all human rights. Access to potable and drinking water advances workforce productivity, educational prospects, and support for equality and dignity (JMP, 2023).

Figure 1 Sourcing for drinking water in the desert through hand dug and shallow wel

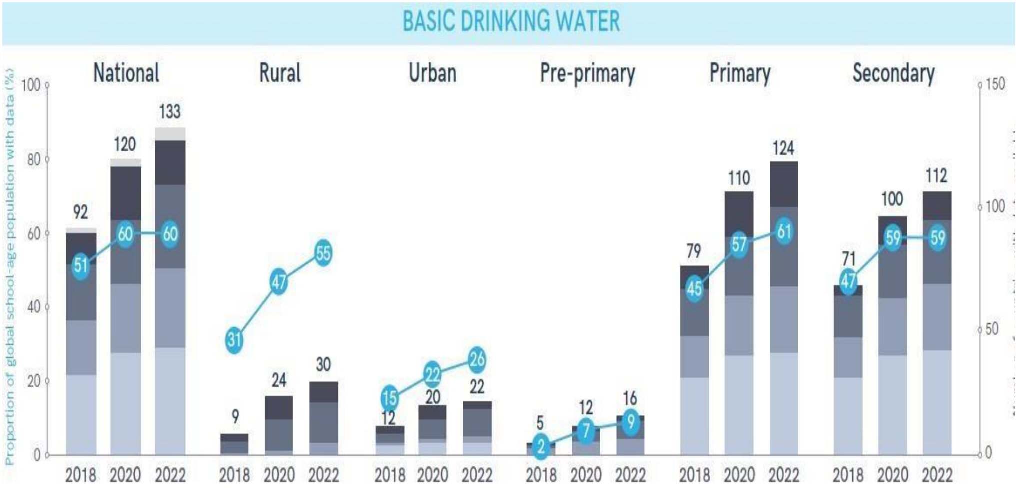


Figure 2 Global access to potable and drinking water between 2018 and 2022 (Source: JMP, 2023)

Table 1 Summary of Sustainable Development Goals (Source: Dalampira and Nastis, 2019)

Title of SDG	Description of SDG
No poverty	Goal 1: End poverty in all its forms everywhere
Zero hunger	Goal 2: End hunger, achieve food security and improved nutrition and promote sustainable agriculture
Good health and well-being	Goal 3: Ensure healthy lives and promote well-being for all at all ages
Quality education	Goal 4: Ensure inclusive and quality education for all and promote lifelong learning
Gender equality	Goal 5: Achieve gender equality and empower all women and girls
Clean water and sanitation	Goal 6: Ensure access to water and sanitation for all
Affordable and clean energy	Goal 7: Ensure access to affordable, reliable, sustainable and modern energy for all
Decent work and economic growth	Goal 8: Promote inclusive and sustainable economic growth, employment and decent work for all
Industry, innovation and infrastructure	Goal 9: Build resilient infrastructure, promote sustainable industrialization and foster innovation
Reduce inequalities	Goal 10: Reduce inequality within and among countries
Sustainable cities and communities	Goal 11: Make cities inclusive, safe, resilient and sustainable
Responsible consumption and production	Goal 12: Ensure sustainable consumption and production patterns
Climate action	Goal 13: Take urgent action to combat climate change and its impacts
Life below water	Goal 14: Conserve and sustainably use the oceans, seas and marine resources
Life on land	Goal 15: Sustainably manage forests, combat desertification, halt and reverse land degradation, halt biodiversity loss
Peace, justice and strong institutions	Goal 16: Promote just, peaceful and inclusive societies
Partnerships for the goals	Goal 17: Revitalize the global partnership for sustainable development

An adequate water supply scheme enhances an upward spiral and progress of well-being and prosperity, supports Sustainable Development Goal (SDG) attainment (Table 1), which is indispensable to a pathway and route out of poverty for communities and individuals (JMP, 2023). With growing in the growing number of people demanding access to potable and drinking water, there is a need to have an equivalent increase in participation, empowerment and social mobilization. Elimination and reduction of inequalities in universal access to drinking and potable water will aid in the reduction of the inequalities between rich nations and poor countries, marginalized assemblies and the rest of the population, and rural and urban dwellers (JMP, 2023). An achievement in the universal safety management of water will aid in bridging the rural-urban, institutional divide, and permit rural dwellers to benefit from time savings, health benefits and the same convenience as the rich people, classified institutions and urban dwellers. With reference to all these challenges, there is a need to re-examine individual water management techniques, which require a source of water, water treatment and production technique, water storage systems, distribution, review of various techniques, performance evaluation and effective design of the systems (Nasier and Abdulrazzaq., 2022). In the case of a good and effective performance system, the distribution of adequate (quality and quantity) potable and drinking water is vital. Transportation and distribution of water pipes and pipe network analysis are essential in the design. It is established that head loss due to friction in pipes is among the foremost parameters of the hydraulic engineering design of water supply distribution and any plumbing system. A suitable pipe for commercial utilisation, its durability and flow characteristics, frictional losses per length of pipe and health limits must fall within a defined and specified range (Jamil and Mujeebu, 2019). It is crucial to design a suitable pipe distribution system and create a reliable pipe network establishing adequate water flow and discharge rate, the velocity of water flow and pressure or head dropped at user nodes. In the design of a suitable pipe distribution system, there are two axioms which are vital. The two axioms are the head loss and continuity equations, which are as follows:

a) Summation of flows or discharges at all nodes must equal zero:

$$\sum_{ki=1}^{ni}\left(Q_{ki}-Q_{wdi}\right) \tag{1}$$

Where; Q_{ki} is the flow in the pipe k node i; n_i is the number of pipes at node i and Q_{wdi} is the water demand or withdrawal at node i.

b) Summation of all the head-losses in a particular closed loop must be equal to zero;

$$\sum_{ji=1}^{nj}\left(H_{Lj}\right)=\sum_{j=1}^{n}\left(E_{Ij}-E_{Lj}\right)=0 \tag{2}$$

Where; H_{Lj} is the head loss in a closed loop of loop j; E_{Lj} is the elevation at node j and E_{Ij} is the elevation at the overhead tank, energy or head of the pump (m)

$$H_{Lij}=\frac{\lambda_i L_i V_i^2}{2gD_i}=K_i Q_i \quad =\frac{16\lambda_i L_i Q_i^2}{2g\pi^2 D_i^5} \tag{3}$$

Where; H_{Lij} is the head loss in pipe i and loop j (m); λ_i is the friction factor in pipe i (dimension less); L_i is the length of the pipe of pipe i (m); g is the acceleration due to gravity (ms^{-2}); Q_i is the discharge through pipe i D_i is the diameter of the pipe i (m); V_i is the mean velocity in the pipe i (ms^{-1});

More information, studies, research and data on pipe network analysis, design of pipes, water supply and distribution systems can be established in the literature such as Swamee and Sharma (2008), Guistolis (2010), Oke (2010), Yong *et al.* (2012), Jha (2012), Adeniran and Oyelowo (2013), Ramana *et al.* (2015), Malm *et al.* (2015), Gonelas and Kanakoudis (2015), Kutylowska and Orlowska-Szostak (2016), Samora *et al.* (2016), Nafi and Afzali (2016), Martinez-Codina *et al.* (2016), Ghorbanian *et al.* (2016), Oke *et al.* (2016), Nafi and Afzali (2017), Adedeji *et al.* (2017), Niazkar and Afzali (2017), Oke (2017), Creaco and Walski (2017), Sinagra *et al.* (2017), Tabesh and Beigi (2017), Gupta and Kulat (2018), Sakr and Gooda (2018), Garmendia *et al.* (2018) , Oyebode and Igbi (2018), Roige Montornes *et al.* (2019), Nafi and Brans (2019), Haider *et al.* (2019), Bermudez *et al.* (2019), Gajghate and Mirajkar (2019), Malm *et al.* (2020), Niazkar and Talebbeydokhti (2020), Moslehi and Jalili (2020), Ahopello and Vahala (2020), Gokayay (2020); Jin *et al.* (2020), Moslehi *et al.* (2020a and b), Abbas and Mohammed (2020), Abdulsamad and Abdulrazzaq (2022), WHO *et al.* (2023), and Abdulsamad and Abdulrazzaq (2023). The literature reported that several computer programs are running on personal computers for pipe network analysis. These water resources and management programs such as SEAWAT, UNWB-LOOP, WATERGEM, WADISO, MODPATH, MODFLOW-USG, MODFLOW, MT3DMS, PHT3D, EPANET, RT3D, U of K KYPIPE and MODFLOW-LGR had been commercial software which was developed, completed, commercialised and made available at an additional cost of the purchase to be utilized for the new or rehabilitation of pipe network analysis. Utilization of these assemblages of software is accessible for pipe network analysis but necessitates progressive knowledge, services and training as well as additional expenses such as purchasing and installation costs. The result of pipe network analysis which includes the flow and discharge rate of water, the velocity of flow and pressure in the pipe network and pipe layout has been of outstanding value and interest for water resources, hydraulic, and Civil engineers, which are people necessitated with the design, construction and maintenance of potable water supply and distribution systems. Analysis and design of pipeline and pipe layout networks are considered relatively complex trouble, particularly when the system consists of a wide range of pipes as it commonly occurs in water supply and distribution systems of large municipal and metropolitan areas. In the absence of an adequate flow of fluid velocity and acceleration, the conduct of a network can be visualized as a chronological sequence of steady-state considerations, which forms a simple use but is a vital component for assessing the adequacy of a network (Sreemathy *et al.,* 2017). The focal aim of this research is to evaluate the hydraulic adequacy in terms of flow or discharge of the Microsoft Excel Solver (MiES) software, with a critical aim of attaining sustainable development goals SDGs 3 (virtuous health and well-being), SDGs 6 (clean and potable water, and sanitation); and SDGs 15 (life on land). With reference to Brkic (2018), progress in computation techniques and the advance of numerous computer packages and systems, there is a need to utilize Microsoft Excel Solver (which is accessible at no extra cost and is simple in applications) in pipe network analysis with unfixed friction factor.

a. MATERIALS AND METHODS

Pipeline and pipe layouts in Elizade University were identified. Elizade University (EU) is one of the private Universities in Nigeria. The University is located in Ilara- Mokin, a mini-city in Ondo State, Southwest, Nigeria (Figures 3a and b). EU has an increasing population of 3,150 people, which includes students and staff members. EU is one of the promising private Universities in Nigeria. Node and valves in these pipelines and pipe layouts were identified and marked. Pipe length, pipe diameter, and elevations at each marked node were measured using Garmin GPS 72H.

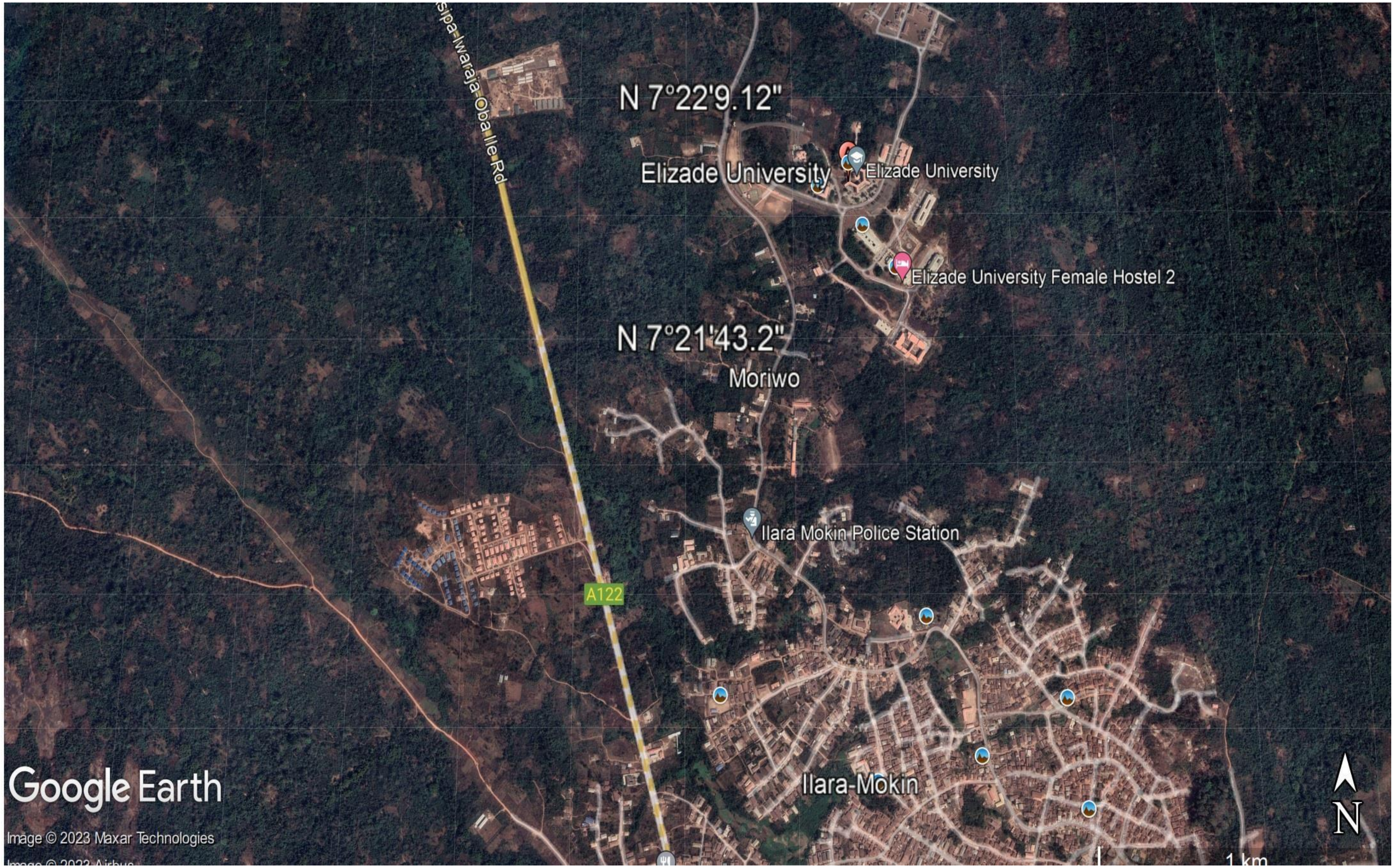


Figure 3a: Location EU in Ilara- Mokin and aerial view of EU and view of the University environment (Source Goggle map, 2023)

Figure 3b: Location and new aerial view of EU with selected view of the University environment (Source Goggle map, 2023)

The population of the institution was collected from 2011 to 2018. The growth rate of the population was identified and computed. The population was projected from 2019 to 2026 (based on the strategic plan of the University Management) by using geometrical progression as follows (equation 4):

$$G_t = G_0\left(1+g_r\right)^p \tag{4}$$

Where; G_t is the EU's projected population; G_0 is the EU's population at the base year, G_r is the EU's population growth rate and p is the life span of the network. Water demands at all the nodes were computed using the projected population at the node and water demand per capita per day as follows (Equation 5):

$$Q_{wd} = G_t q \tag{5}$$

Where; Q_{wd} is the water demand per node and q is the water demand per capita per day which is equivalent to 75 litres per capita per day for students at the hostel, 150 litres per capita per day for staff members at the staff's quarter and 40 litres per capita per day for all the population at the academic areas. The Pipeline and pipe layout were drawn as a pipe network using AutoCAD software. Hydraulic parameters and flows in the pipes were determined using MiES and compared with results from EPANET (Standard software for pipe network analysis) as a follow-up of the previous study (Oke *et al.*, 2023). The general equations for the 43 nodes were developed and written as follows (Equation 6; Table 2 presents information on the pipe number, node number, diameter of the pipe, length and other hydraulic variables):

$$\left(\sum_{i=1}^{n}\left(\frac{H_i - H_j}{K_i}\right)^{0.5} - \sum_{i=1}^{n} Q_{wdi}\right) = 0 \tag{6}$$

Where; H_t is the elevation at node 1(m; overhead tank); H_i is the elevation at node i (m), K_i is the headloss's constant for pipe i $\left(K_i = \dfrac{8\lambda_i L_i}{g\pi^2 D_i^2}\right)$ and Q_{wdi} is the withdrawal at node i. The detailed and comprehensive equations for the network are presented in equations (7) to (50).

At node 2: $$\left(\sum_{i=1}^{n}\left(\frac{H_i - H_2}{K_2}\right)^{0.5} - \sum_{i=1}^{n} Q_{wd2}\right) = 0 \tag{7}$$

At node 3: $$\left(\sum_{i=1}^{n}\left(\frac{H_i - H_3}{K_3}\right)^{0.5} - \sum_{i=1}^{n} Q_{wd3}\right) = 0 \tag{8}$$

At node 4: $$\left(\sum_{i=1}^{n}\left(\frac{H_i - H_4}{K_4}\right)^{0.5} - \sum_{i=1}^{n} Q_{wd4}\right) = 0 \tag{9}$$

At node 5: $$\left(\sum_{i=1}^{n}\left(\frac{H_i - H_5}{K_5}\right)^{0.5} - \sum_{i=1}^{n} Q_{wd5}\right) = 0 \tag{10}$$

At node 6: $$\left(\sum_{i=1}^{n}\left(\frac{H_i - H_6}{K_6}\right)^{0.5} - \sum_{i=1}^{n} Q_{wd6}\right) = 0 \tag{11}$$

At node 7: $$\left(\sum_{i=1}^{n}\left(\frac{H_i - H_7}{K_7}\right)^{0.5} - \sum_{i=1}^{n} Q_{wd7}\right) = 0 \tag{12}$$

At node 8: $$\left(\sum_{i=1}^{n}\left(\frac{H_i - H_8}{K_8}\right)^{0.5} - \sum_{i=1}^{n} Q_{wd8}\right) = 0 \tag{13}$$

At node 9: $$\left(\sum_{i=1}^{n}\left(\frac{H_i - H_9}{K_9}\right)^{0.5} - \sum_{i=1}^{n} Q_{wd9}\right) = 0 \tag{14}$$

At node 10: $$\left(\sum_{i=1}^{n}\left(\frac{H_i - H_{10}}{K_{10}}\right)^{0.5} - \sum_{i=1}^{n} Q_{wd10}\right) = 0 \tag{15}$$

At node 11: $$\left(\sum_{i=1}^{n}\left(\frac{H_i - H_{11}}{K_{11}}\right)^{0.5} - \sum_{i=1}^{n} Q_{wd11}\right) = 0 \tag{16}$$

At node 12: $$\left(\sum_{i=1}^{n}\left(\frac{H_i - H_{12}}{K_{12}}\right)^{0.5} - \sum_{i=1}^{n} Q_{wd12}\right) = 0 \tag{17}$$

At node 13: $$\left(\sum_{i=1}^{n}\left(\frac{H_i - H_{13}}{K_{13}}\right)^{0.5} - \sum_{i=1}^{n} Q_{wd13}\right) = 0 \tag{18}$$

At node 14: $$\left(\sum_{i=1}^{n}\left(\frac{H_i - H_{14}}{K_{14}}\right)^{0.5} - \sum_{i=1}^{n} Q_{wd14}\right) = 0 \tag{19}$$

At node 15: $$\left(\sum_{i=1}^{n}\left(\frac{H_i - H_{15}}{K_{15}}\right)^{0.5} - \sum_{i=1}^{n} Q_{wd15}\right) = 0 \tag{20}$$

At node 16: $$\left(\sum_{i=1}^{n}\left(\frac{H_i - H_{16}}{K_{16}}\right)^{0.5} - \sum_{i=1}^{n} Q_{wd16}\right) = 0 \tag{21}$$

At node 17: $$\left(\sum_{i=1}^{n}\left(\frac{H_i - H_{17}}{K_{17}}\right)^{0.5} - \sum_{i=1}^{n} Q_{wd17}\right) = 0 \tag{22}$$

At node 18: $$\left(\sum_{i=1}^{n}\left(\frac{H_i - H_{18}}{K_{18}}\right)^{0.5} - \sum_{i=1}^{n} Q_{wd18}\right) = 0 \tag{23}$$

At node 19: $$\left(\sum_{i=1}^{n}\left(\frac{H_i - H_{19}}{K_{19}}\right)^{0.5} - \sum_{i=1}^{n} Q_{wd19}\right) = 0 \tag{24}$$

At node 20: $$\left(\sum_{i=1}^{n}\left(\frac{H_i - H_{20}}{K_{20}}\right)^{0.5} - \sum_{i=1}^{n} Q_{wd20}\right) = 0 \tag{25}$$

At node 21: $$\left(\sum_{i=1}^{n}\left(\frac{H_i - H_{21}}{K_{21}}\right)^{0.5} - \sum_{i=1}^{n} Q_{wd21}\right) = 0 \tag{26}$$

At node 22: $$\left(\sum_{i=1}^{n}\left(\frac{H_i - H_{22}}{K_{22}}\right)^{0.5} - \sum_{i=1}^{n} Q_{wd22}\right) = 0 \tag{27}$$

At node 23: $$\left(\sum_{i=1}^{n} \left(\frac{H_i - H_{23}}{K_{23}} \right)^{0.5} - \sum_{i=1}^{n} Q_{wd\,23} \right) = 0 \tag{28}$$

At node 24: $$\left(\sum_{i=1}^{n} \left(\frac{H_i - H_{24}}{K_{24}} \right)^{0.5} - \sum_{i=1}^{n} Q_{wd\,24} \right) = 0 \tag{29}$$

At node 25: $$\left(\sum_{i=1}^{n} \left(\frac{H_i - H_{25}}{K_{25}} \right)^{0.5} - \sum_{i=1}^{n} Q_{wd\,25} \right) = 0 \tag{30}$$

At node 26: $$\left(\sum_{i=1}^{n} \left(\frac{H_i - H_{26}}{K_{26}} \right)^{0.5} - \sum_{i=1}^{n} Q_{wd\,26} \right) = 0 \tag{31}$$

At node 27: $$\left(\sum_{i=1}^{n} \left(\frac{H_i - H_{27}}{K_{27}} \right)^{0.5} - \sum_{i=1}^{n} Q_{wd\,27} \right) = 0 \tag{32}$$

At node 28: $$\left(\sum_{i=1}^{n} \left(\frac{H_i - H_{28}}{K_{28}} \right)^{0.5} - \sum_{i=1}^{n} Q_{wd\,28} \right) = 0 \tag{33}$$

At node 29: $$\left(\sum_{i=1}^{n} \left(\frac{H_i - H_{29}}{K_{29}} \right)^{0.5} - \sum_{i=1}^{n} Q_{wd\,29} \right) = 0 \tag{34}$$

At node 30: $$\left(\sum_{i=1}^{n} \left(\frac{H_i - H_{30}}{K_{30}} \right)^{0.5} - \sum_{i=1}^{n} Q_{wd\,30} \right) = 0 \tag{35}$$

At node 31: $$\left(\sum_{i=1}^{n} \left(\frac{H_i - H_{31}}{K_{31}} \right)^{0.5} - \sum_{i=1}^{n} Q_{wd\,31} \right) = 0 \tag{36}$$

At node 32: $$\left(\sum_{i=1}^{n} \left(\frac{H_i - H_{32}}{K_{32}} \right)^{0.5} - \sum_{i=1}^{n} Q_{wd\,32} \right) = 0 \tag{37}$$

At node 33: $$\left(\sum_{i=1}^{n} \left(\frac{H_i - H_{33}}{K_{33}} \right)^{0.5} - \sum_{i=1}^{n} Q_{wd\,33} \right) = 0 \tag{38}$$

At node 34: $$\left(\sum_{i=1}^{n} \left(\frac{H_i - H_{34}}{K_{34}} \right)^{0.5} - \sum_{i=1}^{n} Q_{wd\,34} \right) = 0 \tag{39}$$

At node 35: $$\left(\sum_{i=1}^{n} \left(\frac{H_i - H_{35}}{K_{35}} \right)^{0.5} - \sum_{i=1}^{n} Q_{wd\,35} \right) = 0 \tag{40}$$

At node 36: $$\left(\sum_{i=1}^{n} \left(\frac{H_i - H_{36}}{K_{36}} \right)^{0.5} - \sum_{i=1}^{n} Q_{wd\,36} \right) = 0 \tag{41}$$

At node 37: $$\left(\sum_{i=1}^{n} \left(\frac{H_i - H_{37}}{K_{37}} \right)^{0.5} - \sum_{i=1}^{n} Q_{wd\,37} \right) = 0 \tag{42}$$

At node 38: $$\left(\sum_{i=1}^{n} \left(\frac{H_i - H_{38}}{K_{38}} \right)^{0.5} - \sum_{i=1}^{n} Q_{wd\,38} \right) = 0 \tag{43}$$

At node 39: (44)

At node 40: $$\left(\sum_{i=1}^{n}\left(\frac{H_i - H_{40}}{K_{40}}\right)^{0.5} - \sum_{i=1}^{n} Q_{wd\,40}\right) = 0 \quad (35)$$

At node 41: $$\left(\sum_{i=1}^{n}\left(\frac{H_i - H_{41}}{K_{41}}\right)^{0.5} - \sum_{i=1}^{n} Q_{wd\,41}\right) = 0 \quad (46)$$

At node 42: $$\left(\sum_{i=1}^{n}\left(\frac{H_i - H_{42}}{K_{42}}\right)^{0.5} - \sum_{i=1}^{n} Q_{wd\,42}\right) = 0 \quad (47)$$

Table 2: A summary of data and information on the pipe layout and pipe line

Pipe Number	Node (Junction)	Length (m)	Diameter (mm)	Water Demand (l/s)	Change in Head (m)	Elevation (m)
1	1	10	150	0	20	370
2	2	70	50	0	33.1	356.9
3	3	144	150	320	35.8	354.2
4	4	60	50	0	36.8	353.2
5	5	100	50	60	39.8	350.2
6	7	375.4	150	20	41.5	348.5
8	8	50	150	0	40.2	349.8
9	9	100	50	0	40.3	349.7
10	10	57.6	150	0	40.9	349.1
11	11	402	150	0	49.9	340.1
12	12	18.9	150	0	40.9	349.1
13	13	29	50	0	42.4	347.6
14	14	34.5	50	80	42.1	347.9
15	15	7.5	150	80	39.3	350.7
16	16	28.5	50	0	46.7	343.3
17	17	55	50	80	40.8	349.2
18	18	85.6	150	80	41.4	348.6
19	19	26.5	50	0	46.7	343.3
20	20	23.4	50	80	44.4	345.6
21	21	27.1	50	80	41.5	348.5
22	22	92.7	150	80	45.6	344.4
23	23	52	50	0	45.6	344.4
24	24	33	50	80	45.3	344.7
25	25	35	50	80	45.5	344.5
26	26	55.6	150	80	45.6	344.4
27	27	81.6	50	45	51.4	338.6
28	28	120	50	80	36.9	353.1
29	29	48.8	50	60	39.3	350.7
30	30	172	50	30	40.9	349.1
31	31	168	150	60	40.3	349.7
32	32	65	50	0	42.7	347.3
33	33	45	50	0	50.9	339.1
34	34	232.9	50	100	42.1	347.9
35	35	168	50	0	35.4	354.6
36	36	87.6	50	280	25.6	364.4
37	37	106.0	150	180	43.1	346.9
38	38	47.0	50	0	39.1	350.9
39	39	40.21	50	480	44.6	345.4
40	40	100	150	450	40	350
41	41	57	50	0	38	352
42	42	66	50	460	39.8	350.2
43	43	100	50	120	25.5	364.5
Tank						390.0

At node 43: $$\left(\sum_{i=1}^{n}\left(\frac{H_i - H_{43}}{K_{43}}\right)^{0.5} - \sum_{i=1}^{n} Q_{wd\,43}\right) = 0 \quad (48)$$

At node 44: $$\left(\sum_{i=1}^{n}\left(\frac{H_i - H_{44}}{K_{44}}\right)^{0.5} - \sum_{i=1}^{n} Q_{wd\,44}\right) = 0 \quad (49)$$

At node 45: $$\left(\sum_{i=1}^{n}\left(\frac{H_i - H_{45}}{K_{45}}\right)^{0.5} - \sum_{i=1}^{n} Q_{wd\,45}\right) = 0 \quad (50)$$

Figure 4 presents the flow chart and summary of Microsoft Excel Solver (MiES) procedures. MiES was utilized for the evaluation, determination, and minimization of the target value of the sum of square errors based on its availability and accessibility at no extra purchasing cost and installation cost. The steps and procedures utilised in the Microsoft Excel solver applications can be breakdown as follows:

a) Purchase Microsoft office, and installed the Office applications
b) Launch Microsoft Excel and check the toolbar for Microsoft Excel Solver at data, if not available then
c) Launch the option, add-ins and go
d) Add Excel solver to the Microsoft Excel at data on the toolbar,
e) Set the target, which is the numerical solution of the iterations, operation which is equal to zero and changing variable and hydraulic parameters (Q, f and K) cells, which are the variables (advance setting many require the degree of accuracy, number of iterations, allowable errors and techniques).
f) Allow Microsoft Excel Solver to conduct the iterations set and with tolerance (by clicking OK).
g) MiES displaced the results for the changing variables after the iterations are completed
h) Record the values for all the hydraulic variables or parameters (Q, f and K, Figure 4).

Models that establish relationships between the friction factor, flow rate and pipe diameter were determined individually and in combination using MiES as follows Equations 51, 52 and 53):

Individually (Model A as follows):

$$f_q = \frac{a}{Q^b} \quad (51)$$

Where; a is the numerical or imperial value that relates the two hydraulic parameters and b is the constant and exponential value for the discharge or flow rate. (Model B as follows):

$$f_d = \frac{A}{D^B} \quad (52)$$

Where; A is the numerical or imperial value that relates the two hydraulic parameters and B is the constant and exponential value for the diameter of the pipe. Combination of diameter of pipe and discharge (Model C as follows):

$$f_{cc} = K_a Q^{bb} D^{aa} \quad (53)$$

Where; K_a is the numerical or imperial value that relates the three hydraulic parameters; aa is the constant and exponential value for the diameter of the pipe, and bb is the constant and exponential value for the discharge or flow rates. These three models and calculated hydraulic parameters using the two methods (MiES and EPANET as standard technique) were evaluated statistically using analysis of variance (to ascertain effects of a selected factor on the hydraulic parameters), total error, relative error, model of selection criterion (MSC), mean squared error, correlation coefficient and coefficient of determination (CD). Total error (T_r) can be calculated utilising equation (54) as follows:

$$T_r = \sum_{i=1}^{n} \left(X_{ei} - X_{ci} \right)^2 \tag{54}$$

Where, X_{ei} is the expected flow in pipe i attained using EPANET and X_{ci} is the calculated discharge or flow in pipe i attained using MiES. MSC values were computed utilising equation (55) as follows:

$$MSC = \ln \left(\frac{\sum_{i=1}^{n} \left(X_{ei} - \overline{X_{ci}} \right)^2}{\sum_{i=1}^{n} \left(X_{ei} - X_{ci} \right)^2} \right) - \frac{2p}{N} \tag{55}$$

Where, p is the total number of hydraulic parameters and N is the total number of pipes in the system. Relative error (R_e) and mean squared error (M_{se}) were calculated using equations (56) and (57), respectively.

$$M_{se} = \left(\frac{\sqrt{\left(\sum_{i=1}^{n} \left(X_{ei} - X_{ci} \right)^2 \right)}}{N} \right) \tag{56}$$

$$R_e = \sum_{i=1}^{n} \left(100 \left(\frac{\left(X_{ei} - X_{ci} \right)}{X_{ei}} \right) \right) \tag{57}$$

Coefficient of Determination (CD) and correlation coefficient (R) were calculated using expressions (58) and (59), respectively:

$$CD = \left(\frac{\sum_{i=1}^{n} \left(X_{ei} - \overline{X}_{ei} \right)^2 - \sum_{i=1}^{n} \left(X_{ei} - X_{ci} \right)^2}{\sum_{i=1}^{n} \left(X_{ei} - \overline{X}_{ei} \right)^2} \right) \tag{58}$$

$$R = \sqrt{\left(\frac{\sum_{i=1}^{n} \left(X_{ei} - \overline{X}_{ei} \right)^2 - \sum_{i=1}^{n} \left(X_{ei} - X_{ci} \right)^2}{\sum_{i=1}^{n} \left(X_{ei} - \overline{X}_{ei} \right)^2} \right)} \tag{59}$$

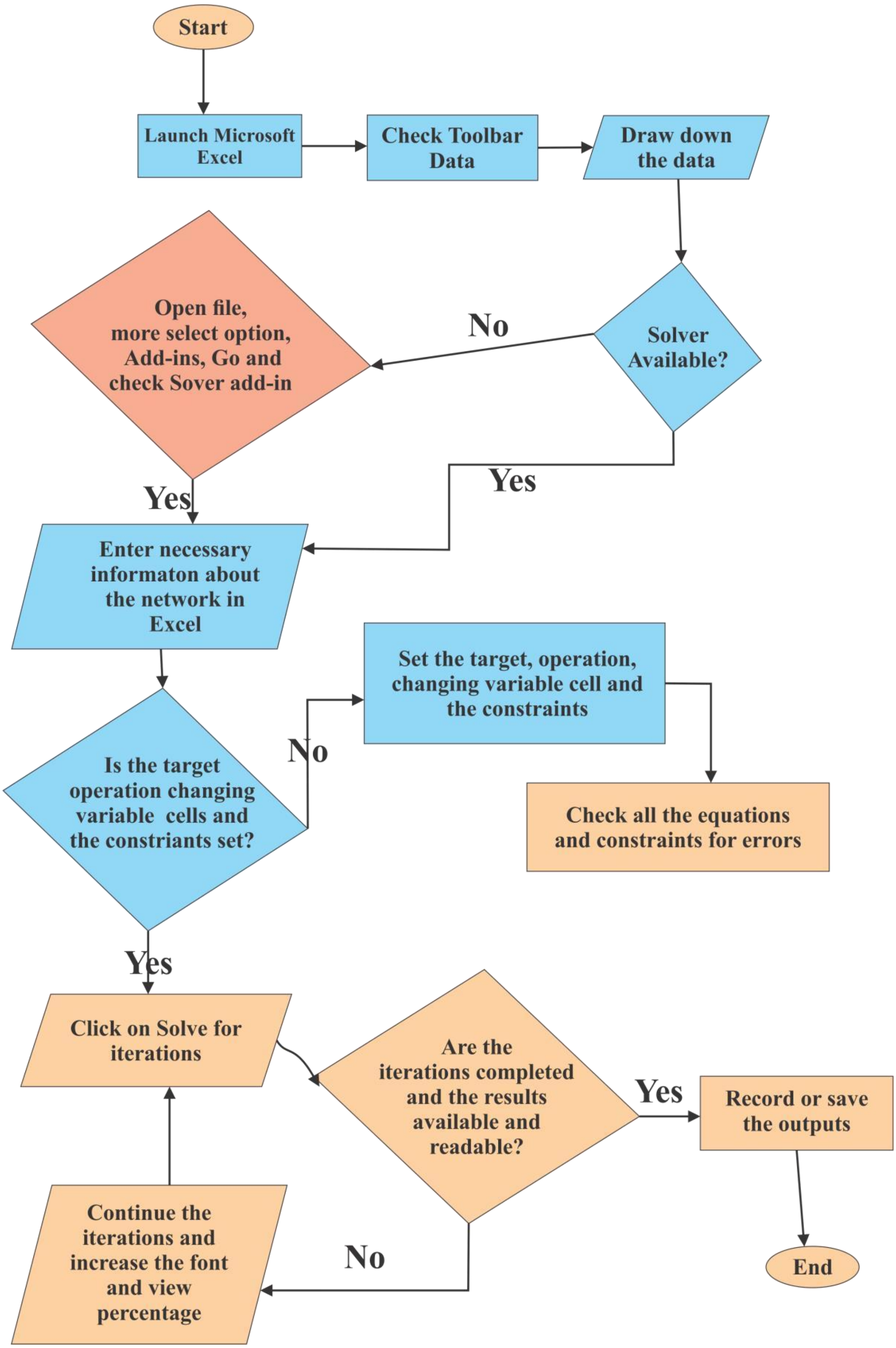


Figure 4 The flow chart and summary of Microsoft Excel Solver (MiES) procedures

b. RESULTS AND DISCUSSION

The results and outputs of the research study and work are presented, provided, discussed and explained in the following categories as follows:

c. **Pipeline and pipe layout:** Figure 5 shows the pipeline and pipe layout, pipe numbers, pipe length, pipe diameters and the elevation at nodes. The figure and Table 2 revealed that the highest elevation was 390m at the overhead tank and the lowest elevation on the pipeline and pipe layout was 339.1 m at the node 34. The difference between the highest and the lowest provided hydraulic head of 50.9 m this value of head supported the distribution or supply of treated and stored water by gravity easily. Table 2 provides the pipe diameters, node number, pipe number and the length of the pipes. The Table revealed that the length of these pipes was between 10 m at the tank to node 2 and 120 m at the node 27. These results show that the length of pipes in this pipeline and pipe layout is a function of bend or intersection and location of the hostel as well as other facilities that in needs of treated water. Table 2 provides the water demand at the nodes and other initial hydraulic parameters utilised. The table revealed that these hydraulic parameters vary with the location and end users.

d. **Pipe Network Analysis:** The analysis of the pipe network (pipeline and pipe layout) was conducted utilising EPANET and MiES. The results and the platform of the utilization of the MiES as well as other necessary data, information and procedures are presented as shown in Figures 6a and b. Figures 6a and b, and Table 3 exhibited the flow, which established that water flows from higher elevations to lower elevations. The Figures and the Table bring home the pipeline and pipe layout and the flows in the pipes, which revealed that the highest flow was 3545 litres per second within pipe 2 (the primary pipe from the tank) and the lowest flow within pipe 6 was 20 litres per second. This result established there are primary pipe (which channels water from the major sources of water such as overhead tanks or reservoirs), secondary pipe (which acquits water from the primary) and tertiary pipe (which conveys water to the consumers). The study revealed that secondary pipes were missing in the network, the pipeline and the pipe layout, which can be attributed to the cost-saving and profit-making techniques by the management, consultant and contractor during or throughout the design, development and construction of the water treatment systems. Table 4 presents the result of the analysis of variance (ANOVA) of the flows obtained using the two methods (EPANET and MiES). The Table established the statistical F-magnitude and probability for the sources of variation and difference between Pipe diameters and flow rates using the two methods to be $F_{41,\ 41} = 0.785774$ and $p = 0.7782333$, which indicated that there were no significant differences between the flow rates obtained from the two methods. These results confirmed that the methods used do not have significant effects on the flow rates within the pipes attained throughout the period of pipe network analysis. The Table (Table 3) also provides the values of friction factors. The highest friction factor was 0.254 which occurred in pipe number 6 and the lowest was 0.012 which occurred in most of the pipes. Classification of the flows and the friction factors in the pipe using Moody's chart (Figure 7) revealed that the majority of the flows in the pipes were expected to be in laminar, critical or transition zones, which indicated a lower risk of burst in the pipe and regular replacement of pipes. A further classification of the pipe revealed that most of the pipes were smooth pipes and plastic products. From Table 4 the F-value and p-value established that there were no significant differences between the friction factors obtained using the two methods (statistical $F_{1,41}$ value was 0.65443 and probability was 0.4232029). Figure 8 presents the relationship between the obtained friction factors (MiES and EPANET). These figures 8a, 8b and 8c revealed that there is a logarithmic relationship between these friction factors.

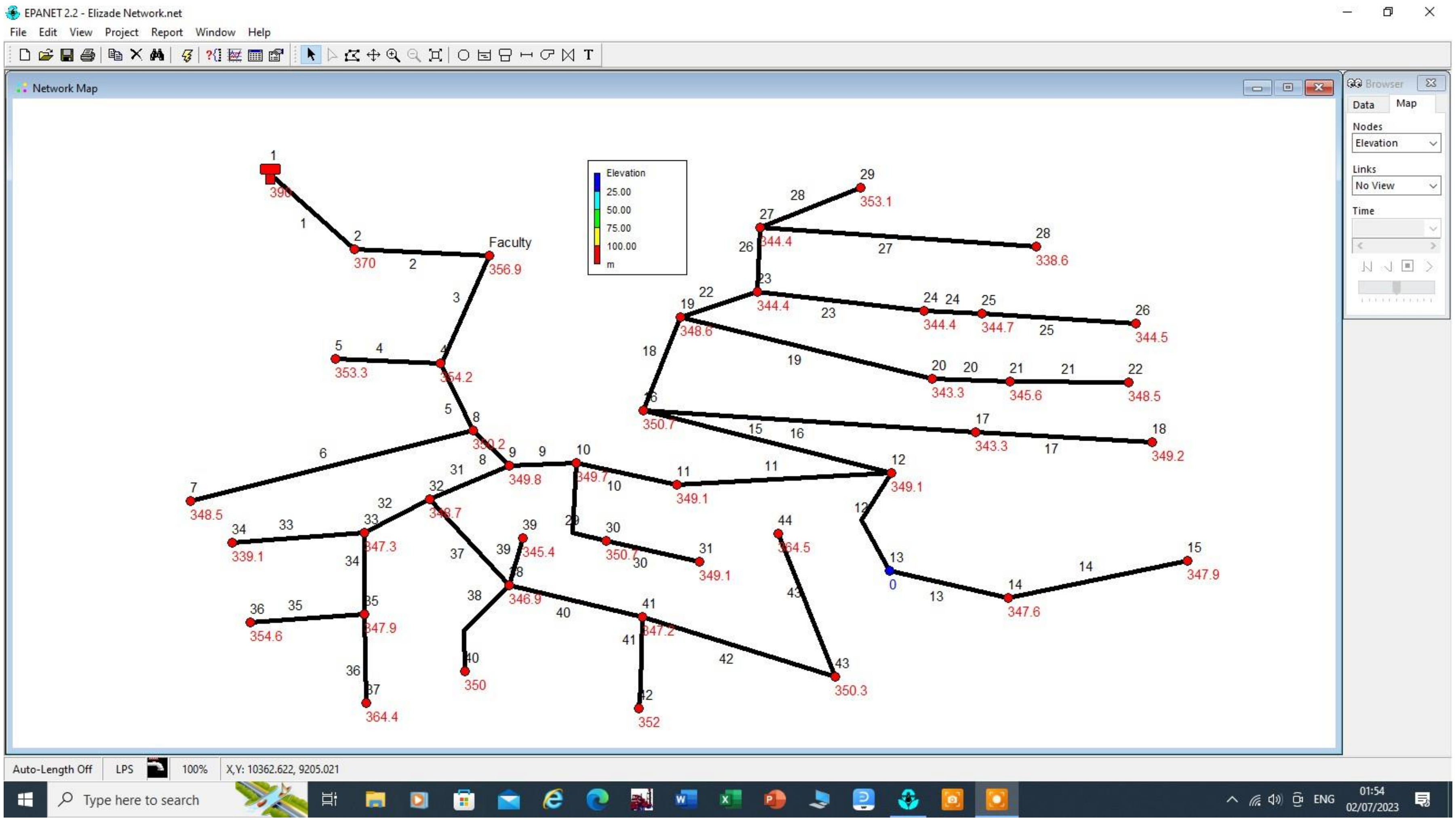


Figure 5a: the pipeline and pipe layout, the Label (Nodes and Pipes numbers) and elevation at the nodes.

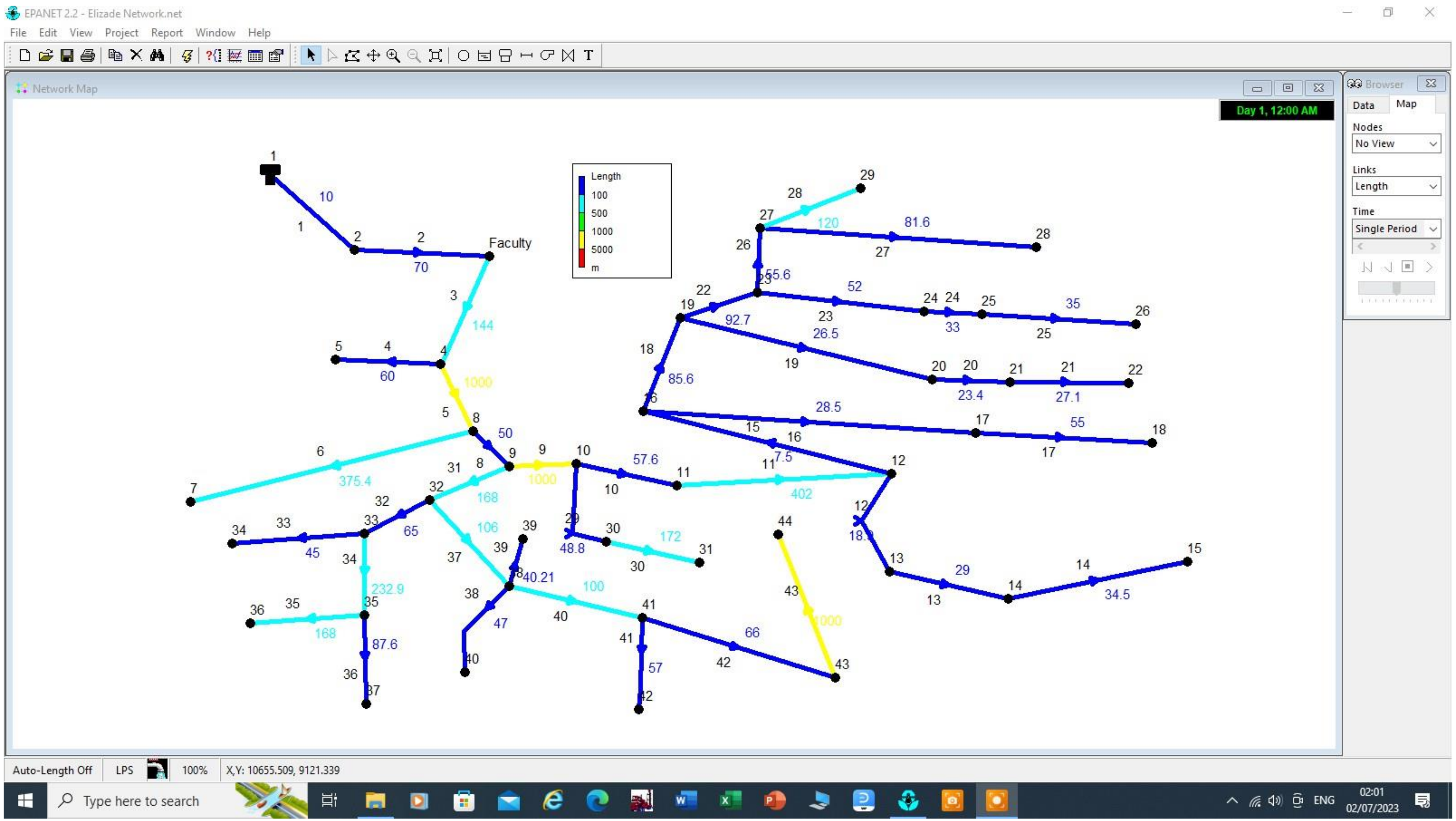


Figure 5b: the pipeline and pipe layout, the Label (Nodes and Pipes length).

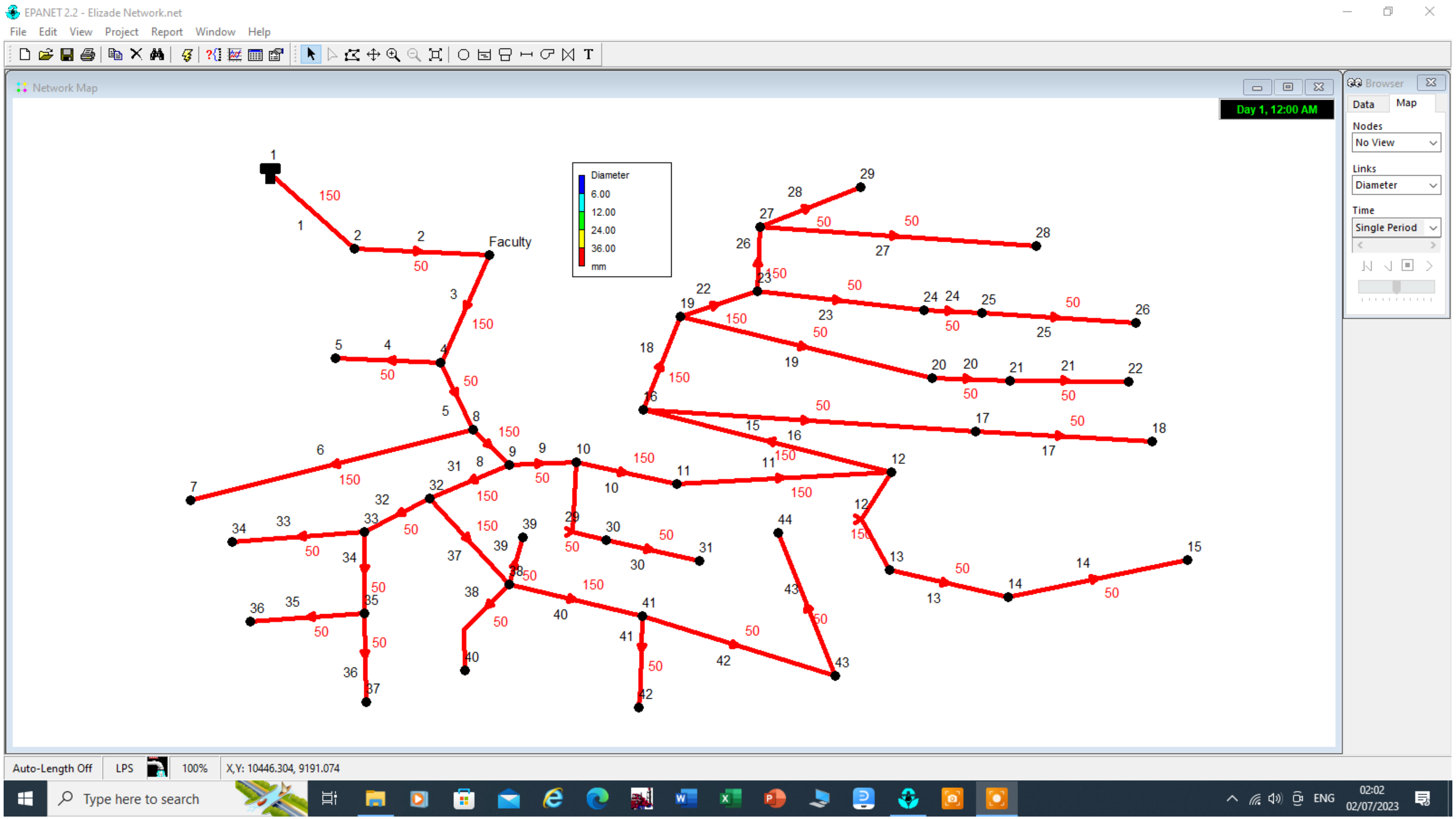


Figure 5c: the pipeline and pipe layout, the Label (Nodes and Pipes diameter).

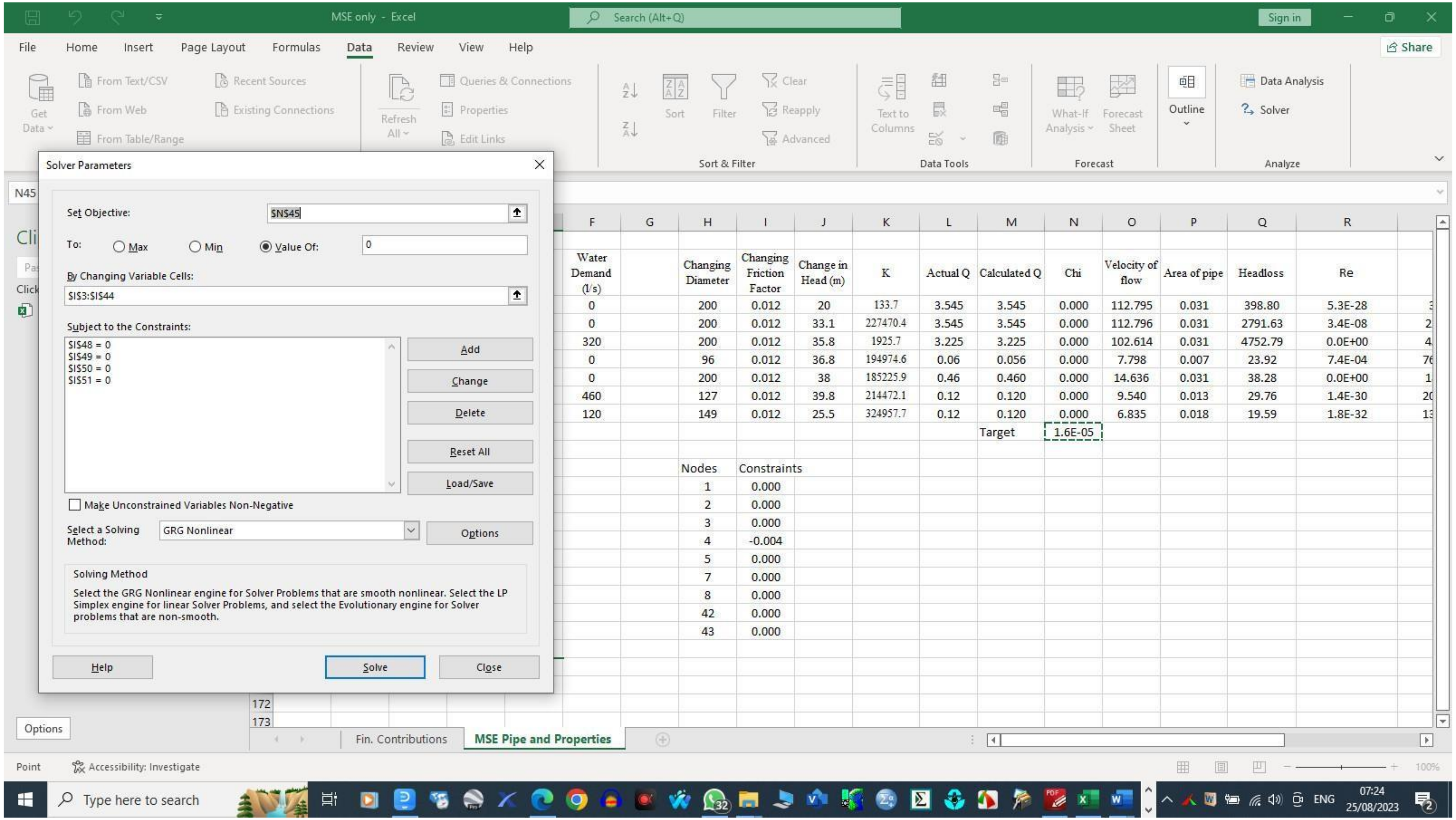
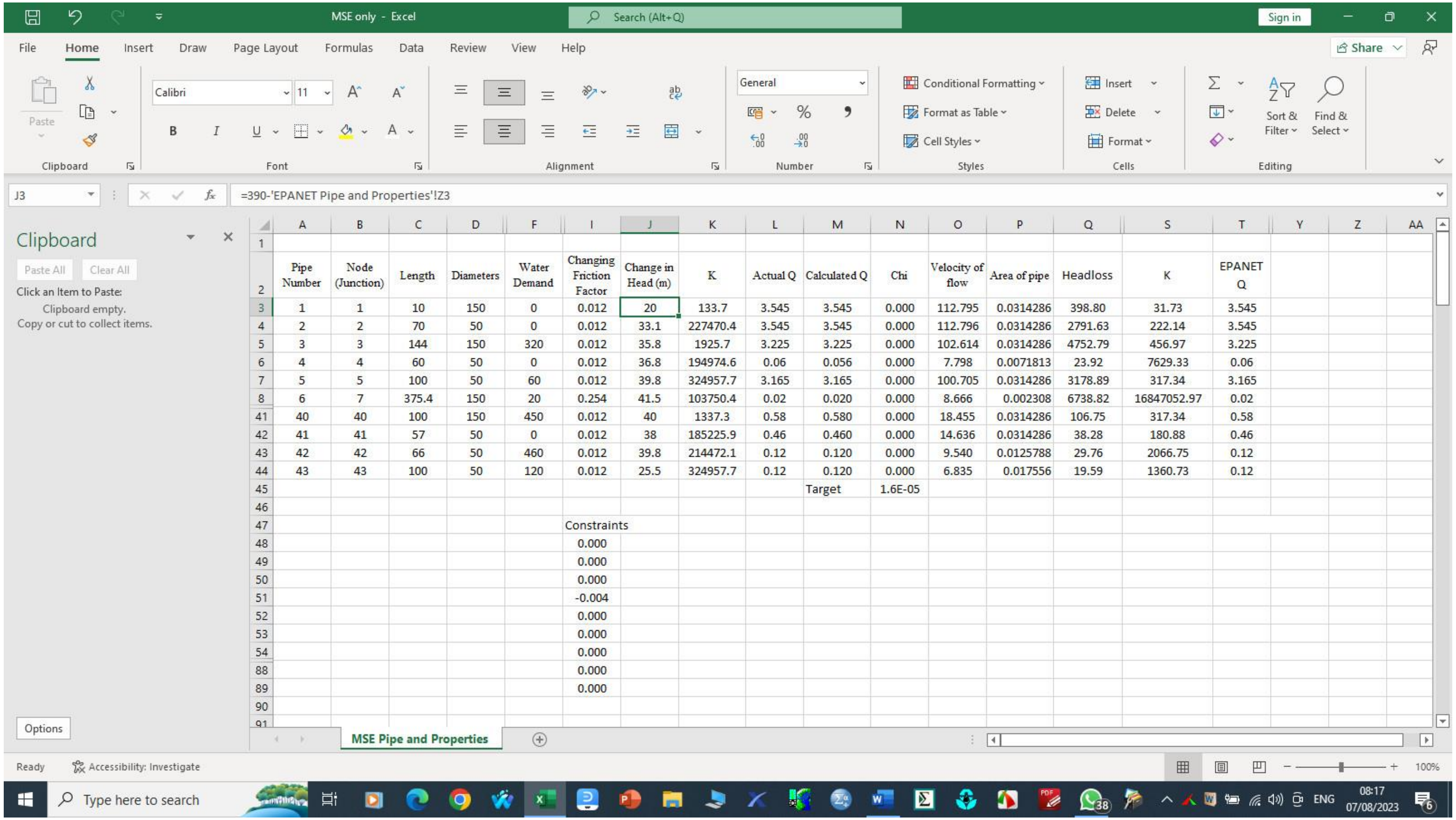


Figure 6a: the MiES working platform, Solver dialogue platform and other data used in the computation of the hydraulic variables.



Row	Pipe Number	Node (Junction)	Length	Diameters	Water Demand	Changing Friction Factor	Change in Head (m)	K	Actual Q	Calculated Q	Chi	Velocity of flow	Area of pipe	Headloss	K	EPANET Q
3	1	1	10	150	0	0.012	20	133.7	3.545	3.545	0.000	112.795	0.0314286	398.80	31.73	3.545
4	2	2	70	50	0	0.012	33.1	227470.4	3.545	3.545	0.000	112.796	0.0314286	2791.63	222.14	3.545
5	3	3	144	150	320	0.012	35.8	1925.7	3.225	3.225	0.000	102.614	0.0314286	4752.79	456.97	3.225
6	4	4	60	50	0	0.012	36.8	194974.6	0.06	0.056	0.000	7.798	0.0071813	23.92	7629.33	0.06
7	5	5	100	50	60	0.012	39.8	324957.7	3.165	3.165	0.000	100.705	0.0314286	3178.89	317.34	3.165
8	6	7	375.4	150	20	0.254	41.5	103750.4	0.02	0.020	0.000	8.666	0.002308	6738.82	16847052.97	0.02
41	40	40	100	150	450	0.012	40	1337.3	0.58	0.580	0.000	18.455	0.0314286	106.75	317.34	0.58
42	41	41	57	50	0	0.012	38	185225.9	0.46	0.460	0.000	14.636	0.0314286	38.28	180.88	0.46
43	42	42	66	50	460	0.012	39.8	214472.1	0.12	0.120	0.000	9.540	0.0125788	29.76	2066.75	0.12
44	43	43	100	50	120	0.012	25.5	324957.7	0.12	0.120	0.000	6.835	0.017556	19.59	1360.73	0.12
45										Target	1.6E-05					
47						Constraints										
48						0.000										
49						0.000										
50						0.000										
51						-0.004										
52						0.000										
53						0.000										
54						0.000										
88						0.000										
89						0.000										

Figure 6b: the MiES platform and other data used in the computation of the hydraulic variables.

Table 3: the pipeline , pipe properties, flows, velocity of flow and the Label (Nodes and Pipes numbers).

Pipe Number	Node (Junction)	Length	Diameters (mm)	Water Demand (l/s)	Changing Friction Factor	Change in Head (m)	K	Actual Q	Calculated Q	Chi	Velocity of flow	Area of pipe	Headloss (m)
1	1	10	150	0	0.012	20	133.7	3.545	3.545	0.000	112.795	0.031	398.80
2	2	70	50	0	0.012	33.1	227470.4	3.545	3.545	0.000	112.796	0.031	2791.63
3	3	144	150	320	0.012	35.8	1925.7	3.225	3.225	0.000	102.614	0.031	4752.79
4	4	60	50	0	0.012	36.8	194974.6	0.06	0.056	0.000	7.798	0.007	23.92
5	5	100	50	60	0.012	39.8	324957.7	3.165	3.165	0.000	100.705	0.031	3178.89
6	7	375.4	150	20	0.254	41.5	103750.4	0.02	0.020	0.000	8.666	0.002	6738.82
8	8	50	150	0	0.012	40.2	668.6	3.145	3.145	0.000	100.068	0.031	1569.42
9	9	100	50	0	0.012	40.3	324957.7	1.075	1.075	0.000	34.205	0.031	366.73
10	10	57.6	150	0	0.012	40.9	770.3	0.985	0.985	0.000	31.341	0.031	177.35
11	11	402	150	0	0.012	49.9	5375.8	0.985	0.985	0.000	31.341	0.031	1237.73
12	12	18.9	150	0	0.078	40.9	1597.7	0.16	0.160	0.000	19.192	0.008	267.80
13	13	29	50	0	0.012	42.4	94237.7	0.16	0.160	0.000	14.345	0.011	31.40
14	14	34.5	50	80	0.012	42.1	112110.4	0.08	0.080	0.000	11.581	0.007	30.94
15	15	7.5	150	80	0.012	39.3	100.3	0.825	0.825	0.000	37.758	0.022	40.20
16	16	28.5	50	0	0.012	46.7	92612.9	0.16	0.160	0.000	14.996	0.011	34.48
17	17	55	50	80	0.012	40.8	178726.7	0.08	0.080	0.000	9.131	0.009	27.22
18	18	85.6	150	80	0.012	41.4	1144.7	0.665	0.665	0.000	21.159	0.031	120.13
19	19	26.5	50	0	0.012	46.7	86113.8	0.24	0.240	0.000	15.795	0.015	29.81
20	20	23.4	50	80	0.012	44.4	76040.1	0.16	0.160	0.000	15.876	0.010	32.64
21	21	27.1	50	80	0.012	41.5	88063.5	0.08	0.080	0.000	12.627	0.006	30.17
22	22	92.7	150	80	0.012	45.6	1239.7	0.425	0.425	0.000	13.523	0.031	53.14
23	23	52	50	0	0.012	45.6	168978.0	0.24	0.240	0.000	12.898	0.019	35.24
24	24	33	50	80	0.012	45.3	107236.0	0.16	0.160	0.000	13.997	0.011	33.61
25	25	35	50	80	0.012	45.5	113735.2	0.08	0.080	0.000	11.863	0.007	33.33
26	26	55.6	150	80	0.022	45.6	1332.4	0.185	0.185	0.000	12.468	0.015	70.66
27	27	81.6	50	45	0.012	51.4	265165.5	0.08	0.080	0.000	8.969	0.009	38.62
28	28	120	50	80	0.012	36.9	389949.2	0.06	0.060	0.000	6.224	0.010	26.31
29	29	48.8	50	60	0.012	39.3	158579.3	0.09	0.090	0.000	10.079	0.009	29.15
30	30	172	50	30	0.012	40.9	558927.2	0.06	0.060	0.000	5.575	0.011	28.63

Table 3: Continued

Pipe Number	Node (Junction)	Length	Diameters (mm)	Water Demand (l/s)	Changing Friction Factor	Change in Head (m)	K	Actual Q	Calculated Q	Chi	Velocity of flow	Area of pipe	Headloss (m)
30	30	172	50	30	0.012	40.9	558927.2	0.06	0.060	0.000	5.575	0.011	28.63
31	31	168	150	60	0.012	40.3	2246.6	2.07	2.070	0.000	65.864	0.031	2284.42
32	32	65	50	0	0.012	42.7	211222.5	0.56	0.560	0.000	17.818	0.031	64.69
33	33	45	50	0	0.012	50.9	146231.0	0.1	0.100	0.000	11.717	0.009	37.16
34	34	232.9	50	100	0.012	42.1	756826.4	0.46	0.460	0.000	14.636	0.031	156.39
35	35	168	50	0	0.012	35.4	545928.9	0.28	0.280	0.000	8.909	0.031	41.80
36	36	87.6	50	280	0.012	25.6	284662.9	0.18	0.180	0.000	7.922	0.023	20.27
37	37	106	150	180	0.012	43.1	1417.5	1.51	1.510	0.000	48.045	0.031	766.98
38	38	47	50	0	0.012	39.1	152730.1	0.45	0.450	0.000	14.708	0.031	32.30
39	39	40.21	50	480	0.012	44.6	130665.5	0.48	0.480	0.000	16.655	0.029	36.51
40	40	100	150	450	0.012	40	1337.3	0.58	0.580	0.000	18.455	0.031	106.75
41	41	57	50	0	0.012	38	185225.9	0.46	0.460	0.000	14.636	0.031	38.28
42	42	66	50	460	0.012	39.8	214472.1	0.12	0.120	0.000	9.540	0.013	29.76
43	43	100	50	120	0.012	25.5	324957.7	0.12	0.120	0.000	6.835	0.018	19.59

Table 4: Effects of flow rate and diameters of the pipe on friction factors (EPANET and MiES)

Source of Variation	*Sum of Square*	*Degree of freedom*	*Mean Sum of Square*	*Statistical F-Value*	*Probability value*	*Statistical F critical at 95 % confidence level*
Between Pipe diameters and flow rates using the two methods	0.026762	41	0.0006527	0.785774	0.7782333	1.681644
Within the friction factors using the two methods	0.000544	1	0.0005436	0.65443	0.4232029	4.078546
Error	0.034059	41	0.0008307			
Total	0.061365	83				

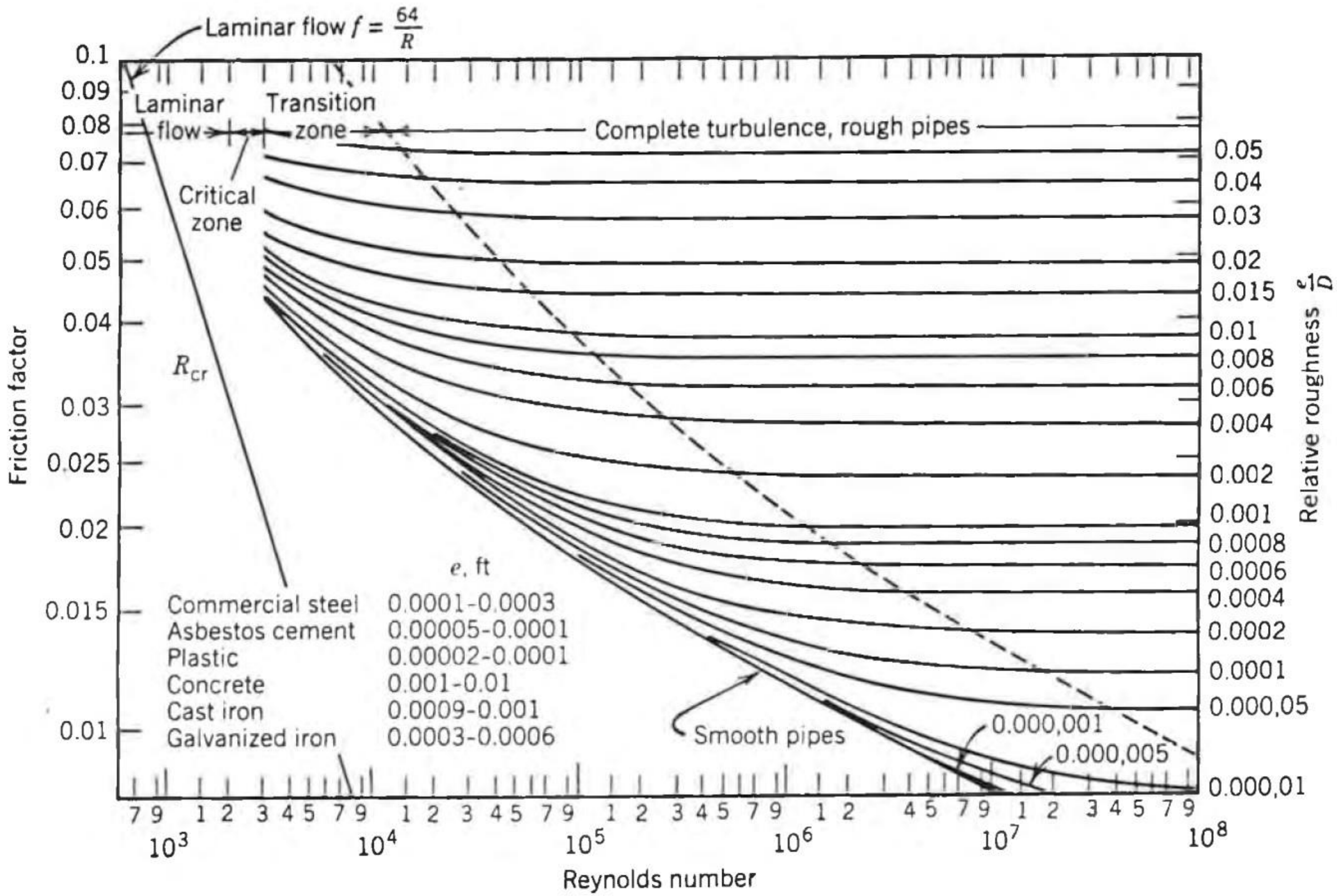


Figure 7: Standard Moody Chart for friction factor estimate

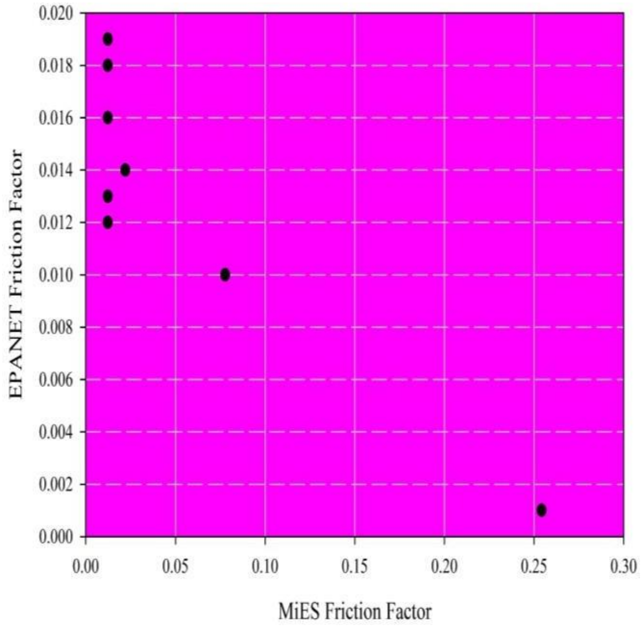


Figure 8a Relationship between the Friction factor calculated and expected

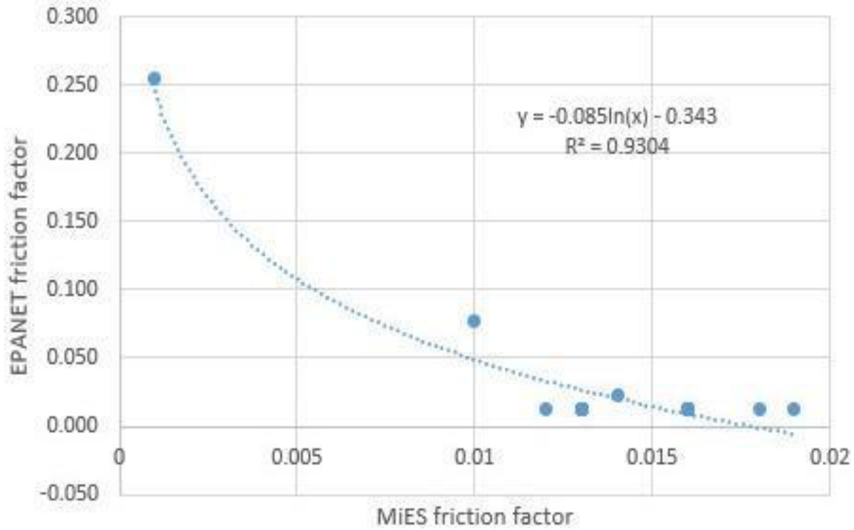


Figure 8b Relationship between the Friction factor calculated and expected

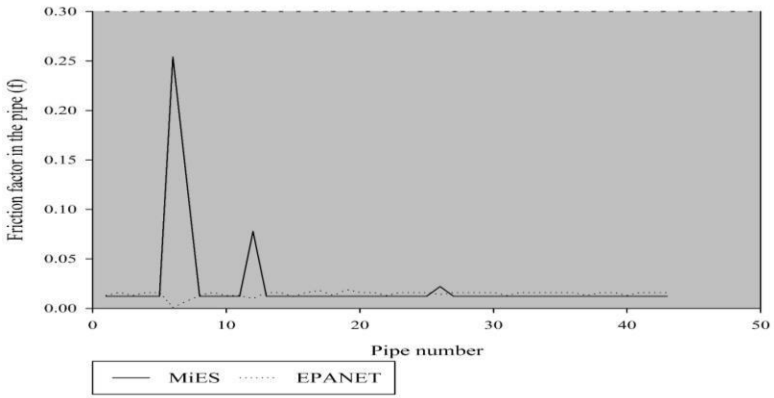


Figure 8c Relationship between the pipe, friction factor calculated and expected

With a better coefficient of determination (R^2 = 0.9304) the result established that there was an excellent relationship between these two friction factors. This observation confirmed the literature**,** which reported that the friction factor of the pipe is not a constant, but it is a function of the diameter of the pipe, flow and velocity of the pipe. This agreed with the comments and observations made in the literature by Brikc (2018). Table 3 also presents the values of K for all the flows and pipe diameters. The lowest value of K (100.30) occurred in pipe number 15 and the highest value (756826.4) occurred in pipe number 34. Figures 9a, 9b, 9c and 9d provide the relationship between flow rate, diameter of pipe, K, and length of pipe, respectively. These figures revealed and confirmed that there is a non-linear relationship between K and selected hydraulic parameters and variables (flow rate, diameter of pipe, friction factor, and length of pipe,). Table 3 shows the value of the headloss for all the flows and pipe diameters. The lowest value of headloss (20.27 m) occurred in pipe number 36 and the highest value (6738.82m) occurred in pipe number 6. These values of headloss revealed that headloss is a function of the length of the pipe, friction factor, diameter of the pipe and the flow in the pipe. Figures 10a, 10b, 10c, 10d and 10e provide the relationship between the friction factor (MiES, models A, B and C) and selected hydraulic parameters and variables such as flow rate, diameters of the pipe, and computer friction factors. Figures 11a and 11b provide the relationship between flow rate, the diameter of the pipe, friction factor, and headloss, respectively. These two figures revealed the relationship between the friction factors. The relationships are non-linear relationships, which establish statement and documentation on the subject matter in literature such as Nafi and Afzali (2017), Adedeji *et al.* (2017), Niazkar and Afzali (2017), Oke (2017), Creaco and Walski (2017), Sinagra *et al.* (2017), Tabesh and Beigi (2017), Gupta and Kulat (2018), Sakr and Gooda (2018), Garmendia *et al.* (2018) , Oyebode and Igbi (2018), Roige Montornes *et al.* (2019), Nafi and Brans (2019), Haider *et al.* (2019), Bermudez *et al.* (2019), Gajghate and Mirajkar (2019), Malm *et al.* (2020), Niazkar and Talebbeydokhti (2020), Moslehi and Jalili (2020), Ahopello and Vahala (2020), Gokayay (2020); Jin *et al.* (2020), Moslehi *et al.* (2020a and b), Abbas and Mohammed (2020), Abdulsamad and Abdulrazzaq (2022), and Abdulsamad and Abdulrazzaq (2023).

Table 5 presents the values of the empirical parameters for the three proposed models (Models A, B and C). The Table revealed that the friction factor is a negative function of the discharge or flow rate and the diameters of the pipe. These results indicated that the higher the flow rate or discharge the lower the friction factor. In summary, higher flow rates and diameters of the pipe had the lowest friction factor (Table 5). The proportional values or relation constant vary with hydraulic parameters (flow rate, diameter of pipe, friction factor, and length of pipe). These empirical parameters were 7.79×10^{-5} for the relationship between friction factor and flow rates in the pipe (Model A), 0.000298 for the relationship between friction factor and diameter of the pipe (Model B) and 3.56×10^{-6} for the relationship between friction factor combination of pipe diameter and flow rates in the pipe (Model C). Statistical evaluation of the models revealed that model C was the best based on the highest vales of R, MSC and CD, with the lowest values of errors. Table 6 shows the effects of the flow rate and diameters of the pipe on friction factors (computed, MiES) for the three models. The Table revealed the sources of variations between the diameter and the flow rate in the pipe were statistically $F_{41, 82}$ magnitude was 4.285399 and probability was 1.06×10^{-08}. This result indicated that the diameter and the flow rate in the pipe had significant effects on the friction factors in a pipe at a 95 % confidence level, which supported previous studies documented in the literature. In the same Table, the sources of variations within the three models were statistically $F_{2, 82}$ magnitude was 1.782655 and probability was 0.1746469.

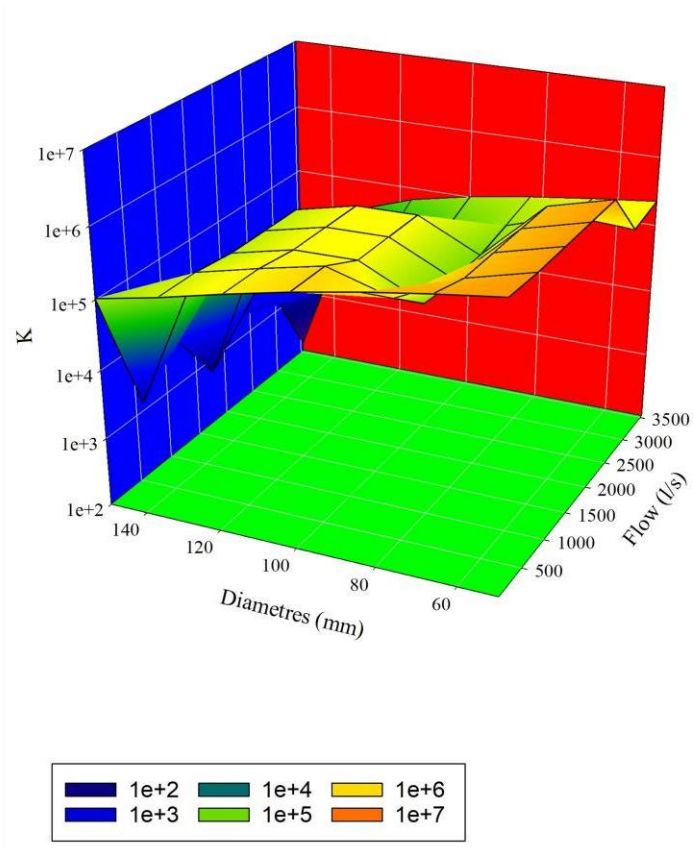


Figure 9a: Relationship between flow rate, diameter of pipe, and K,

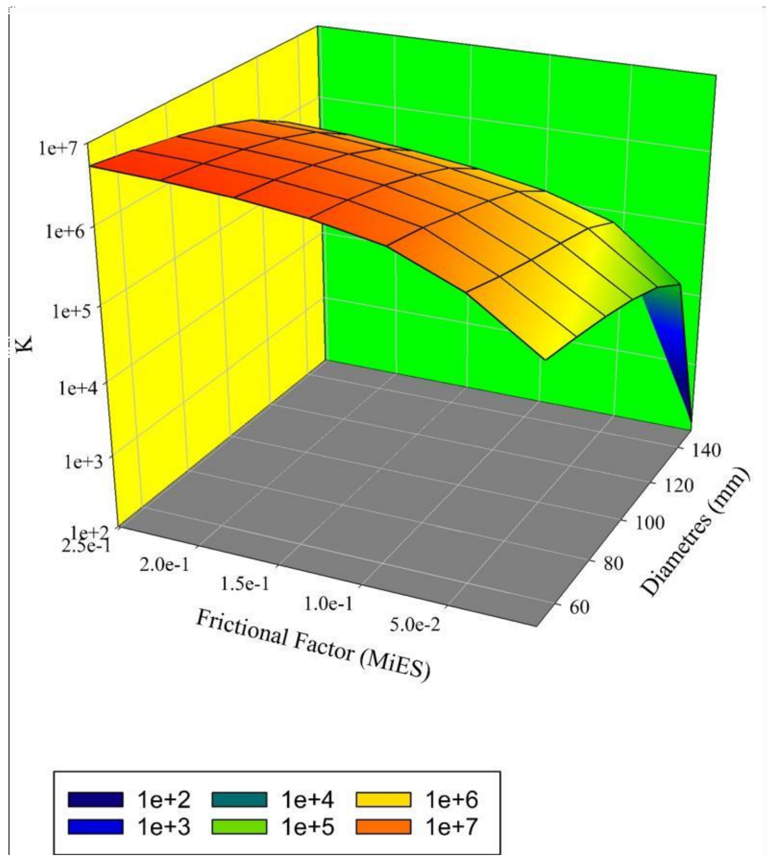


Figure 9b: Relationship between friction factor, diameter of pipe, and K

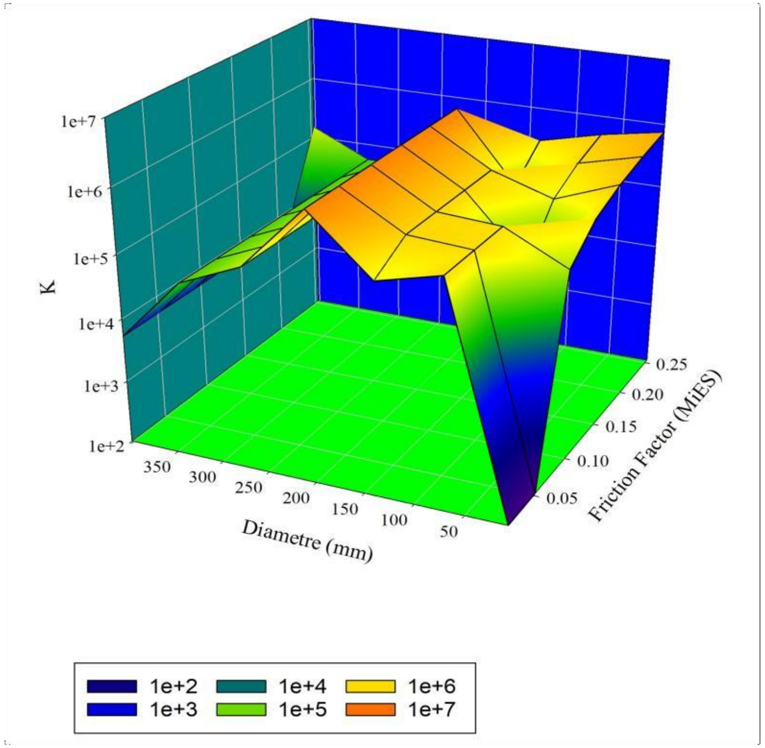


Figure 9c: Relationship between friction factor, diameter of pipe, and K

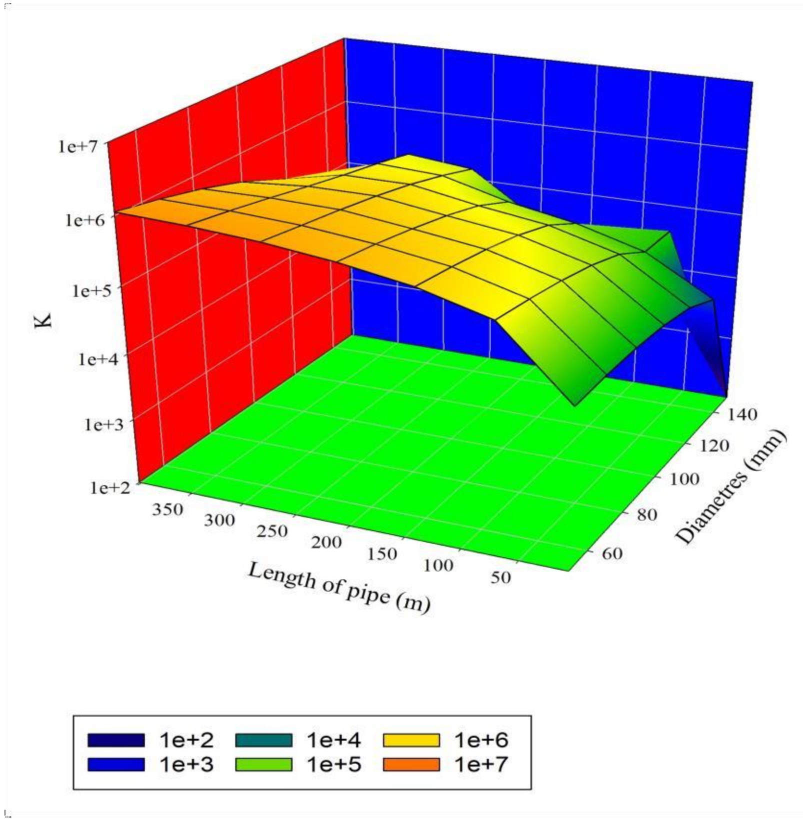


Figure 9d: Relationship between diameter of pipe, K, and length of pipe

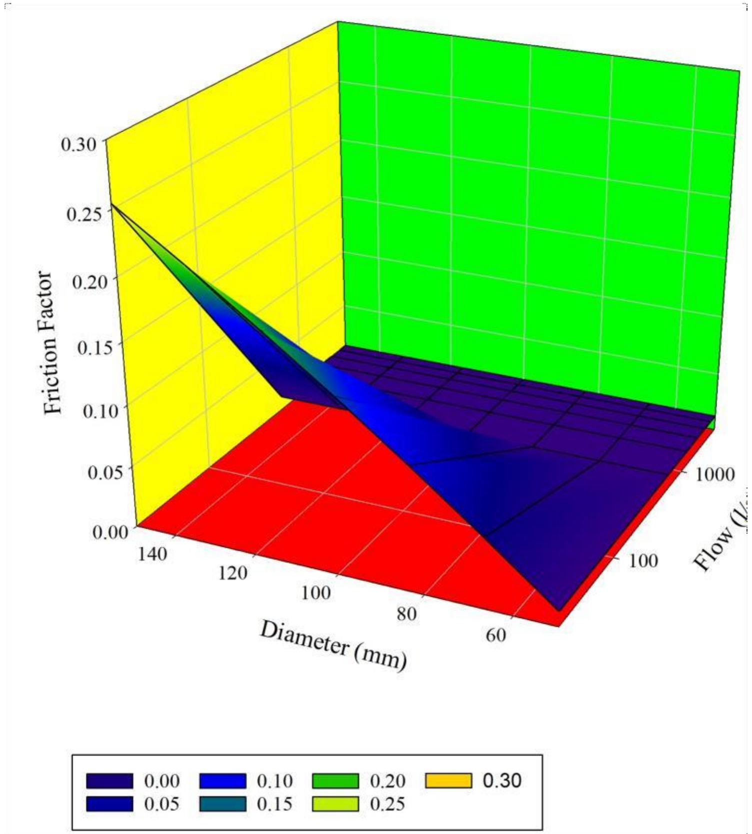


Figure 10a: Relationship between flow rate, diameter of pipe, and Computed friction factor using EPANET

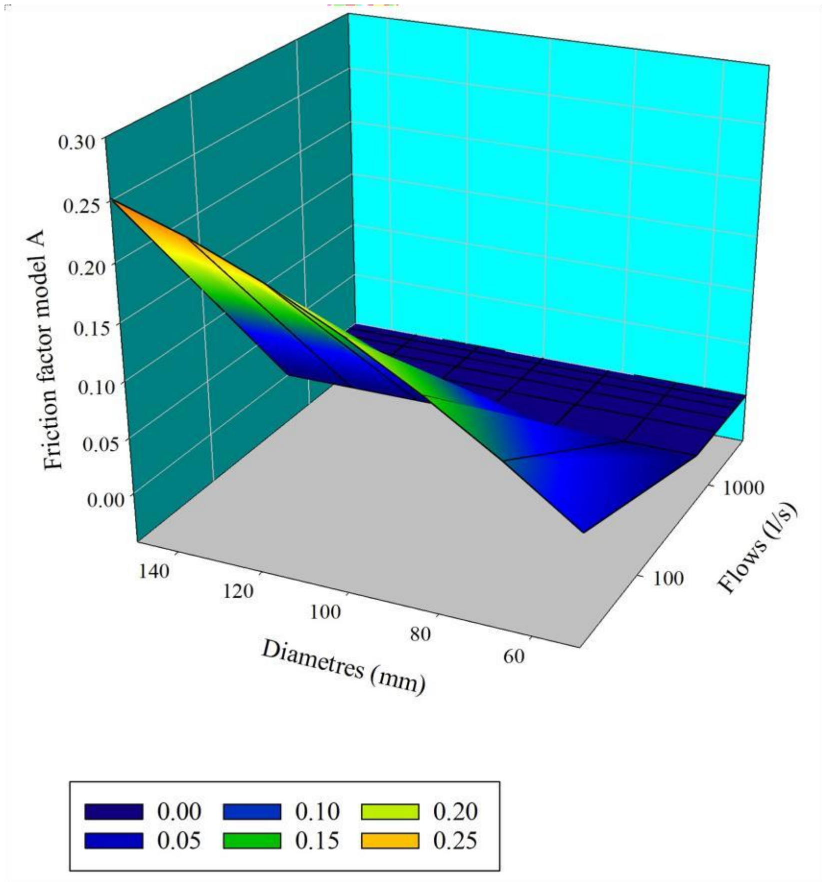


Figure 10b: Relationship between flow rate, the diameter of pipe, and Computed friction factor using MiES and Model A

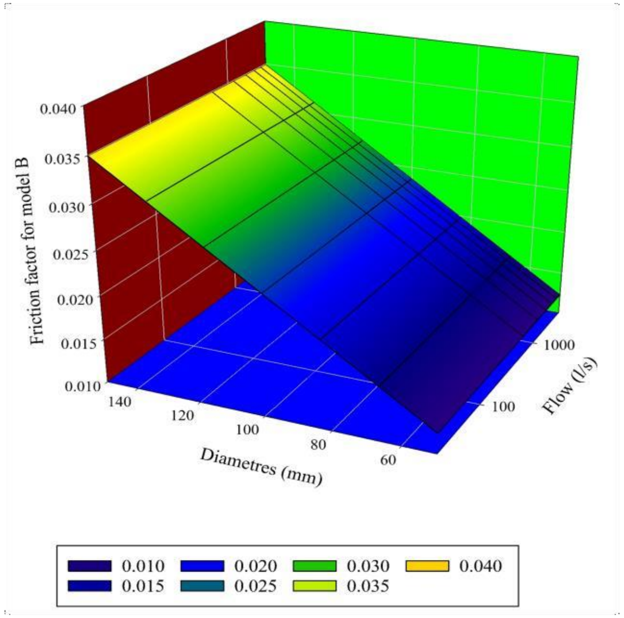


Figure 10c: Relationship between flow rate, the diameter of pipe, and Computed friction factor using MiES and Model C

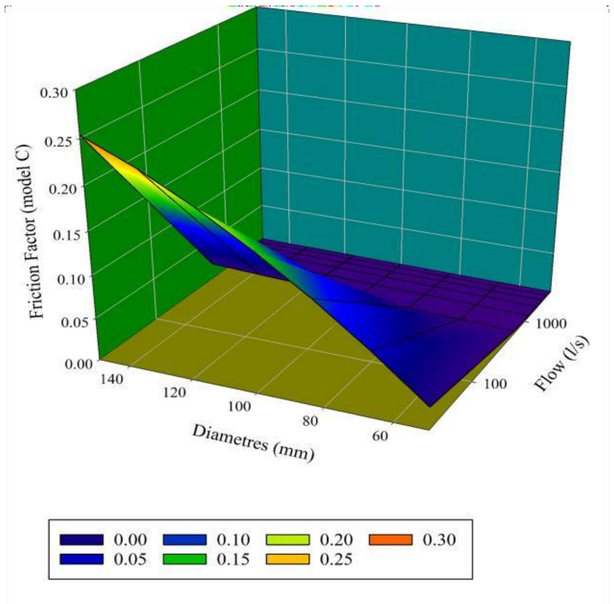


Figure 10d: Relationship between flow rate, the diameter of the pipe, and Computed friction factor using MiES and Model C

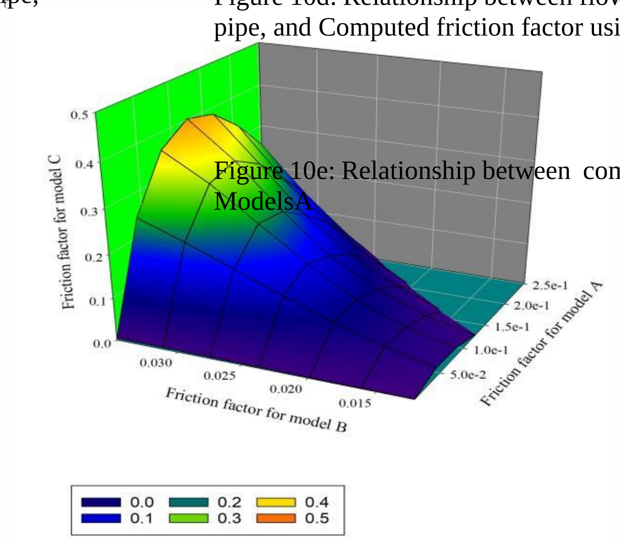


Figure 10e: Relationship between computed friction factors using MiES and the three ModelsA

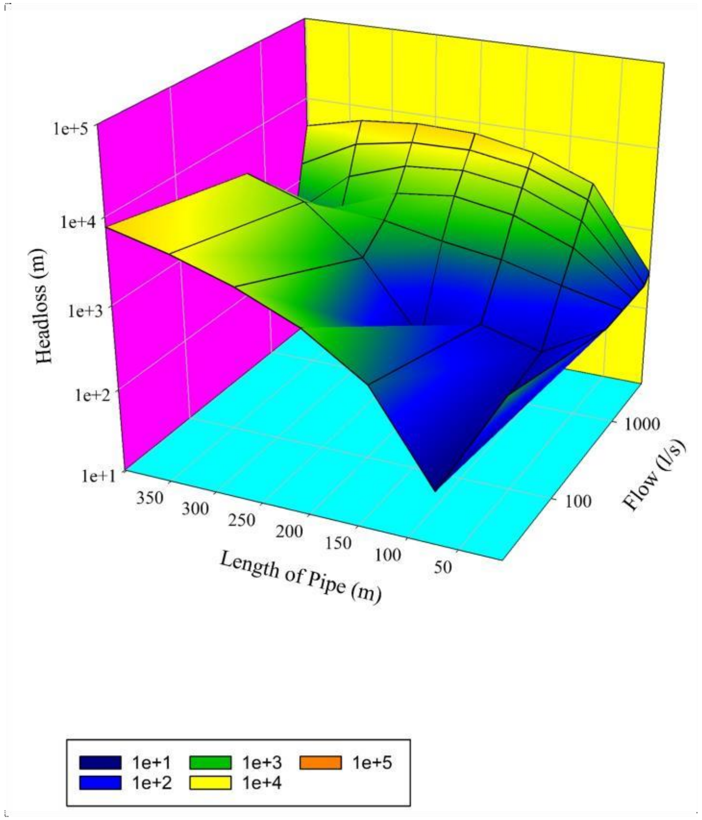


Figure 11a: Relationship between flow rate, the length of pipe, and Computed friction factor using EPANET

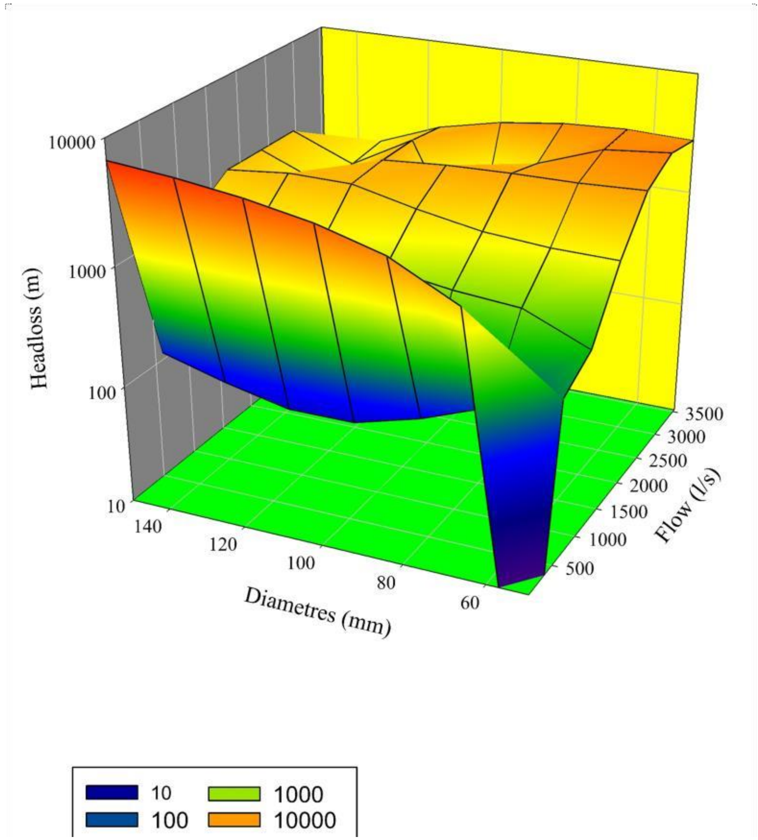


Figure 11b: Relationship between flow rate, the length of pipe, and Computed friction factor using MiES

Table 5: A summary information on the model empirical constant and statistical evaluation of the models

Evaluation parameters	Cal f(Q)	Cal f(D)	Cal f(D,Q)	Model Constants			
MSC	1.838	0.082	3.094	a	7.79×10^{-5}	K_a	3.56×10^{-6}
CD	0.841	0.079	0.955	b	2.065807	aa	1.633429
R	0.917	0.281	0.977	A	0.000298	bb	-0.76346
Means Square error	0.101	0.236	0.052	B	-0.95057		
Total error	0.010	0.056	0.003				

Table 6: Effects of flow rate and diameters of the pipe on friction factors (Calculated, MiES)

Source of Variation	*Sum of Square*	*Degree of freedom*	*Mean Sum of Square*	*Statistical F-magnitude*	*Probability*	*Statistical F critical*
Pipe diameters and flow rate	0.087014	41	0.0021223	4.285399	1.06×10^{-08}	1.536882
Between three Models	0.001766	2	0.0008828	1.782655	0.1746469	3.107891
Error	0.04061	82	0.0004952			
Total	0.12939	125				

Table 7: Effects of the techniques (EPANET and MiES) on the flow rates within the pipes

Source of Variation	*Sum of Square*	*Degree of freedom*	*Mean Sum of Square*	*Statistical F-magnitude*	*Probability*	*Statistical F critical*
Between Flows (EPANET and MiES)	1.90×10^{-07}	1	1.901×10^{-07}	1.72×10^{-07}	0.9996702	3.957388
Within flows	90.70206	82	1.1061227			
Total	90.70206	83				

Table 8: Effects of water demand and diameters of the pipe on flow rate (EPANET and MiES)

Source of Variation	*Sum of Square*	*Degree of freedom*	*Mean Sum of Square*	*Statistical F-magnitude*	*Probability*	*Statistical F critical*
Between water demand and flow rate from the techniques	90.70205	41	2.2122451	11595572	1.4×10^{-137}	1.674758
Within Groups	8.01×10^{-06}	42	1.908×10^{-07}			
Total	90.70206	83				

This result indicated that the model used had significant effects on the friction factors in a pipe at 95 % confidence level, which supported previous studies documented in the literature such as Nafi and Afzali (2017), Adedeji *et al.* (2017), Niazkar and Afzali (2017), Oke (2017), Creaco and Walski (2017), Sinagra *et al.* (2017), Tabesh and Beigi (2017), Gupta and Kulat (2018), Sakr and Gooda (2018), Garmendia *et al.* (2018) , Oyebode and Igbi (2018), Roige Montornes *et al.* (2019), Nafi and Brans (2019), Haider *et al.* (2019), Bermudez *et al.* (2019), Gajghate and Mirajkar (2019), Malm *et al.* (2020), Niazkar and Talebbeydokhti (2020), Moslehi and Jalili (2020), Ahopello and Vahala (2020), Gokayay (2020); Jin *et al.* (2020), Moslehi *et al.* (2020a and b), Abbas and Mohammed (2020), Abdulsamad and Abdulrazzaq (2022), and Abdulsamad and Abdulrazzaq (2023).

Table 7 provides the effects of the techniques (EPANET and MiES) on the flow rates within the pipes. The Table revealed the sources of variations between the techniques and the flow rate in the pipe were statistically $F_{1,\ 82}$ magnitude was 1.72×10^{-07} and probability was 0.9996702. This result indicated that the techniques used had no significant effects on the flow rates in a pipe at 95 % confidence level, which supported previous studies documented in the literature. Table 8 provides the effects of the water demand at the nodes and the diameter of the pipe on the flow rates within the pipes. The Table revealed the sources of variations between the water demand and the diameter of the pipe were statistically $F_{41,\ 42}$ magnitude was 11595572 and probability was 1.4×10^{-137}. This result indicated that the water demand and diameter of the pipe had significant effects on the flow rates in a pipe at a 95 % confidence level, which supported previous studies documented in the literature.

e. CONCLUSION

It was concluded that the MiES can be used for open loop pipe layout and pipeline based on the statistical evaluation of the flow rates, headloss and friction factors, which are key hydraulic engineering design parameters. The calculated flow rates using MiES were similar to the computed flow rate using the EPANET technique and there was no significant difference between these calculated flow rates using the two techniques. Cost-wise utilization of the MiES can be said to be economical based on no additional costs of purchase and installation. The numerical model of correlation between the friction factors, flow rate and diameters of the pipe revealed that friction factors are a function of flow rate and diameters of the pipe based on the value of MSC.

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