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A Simplified Approach to the Analysis of Complex Pipeline Networks

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ABSTRACT
A simple analysis software (pipe) was developed to analyze complex pipeline networks using JavaScript. The software utilized the Colebrook implicit equation for the determination of friction factor and the Hardy Cross procedure for the analysis of the pipeline networks. This research was motivated by the world's ever increasing energy demand and the need to simplify and optimize the often cumbersome solution methods available for gas flow through pipeline networks. The designed software was used to analyze a simple rectangular network model with 6 nodes, 7 pipe legs and 2 loops. The validity of the software was established by manually implementing Hardy Cross on the same network using Excel spreadsheet and also running a single period flow analysis on it with Pipe 2016 (KYPIPE) computer program developed by Curtis and Reid of the Theoretical Physics Division, UKAEA Research Group, Harwell, England. The results obtained showed a 98% agreement between the software and the other solution models as also corroborated by the Clustered column plot. Also ANOVA test set at 5% significant level showed that no statistically significant difference exists between the results; making the software suitable for use in gas pipeline flow analysis.

Key words: Hardy Cross, Pipeline flow analysis, Pipeline software, Gas pipeline networks, Pipe 2016 (KYPIPE)

INTRODUCTION

Natural gas is the cleanest burning fossil fuel, and is abundantly available in Nigeria. According to the Nigeria National Petroleum Corporation (NNPC); Nigeria has the largest gas reserves in Africa and is reputed to be the 9th largest gas reserves owner in the world. It has around 182 trillion cubic feet (TCF) of proven gas reserve plus about 600 TCF unproved gas reserves unleashing a huge potential for power generation and exportation [1], figure 1 below presents the global ranking according to gas reserves. In spite of this huge gas reserves, the lack of transmission facilities and the inefficient utilization of the available ones have largely accounted for the flaring of a significant percentage of this gas, thereby resulting into wastage of valuable foreign exchange for the country. Pipelines provide an economic way of transporting gas over great distance. They have been described as the best means of gas transport when compared with Tanked cars, Tanked trucks and ships because they are cheaper, safer and environmentally friendlier [2]. For an increased deployment of natural gas as a complementary energy source in Nigeria, a proper understanding of gas flow through pipeline networks and the solution technique to the resulting non-linear equations is needed.

Gas pipelines are made up of three main pipeline systems, namely the gathering lines, transmission lines and distribution lines. Figure 2 shows an assemblage of the various pipe systems. The gathering lines are low pressure pipelines linking the production area to the central collection point, the transmission lines serve as the middle transportation link between the gathering system and the distribution system, they transport natural gas from the gathering area to the gas treatment facilities while the distribution lines are low-pressure small diameter pipelines transporting natural gas from the processing facilities to the consumers [3]. Also, pipelines conveying treated natural gas may be arranged in series, parallel or loops (combination of series and parallel arrangement) depending on the amount of gas to be transported, the flowrate and the allowable pressure drop [4].

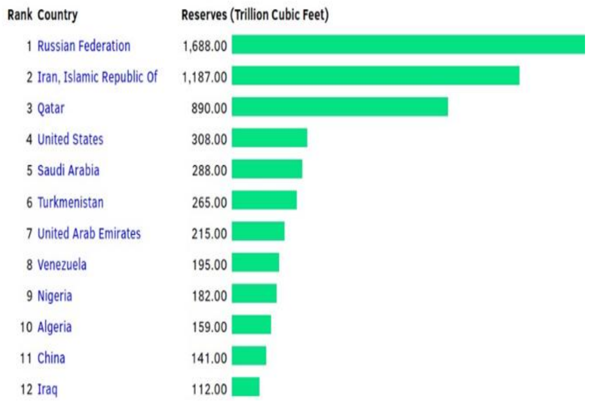

Fig. 1 Global Ranking According to Gas reserves [5]

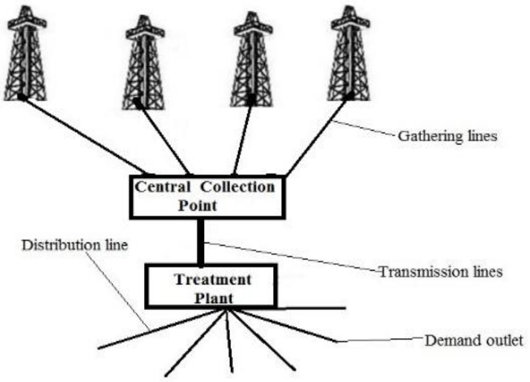

Fig. 2 Assemblage of Gas Pipeline

Based on the complexity of the pipeline topology, pipeline can be analyzed using the Hardy Cross method, the Node method, the Loop method and the Loop-node method. The node method is based on Kirchhoff first law (which states that the algebraic sum of the flows at any node is zero) while the loop method is based on Kirchhoff's second law (which state that the pressure drop around any closed loop is zero). The Loop-node method is a synergy of both the node and the loop method. The Hardy Cross method is widely preferred of the four methods because it is less sensitive to initial value prediction [6,7].

The aim of this research is to provide a novel simplification to the often cumbersome solution methods which are necessary to solve the resulting myriads of non-linear equations by designing a robust software application (pipe) that is capable of analyzing fluid flow in pipelines. Also, this paper seeks to make a comparative analysis of the result obtained from pipe (the designed software) against a known software (Pipe 2016) and manually computed Hardy Cross.

MATERIAL AND METHODS

Materials

The materials used in this project are:

- pipe (Designed software)
- Microsoft Excel spreadsheet for manual computation of Hardy Cross.
- KYPIPE Software (PIPE 2016) [8]

Methods

For effective illustration of solution technique, the network is limited to a simple rectangular network model with 6 nodes, 7 pipe legs and 2 loops. The designed software (pipe) was used to analyze gas flow in the selected network. Code for pipe was developed based on an earlier study by [7]. The result obtained from pipe was validated by manually implementing Hardy Cross on the same network using Excel spreadsheet and also running a single period flow analysis on it with Pipe 2016 (KYPIPE) computer program developed by Curtis and Reid of the Theoretical Physics Division, UKAEA Research Group, Harwell, England. The network analyzed in this research is given below as Figure 3. Other predefined parameters are given as;

Gas specific gravity = 0.67 Pipe roughness = 0.0006ft

Base Pressure = 14.7 Psia Base Temperature = 60^0F

Elevation changes are neglected.

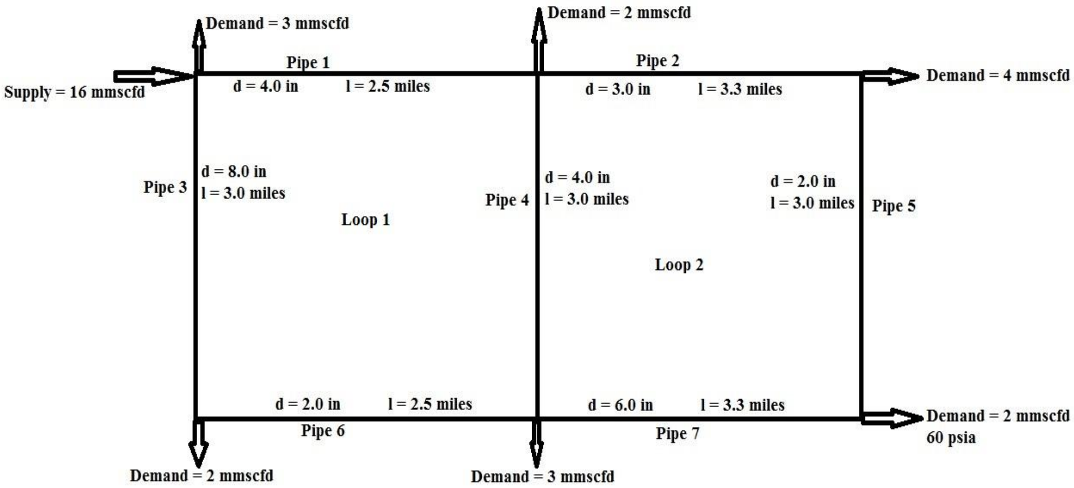

Fig. 3 Selected Network

Where, d = pipe diameter; l = pipe length, Supply = Network inflow, Demand = Network Outflow
Also, nodes are junction points where fluids enter or leaves the networks while a loop is a closed path of interconnected pipes and nodes.

Method 1: Solution using pipe (Designed Software)

pipe was designed to accept information about the network by prompting the user to supply information about the properties of individual pipe within a loop as the input. The network was resolved using the following steps;

Step 1: Making an initial guess of flow

An initial guess of possible flowrate and flow direction in each pipe was made. It should be noted that the total inflow at each node must be equal to the total outflow at each junction. Figure 4 below shows the assumed flow distribution in the selected network while Table 1 presents the assumed flowrate and other pipe properties for each pipe arranged according to loops.

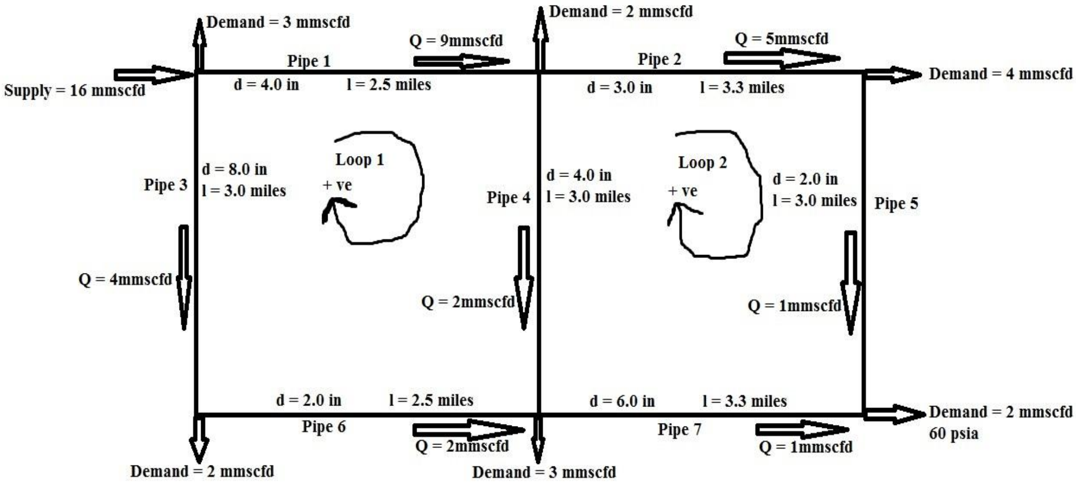

Fig. 4 Assumed Flow Distribution

Table -1 Assumed Flowrate and Other Pipe Properties

Loop	Pipe	Assumed Flowrate (mmscfd)	Assumed Flowrate (M^3/Sec)	Flow Direction	Diameter (inches)	Length (miles)
1	Pipe 1	9.0	2.948	Clockwise	4.0	2.5
	Pipe 3	4.0	1.310	Anticlockwise	8.0	3.0
	Pipe 4	2.0	0.655	Clockwise	4.0	3.0
	Pipe 6	2.0	0.655	Anticlockwise	2.0	2.5
2	Pipe 2	5.0	1.638	Clockwise	3.0	3.3
	Pipe 5	1.0	0.328	Clockwise	2.0	3.0
	Pipe 4	2.0	0.655	Anticlockwise	4.0	3.0

	Pipe 7	1.0	0.328	Anticlockwise	6.0	3.3

Step 2: Launching and Creation of New File

Launching of the software opens up the user interface. A new workspace is automatically created when the application is launched.

Fig. 5 Software Interface

Step 3: Addition of loops and computation of pipe properties

The file option on the top-left corner provides a drop-down list from which ‘add loop’ option can be selected. The add loop option allows the computation of pipe name, assumed flowrate for pipe, pipe diameter, pipe length and assumed flow direction. Figure 6 shows the loop populator used to input pipe properties.

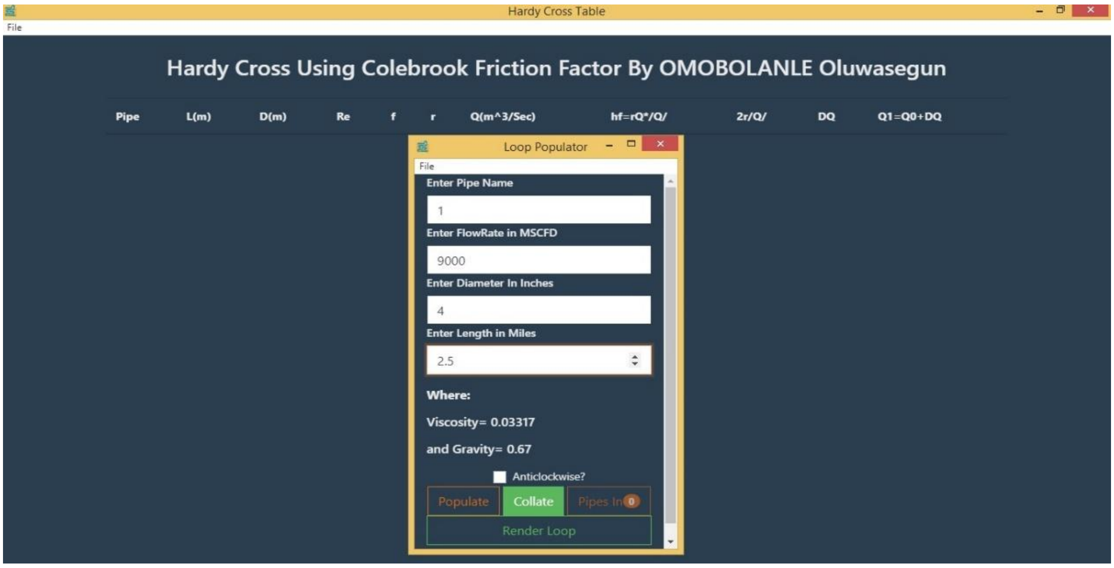

Fig. 6 Loop Populator

After all the information for a particular pipe has been full computed, the ‘Populate’ option was selected to allow the computation of properties for the next pipe within a single loop. When all the pipes for a particular loop has been fully defined. The ‘Collate’ button was used to signal the complete declaration of pipes within the first loop. The populator was subsequently closed to allow the addition of a new loop. The ‘add loop’ option is again reselected to use the loop populator to add as many pipe and loop to the network as desired.

Step 4: Network analysis and loop rending

Once the last loop has been populated and pipe within collated, the ‘Render loop’ button was used to analyze the whole network in a single sweep. Within seconds, pipe calculate the Reynold’s number, Colebrook’s friction factor, flow resistance, head-loss, change in pipe flowrate and the corrected flowrate for each pipe in all defined loop. Pipe also execute a series of iteration based on the Hardy Cross procedure until the network is completely resolved. The result of the analysis is the value obtained for Q_1 in the last iteration outputted. Figure 7 shows the first two iteration obtained from pipe while figure 8 shows the result obtained for the last iteration.

Hardy Cross Table

File

Hardy Cross Using Colebrook Friction Factor By OMOBOLANLE Oluwasegun

Pipe	L(m)	D(m)	Re	f	r	Q(m^3/Sec)	hf=rQ*/Q/	2r/Q/	DQ	Q1=Q0+DQ (m3/sec)
Pipe1	4023	0.1016	908954	0.02281	2803293	2.94795	24361763.284503832	16527935.1987	0.12806766225619323	3.076017662256193
Pipe3	4827	0.2032	201990	0.01935	89179	-1.3102	-153086.81526316	233684.6516	0.12806766225619323	-1.1821323377438069
Pipe4	4827	0.1016	201990	0.02291	3378880	0.6551	1450066.6590688	4427008.576	0.12806766225619323	0.7831676622561933
Pipe6	4023	0.0508	403979	0.02760	108555748	-0.6551	-46587351.67424548	142229741.0296	0.12806766225619323	-0.5270323377438068
							-20928608.545936003	163418369.45589998		
Pipe2	5310	0.0762	673299	0.02463	16838731	1.63775	45165266.30889569	55155263.3905	-0.39015013920384206	1.247599860796158
Pipe5	4827	0.0508	201990	0.02764	130455508	0.32755	13996441.323950771	85461403.2908	-0.39015013920384206	-0.06260013920384205
Pipe4	4827	0.1016	201990	0.02291	3378880	-0.7831676622561933	-2072441.41097128	5292459.101288413	-0.39015013920384206	-1.1733178014600354
Pipe7	5310	0.1524	67330	0.02100	448639	-0.32755	-48134.0307925975	293903.4089	-0.39015013920384206	-0.717700139203842
							57041132.19108259	146203029.19148842		
Pipe1	4023	0.1016	908954	0.02281	2803293	3.076017662256193	26524435.030014236	17245957.5609583	-0.006427639695522179	3.069590022560671
Pipe3	4827	0.2032	201990	0.01935	89179	-1.1821323377438069	-124622.02208927297	210842.7594953099	-0.006427639695522179	-1.188559977439329
Pipe4	4827	0.1016	201990	0.02291	3378880	1.1733178014600354	4651618.486070967	7929000.105994569	-0.006427639695522179	1.1668901617645133
Pipe6	4023	0.0508	403979	0.02760	108555748	-0.5270323377438068	-30152779.461969793	114424779.28793515	-0.006427639695522179	-0.5334599774393289
							898652.0320261382	139810579.71438333		
Pipe2	5310	0.0762	673299	0.02463	16838731	1.247599860796158	26209575.94380204	42015996.9031679	-0.31200510392035097	0.9355947568758071
Pipe5	4827	0.0508	201990	0.02764	130455508	-0.06260013920384205	-511226.1001530809	16333065.921415862	-0.31200510392035097	-0.374605243124193
Pipe4	4827	0.1016	201990	0.02291	3378880	-1.1668901617645133	-4600793.327157527	7885563.659565758	-0.31200510392035097	-1.4788952656848644
Pipe7	5310	0.1524	67330	0.02100	448639	-0.717700139203842	-231091.02817631062	643976.545504545	-0.31200510392035097	-1.029705243124193
							20866465.48831512	66878603.02965408		

Fig. 7 Pipe analysis for the first two iteration

Hardy Cross Table

File

Hardy Cross Using Colebrook Friction Factor By OMOBOLANLE Oluwasegun

Pipe	L(m)	D(m)	Re	f	r	Q(m^3/Sec)	hf=rQ*/Q/	2r/Q/	DQ	Q1=Q0+DQ (M3/Sec)
Pipe1	4023	0.1016	908954	0.02281	2803293	3.056113436480189	26182278.200582843	17134362.80738172	6.524449488398073e-13	3.0561134364808415
Pipe3	4827	0.2032	201990	0.01935	89179	-1.202036563519811	-128854.01475353485	214392.83739626643	6.524449488398073e-13	-1.2020365635191586
Pipe4	4827	0.1016	201990	0.02291	3378880	1.3784078101300001	6419899.338610603	9314949.16298411	6.524449488398073e-13	1.3784078101306525
Pipe6	4023	0.0508	403979	0.02760	108555748	-0.5469365635198106	-32473323.52453478	118746215.5228851	6.524449488398073e-13	-0.5469365635191581
							-0.00009487196803092957	145409920.3306472		
Pipe2	5310	0.0762	673299	0.02463	16838731	1.0226056263501895	17608635.955448307	34438762.1223947	5.081221090509977e-14	1.0226056263502403
Pipe5	4827	0.0508	201990	0.02764	130455508	-0.2875943736498107	-10790043.393408107	75036540.22485574	5.081221090509977e-14	-0.2875943736497599
Pipe4	4827	0.1016	201990	0.02291	3378880	-1.3784078101306525	-6419899.3386166785	9314949.162988517	5.081221090509977e-14	-1.3784078101306017
Pipe7	5310	0.1524	67330	0.02100	448639	-0.9426943736498107	-398693.22342960094	845858.9221997549	5.081221090509977e-14	-0.9426943736497598
							-0.000006078975275158882	119636110.4324387		

Fig. 8 Result for the last Iteration (Q_1 (M^3/Sec) is the result for the network)

Method 2: Hardy Cross using Microsoft Excel spreadsheet

Step 1: Data Preparation

Since the initial flowrate and flow direction have already been assumed, the data from figure 4 was aggregated for analysis.

A. Unit Conversion

Although quantities in the Oil and Gas industry are measured in Field unit (English Unit), the Hardy Cross method uses S.I. unit and as such all parameters including length, diameter and flowrate were converted to S.I. unit.

Since, 1MMSCFD = O.32755M^3/Sec, 1 Miles = 1609.344 Meters, 1 Inches = 0.0254 Meters

Table -2 Conversion of Parameters

Pipe	Assumed Q (mmscfd)	Assumed Q (M^3/Sec)	L (miles)	L (m)	D (in)	D (m)
Pipe 1	9.0	2.948	2.5	4023.36	4.0	0.1016
Pipe 2	5.0	1.638	3.3	5310.84	3.0	0.0762
Pipe 3	4.0	1.310	3.0	4828.03	8.0	0.2032
Pipe 4	2.0	0.655	3.0	4828.03	4.0	0.1016
Pipe 5	1.0	0.328	3.0	4828.03	2.0	0.0508
Pipe 6	2.0	0.655	2.5	4023.36	2.0	0.0508
Pipe 7	1.0	0.328	3.3	5310.84	6.0	0.1524

B. Determination of Friction Factor

The choose of Colebrook friction factor was based on the experimental findings of [7] and the Fortran 95 program developed in the process. Colebrook Implicit equation used is given as

$\frac{1}{\sqrt{F}} = 1.74 - 2Log\left(\frac{2e}{D} + \frac{18.7}{N_{Re}\sqrt{F}}\right)$ ………..… Equation 1

Where, N_{Re} = Reynold's Number F = Friction factor e= Pipe roughness D = Diameter

C. Determination of Flow resistance

Flow resistance is used to determine the effect of the various pipe properties on the flowing fluid (pressure losses). This depends on the hydraulic equation used; for this project, the Darcy-Weisbach equation was used. The head-loss and flow resistance are defined by equations 2 and 3 respectively.

$H_f = r * Q * |Q|$…………...Equation 2

$r = \frac{32Fl}{g\pi^2 D^5}$………………..... Equation 3

Where, H_f = Head-loss Q = Flowrate L = Length g = Acceleration due to gravity π = 3.142
F = Friction factor D = Diameter of pipe r = Flow resistance

Step 2: Determination of closed loop and head-loss

The two closed loops in the system were identified and clockwise direction of flow was assumed positive for head loss analysis (flow in the anticlockwise direction are assigned negative flowrate) as shown in figure 4. Equation 2 was used to calculate the head-loss. It should be noted that the total sum of head-losses in a loop should be equal to zero. The total head-loss was calculated by summing up the various calculated head-losses for each pipe within a loop.

Total Head loss = $\sum hf = \sum_i^n (r * Q * |Q|)$ ………Equation 4

Step 3: Determination of the correction factor

Since an initial guess of flow was made for each pipe, balancing of head by the addition of a correction factor was done. This was done to achieve continuity of potential over the closed loop. The change in flow that will balance the head in the closed loop is given by:

$\Delta Q = \frac{-1 * \sum(r*Q*|Q|)}{\sum(2*r*|Q|)} = \frac{-1 * \sum_{i=1}^n Hf}{\sum_{i=1}^n (2*r*|Q|)}$………………… Equation 5

The calculated change in flow is added up to the assumed flow Q_0 for each pipe.

$Q_1 = Q_0 + \Delta Q$...……………….……………………Equation 6

Step 4: Correction for Joint Pipe

For pipes that are shared by two or more loops, the flow in the pipes must be balanced to satisfy the conditions in the two loops; this is generally done by using the calculated value (Q_1) for the pipe in the first loop as the Q_0 for the same pipe in the second loop. Depending on the flow direction, (-1) is used to multiply the Q_0 now computed as Q_1 to correct for direction change. The correction for flow and direction are repeated at every point the joint pipe appears for the two loops.

For instance, pipe 4 is shared between Loop 1 and 2, the assumed flow for pipe 4 and the direction assigned is used as its Q_0 and direction in Loop 1; the head loss is calculated for this value and subsequently corrected based on the calculated ΔQ for loop 1. The corrected value Q_1 for Pipe 4 in Loop 1 is then used as Q_0 for Pipe 4 in Loop 2, since the direction of

pipe 4 in loop 1 and 2 are opposite, (-1) is used to multiply the value thus Q_0 for pipe 4 in loop 2 become -1*Q_1 (value obtained from pipe 4 in loop 1).
For the second iteration, the Q_1 for pipe 4 in loop 2 of the first iteration becomes the Q_0 for pipe 4 in loop 1 of the second iteration, change in direction is also corrected, therefore, Q_0 in loop 1 becomes -1*Q_1 (value obtained from pipe 4 in loop 2 of iteration 1). This is done for every shared pipe across loops but for this network, only pipe 4 is shared. The iteration is repeated until $\Delta Q = 0$.
If $\Delta Q = 0$, then $Q_1 = Q_0$.
The result obtained from the analysis is presented in the result and discussion section of this paper.

Method 3: Using Pipe 2016 (KYPIPE)
Figure 3 was analyzed with Pipe 2016 (KYPIPE) using the following procedures
Step 1 - Initial Preparation
Initial steps include file selection, background preparation, and system data selections.
a. File Selection – Pipe 2016 was launched and a new data file was created.

Fig. 9 New file specification on KYPIPE (Pipe 2016)

b. System Data Selection – It was used to specify system data such as Unit for flow rate, the default head loss equation (Hazen-Williams or Darcy-Welsbach's equation), the fluid property and other network and flow associated defaults. For this project, Darcy-Welsbach head loss equation was used, also English unit was unit and the flowrate was in MSCFD as opposed to the MMSCFD in the network, so the values were multiplied by 1000 to accommodate for unit difference.

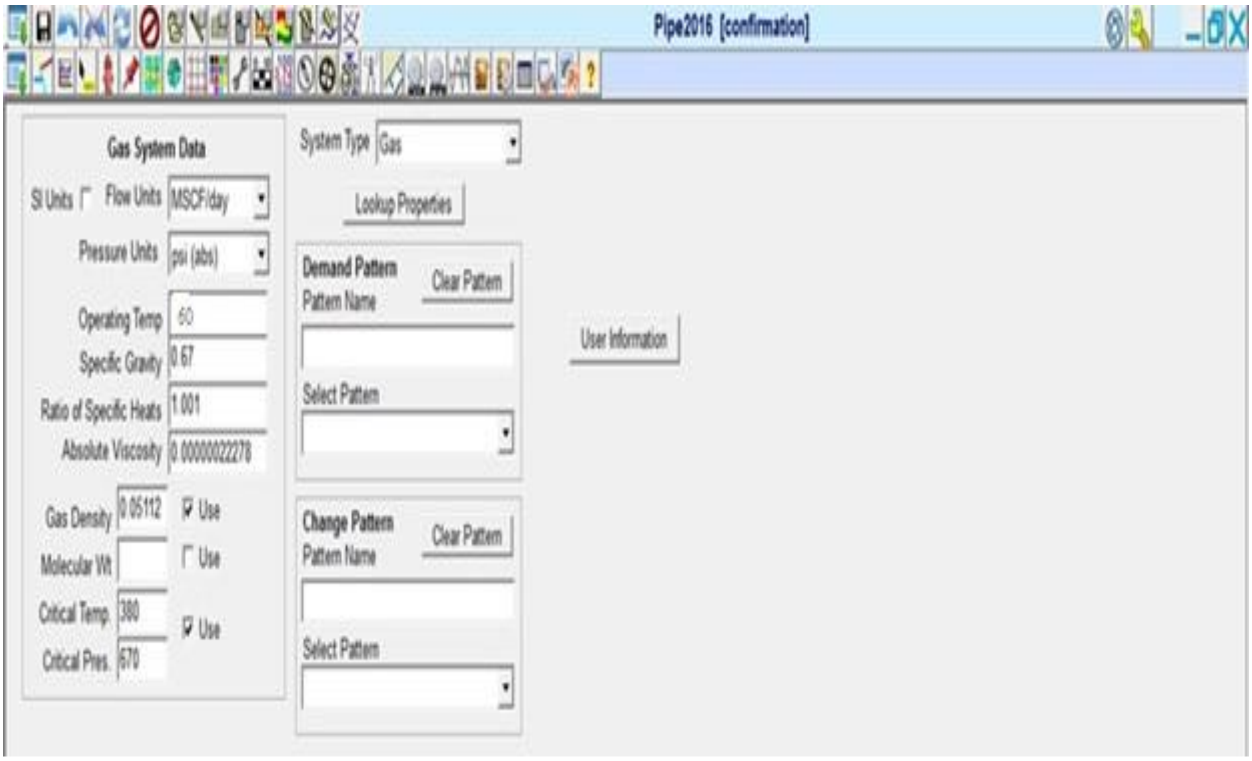

Fig. 10 Gas Property Specification

Fig. 11 Selecting of Gas for property determination

c. Background Preparation: This is generally used to import a drawing, map image, utilize grid lines or choose not to use a background. For area with well-defined aerial map, such map can be downloaded for upload for proper layout definition. Skeletonized image of the network pipe distribution was drawn on the selected grid with specification of distance between points.

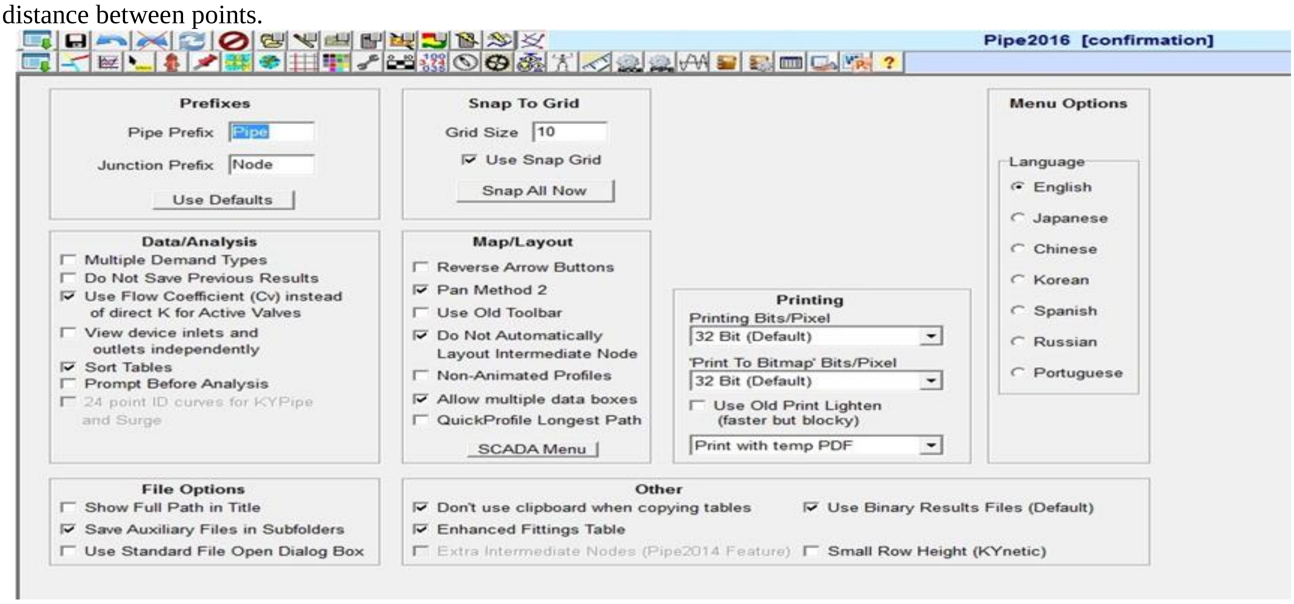

Fig. 12 Grid Selection

Step 2 - System Layout

The system was laid out accordingly on the grid and relevant pipe specifications (including pipe length, diameter, roughness and material), node demand and supply were made.

a. Pipe Layout: Single Right click was used to add Junction node, while pipes were automatically laid between junctions.

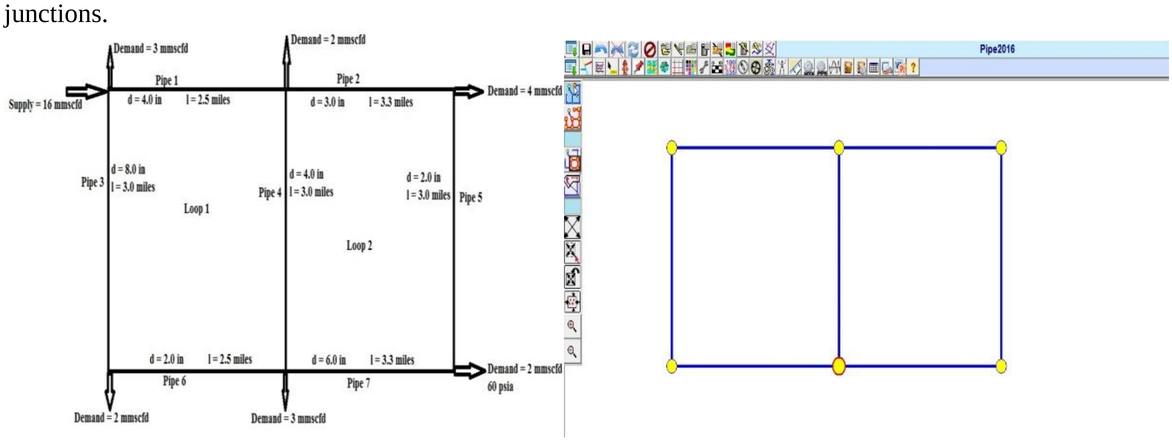

Fig. 13 Pipe layout of structure

b. Pipe data specification: This was used to edit pipe properties for each pipe, each pipe was left click upon to edit its properties.

c. Node data specification: Node demand and supply were computed for each node; pressure was also specified for fixed grade node (nodes where demand pressure required is specified).

Step 3: Analyze System and Review Results

This was used to analyze the system for error check, unspecified parameters and complete flow analysis of the network.

a. Data Check and Run Analysis: Error Check was selected under the system analysis option to check for any error in network. If errors are flagged, necessary corrections should be made so that network can be analyzed. If its message "No Errors", analysis can be completed.

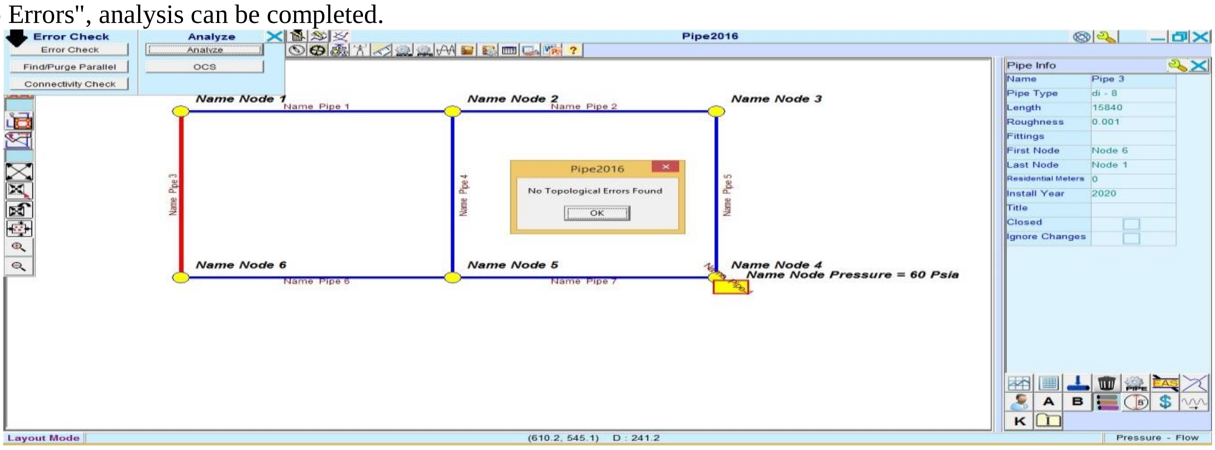

Fig. 14 Error check and analysis

b. Result Presentation: Results Obtained are presented in subsequent section.

The results obtained are analyzed for the presence of a statistically significant difference between the means of the various data set using a ONE-WAY ANALYSIS OF VARIANCE (ANOVA) TEST. ANOVA tests to validate the null hypothesis, H_0;

$H_0 = \mu_1 = \mu_2 = \mu_3 = \mu_4$ ……………….. $= \mu_n$ …… equation 7

Where, H_0 = Null Hypothesis   µ1 = Group mean   n = No of data set

If, however, the test returns a statistically significant result, we accept the alternative hypothesis, H_A;

H_A = µ is not equal

RESULT AND DISCUSSION

The result obtained from the various calculation is presented below in Table 3;

Flowrate in pipes

Table -3 Flowrate obtained from the various calculations

Pipe	**Pipe (m^3/Sec)**	**Pipe (MMSCFD)**	**Excel Colebrook (MMSCFD)**	**Pipe 2016 (MMSCFD)**
Pipe 1	3.05614661	9.3316	9.3304	9.291
Pipe 2	1.023849645	3.1225	3.1258	3.14
Pipe 3	1.20185339	3.6703	3.669	3.708
Pipe 4	1.377296964	4.20888	4.2048	4.151
Pipe 5	0.286150355	0.87815	0.8736	0.8598
Pipe 6	0.54685339	1.670035	1.6695	1.709
Pipe 7	0.942150355	2.878456	2.8764	2.859

Since the software was modelled to simulate the manual Hardy Cross procedure, it can be observed that the result obtained from pipe and the manual Hardy Cross computation are very similar, indicating that the designed software perfectly models the Hardy Cross procedure and can be effectively and efficiently used for such analysis. Overall, it is evident from Table 3 that a 98% agreement exist between the three results. This is further corroborated by theClustered column plot (Figure 14) of the obtained results which visually shows the agreement between the results.

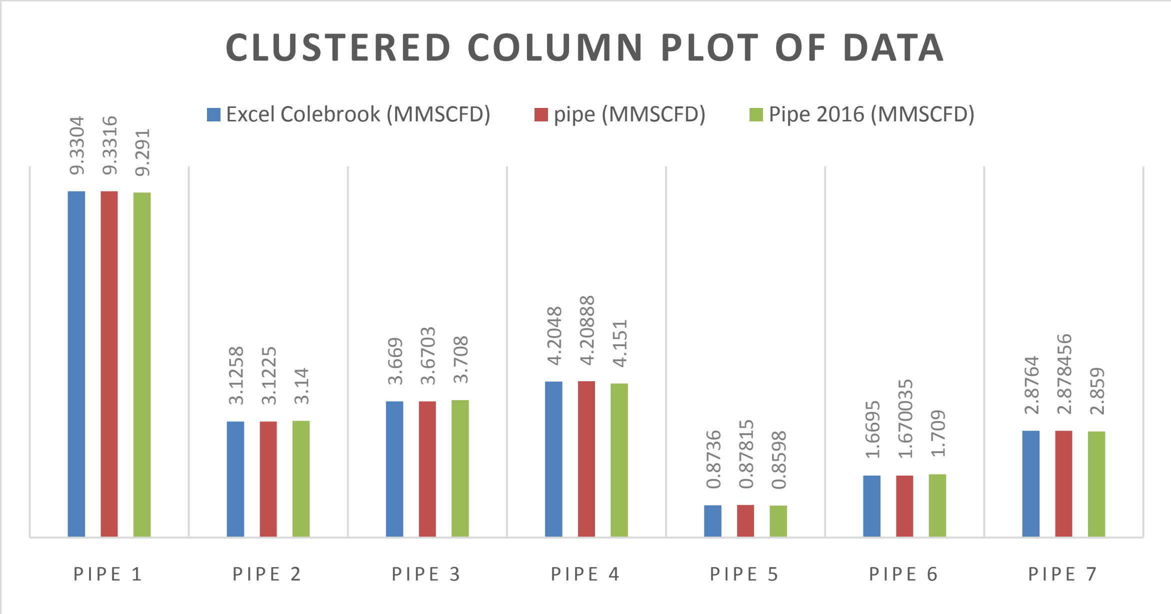

Fig. 14 Clustered Column plot showing flowrate in each pipe for the three solution models

To further verify the suitability of the software for gas pipeline analysis, the result obtained from the ANOVA test presented in Table 4 shows that $F < F_{Crit}$, therefore we accept the null hypothesis as defined in equation 7 that there is no statistically significant difference between the various data sample compare in the test, meaning the three results obtained are statistically the same.

Table -4 ANOVA Test Result (ANOVA: Single Factor)

SUMMARY						
Groups	**Count**	**Sum**	**Average**	**Variance**		
Excel Colebrook	7	25.7495	3.6785	7.51224		
pipe	7	25.75992	3.679989	7.510665		
Pipe 2016	7	25.7178	3.673971	7.418284		
ANOVA						
Source of Variation	**SS**	**df**	**MS**	**F**	**P-value**	**F crit**
Between Groups	0.000137508	2	6.88E-05	9.19E-06	0.999991	3.554557
Within Groups	134.6471364	18	7.480396			
Total	134.6472739	20				

CONCLUSION

Since the results obtained from the research have shown that the software perfectly models the Hardy Cross procedure and also displaced a 98% agreement with a commercially used software (Pipe 2016 [KYPIPE]) and an accepted procedure (Hardy Cross), it can be inferred that pipe can be efficiently and effectively used to accurately analyze gas flow in pipelines. Also, since the null hypothesis is accepted in the ANOVA test indicating the absence of a statistically significant difference between the results compare, it can be concluded that results obtained from pipe is accurate, comparable with other solution models and thus suitable for use in gas pipeline flow analysis.

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Download Link

pipe can be downloaded and installed for use on Windows, Linus and mac using the link below.
http://drive.google.com/open?id=1hZo-94-PsSBuMG0OaMoHfsg1Hx1E1T2

REFERENCE

[1]. Unknown Author, Shell in Nigeria: Unlocking Nigeria's potential in Natural Gas, *Shell Briefing Note*, Web. https://www.google.com/url?q=http://s05.static-shell.com/content/dam/shell-new/local/country/nga/downloads/pdf/unlocking-natural-gas-em.pdf&sa=U&ved=2ahUKEwjWrchu5zpAhWlrHEKHA9UB3sQFjAMegQlBxAB&usg=AOvVaw2kuqu7bZu3VXyKGU0cW67m, 2019.

[2]. E.H. Megan and E. Dursteler, Economic, Environmental and Safety Impacts of Transporting Oil and Gas in the US, *STRATA Newsletter*, 2015.

[3]. C.I.C. Anyadiegwu, N.P. Ohia and C.M. Ukwujiagu, Natural Gas Transmission and Distribution in Nigeria, *Journal of Multidisciplinary Engineering Science and Technology (JMEST)*, 2015, 2(8), 2033-2039.

[4]. C.U. Ikoku, *Natural Gas Production Engineering*, Original Edition, Krieger Publishing Company, Malabar, Florida, USA, 1984.

[5]. Unknown Author, Natural Gas Reserves by Country, *United State Energy Information Administration*, Web. https://www.indexmundi.com/energy/?product=gas&graph=reserves&display=rank, 2020.

[6]. D. Brkić, Gas Distribution Network Topology Problem, *Mathematica Balkanica*, 2012, Vol 26, Fasc 3-4.

[7]. O.C. Omobolanle, Analysis of Flowrate in Loop Gas Pipeline Networks Using Pipe 2016 and Hardy Cross Method, *Saudi Journal of Engineering and Technology*, 2020, 5(2), 49-62, DOI:10.36348/sjet.2020.v05i02.003, https://saudijournals.com/media/articles/SJEAT_52_49-62.pdf.

[8]. W. Don, KYPIPE (PIPE 2016) Software, Web. https://www.kypipe.com/download.

[9]. S. Lukman, A. Ismail, A. Ibrahim and B. Saulawa, Development, utilization and statistical evaluation of Hardy Cross pipe network analysis softwares, *International Journal of Water Resources and Environmental Engineering*, 2012, Vol. 4(8), pp. 252-262.

[10]. I.I. Nwajuaku, Y.M. Wakawa, O.J. Adibeli, Analysis of Head-loss Equations under EPANET and Hardy Cross Method, *Saudi Journal of Engineering and Technology*, 2017, 2(3), DOI:10.21276/sjeat.2017.2.3.1125.

[11]. D. Brkic, Two Efficient Methods for Gas Distributive Network Calculation, *Ministry of Science and Techological Development, Beograd, Serbia*,2018,http://dx.doi.org/10.20944/preprints201808.0277.v1

[12]. A.E. Adeleke and S.O.A. Olawale, Computer Analysis of Flow in the Pipe Network, *Transnational Journal of Science and Technology*, 2013, 3(2), 45-71.