Design of Enhancement in Water Filling System in Rake of Train

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Abstract - *In Indian railways there are some problems related to water filling system in rake. The Indian trains have to carry a huge number of passengers due to which the demand of water throughout the train increases and though the water is fully available at first station, it suddenly gets decreased due to the usage and also due to huge demand of water. Secondly when the time come to fill the tank it takes at least 15-18 minutes due to which idle time of trains increase and the labour force required are also quite more. Our work is to find out the best suitable solution of water filling system through reducing the labours required to fill the tanks of bogies and to reduce the water filling time while minimizing the wastage of overflow of water. In this project the modification of water filling system has been designed. In the traditional way of water filling system each tank of bogie is individually filled and requires at least 12-13 labours but in the modern way of water filling system all individual pipes of bogies will be connected to the two high pressure inlets which will significantly reduce the labour cost as well as it also deduce the idle time of train. In this project fluid parameters (like pressure, Velocity, discharge) have been computed by standard analytical practices then simulated the flow of water & then verified simulated result experimentally.*

Key Words: **15-18 minutes, idle time, overflow of water, 12 -13 labour, fluid parameters.**

1. INTRODUCTION

In all over world railways play an important role in our life, whether it may be for transporting goods or people from one place to another. Apart from this our engineers have implemented many facilities in the train like wash room, air conditioning systems, etc. These facilities provide comfort to the human being.

In spite of all these facilities, especially in passengers train there are some problems related to water filling system in rake. First of all let me tell you that passenger trains have to carry a huge number of passengers due to which the demand of water throughout the train increases and though the water is fully available at first station, it suddenly gets decreased due to the usage and also due to huge demand of water. Secondly when the time come to fill the tank it takes at least 15-18 minutes and the labours required are quite more.

So in order to reduce the labors required to fill and to reduce the water filling time while minimizing the wastage of overflow of water, we have come across the project which will solve all these problems.

Table -1: Pipes comparison

Parameters	GI Steel Pipe	PVC Pipe	HDPE Pipe
Density (kg/m^3)	7850	1467	**941**
Yield strength (Mpa)	**250**	45	29.5
Young's Modulus (Gpa)	**200**	2.5	0.8
Pressure Rating (kg/cm^2)	**158.75**	11.10	23
Bursting pressure (kg/cm^2)	**347.31**	59.05	91.8
Life (year)	35	60	**100**
Roughness (mm)	0.1500	0.0050	**0.001524**
Friction factor at Ø70 mm	0.025	0.017	**0.015**
Price for Ø70 mm, (per meter)	629.60	**160**	182.66
Rusting	Yes	No	**No**

By referring the above table we can observe that some mechanical properties of GI steel pipe such as yield strength, pressure rating, young's modulus and bursting pressure are dominating the PVC and HDPE pipe and likewise some mechanical properties of HDPE pipe such as density, roughness, life, friction factor, price, rusting are also dominating the GI steel and PVC pipe. But the point here to be considered is that which best parameter is required for the application of water filling system.

Since, the pressure rating of PVC pipe is relatively smaller, that is why we have eliminated the PVC pipe from our pipe selection. Although both the GI steel and HDPE pipe have their own merits, they should match our requirement too. GI Steel pipe has pressure rating more than HDPE pipe but our required pressure ranges between 1 to 5 kg/cm^2. Roughness value, friction factor, price of HDPE pipe is far lesser than GI steel pipe and also there is no rusting problem in concern with HDPE pipe and life offered by the HDPE pipe is far more than GI steel pipe. So this leaves no option to select GI steel pipe rather than selecting HDPE pipe.

2. LITERATURE SURVEY

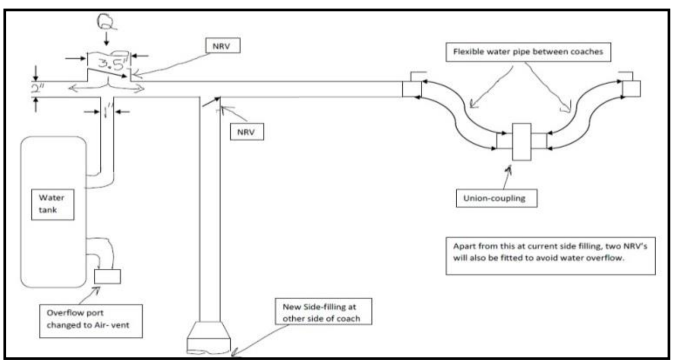

Fig -1: Constructional layout

Let us first go through the constructional details. In this as we can see that all the tanks of coaches are connected to common pipe having diameter of 2 inches & this 2 inch pipe is connected in the high pressure pipe which is 3.5 inches in diameter, and the outflow pipe of the water tank is attached with an air-vent to avoid the overflow of the water. And the one side filling is provided with the 2 inch pipe & this same design is continued to further coaches. So, this was all about construction & now let us sees the problem faced by section engineer while conducting an experiment.

So the first problem was less discharge rate at the last coach, the second was requirement of high discharge rate and the third problem was that they were unable to predict that each coach has filled or not. So, in this way many such problems were faced by him.

The experiment results which were obtained by him were as follows-

1) The first observation result was that the coach nearest to the inlet valve was getting filled rather than the second coach and this causes discharge malfunctioning.

2) The second result was loss of head due to friction in galvanized iron pipe which was very high due to high relative roughness.

3) The third result was increased flow restriction due to smaller diameter of pipe.

4) 8 drums experiment were conducted by using ½” GI pipes having 8 Tee showed 21-24 % discharge losses.

5) Due to fittings like NRV, isolation valves, coupler, flexible pipe losses will increases.

6) While replacing 22 hose pipes by 2 hose pipes, the discharge must be greater than 11 times so as to compensate friction losses.

3. METHODOLOGY

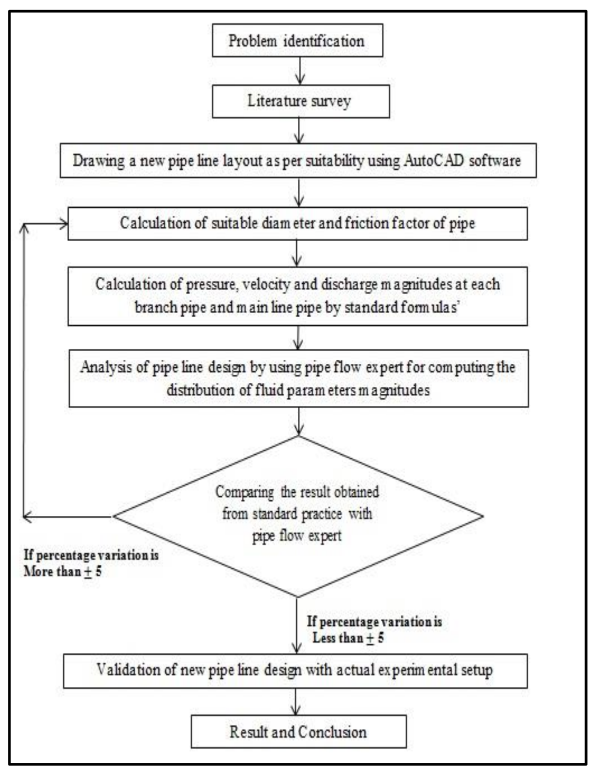

Fig -2: Flow of methodology

4. DESIGN CALCULATIONS

4.1 Selection of Pipe Diameter:-

We had a visit with section engineer at lower frame of bogie. There we observe that the maximum space available in the lower frame of bogie was around 3”. So, in order to reduce the friction losses in pipe the section engineer had suggested us to take a ⌀ 2” pipe and do the calculation accordingly. But we addressed some problems related to ⌀ 2” pipe. The problems were as follows,

- As we had some data,
    1. Length of pipe = 123 m
    2. Roughness of pipe = 0.001524 mm
    3. Discharge = 550 lit/min = 0.009167 m^3/s
    4. Diameter of pipe = ⌀50.8 mm = ⌀2”
    5. Velocity in main pipe = 4.523 m/s
    6. Reynolds number = 257383
    7. Friction factor = 0.0158

And had formula for head loss due to friction i.e. Darcy-Weisbach equation, we got head loss as below

$$h_f = \frac{8 \times 0.0158 \times 123 \times 0.009167^{2}}{\pi^2 \times 9.81 \times 0.0508^{5}}$$

$$\boxed{h_f = 39.886 \text{ m of water}} \longrightarrow$$ *Only major losses, considering it as a long straight pipe*

- Since, $h_f = \frac{8 \times f \times L \times Q^2}{\pi^2 \times g \times D_M^5} \longrightarrow h_f \propto \frac{1}{D_M^5}$

Therefore, from the above relation we found that, as the diameter of pipe increases, the head loss due to friction will decrease drastically in power 5. Due to this reason we decided to increase the diameter of pipe up to some extent. After some calculation of several diameters while satisfying the restriction of space available at lower frame of bogie, we have chosen a ⌀2.75” and compared it with ⌀2” pipe.

- Comparison between ⌀2” and ⌀2.75” pipe

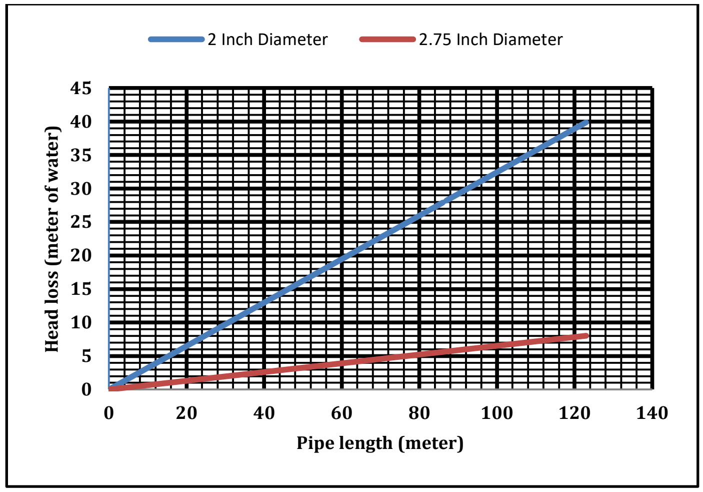

Chart-1: Comparison between ⌀2” and ⌀2.75” pipe.

Since, we have done the calculations for the $1/4^{th}$ rake, the ⌀2” pipe shows near about 40 m of water head loss which is way more than the head loss shown by ⌀2.75” pipe. Therefore from the above graph if we place ⌀2.75” pipe instead of placing ⌀2” pipe the frictional losses will be much lesser.

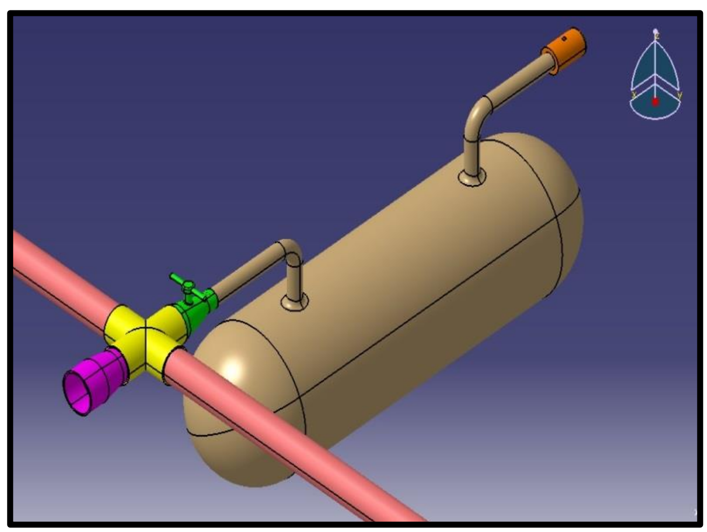

Fig -3: Single coach pipe line connection.

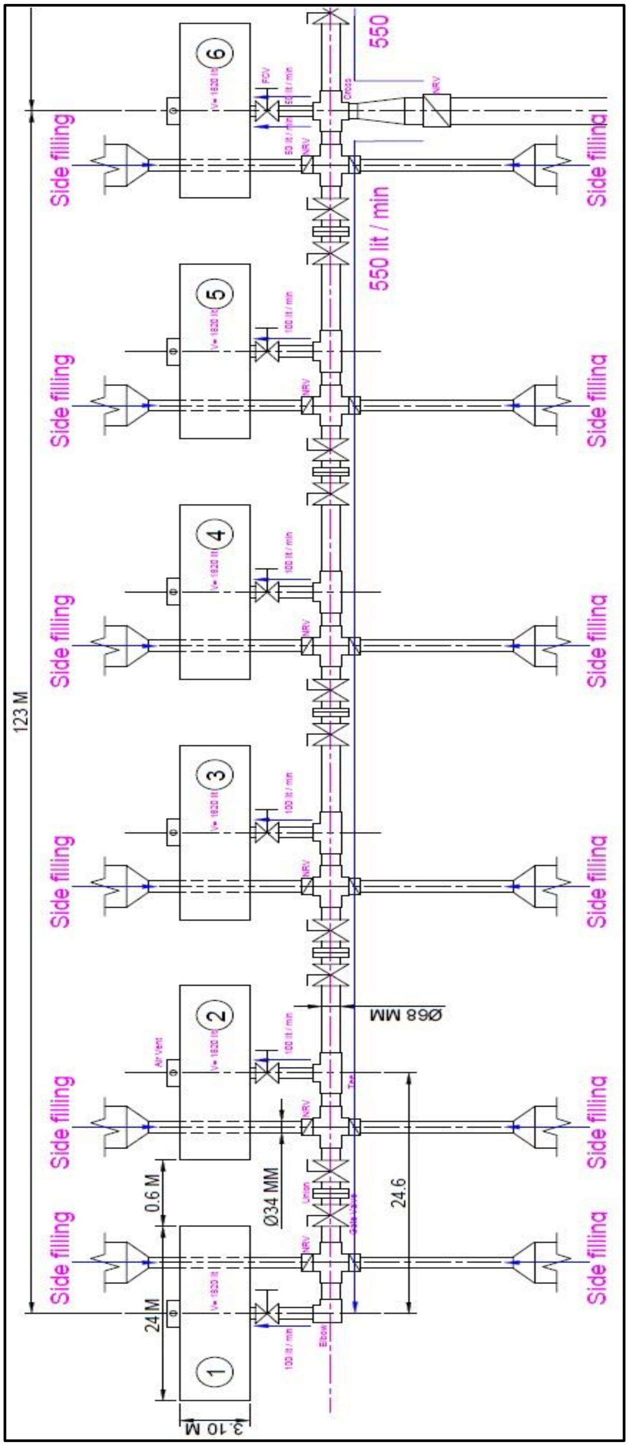

Fig -4: Pipe line layout for $^1/_4{}^{th}$ train.

4.2 Branching of Main Line:-

The flow carried by main line is distributed through branch lines. The number of connections which can be provided from one main is a matter of concern. This situation can be analysed in a simple manner by making following assumptions.

1) The flow carried by all branches will be equal.
2) The material, diameter and length of all branches will be same.

$$\frac{8 \times f \times L_{eq} \times Q^2}{2 \times \pi^2 \times D_m^5} = \frac{8 \times f \times L_{branch} \times (Q / n_b)^2}{2 \times \pi^2 \times d_{branch}^5}$$

$$\xrightarrow{\text{yields}} \quad D_m = d_{branch} \times n_{branch}^{2/5}$$

Where,
D_m = Diameter of mainline,
d_{branch} = Diameter of proposed service branches,
n_b = Number of branches.

$$\therefore \; d_{branch} = \frac{0.068\ (m)}{6^{2/5}} \qquad (\because \; n_b = 6)$$

$$\mathbf{d_{branch} = 0.0332\ m \cong 35\ mm}$$

4.3 Fluid parameter Calculations:-

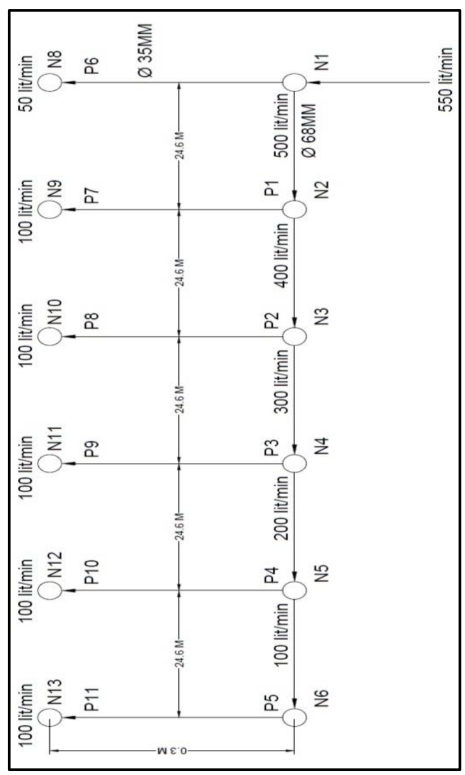

Fig -5: Pipe line network for calculation.

4.3.1 Discharges (Q) and Velocities in Main, Branch Pipe:-

Table -2: Discharges and velocities in main, branch Pipe.

Pipe Number	Discharges (m^3/s)	Calculations	Velocities (m/s)
1	0.00833	$V_{M1} = \frac{0.00833\ (m^3/s) \times 4}{\pi \times 0.068^2\ (m)}$	2.2937
2	0.00667	$V_{M2} = \frac{0.00667\ (m^3/s) \times 4}{\pi \times 0.068^2\ (m)}$	1.8366
3	0.005	$V_{M3} = \frac{0.005\ (m^3/s) \times 4}{\pi \times 0.068^2\ (m)}$	1.3767
4	0.00333	$V_{M4} = \frac{0.00333\ (m^3/s) \times 4}{\pi \times 0.068^2\ (m)}$	0.9169
5	0.00167	$V_{M5} = \frac{0.00167\ (m^3/s) \times 4}{\pi \times 0.068^2\ (m)}$	0.4598
6	0.00083	$V_{B6} = \frac{0.00083\ (m^3/s) \times 4}{\pi \times 0.035^2\ (m)}$	0.8626
7	0.00167	$V_{B7} = \frac{0.00167\ (m^3/s) \times 4}{\pi \times 0.035^2\ (m)}$	1.7357
8	0.00167	$V_{B8} = \frac{0.00167\ (m^3/s) \times 4}{\pi \times 0.035^2\ (m)}$	1.7357
9	0.00167	$V_{B9} = \frac{0.00167\ (m^3/s) \times 4}{\pi \times 0.035^2\ (m)}$	1.7357
10	0.00167	$V_{B10} = \frac{0.00167\ (m^3/s) \times 4}{\pi \times 0.035^2\ (m)}$	1.7357
11	0.00167	$V_{B11} = \frac{0.00167\ (m^3/s) \times 4}{\pi \times 0.035^2\ (m)}$	1.7357

4.3.2 Reynolds Number (R_e) and Friction Factor in Pipes (f):-

We have,

a) Reynolds number (R_e) = $\frac{\rho \times V \times D}{\mu}$

Where,

ρ = Density of water 997 in kg/m^3.
V = Velocity in pipe in m/s.
D = Diameter of pipe in meter.
μ = Dynamic Viscosity in pa.s.

b) Colebrook – White equation,

$$\frac{1}{\sqrt{f}} = -2.0 \log_{10}\left(\frac{\varepsilon/D}{3.7} + \frac{2.51}{R_e\sqrt{f}}\right)$$

Pipe friction is calculated by using moody chart. In fact, the moody chart is a graphical representation of this equation, which is an empirical fit of the pipe flow pressure drop data. Equation above is called the ***Colebrook-White formula.*** A difficulty with its use is that it is ***implicit in the dependence of f*** .

We have,

The Colebrook-White equation is implicit in f, and thus the determination of the friction factor requires iteration. An approximate explicit relation for f was given by **S. E. Haaland** in 1983 as

$$\frac{1}{\sqrt{f}} = -1.8 \log_{10}\left[\left(\frac{\varepsilon/D}{3.7}\right)^{1.11} + \frac{6.9}{R_e}\right]$$

The results obtained from this relation are within 2 percent of those obtained from the Colebrook-White equation.

Table -3: Reynolds number and friction factor in pipes.

Pipe Number	Pipe Diameter (m)	Reynolds Numbers	Friction Factors
1	0.068	174723.2418	0.016043496
2	0.068	139903.5209	0.016746961
3	0.068	104870.5092	0.017738536
4	0.068	69845.11506	0.019307066
5	0.068	35025.39416	0.022520859
6	0.035	33820.70449	0.023731554
7	0.035	68053.09157	0.020943869
8	0.035	68053.09157	0.020943869
9	0.035	68053.09157	0.020943869
10	0.035	68053.09157	0.020943869
11	0.035	68053.09157	0.020943869

Note: Here R_e in all pipes is > 4000 and hence ***Flow is Turbulent.***

4.3.3 Head Loss and Pressure Drop Due To Pipe Friction:- *(Referee Table 3)*

$$h_{L,\,Total} = \left(\Sigma f \frac{L}{D} + \Sigma K_L\right)\frac{V^2}{2g}$$

Where,

f = Friction factor of pipe
L = Length of pipe in m
D = Diameter of pipe in m
K_L = Loss coefficient of pipe fittings
V = Velocity in pipe in m/s

$h_{L,\,Total}$ = **4.9421 m of water**

Therefore,

a) $\Delta P = \rho \times g \times h_{L,\,Total} = 997\ (kg/m^3) \times 9.81 (m/s^2) \times 4.9421\ (M\ of\ H_2O)$
$= \mathbf{0.4834\ bar = 0.5\ kg/cm^2}$

b) Power required to overcome the pipe friction (P_{loss})

$P_{loss} = \rho \times g \times Q \times h_{L,\,Total}$
$= 997\ (kg/m^3) \times 9.81\ (m/s^2) \times 0.009167\ (m^3/s) \times 4.9421\ (m)$
= 0.5943 HP

4.3.4 Turbulence Calculation of Main Pipe:- (*Referee Table 3)*

a) Centreline Velocity ($\mathbf{u_{max}}$):-

$$\frac{u_{max}}{u^*} = 5.75\ \log_{10}\left(\frac{u^* y}{\nu}\right) + 5.55$$

The velocity will be maximum when, $y = R_m$

$$= \frac{D_m}{2} = \frac{0.068(m)}{2} = 0.034\ m$$

b) Distance from the pipe at which local velocity (u) = Average velocity (V_M):-

$$\frac{u}{u^*} = 5.75\ \log_{10}\left(\frac{u^* y}{\nu}\right) + 5.55$$

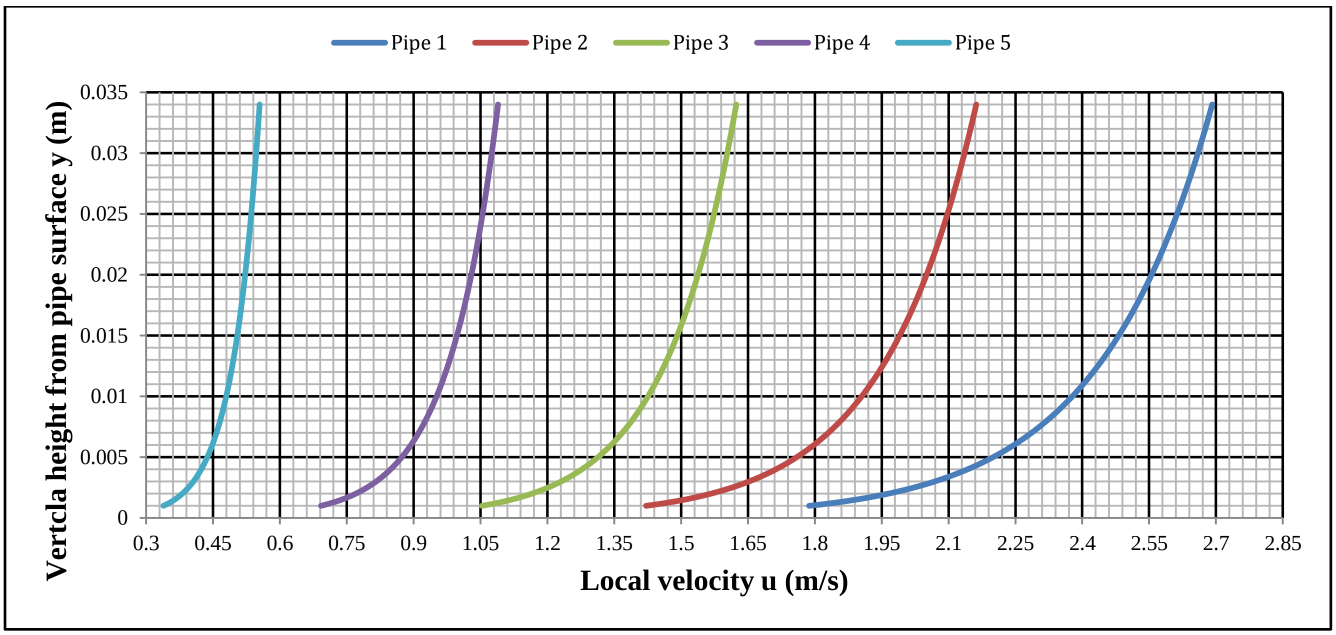

Chart-2: Velocity distribution in pipes.

Table -4: Head loss and pressure drop due to pipe friction.

Pipe No	**Dia of pipe (m)**	**Length of pipes (m)**	**Pipe fittings**				**Head loss in pipe (Major) (m)**	**Head loss due to pipe fittings (m)**	**Total head loss (m)**
-	-	-	Name	Qty	Loss Coeff. (K_L)	Total loss coeff. ($K_{L,T}$)	$h_f = \frac{f L V^2}{2 g D}$	$h_m = K_{L,T} \frac{V^2}{2 g}$	$h_{L,\,Total} = h_f + h_m$
1	0.068	24.6	Line Tee	2	0.32 × 2 = 0.64	2.02	1.5563	0.5417	2.098

			Branch Tee	1	1.08				
			Gate valve	2	0.15 × 2 = 0.3				
2	0.068	24.6	Line Tee	2	0.32 × 2 = 0.64	2.02	1.0415	0.3473	1.3888
			Branch Tee	1	1.08				
			Gate valve	2	0.15 × 2 = 0.3				
3	0.068	24.6	Line Tee	2	0.32 × 2 = 0.64	2.02	0.6199	0.1951	0.8150
			Branch Tee	1	1.08				
			Gate valve	2	0.15 × 2 = 0.3				
4	0.068	24.6	Line Tee	2	0.32 × 2 = 0.64	2.02	0.2992	0.0865	0.3857
			Branch Tee	1	1.08				
			Gate valve	2	0.15 × 2 = 0.3				
5	0.068	24.6	Line Tee	1	0.32	1.9	0.0877	0.0217	0.1094
			Branch Tee	1	1.08				
			Elbow	1	0.5				
6	0.035	0.3	No Fittings				0.0077	-	0.0077
7	0.035	0.3					0.0275		0.0275
8	0.035	0.3					0.0275		0.0275
9	0.035	0.3					0.0275		0.0275
10	0.035	0.3					0.0275		0.0275
11	0.035	0.3					0.0275		0.0275
Total loss of head due to friction									**4.9421**

Table-5: Turbulence calculation.

Pipe No.	**Velocity (m/s)**	**Friction factor**	**τ_{wall} (N/m^2)**	**u^*(m/s)**	**δ' (m)**	**Hydro-Dynamic Boundary**		**u_{max} (m/s)**	**At y $u = V_M$**
			$\frac{\rho \times f \times V_m^2}{8}$	$\sqrt{\frac{\tau_{wall}}{\rho}}$	$\frac{11.6 \times \nu}{u^*}$	$\frac{\varepsilon}{\delta'} < 0.25$	Smooth		mm
						$\frac{\varepsilon}{\delta'} > 6.0$	Rough		

						$0.25 < \frac{\varepsilon}{\delta'} < 6.0$	Transition		
1	2.2937	0.016043496	10.52	0.1027	0.000101	0.01508	Smooth	2.6916	7.2124
2	1.8366	0.016746961	7.04	0.0841	0.000123	0.01239	Smooth	2.1621	7.2218
3	1.3767	0.017738536	4.19	0.0648	0.000159	0.00958	Smooth	1.6238	7.3918
4	0.9169	0.019307066	2.03	0.0451	0.000229	0.00665	Smooth	1.0893	7.3624
5	0.4598	0.022520859	0.60	0.0245	0.000426	0.00358	Smooth	0.5544	7.2476

5. VELOCITY CONTOURS

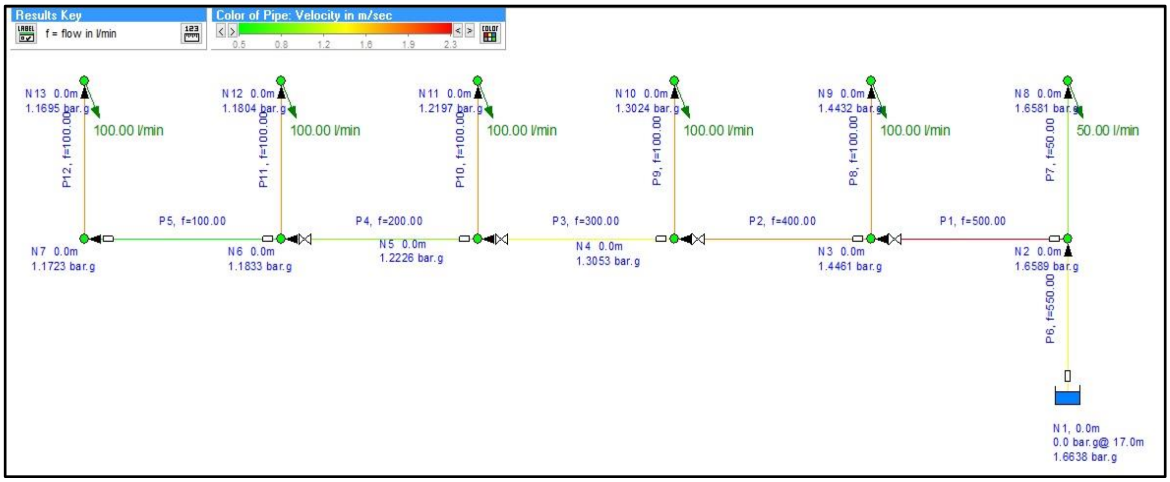

Fig -6: Contours of velocity magnitudes (m/s)

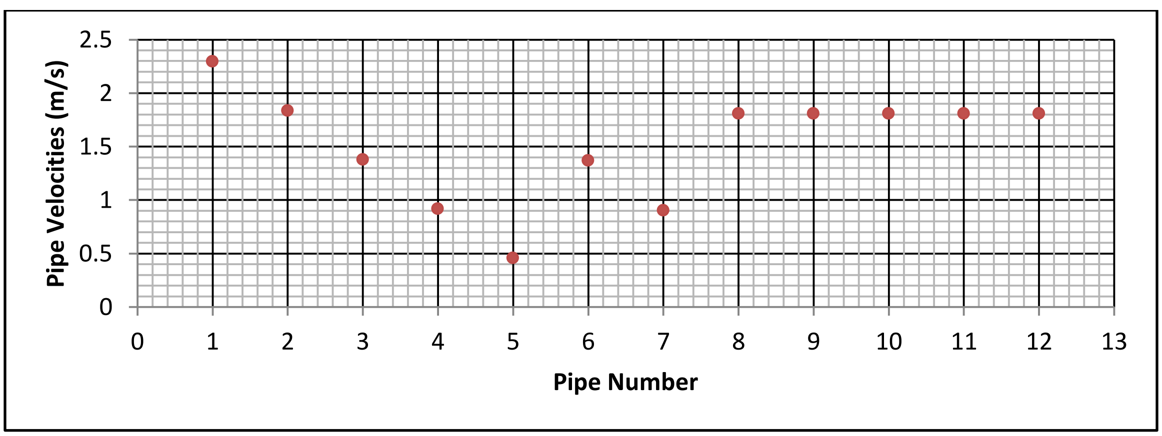

Chart-3: Discrete plot of pipe velocity variations

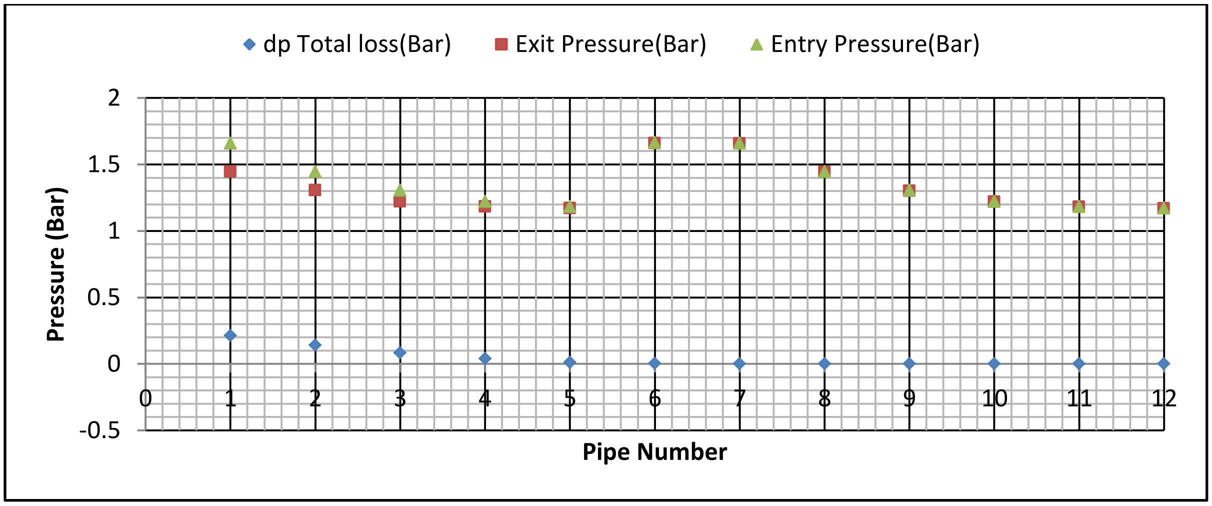

Chart-4: Discrete plot of entry pressure, exit pressure & pressure Drop

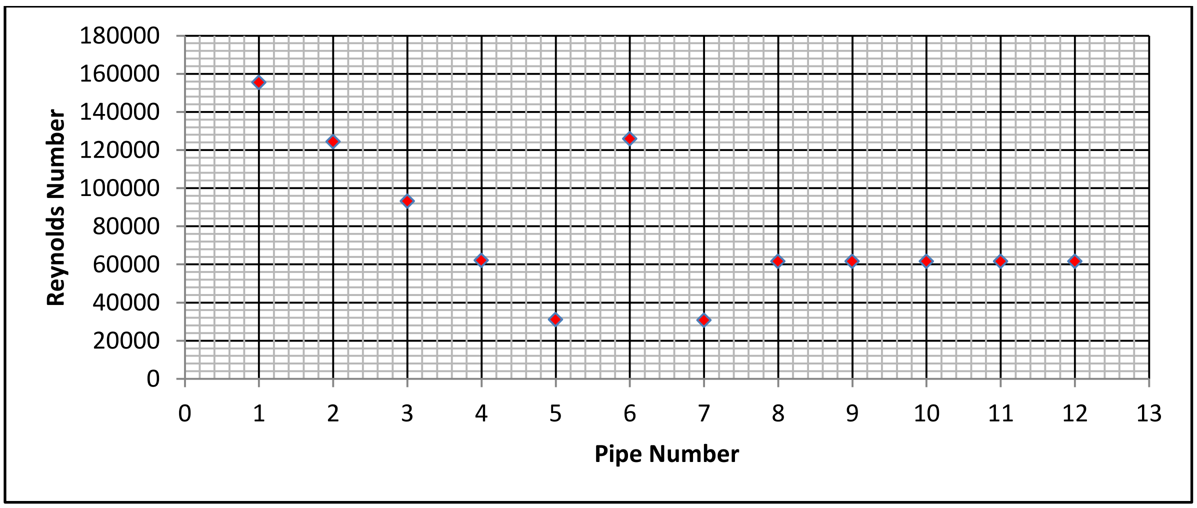

Chart-5: Discrete plot of Reynolds number variation in pipes

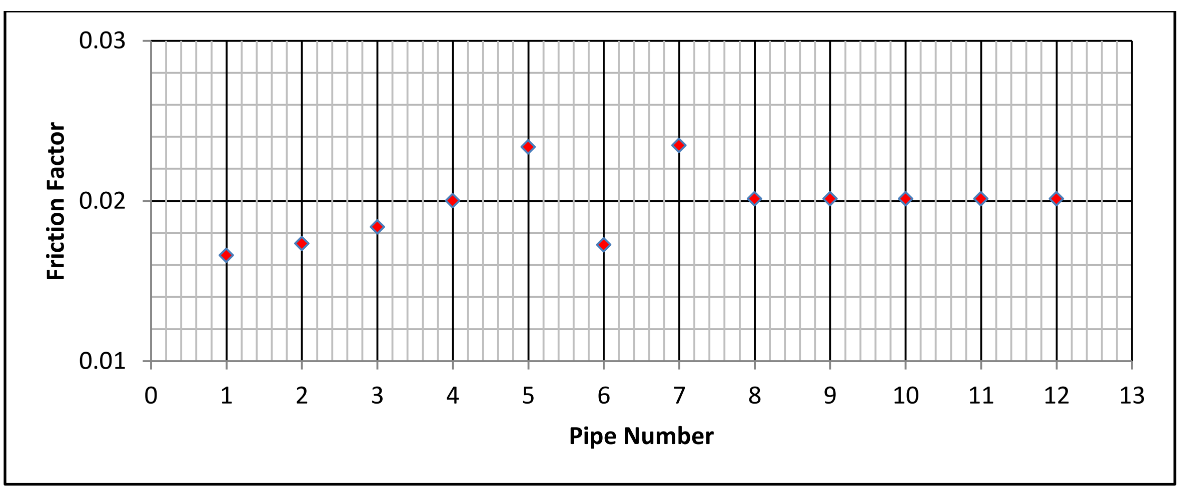

Chart-6: Discrete plot of Pipe friction factor

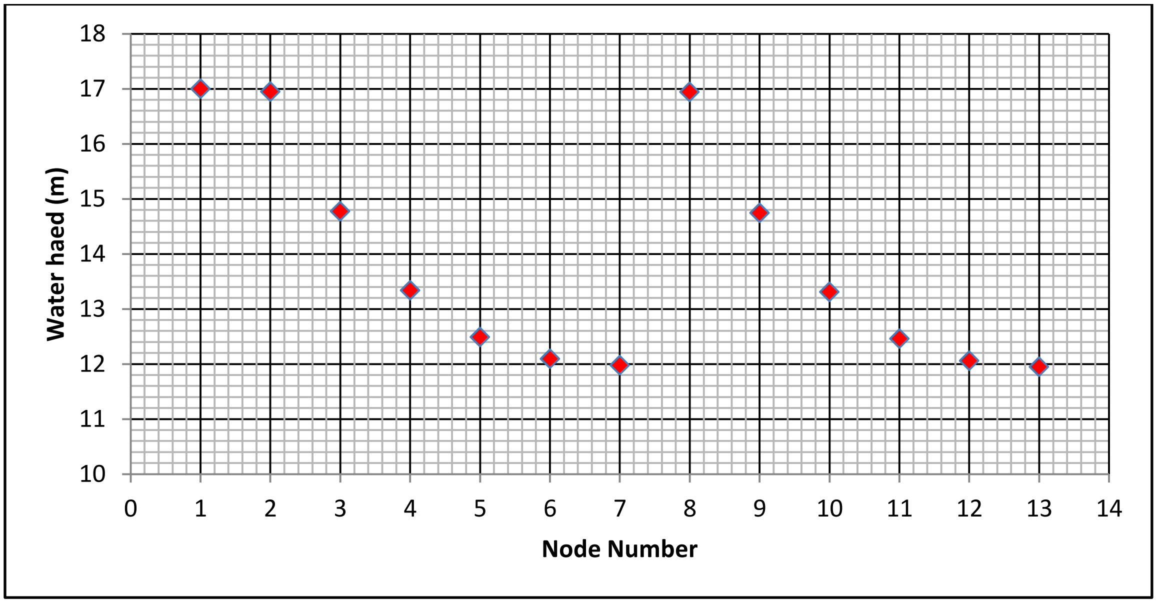

Chart-7: Discrete plot of hydraulic gradient line

6. EXPEIMRNTATION

After all the calculations we conducted an experiment with the permission of railway section engineer. In this experiment they provided us three coaches equipped with 3 tanks holding a capacity of 1820 liters each and each tank was already filled 320 liters before the experiment (In railway this 320 liter is considered as TOP-UP water for each tank). Here the task was to check whether calculation result meet the experiment result or not. So in order to start with experiment we first set the discharge as per the requirement i.e.300 lit/min, which will fill the 3 tanks within 10-15 min's.

After conducting the experiment certain result were obtained those result were-

1) Three tanks were filled within 15 min, since each tank had 320 liters previous filled as TOP-UP water.
2) Loss of head due to pipe friction as well as pipe fittings is was 1.5626 m of water.

7. CONCLUSION

1) The Traditional time is 20.42 min and new time obtained from project is 14.3 min.
2) The labour is reduced to 3 from 12.
3) Idle time of train has been reduced by approximately 5 min.

8. FUTURE SCOPE

1) A manually controlled valve gradually degrades and may be subjected to the failure, so sensor based valves should be taken into account in future.
2) In this project work we have not taken the leakage loss in to account. Therefore factor for leakage should be taken in the future in order to compensate the leakage loss.
3) Each tank of coaches must be fitted with water level indicator in order to ensure that the tank is completely filled or not.
4) Considering a situation where tank 1, tank 2, tank 3 have water percentages of 85, 66, 45 respectively. As now we will be unknown of these percentages, so in future we may have scope to design such a data base system which will directly send the notification of these percentages to the next platform.
   In this way the worker will be able to decide whether to fill tank manually through side filling pipe or to connect directly to the high pressure inlet.

CONFLICTS OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this paper.

AUTHORS' CONTRIBUTIONS

Rushikesh Dhulam, Shivaratan Sunkoji, Nikhil Ankushe and Rohan Akade contributed equally to this study.

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