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Pipe Flow Kinetics In Innovative Distribution Network Flow Design (Of Hydraulic Pressure Demand)

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Abstract: This study is especially regarding the flow hydraulics in the network of water supply pipes. Water pressure requirement is the guiding principle of this study of water supply distribution network. Continuity of flow is the simultaneous happening required to be implemented into it along with that. Besides, the other flow-variables such as velocity, length of flow, pipe bed slopes etc. remain in their own degree of presence, directly or indirectly. So far, design of the pipe network is done by the Darcy-Weisbach & Hazen-Williams equation, following the famous Hardy-Cross method – these are conventional. In this study, formulations required for the network design have been developed in a new way of new invisionary mathematical exploration. Innovative applications of flow-mechanics, including 'differential' presence, have been applied to determine the flow equation of subjection. And, lastly, it has been shown how to obtain utilization of the derived equations by giving a simple but innovative approach of the flow design. With prospective future scopes, this study must prove to be giving various new insights of engineering discovery.

KEYWORDS: Flow Kinetics, Water Supply, Head Loss, Pipe Loop, Distribution Network, Velocity-Gain, Innovative Network Design.

A. Introduction

Sector of infrastructure has experienced developments over decades. Its uprising demands are functional to various causes; created by human & its needs by ages. In dealing of the infrastructure, it is often observed that the more developed a country is, the higher is its infrastructure of stock and hence the lower the payoff from additional investment, unless it aims at addressing a major bottleneck or introducing a major technological improvement. The water supply project has been an integral section of it, i.e., the infrastructure. Besides creating rising economy & development, infrastructure has also adverse impacts on environment, especially to the Groundwater Table. Underground structures and infrastructures (i.e. metro tunnels and stations, deep foundations, etc.) locally affect the groundwater level of the aquifers in urban area, and they can bring about hydro-geological hazards especially in areas interested by a regional raising trend of the water table. But in spite of all odds & suspicious eyes on 'infrastructure' larger budgets, water supply projects keep its continuous uprising trend as it often subjects to lesser hazards & bad adverse effects. This trend is also based on the picture of reality – particularly the concern of diminishing groundwater quantity.

A propositive methodology is given, in this study, in some various innovative ways to develop the required formulation, of the distribution network design particularly. Methodology of this study is to estimate the variables required in the design of water supply network of pipes, along with its necessary corrections. The entire extracted variables of this study are only for the drinking water supply facility but it could be equally applicable to the kinds of other types of liquid-conveyance design systems like the raw water distribution pipes, oil distribution pipes, etc. etc. to wherever the fundamental of the methodology is to be the basis of the description.

A schematic network diagram is given in the Figure 1 which shows the layout of some typical distribution pipes which are here as exemplary purpose. The pipes (say, P0, P1, . . . P4) in the network always form a pipe loop in the sense that they are in having with the continuity principle of flow. There should always be a balance in the inflows & outflows in the loops. Here, on entirety, the pipe loop 1-2-4-3-1 or simply 12431 is comprised of the pipes P1 to P4. The Nodal points (1,2,3,4 etc.) which represent the points of junctions (of flow, head-loss etc.) in the pipe network at 1, 2, 3 & 4 are the points of withdrawal of water pressure from the flowing stream of the pressure. The term 'Loop' is defined here as the framework of no. of pipes subjected to flows from its adjoining pipes & the framework is subjected to the continuity property of flow-hydraulics & in this way the entire network consists of no. of such loops of different configuration & characteristic to regulate its design flow. There must be different patterns of layouts of the type of pipe-loops in a network distribution as shown in the Figure 1, but most of the network loops shall satisfy each of the entire loops as considered, explained & shown in the network. The flow distribution is required to be so balanced that the loop-network can be solved to its best possibility (Table 9).

The entire design of this study may be divided loop-wise & pipe-wise & it is of the applicable sign-convention as to be applied with along with this study's formulation by the physical formation. Irrespective of giving detail designing of the flow-distribution process, this study has emphasized on how its background equations can be formed using its formative fundamentals. This study has described the network design in detail by determining the equations given by the head-loss & the applied head (as water pressure) at the pipe-junction like 1, 2, 3 etc. as shown in the Figure 1. The entire study could be divided into the following three stages:

(1) Differential Head-loss Formulation with velocity-gradient.
(2) The Differential Formulation into 'design' Flow Variables.
(3) The Facilitative study to incorporate into distribution network.

Each of these stages, especially the stage (3), has been discussed in the respective discussion. Although the way or sequence they are described in here does not have any implication of strictness that it always requires to be applied in that sequence or else. The study shall take onto that level of understanding where the implementation shall come into the fore of the knowledge afterwards & it is proposed with lots of other usages. It is mentioned here all the dimensions shown in the Figure 2, are not to any scale, unless mentioned otherwise. And, all the discussions are meant to define & describe for the section I to II, unless mentioned otherwise, to go to the integrative or else.

B. GOALS OF THE STUDY

a) To establish design formulations required to design the pipe flow network distribution system on flow pressure & its 'design' flows.
b) To achieve a design methodology of the pipe-flow, subject to the guideline & utility, providing the cutting-edge solution as a whole.
c) To incorporate & examine the pipe-flow mechanics in a new & broader field by the innovative design methodology as mentioned.

C. METHODOLOGY

Criticality or the equilibrium mobility is given prime consideration & it has shown the path of deriving the required formulations of the pipe-line distribution network. The parameters Q & H have thereby been given the (respective) importance & used alternatively in its differential form as (dH/dQ). One of the applicable insights of this methodology is that this differential ratio of Q and/or H may be having any numerical value, even of desired kinds also, based on its dimensional unit in the flow-dynamics. The value of the differential ratios may be zero or more or less than the zero, depending on the

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designer's prospective & creative views in creating an effective water supply system & management. This selection of zero-centric (or almost zero) is highly important to design a better distribution network. In this study, the capacity, range & mobility of the flow-dynamics in a distribution network has been said to be highly dependent on the particular selection of the value of this ratio.

Simple 'differential' derivation has been done on the Darcy-Weisbach formula which is in order to determine the 'defining' derivational ratio, (dH/dQ), as the design factor herein.

In distribution network, it is always a matter of concern of how to generate & maintain a particular head-loss or water pressure, on all along even up to its dead-ends. Here, as said, the 'stable' variability of the design has come from using the functional form of the Darcy-Weisbach equation (D-W) which is $H = KQ^x$ where, x = numerical value. The x-value is 1.85 & 2.00 for the Hazen-Williams Formula & the Darcy-Weisbach Formula respectively. Head-loss & Discharge once ready as given by this study's explanation, it'll give the innovative design outcome. Subjectively, the K value is here realized with its usual impact on the network design & it is by the Hazen-Williams (H-W) formula, $K = (1/470)*(L/D^{4.87})$ of the conventional in the subjective interest. By this expression of K the limitation in the network design of this study can also become quite interesting to the design formulation. The value of the 'x' & 'K' is kept & used as conventional in this study as these are in the D-W equation. The detail description is given as followed.

C.1 DESCRIPTION OF THE METHODOLOGY

In most of the cases of network design pipe-loops, the value of H is considered to be zero in order to maintain the zero pressure over the loop, so that extra pressures do not exist & create accumulative effects of 'endangering' pressures in the network – it is when the H is the matter of reference in the design along with its flow-continuity aspect. This study has applied & explained the design by withdrawing this rigidity of 'H' as the zero implication completely & absolutely (APPENDIX A). This 'breakthrough' in treating the H guideline in that manner has created the design in a new way of innovation by showing of how the varying 'optative' pressure can be distributed over & solved without difficulty. A typical sectional detail is given in the Figure 2 where a pipe section has been shown & chosen to describe its flow mechanics, variables, etc. Here, a datum is chosen & selected to find out the water heads & it is the ground level on which the overhead storage tank is positioned. The pipe sections are shown with the detailing along with their energy gradient of the flow. Like the one shown in the Figure 2 for the section I to II, there are the similar kinds of the pipes or pipe-flows or pipe sections found in all across the distribution network everywhere whose sectional detailing would be similar like the Figure 2. The section I & II shown with their pressure head demand H_I & H_{II} respectively is at a (longitudinal) length L_{II} keeping the sectional length at a bed slope to inaugurate (may be) & regulate the flow in between & beyond. In each of the sectional length, there is a head-loss & it's for the depicted section (I to II) would be the H_{I-II}. The junction points 1, 2 of the Figure 2 are the section I & section II respectively & so on. So there would be the same way of the water conveyance (as shown in the Figure 2) for all the junction points (Figure 1). Thereby the Figure 1 is having the inter-connection with the Figure 2 in all respects as described. To give the discussion of the differential effects of the pipe flow dimensions, the Figure 2 is given with the dimensions 'differentially', except the pressure heads like H_I, H_{II} etc.

In doing the formulation, the differential effects are considered also for Area (A), Diameter (D), Velocity (V), Length (L) (sectional) of the pipe flow (Figure 2). In the methodology section of this study, effect of the differential increase (or decrease) of (dH) in pressure head (H) has been formulated which gives its self-explanatory presence & the differential needs of the representation. All the dimensions are here thereby in their (small) derivative forms of theirs' corresponding entire identity. It'd be quite clear from the given Figure 2 about how the differential changes in the pressure heads (H), area (A), velocity (V) etc. could bring their presences into the distribution network design till the fulfillment of the pressure head requirement. Also, the small change in the time, i.e., dT, from one section to another section is also given to find out its effect in the discussion. So the Figure 2 as shown here to express & account the differential improvements in the pipe-flows is the pipe flow distribution representation to be watched out of always. It is commonly a general fact that the head-loss (H) is expressed as 'meter (m)' or Newton/m^2 as the pressure intensity. On all across this study, the International System of units (S.I) is followed.

C.2 DESIGN CONSIDERATION

The design measures given in this study have been found to be true, reasonable & realistically valid if the nodal head (H) around the loop in the water supply distribution system is provided by a value apart from the value of the absolute 'zero' quantity. In most of the design, the zero value of the head is though maintained as its design basis. Now, followings are the design considerations of this study –

(a) Continuity of flow, (b) Pipe is rough and/or smooth, (c) Pipe flow is by gravity, (d) The suitable flexibility in the Head-loss, (e) Compatibility in flow energy adjustments, (f) The relation L = (V*T) is valid in pipe flow.

Suitable flow-estimation along with its viable flow-dynamics should be provided in effect of the H value as non-zero quantity, and, its innovative design requires to be done by the foregoing procedure. With these, the subjective formulations, could although apply to the more beyond aspects than that said in here. Say, the gravity pipe-flow which could be optional & flexible as shown in the Figure 2.

C.3 INNOVATIVE (DESIGN) APPROACH

Innovative discussion of this study shall go on explaining & establishing the goals as explained. Interests of this study are to find out the nature & pattern of the H with respect to its attributing flow elements in forming the various prospective equation of useful nature by the innovation kinds. The design of flow-estimation could be used as a rough estimation or as a more elaborative design towards more precision & detailing.

The design aspects are applied & discussed in detail in C.5. Several graphical determinations in different suitable ways are found out as for the selective determination while going through this study & it's also truthful for several analytical possibilities although as already told. So, let's start the innovative approach as explained.

So far as the D-W equation is concerned, we know it (head-loss) is to be as given as, $H = KQ^x$; where 'x' is constant.

Derivating H with respect to Q,

$$\left(\frac{dH}{dQ}\right) = K\left(\frac{dQ^x}{dQ}\right) + Q^x\left(\frac{dK}{dQ}\right) = K(x)(Q^{x-1}) + Q^x\left(\frac{dK}{dQ}\right) = (x)\left(\frac{H}{Q}\right) + (Q^x)\left(\frac{dK}{dQ}\right) \quad \ldots(1)$$

The Eq.(1) is one of the important innovative measures to design the network by its procedural innovation. Evaluation & utilization of the Eq.(1) & significance of its components or terms is the primary concern of this study so far as the K is defined. Noted here again that H the head-loss is like of the one as H_{I-II} as shown in the Figure 2.

The term (dK/dQ) so found in the Eq.(1) is the differential contribution of the loop-wise head values with respect to its corresponding discharges of the total H & Q, entering the loop. So long as the Darcy-Weisbach equation, i.e., $H = KQ^x$ is defined & expressed by the Eq.(1), the terms of it shall be accordingly in use to determine its innovative evaluations suitably.

C.3.1 EVALUATION OF $\left(\frac{dH}{dQ}\right)$

Mathematically, by the first criteria of the methodology & using the unitary and/or dimensional concept, the term (dH/dQ) is, in general, given as, $(dH/dQ) = (\Delta H/\Delta Q) = (h_L/q) \ \ldots(2)$; where, h_L & q be the head (ΔH), flow-rate $(q = \Delta Q)$, by their respective differential amounts of (H) & Q. The Eq.(1) of the general expansion of the D-W equation & the Eq.(2) are to be the satisfactory equations from the dimensional justification.

A quantity 'ʋ' is herein designated to notify the (dH/dQ) whose unit is sec/m^2 & dimensionally, it is (TL^{-2}), where L = Flow length in meter (m); & T = Time of Flow in sec. in the pipe flow (Figure 2). Let's this term, (ʋ), be called as "Velocity-Gain" co-efficient or shortly, V.G co-efficient as it involves in the gaining of the pressure gradient in the network. Dimensionally, the co-efficient is thereby expressed as, $(\hbar) = \left(\frac{dH}{dQ}\right) = \frac{L}{L^2/T} = \left(\frac{T}{L^2}\right)$ ... (3). The Eq.(3) is by the unit convention of the terms so associated with it. Like this, there could be various expressions based on the (dH/dQ)'s existence criteria, as told. Functionally, to reach up to the physical requirement of the dimensional satisfaction, the co-efficient can be now given as, $(\hbar) = \left[\left(\frac{1}{dV}\right) * \left(\frac{1}{dH}\right)\right]$ ... (4); subject to the functional fulfillment & formative satisfaction. The Eq.(4) is very useful equation to the design outcome, is also of research interests. The Eq.(4) is now written approximating the profile of the involved variables by a straight-line variation such as $Y = M * X + C$ which is as, $(dV) = [(1/\hbar) * (1/dH) + 0]$. The functional value of '$\hbar$' is now given with the determination from a (chosen) curve of (dV) versus $(1/dH)$ by estimating the gradient so made under the (ideological) straight-line graph well up to the region of its existence (as to be chosen of) in the value along the X-axis & Y-axis respectively (Figure 3). From the straight-line comparison or variation, the gradient (M) is observed to be giving the value of $(1/\hbar)$ which is the inverse of the V.G coefficient with 'zero' intercept (C) value. The selection of the parameter, dV or dH, as its X axis or Y axis variable is not restrictive although; rather, it is flexible to apply as it could be clearly visible to to the physicality. The Figure 3 is a representative graph of the numerical values so (to be) selected out for the X & Y axes, by the physical features of the pipe-flow. This physical feature (associated with V & others) is to be chosen in such a way to re-present like the Eq.(4) so that it does not lead to invalid situation of the pipe-flow. There might thus be various expressions like the one as presented by the Eq.(4). From Eq.(2) it's now quite clear that the ratio (dH/dQ) signifies the $(\hbar)$ value whose estimation is herein proposed to be done with the extraction from such straight-line graph (Figure 3) in order to assign & design the flow-variables in the pipe network on suitability of the innovative methodology & its design procedures. Also, the Eq.(4) or the Figure 3 could be compared with & better understood by the Figure 5. In terms of the integrated view, the Eq.(4) is further expressed as for circular pipe as,

$$(\hbar) = (1/dV) * (1/dH) = (1/V) * (1/H)$$

Or, $(\hbar) = (A/Q) * (1/H) = 0.785 * (D^2/Q) * (1/H)$ ... (5)

And, all the possible presentable forms of the Eq.(2) by the satisfactory physical mechanism should need to be expressed by the graphical analysis as like the Figure 3 (& Figure 5 for better design variability).

There are other forms of the quantity (dH/dQ) given as followed –

C.3.2 OTHER FORMS OF (dH/dQ)

Each formative evaluation is always required to be guided by the Figure 2 & Figure 3. The positive sign in the formulation given indicates the angle or pressure direction to be on the pattern of the description style as shown by the relevant figures & its discussions. The one typical type of the quantity (dH/dQ) is discussed in the earlier section with its numerous possibilities to be having the various different formations of the physical concern. Now its various other forms are given in the following evaluations by applying a different aspect of the physical applicability –

EVALUATION 1:

In this, the quantity (dH/dQ) is hereby expressed as (for differential), $\left(\frac{dH}{dQ}\right) = (\hbar) = \left[\frac{dH}{(dA)(dV)}\right] = \left[\frac{(dH)(dT)}{(dA)(dL)}\right]$ ... (6); where, the details of the parameters are given in the APPENDIX A.

For the pipes in a loop of the flow direction (Figure 2), followings are the head-losses (of the differential nature) relevant to the given pipe sections of a schematic L_n length of the pipe flow,

For 0-I segment, $(H)_I = (H)_0 + (H)_{0-I}$;

where, $(H)_{0-I}$ = Head-loss at the section I.

Or, $(dH)_{0-I} = [(dH)_I - (dH)_0]$;

where, $(dH)_{0-I}$ = Differential head-loss at the section I.

For I-II segment, $(H)_{II} = (H)_I + (H)_{I-II}$

Or, $(dH)_{I-II} = +[(dH)_{II} - (dH)_I]$;

where, $(dH)_{I-II}$ = differential head loss at the section II.

For II-III segment, $(H)_{III} = (H)_{II} + (H)_{II-III}$

Or, $(dH)_{II-III} = +[(dH)_{III} - (dH)_{II}]$;

where, $(dH)_{II-III}$ = differential head loss at the section III.

. . . .

For (n-2) to (n-1) segment, $(H)_{n-1} = (H)_{n-2} + (H)_{(n-2)-(n-1)}$

Or, $(dH)_{(n-2)-(n-1)} = +[(H)_{n-1} - (H)_{n-2}]$; where, $(dH)_{(n-2)-(n-1)}$ = differential head loss at the section (n-1).

For (n-1) to n-th segment, $(H) = (H)_n = (H)_{n-1} + (H)_{(n-1)-n}$

Or, $(dH)_{(n-1)-n} = +[(H)_n - (H)_{n-1}]$;

where, $(dH)_{(n-1)-n}$ = differential head loss at the section 'n'.

In summary, for the total Head-loss (H) for a Pipe loop or network or any sectional pipe length, the followings are determined for the integrated values as obtained as followed:

$(\mathbf{L}) = (\mathbf{L})_n = (\mathbf{L})_I + (\mathbf{L})_{II} + (\mathbf{L})_{III} + \dots + (\mathbf{L})_{n-1} + (\mathbf{L})_n$;

where, L = flow length of the pipe.

$(\mathbf{T}) = (\mathbf{T})_n = (\mathbf{T})_{0-I} + (\mathbf{T})_{I-II} + (\mathbf{T})_{II-III} + \dots + (\mathbf{T})_{(n-1)-n}$

where, T = Total Time of flow (over the section).

$(\mathbf{A}) = (\mathbf{A})_n = (\mathbf{A})_I + (\mathbf{A})_{II} + (\mathbf{A})_{III} + \dots + (\mathbf{A})_{n-1} + (\mathbf{A})_n$;

where, A_n= flow-area at section n, i.e. it is the $A_{eff.}$

For the flow lengths (sectional),

$(\mathbf{A_L}) = (\mathbf{A_L})_n = (\mathbf{A_L})_{0-I} + (\mathbf{A_L})_{I-II} + (\mathbf{A_L})_{II-III} + \dots + (\mathbf{A_L})_{(n-1)-n}$

; where, A_L= the flow-area over the sectional length. And,

$$(\mathbf{H}) = (\mathbf{H})_n = \begin{bmatrix} (\mathbf{H})_{0-I} + (\mathbf{H})_{I-II} + (\mathbf{H})_{II-III} + \cdots \\ + (\mathbf{H})_{(n-2)-(n-1)} + (\mathbf{H})_{(n-1)-n} \end{bmatrix}$$

where, H = Loss of water pressure heads over the lengths of the pipe. These findings are given at one place destination in Table 1, 2 & 3. Now, applying the above extractions on the Eq.(6),

For the section 0 - I, $\left(\frac{dH}{dQ}\right)_{0-I} = (\hbar)_{0-I} = \left[\frac{(dH)(dT)}{(dA)(dL)}\right]_{0-I}$

$$(dH)_{0-I} = +[(dH)_I - (dH)_0] = \left[\frac{(dA)(dL)}{(dT)}\right]_{0-I} * (\hbar)_{0-I} \quad \dots (7)$$

$$(dH)_I = (dH)_0 + \left[\frac{(dA)(dL)}{(dT)}\right]_{0-I} * (\hbar)_{0-I} \quad \dots (7a)$$

For the section I - II, $(dH)_{I-II} = +[(dH)_{II} - (dH)_I]$

$$(dH)_{I-II} = \left[\frac{(dA)(dL)}{(dT)}\right]_{I-II} * (\hbar)_{I-II} \quad \dots (8)$$

$$(dH)_{II} = (dH)_I + \left[\frac{(dA)(dL)}{(dT)}\right]_{I-II} * (\hbar)_{I-II} \quad \dots (8a)$$

For the section II - III, $(dH)_{II-III} = +[(dH)_{III} - (dH)_{II}]$

$$(dH)_{II-III} = \left[\frac{(dA)(dL)}{(dT)}\right]_{II-III} * (\hbar)_{II-III} \quad \dots (9)$$

$$(dH)_{III} = (dH)_{II} + \left[\frac{(dA)(dL)}{(dT)}\right]_{II-III} * (\hbar)_{I-II} \quad \dots (9a)$$

. . . .

For the section (n-1) – (n), $(dH)_{(n-1)-n} = +[(dH)_n - (dH)_{n-1}]$

$$(dH)_{(n-1)-n} = \left[\frac{(dA)(dL)}{(dT)}\right]_{(n-1)-n} * (\hbar)_{(n-1)-n} \quad \dots (10)$$

$$(dH)_n = (dH)_{n-1} + \left[\frac{(dA)(dL)}{(dT)}\right]_{(n-1)-n} * (\hbar)_{(n-1)-n} \quad \dots (10a)$$

Thereby, for the pipe-flow having the n-th segments in pipe network,

$$(dH)_n = (dH)_{n-1} + \left[\frac{(dA)(dL)}{(dT)}\right]_{(n-1)-n} * (\hbar)_{(n-1)-n} \quad \dots (11)$$

$$(\hbar)_{(n-1)-n} = [(\mathbf{dH})_n - (\mathbf{dH})_{n-1}] * \left[\frac{(dT)}{(dA)(dL)}\right]_{(n-1)-n} \quad \dots (11a)$$

Thereby for the segment of the section from I to the n-th, following would be the equation,

$$(\hbar)_{I-n} = [(\mathbf{dH})_n - (\mathbf{dH})_I] * \left[\frac{(dT)}{(dA)(dL)}\right]_{I-n} \quad \dots (12)$$

Again in a different aspect of the physicality, followings are evaluated & determined in order to find out the required essential applying the Eq.(6),

For the pipe segment between section 0 to section I,

$$(\hbar)_{0-I} = \left(\frac{dH}{dQ}\right)_{0-I} = \left[\frac{\{(dH)_I - (dH)_0\}\{(dT)_I - (dT)_0\}}{\{(dA_{eff})_I - (dA_{eff})_0\}(dL_I - dL_0)}\right]$$

$$= \{(dH)_I - (dH)_0\} * \left[\frac{(dT)_I - (dT)_0}{\{(dA_{eff})_I - (dA_{eff})_0\}(dL_I - dL_0)}\right] \quad \dots (13)$$

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For the pipe segment between the section I to section II, $(\hbar)_{I-II} = \left(\frac{dH}{dQ}\right)_{I-II} = \left[\frac{\{(dH)_{II}-(dH)_{I}\}\{(dT)_{II}-(dT)_{I}\}}{\{(dA_{eff})_{II}-(dA_{eff})_{I}\}(dL_{II}-dL_{I})}\right]$

$$= \{(dH)_{II} - (dH)_{I}\} * \left[\frac{(dT)_{II}-(dT)_{I}}{\{(dA_{eff})_{II}-(dA_{eff})_{I}\}(dL_{II}-dL_{I})}\right] \quad ...(14)$$

For the pipe segment between the section II to section III,

$(\hbar)_{II-III} = \left(\frac{dH}{dQ}\right)_{II-III} = \left[\frac{\{(dH)_{III}-(dH)_{II}\}\{(dT)_{III}-(dT)_{II}\}}{\{(dA_{eff})_{III}-(dA_{eff})_{II}\}(dL_{III}-dL_{II})}\right]$

$$= \{(dH)_{III} - (dH)_{II}\} * \left[\frac{(dT)_{III}-(dT)_{II}}{\{(dA_{eff})_{III}-(dA_{eff})_{II}\}(dL_{III}-dL_{II})}\right] \quad ...(15)$$

. . . .

For the n-th segment, between section (n-1) to the section n, $(\hbar)_{(n-1)-n} = \left(\frac{dH}{dQ}\right)_{(n-1)-n}$

Or, $(\hbar)_{(n-1)-n} = \left[\frac{\{(dH)_{n}-(dH)_{n-1}\}\{(dT)_{n-1}-(dT)_{n}\}}{\{(dA_{eff})_{n-1}-(dA_{eff})_{n}\}(dL_{n-1}-dL_{n})}\right]$

$$= \{(dH)_{n} - (dH)_{n-1}\} * \left[\frac{(dT)_{n-1}-(dT)_{n}}{\{(dA_{eff})_{n-1}-(dA_{eff})_{n}\}(dL_{n-1}-dL_{n})}\right] \quad ...(16)$$

Thereby for the segment of the section from I to n-th, following is the equation, $(\hbar)_{I-n} =$

$$\{(dH)_{n} - (dH)_{I}\} * \left[\frac{(dT)_{I}-(dT)_{n}}{\{(dA_{eff})_{I}-(dA_{eff})_{n}\}(dL_{I}-dL_{n})}\right] \quad ...(17)$$

where, $(H)_n =$ Head loss for the pipe flow at its n-th segment; $(\hbar)_n =$ V.G co-efficient for the n-th segment in the network. The terms such as $\{(H)_n\}, \{(T)_n\}, (A_n), (L_n - L_{n-1})$ in the Eq.(11) or Eq.(12) & Eq.(16) or Eq.(17) are subject to change in sign depending on the flow's considered design direction in a loop as positive or negative & here, +ve sign is for the flows as shown in the Figure 2. This convention is a basic fundamental in the design of distribution network, in order to distribute & determine the pipe-flows of corrective nature & these are given in Table 3 & Table 4 &, further with this, the network softwares could also be prepared of.

EVALUATION 2:

In this evaluation, the area corresponding to the head-loss (example, H_{I-II} for the section I-II) is determined & brought into the network design determination. The area of flow which is lost by the transmission of the water from one section to another section is represented here as A_L or, $A_{eff.}$ For the section I-II, it should be $(A_{eff.})_{I-II}$.Thereby, this head-loss area which is here considered as the 'effective' mobility worked in the background of the causation of the satisfactory sanction of the water demands at the sections & is given by its functional way of representation as, $(A_{eff.})_{I-II} = (H)_{I-II} * (B)_{I-II}$; Or, $(H)_{I-II} = [(A_{eff.})_{I-II}/(B)_{I-II}]$; where, $(B)_{I-II} =$ the component variable which is not constant (>0); $(H)_{I-II} =$ the head loss on the section I-II; $A_{eff.}$ = Pipe-flow area (sectional) = $(\Pi D^2/4)$; D = Pipe diameter for the section.

Differentiating on both sides,

$$\left(\frac{d}{dQ}\right)[(H_{I-II})] = (\hbar)_{I-II} = \frac{d}{dQ}\left[\left(\frac{A_{eff}}{B}\right)_{I-II}\right] \quad ...(18)$$

The Eq.(18) is giving the V.G co-efficient for a particular pipe segment of the flow. Now, the analysis of the Eq.(18) could be done in several ways of mathematical application. Here is given one of them. Considering the head-loss area for a particular section of the pipe flow not to be as constant, the required equation of this graphical evaluation is given by straight-line equation of Y = MX+C as, $d(A_{eff.})_{I-II} = (\hbar)_{I-II} * dQ[(B)_{I-II}] + 0$. The intercept value is evidently zero & the straight-line graph might be with negative slope or gradient. The –ve sign, if observed in the estimation of the Eq.(18), should indicate the improper axial justification which should be suitable adjusted with. This –ve in the value of the gradient of the Eq.(18) has the only implication to show the pattern of the variation of the said variables in the given relation & to be corrected as well.

EVALUATION 3:

In this evaluation, the differential consideration is also given on to the hydraulic gradient (i) of the pipe flow. In doing so, the differential pipe-flow lengths have come into the picture. The term 'differential' as used thoroughly defines the segmental magnitudes. The head-loss as explained in the Evaluation 1, is hereby as, $\left(\frac{dH}{dQ}\right) = \left(\frac{\Delta H}{\Delta Q}\right) = \left(\frac{h_L}{\Delta Q}\right) = (\Delta i)\left(\frac{\Delta L}{\Delta Q}\right) = \hbar$

In a pipe flow, for a pipe of length 'L' carrying the flow 'Q', $\hbar = \left(\frac{dH}{dQ}\right) = (di)\left(\frac{dL}{dQ}\right) \quad ...(19)$; where, variables like $h_L(or, \Delta H), dQ(or\ \Delta Q), \Delta i(or\ di) \& \Delta L$ be the differential amounts of $H, Q, i \& L$ respectively; $(i) =$ hydraulic gradient (head lost per unit length of traverse of the fluid flow) of the pipe flow which is here under the consideration of the sectional length (L) of pipe. The differential hydraulic gradient is hereby expressed as, $(i) = \left(\frac{H}{L}\right) = \sum_{z=I}^{n}(di)_z = \sum_{z=I}^{n}\left(\frac{h_L}{L_e}\right)_z$; where, H = (Total) Head lost due the pipe flow over the length L; z or Z = the I-th segment to n-th segment of the sectional pipe flow; L_e = segmental pipe-flow length & (i) be the slope of the pipe-bed bearing the segmental head-losses (h_L) of the pipe-flow. And, as said, ΔL & dL have the same meaning & so is (di) for (Δi). Precisely, the Eq.(19) transforms to be for the pipe flow as, $\hbar = \left(\frac{dH}{dQ}\right) = \left[\sum_{z=I}^{n}\left(\frac{h_L}{L_e}\right)_z\left(\frac{dL}{dQ}\right)_z\right] \quad ...(20)$; thereby, the evaluated equations of the V.G. co-efficient (dH/dQ) are obtained by the Evaluation 1, 2 & 3 which can be suitably determined whenever to be required in the foregoing discussion. All these equations, particularly those of the differential forms, are although to be useful in the determination of various subjective laboratorical examinations or model tests to get them on to the checking stage or required direct estimation in order to make this research into better confidences. The findings of the V.G co-efficient are given in the Table 5.

Designers always remain aware of this fact of the hydraulic pressure. So it is a very important physical element of the supply scheme. Keeping this growing scenario of hydraulic pressure requirement, also for future urbanization, detail analysis of the head-loss & its variability concern has been discussed, analyzed & interpreted with schematically representative discussion. A more balance in the design flexibility the network design has gained by this. This explanation is done in the foregoing through the effect of K's presence to deriving out of the defining equations meant to be the path-breaking of design hesitation due to perceptible risk & solving to various design problems related to stability & flexibility.

C.4.0 IMPLICATION OF K

Significance of 'K' could be synthesized & applied by considering it as 'variable' & 'constant' nature, as because of its functional association with the D & L of the pipe-flow so far it is found by the Hazen-Williams formula. This study has examined & derived in its own methodological ways to find the effects of the K only on its variable presence; the 'constant' nature of it may be discussed in continuation of this study although. By the functional presence of 'variable' K, the related functional extractions have been done using the assumption, design consideration, criteria & by the famous Darcy-Weisbach formula $H = KQ^x$ in order to find out the associative estimation of its flow-variables.

C.4.1 THE IMPLICATION – K AS 'VARIABLE'

In this section, the discussion is regarding finding of the behavior & nature of the K on the entire research of network design of flow-variables. Design flow variability or mobility becomes more transparent while a detailed knowledge of the nature of K on the pipe flow & its design optimization is well categorized & indicated through better understanding. Now, in obtaining the general design equation based on the V.G Co-efficient of the Eq.(4), placing the Eq.(10) into the Eq.(1) as, $\left(\frac{dH}{dQ}\right) = (\hbar) = (x)\left(\frac{H}{Q}\right) + (Q^x)\left(\frac{dK}{dQ}\right)$

Or, $(x)\left(\frac{H}{Q}\right) = (\hbar) - (Q)^x\left(\frac{dK}{dQ}\right)$

Or, $H = \left(\frac{Q}{x}\right)\left[(\hbar) - (Q)^x\left(\frac{dK}{dQ}\right)\right] \quad ...(21)$

The Eq. (21) is the network design equation & can be analyzed further by the straight-line graphical representation in order to have the corresponding estimation knowledge & its behavioral pattern by nature of involved variables in itself (Table 6). The criterion & others to make the design subjective are required to be applied into the Eq.(21) to determine the design variables of the pipe flow. The Eq.(21) is further analyzed as follows –

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$$\left(\frac{dK}{dQ}\right) = \left[\left\{(ƕ)\left(\frac{Q}{x}\right)\right\} - (H)\right]\left(\frac{x}{Q^{x+1}}\right)$$

Writing the V.G Coefficient as $\left(\frac{1}{V}\right)*\left(\frac{1}{H}\right) = \left(\frac{A}{Q}\right)*\left(\frac{1}{H}\right)$ as for its functional attachment, $\left(\frac{dK}{dQ}\right) = \left[\left\{\left(\frac{A}{QH}\right)\left(\frac{Q}{x}\right)\right\} - (H)\right]\left(\frac{x}{Q^{x+1}}\right)$

Or, $(H)^2 + \left(\frac{dK}{dQ}\right)\left(\frac{Q^{x+1}}{x}\right)(H) - \left(\frac{A}{x}\right) = 0$

It is quadratic equation & its roots are given in the following equation as the Eq.(22),

$$(H) = \left(\frac{1}{2}\right)\left[-\left(\frac{dK}{dQ}\right)\left(\frac{Q^{x+1}}{x}\right) \pm \sqrt{\left\{\left(\frac{dK}{dQ}\right)\left(\frac{Q^{x+1}}{x}\right)\right\}^2 + 4\left(\frac{A}{x}\right)}\right]$$

Or, $(\mathbf{H}) = \pm\sqrt{\left(\frac{A}{x}\right)}$ ...(23) ; where, $\left(\frac{dK}{dQ}\right) = 0$ (assumed).

This is the equation describing the effect of frictional co-efficient (K) on the head loss with its ignorance. Way of this type of formulation is not to be the least or maximum aim like the kind but there should always be the similar ones to derive out the flow behaviors for better application. The finding of the equation of the term (dK/dQ) is given in the segment C.4.1.1 & the findings of the effect of the K's inclusion are tabulated & given in the Table 6 & Table 7.

C.4.1.1 DETERMINATION OF THE 'COMPONENT' $\left(\frac{dK}{dQ}\right)$

From the Eq.(1) the following derivation could be made as –

$\left(\frac{dK}{dQ}\right) = \left(\frac{1}{Q^x}\right)\left(\frac{dH}{dQ}\right) - (x)\left(\frac{H}{Q^{x+1}}\right)$ ...(24) ; From this equation it is found that the unit of the ratio (dK/dQ) is (sec^2/m^5) whose dimensional representation would be ($T^2 L^{-5}$). Now the Eq. (24) is written in the following format of the straight-line as,

$H = \left\{-\left(\frac{dK}{dQ}\right)\right\}\left(\frac{Q^{x+1}}{x}\right) + \left\{(ƕ)\left(\frac{Q}{x}\right)\right\}$ ...(25). The Eq. (25) is similar to the form of the straight-line form of Y = MX + C; where, Y = H ; X = $\left(\frac{Q^{x+1}}{x}\right)$; M = the Gradient of the straight-line curve = $\left\{-\left(\frac{dK}{dQ}\right)\right\}$; C = the Intercept = $\left\{(ƕ)\left(\frac{Q}{x}\right)\right\}$. Thereby a graph plotted as $\left(\frac{Q^{x+1}}{x}\right)$ versus H along the X & Y axis respectively, shall give the straight-line curve with its gradient M & the intercept value C to be determined as explained in this description (Figure 4a). To determine the Component, here the straight-line nature of the Eq.(1) has been discussed, although this consideration may be by any curve of the other nature of the description. In this way, choosing the design methodology of this study, the defining as well as the designing equations could be taken along & applied also in the subsequent necessity to make the effective design estimation determination whose process is given & detailed in Table 7 which must be in accordance to the Table 6.

C.5 NETWORK DESIGN FORMULATION

Respective ideology of each such derived equation as well as outcome should always be by the design basis of consideration & requires to be handled with utmost care in its procedural steps & application ultimately.

Followings are the criteria of the network design –

Design Criteria No. 1: The H value is equal to 'representative' physical quantity by derived outcome.

Design Criteria No. 2: Absolute 'zero' magnitude of the 'H' is not to be as mandatory one for design.

Design Criteria No. 3: Flow-distribution may be proportionate.

It's required to be mentioned here that only the design criteria (criteria no. 1), is found to be the 'best defined' by implementation of the V.G co-efficient, so long as the significance of the criteria is concerned. Various aspects of the network design have got focused in the light of this derivational innovation. In determining the other evaluated equations of the head lost by the various forms of V.G, the pipe flow design equations, treating K as a variable quantity, are going to be discovered by the three subjective criterias as followed –

In each case of the network design determinations, the ratio (dK/dQ) is, to be required on giving its variable nature into the determination, given in the section C.4.1.1 & Figure 4a. Once again, as explained earlier, all the design equations are given here for the deputed section I-II, though it's indeed exemplary & could be applied eventually to all the required other sections along the flow length of pipe.

C.5.1 NETWORK DESIGN 1

It is corresponding to the Evaluation 1. In this, the equation from the Eq.(7) to the Eq.(17) could be applied into the Eq.(1) to formulate the desired design equation to determine the head-loss, H.

C.5.2 NETWORK DESIGN 2

Here, the Evaluation 2 is to be applied on to the Eq.(1) & it is found as, $ƕ = \left(\frac{dH}{dQ}\right) = \frac{d}{dQ}\left[\left(\frac{A_{eff}}{B}\right)_{I-II}\right] = (x)\left(\frac{H}{Q}\right) + (Q^x)\left(\frac{dK}{dQ}\right)$

Or, $H = \left[\frac{d}{dQ}\left(\frac{A_{eff}}{B}\right)_{I-II} - (Q^x)\left(\frac{dK}{dQ}\right)\right]\left(\frac{Q}{x}\right)$ ...(26)

Eq.(26) is the design equation which could be evaluated & discussed in various of its (possible) forms.

C.5.3 NETWORK DESIGN 3

Applying the Evaluation 3 into the Eq.(1),

$$H = \left[\sum_{z=I}^{n}\left(\frac{h_L}{L_e}\right)_z\left(\frac{dL}{dQ}\right)_z - (Q^x)\left(\frac{dK}{dQ}\right)\right]\left(\frac{Q}{x}\right) \quad ...(27)$$

Eq.(27) is the equation describing the implication of the variable (differential) slopes segmentally.

C.5.4 NETWORK DESIGN 4

In this case, the design equation is given without applying or derivating directly the V.G. Coefficient whereas applying the flow-hydraulics of the pipe-flow & the definition of the gradient (i) as, $H = (i)L = KQ^x$; Or, $L = (K/i) * Q^x$

Differentiating L with respect to Q (considering K as variable),

$H = (i)\left(\frac{dL}{dQ}\right)\left(\frac{Q}{x}\right) - \left(\frac{Q^{x+1}}{x}\right)\left(\frac{dK}{dQ}\right)$ ...(28). The Eq.(28) is thereby the equation describing the implication of the absolute slope (i) with full integrity in presence instead of its differential application – this is the only difference between the Eq.(27) & Eq.(28), although the differential term so brought into it is 'optional' here to the suitable mode of application on as & when basis along the network pipes. The 'new' term (dL/dQ) given here as in the Eq.(27) could also be able to be obtained applying the H-W equation $K = \left(\frac{1}{470}\right)(L/D^{4.87})$, treating K as variable or else & it's one of the research field of interests. The functional variable L & D to the K from its relation is evidently observable to get it on explored which should conform to the related flow mechanics. The Component (dK/dQ) can also be derived out from this relation of K with the L & D in which K case shall be as variable indeed. This term (dK/dQ) is here called as the 'Component' of the equation developed by $H = KQ^x$ for the 'variable' nature of the K value. This component (dK/dQ) which has the functional attachment in terms of the L & D as explained, is also possible to be determined in the way as explained by the Figure 4a, so far as the K is concerned for the pipe-flow by its own nature of variability as considered.

D. RESULTS & DISCUSSION

1) The selection of the axial variables(X,Y) may be of different kinds which are in the equation's extensive involvement. This suitable application of the variables, desirably & alternatively, could evolve the behaviours of the network design equations out to more dimensions to better understanding using tests/validation. These are essentials prior to desired implementation & making the final design layout of the pipe loop in its distribution network. The introduction of the V.G. co-efficient, 'ƕ', has made the network design flexible enough by giving lots of scopes to include & design suitably.
2) The equations obtained & given in the Table 7 need to be evaluated further for exploring its inner meanings on the physical functions of the pipe-flow hydraulics & its corresponding improvements that needs to be checked through with mathematical tools and to be innovated subsequently.

   One example of this type of the exploration is given here. In here, for the feature of the 'general physicality' (Table 7), the required equation is explored as followed – $H = [(ƕ)(Q/x) - \{(Q)^{x+1} \text{ divided by } (x)\} * (dK/dQ)]$ ... (29) which is now represented into the functional form as, Z = (CP1 + DP2); where, functional variable, $C = (ƕ)$, $D = (dK/dQ)$, $P1 = (Q/x)$ &, $P2 = \{(Q)^{x+1} \text{ divided by } (x)\}$. Truthfully C, D, P1 & P2 be all the variables for a particular pipe-flow mechanics so as to satisfy the H as (to be) desired of (Table 8). The flow-estimation determination for the said equation is here done by treating the (ƕ) value as its prime significant feature & it's given in the Table 8 which could also serve as a guiding one (to the other equations) to make check for gaining the design confidence. The procedure of this estimation is the prospective design methodology of the network & it's simple. It's iterative kind of work. In the Table 8, it is shown. In the 1st iteration, the value of Z1 is first to be the estimated based on the 'derived' functional values involved with the Eq.(21) of the Table 7 for the 'general physicality' concern. Then next assumption of the Q needs to be done on the basis of the requirement of the head-loss from the prior (1st iteration) to the desired destination of the head-loss value. This procedure is required to be given the repetition into number of iterations in order to find out better set of the values of the variables. This number depends on the desired value of the head-loss or others as such & the type of the set of values of the variables desired. In this way, by simple iteration method of the Table 8 the design variables could be determined & this procedural estimation should be for all the equations so found & given in the Table 7.

Now, regarding the confidence in the development of the tabulation as well as graphical establishment or the elaboration as described by the Table 8 could be acquired by giving the emphasization on (ƕ) & the procedure in gaining the (design) confidence is quite now given here with the following discussion – As discussed, we've the following straight-line form (Y=MX+C) of the equation as, $(ƕ) = \left(\frac{dK}{dQ}\right)(Q)^x + \left(\frac{x}{Q}\right)(H)$ ... (30)

Now using this Eq.(30), several curves can be plotted in a graph as shown in the Figure 4b for different values of the (H). The graph is (ƕ) versus Q. Thereby, for a particular (H) value, the (ƕ) value of the pertinent equation, Eq.(30), could be determined for the given set of the axial values from the Figure 7 & this variable, ƕ, may be cross-checked with its description in various determinations given earlier. It is essential to mention that the suitable correction needs to be applied accordingly to the pipe 'common' to its adjoining pipes/loops in the distribution network (Figure 1). This correction should conform to achieving to the desired head-loss & etc. In doing this correction, suitable sign conventions should be given to making the adjustments in the flow (by direction) to reach at the desired level of estimation finally.

3) The most useful D-W equation is defined as that the head lost is directly proportional to the Q^x where Q is the pipe flow & 'x' is constant. Mathematically it is written as, $H \propto Q^x$; Or, $H \propto (VA)^x$. For a particular pipe flow having the given flow-area & pipe characteristics, $H \propto (V)^x$ the existence of which has been thoroughly applied in this study to wherever applicable. Here, the inter-relation of the V with H is discussed in a graphical way (Table 9). The Table 8 is prepared for various numerical magnitudes of the V against which the H values are estimated using this functional attachment, $H \propto (V)^x$, for the given pipe characteristic condition of functional terms. The variation or the profile of the V against H is shown in the Figure 5. Findings so determined provide the nature, behaviour & inter-characteristics of the D-W equation subjectively. In the design estimation, suitable use could be done by the Figure 5 depending on the applicability of the derived equations as determined by this study.

E. CONCLUSION (with Future Scope)

(1) The following terms are found to be important –
(a) the rational value of (dH/dQ).
(b) the significance of (dK/dQ).
These terms are having the immense research field of interests. These should be made into established tabular charts to provide as a standard guide in the network design.
(2) The evaluations this study's made are consisting of using themselves to the scopes beyond of this study's range also, to the subjective binding's satisfactory culmination.
(3) As the equations given in the Table 7 are each is having with lots of suitable application oriented outputs, there must be various possible ways of the further determinations & checking which could give excellent results with less errors & further possible research of inter-relations.
(4) From the graphs & tables (including the standard preparatory kinds), lots of its knowledge shall become available in having the pipe network design more visionary, also a lot more new inventions, characteristically.

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APPENDIX A: THE NOTATION APPLIED

Symbol	Description (subject to the flow)	Symbol	Description (subject to the flow)
D	Pipe Diameter	H_{I-II}	Pressure Loss (Pipe Section I to II)
L	Pipe Length	K	Roughness Coefficient
S	Pipe Slope	x	Numerical constant
A	Area of Pipe-flow	ƕ	Velocity-Gain (V.G) co-efficient
V	Velocity in Pipe	d(L)	Differential or Derivative of L
T	Time Of Flow in Pipe	d(T)	Differential of T
Q	Flow-rate in Pipe	d(V)	Differential of V
q	Flow-volume(unit time)	d, Δ	Differential or Derivative
H	Pressure Head Loss in Pipe	0, I. . .n	Pipe section
H_I	Pressure (at section I)	*, /	Multiplication, Division sign, unless mentioned otherwise
H_{II}	Pressure (at section II)	i	Hydraulic Gradient

LIST OF FIGURES:

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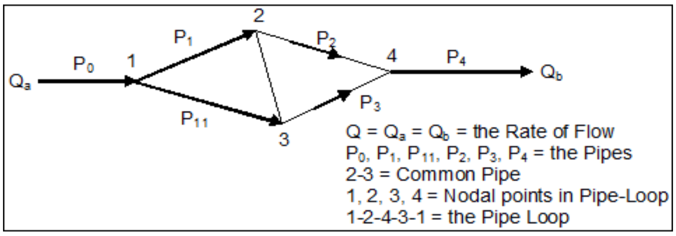

Figure 1: Plan of A Pipe Network (with continuity consideration)

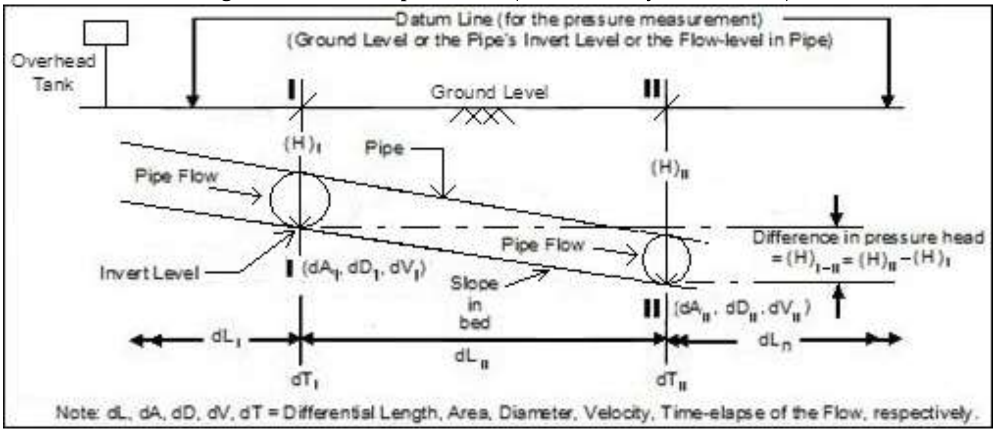

Figure 2: Profile Of Pressure Head & Loss In The Distribution Flow Dynamics

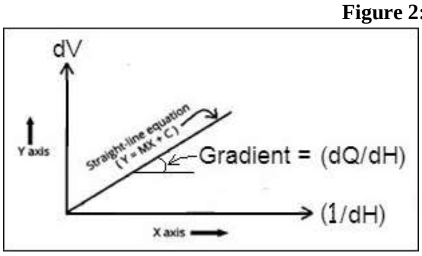

Figure 3: The V.G Co-efficient (dH/dQ)

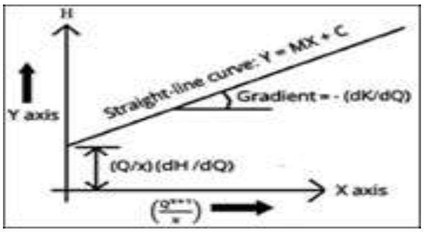

Figure 4a: Determination of (dK/dQ)

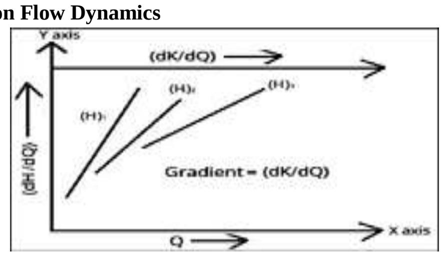

Figure 4b: The Particularly Emphasized Confidence (Both-way Application)

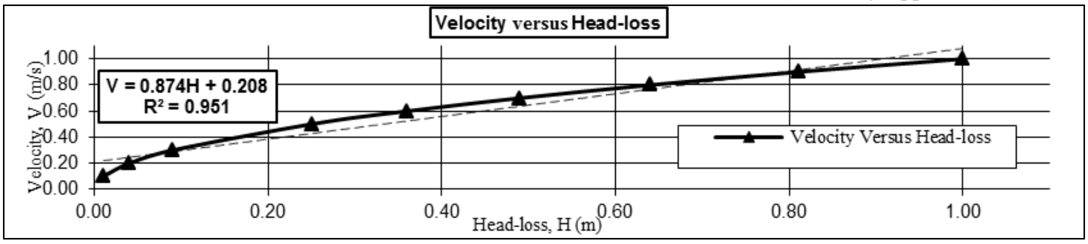

Figure 5: Profile Of The Head-Loss With Flow Velocity (V)

<u>LIST OF TABLES</u>:

Table 1: Kinetic Details At The Section

Section	Time (T) of flow	Velocity (V)^	Area in terms of Pipe Diameter	Energy parameter in terms of Pressure Head
col.(1)	col.(2)	col.(3)	col.(4)	col.(5)
0	T_0	V_0	D_0	H_0
I	T_I	V_I	D_I	H_I
II	T_{II}	V_{II}	D_{II}	H_{II}
III	T_{III}	V_{III}	D_{III}	H_{III}
. . .	. . .	. . .	. . .	. . .
n-1	T_{n-1}	V_{n-1}	D_{n-1}	H_{n-1}
n	T_n	V_n	D_n	H_n

^a representative of the flow-duration as like the col.(4); the area subjected to the sectional length is necessarily to convenience aspect & of research interests.

Table 2: Kinetic Details On The Section

Section		Length (L)	Velocity (V)	Area@	Energy parameter in terms of Head-loss
From	To				
0	I	L_{0-I}	V_{0-I}	A_{0-I}	H_{0-I}
I	II	L_{I-II}	V_{I-II}	A_{I-II}	H_{I-II}
II	III	L_{II-III}	V_{II-III}	A_{II-III}	H_{II-III}
. . .	. . .	. . .	. . .	. . .	. . .
n-1	n	$L_{-(n-1)-n}$	$V_{(n-1)-n}$	$A_{(n-1)-n}$	$H_{(n-1)-n}$

@given in the Table 3 in detail; the diagram area H.P.D or L.P.D is necessarily of the convenience aspect.

Table 3: Effects Of Differential Heads On V.G. Co-Efficient

Section	Differential Head-loss, $[(dH)]$	The V.G co-efficient, $(\text{ƕ}) = \left[\frac{dH}{(dA)(dV)}\right]$
0 to I segment	$(dH)_{o-I} = +[(dH)_I - (dH)_o]$	$(\text{ƕ})_{o-I} = [(dH)\text{divided by}(dA)(dV)]_{o-I}$
I to II segment	$(dH)_{I-II} = +[(dH)_{II} - (dH)_I]$	$(\text{ƕ})_{I-II} = [(dH)\text{divided by}(dA)(dV)]_{I-II}$
II to III segment	$(dH)_{II-III} = +[(dH)_{III} - (dH)_{II}]$	$(\text{ƕ})_{II-III} = [(dH)\text{divided by}(dA)(dV)]_{II-III}$
…	…	…
(n-1) to n-th segment	$(dH)_{(n-1)-n} = +[(H)_n - (H)_{n-1}]$	$(\text{ƕ})_{(n-1)-n} = [(dH)\text{divided by}(dA)(dV)]_{(n-1)-n}$

Table 4: Effect On The Entirety

Section	Differential Head-loss, $[(dH)]$	The V.G co-efficient, $(\text{ƕ}) = \left[\frac{dH}{(dA)(dV)}\right]$
I to n-th segment	$(dH)_{I-n} = +[(dH)_n - (dH)_I]$	$(\text{ƕ})_{I-n} = [(dH)\text{divided by}(dA)(dV)]_{I-n}$

Table 5: Determination of V.G co-efficient (for the segment I to n-th)

$(\text{ƕ})_{I-n} = \left(\frac{dH}{dQ}\right) = \textbf{Function of} \left[\left(\frac{1}{V}\right) * \left(\frac{1}{H}\right)\right] = \textbf{Function of} \left[\left(\frac{A}{Q}\right) * \left(\frac{1}{H}\right)\right]$		
Evaluation 1	**Evaluation 2**	**Evaluation 3**
$[(dH)_n - (dH)_I] * [(dT)\text{divided by }(dA)(dL)]_{I-n}$ $\{(dH)_n - (dH)_I\} * [\{(dA_{eff})_I - (dA_{eff})_n\}(dL_I - dL_n)\text{ divided by }\{(dT)_I - (dT)_n\}]^{-1}$	$\frac{d}{dQ}\left[\left(\frac{A_{eff}}{B}\right)_{I-II}\right]$	$\sum_{z=I}^{n}\left(\frac{h_L}{L_e}\right)_z\left(\frac{dL}{dQ}\right)_z$

Table 6: Profile of Head-loss ($H = KQ^x$) with K

H with K	Description	Remarks
Equation of H (K as constant)	$(dH/dQ) = K(x)(Q^{x-1})$	Effect of K is here kept as constant.
Equation of H (K as variable)	$H = (\text{ƕ})\left(\frac{Q}{x}\right) - \left\{\left(\frac{dK}{dQ}\right)\right\}\left(\frac{Q^{x+1}}{x}\right)$ $(H) = \left(\frac{1}{2}\right)\left[-\left(\frac{dK}{dQ}\right)\left(\frac{Q^{x+1}}{x}\right) \pm \sqrt{\left\{\left(\frac{dK}{dQ}\right)\left(\frac{Q^{x+1}}{x}\right)\right\}^2 + 4\left(\frac{A}{x}\right)}\right]$ $(H) = \pm\sqrt{(A/x)}$	Effect of K is here kept as variable, with approximation as suitable & desired in the determination.

Table 7: Network Design Equations, treating K as Variable

Feature	(ƕ), In terms of the Head-loss (H)
General Physicality (By Evaluation 1)	$[H + (dK/dQ) * (Q)^x](Q/x)$
General Physicality (By Evaluation 2)	$[(2/x) * (A_{eff}/L) - (1/x) * \{(Q)^{x+1}/x\}(dK/dQ)]$
Hydraulic Gradient (differential) (Evaluation 3)	$(1/x) * (Q/dQ)[\{\sum_{z=I}^{n}(h_L/L_e) * (dL)\}_z - (Q^x)(dK)]$
Hydraulic Gradient (absolute kind)	$(i) * (dL/dQ) * (Q/x) - (Q^{x+1}/x) * (dK/dQ)$

Table 8: Variation of the Head-loss (x = 2)

V(m/s)	0.10	0.20	0.30	0.50	0.60	0.70	0.80	0.90	1.00
H(m)	0.01	0.04	0.09	0.25	0.36	0.49	0.64	0.81	1.00

Table 9: The Particularly Emphasized Procedure in Gaining Applicationary Confidence

Variables	Iteration Process				Direction of Estimation
	1st iteration	2nd iteration	3rd iteration	4th iteration	
Q	Assume	Assume (revised)	Assume (2^{nd} revised)	Assume (say the defining one satisfying the desired H)	↓
P1				↕	
P2					
C^					
D%					
Z	Z1	Z2	Z3	Z4 ~ say the final one	

^this value can be determined using the Figure 3.
%derived earlier by the Figure 4.