Simplified Equations and Ansys Simulation of Head Loss on Nonlinear (Sliced) Bend for Piping Network

Moh Abduh[1]*, Suhardjono[2], Sumiadi[2], Very Dermawan[2].

[1]Department of Civil Engineering, Universitas Muhammadiyah Malang, Malang, Indonesia

[2]Department of Water Resources Engineering, Universitas Brawijaya, Malang, Indonesia.

*abduh@umm.ac.id

Abstract. The head loss in the nonlinear bend caused by the friction of the wall along the bend and the direction change of the flow due to suddenly angle change. The essential elements include velocity (U) number of slices (n), length of the average slices wall (Li), angle change (α), friction coefficient (f), acceleration of gravity (g), and slope of the pipe base (S). Based on equation 12, with fixed discharge, the bigger diameter, and more number of slices in used, then the smaller head loss. Conversely, if the diameter used is getting smaller and less the number of slices, then the head loss bigger. This analysis is expected to provide optimal benefits for activities related design to piping networks, especially main networks that use large diameter pipes. Especially piping networks with the use of steel pipe or High-Density Polyethylene pipe materials. Such as oil pipes, gas pipes, and freshwater distribution pipes. The head loss that occurs will more measurable, fast, easy, and economical in implementation.

1. Introduction

As one of the infrastructures needed by the community to support daily life, the pipeline network serves as a means of transportation of fuel, both liquid, gas, and freshwater. The function of the piping network being adequate if each pipe has been assembled into one unit and forms a network. Form a network, and it is necessary to connect each part using a connecting device, one of which is a bend. These connections throughout the trip caused head loss of bend besides head loss due to straight pipe friction.

The theoretical of head loss in bends generally uses the curve bend, and in the field usually is often used nonlinear bend (slices), especially in large diameter of pipes (steel and HDPE). The previous researches and literature studies related different about the head loss in bends. Therefore is needed further research to get efficient equation more for the head loss of bends. The theory of head loss that used is due to friction and due to the direction changes of the flow. Theory of head loss due to friction that occurs in pipelines, the basis of reference refers to the Darcy Weisbach[1] as equation 1:

$$ hf = f \frac{L}{D} \frac{U^2}{2g} \tag{1} $$

With is the head loss due to friction, f is the friction coefficient, L is the length of flow, D is the pipe diameter, U is the velocity, and g is the gravitational acceleration. The basis for head loss due to

changes in flow direction is the head loss caused by the reduced yield of a force due to changes in the direction of the velocity of fluid flowing in the pipeline network.

The head loss that occurs at bend 90°[2]; [3], flow behavior at 90° bend with large curvature ratio using numerical investigations [4], flow characteristics due to bend in the velocity field [5], [6], efficiency and optimization of flow through bend pipes [7].

Research and investigation on vibration at laminar flow through a 90o bend pipe [8], analysis, and study of turbulent flow at pipe bends [9]. Effect of bend radius on erosion that occurs in S-shaped pipe bend wall [10], Study of heat transfer, and fluid flow on U-shaped pipe bend [11], flow changes, and velocity distribution occur due to the influence of the guide on the 90° bend pipe [12].

The developing model in this research is a combination of factors that affect the head loss on the bend. The bend model is nonlinear has various pieces of slice considering the effectiveness and efficiency of the application in the field. Referring to the previous reference, the results of the analysis show differences. Past literature and research only cover two types of curves, curves, and nonlinear. Identification obtained is; bend research results vary, and almost all studies focus on curvilinear curves; Because this subject needs further analysis to obtain a new equation model that is closer.

2. Main Results

2.1. The geometry of Nonlinear Bends 90 deg.

The analysis used in this research, conditions in the field that often occur in Indonesia were usually an obstacle when the existing bend planned but constrained by the provision of curved bend material. Curved bend pipe products are limited, unusually large diameter pipes (Steel and HDPE). Based on the background and field conditions that often encountered, it has illustrated conducting scientific studies so that the phenomenon in the field can be finished and can use as a scientific basis. This phenomenon is closely related to the implementation in the field so that it can be analyzed proportionally.

The head loss in nonlinear bend occurred because due to the friction of the wall of bend (Li) and influenced by changes in the angle of bend (α), and flow becomes slowdown. The elements that influence are velocity (U) number of slices (n), the average length of nonlinear walls (Li), angle changes (α), friction coefficients (f), gravitational acceleration (g) and pipes slope (I) if added. According to the hypothesis described before, the nonlinear bend to explaining the analysis concept as Figure 1 below;
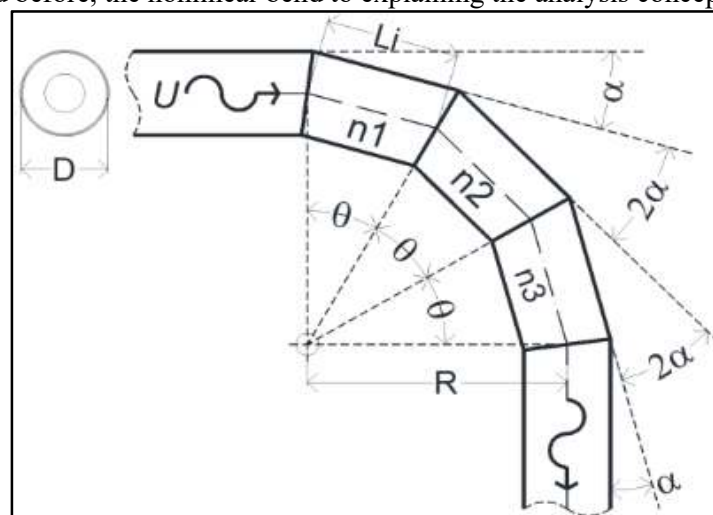

Figure 1. Pipe with a nonlinear bend 90o model

Base on figure 1, the pressurized pipeline used D (diameter), U (velocity), the scheme of the model as Figure 1 above. The bend uses a nonlinear model, the number of slices (n), the radius (R), length of the wall by Li, the direction change of flow as n+1. The angle divide by the number of slices (n), and angle of change first and last is α, for the upstream and downstream sections, the angle of change in the intermediate direction is 2α as n−1. Total of head loss the fluid in the pipe network as passes the 90° bend is pressure loss due to friction and angle changes of the bend. Head loss as friction occurs between

the fluid and the wall of the pipe, while the pressure loss is due to changes in direction because the flow angle changes suddenly on a nonlinear bend.

2.2. Analytical Considerations

Generally, the main problem that always arises is during implementation when using curved curves. To simplify the implementation, a suitable, practical, and economical method needed in the sense that it is easy, fast, and economical to implement. The concept was developed based on the scheme as Figure 1; equation decrease described by calculating the head loss coefficient that occurs using the scheme as in Figure 2 description below. Figure 2, explain about two kinds of slice models, with one slice and with 3 slices. Every section of the slice are equal segments, but the angle of bend is always different, the angle after first and before the last bend is α, but the angle between first and last bend always 2α.
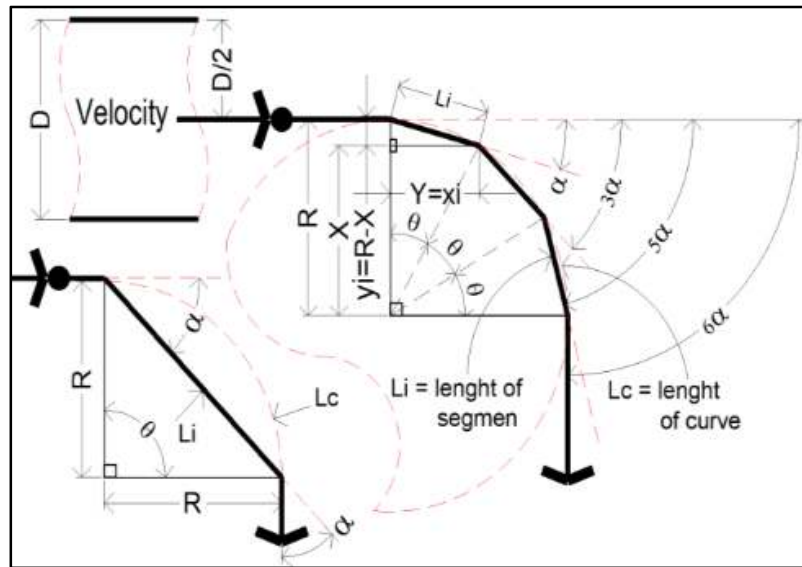

Figure 2. Scheme of nonlinear bend 90° model

Next, the number of slices (n)= 3, the equation calculate as follows:

$$X = R \cos \theta \tag{2}$$
$$Y = R \sin \theta \tag{3}$$
$$\tan \alpha = \frac{Y_i}{X_i} \tag{4}$$

also,

$$\alpha = \tan^{-1}\left[\frac{(R-X)}{Y}\right] = \tan^{-1}\left[\frac{Y_i}{X_i}\right] \tag{5}$$

Length of a linear segment (Li);

$$Li = \frac{Y}{\cos \alpha} = \frac{R \sin \theta}{\cos \alpha} \tag{6}$$

the radius of nonlinear bend (R), angle every slice (θ), direction change angle (α), length of the linear segment (Li), length of a curve (Lc), and the number of a slice (n).

The angle change suddenly causes the flow of a slowdown, with the analytical approach of vector, angular changes as a function of the direction changes. The initial equation is the angle difference of a single bend as in Figure 2, and completely can be explained as follows;

a. the angular changes formed by the nonlinear bend on the angle of direction change first and last are equal to α,

b. the angles of change in the after first and before last of direction change angles formed equal to 2α,

c. the number of slices (n) is 3 then angles α (2 points) and angles 2α (2 points), so the value of vectors is $Cos^2\alpha \times Cos^{(n-1)}2\alpha$,

d. when the number of slice (n) = 1; $Cos^{(n-1)}2\alpha = Cos^{(0)}2\alpha = 1$, equation (7) is $Cos^2\alpha\, Cos^{(0)}2\alpha = Cos2\alpha$.

3. Salient Points

3.1. Frictions

The head loss in a nonlinear bend due to friction must take into account because it occurs in this research. According to the Darcy Weisbach equation, the head loss due to friction that occurs wall along with slices of the pipe (n.Li), the equation 6 substituted in equation 1, if the coefficient of loss due to friction denoted as δ_a the equation becomes;

$Li = \dfrac{Y}{\cos\alpha} = \dfrac{R\,\sin\theta}{\cos\alpha}$ substitution to equation (1) ; $\delta_a = f\dfrac{L}{D}$, so the equation is;

$$\delta_a = f\frac{L}{D} = f\frac{Li}{D} = f\frac{R\,\sin\theta}{D\cos\alpha} \tag{7}$$

If the sum of slices more than 1 or n > 1, the equation is;

$$\delta_a = f\frac{n\,.\,R\,\sin\theta}{D\cos\alpha} \tag{8}$$

The coefficient of friction (f) as equation 8 and the value of the Reynold number (Re) used to get the coefficient friction value. Then the value of friction coefficient (f)[13] as table 1.

Table 1. The friction coefficient for smooth pipes Equation's Friction

Equations	Friction coefficient (f) formulas	(Re) range	Notes
Darcy Weisbach	$f = 64\,Re^{-1}$	$< 3 \times 10^3$	Laminar
Blasius	$f = 0{,}3164\,Re^{-1/4}$	$3 \times 10^3 \sim 1 \times 10^5$	Turbulent
Nikuradse	$f = 0{,}0032 + 0{,}221\,Re^{-0{,}237}$	$1 \times 10^5 \sim 3 \times 10^6$	Turbulent
Karman-Nikuradse	$f = 1 / [2\log_{10}(Re\sqrt{f}) - 0{,}8]^2$	$3 \times 10^3 \sim 3 \times 10^6$	Turbulent
Itaya	$f = 0{,}314 / [0{,}7 - 1{,}65\log_{10}(Re) + (\log_{10}Re)^2]$	-	Turbulent

Source : Nakayama, Y. and Boucher. R. F., (1998), p115-116

3.2. Flow direction changes

The head loss, which is caused by direction change of the flow, accumulates the angle change suddenly in that nonlinear bend. The accumulation of flow direction changes that occur due to changes in angle suddenly is the accumulate of the angular changes suddenly that occur in that nonlinear bend. To find out of the coefficient value of total head loss due to direction changes of flow can use $Cos^2\alpha \times Cos^{(n-1)}2\alpha$, initial flow in upstream of the nonlinear bend is still 100%, and after downstream of the nonlinear bend, the flow is not 100% anymore. Furthermore, the direction change of flow coefficient denoted as δ_b, and then the equation is;

$$\delta_b = 1 - [Cos^2\alpha.\,Cos^{(n-1)}2\alpha] \tag{9}$$

$Cos^2\alpha \times Cos^{(n-1)}2\alpha$ is an upstream flow value (100%) and then due to accumulative of angle change suddenly in nonlinear bend, so the coefficient becomes equation (9).

4. Head Loss Equations

The head loss in a nonlinear bend usually becomes by the friction of pipe wall and direction change of the flow. The combination of friction coefficients and coefficient of direction change of the flow are total head loss in nonlinear bend. If Kb is the total loss coefficient in nonlinear bend, so the final value is equation 8 + equation 9, and the value of Kb is ;

$$Kb = \delta_a + \delta_b = f\frac{n . R \sin \theta}{D \cos \alpha} + 1 - [Cos^2\alpha . Cos^{(n-1)}2\alpha] \tag{10}$$

So the head loss of the nonlinear bend becomes;

$$hL = Kb\frac{U^2}{2g} = \left[f\frac{n . R \sin \theta}{D \cos \alpha} + 1 - [Cos^2\alpha . Cos^{(n-1)}2\alpha]\right]\frac{U^2}{2g} \tag{11}$$

5. Behavior of Flow

Philosophically, the fluid flowing in the pipeline cause contraction when the pipe passed through constriction/enlargement, direction changes of flow. The contraction causes collisions between water particles, causing turbulence in the flow of the pipe. The discussion of this research focuses on changing the direction of flow due to bend, and the friction of the wall in bend, the type of bend being research is a nonlinear bend (various number of slices). With this nonlinear bend model, the behavior of contraction from the water flow causes turbulence up to the downstream part of the pipe. The length of turbulence in the downstream part of the bend shown in figure 3. Besides turbulence of flow, in the downstream of the nonlinear bend creates a pressure drop or head loss.
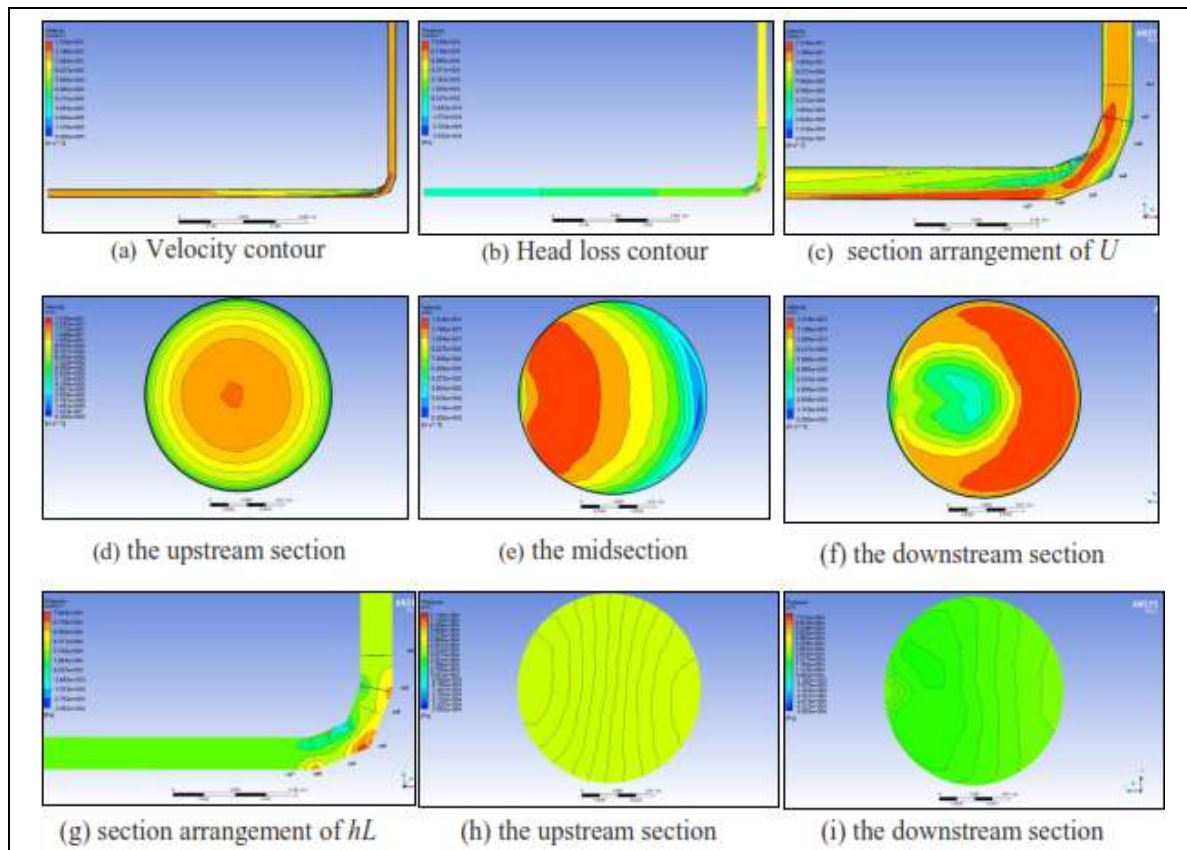

(a) Velocity contour   (b) Head loss contour   (c) section arrangement of U

(d) the upstream section   (e) the midsection   (f) the downstream section

(g) section arrangement of hL (h) the upstream section   (i) the downstream section

Figure 3. The behavior of flow and head loss of nonlinear bend

The simulations of flow in this study providing 10 m/s initial velocity with 25.4 mm diameter of the pipe and used the variation of slices (n) = 2; normal flow occurs at 22D after the nonlinear bend.

While the pressure that occurs in the simulation is $4{,}371 \times 10^4$ Pa in the upstream of bend and downstream of bend becomes $3{,}182 \times 10^4$ Pa. So, the head loss in the nonlinear bend with the variation of slices (n) = 2 is equal to $1{,}189 \times 10^4$ Pa.

6. Case study

The nonlinear bend model of 90o from a pressurized pipeline n = 3 surrounded by water (25oC ε = 0.0000089 kg/cm.s) discharge (Q) = 0.50 liter/s, diameter (D) = 5/8 ", 3/4", 1 ", 5/4" and 6/4" radius of bend (R) = 2D, if Re > 4000 then f = 0.316/(Re^0.25); Calculate : (a) the head loss (hL) on the bend! (b) the coefficient of head loss used to 5/8" diameter of pipe and number of slices (n) = 1 until 20!

Analyzed : Pressurized pipes with a diameter of 5/8" = 1.59 cm so that R = 3.18 cm. Discharge 0.50 liter/s = 500 cm3/s. Pipe cross-sectional area (A) = 1.98 cm2, so that the velocity (U) = 252.74 cm/s. Tested with a friction coefficient (f) = 0.00386 then the Reynolds number (Re) = 45.081 x 106 > 4000 (yes), then with the number of slices (n) = 3 pieces, the angle $\theta = 30^\circ$ and $\alpha = 15^\circ$, with the equation (10) then the value of δ_a = 0.01240 and δ_b = 0.30007 then Kb = 0.31247, for pipes with a diameter of 5/8" with a discharge of 0.50 liter/s = 30 liter/minute, hL = 10,17 cm. In succession with D above, the full value obtained as in the following table 2.

Table 2. Head loss of Nonlinear bend 90 deg.

Item	Unit	90º Nonlinear bend				
		5/8"	3/4"	1"	5/4"	6/4"
Pipe diameter (D)	(inch)	5/8"	3/4"	1"	5/4"	6/4"
Discharge (Q)	(liter/minute)	30	30	30	30	30
Frictione (δ_a)	-	0,01240	0,01298	0,01395	0,01475	0,01543
Direction change (δ_b)	-	0,30007	0,30007	0,30007	0,30007	0,30007
Coeff. of head loss (Kb)	($\delta_a + \delta_b$)	0,31247	0,31298	0,31395	0,31475	0,31543
Head loss (hL)	(cm)	10,17000	4,92000	1,56000	0,64000	0,31000

Source: *Analysis result*

According to the calculation method, the discharge (Q) is 0.60 to 39.00 liters/minute, then the graph of the relationship between the discharge and the head loss 90º nonlinear bend with n = 3, as shown in Figure 4.
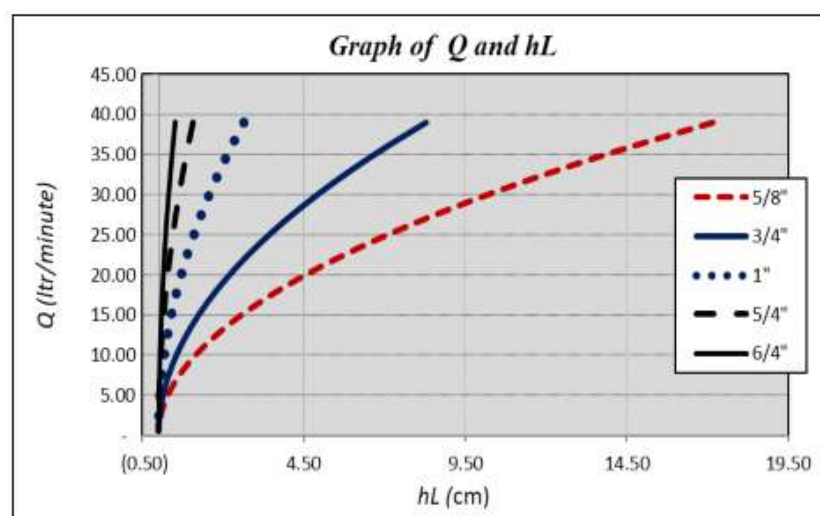

Figure 4. Graph of discharge (Q) and hL

Pressurized pipes with a diameter of 5/8" = 1.59 cm, R = 3.18 cm. Discharge (Q) = 0.50 liter/s = 500 cm3/s = 30 liters/minute. Pipe cross-sectional area (A) = 1.98 cm2, and then the velocity (U) = 252.74 cm/s. Tested with a friction coefficient (f) = 0.00386 then the Reynolds number (Re) = 45.081 x 10^6 > 4000 (yes), using the number of slices (n) from 1 piece into 20 pieces, the angle θ and α depend on n, according to the equation (10) the value of δ_a and δ_b then Kb is obtained as in the following table 3.

Table 3. Head loss coefficient of Nonlinear bend 90 deg. with a variety of slices

Item	Unit	90° Nonlinear bend						
Discharge (Q)	l/minute	30	30	30	30	30	30	30
Number of slices (n)	pieces	1	2	3	4	5	6	7
Frictione (δ_a)	-	0,01543	0,01278	0,01240	0,01227	0,01222	0,01219	0,01217
Direction change (δ_b)	-	0,50000	0,39644	0,30007	0,24139	0,20187	0,17347	0,15207
Coeff. of head loss (Kb)	($\delta_a + \delta_b$)\	0,51543	0,40922	0,31247	0,25366	0,21409	0,18566	0,16424
Number of slices (n)	pieces	8	9	10	11	12	13	14
Frictione (δ_a)	-	0,01215	0,01215	0,01214	0,01214	0,01213	0,01213	0,01213
Direction change (δ_b)	-	0,13538	0,12199	0,11101	0,10184	0,09407	0,08741	0,08162
Coeff. of head loss (Kb)	($\delta_a + \delta_b$)\	0,14753	0,13414	0,12315	0,11398	0,10620	0,09954	0,09375
Number of slices (n)	pieces	15	16	17	18	19	20	21
Frictione (δ_a)	-	0,01213	0,01212	0,01212	0,01212	0,01212	0,01212	
Direction change (δ_b)	-	0,07208	0,06810	0,06454	0,06133	0,05843	0,05522	
Coeff. of head loss (Kb)	($\delta_a + \delta_b$)\	0,08421	0,08022	0,07666	0,07345	0,07055	0,06734	

Source: *Analysis result*

Based on table 3, we implemented the head loss coefficient and the number of slices, as shown in Figure 5.
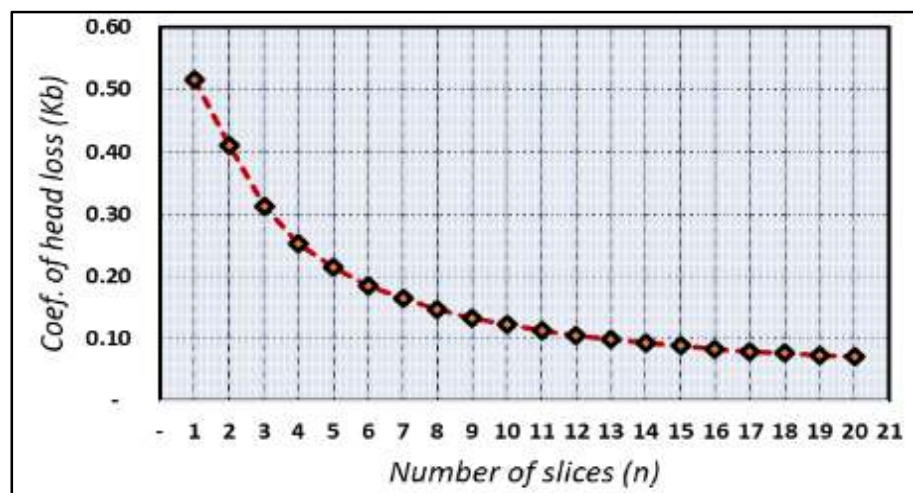

Figure 5. The value of *Kb* and *n* of a nonlinear bend 90°

Figure 4 an explanation of the results of simulating equations only if a nonlinear bend with the number of slices varies. It gives a different head loss coefficient. The graph (Figure 5) also explains that the trend obtained from the simple simulation is by the hypothesis, if the nonlinear bend with a more significant number of slices, then the shape of the bend more excellent or perfectly curved. Similarly, the head loss coefficient, the more slices the head loss coefficient will smaller.

7. Conclusion

The head loss at 90o nonlinear bend is a combination of friction as long as the nonlinear bend, and due to a change in the direction of the bend, the head loss (hL) becomes equation (11). According to equation (11) above, if the flow fixed discharge through the bend, the larger diameter of the pipe passed, the smaller head loss, and the number of slices (n) are more on one diameter, the pipe head losses are also smaller. Conversely, if the diameter used minimum, then the head loss is more significant, also if the value of n smaller.

The contraction of flow causes turbulence when entering upstream and after through the bend. Turbulence due to nonlinear bend occurs quite long in the downstream part of the bend. Following the hypothesis used, it concluded that the trends obtained from these equations showed the relevant results and provided an identical picture when applied to pipe networks to facilitate implementation, time efficiency and can reduce costs incurred.

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