HSR (LONDON),
HOUGHTON STREET REVIEW JOURNAL
ISSN: 2058-5519|Impact factor-15.9
http://houghtonstreetreview.com/index.php/hsr

CALCULATING SPEED PROFILE AND HYDRAULIC RESISTANCE BASED ON FIXED PARAMETERS IN A SMOOTH PIPE AND TESTING IN ANSYS FLUENT

O.Sh. Suvonov, Zh.D. Rakhmanov

doctoral students

Doctor of Technical Sciences (DSc) **B.M. Norkulov**
Samarkand state technical university

Doi: https://doi.org/10.5281/zenodo.23373335

Annotation: The article examines the mutually consistent calculation of local velocities, hydraulic resistance coefficients, and head losses when the parameters of the logarithmic velocity profile in a smooth pressure pipeline are assumed to be constant across the cross-section. Empirical expressions of the Karman parameter κ and the free term C^1 depending on λ were analyzed. When converting the implicit equation determining the resistance coefficient to the Reynolds number, an algebraic inconsistency with respect to the constant term was determined, and the corresponding form was substantiated. An algorithm for the iterative determination of water discharge capacity has been developed. In the conditional example with D=1 m and Q=31.4 m^3/s, the sensitivity to velocity and erosion intensity near the rim of the ring was evaluated. To fully verify the risk of cavitation, a mixture multiphase model, a Zwart–Gerber–Belamry or Schnerr–Sauer cavitation model, and a methodology for assessing local pressure and the proportion of vapor phase in ANSYS Fluent were proposed.

Keywords: smooth pipe, turbulent flow, log speed profile, hydraulic resistance, iterative calculation, cavitation, ANSYS Fluent.

Introduction When calculating pressure pipelines, head losses along the length of the pipeline and local velocities in the flow section must rely on the same physical model. In practice, λ is often determined

by a separate resistance formula, while the velocity profile is determined by constants κ and C_1. If these two approaches are not compatible, the mean velocity, wall shear stress, and local velocities may yield conflicting results.

The problem is particularly significant at high Reynolds numbers and near bulges, rings, or welds within the pipe. A small difference in local velocity creates a large difference in criteria related to a high level of velocity, such as cavitation erosion. At the same time, only the velocity value does not confirm cavitation; local static pressure, steam pressure at water temperature, and the volume fraction of the steam phase must also be determined.

Research method

The object of the study is a turbulent flow formed in a straight circular pressure pipe with a hydraulically smooth internal surface. In the calculation, water was taken as an incompressible liquid, and a section where local resistances were not specified separately was analyzed. The velocity in the logarithmic region is expressed as:

HSR (LONDON),
HOUGHTON STREET REVIEW JOURNAL
ISSN: 2058-5519|Impact factor-15.9
http://houghtonstreetreview.com/index.php/hsr

$$\frac{u(y)}{u*}=\frac{1}{k}In(\frac{u*y}{v})+C_1 \qquad (1)$$

Here u(y) is the average velocity over time at a distance y from the wall; u* is the friction velocity; ν is the kinematic viscosity; κ and C_1 are the profile parameters. In this calculation variant, κ and C_1 are assumed to be constant in cross-section but dependent on λ:

$$K=0.8\sqrt{\lambda}+0.27, \qquad C_1=39.6\sqrt{\lambda}-1.33 \qquad (2)$$

The implicit dependence analyzed for the resistance coefficient is as follows:

$$\frac{1}{\sqrt{\lambda}}-11.8\sqrt{\lambda}-41.5\lambda=3lg(\frac{u*R}{v})-5.42 \qquad (3)$$

R=D/2, where u* and the logarithm argument are related to Re by the following relations:

$$u_*=U\sqrt{\frac{\lambda}{8}}, \qquad \frac{u*R}{v}=\frac{Re\sqrt{\lambda}}{2\sqrt{8}} \qquad (4)$$

The calculation sequence consists of finding U and Re from *Q, D*, and ν, selecting an initial approximation for λ, numerically solving the implicit equation, and then reconstructing the local velocity profile through *u**, *κ*, and C_1.

Algebraic inconsistency in implicit equation

If relation (4) is added to the argument of the logarithm in equation (3), an additional constant term 3lg (2√8) ≈ 2.26 will appear. Therefore, the algebraically consistent form through the Reynolds number should be:

$$\frac{1}{\sqrt{\lambda}}-41.5\lambda-11.8\sqrt{\lambda}-3lgRe-7.68 \qquad (5)$$

Keeping −5.42 on the right side is not equivalent to equation (3). Although this discrepancy appears to be a simple typo, it has a systematic impact on the iterative solution of λ. Therefore, all results in the calculation program, flowchart, and table must be verified based on the given equation.

In the numerical solution, the function f (λ) =0 is constructed and the bracketing method is applied in a positive interval with physical meaning. When using Newton's method, the solution may be unstable if the initial value is chosen incorrectly or the derivative is small. For practical calculations in the range $\lambda\in[0{,}002;0{,}12]$, the Brent method or bisection is more reliable.

HSR (LONDON),
HOUGHTON STREET REVIEW JOURNAL
ISSN: 2058-5519|Impact factor-15.9
http://houghtonstreetreview.com/index.php/hsr

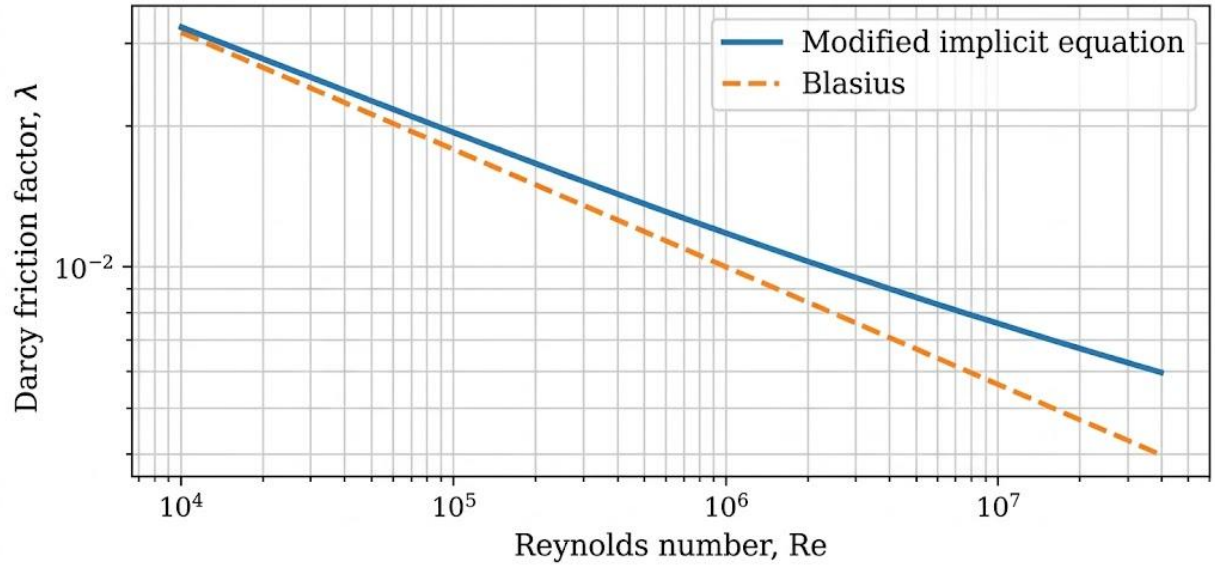


Figure 1. Comparative results of corrected implicit equation and Blasius formula

Re	λ, corrected equation	λ, Blazius	Difference, %
10 000	0.03241	0.03164	2.4
30 000	0.02532	0.02404	5.3
100 000	0.01933	0.01779	8.6
300 000	0.01520	0.01352	12.5
1 000 000	0.01181	0.01001	18.1
2 300 000	0.01000	0.00812	23.1
40 000 000	0.00596	0.00398	49.9

Table 1. Design resistance coefficient values

Calculation of hydraulic resistance and head losses

For given Q, D, and ν, the pipe cross-section, average speed, and Reynolds number are determined as follows:

$$A=\frac{\pi D^2}{4}, \qquad U=\frac{Q}{A}, \qquad Re=\frac{UD}{\nu} \qquad (6)$$

Based on the found λ, u*, κ, and C_1 are determined. Local velocity should only be calculated in the area where the logarithmic law applies. In the immediate vicinity of the wall, a viscous sublayer is required, and in the area near the pipe axis, an external layer is required.

The formal expression for head loss along the length of the pipeline and water flow rate at a given h_f is as follows:

$$h_f=\lambda\frac{L}{D}\frac{U^2}{2g}, \qquad Q=\frac{\pi D^2}{4}\sqrt{\frac{2gDh_f}{\lambda L}} \qquad (7)$$

HSR (LONDON),
HOUGHTON STREET REVIEW JOURNAL
ISSN: 2058-5519|Impact factor-15.9
http://houghtonstreetreview.com/index.php/hsr

In the second expression, λ also depends on Re through Q. Therefore, throughput capacity is determined iteratively rather than directly. Select the initial value Q; Re and λ are calculated; the new Q value is found from the Darsi–Veysbax equation; the process is repeated until the difference between the consecutive values is less than the specified accuracy.

Stage	Calculation operation	Control
1	$A=\pi D^2/4$ and i=h_f/L	Initial data
2	Accept Q_0 or λ_0	Positive physical value
3	Determining U, Re, and λ	Remainder of equation$<10^{-6}$
4	New Q from Darsi–Veysbax	$\lvert Q_{i+1}-Q_i\rvert/Q_i<0{,}1$ %
5	u*, κ, C_1 and k_s^+	Check stream mode
6	recheck u(y) and h_f	Balance and scope

Table 2. Algorithm for determining water flow capacity

Hydraulic smoothness is not determined by a single universal boundary of k_s^+. The shape, density of the surface elements, and the roughness function in the turbulence model also affect the result. Therefore, the $k_s^+<10$ criterion should not be used as a strict limit for all technical surfaces.

Calculation example and speed profile sensitivity

In the conditional example, if D = 1 m, Q = 31.4 m^3/s, and ν = 1.0·10−6 m^2/s, then A ≈ 0.785 m^2, U ≈ 40 m/s, and Re ≈ 4.107 m^2/s. This rate is not typical for drinking water pipes and the source data should be verified with the original source. The corrected equation yields a value of λ≈0.00596; the source also provides a value of λ≈0.009 for comparison.

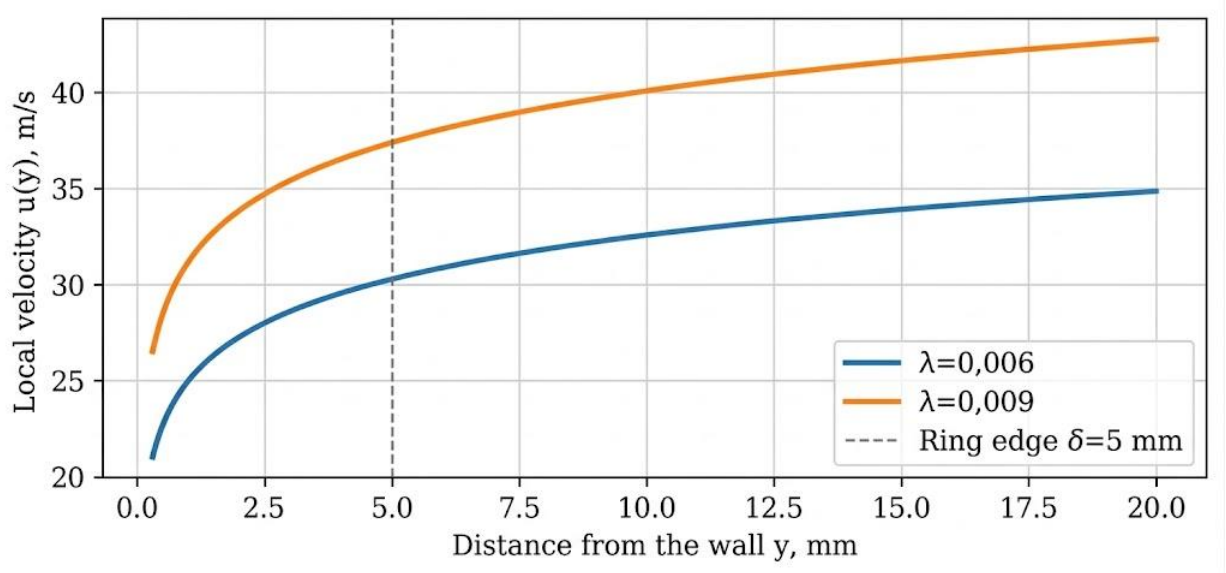


Fig. 2. Effect of the λ value on the design velocity profile near the rim of the ring.

HSR (LONDON),
HOUGHTON STREET REVIEW JOURNAL
ISSN: 2058-5519|Impact factor-15.9
http://houghtonstreetreview.com/index.php/hsr

local velocities at a height of δ=5 mm were estimated at the source as 29.6 and 37.4 m/s, respectively. The difference is 7.8 m/s, or approximately 26% of the first result. This difference arises from the dependent variation of λ, κ, and C_1. However, the direct application of the logarithmic profile to the separated, three-dimensional flow in front of the ring introduces an additional error.

Assuming that the erosion intensity is proportional to the fifth degree of local velocity, the sensitivity is as follows:

Assuming that the erosion intensity is proportional to the fifth degree of local velocity, the sensitivity is as follows:

$$l_e \alpha\, u^5, \qquad \frac{l_{e,2}}{l_{e,1}} = \left(\frac{37.4}{29.6}\right)^5 \approx 3.22 \qquad (8)$$

This coefficient of 3.22 is only a conditional calculation comparison. It does not indicate the actual wear rate of the material. For a final conclusion, the pressure pulsations around the ring, the cavitation cloud, material properties, and test duration must be measured.

Criteria for assessing cavitation risk

Cavitation occurs when the local static pressure approaches or falls below the saturated vapor pressure corresponding to the water temperature. Therefore, in the risk assessment, along with velocity, the criterion for cavitation number and dimensionless roughness is considered:

$$\sigma = \frac{p - p_v}{0.5 p U^2}, \qquad k_s^+ = \frac{u^* k_s}{\nu} \qquad (9)$$

Here p is the local static pressure, and p_v is the vapor pressure of the water. If the total inlet pressure or the average pressure in the pipe is unknown, σ cannot be reliably determined. Consequently, it is scientifically insufficient to conclude that "cavitation exists" based only on the value U=40 m/s.

The edge of the ring narrows the flow, creating a zone of separation and low-pressure recycling at the edge. This process is not fully represented by a one-dimensional logarithmic profile. A three-dimensional numerical model or physical experiment is required to determine the local pressure minimum and the steam phase fraction.

ANSYS Fluent Model

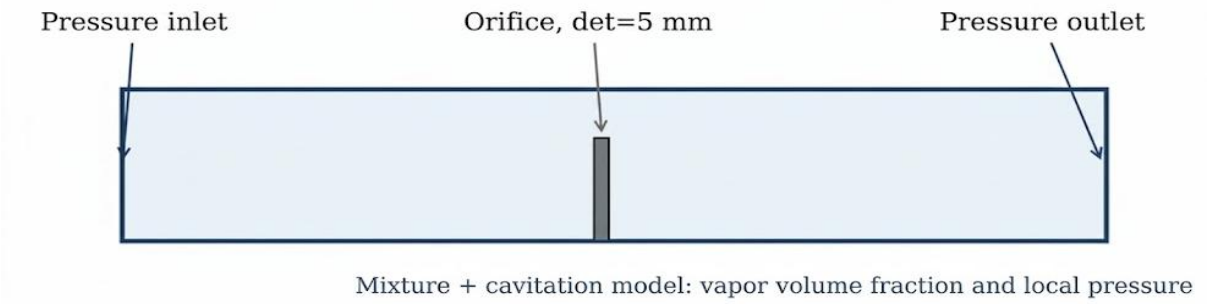


Figure 3. ANSYS Fluent calculation scheme for ring pipeline

HSR (LONDON),
HOUGHTON STREET REVIEW JOURNAL
ISSN: 2058-5519|Impact factor-15.9
http://houghtonstreetreview.com/index.php/hsr

In ANSYS Fluent, a pressure-based solver, a water-vapor two-phase mixture model, and cavitation mass transfer are selected. The Zwart-Gerber-Belamri or Schnerr-Sauer model can be used. First, the solution of the single-phase liquid is approximated, then the cavitation model is enabled. Absolute inlet and outlet pressures, water temperature, turbulence intensity, and hydraulic diameter are specified.

Organizing an ANSYS numerical experiment

Since the velocity and pressure gradients around the edge of the ring are sharp, the local mesh is compacted. The SST k-ω model is used as the primary option for flows with separation and an unfavorable pressure gradient, while the realizable k-ε model is used for sensitivity analysis. The y^+ value must be maintained in accordance with the selected wall approach.

Model element	Acceptable parameter	Result
Geometry	D = 1 m; ring δ = 5 mm.	Separation zone
Phase	Suv va suv bug‘i	Volume fraction of steam
Cavitation	ZGB or Schnerr–Sauer	Interphase mass transfer
Turbulence	SST k–ω; k–ε perceptiveness	u, p or τ_w
Boundary condition	Pressure inlet/outlet	Absolute pressure forced
Net	Locally dense around the edge	3rd degree of independence
Control	p_{min}, α_v, Δp, u_{max}	Cavitation and resistance

Table 3. Basic settings of the ANSYS Fluent computational model

Numerical results cannot be limited solely to the velocity contour. The following values are taken: p_{min} along the ring edge, the maximum volume fraction of the vapor phase α_v, the length of the cavitation zone, the shear stress of the wall, and the total pressure loss. The independence of the mesh is checked separately for p_{min} and α_v, as cavitation results may show high sensitivity to the mesh.

When testing the model experimentally, static pressure sensors, high-speed imaging or an acoustic signal, as well as mass loss on the material surface, are used. The ANSYS model does not replace the experiment; it is a tool for interpreting the pressure and velocity field and identifying the danger zone.

Conclusions and practical recommendations

1. In a smooth pipe, λ, u*, κ, C_1 and $u(y)$ must be calculated in relation to each other; the inconsistent use of separate formulas increases the local velocity error.
2. When writing the resistance equation through Re, the algebraically appropriate constant term is −7.68; Leaving the value −5.42 unchanged is not equivalent to the original equation.
3. Due to the dependence of water discharge capacity λ on Re, it should be determined iteratively and the criteria for convergence regarding residual and flow rates should be specified.
4. The result at Re=4·107 is an extrapolation outside the range specified in the experiment and must be verified by independent experiment or DNS/CFD.
5. The risk of cavitation near the ring edge should be assessed not only by velocity, but also by p_{min}, p_v, and the fraction of the vapor phase.

HSR (LONDON),
HOUGHTON STREET REVIEW JOURNAL
ISSN: 2058-5519|Impact factor-15.9
http://houghtonstreetreview.com/index.php/hsr

6. A three-dimensional mixture-cavitation model, grid independence, and a sensitivity analysis of at least two turbulence/cavitation models are recommended in ANSYS Fluent.

References

1. Nikuradse, J. (1950). Laws of flow in rough pipes. NACA Technical Memorandum 1292.
2. Prandtl, L. (1932). Zur turbulenten Strömung in Rohren und längs Platten. Ergebnisse der Aerodynamischen Versuchsanstalt zu Göttingen, 4, 18–29.
3. Colebrook, C. F. (1939). Turbulent flow in pipes, with particular reference to the transition region between the smooth and rough pipe laws. Journal of the Institution of Civil Engineers, 11, 133–156.
4. Moody, L. F. (1944). Friction factors for pipe flow. Transactions of the ASME, 66, 671–684.
5. Haaland, S. E. (1983). Simple and explicit formulas for the friction factor in turbulent pipe flow. Journal of Fluids Engineering, 105(1), 89–90. https://doi.org/10.1115/1.3240948
6. Bailey, S. C. C., Vallikivi, M., Hultmark, M., & Smits, A. J. (2014). Estimating the value of von Kármán's constant in turbulent pipe flow. Journal of Fluid Mechanics, 749, 79–98. https://doi.org/10.1017/jfm.2014.208
7. Pope, S. B. (2000). Turbulent Flows. Cambridge University Press.
8. Schlichting, H., & Gersten, K. (2017). Boundary-Layer Theory (9th ed.). Springer.
9. White, F. M. (2016). Fluid Mechanics (8th ed.). McGraw-Hill Education.
10. Franc, J. P., & Michel, J. M. (2004). Fundamentals of Cavitation. Kluwer Academic Publishers.
11. Brennen, C. E. (1995). Cavitation and Bubble Dynamics. Oxford University Press.
12. ANSYS, Inc. (2026). Ansys Fluent Theory Guide: Cavitation Models.
13. ANSYS, Inc. (2025). Ansys Fluent User's Guide: Steps for Using a Multiphase Model.
14. Zwart, P. J., Gerber, A. G., & Belamri, T. (2004). A two-phase flow model for predicting cavitation dynamics. International Conference on Multiphase Flow.
15. Schnerr, G. H., & Sauer, J. (2001). Physical and numerical modeling of unsteady cavitation dynamics. Fourth International Conference on Multiphase Flow.