ACTA TECHNICA CORVINIENSIS – Bulletin of Engineering
Tome V (Year 2012). FASCICULE 3 [July–September]. ISSN 2067-3809

[1.] Vasile ALEXA

SIMULATION OF HYDRAULIC LOAD LOSSES IN PIPES, USING THE WORKING MEDIUM "ADINA"

[1.] UNIVERSITY POLITEHNICA TIMISOARA, FACULTY OF ENGINEERING HUNEDOARA, HUNEDOARA, ROMANIA

ABSTRACT: *The fluid analysis module of the program is fluid solver for compressible and incompressible fluid provides a world-class finite element solutions and the ability to control the flow, fluid can contain free surface and fluid, as well as fluid flow and structure of the interface between. This paper presents a method of simulation and presentation of the load losses in a fluid flowing through a pipe. It also presents a study on the algorithm for calculating these losses depending on the flow regime & pipe type, and the determination of the longitudinal load loss coefficient. The theory and numerical methods used in the program for laminar and turbulent flow are summarized and then the solutions of various problems are presented.*

KEYWORDS: *hydraulic load losses, pipes, simulation, Adina program*

INTRODUCTION

ADINA has a wide range of simulation capabilities in mechanical field and has applications in such areas. ADINA program is the basic structure of the solver for solid, truss, beam, pipe, metal plate, shell and crannies provide diversification and general finite element analysis capabilities.

ADINA is based on the finite element and finite volume discrete map, with a very comprehensive and efficient solution to address all of arbitrary geometry flows. The fluid analysis module of the program is fluid solver for compressible and incompressible fluid provides a world-class finite element solutions and the ability to control the flow, fluid can contain free surface and fluid, as well as fluid flow and structure of the interface between.

Besides being used widely in industries, the ADINA System is also used effectively in teaching and research at universities all around the world. ADINA offers many attractive capabilities for use as a teaching and research tool.

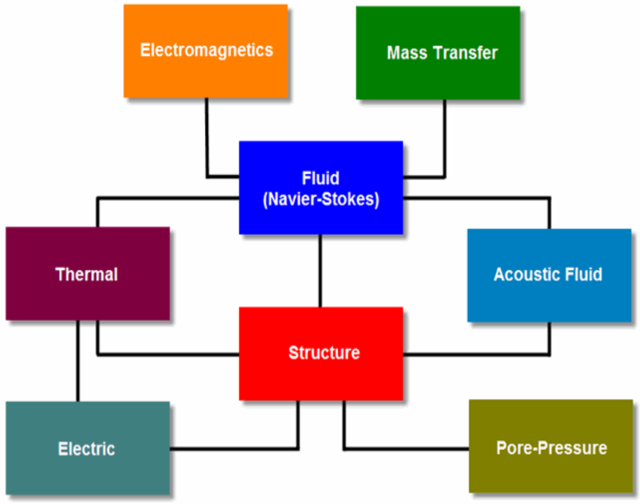

Figure 1. Fluid structure interaction [1]

Fluid-structure interaction (FSI) occurs when fluid flow causes deformation of the structure. This deformation, in turn, changes the boundary conditions of the fluid flow.

The above presented figure showed the fluid-structure interaction analysis of a membrane valve. Here, the fluid pressure deforms the membrane which changes the boundary conditions of the flow [1].

When the real fluids flow through pipes, two types of hydraulic losses occur:

- Linear losses h_{pd}, (longitudinal or distributed), mathematically expressed by the Darcy's formula:

$$h_{pd} = \lambda \frac{l}{d} \frac{v^2}{2g} \tag{1}$$

- Local losses h_{pl}, mathematically expressed by the Weisbach's formula:

$$h_{pl} = \xi \frac{v^2}{2g} \tag{2}$$

where:

- l - lenght of pipe $[m]$;
- d - diameter pipe $[m]$;
- v - average speed section $\left[\frac{m}{s}\right]$;
- g - acceleration of gravity $\left[\frac{m}{s^2}\right]$;
- λ - linear coefficient of hydraulic losses;
- ξ - local hydraulic loss coefficients to different types of hydraulic resistance.

The flow regime in pipes is characterised by the Reynolds similarity criterion value, Re, in relation to its critical value:

$$Re = \frac{vd}{\nu} \tag{3}$$

where: "ν" represents the constitutive coefficient of the kinematics' viscosity.

The flow regime can be:

- ☐ *laminar:* $Re < Re_{crt} = 2320$;
- ☐ *turbulent:* $Re > Re_{crt} = 2320$.

The problem of determining the λ coefficient is the fundamental problem of pipe calculation. Nikuradse is the first who undertook a systematic study of this coefficient, establishing its relationship with the flow regime and the relative roughness, and drawing the diagram that bears his name [2].

An American engineer Lewis F Moody (1880-1953) prepared the diagram shown in figure 1 for use with ordinary commercial pipes. Today, the Moody diagram is still widely used and is the best means available for estimating the friction factor.

The fact that λ depends both on the Reynolds number and the wall roughness, makes it difficult to use unique formulas to calculate it, assuming that l, ν, d, v and k (equivalent roughness) are known [2].

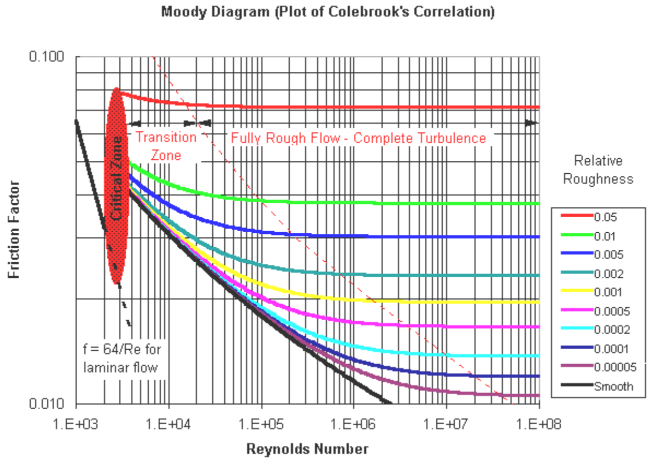

Figure 2. Moody diagram

a) If $Re < Re_{crt} = 2320$ (the flow regim laminar), for calculation of the Hagen-Poiseuille's relationship using:

$$\lambda = \frac{64}{Re} \tag{4}$$

b) If $Re > Re_{crt} = 2320$ (the flow regim turbulent), using Moody's criterion:

$$CRIT = Re\sqrt{\lambda_i}\,\frac{k}{d} \tag{5}$$

To assess this criterion, we approximate λ, admitting that its value is within the range:

$$\lambda_i = (0.02\text{-}0.04).$$

Depending on the value of this criterion, which describes the nature of the pipe, we shall apply one of the relations:

b.1. *Hydraulically smooth pipe – CRIT < 9.4, the linear loss coefficient depends only on the flow regime λ=λ(Re). Therefore, we shall apply one of the relations:*

- ☐ Blasius - for $Re < 10^5$

$$\lambda = \frac{1}{\sqrt[4]{100Re}} \tag{6}$$

- ☐ Prandtl - for $10^5 < Re < 3\cdot 10^6$

$$\frac{1}{\sqrt{\lambda}} = 2\lg\left(Re\sqrt{\lambda_i}\right) - 0,8 \tag{7}$$

- ☐ Konakov - for $3\cdot 10^6 < Re < 10^7$

$$\frac{1}{\sqrt{\lambda}} = 1,8\lg Re - 1,5 \tag{8}$$

b.2. *The pipe is under transition from hydraulically smooth to hydraulically rough 9.4 < CRIT < 200, the linear loss coefficient depends on the flow regime, but also on the equivalent roughness of the pipe $\lambda = \lambda(Re, \frac{k}{d})$, being applicable the relation of Colebrook-White:*

$$\frac{1}{\sqrt{\lambda}} = -2\lg\left(\frac{2.51}{Re\sqrt{\lambda_i}} + \frac{k}{3.71d}\right) \tag{9}$$

b.3. *Hydraulically rough pipe – CRIT > 200, the linear loss coefficient depends only on the equivalent roughness of the pipe $\lambda = \lambda\left(\frac{k}{d}\right)$, being applicable the relation of Karman-Nikuradse:*

$$\frac{1}{\sqrt{\lambda}} = 2\lg\left(\frac{k}{d}\right) + 1.14 \tag{10}$$

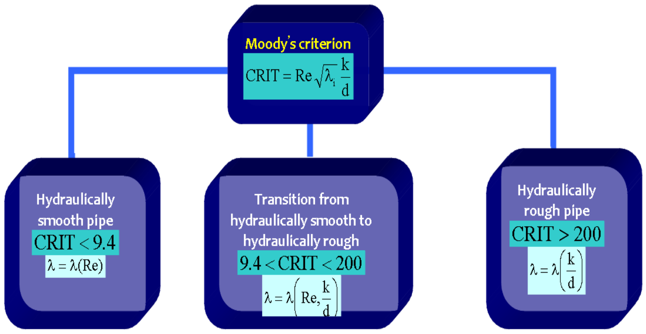

Figure 3. Algorithm to determinate the linear loss cofficient λ

Having the λ coefficient calculated with one of the above relations (case of the turbulent regime), we will check the value of Moody's criterion, which must correspond to the initially admitted domain. Otherwise, "λ" shall be recalculated applying the formula of the new value of the criterion, i.e. of the new hydraulic character of the pipe.

SIMULATION OF LINEAR LOAD LOSSES, USING THE WORKING MEDIUM "ADINA"

The ADINA CFD program provides state-of-the-art finite element and control volume capabilities for incompressible and compressible flows. The flows may contain free surfaces and moving interfaces between fluids, and between fluids and structures.

The procedure used in ADINA CFD is based on finite element and finite volume discretization schemes, with a most general and efficient solution approach. General flow conditions in arbitrary geometries can be solved.

The steps taken to realise the simulations, using the CFD-3D model, were as follows:

a) Establishing the scope of analysis – From the point of connection in the basement to the first consumer who lives on the ground floor, the length is 3.5 meters, and the other consumers are placed vertically, three meters apart from each other.

The maximum circulated flow is $1.25 \cdot 10^{-3} \left[\frac{m^3}{s}\right]$ (Figure 4).

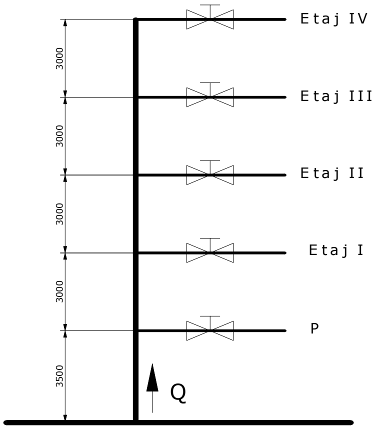

Figure 4. Case studied

b) Establishing the flow parameters – To determine the linear loss coefficient, we will consider the vertical water column (pipe) of a block P+4 (ground floor + 4 floors), which has the diameter d = 0.03 [m] and the roughness k = 0.0014 m.

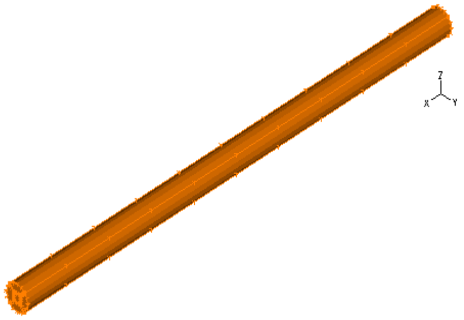

Figure 5. Establishing the flow parameters

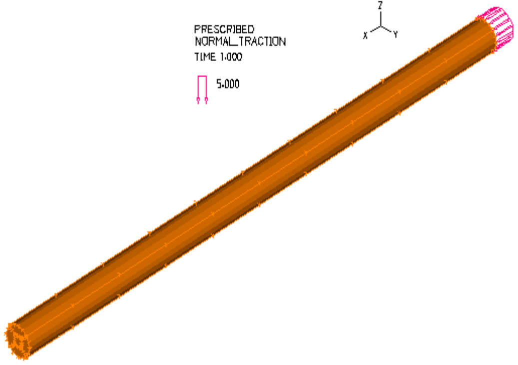

Figure 6. Establishing the loads (5 bar)

c) Establishing the properties of the material – thermo-physical properties of the material and fluid, respectively;

d) Establishing the loads – as loads, we have the 5 bar pressure

e) Finite element discretisation of the analysis domain. After generating the discretisation network, we obtained 979 nodes and 4800 finite elements.

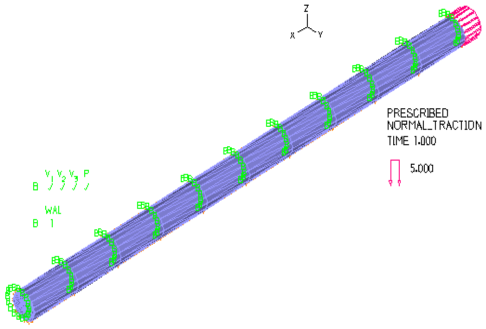

Figure 7. Finite element discretisation of the analysis domain

f) Establishing the conditions on the outline – the pipe was assimilated as a wall with 1.4 µm roughness and 0.03 m diameter.

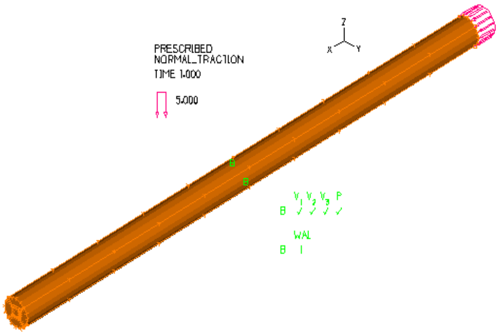

Figure 8. Establishing the conditions on the outline

CONCLUSION AND RESULTS OF NUMERICAL SIMULATIONS

The theory and numerical methods used in the program for laminar and turbulent flow are summarized and then the solutions of various problems are presented.

In this paper we presented the methodology for determining the linear pressure loss coefficient and pressure fluctuation in the pipe, using the working medium "ADINA".

The pressure variation in the pipe:

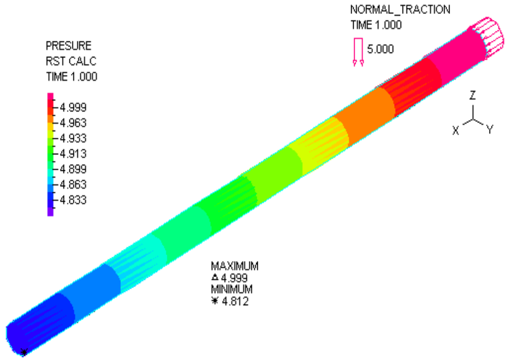

Figure 9. The pressure variation in the pipe

The velocity field in different planes:

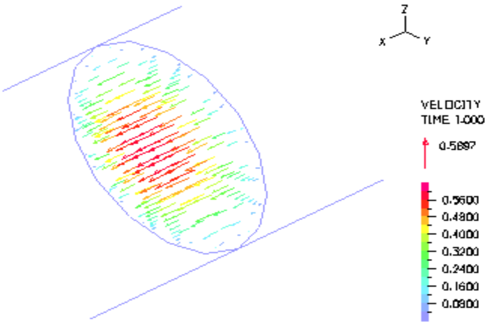

Figure 10. The velocity field in a plane perpendicular to the X-axis

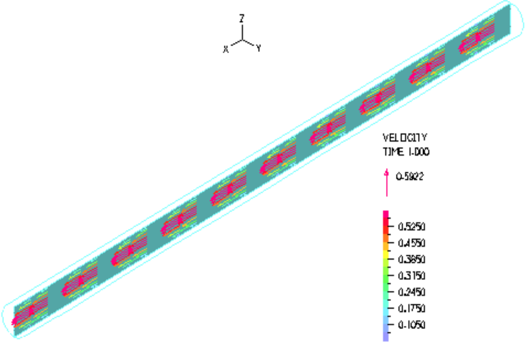

Figure 11. The velocity field in a plane perpendicular to the Y-axis

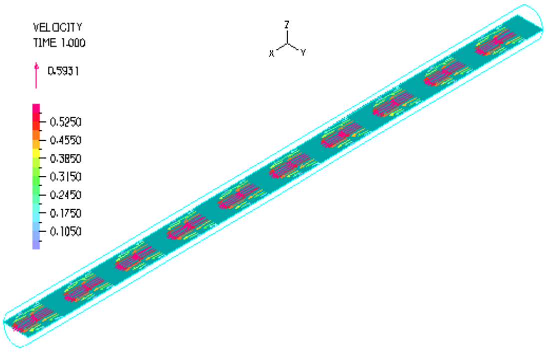

Figure 12. The velocity field in a plane perpendicular to the Z-axis

Fluid–structure interaction (FSI) can be simulated the velocity field in different planes and the pressure variation in the pipe.

REFERENCES

[1.] *Mark A. Robinson, Paul R. Sparrow, Chris Clegg, Kamal Birdi, Design engineering competencies: future requirements and predicted changes in the forthcoming decade, Design Studies, Volume 26, Issue 2, March 2005, Pages 123-153*

[2.] *V. Braibant, G. Sander, Optimization techniques: Synthesis of design and analysis, Finite Elements in Analysis and Design, Volume 3, Issue 1, April 1987, Pages 57-78*

[3.] *H.W. Wagener, K.J. Pahl. Energy flow, energy losses and efficiency of the hydraulic press system, Journal of Mechanical Working Technology, Volume 17, August 1988, Pages 93-102*

[4.] *P. Doron. D. Barnea, Flow pattern maps for solid-liquid flow in pipes, International Journal of Multiphase Flow, Volume 22, Issue 2, April 1996, Pages 273-283*

[5.] *T. Kava. R. Pérez, C. Gregori, A. Torres, Numerical simulation of transient operation of loop heat pipes, Applied Thermal Engineering, Volume 28, Issues 8–9, June 2008, Pages 967-974*

[6.] *K. Dasgupta, A. Chattapadhyay, S.K. Mondal, Selection of fire resistant hydraulic fluids through system modeling and simulation, Simulation Modelling Practice and Theory, Volume 13, Issue 1, January 2005, Pages 1-20*

[7.] *W. Borutzky, B. Barnard, J. Thoma, An orifice flow model for laminar and turbulent conditions, Simulation Modelling Practice and Theory, Volume 10, Issues 3–4, 15 November 2002, Pages 141-152*

[8.] *Dídia Covas, Iva N. Stoianov, Joao F. Mano, Helena Ramos, Nigel Graham, Cedo Maksimovic, The dynamic effect of pipe-wall viscoelasticity in hydraulic transients. Part II—model development, calibration and verification, Journal of Hydraulic Research, Volume 43, Issue 1, 2005, pages 56-70*

[9.] *Valentin Heller, Scale effects in physical hydraulic engineering models, Journal of Hydraulic Research, Volume 49, Issue 3, 2011, pages 293-306*

[10.] *Michael B. Abbott, Karsten Havn, Sten Lindberg, The fourth generation of numerical modelling in hydraulics, Journal of Hydraulic Research, Volume 29, Issue 5, 1991, pages 581-600*

[11.] *Hricová, B., Nakatová, H., Badida, M., Lumnitzer, E.. (2009) Aplication of ecodesign and life cycle assessment in evaluation of machine products, MMA 2009, Novi Sad, Serbia, p. 250-253*

[12.] *Hricová, B., Nakatová, H., Badida, M., Lumnitzer, E.. (2009) Utilisation of tools of environmental management in evaluation of environmental profile of products, MTeM 2009, Cluj-Napoca , Romania, p. 317-320*

[13.] *Košťál, P., Mudriková, A., Velíšek, K. (2008). Material flow in flexible manufacturing. 4th International Scientific Conference of the Military Technical College. The 13th International Conference on Applied Mechanics and Mechanical Engineering, Arab Republic of Egypt, Cairo*

[14.] *Lamár, K. (2004), Digital Control of Permanent Magnet Synchronous Motors, Proceedings of the Budapest Tech Jubilee Conference, Budapest, Hungary, pp. 213-228*

[15.] *Antal, G., Lamár, K. (2002), Modern Solutions to Integrated Building Automation Systems, Proceedings of the International Conference "Kandó 2002", Budapest, Hungary, p.5-10*

[16.] *Neszveda, J. (2009). Safety Lifecycle of Intermittenly Operated Device, Academic and Applied Research in Military Science, Vol.8, Issue 2, pp. 203–211*

[17.] *Anagnostopoulos, J. (2003), Discretization of transport equations on 2D Cartesian unstructured grids using data from remote cells for the convection terms. International Journal for Numerical Methods in Fluids 42(3), 297 – 32*

[18.] *Choudhary, K., Mazumdar, Dipak, (1995). Mathematical modeling of fluid flow, heat transfer and solidification phenomena in continuous casting of steel, Steel Research, 66, No. 5*

[19.] *F. Stella, M. Giangi, F. Paglia, A. Casata, D. Simone, P. Gaudenzi, A numerical simulation of fluid–structure interaction in internal flows, Numerical Heat Transfer, Part B: Fundamentals: An International Journal of Computation and Methodology, Volume 47, Issue 5, 2005, pages 403-418*

[20.] *Peter Beater, Modeling and Digital Simulation of Hydraulic Systems in Design and Engineering Education using Modelica and HyLib, Modelica Workshop 2000, 2000, Lund, Sweden*

[21.] *W. Borutzky, B. Barnard, J. Thoma, An orifice flow model for laminar and turbulent conditions, Simulation Modelling Practice and Theory, Volume 10, Issues 3–4, 15 November 2002, Pages 141–152*