TECHNICAL UNIVERSITY OF LIBEREC

Faculty of Mechanical Engineering

Department of Power Engineering Equipment

Fluid Mechanics 2
Hydrodynamics

doc. Ing. Václav Dvořák, Ph. D.

Liberec 2018

Reviewed by: prof. Ing. Pavel Šafařík CSc.

ISBN 978-80-7494-440-6

Preface

This textbook is intended for additional study of the subject “Fluid Mechanics” taught at the Department of Power Engineering Equipment of the Faculty of Mechanical Engineering of the Technical University of Liberec. This is the subject taught in the third year of the Bachelor’s and Master’s degree programmes.

The examples contained in the textbook are based on the examples for the exams of the subject between 2006 and 2015 when I used to publish the examples including solutions after the exam. Because students repeatedly show their interest in our own collection of examples from the field of fluid mechanics and because I feel the need to improve their preparation before the exam, I decided to go through the older examples for the exams, to complete them, to correct any errors and to publish them as a textbook.

Besides the examples and results, the textbook includes solution procedures. It is therefore up to the student whether he/she chooses more difficult but more correct procedure in the preparation for the exam or credit, i.e. he/she tries to calculate the example by himself/herself and subsequently “consults” his/her procedure with the procedure referred to in the textbook. A few example has only one correct solution procedure. The other, easier but also less effective, methodology of the study is to check the procedure step by step, which can lead to the fact that the student more and more looks at the example resolved and only “copies” the example. We should have no illusions about the efficiency of the procedure when the student only “reads” the examples, where possible, on the tablet or mobile phone screen.

I believe that the textbook will become a welcome addition to the study of fluid mechanics. Finally, I wish to thank those colleagues from the department, who were forced to correct the examples solved by students during each exam, thus contributing indirectly to this textbook. Last but not least, I thank my colleague Ing. Jan Drobeček for his help in completing the textbook, especially for editing and rewriting formulas and text formatting.

In Liberec, 09/11/2017

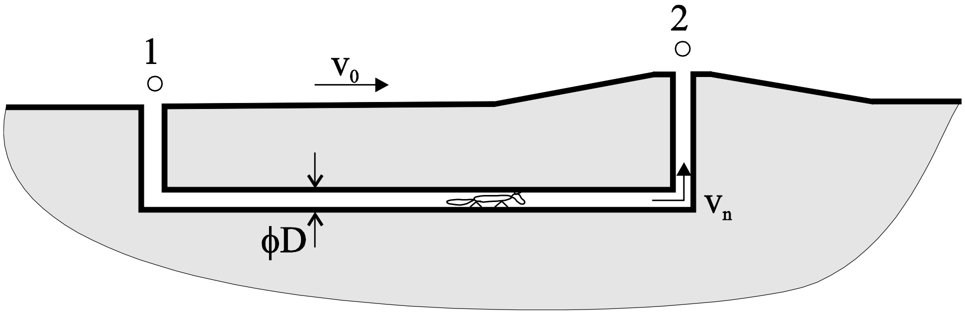
Václav Dvořák

Content

2. Hydrodynamics

2.1. Flow of Inviscid Fluid

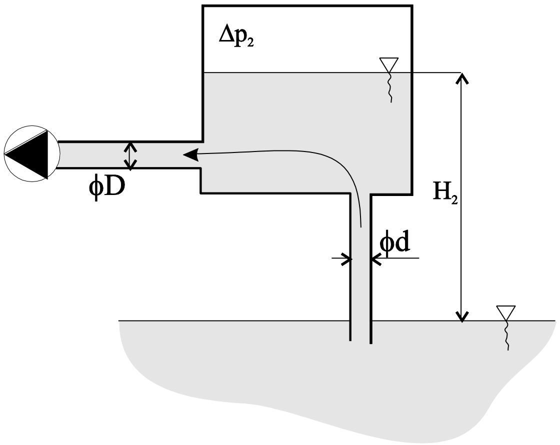
Example 2.1.1.



Some animals use the Bernoulli's principle even without completing the course of fluid mechanics. The animal hole shown in the figure has two exits. The front entrance (1) provided on the flat ground and the rear entrance (2) dug on a small mound. The air flow rate v_0 causes the air flow rate to increase by 7% in the place of small mound (2). Determine the pressure differential between points (1) and (2) at an air flow rate $v_0 = 10\ m\ s^{-1}$ at a density of air $\rho = 1.2\ kg\ m^{-3}$.

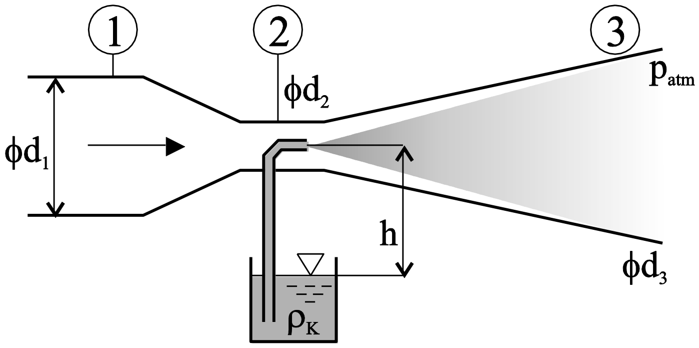
In addition, determine the air flow rate in the hole v_n and the volumetric flow rate of air through the hole with a diameter of 15 cm for the given pressure differential. Neglect resistance of a fox in a hole.

Example 2.1.2.



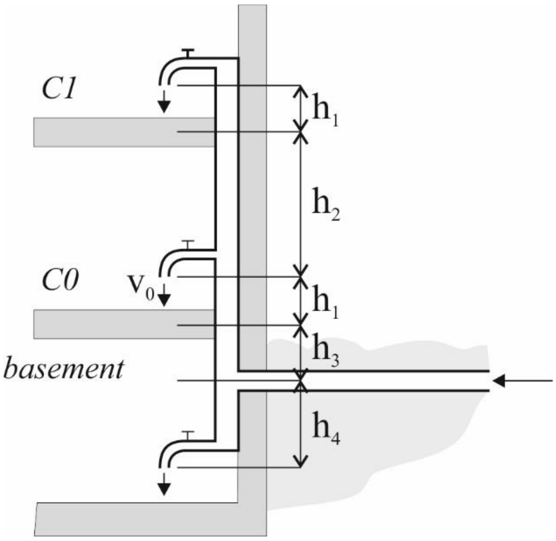
Calculate the volumetric flow of the water sucked in by the pump shown in the figure, if the pipe diameter is $D = 100\ mm$, $d = 64\ mm$, water level is $H_2 = 2\ m$ and tank vacuum is $\Delta p_2 = 25\ kPa$.

Example 2.1.3.



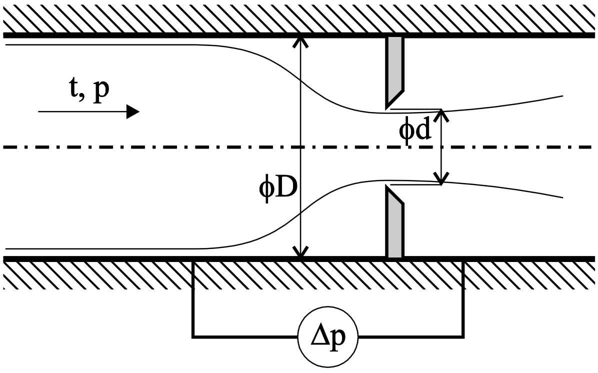
The airbrush shown in the figure sucks in the fluid with a density $\rho_k = 800\ kg\ m^{-3}$ from the container. Calculate the minimum air velocity at point (1), at which the fluid is sucked.
The values are as follows: $d_1 = 12\ mm$, $d_2 = 6\ mm$, $d_3 = 16\ mm$, $h = 8\ cm$ and air density $\rho = 1.2\ kg\ m^{-3}$.

Example 2.1.4.



Water emerges from the tap in the classroom C0 (ground floor of building C in the figure) at a maximum velocity $v_0 = 18\ m\ s^{-1}$. Determine the maximum velocity at which water emerges in the classroom C1 and in the basement. Different heights are $h_1 = 1.2\ m$, $h_2 = 3\ m$, $h_3 = 1.8\ m$ and $h_4 = 1.5\ m$.

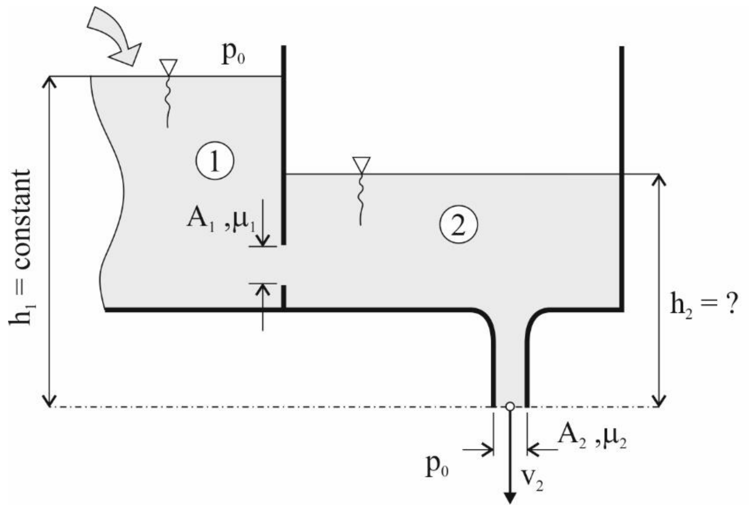
Example 2.1.5.



Determine the mass and volumetric flow rate of air in a pipe with a diameter $D = 71\ mm$ if the differential pressure measured on an orifice plate inserted in a pipe is $\Delta p = 760\ Pa$. The ratio of diameters of orifice plate to pipe is $\beta = d/D = 0.45$, temperature and absolute pressure measured upstream of the orifice place were $t = -32.8°C$ and $p = 240\ kPa$, respectively. Solve the task as the flow of an incompressible fluid. Determine the density by using the equation of state for ideal gas. Determine also the velocity in an orifice plate.

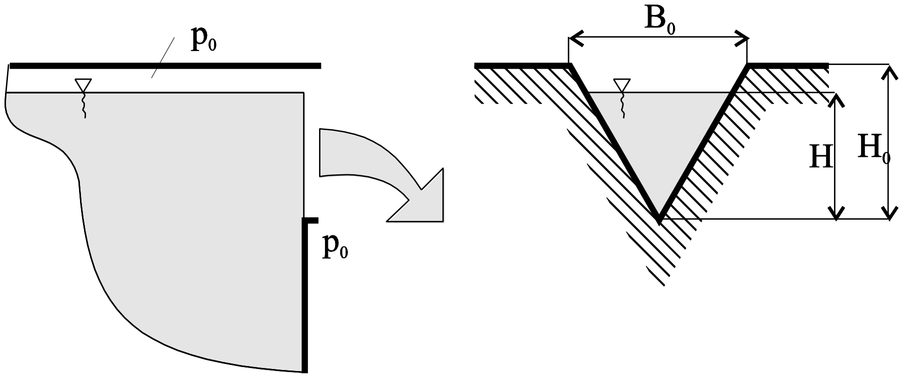
2.2. Emptying of Vessels

Example 2.2.1



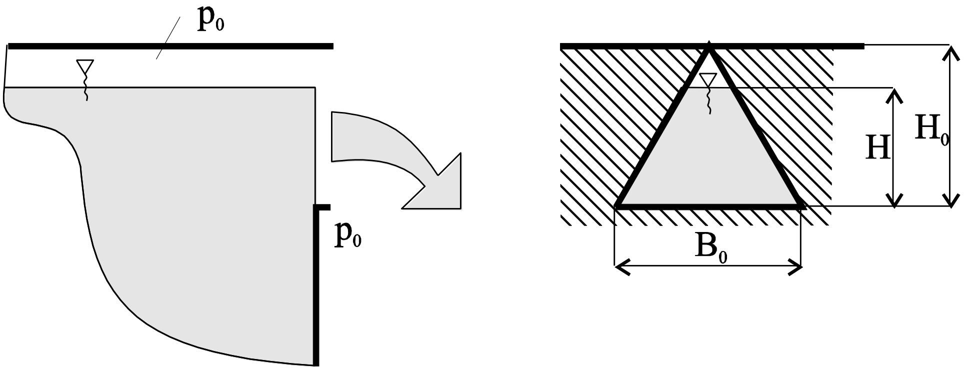
Water flows from tank 1, in which there is an opening with a size $A_1 = 0.01\ m^2$, into tank 2. From here, water flows out through an opening with a size $A_2 = 0.02\ m^2$ into the surrounding atmosphere. Calculate the mass flow rate of water through tanks and the height h_2, at which water stabilises in tank 2. The flow coefficients of openings are $\mu_1 = 0.6$ or $\mu_2 = 0.91$.

Example 2.2.2.



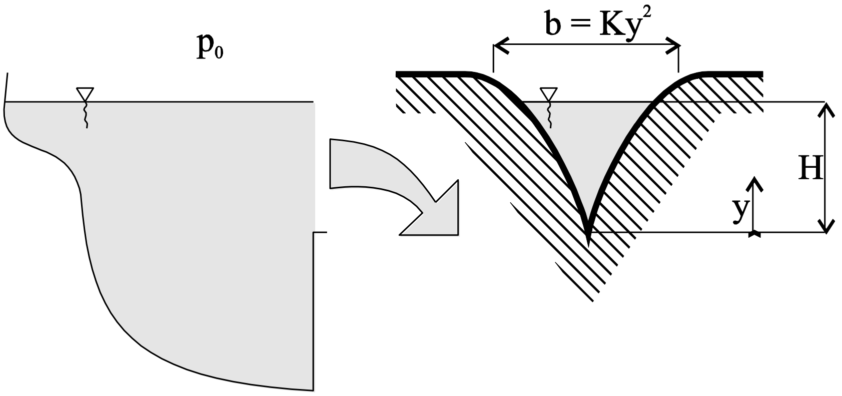
The fluid is located in a large tank (figure on the left) and flows out through a triangular opening (figure on the right). Calculate the volumetric flow rate of fluid through this triangular opening with a width $B_0 = 3\ m$ and a height $H_0 = 2.8\ m$ if fluid level from the top of the triangle is $H = 1.9\ m$.

Example 2.2.3.



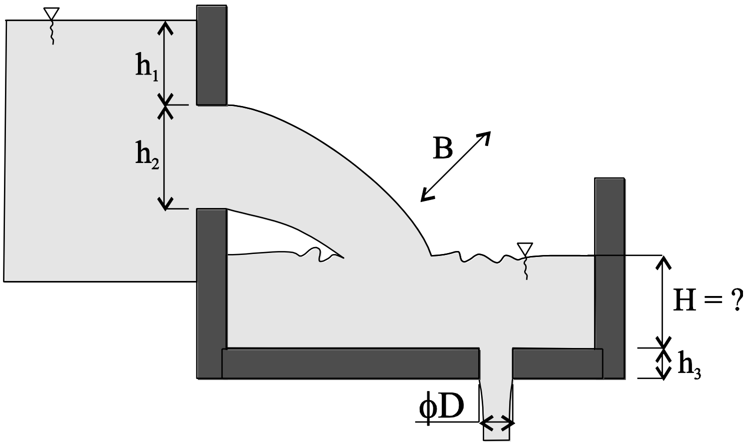
The fluid is located in a large tank (figure on the left) and flows out through a triangular opening (figure on the right). Calculate the volumetric flow rate of fluid through this triangular opening with a width $B_0 = 4\ m$ and a height $H_0 = 2.3\ m$ if fluid level from the base of the triangle is $H = 1.85\ m$.

Example 2.2.4.



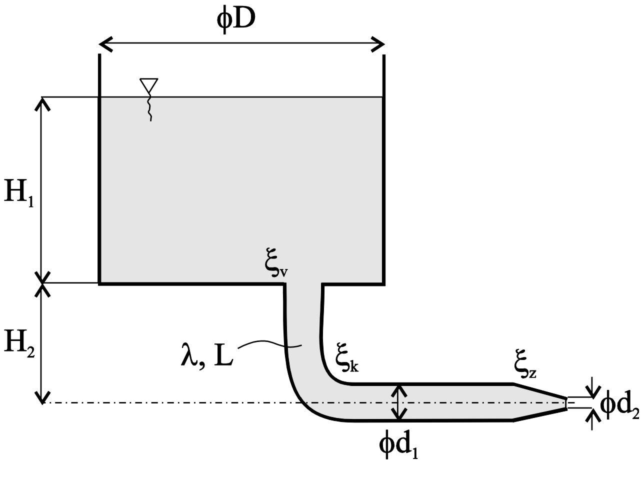
Determine the flow rate through an overflow weir, whose width is defined by the relation $b = Ky^2$, where the constant is $K = 0.5\ m^{-1}$. Water level in the overflow weir is $H = 0.9\ m$.

Example 2.2.5.



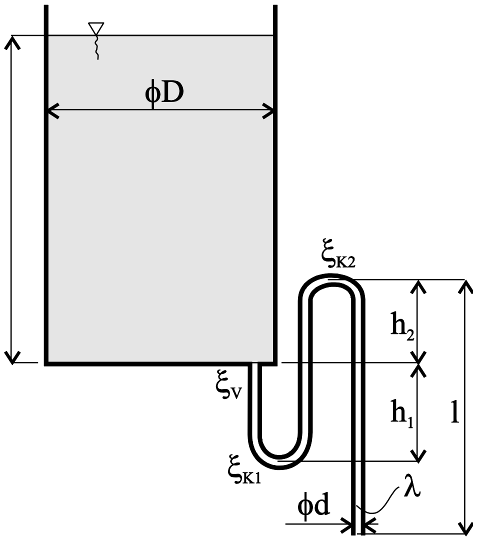
Determine the equilibrium water level in the lower tank into which the water flows through a rectangular opening with a width $B = 1.3\ m$ and a height $h_2 = 0.7\ m$ if water in the upper tank reaches a height $h_1 = 0.96\ m$ above the upper edge of the outlet drain. The diameter of the opening in the bottom of the lower tank is $\phi D = 0.6\ m$, the wall thickness of the lower tank is $h_3 = 22\ cm$. The upper opening is considered as large.

Example 2.2.6.



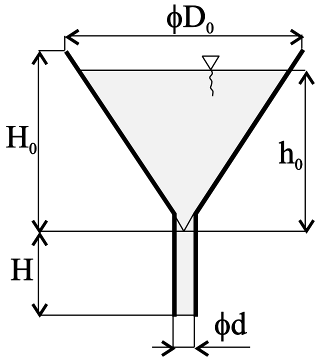
Calculate the time at which the level drops in the tank shown in the figure to the level of the pipe inlet (level drop by a height $H_1 = 4\ m$). The height is $H_2 = 3\ m$ and the diameters are $\phi D = 5\ m$, $\phi d_1 = 315\ mm$, $\phi d_2 = 80\ mm$. The loss coefficients for pipe inlet, bend and narrow section are $\xi_v = 0.5$, $\xi_k = 0.3$ and $\xi_z = 0.15$, respectively. The coefficient of friction on pipe wall is $\lambda = 0.026$ and the overall length of a pipe is $L = 8.2\ m$. There is water in the tank.

Example 2.2.7.



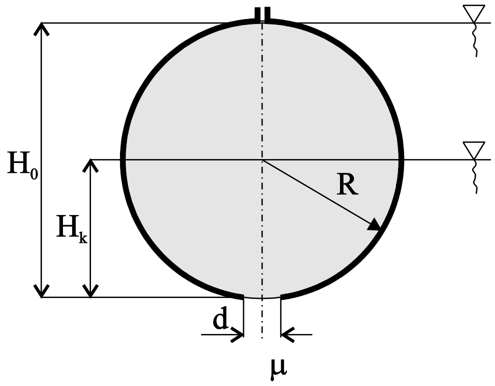
Calculate the time at which a vessel with a diameter $D = 650\ mm$ shown in the figure is emptied. The outlet drain is connected to a hose with a diameter $d = 12.5\ mm$. Other dimensions are $h_1 = 0.38\ m$, $h_2 = 0.61\ m$, $l = 1.28\ m$. The original level is at a height $H = 0.95\ m$. Consider local losses $\xi_V = 0.5$, $\xi_{K1} = 0.4$, $\xi_{K2} = 0.6$ and the coefficient of friction $\lambda = 0.03$.

Example 2.2.8.



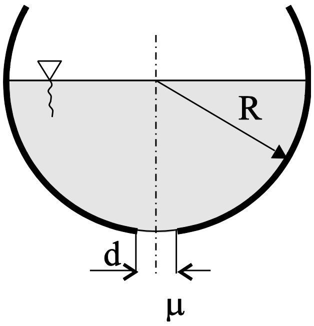
Calculate the time at which a conical vessel with a height $H_0 = 3\ m$ and a diameter $D_0 = 1.8\ m$ is emptied if filled with water up to a height $h_0 = 2.3\ m$ and with a tube with a length $H = 1.3\ m$ and a diameter $d = 60\ mm$ connected to the vessel. Neglect flow losses, neglect also the time needed to empty the connected tube.

Example 2.2.9.



Calculate the time at which the level drops in a spherical tank shown in the figure from the initial height $H_0 = 2R$ to the final height $H_k = R$. The spherical tank has a radius $R = 3\ m$, fluid flows out through an opening with a diameter $d = 100\ mm$ with a discharge coefficient $\mu = 0.67$.

Example 2.2.10.



Calculate the time needed to empty a spherical vessel with a radius $R = 1.3\ m$ if water flows out through an opening with a diameter $d = 60\ mm$. The initial fluid level in the tank is exactly in the centre of the sphere, i.e. the level is R. The discharge coefficient of the opening is $\mu = 0.86$.

Title:	Fluid Mechanics 2, Hydrodynamics
Author:	doc. Ing. Václav Dvořák, Ph.D.
Publisher:	Technical University of Liberec, Studentska 1402/2, Liberec
Dedicated for:	students of Faculty of Mechanical Engineering at the TUL
Approved by:	Rector's office at the TUL (4. 12. 2018), čj. RE 53/18
Published:	January 2019
Edition:	2nd (1st in English)
Printing office:	Vysokoškolský podnik Liberec, spol. s.r.o. Studentská 1402/2, Liberec
Publication no.	55-053-18

ISBN 978-80-7494-440-6

Annotation: The textbook is intended for additional study of the subject "Fluid Mechanics" taught at the Department of Power Engineering Equipment of the Faculty of Mechanical Engineering of the Technical University of Liberec. The examples contained in the textbook are based on the examples for the exams of the subject between years 2006 and 2015. Besides the examples and results, the textbook includes solution procedures.