

INFLUENCE OF BOUNDARY SHAPE VARIATION OF SUDDEN PIPE CONTRACTION ON HEAD LOSS

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Pressure regulation by known means is carried out only in the direction of its reduction. This paper examines local flow control devices in fluid systems, namely local hydraulic resistances. Under turbulent flow conditions, pressure losses in a sudden pipe contraction primarily occur during flow expansion downstream of the vena contracta, in the vortex region that forms behind the diameter transition plane. For sudden pipe contraction, flow resistance can be reduced by altering the shape of flow boundaries – by influencing the fluid stream, acting on the pipe wall, or modifying the cross-section along the flow direction. The methods discussed for reshaping boundaries can reduce the size of the vortex region behind the pipe contraction. In certain cases, these methods can even eliminate the vortex region entirely. The resulting flow behavior becomes similar to that of a sudden pipe contraction with a higher contraction ratio.

Keywords: local hydraulic resistance, sudden pipe contraction, boundary geometry, pressure regulation, reduction of sizes of vortex regions, reduction of head loss.

Introduction

Pressure regulation by known means is carried out only in the direction of its reduction (Chernyuk, 2000). According to their effect on the flow, methods of controlling the flow in fluid systems are divided, in particular, into local ones, which are adjustable local hydraulic resistances (Chernyuk, 2010). In the case of a sudden pipe contraction, the fluid exhibits non-uniform flow both before and after the diameter change plane (Fig. 1). The pressure losses under turbulent conditions in a sudden pipe contraction arise in the vortex region II following the vena contracta (Idelchik, 2008) (Fig. 2). Moreover, flow separation near the diameter transition plane causes erosion of the internal pipes surface (Satish, Ashok Kumar, Vara Prasad & Pasha, 2013), shortening the pipe's service life.

The flows in regions of pipelines with local pipe contractions are of significant interest (Borisyuk, 2022). To alter turbulent fluid flow and consequently change the hydraulic resistance of a pipeline, it is essential to analyze and calculate how the flow is affected by the boundary geometry (Mollo-Christensen, 1971).

For sudden pipe contractions, resistance can be reduced through the following: influencing the fluid stream; modifying the pipe wall; changing the cross-section along the flow (Orel, 2003).

This article presents a literature review on reducing head losses by modifying the size of the vortex zone II in sudden pipe contractions.

Materials and methods

In general, energy loss reduction is achievable in such contractions when the pipe diameter ratio is $d/D \geq 0.5$ (Orel, 2013).

One way to influence the fluid flow is to install passive devices in the pipeline. These include, for example, a small ring-shaped obstacle of height b located before the diameter transition in a sudden pipe contraction (Fig. 3). Installing such an obstacle can reduce the height H_2 of the vortex region II (Fig. 2) even to the complete disappearance of this vortex region at increasing the distance L between the obstacle and the diameter transition plane (Ando & Shakouchi, 2004). This behavior resembles flow through a sudden pipe

contraction with a high ($d/D = 0.9$) diameter ratio (González, Meana-Fernández, Pérez & Oro, 2024). At this diameter ratio d/D , the share of irreversible pressure loss Δp_I in the total pressure loss Δp , when the energy dissipation occurs, equals $\Delta p_I/\Delta p = 0.312$. This value is calculated using the formulae (Orel, 2013):

$$\frac{\Delta p_I}{\Delta p} = -1,7 \cdot m^2 + 0.853 \cdot m + 0.737 \quad (1)$$

where m is the contraction ratio,

$$m = \left(\frac{d}{D} \right)^2. \quad (2)$$

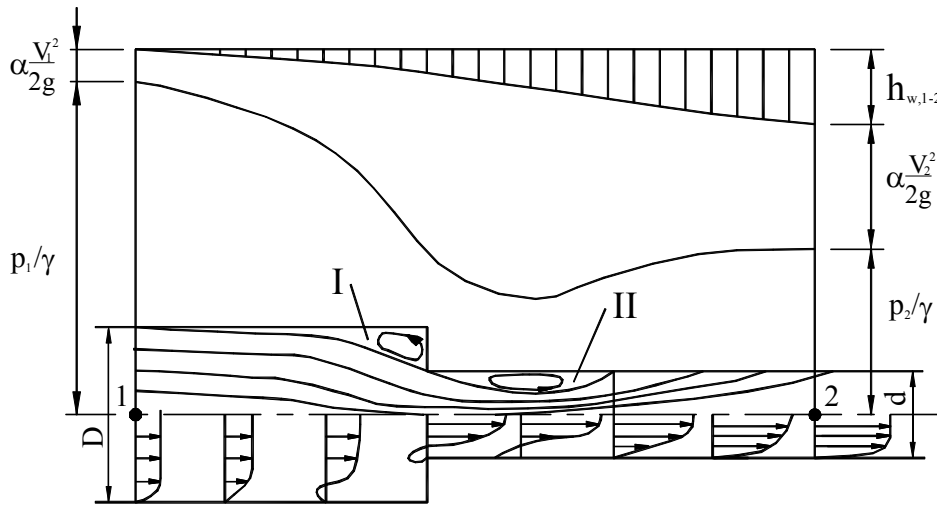


Fig. 1. Scheme of fluid flow at a sudden pipe contraction with sharp edges:

I, II is the vortex region of upstream and downstream; p_1/γ is the piezometric or hydraulic head at the point 1; $\alpha V_1^2/2g$ is the velocity head at the point 1; p_2/γ is the piezometric or hydraulic head at the point 2; $\alpha V_2^2/2g$ is the velocity head at the point 2; $h_{w,1-2}$ is the total head loss between the points 1 and 2

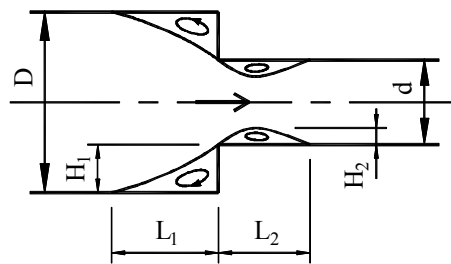


Fig. 2. Scheme of sizes of vortex regions at a sudden pipe contraction with sharp edges:

L_1 is the length of the vortex region I; H_1 is the height of the vortex region I;
 L_2 is the length of the vortex region II; H_2 is the height of the vortex region II

When additional fluid of flow rate q is radially injected into the main stream with flow rate $Q > q$ before the sudden pipe contraction, the vortex region II can be reduced or even eliminated (Fig. 4). This is explained by energy redistribution and the return of part of the energy to the main flow (Nosko & Shevchuk, 2013).

Pipe wall modification involves altering parameters such as internal surface roughness. For example, in the case of a rough upstream wall, the vortex length L_2 behind a forward-facing step of height h (Fig. 5) is shorter compared to a smooth wall (Essel & Tachie, 2017). A forward-facing step is a two-dimensional case

of a sudden pipe contraction (Ando & Shakouchi, 2004). Therefore, the effect of artificially roughening the surface before the sizes of pipe transition plane is comparable to installing a ring-shaped obstacle (Ando & Shakouchi, 2004) or increasing the sudden pipe contraction diameter ratio from $d/D = 0.5$, which reduces pressure loss (González, Meana-Fernández, Pérez & Oro, 2024).

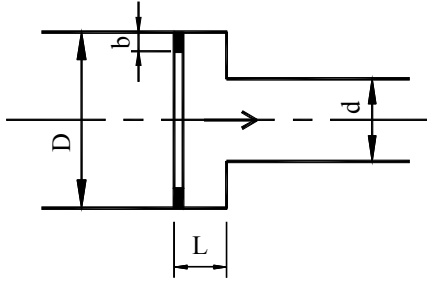


Fig. 3. Scheme of fluid flow at a sudden pipe contraction with sharp edges and with a small ring shaped obstacle

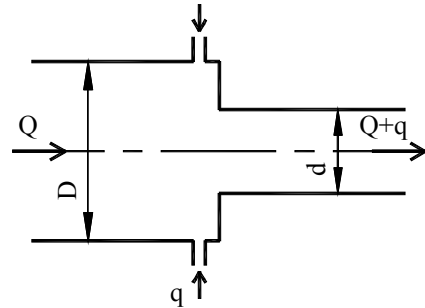


Fig. 4. Scheme of fluid flow at a sudden pipe contraction with sharp edges and with radial inflow of additional fluid of flow

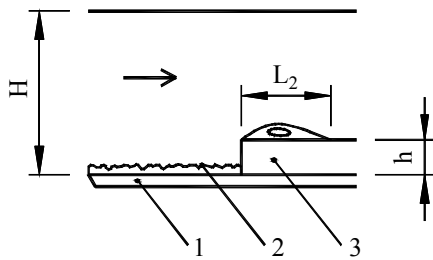


Fig. 5. Scheme of fluid flow over forward facing step with rough upstream wall:
1 – smooth wall; 2 – rough coating;
3 – forward facing step

Cross-sectional modification is achieved through specially profiled pipe sections, which may lead to high losses (Fig. 6, a) (Rennels & Hudson, 2012; Idelchik, 2008; Miller, 1990), moderate losses (Fig. 6, b) (Rennels & Hudson, 2012; Idelchik, 2008; Miller, 1990) and (Fig. 6, c) (Rennels & Hudson, 2012; Idelchik, 2008) or low losses (Fig. 6, d) (Rennels & Hudson, 2012; Idelchik, 2008; Miller, 1990) and (Fig. 6, e) (Rennels & Hudson, 2012). Rectilinear boundaries (Fig. 6, b and Fig. 6, c) educe vortex region II, while curvilinear boundaries (Fig. 6, d and Fig. 6, e) eliminate the vortex region altogether (Rennels & Hudson, 2012). Thus, any

deviation from a sharp-edged sudden pipe contraction changes the flow field and consequently results in lower pressure losses (Bullen, Cheeseman & Hussain, 1996).

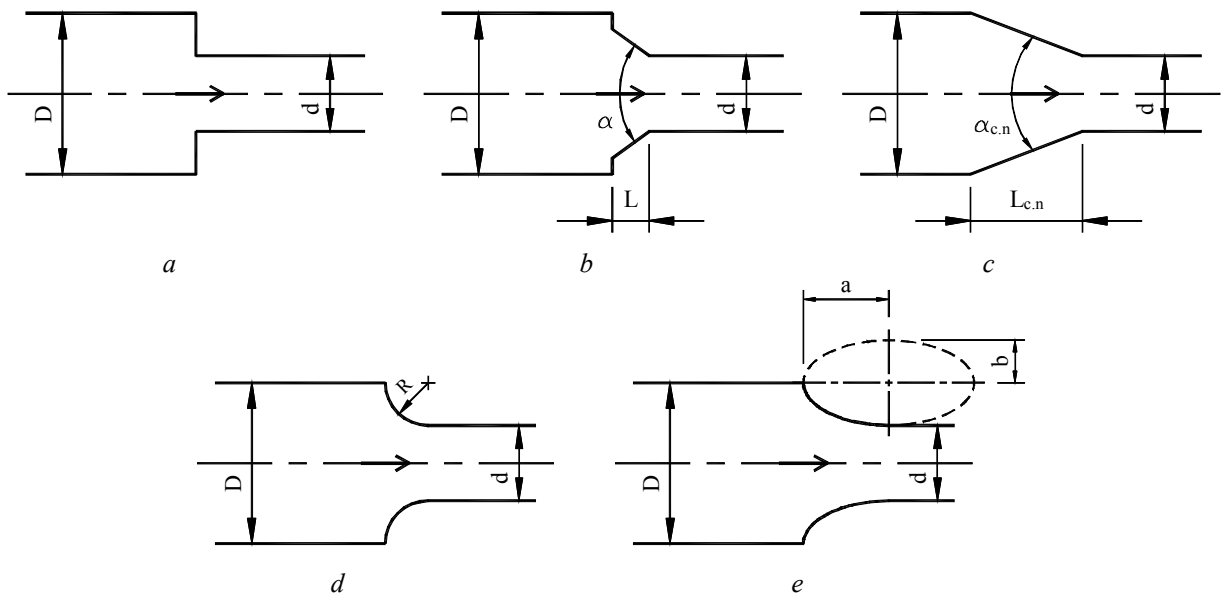


Fig. 6. Schemes of pipe contraction:
sudden (a); beveled (b); conical (c); rounded with circular rounding (d) and rounded with elliptical rounding (e)

The regulation function, that takes into account measures necessary for changing energy losses in a pressure short pipeline to take the form (Sydor & Orel, 2025)

$$f(\text{reg}) = k - 1, \quad (3)$$

where k is the loss reduction coefficient, which accounts for the decrease of energy losses when replacing a sudden pipe contraction (Fig. 6, *a*) with a conical pipe contraction (Fig. 6, *c*) using a confuser (converging section).

Conclusions

1. The discussed methods of modifying boundary shapes in sudden pipe contractions help reduce the size of the vortex region II, which is the main source of pressure loss in such local hydraulic resistances. In certain cases, this vortex region can be entirely eliminated.

2. When reducing the size of the vortex region II, the use of the considered methods at a sudden pipe contraction with a certain contraction ratio m is equivalent to a sudden pipe contraction with a larger contraction ratio m .

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ВПЛИВ ЗМІНЮВАННЯ ФОРМИ ГРАНИЦЬ РІЗКОГО ЗВУЖЕННЯ ТРУБИ НА ВТРАТИ НАПОРУ

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За турбулентного режиму руху рідини втрати напору на різкому звуженні труби виникають переважно у разі розширення потоку рідини після стисненого перерізу у вировому поясі, який утворюється за площиною зміни діаметрів. Цей вировий пояс спричиняє основні втрати напору на цьому місцевому гідравлічному опорі. Крім того, відривання потоку рідини поблизу площини зміни діаметрів на різкому звуженні труби спричиняє ерозію внутрішньої поверхні труб, що зменшує термін їхньої експлуатації. Регулювання тиску відомими засобами здійснюють лише в напрямі його зменшення. Розглянуто локальні засоби керування потоками плинних систем, якими є місцеві гідравлічні опори. Для різкого звуження труби зменшення опору можна досягти, змінюючи форми її границь. Розглянуто способи змінювання форми границь, які дають змогу зменшити розміри вирового пояса за площиною зміни діаметрів на різкому звуженні труби. Вплив на потік рідини здійснюють, встановлюючи кільцеву перешкоду невеликої висоти перед перерізом зміни діаметра труби із різким звуженням чи радіальним підведенням додаткової витрати рідини до основного потоку перед перерізом зміни діаметра труби із різким звуженням. На стінку труби діють, змінюючи параметри внутрішньої поверхні стінок труб, а саме шорсткість труби перед перерізом зміни діаметра труби із різким звуженням. Змінювання поперечного перерізу труби здійснюють, переходячи від труби із більшим діаметром до труби з меншим діаметром за допомогою колектора із прямолінійними чи криволінійними твірними. За зменшенням розмірів вирового пояса використання розглянутих способів на різкому звуженні труби із певним ступенем звуження потоку аналогічне до різкого звуження труби з більшим ступенем.

Ключові слова: місцеві гідравлічні опори, різке звуження труби, форма границь труби, регулювання тиску, зменшення розмірів вирових зон, зменшення втрат напору.