**Modern fluid motion physics**
**Part 4: influence of the incident flow velocity**
**on the outflow velocity out of the pipe flow element**

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It is shown that an introduction into a radicand of the Saint-Venant – Wantzel formula of a free component in the kind of the velocity squared of the gas flow, running against inlet of the pipe flow element, that was offered at the close of the XIX century and is remained till now, it is not physically adequate. It is shown that this way is doubtful for hydrodynamics and it is quite not admissible for gas dynamics. Sound form of the static head law for the pipe flow element and modern modification of SVW formula, corresponding to the given case, have been produced. The obtained expressions allow physically correctly taking into account both the combined and isolated influence of a pressure drop, applied to the flow element, and the gas flow, running against its inlet, onto the outflow velocity of gas stream out of the flow element, system. The obtained expressions are valid for subsonic velocity of the gas flow, running against inlet of the flow element. Particular expressions are obtained for the liquid flow.

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**Nomenclature**

$g$ – gravity acceleration;
$L$ – general metric length of the flow element;
$\bar{L}$ – general caliber length of the flow element, L/D;
$l$ – metric length of stream from the outlet section of the flow element up to running point;
$p_0, p_h$ – pressure at inlet and outlet of the flow element respectively;
$p_{st}(l)$ – static pressure along the fluid stream;
$V_{en}$ – flow velocity, running against the flow element;
$\gamma_{en}$ – weight density of fluid;
$\zeta_{in}$ – coefficient of local hydraulic resistance for inlet into the flow element;
$\zeta_{ex}$ – coefficient of local hydraulic resistance for outlet from the flow element;
$\zeta_{loc}$ – coefficient of local hydraulic resistance within the limits of the flow element;
$\lambda$ – hydraulic friction – Darcy -- coefficient.

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## Introduction

A problem on a combined action of pressure drop, applied to the pipe flow element, and velocity of a fluid flow, running against an inlet of the flow element, is general problem on description of a fluid - gas and liquid – motion. In hydraulics, the problem was solved by introduction into radicand of the Torricelli – Galilei – Borda – Du Buat (TGBD) formula of additional free component in the kind of the velocity squared of the fluid flow, running against an inlet of the flow element, [1]. In that way, the first component in radicand of the TGBD formula takes into account influence of pressure drop, applied to the flow element, and the second component takes into account influence the velocity of a fluid flow, running against an inlet of the flow element, onto the outflow velocity out of the flow element; and then a square root of the sum - with taking into account of the velocity empirical coefficient before the root as its multiplier – determines the outflow velocity out of the flow element. Such structure of the TGBD formula exists in hydraulics since the second half the XIX century till now. At the close of the XIX century, this mode was adopted for the gas dynamics: the additional free component in the kind of the velocity squared of the fluid flow, running against an inlet of the flow element, was also introduced into a radicand of the Saint-Venant – Wantzel (SVW) formula [2, 3]. The velocity empirical coefficient is present before the root as its multiplier, just as in hydraulics. Empirical-speculative character of the described approach is evident in hydraulics and especially in the gas dynamics. For example, if velocity of the gas flow, running against an inlet of the flow element, acts alone, without pressure drop -- “flying pipe” version, then the outflow velocity out of the flow element – leaving out of account of the velocity coefficient – will be equal to velocity of the fluid flow, running against an inlet of the flow element. In this case, the strange situation is arisen: the friction does not influence upon the gas stream, moving in the flow element. This is not the gas fluid; this is physically empty medium, so-called ideal fluid. The problem is how does the given situation, with a stale more than 175 years, to solve physically adequately and mathematically definitely?

## Approach

The overcoming of problem of a contact interaction of a fluid flow with a streamlined surface has allowed finding the unitized expression for distribution of static head of the gas or liquid stream along the length of the pipe flow element in the kind of the static head law [4, 5]. Side by side with it, SVW formula was also led to the final physically correct form [6]. If these expressions have the property of adequate reflection of the physical reality, then ones should allow taking into account all multiplicity of mechanical action onto fluid stream. Including, they should allow taking into account the combined action of a pressure drop and velocity of a fluid flow, running against an inlet of the flow element and, moreover, without any tales like to the velocity and weight flow coefficients, polytropic “process” [7] and other well-known small “betterments”.

## Solution

Despite of the brevity of the approach, solution of the problem appears rather simple. It is enough, a velocity head of the fluid flow, running against inlet of the flow element, to add to $p_0$ in the law of static head, and the solution is reached.
So, a velocity head of the fluid flow, running against inlet of the flow element, is

$$p_{en} = \gamma V^2/(2g). \qquad (1)$$

In this case, the law of static head for the gas stream in the pipe flow element has the kind

$$p_{st}(l) = [(p_0 + p_{en}) - p_h] \cdot \lambda \bar{L} K_l/(1 + \lambda \bar{L} K_l + \zeta_{in} + \zeta_{ex}) + p_h, \qquad (2)$$

where $K_l = (1 - l/L)$ is relative distance from the inlet cross-section of the flow element [4]: $K_l = 0$ at inlet into the flow element and $K_l = 1$ at outlet out of the flow element.
At substitution of expression (2) into modern form of the SVW formula [6], the last will accept a form

$$V_{ex} = \sqrt{\frac{2}{k-1} kgRT_0 \left\{1 - \left[\frac{(p_0 + p_{en} - p_h)\lambda\bar{L}}{p_0(1 + \lambda\bar{L} + \zeta_{in} + \zeta_{ex})}\right]^{\frac{k-1}{k}}\right\}}. \tag{3}$$

The law of static head for a liquid stream in the flow element, with taking into account that the expression (1) for a velocity head of the liquid flow, running against the flow element, has the same form as for gas flow, looks like

$$p_{st}(l) = (p_0 + p_{en} - p_h)\lambda\bar{L}K_l/(1 + \lambda\bar{L} + \zeta_{in} + \zeta_{ex}) + p_h. \tag{4}$$

In this case, the TGBD formula [4] will accept appropriate for hydromechanics form

$$V \equiv V_{ex} = \sqrt{2\frac{g(p_0 + p_{en} - p_h)}{\gamma(1 + \lambda\bar{L} + \zeta_{in} + \zeta_{ex})}}, \tag{5}$$

when the outflow of liquid stream is going on under the reposing liquid level. Also it will look like

$$V \equiv V_{ex} = \sqrt{2\frac{g(p_0 + p_{en} - p_h)}{\gamma(1 + \lambda\bar{L} + \zeta_{in})}}, \tag{6}$$

when the outflow of liquid stream is going on into atmosphere.
When the gas flow, running against the pipe flow element, acts alone, in absence of a pressure drop, we are obtaining the "flying pipe" variant. In this case, the law of static head has the appearance

$$p_{st}(l) = (p_{en} + p_h - p_h)\lambda\bar{L}K_l/(1 + \lambda\bar{L}K_l + \zeta_{in} + \zeta_{ex}) + p_h \equiv \tag{7}$$
$$\equiv p_{en} \cdot \lambda\bar{L}K_l/(1 + \lambda\bar{L}K_l + \zeta_{in} + \zeta_{ex}) + p_h.$$

Substitution of this expression into modern form of the SVW formula brings it to such its kind

$$V_{ex} = \sqrt{\frac{2}{k-1} kgRT_0 \left\{1 - \left[\frac{p_{en} \cdot \lambda\bar{L}K_l}{p_h(1 + \lambda\bar{L}K_l + \zeta_{in} + \zeta_{ex})}\right]^{\frac{k-1}{k}}\right\}} \tag{8}$$

in the case of subsonic velocity of the gas flow, running against the pipe flow element.

**Final remarks**

Thus, the problem on physically adequate and mathematically precise taking into account of influence of the gas flow, running against the pipe flow element, onto the outflow velocity out of the flow element is resolved for two practically important cases: an isolated action of the factor and its action in combination with the pressure drop. The particular solutions are given for a fluid flow.

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