Methods to Reduce and Control Risks Arising from Head Loss in the Transportation of Water through Pipes and Fittings Used for Firefighting

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Abstract: *The article presents a series of cases transformed in methods, which can be used to reduce and control the losses of energy at water transportation through pipes and fire extinguishing equipment.*

Keywords: *Pressure control, pipes, fire extinguishing, pressure drop*

1. Introduction

To enhance the efficiency of water transportation in firefighting systems, various methods for reducing hydraulic head losses have been investigated. One effective approach involves modifying the pipe roughness and utilizing polymer additives to decrease turbulent flow and velocity pulsations. By incorporating synthetic or natural polymer solutions, frictional resistance within pipes and hoses can be significantly reduced, leading to more efficient water flow and lower pressure drops. This technique addresses both the structural and fluid dynamic aspects of firefighting systems, offering a practical solution to common performance issues.
Furthermore, optimizing pipe design and suction conditions plays a critical role in minimizing pressure losses. Careful consideration of pipe diameter transitions and suction height can substantially affect the system's overall efficiency. Implementing strategies to reduce linear and local resistance, combined with the use of polymer additives, ensures that firefighting operations are more effective and reliable. These measures are crucial for maintaining operational effectiveness in emergency situations, highlighting the importance of both material selection and design optimization in firefighting systems.

2. Methods using polymer additives

The main methods to reduce the head losses in the transportation of water through pipes and fittings used in firefighting are:
- by modifying the absolute roughness Δn of pipes, hoses, etc., in order to choose the lowest possible values in service; this method is technically limited in relation to cost [1];
- by decreasing the velocity pulsations which have the effect of reducing the turbulent intensity; this can be achieved by: the use of synthetic or natural polymer additives; the use of additives such as suspensions of association materials and colloids, fibrous particles, suspensions of fiber-polymer mixtures (by injecting polymers into the layer near the inner wall of the pipe or in the center of the pipe) [2-6];
- use of specific firefighting methods [7,8];
- by optimizing load losses (linear and local) in the design phase;
- by the combined use of the methods presented.

2.1 Reducing load losses by modifying roughness

For cases where the flow is permanent $\partial u/\partial t=0$ with constant pressure and flow rate, by introducing dilute polymer solutions, the linear resistance coefficient decreases and thus the absolute roughness coefficient denoted by Δn decreases, becoming:

$$\Delta n = n_0 - n \tag{1}$$

which generates load loss reduction.

In the above assumptions, the head loss using Chézy's and Manning's relation for the hydraulic slope I is given by the relation [1]:

$$I = \frac{\bar{u}^2}{c^2 \cdot R} = \frac{Q^2 \cdot n^2}{S^2 \cdot R^{4/3}} = \frac{Q^2 \cdot n^2}{\bar{n}^2} \tag{2}$$

where

$$\bar{n} = S \cdot R^{2/3};\ c = \frac{1}{n} \cdot R^{1/6} \tag{3}$$

At constant flow, the pressure drop is [9]:

$$\Delta h_r = I \cdot l = \frac{Q^2 \cdot k^2}{A^2 \cdot R^{4/3}} \cdot l = C \cdot n^2 \tag{4}$$

where: R = hydraulic radius
C = constant
S = pipe cross section
Under these circumstances:

$$\Delta h_r = C \cdot n^2 = \Delta h_0 \cdot \left(1 - \frac{\Delta n}{n_0}\right)^2 \tag{5}$$

where: Δh_0 = pressure drop for water without additive content
Reducing pressure drop is due to:

$$\Delta(\Delta h_r) = \Delta h_0 - \Delta h = -C \cdot \Delta n^2 + 2 \cdot C n_0 \cdot \Delta n \tag{6}$$

Equation (6) shows that the function *Δ(Δh$_r$)* admits a maximum whose vertex, which is defined by the coordinates:

$$V(n_0, C \cdot n_0^2) \tag{7}$$

From a technical point of view, fire-fighting fittings (fire hoses, etc.), metal pipes, plastic pipes, etc., by their construction, allow a limit on the roughness values resulting from the technological processing

2.2 The influence of roughness on pressure drop

Experimental determinations carried out by Olsen and Eckart [5] have shown that an increase in the radial component of the velocity (due to the additional flow input) leads to a decrease in friction, and thus to a reduction in hydraulic head losses.
In this case, the determinations showed that the coefficient of linear hydraulic resistance is less dependent on the main flow.
The model evaluates the load losses due to friction in the vicinity of the solid walls; the roughness is modeled by means of cavities distributed at different distances through the damped eddies that are generated in the cavities.
The pressure drop is equal to the energy given up by the fluid unit at a reference cross section, i.e.:

$$\Delta h_r = \Delta E_c \cdot \frac{L}{d^*} \cdot \frac{1}{S \cdot \bar{u} \cdot \rho \cdot g} \tag{8}$$

where: L = the analysis distance in the flow direction
d* = the distance between two successive cavities
$\frac{L}{d^*}$ = the number of cavities per unit length
S = the cross-sectional area
ΔE_c = the energy transmitted in unit time, additional to one cavity
By analogy with Darcy's relation, we obtain [10-12]:

$$\lambda = \frac{8 \cdot \Delta E_c}{\pi \cdot \bar{u}^3 \cdot {d^*}^3 \cdot \rho} \tag{9}$$

2.3. Reducing load losses when using polymer additives

The intensity of axial turbulent fluctuations when polymer solutions are used increases compared to the case when water is not additivated, while the intensity of radial fluctuations decreases (in fibers, the phenomenon behaves the other way around) [5].

2.3.1. Mechanisms/theories to reduce pressure drop

There is controversy in the scientific world regarding the parameters that determine the onset of the charge loss reduction phenomenon (length scale or time scale) [5,6].
Such scales that characterize the macromolecule, are for length: the average radius of gyration of the macromolecule determined by the free compound chain model or the radius of gyration RG and for time, the relaxation time of the macromolecule.
Often solutions that have undergone mechanical degradation result in reduced flow friction, which is much smaller in larger diameter pipes than in smaller diameter pipes. This is most likely due to the fact that in larger diameter pipes the tangential wall stress is below the value required for most macromolecules to degrade.
Since both length and time scales are reduced by degradation, degradation experiments cannot distinguish between the two scales. There are theoretical motivations that argue in favor of the ratio of the time scales as the determining factor and none in favor of the length scale.
Microscale determinations confirm the change of the length scale in turbulent flow, with the entire energy spectrum being shifted to lower frequencies. Following the action of the centrifugal force in the vortex, macromolecules expand and can reach almost open conformations taking the shape and size of small vortices. Their size is determined by the velocity profile.
Related to the above, some theories consider additive interaction with small vortices. Indications of the smallest possible size of eddies in turbulent flow can be obtained for example, using Kolmogorov [1,6] length and time microsamples, with the following relations:
- length microsamples:

$$l = (\nu^3/u_d)^{1/4} \tag{10}$$

- time microsamples:

$$t = (\nu/u_d)^{1/2} \tag{11}$$

where: u_d = the energy dissipation rate per unit mass
ν = kinematic viscosity
The lowest vortices, in the high energy end of the spectrum, occur in turbulent flow near the wall, outside the viscous substrate, for which the tangential effort τ can be assumed to be approximately equal to the tangential effort at the wall τ_p. If $\bar{u}$ is the mean axial velocity, ρ – the density, d – the diameter of the pipe, the equation for the microscale of length [6] is:

$$l = \left(\frac{\nu^3 \cdot d}{2 \cdot \bar{u}^3 \cdot \lambda}\right)^{1/4} \tag{12}$$

which can be rewrite as:

$$l/d = 0.84 \cdot Re^{-3/4} \cdot \lambda^{-1/4} \tag{13}$$

The time scale corresponding to small eddies is given by the relation:

$$t = (\nu \cdot d/2 \cdot \bar{u}^3 \cdot \lambda)^{1/2} \tag{14}$$

which can be also rewrite:

$$t \cdot \bar{u}/d = 0.72 \cdot Re^{-1/2} \cdot \lambda^{-1/2} \tag{15}$$

Large vortices lose energy at the base of the viscous substrate and gain energy from the mean motion by stretching the vortices. Large vortices are not permanent formations; they are randomly generated, grow by extracting energy, reach a maximum, and gradually disappear to appear in another area.

The particle length of fibrous materials, which generate reductions in pressure drop, is much larger than the length scale of the energy dissipative vortices, so these particles will affect larger vortices that are farther away from the wall [6].
If the direct interaction between macromolecules and vortices is not possible, it has been suggested that the reduction in the linear hydraulic flow resistance coefficient is due to energy transfer from the vortices to the polymer molecules [6].
The correct determination of the relaxation time required for the macromolecule to regain its original shape and dimensions can be made using the theories of Rouse and Zimm [6].
In the region of charge loss reduction, the relaxation time of the polymer macromolecules is equal to or greater than the time scales of the smallest vortices. When the relaxation time of the macromolecules is larger than the time scales of the vortices, the macromolecules are likely to deform and thus absorb or dissipate energy from the smaller vortices.
Other theories consider that energy, cascading from the large to the small vortices, is partially transmitted to the polymer molecules towards the high-frequency end of the spectrum, which may lead to the alteration of the entire energy balance in turbulent flow [6].
There are theories that explain the mechanism of reduced charge loss reduction by the fact that polymer molecules can store strain energy and then release it to another region, thereby altering the energy balance [6].
Experimental evidence, based on flow visualization studies, has shown that in polymer solutions the structure of the near-wall layer is different and that the turbulence generation process is modified in the direction of decreasing turbulence intensity [5,6].
In turbulent flow, given the large variety of eddies with different energies, one can practically speak of a continuous distribution of eddies or an energy spectrum to which a frequency spectrum corresponds.
Determinations for turbulence emphasize that the reduction in pressure drop is not associated with an overall reduction in turbulence intensity [5,6].
Most of the results emphasize the attenuation of very small eddies at the high-frequency end of the energy spectrum, resulting in a shift of the entire energy spectrum to lower frequency domains, which shows that additives are more effective at suppressing small eddies [5,6].

2.4. Reducing firefighting pressure drop

Such situations can be identified in the use of fire hoses, water pipes for internal/external fire hydrant systems, the use of fire engines, etc.

2.4.1. Assessment and control of local head losses when increasing sudden increase in pipe cross-section

Consider the transition from a pipe of diameter d_1 to a pipe of diameter d_2 ($d_1<d_2$). It is assumed that the fluid motion is permanent, the upstream/downstream system is at the same level ($z_1 = z_2$) with respect to a given reference system, and the motion is turbulent [7,8].

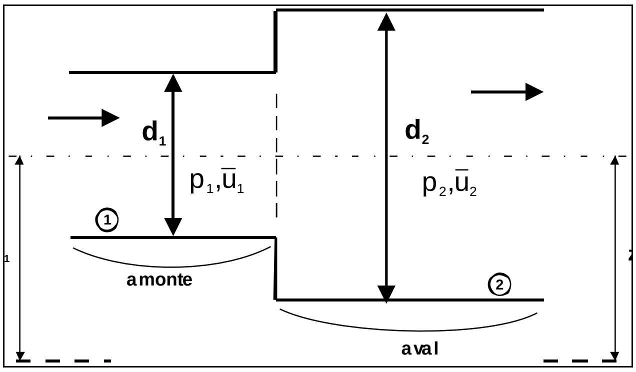

Fig. 1. Longitudinal section (upstream/downstream) in a pipeline section

With a sudden increase in cross-section, the local load loss coefficient (chapter 3) is:

$$\xi \cong (1 - S_1/S_2)^2 \quad (16)$$

The pressure drop between points (1) and (2) admits the maximum value:

$$\Delta p_{max} \cong 148.13 \cdot \bar{u}_1^2 \tag{17}$$

where:

$$d_1 = 0.67 \cdot d_2 \tag{18}$$

The relation shows that when switching from pipe diameter d_1 to pipe diameter d_2, ($d_1<d_2$) the pressure drop between points (1) and (2) is maximized; the method is also applicable with good approximation to the use of fire hoses [13,14].

$$(\Delta h_r)_{max} \cong 0.01 \cdot \bar{u}_1^2 \tag{19}$$

2.4.2. Assessment and control of suction pressure drop from artificial/natural water sources

The suction height h_a expressed in m, for the supply of fire-fighting appliances from artificial/natural water sources (chapter 4) shall be [15-17]:

$$\Delta h_r \cong 10{,}33 - \left(\frac{p_a}{\gamma} + \frac{z}{900} + 1.21 \cdot \frac{\bar{u}_a}{2g} + h_a\right) \tag{20}$$

where: p_a = the pressure at pump inlet;
γ = specific gravity of water;
z = altitude;
$\bar{u}_a$ = average velocity at pump inlet.
Δh_r = total value of head losses (linear and local)

From a technical point of view, h_a is limited and admits the maximum value 7.50m [18,19]. The decrease and control of total head loss Δh_r is achieved by:
- reducing linear head losses by using hose runs with the shortest possible lengths;
- reducing local load losses by using as few elbows, fittings, etc. as possible.

3. Sudden increase in cross-section of a circular pipe

3.1. Pressure drop assessment

The requirement of the problem is to determine for which ratio d_1/d_2 a minimum pressure drop is obtained when the cross-section of a circular pipe increases abruptly. For this purpose, consider the transition from section S_1 to section S_2 ($d_1<d_2$), under the assumptions:
- the movement of the quantity of water is considered to be permanent ($d\bar{u}/dt = const$) – the reporting is done in terms of the average velocity;
- the system characterized by the sections ($S_1< S_2$) is located at the same elevation $z_1 = z_2$, relative to a given reference system;
- the motion is considered to be turbulent Re >> 2300, for which the Coriolis coefficient $\alpha_1=\alpha_2=1{,}21$;
- neglects the influence of pipe roughness.

The continuity equation, applied to points (1) and (2), gives:

$$Q_1 = Q_2 \Leftrightarrow \bar{u}_2 = \bar{u}_1 \cdot \left(\frac{d_1}{d_2}\right)^2 \tag{21}$$

Bernoulli's theorem written for (1) and (2) is:

$$\frac{p_1}{\gamma} + \alpha_1 \cdot \frac{\bar{u}_1^2}{2g} = \frac{p_2}{\gamma} + \alpha_2 \cdot \frac{\bar{u}_2^2}{2g} + \Delta h_r \tag{22}$$

and

$$\Delta h_r = \xi \cdot \frac{\bar{u}_1^2}{2g} \tag{23}$$

is the load loss for the sudden increase in section from S_1 to S_2, where:

$$\xi = \left(1 - \frac{S_1}{S_2}\right)^2 = \left[1 - \left(\frac{d_1}{d_2}\right)^2\right]^2 \tag{24}$$

so that

$$\Delta h_r = \left[1 - \left(\frac{d_1^2}{d_2^2}\right)\right]^2 \cdot \frac{\bar{u}_1^2}{2g} \tag{25}$$

In these circumstances, we have:

$$\frac{p_1}{\gamma} + \alpha_1 \cdot \frac{\bar{u}_1^2}{2g} = \frac{p_2}{\gamma} + \alpha_2 \cdot \frac{\bar{u}_1^2}{2g}\left(\frac{d_1}{d_2}\right)^4 + \left[1 - \left(\frac{d_1}{d_2}\right)^2\right]^2 \cdot \frac{\bar{u}_1^2}{2g} \tag{26}$$

For simplicity, denote $0<(d_1/d_2)^2=x<1$ and the result is:

$$\frac{p_1}{\gamma} + \alpha_1 \cdot \frac{\bar{u}_1^2}{2g} = \frac{p_2}{\gamma} + \alpha_2 \cdot \frac{\bar{u}_1^2}{2g}x^2 + (1-x)^2 \cdot \frac{\bar{u}_1^2}{2g} \tag{27}$$

from where

$$\frac{\Delta p}{\gamma} = \frac{p_2 - p_1}{\gamma} = (-2.21 \cdot x^2 + 2 \cdot x + 0.21) \cdot \frac{\bar{u}_1^2}{g} \tag{28}$$

The first derivative is:

$$\frac{d}{dx}\left(\frac{\Delta p}{\gamma}\right) = (-4.42x + 2)\frac{\bar{u}_1^2}{2g} \tag{29}$$

which equalled to zero gives the value x=0,45 from which it follows that $d_1=0{,}67d_2$.
To determine the nature of the extreme, calculate:

$$\frac{d^2}{dx^2}\left(\frac{\Delta p}{\gamma}\right) = -\frac{2{,}21\bar{u}_1^2}{g} < 0 \tag{30}$$

where the extremum is a maximum.
In conclusion, pressure drop is optimal and admits expression:

$$\left(\frac{\Delta p}{\gamma}\right)_{max} = (\Delta h_r)_{max} = 0.302 \cdot \frac{\bar{u}_1^2}{2g} \tag{31}$$

4. Suction from natural/artificial water sources

4.1. Atmospheric pressure variation with altitude

For altitude values z≤10.500 m, the temperature decreases close to the function:

$$T(z) = T_0 - c_1 \cdot z \tag{32}$$

where: $z_0 = 0$;
$T_0 = 288$ K;
$C_1 = 0{,}0065^oC/m$, for Earth's atmosphere.
The state of perfect gases equation is:

$$p \cdot V = \nu \cdot R \cdot T = \frac{m}{\mu} \cdot R \cdot T \tag{33}$$

where:

$$\frac{p}{\rho} = \frac{R \cdot T}{\mu} = \frac{R}{\mu} \cdot (T_0 - c_1 \cdot z) \tag{34}$$

or

$$\rho = \frac{p}{\mu} \cdot \frac{1}{T_0 - c_1 \cdot z} \tag{35}$$

For the terrestrial gravity field, where $U=g \cdot z+c_2$, c_2 is a constant and the mass forces is derived from a force function U [20]:

$$dU + \frac{dp}{\rho} = 0 \tag{36}$$

or

$$g \cdot\ dz + \frac{\mu}{p} \cdot (T_0 - c_1 \cdot z) \cdot\ dp = 0 \tag{37}$$

Separating the variables and integrating, we obtain:

$$-\frac{g}{c_1}\cdot\ln(T_0 - c_1\cdot z) + \mu\cdot\ln p = const \quad (38)$$

and if you put the condition $p=p_0$ for $z=0$, then:

$$\frac{p}{p_0} = 1 - \left(\frac{c_1\cdot z}{T_0}\right)^{g/c_1\cdot\mu} \quad (39)$$

Expanding the right-hand side of the relation (39) serially and neglecting all but the first two terms, we obtain:

$$p = p_0\cdot\left(1 - \frac{g\cdot z}{\mu\cdot T_0}\right) \quad (40)$$

which will be [20]:

$$\frac{p}{\gamma} \cong 10.33 - \frac{z}{900} \quad (41)$$

4.2. Suction from natural/artificial water sources

The suction height denoted by h_a, where (P) is taken generically as the p.s.i. centrifugal pump, for specified working conditions, is as follows.

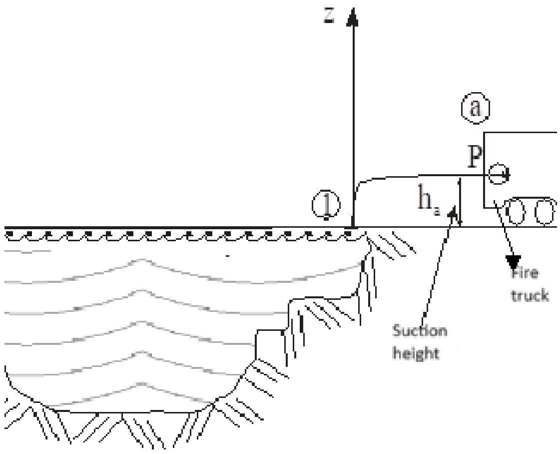

Fig. 2. Suction in the case of a p.s.i. fire truck

Applying Bernoulli's theorem between points (1) and (a), we have:

$$\frac{p_i}{\gamma} + \alpha_i\cdot\frac{\bar{u}_1^2}{2g} + z_i = const, i\in\{1,a\} \quad (42)$$

or

$$\frac{p_1}{\rho g} + \alpha_i\cdot\frac{\bar{u}_1^2}{2g} + z_1 = \frac{p_a}{\rho g} + \alpha_2\cdot\frac{\bar{u}_a^2}{2g} + z_a + \Delta h_r \quad (43)$$

if: z_a-z_1=h_a, $\bar{u}_a$>>$\bar{u}_1$, $\bar{u}_1$=0, p_1=p_{atm}, α_1=α_2=1,21, then [21]:

$$h_a = \frac{p_{atm}}{\rho g} - \frac{p_a}{\rho g} - \alpha_2\cdot\frac{\bar{u}_a^2}{2g} - \Delta h_r \quad (44)$$

or

$$h_a = \frac{p_{atm} - p_a}{\gamma} - 1.21\cdot\frac{\bar{u}_a^2}{2g} - \Delta h_r \quad (45)$$

It is technically necessary and sufficient that:

$$h_a \le \frac{p_{atm} - p_a}{\gamma} - 1.21\cdot\frac{\bar{u}_a^2}{2g} - \Delta h_r \quad (46)$$

where: Δh_r= total suction path pressure drop [m]
Substituting the relation:

$$\frac{p_{atm}}{\gamma} \cong 10.33 - \frac{z}{900} \quad (47)$$

in relation (45), we have:

$$h_a \cong 10{,}33 - \left(\frac{p_a}{\gamma} + \frac{z}{900} + 1{,}21 \cdot \frac{\bar{u}_a^2}{2g} + \Delta h_r\right) \quad (48)$$

in which: p_a= suction pressure at pump inlet [N/m^2];
γ= specific weight of water [kg/m^{2}s^2];
z= altitude [m];
ūa= average suction velocity at pump inlet [m/s];
Δhr= total amount of pressure drop [m].

Linear pressure losses are defined by:

$$\Delta h_{lin} = \lambda \cdot \frac{1}{d} \cdot \frac{\bar{u}_a^2}{2g} \quad (49)$$

and local pressure losses are defined by:

$$\Delta h_{loc} = (\xi_1 + \xi_2 + \xi_3 + \xi_4) \cdot \frac{\bar{u}_a^2}{2g} = \sum_{i=1}^{4} \xi_i \cdot \frac{\bar{u}_a^2}{2g} \quad (50)$$

where: λ= coefficient of linear hydraulic resistance;
l= suction path length [m];
d= diameter of the suction path [m];
$\bar{u}_a$= average suction water velocity [m/s];
ξ_1= coefficient of local pressure drop for sorb;
ξ_2= coefficient of local pressure drop in elbows;
ξ_3= coefficient of local pressure drop for connections;
ξ_4= coefficient of local pressure drop at pump inlet.

5. Dependence of h_a on specified parameters

5.1. Variation-h_a versus altitude-z

This variation depends on:
- the higher the value of this parameter, the lower the height h_a from which the suction is to be performed.

5.2. Variation-h_a versus suction pressure-p_a

This variation depends on [22]:
- the suction head is dependent on the atmospheric pressure; at the vacuum operation, the pa pressure becomes a suction (absorption) pressure for a period of time that the transition to the discharge regime for the truck is made, in the sense that the valves for the discharge can be gradually opened;
- in the case of vacuum, the suction pressure must be much higher than the water vaporization pressure ($p_a >> p_v$), since the practical suction head is negative for temperatures between 72ºC and 100ºC; in such cases, the pump truck must be placed at a lower level than the water source (flooded system); otherwise, cavitation is generated, which adversely affects the suction process and hence the pump efficiency.

5.3. Variation-h_a versus pressure drop-Δh_r

This variation depends on:
- the pressure losses consist of linear pressure losses (51) and local pressure losses (52):

$$\Delta p_{lin} = \rho \cdot g \cdot \Delta h_{lin} = \lambda \cdot \frac{l}{d} \cdot \frac{\bar{u}_a^2}{2} \cdot \rho \quad (51)$$

$$\Delta p_{loc} = \rho \cdot g \cdot \Delta h_{loc} = \rho \cdot g \cdot \sum_{i=1}^{4} \xi_i \cdot \frac{\bar{u}_a^2}{2 \cdot g} \quad (52)$$

- the total value of the pressure losses is [6]:

$$\Delta h_r = \Delta h_{lin} + \Delta h_{loc} = \left(\lambda \cdot \frac{l}{d} + \sum_{i=1}^{4} \xi_i\right) \cdot \frac{\bar{u}_a^2}{2 \cdot g} = \lambda^* \cdot \frac{l}{d} \cdot \frac{\bar{u}_a^2}{2 \cdot g} \quad (53)$$

The suction head h_a may also decrease due to head losses; therefore, it is necessary to reduce them by:
- using hoses of the shortest possible length between the water source and the longitudinal axis of the centrifugal pump;
- reducing local pressure losses by reducing the number of bends, tight coupling of connections, etc.

5.4. Variation-h_a versus suction speed-$\bar{u}_a$

This variation depends on:
- centrifugal pumps [23]

$$\bar{u}_a = (0.07 \dots 0.1) \cdot Q^{1/3} \cdot n^{2/3} \quad (54)$$

where: Q= aspirated flow [m^3/s];
n= centrifugal pump speed [rot/s].
which means:

$$\frac{\bar{u}^2}{2 \cdot g} \cong Q^{2/3} \cdot n^{4/3} \quad (55)$$

- h_a decreases with decreasing speed $\bar{u}_a$.
In these circumstances, the relationship (48) will be:

$$h_a = 10.33 - \left(\frac{p_a}{\gamma} + \frac{z}{900} + 1.21 \cdot Q^{2/3} \cdot n^{4/3} + \lambda^* \cdot \frac{l}{d} \cdot \frac{\bar{u}_a^2}{2 \cdot g}\right) \quad (56)$$

6. Conclusions

The use of polymer additives in firefighting water systems markedly decreases hydraulic head losses. By modifying turbulent flow characteristics and reducing velocity pulsations, these additives lower both the frictional resistance and pressure drops in the system. The reduction in small, high-frequency turbulent eddies, as influenced by the polymer solutions, leads to a more efficient water transport mechanism. This finding highlights the practical benefits of incorporating polymer additives for enhancing the performance and efficiency of firefighting operations.
Effective firefighting system design must address both pipe roughness and suction conditions to minimize pressure losses. Lowering pipe roughness and employing polymer additives can reduce linear and local resistance, while careful management of pipe diameter transitions and suction height further optimizes system efficiency. Ensuring minimal pressure drops through strategic design and material selection is essential for improving the overall functionality and reliability of firefighting systems in emergency scenarios.

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