2011 WJTA-IMCA Conference and Expo
September 19-21, 2011 ● Houston, Texas
Paper

THEORETICAL AND EXPERIMENTAL BASIS OF WATER PIPELINE RENOVATION WITH HIGH-PRESSURE WATER JET TECHNIQUE

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ABSTRACT

After several dozen years of water pipeline usage, thick and hard pollutions layers in the form of stone are deposit inside. Such impurities are characterized with great hardness and adhesion to the substrate because the main compounds of them are iron, manganese, calcium and silicon. Effective cleaning of such pipeline is a real problem. Theoretical and experimental profile of developed hydrodynamic method of pipeline renovation using high-pressure water jet is presented too.

Based on the whole work it should be mentioned here that this method of water pipe cleaning ensures high effectiveness of the process, since solid sediment is removed from 93-96% of total inside area of a pipe. A significant rate of pipeline cleaning (of the order of 100-120 m/h) at low consumption of process water (less than 6 m^3/h) ensures low cost and short processing time. Moreover, this cleaning method is environmentally friendly because a working medium is clear water.

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1. INTRODUCTION

The long-term operational use of pipelines causes that thick and nodular layers of hard sediment are being deposited inside. Effective cleaning of the water-pipe network with hard sediments deposited inside is a problem difficult to deal with [1, 3]. This sediment is distinguished by high hardness and adhesion to the substrate because of its major constituents i.e. compounds of iron, manganese, calcium, aluminum and silicon [2, 4]. It accumulates on inner surfaces of the water-pipe network mostly in the form of scale [6].

This sediment, until recently, was removed by chemical or mechanical methods using different types of scrappers or spongy (i.e. flexible and porous) plugs forced through pipes. Work on cleaning the pipes making use of high-pressure water jets was started in Ireland [11] and Great Britain [10] where nuclear systems were cleaned this way. This useful method at the end of the 80s was modernized and adapted [6] to the efficient cleaning of long water-pipe sections. A visible increase in effectiveness of cleaning such the pipelines had been achieved when the conditions of using this method [5, 7] were optimized [4] and its further development was stimulated [1]. Nowadays, similar techniques have also been used for the cleaning of sewage systems [7, 9] and various pipelines [12, 13]. Cleaning of pipes in petrochemical industry [13] demands usage of water jet with chemical additions [8] and electro-aerosol [14] making easy removing of deposits.

This work presents unaided accomplishments in the field of efficient water pipe cleaning using high-pressure water jets.

2. THEORETICAL BASIS

The fundamentals of hydrodynamic pipeline cleaning technology were worked out on the basis of long practical experience and previous unaided analyses [6] of parameters of various materials cleaning. The most important practical quantity i.e. a coaxial pull force of a cleaning nozzle was determined as a result of multi-aspect theoretical analysis [2] of a pipeline cleaning model and process kinetics, and hydrodynamics of elementary flows:

$$F_p = p\left(\sum_{i=1}^{i=n} A_i \eta_i \cos\alpha \cdot \cos\beta - \sum_{j=1}^{j=m} A_j \eta_j \cos\gamma \cdot \cos\delta\right), \qquad (1)$$

Sample results of the pull force defined by formula (1) for a dozen nozzles selected are presented in Fig. 2. These graphs can be used to determine a hydrodynamic state under different conditions of pipeline cleaning. Thus it is possible to estimate the pull force and the rate of working system (cleaning nozzle - feeding hose) along a pipeline in the course of cleaning as well.

3. EXPERIMENTAL

Theoretical analyses let to design a few types of nozzles (Fig. 3). They underwent versatile trials on test stands fed with water at very high pressure (up to 155 MPa). They were [2] used to carry out complex investigations on losses of pressure, water flow rates, and shapes of water jets, thrust, recoil and pull forces along with unit pressure, energy and water jet power for several dozen combinations of technological equipment. Results of these investigations confirmed validity of theoretical assessments fully. The loss of working pressure in the function of hose length and water orifice diameter of six-orifice nozzle is presented in Fig. 4.

king into account a limited length of the paper, only a sample dependence of the pull force for a few different nozzles on the water pressure are presented here. For example, in the Fig. 5, there are presented diagrams of pull forces for several nozzle types equipped in water orifices directed only backwards.

The comparison of these graphs with theoretical analyses (Fig. 2) points a close analogy between them.

4. BASIS OF HYDRODYNAMIC METHOD OF SEDIMENTS WASHING OUT

Hydrodynamic method that can be expressed as water-jet pull force, which is formed inside the working head, let to cut off sediments layers, their overgrinding and finally washing out. The character and shape of sediments washing out mainly depend on jet type, spraying angle and working jet length what is exemplary presented in Fig. 6.

Such kind results influence on the character of sediments cutting model with water jet and the type of their washout occurring in the pipe surface. Fig. 7 shows out the schema of such washout. According to realized experiments, such a sediments washout width is connected to their thickness. This can be expressed by the following relation:

$$S=(1.7\,d+1)\,h \qquad (2)$$

Water hole diameter has the most dominant influence on working head feed rate. Increase of this diameter let to progressive increase of feed rate as it is presented on exemplary Fig. 8. It should be mentioned also that water hole diameter as well as water pressure are the main factors influencing power of high-pressure water jet as an effective tool for sediments washing out (Fig. 9).

Analyses of these investigations made it possible to form many detailed conclusions concerning the physical phenomena and allowed to determine the following technological fundamentals of the process:

- Mean rate of nozzle travel while removing the very hard solid sediments from pipelines should amount to v_p=1.5-3 m/min.
- Number of water orifices arranged in the nozzle depends on a pipeline diameter and a thickness of sediment.
- Minimal value of the relative water requirement index amounts to w=0.5 l/dm^2.
- Unit thrust and pull forces are a derivative of a recoil force of a single water jet, whereas their vector sum gives a pull force of a cleaning nozzle.

5. OUTLINE OF HYDRODYNAMIC CLEANING TECHNOLOGY

Usually decision of pipeline cleaning is made basing on valuation of its contamination degree. Such a valuation is make using special monitoring TV cameras that uses trolleys for motion and are equipped with lighting systems (Fig. 10). Computer assist of TV cameras let to operate the trolley precisely and helps use adequate light intensity as well as inspection video recording.

In order to realize the hydrodynamic cleaning of pipelines [5, 8] it is necessary to carry out excavation and cut out an opening in a pipe allowing a nozzle with a water feeding hose to introduce inside. A number of water holes in the nozzle are selected as a dependence of pipeline diameter and sediments washout width [2]. The nozzle has suitable water orifices that discharge at a rate of 200-400 m/s coherent water jets with high concentration of unit power. Hydrodynamic interaction of such high-pressure water jets causes all the sediment to loosen and disintegrate and then remove it outside the pipeline. If process parameters were selected properly, it would be possible to clean a 400-500 m pipeline from one opening. When cleaning of the pipeline section is completed it is necessary to reassemble the opening fixing it with watertight joints. Selection of proper design for a nozzle and optimal cleaning process parameters is carried out each time depending on a quantity and hardness of sediment, a type, a diameter and an operational period of a pipeline. It enables to obtain a satisfactory value of coaxial pull force (Fig. 5) of a self-driven cleaning nozzle and proper trajectories of respective cavitations stream [4].

A field investigation is the final test verifying the developed profile of pipeline cleaning technology. Technological car systems (Fig. 11) were build in the Center of Pro-Ecological Technologies that enables such water pipe-line cleaning process [6].

Based on the whole work it should be mentioned here that this method of water pipe cleaning ensures high effectiveness of the process, since solid sediment is removed from 93-96% of total inside area of a pipe. A significant rate of pipeline cleaning (of the order of 100-120 m/h) at low consumption of process water (less than 6 m^3/h) ensures low cost and short processing time. Such cleaning does not result in any strain or other damage to the pipeline and therefore it may be applied to all types of pipelines from 25 mm to 1000 mm in diameter.

Moreover, this cleaning method is environmentally friendly because a working medium is clear water.

6. REFERENCES

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7. NOMENCLATURE

d – water nozzle diameter,
p – working pressure of a water jet,
$n, m,$ - number of water orifices in a nozzle directed backwards and forwards respectively,
A_1, A_2 – cross-section areas of respective water orifices,
α, γ – angles of water-orifice orientation in coaxial jet cross-section (Fig. 1),
β, δ - angles of water-orifice orientation in normal jet cross-section,
η_i, η_j –coefficients of water flow efficiency through the nozzle.

8. GRAPHICS

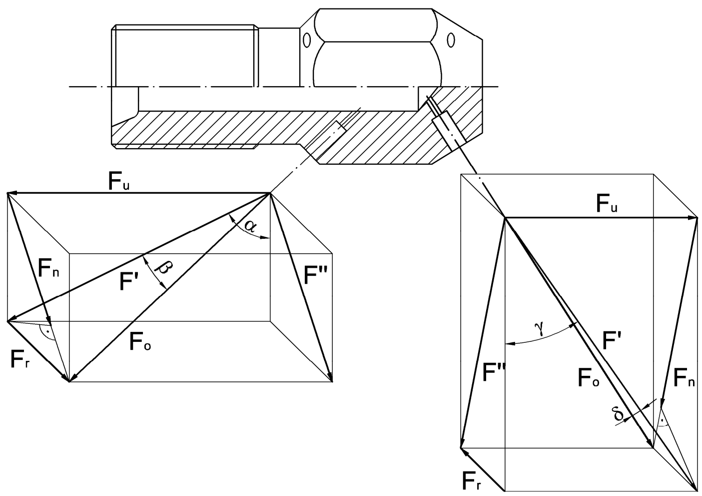

Fig. 1. Geometrical location of water holes drilled in the nozzle characterized by progressive motion showing forces configuration occurred in the orifices.

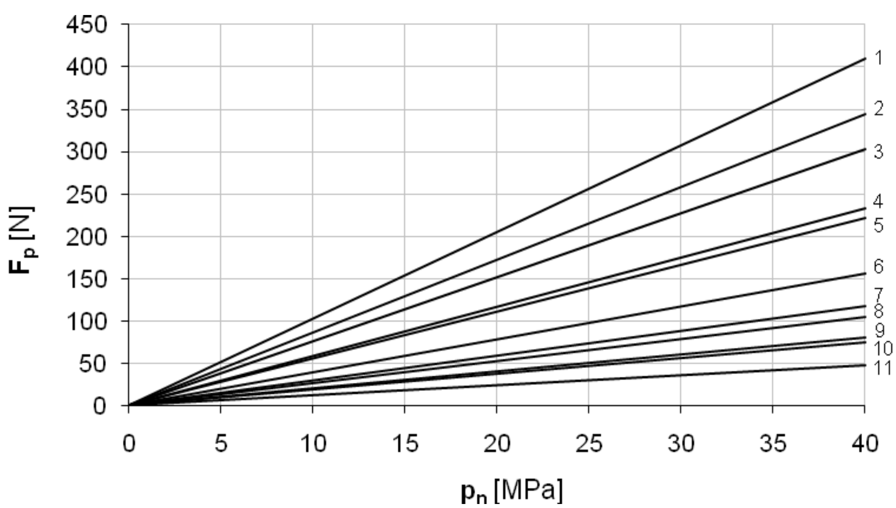

Fig. 2. Theoretical interdependence between pull forces and water pressure for different nozzles: **1** - 4xϕ2,0mm; **2** - 6xϕ1,5mm; **3** - 6xϕ1,4mm; **4** - 4xϕ1,5mm; **5** - 6xϕ1,2mm; **6** - 6xϕ1,0mm; **7** - 4xϕ1,2mm + forwards ϕ1,0mm; **8** - 4xϕ1,0mm; **9** - 3xϕ1,2mm + forwards ϕ1,0mm; **10** - 4xϕ1,0mm + forwards ϕ1,0mm; **11** - 3xϕ1,0mm + forwards ϕ1,0mm

Fig. 3. View of sample cleaning nozzles

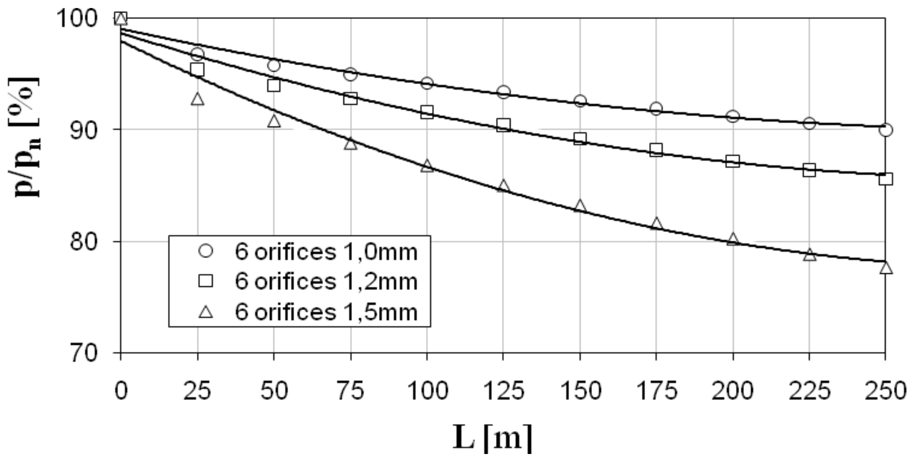

Fig. 4. The influence of hose length and water orifice diameter of six-orifice cleaning nozzle on the working pressure for hose diameter of 12,5 mm (p_n=25 MPa)

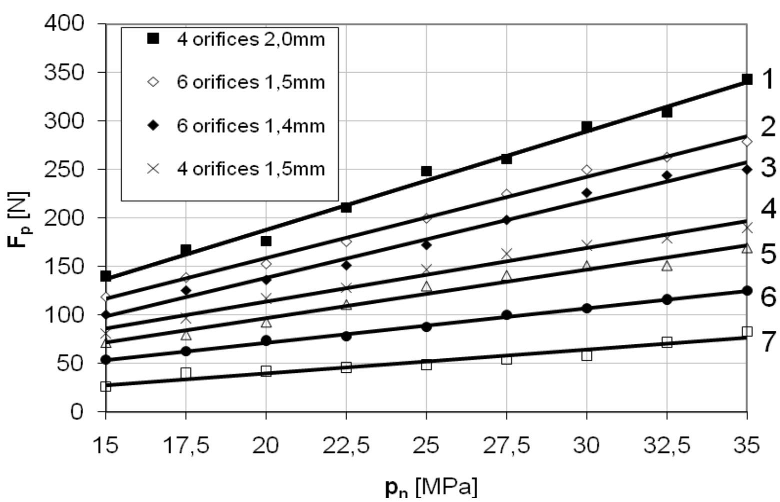

Fig. 5. Real values of pull forces for different nozzles as a function of water pressure (feeding hose: D_n=12,5 mm, L=100 m)

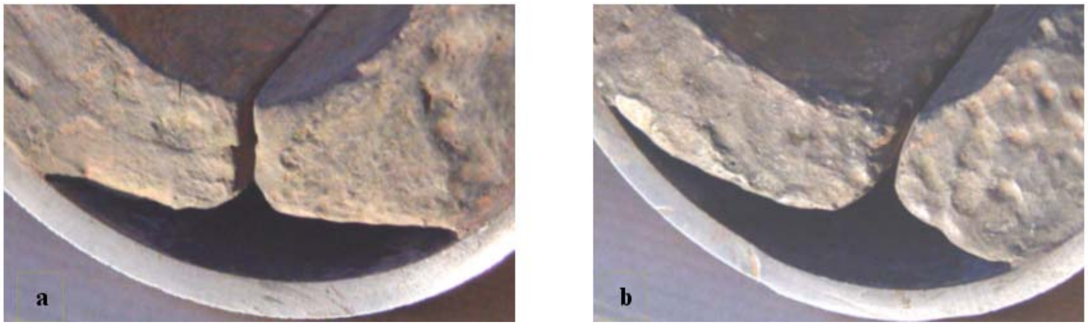

Fig. 6. Examples of sediments washout in the pipeline after high-pressure water jet cleaning:: a – perpendicular jet action effect, b – skew jet action effect

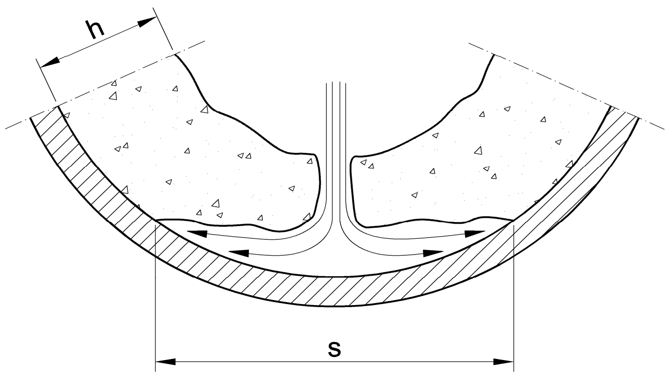

Fig. 7. Schema of sediments cutting and washing out using high-pressure water jet.

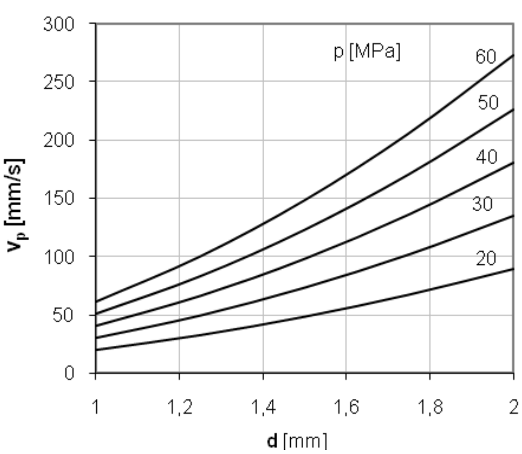

Fig. 8. Dependence of nozzle diameter (*l*=10 mm, h=20 mm) and water pressure on water jet feed rate during pipeline cleaning process

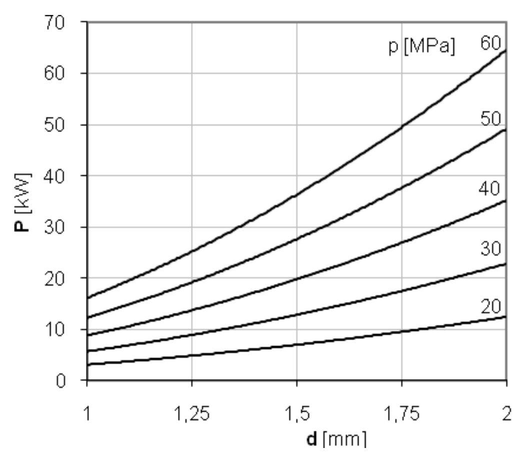

Fig. 9. Influence of nozzle diameter and water pressure on elementary water jet power (*l*=10 mm, h=20 mm)

Fig. 10. Pipelines monitoring TV-camera type SVC 110, Supervision ModularMainlineSystem.

Fig. 11. General view of two mobile test stands based on a hydro monitor with a high-pressure pump

Fig. 12. Exemplary effectiveness of water pipe cleaning
(approx. 60 years old cast iron pipeline, nominal inside diameter 100 mm)