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# THE MEASUREMENTS OF FRICTIONAL LOSSES IN A SLOTTED SIEVE

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Solid-liquid separation exists in a variety of industrial applications, mainly in chemical and petrochemical plants, including paper, food, and pharmaceutical processing. In several industrial applications filtration could be dedicated to protect mechanical devices against specific size of solid particles or to feed subsequent processing of the solid or liquid products. In some other cases reduction of loaded solid phase could be required. If filtration through a sieve is considered its elements consist of wire mesh screens, simple perforated and slotted plates or fibre-based filter or screen elements. In such a case major disadvantages are high-pressure drops on a sieve and clogging as well as the wear, and tear of mechanical elements. While designing a new slotted sieve as an intrusive element in a pipeline, the first step is to perform experiment in order to measure the local frictional coefficient.
The paper presents experimental stand, methodology and results of measurements of local frictional losses in a chosen slotted sieve installed in a horizontal pipeline. Experiments are conducted for carrier liquid flow only in case of the first step being focused on tuning of the experimental stand. Such experiments are useful because they provide a reference point for further measurements of local frictional losses in slotted sieves in cases when solid-liquid flow is considered.

KEY WORDS: local frictional losses, flow in a slotted sieve, experimental stand for local losses.

## 1. INTRODUCTION

Transport of solids with water as a carrier liquid commonly appears in mining and processing industry. In some cases the separation of solid phase is required. Such a separation exists in a variety of industrial applications, mainly in chemical, petrochemical and food plants. The separation of two phases can be performed using chemical or mechanical techniques, Wakeman (2011). The chemical techniques include additives, such as flocculants, Garcia et al. (2009), Sarnecki and Bartosik (2014), Jaworska and Bartosik (2014), while the mechanical methods include gravity (thickening, sediment tank, slotted sieves) or centrifugal techniques such as hydrocycloning, Priestman et al. (1996), Rawlins et al. (2000), Gao et al. (2002). It is worthwhile to mention that modern techniques, which utilize magnetic, electrical or sonic force fields, are also available.

Solid-liquid separation is often designed as a *stand-alone* unit in a plant or is installed as intrusive equipment in a pipeline or open channel, such as slotted sieve. Solids separation often involves filtering. In several industrial applications filtration is dedicated to protect mechanical devices against specific size of solid particles or to feed subsequent processing of the solid or liquid products. In some other cases reduction of loaded solid phase can be required. If a sieve is used for filtration its elements consist of wire mesh screens, simple perforated and slotted plates or fibre-based filter or screen elements. In such a case major disadvantages are high-pressure drop on a sieve, clogging, as well as the wear, and tear of mechanical elements.

When a new slotted sieve is designed as intrusive element in a pipeline, the first step is to perform experiments in order to measure the local frictional coefficient, which is required for a proper design of pipeline characteristics. Modelling of a slotted sieve requires mainly high efficiency of separation of solids from liquid, keeping frictional losses of a slotted sieve as low as possible to minimalize energy consumption, and keeping operational and maintenance costs low.

The main objective of the paper is to present experimental stand and initial results of measurements of local frictional losses in a chosen slotted sieve situated in a horizontal pipeline of the inner diameter equal to 0.0545 m. The measurements of the local frictional losses have been made for a slotted sieve with the width of each slot equal to 0.24 mm, thickness of about 1 mm and the opening area of the pipeline of about 16.32%.

## 2. SLOTTED SIEVES

Slotted sieves are produced from specially profiled rods (working bars), which are welded together with assisting bars usually by means of the electro resistance method. They are used mainly in engineering sectors, such as:

– the mining sector, including coal richness (dust separation)
– food sector, including extraction, sorting, drying
– the oil and gas sector, including production of fuels and lubricants
– the chemical sector, including handling of chemicals and polymers
– the paper industry sector, including dehydration, refining
– technology of water purification

While modelling or designing slotted sieves one should take into account some major features, such as: ability to carry heavy loads, high precision of performance, low local frictional losses, smooth and flat plane structure, self-cleaning structure, a large open area, long life cycle, etc.

Slotted sieves are made of stainless and acid resistant steel. As filtering elements, they are stable at extreme conditions of pressure and temperature, and are distinguished by high mechanical stability. The connection of working rods with the supporting rod in a slotted sieve is presented in Fig. 1.

Fig. 1 The connection of working rods with the supporting rod in a slotted sieve

In order to prevent solid particles from stocking to the surface of a slotted sieve the shape of working rods allows for the achievement of diffusion process, which is presented in Fig. 2. When a flow passes through the slots the cross section of the flow increases causing the decrease of flow velocity and the increase of static pressure. Such a phenomenon decreases the ability of particles to stick to the slotted sieve surface. Of course, if a slotted sieve is installed in a horizontal pipeline it is necessary to remove solid particles collected at the bottom of a pipe. There are several techniques available, one of them being periodical suction at the bottom of a pipe.

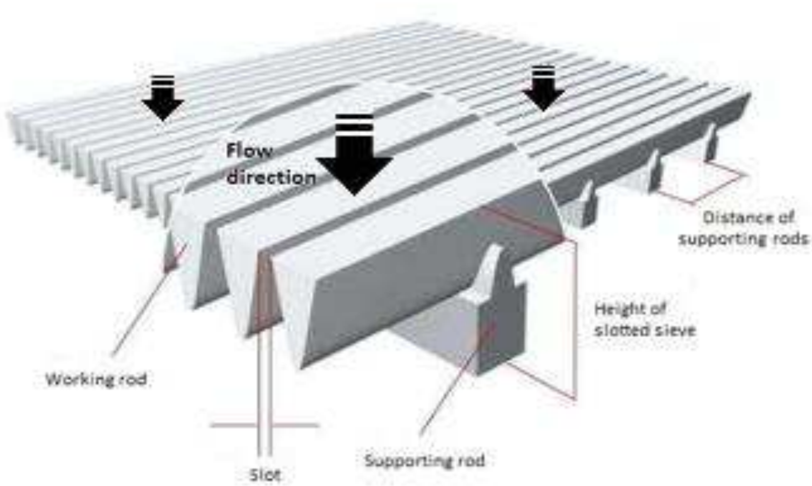


Fig. 2 View of a slotted sieve

Taking into account technical parameters of a slotted sieve one has to recognise the coefficient of open area, also known as active surface (working surface) and denoted as $F_o$. The coefficient expresses percentage ratio of open area to the cross section area of a pipe, which is described by equation (1).

$$F_o = \frac{S}{S+A} 100 \qquad (1)$$

where
A – area of working rods
S – area of slots (open area)

Local frictional losses caused by a slotted sieve (ξ) are known also as local frictional coefficient or fitting losses. They play crucial role in determining pipeline characteristics, Duffy et al. (1972), Vlasak et al. (2014). They often cause a substantial portion of a pipeline flow resistance. If typical pipeline elements, such as, for example, bends, valves or fittings available on a commercial market are used, a local frictional coefficient (ξ) usually dependent on the Reynolds number can be easily identified in literature. However, if a new construction of a fitting such as slotted sieve is developed or the liquid is not Newtonian we have to determine the losses through experiments.

## 3. EXPERIMENTAL STAND

Experimental stand is situated at the Reo-flow Laboratory at the Kielce University of Technology and is presented in Figure 3. It consists of a closed loop of inner diameter D=0.0545 m with the following major elements: centrifugal pump, magnetic flow meter, four pressure transducers, heat exchanger, feeder and slurry mixing tank, valves, analogue pressure gauges and pressure taps. The slotted sieve being tested has been localised between pressure taps $p_2$ and $p_3$. The flow rate is measured by magnetic flow meter Optiflux 1050, which allows for measurements in the range from 0 to 60 $m^3/h$. The experimental stand allows us to measure pressure drops $p_2$-$p_3$ and $p_1$-$p_4$ using pressure transducers IP66 with proper ranges. The temperature of flowing liquid is measured by a thermocouple (T1). The centrifugal pump is steering by drive inverter in the range from 0 to 3000 rot/s.

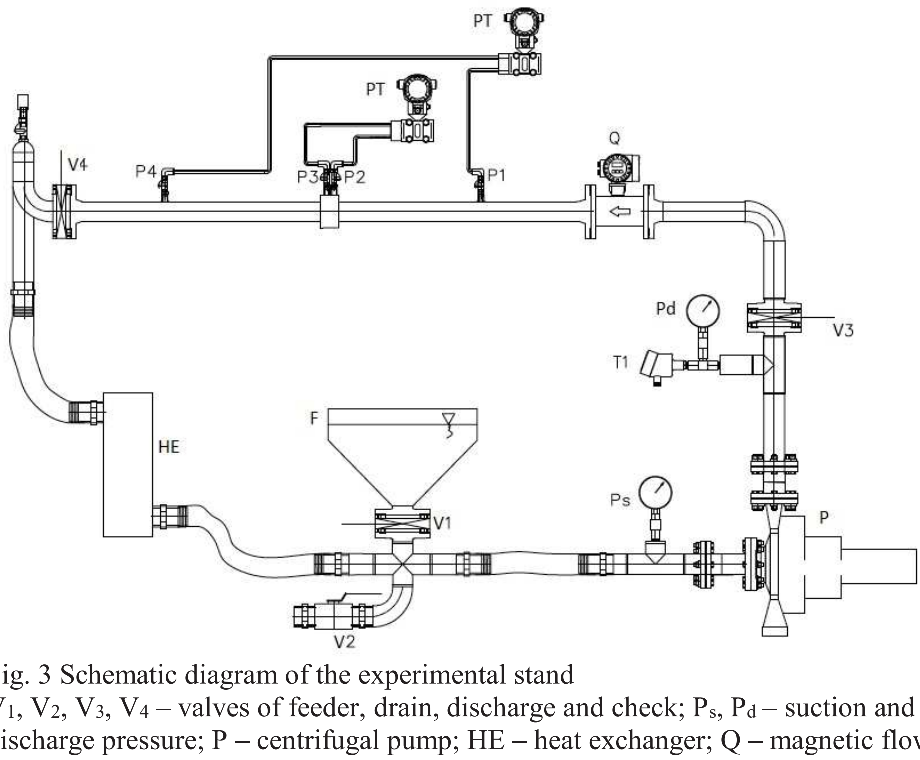


Fig. 3 Schematic diagram of the experimental stand
$V_1$, $V_2$, $V_3$, $V_4$ – valves of feeder, drain, discharge and check; $P_s$, $P_d$ – suction and discharge pressure; P – centrifugal pump; HE – heat exchanger; Q – magnetic flow meter; PT – pressure transducer; $p_1$, $p_2$, $p_3$, $p_4$ – pressure taps; $T_1$ – thermocouple

A 12-byte data acquisition station has recorded experimental measurements, including pressure drops and the flow rate.

## 4. EXPERIMENTS

The measurements of local frictional coefficient ($\xi$) on a slotted sieve can be done using direct or indirect method. The direct method allows us to measure pressure drop between two taps situated at the inlet and outlet of the slotted sieve ($p_2$ and $p_3$ in Fig.3). This method, however, demonstrates high-pressure fluctuations, which is due to swirls occurring downstream across a pipe, Brodkey (1969). As a result we expect that the time averaged local frictional coefficient will exhibit an error during measurements. If larger fluctuations exist a large error can appear.

The indirect method includes pressure drop measurements if the first pressure tap is localised at some distance before a slotted sieve, while the second tap is situated at some distance downstream from a slotted sieve. This is shown in Figure 3, where $p_1$ is the first pressure tap, while $p_4$ is the second pressure tap. In this case the pressure drop equals $\Delta p_{1-4}=(p_1-p_4)$ and is associated with the physical length of straight pipe ($L_x$), the length of the slotted sieve, the shape of the slotted sieve and requires the inclusion of frictional coefficient ($\lambda$).

Taking into account Bernoulli equation for horizontal pipeline for cross sections 1 and 4, which corresponds to $p_1$ and $p_4$, we can get:

$$\frac{\rho U_1^2}{2} + p_1 = \frac{\rho U_4^2}{2} + p_4 + \sum \Delta p_{1-4} \tag{2}$$

Assuming that $U_1$ and $U_4$ are the same, which is true for the constant pipe inner diameter, the pressure drop between taps $p_1$ and $p_4$ can be described by equation (3) as follows:

$$\Delta p_{1-4} = \lambda \frac{L_x}{D}\frac{\rho U^2}{2} + \xi \frac{\rho U^2}{2} \tag{3}$$

where $L_x$ is the sum of horizontal distances between $p_1$ and slotted sieve, and between the slotted sieve and $p_4$, while $\rho$ is a carrier liquid density.
Finally, the local frictional coefficient can be described as:

$$\xi = \frac{\pi^2 D^4 \Delta p_{1-4}}{8\rho Q^2} - \lambda \frac{L_x}{D} \tag{4}$$

where Q is a flow rate in $m^3/s$.

The indirect method of measurements, expressed by equation (4), uses the frictional coefficient ($\lambda$), which appears in equation (4). The frictional coefficient ($\lambda$) is not the same before and after the slotted sieve if pressure taps $p_1$ and $p_4$ are not properly situated. In order to ensure the same values of $\lambda$ the pressure tap $p_1$ has to be localised 40D after the flow meter Q (Fig.3), while the pressure tap $p_4$ has to be situated 40D after the slotted sieve and at least 5D before the valve $V_4$.

If the direct method of measurements is considered the local frictional coefficient ($\xi$) for the slotted sieve has to be calculated by following equation:

$$\xi = \frac{\pi^2 D^4 \Delta p_{2-3}}{8\rho Q^2} \tag{5}$$

Before the experiments the pressure transducer IP66 was examined by comparing its measurements with the U-tube measurements and a proper desaturation of the pipeline and pressure ducts was made. During experiments the temperature of the flowing medium was kept in the range from 19.9 ºC to 20.1 ºC.

The slotted sieve chosen for experiments is characterised by following parameters:

- Width of the working rods: 1 mm
- Width of the slots: 0.24 mm
- Active surface of the slotted sieve: $F_o$=16.32 %

This means that solid particles of diameter higher than 0.24 mm will not pass the slots.

Pressure drop $\Delta p=p_2-p_3$ measured directly on the slotted sieve is shown in Fig. 4. It can be seen that experimental data correspond to the turbulent flow, as the lowest flow rate is about 3.7 $m^3/h$, which corresponds to the Reynolds number of about Re=24,000.

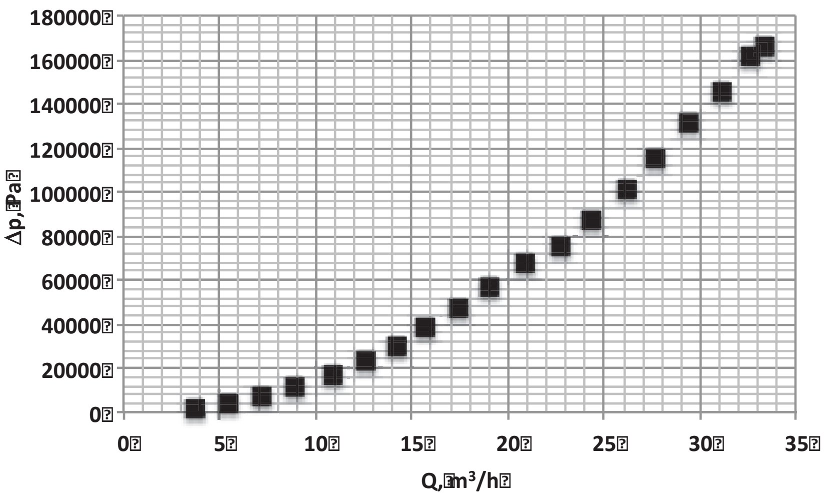


Fig. 4 Measured characteristics of the slotted sieve in a pipeline of inner diameter D=0.0545 m, width of slots S=0.00024 m, open area 16.32%

Taking into account the measured pressure drops and equations (4) and (5) the local frictional coefficient of the slotted sieve ($\xi$) has been calculated. The results are presented in Fig. 5. There are two sets of experimental data referred to the direct and indirect methods of measurements. The difference between experimental data obtained by two methods is surprisingly small. So, one can conclude that both methods are useful for the presented stand. It can be seen that experimental stand with the inner pipe diameter D=0.0545 m and a chosen centrifugal pump allows us to achieve Reynolds number in the range from Re≈24,000 to Re≈220,000. It can be seen in Figure 5 that the local frictional coefficient ($\xi$)

increases significantly with the increase of Reynolds number up to Re≈100,000 and is almost stabilized if the Reynolds number is higher than100,000.

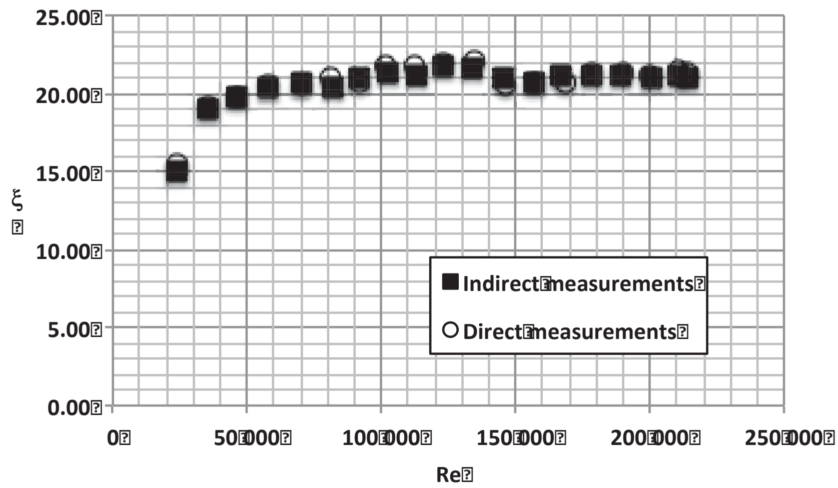


Fig. 5 Experimental data of local frictional coefficient measured using direct and indirect methods in pipeline of inner diameter D=0.0545 m, width of slots S=0.00024 m, open area 16.32%

The presented experiments have been conducted for carrier liquid flow only, which was pure water. It is important to carry them out before solid-liquid flow is analysed. Such experiments for carrier liquid flow are necessary to build mathematical model suitable for the prediction of frictional losses of a slotted sieve without necessity to perform measurements. If such a model is created it will be useful for the design of new slotted sieves for industrial application without necessity to perform experiments.

## 5. CONCLUSIONS

The process of solid-liquid transport through a slotted sieve is very complex as we are dealing with multiple boundary layers affecting each other, Hinze (1959), Bird et al. (1960), Brodkey (1969). Rapid reduction of the cross section of a flow, which appears in a slotted sieve, may cause changes of a flow regime from turbulent to transitional or even laminar. As a result, the simulation of flows passing the slotted sieve is complex and difficult to implement. However, it is possible to obtain empirical or semi-empirical function describing the influence of slotted sieve geometry on the local frictional coefficient. Of course, we expect some limitations of such function, which are almost impossible to define in advance. In order to optimise a slotted shape, which is useful in the process of factory designing for a variety of industrial applications, especially if diffusion processes have a special meaning, such a function can decrease the number of measurements of local frictional losses. This will help to reduce the time necessary to optimize slotted sieve geometry. A computationally efficient algorithm can be used to reduce the costs of simulations.

The experiments demonstrate a high-pressure drop for a chosen slotted sieve, with the width of slots equal to 0.24 mm, thickness of 1 mm and opening area of the pipeline 16.32%, which depends on flow rate. The results of experiments of local frictional coefficient ($\xi$) do not confirm significant differences between direct and indirect methods of measurements. Experimental points of the frictional coefficient are not very smooth in the range of Reynolds number Re=(100,000 - 150,000) which is probably due to specific geometry of the slotted sieve responsible for generation of high order turbulence. The chosen slotted sieve exhibits high frictional losses, which are significantly greater compared to typical fittings, such as bends or valves. The reduction of losses in a slotted sieve without decreasing its efficiency could contribute to energy savings and lower operational costs.


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