Mathematical model of ejector and experimental verification

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Abstract This paper deals with the reduction of the water suction time into the rotating impeller of the centrifugal pump used in firesport. The suction is carried out by the ejector, which is powered by exhaust gases of combustion engine. A created mathematical model describes the flow in the ejector, and was verified by an experiment. It was also used as a base for the creation of a new ejector, which has an increased airflow.

1 Introduction

It is desirable to reduce the suction time into the impeller of the centrifugal pump in order to achieve better, i.e. shorter, times in firesport competitions. Often original ejectors (vacuum pumps) are used which are adapted for sucking water from great depths, but not for faster suction. There are adjustments that allow enhance this effect. The selected variant was measured at the Department of Hydraulic Machines VUT Brno laboratory. For example Friedrich 2006 [3] deals with the calculating and measuring of ejector.

A mathematical model was created and verified with this experiment. After that the mathematical model served for designing an improved ejector.

2 Input parameters

p_p	164500	[Pa]	D_v	54	[mm]	D_k	30	[mm]	T_{1p}	226	[°C]
p_v	98000	[Pa]	D_s	50	[mm]	D_d	15,4	[mm]	T_{2s}	19	[°C]
$\dot{m}_1$	0,0359	[kg s^{-1}]	D_p	50	[mm]						

3 Mathematical model

All input properties of gases are known and the ejector can be described by using the law of energy conservation and momentum.

Bernoulli equation is used for the P and D positions [2].

$$\frac{v_{1p}^2}{2} + i_{1p} = \frac{v_{1d}^2}{2} + i_{1d} \quad (1)$$

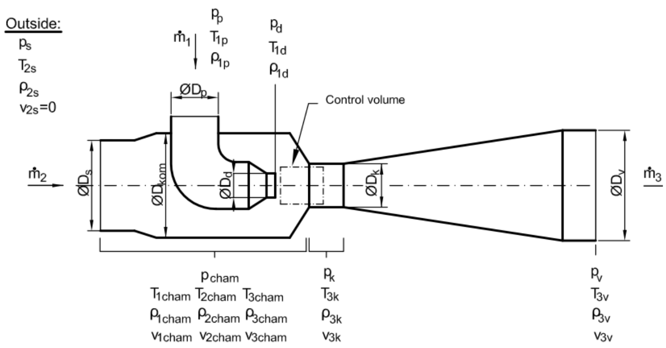


Fig. 1 Scheme of modeled ejector

Next, it is assumed that a critical speed is in the *D* position and polytropic process comes [1].

There are two unknowns in this equation – pressure p_d and exponent of polytropic process $n_{p,d}$. Polytropic exponent is chosen so that the velocity is critical and pressure in the D position is about 73 kPa (this is the minimum value which was measured). From the measurement input mass flow rate ($\dot{m}_1$) and pressure in position P (p_p) are obtained and constant values are assumed.

The minimum pressure p_d can be achieved when this ejector is used. This value will be in this position every time when using the ejector. The pressure in the mixing chamber is not constant and the adiabatic process between the D position and the mixing chamber is assumed (its short distance so loss of heat can be neglected). Pressure p_{cham} is identical with the pressure in the suction branch.

Bernoulli equation is used for suction branch (from suction vessel to mixing chamber) [2]. Adiabatic process is considered [1]. Zero velocity is defined in the vessel.

$$\frac{v_{2s}^2}{2} + i_{2s} = \frac{v_{2cham}^2}{2} + i_{2cham} \tag{2}$$

Next, momentum equation is used for mixing chamber [2].

$$\rho_{1cham} \cdot Q_{1cham} \cdot v_{1cham} + \rho_{2cham} \cdot Q_{2cham} \cdot v_{2cham} + p_{cham} \cdot S_k = \rho_{3k} \cdot Q_{3k} \cdot v_{3k} + p_k \cdot S_k \tag{3}$$

Adiabatic process, polytropic process and equation state has to be added to the previous relationship [1].

Exponent of adiabatic process and exponent of polytropic process are not constant value and are calculated as ratio of mass flow rate (flow $\dot{m}_2$ is changed during using ejector).

Bernoulli equation is used for throat and for outflow (diffusor of ejector) [2].

Bernoulli equation is completed by state equation, polytropic process and equation of continuity [1].

$$\alpha_k \cdot \frac{v_{3k}^2}{2} + i_{3k} = \alpha_v \cdot \frac{v_{3v}^2}{2} + i_{3v} \tag{4}$$

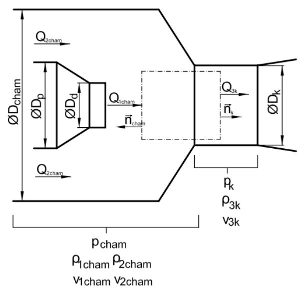


Fig. 2 Mixing chamber

Specific constant of gas, exponents of polytropic and adiabatic process and specific heat capacity are calculated as ration of mass flow rate (flow $\dot{m}_2$ is changed during using ejector).

3 equations are known. There are 7 unknowns here.

- Mass flow rate of air | $\dot{m}_2$ | [kg/s]
- Pressure in mixing chamber | p_{cham} | [Pa]
- Pressure in throat | p_k | [Pa]
- Exponent of polytropic process in mixing chamber at m_2=0 | $n_{cham.k.s}$ | [-]
- Exponent of polytropic process in diffusor at m_2=0 | $n_{k.v.s}$ | [-]
- Coriolis number in throat | α_k | [-]
- Coriolis number in outside | α_v | [-]

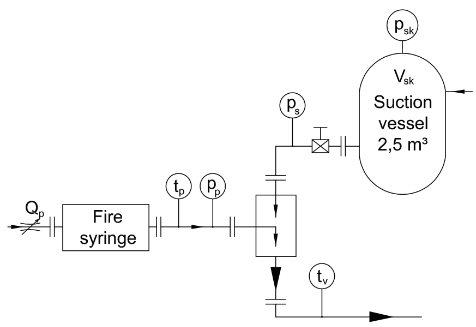
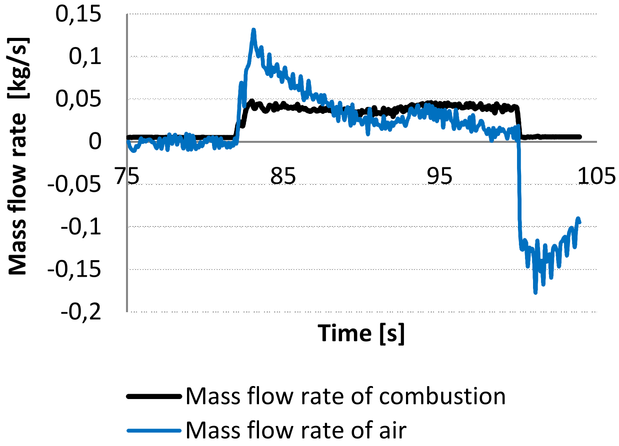


Fig. 3 Scheme of measurement

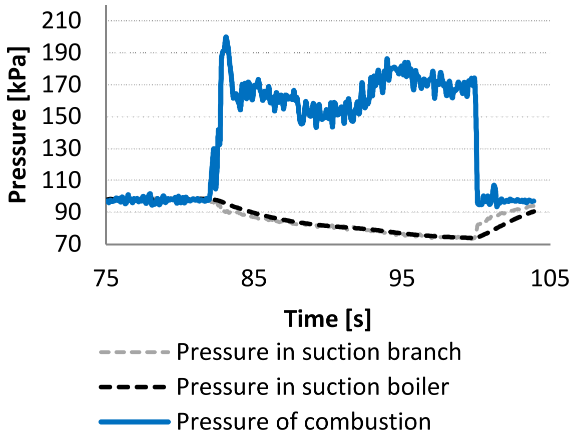
Exponents of polytropic process and Coriolis numbers are chosen so that mathematical model fit measurement and we calculate others unknowns ($\dot{m}_2$, p_{cham}, p_k) with numerical method.

4 Measurement

Characteristic of ejector, which was installed in fire syringe, was measured. Time, mass flow of combustion, pressure and temperature from ejector in pressure branch, pressure in suction vessel before ejector in suction branch and temperature behind ejector were measured. Results of measurement are presented in the next graphs.



Graph 1 Measurement results - Mass flow rate



Graph 2 Measurement results - Pressure

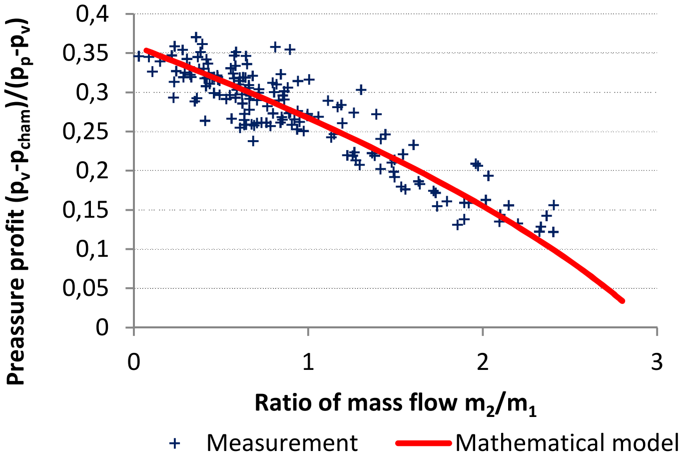
5 Comparing measurement with mathematical model

Exponents of polytropic process and Coriolis numbers are chosen so that model fit the experiment best.

$\alpha_k = 1{,}02$	[-]	$n_{cham.k.s} = 1{,}2$	[-]
$\alpha_v = 1{,}01$	[-]	$n_{k.v.s} = 1{,}35$	[-]

Next, coefficients for plotting the graph are defined.

- Ratio of mass flow rate $\frac{\dot{m}_2}{\dot{m}_1}$ [-]
- Pressure profit $\frac{p_v - p_{cham}}{p_p - p_v}$ [-]



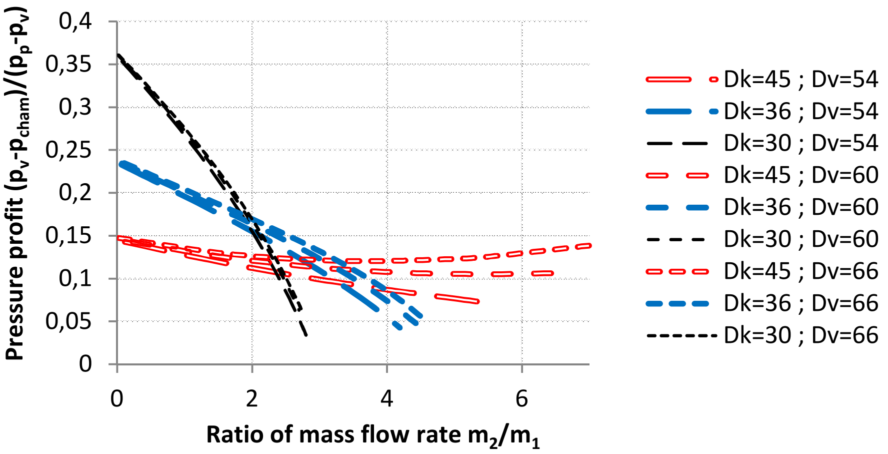
Graph 3 Comparing measurement with mathematical model

6 Design of new ejector and comparison with measured ejector

We will find the new ejector which has greater mass flow rate in the suction branch (mass flow of air) than the original ejector for pressure 90-100 kPa. This we must find new dimensions of ejector which meets this conditions.

Diameter of throat (D_k) and diffusor (D_v) are changed. Diameter of nozzle cannot be changed (we don't know the change in input parameters that would come).

Characteristics of some selected ejectors are shown in the next graph. It is possible to observe the behavior of the ejector when particular dimensions are changed. It is evident that ejectors with identical diameter of the throat which have the same closure point and bigger diameter of the diffusor increases the flow of air. The final choice of sizes depends on specific requirements and manufacturing possibilities.



Graph 4 Mathematical models of the selected ejectors with different dimensions

7 Conclusion

The mathematical model describing flow inside the real ejector is introduced in this paper. The comparison of the calculations with the measurement is more than satisfactory and this method seems to be suitable for similar devices with convergent nozzle.

Ejector, which has different diameters of throat and diffusor, could be designed with the model. Such ejector can have an increased flow rate in suction branch, but degreased suction height. The specific choice of dimensions depends on the particular type of use.

This model could be improved by better search of exponents of polytropic processes. Find these values with genetic algorithm would be interesting variant. Dynamic shock (shock wave) is not assumed, this is next possibility for improving this model.

Acknowledgement I would like to thank grants FSI-J-12-21/1698 and FSI-S-12-2 for their support in this research.

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