Air ejector with diffuser with boundary layer suction – preliminary study

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Abstract The article deals with axi-symmetric subsonic air to air ejector with diffuser adapted for boundary layer suction. The diffuser, which is placed behind the mixing chamber of the ejector, has high angle enlargement and therefore low efficiency. To increase the efficiency, the diffuser is equipped with slot enabling boundary layer suction. The effect of boundary layer suction on flow in ejector, static pressure distribution and characteristic were measured. Both diffuser and ejector efficiency were evaluated. The diffuser efficiency were increased, however, the efficiency of ejector itself remained low.

1 Introduction

The diffusers often play an essential role in many application, so many researchers were concerned in diffuser design, as it was summarized by Japikse and Baines in work [1]. The efficiency of diffusers with high enlargement can be improved by boundary layer suction. For example, Furuya et all. [2] published a detailed, quantitative investigation of the simple conical diffuser with inlet suction similar to the one shown in Fig. 1. They found that the diffuser effectiveness could be improved substantially, especially at large divergence angles, with the use of fairly modest suction levels of 2-5%. These authors found, by experimentation and detailed measurement, that the optimum rate of suction corresponded roughly to the condition where the initial boundary layer thickness was decreased to zero by the suction through a single slit.

Another approach was used by Rockwell [3], who applied perforated walls for boundary layer suction, but these results were not so excellent. By contrast to the technique described above, the suction rates were quite high and the flow stability was limited.

If the diffuser is a part of an ejector, the boundary layer suction can be performed by ejector itself. For example, Earl in work [4] used described arrangement while a supersonic ejector was investigated, but boundary layer suction did not bring any improvement. Firstly, the diffuser with low enlargement angle of 6° was used. Secondly, the sucked fluid was return in front of the diffuser and thus the energy obtained by the fluid was dissipated.

2 Methods

On the base of knowledge obtained in works [2] and [3], a diffuser with enlargement angle of 40° equipped with adjustable slot for boundary layer suction was designed, as it is shown in Fig. 1. The diffuser was manufactured by turning from silone. As was proved by work [4], the sucked fluid should be brought back in to the mixing chamber. Firstly, to use the energy obtained by sucked gas, and secondly, to enhance mixing process in its beginning. The problem is a proper design of such system, because we get several unknown constructive parameters. In our case, a system applying 4 nozzles with diameter of 5mm inclined by 15° to ejector axis was chosen. This inlet part of the mixing chamber including return nozzles were manufactured by rapid prototyping, its dimensions are also visible in Fig. 1.

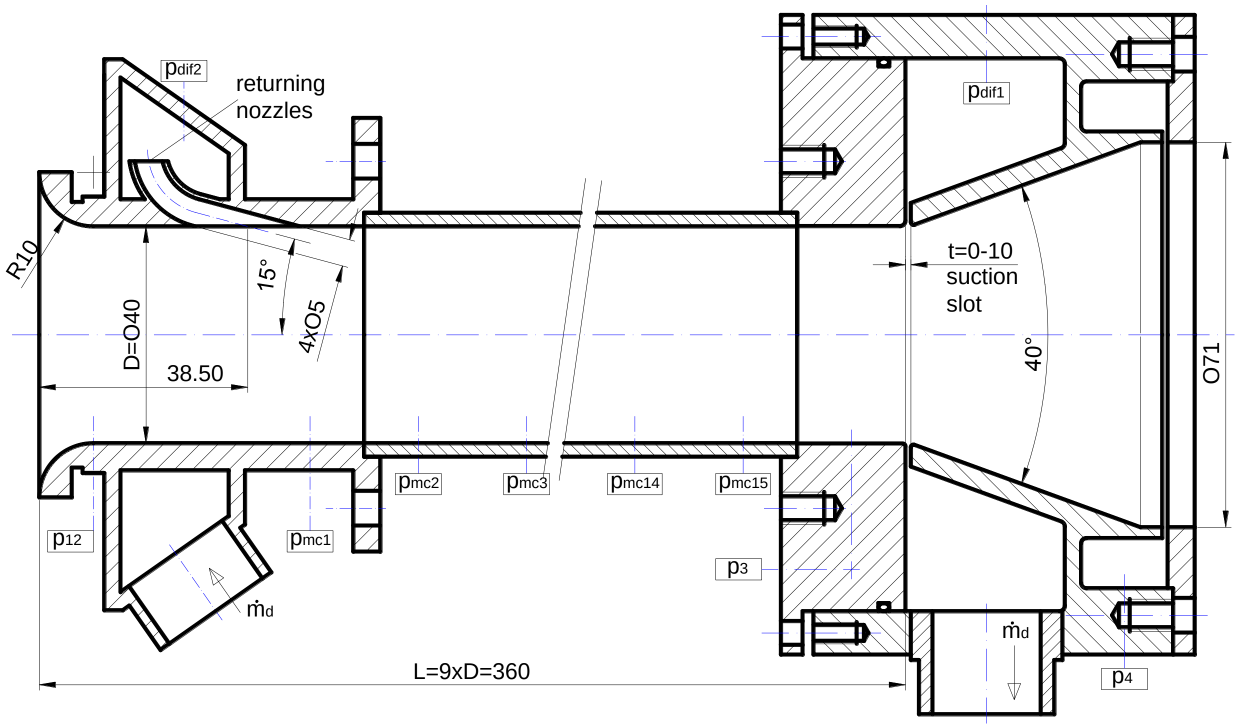

Fig. 1 Dimensions and positions of static pressure taps of the experimental air ejector with diffuser with an adjustable suction slot for boundary layer suction in the inlet of the diffuser.

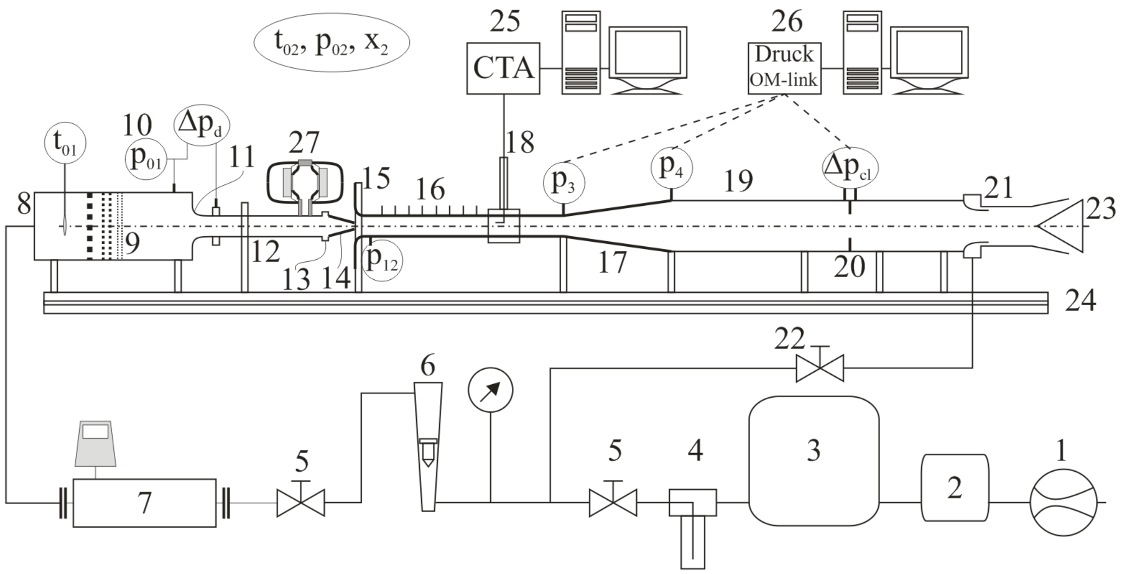

Fig. 2 Experimental arrangement: 1 - compressor, 2 - air dryer, 3 - tank, 4 - filter, 5 - reduction valve, 6 - rotameter, 7 - Coriolis mass flow meter, 8 - stilling chamber, 9 - stilling riddles, 10 - measuring of primary stagnation pressure p01, 11 - measuring of primary mass flow rate, 12 – primary flow supply tube, 13 – holder of primary nozzle, 14 – primary nozzle, 15 - secondary nozzle, 16 - mixing chamber with static pressure taps, 17 – diffuser, 18 – probes of constant temperature anemometry, 19 – outflow pipe, 20 - measuring of total mass flow rate, 21 - suction ejector, 22 - control valve, 23 – chocking, 24 - base, 25 - CTA measuring, 26 – pneumatic measuring.

The experimental arrangement is shown and described in Fig. 2. We used primary nozzle with diameter of 19.2mm and mixing chamber of diameter of 40mm, i.e. the inlet area ratio of nozzles are $\mu = A_1/A_2 = 0.3$. The length of the mixing chamber was 9D=360mm, the diffuser has angle 40° and enlargement ratio 3.15. To evaluate the diffuser effectiveness we used the equation (1), for evaluation of ejector efficiency, see work [5].

$$\eta_D = \frac{p_{03} - p_{04}}{p_{d3} - p_{d4}}\left(1 - \frac{m_d}{m_3}\right) \tag{1}$$

3 Results and discussion

The results of experimental investigation of the ejector performance are in Fig. 3. There are ejector efficiency for various adjustments of the suction slot and comparison with results obtained on the same ejector with 6° diffuser [5]. The ejector with 40° diffuser without suction through slot of width of 0mm had the lowest efficiency. The ejector efficiency was increased by applying the boundary layer suction through the slot of width of 2mm and again slightly decreased by further opening of the slot on 4mm. In all cases, the ejector efficiency remained substantially lower than the efficiency of the diffuser with 6° diffuser without suction. As we can see in Fig. 4, the different efficiencies are given by differences in measured back pressures.

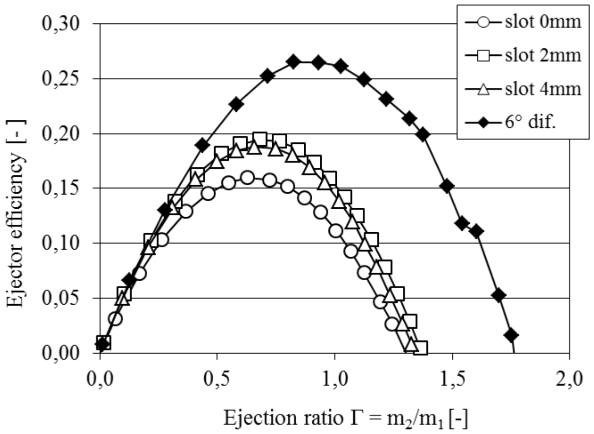

Fig. 3 Ejector efficiency for different adjustment of suction slot and comparison with ejector with 6°diffuser.

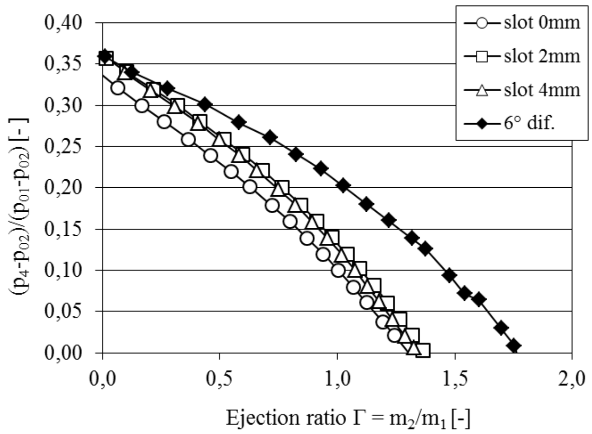

Fig. 4 Relative back pressure (p_4 - p_{02}) / (p_{01} - p_{02}) behind the diffuser for various adjustment of suction slot.

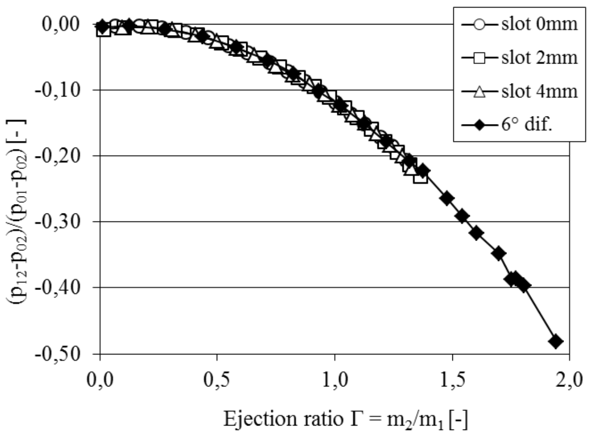

Fig. 5 Relative expansion pressure (p_{12} - p_{02}) / (p_{01} - p_{02}) in the beginning of the mixing chamber for various adjustment of suction slot.

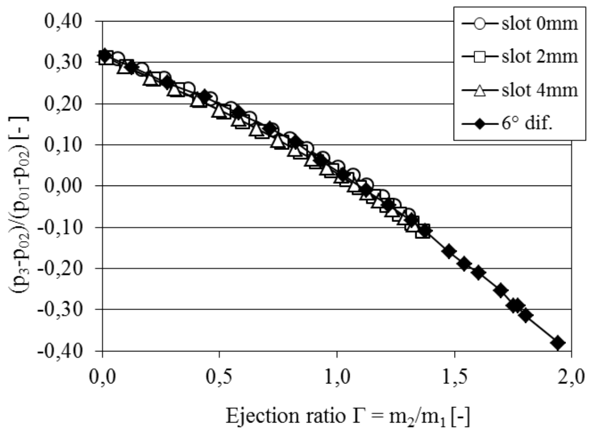

Fig. 6 Relative mixing pressure (p_3 - p_{02}) / (p_{01} - p_{02}) at the end of the mixing chamber for various adjustment of suction slot

As we can further see on Fig. 5 and 6, the suction, slot opening and design of the diffusers have no influence on pressures p_{12} and p_3. The expansion pressure p_{12} is measured in the beginning of the mixing chamber and is fully determined by ejection ratio. The mixing pressure p_3 is measured at the end of the mixing chamber, i.e. in front of the diffuser. It seems that entrancing the returned fluid back into the mixing chamber affects the mixing processes insignificantly.

The effectiveness of the diffuser itself is plotted in Fig. 7 and suction rates are in Fig. 8. Suction rates are mostly given by pressure difference p_3 - p_{12}, i.e. pressure difference between the suction and return points, while the width of the slot opening is not so important. This pressure difference decreases with higher ejection ration, but this is not the only one influencing factor. As we can see, diffusers efficiency is high for high pressure difference, high suction ratio, low ejection ratio and also fast mixing. For high ejection ratio, the low diffuser efficiency could be also caused by slow mixing which is not finished at the end of the diffuser.

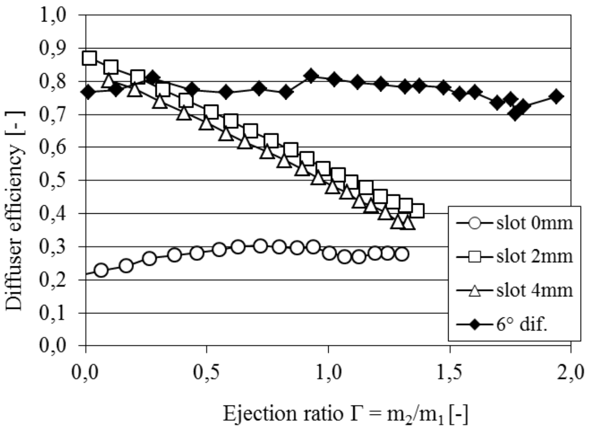

Fig. 7 Diffuser efficiency for various adjustment of suction slot and ejection ratio.

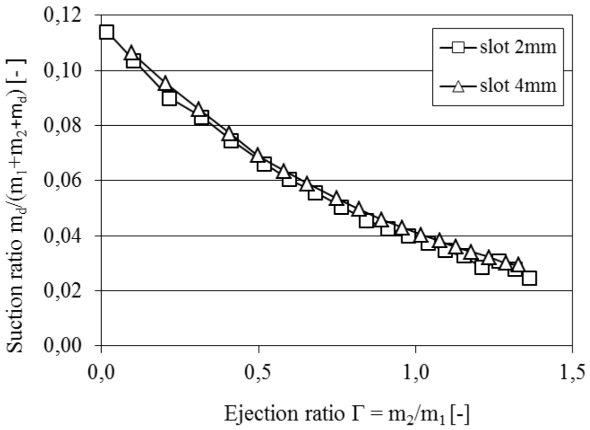

Fig. 8 Suction ratio for various adjustment of suction slot and ejection ratio.

4 Conclusions

The effect of boundary layer suction on flow in ejector was investigated. Both diffuser and ejector efficiency were evaluated. The diffuser efficiency were increased, however, the efficiency of ejector itself remained low. In further work, the flow in the ejector with more adjustments of suction slot will be investigated. The back pressure should be also evaluated further behind the diffuser to involve influences of slow mixing. Next, constant temperature anemometry and numerical simulation will be applied and compared to obtain more detailed view into the problem.

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