# STUDY OF OPTIMIZATION OF LOBED NOZZLE FOR MIXING

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## Introduction

It is well known that mixing process in ejectors is effected by the shape of the trailing edge of primary nozzle [1]. The article deals with a simple optimization algorithm used for design of lobed nozzle. Influences of number and size of lobes are studied with the help of numerical simulation. It was found out that the objective function is not unimodal and one of the local optimum is represented by the circular nozzle.

## Methods

First cycle of Rosenbrock method was used as an optimization procedure. Only one parameter was changed in each optimization step. The cross-section shape of the nozzle is given by relation with optimization parameters $H$ and $n$

$$r = R + H/2 \cdot \cos(n\varphi)\,, \tag{1}$$

where $[\varphi, r]$ are polar coordinates of the mixing chamber, $H$ represents the high of lobes and $n$ number of lobes. $R$ is middle radius of generating curve, which is calculated from the last optimization parameter, the equivalent diameter of the nozzle $d_e$

$$R = \sqrt{d_e^2/4 - H^2/8}\,. \tag{2}$$

Program Fluent 6.1 is used to evaluate the objective function, which is secondary mass flow rate. We used coupled solver, second order upwind, turbulence model k-ε realizable with enhanced wall treatment. The mixing chamber diameter is 40 mm and its length is only 200 mm. This length is too short to mix the streams properly and so the static pressure still rises on the end of the mixing chamber. Thus variants with faster mixing are advantaged. Boundary condition are seen in Fig. 1.

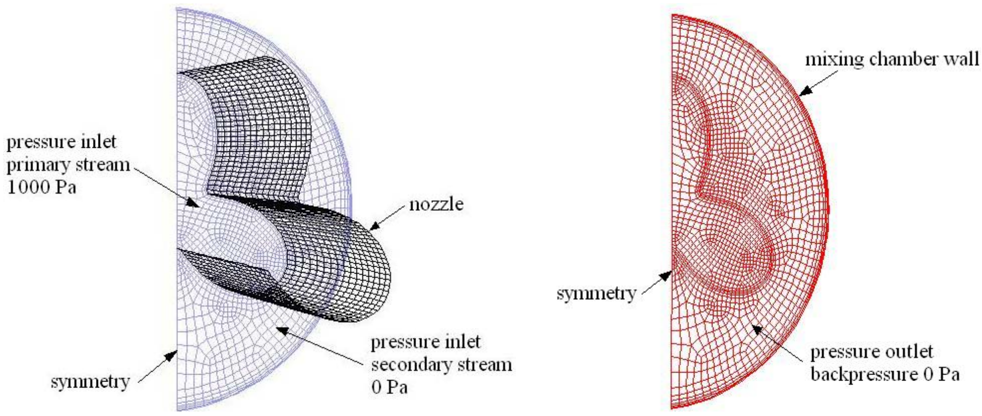


*Fig. 1: Boundary conditions of computational model.*

## Results and discussion

Changes of three optimization parameters during optimization are seen in fig. 2a. Optimal value of equivalent primary nozzle diameter $d_e$, which is the main design value of the ejector, is almost unchanging. First run of the optimization between steps 0 and 15 began with $n = 8$ and $H = 4$ mm and led to the nozzle with negligible lobes of the high 1 mm, while the circular nozzle of the same equivalent diameter $d_e = 19$ mm performed comparable results. It seems that too many lobes yield higher friction losses, while flow structure disappeared rapidly. Second optimization between steps 16 and 22 began with less but bigger lobes, $n = 4$, $H = 8$. In this case the optimum was found for $n = 3$, $H = 10$, while the equivalent diameter is $d_e = 18.76$ mm. Resulting shapes of nozzles are in fig. 2b. Difference of objective function value between two local maximums is 2.1%. The chosen objective value is not unimodal for given shape of lobed nozzle and more suitable optimization method capable to find global maximum should be used in next optimization.

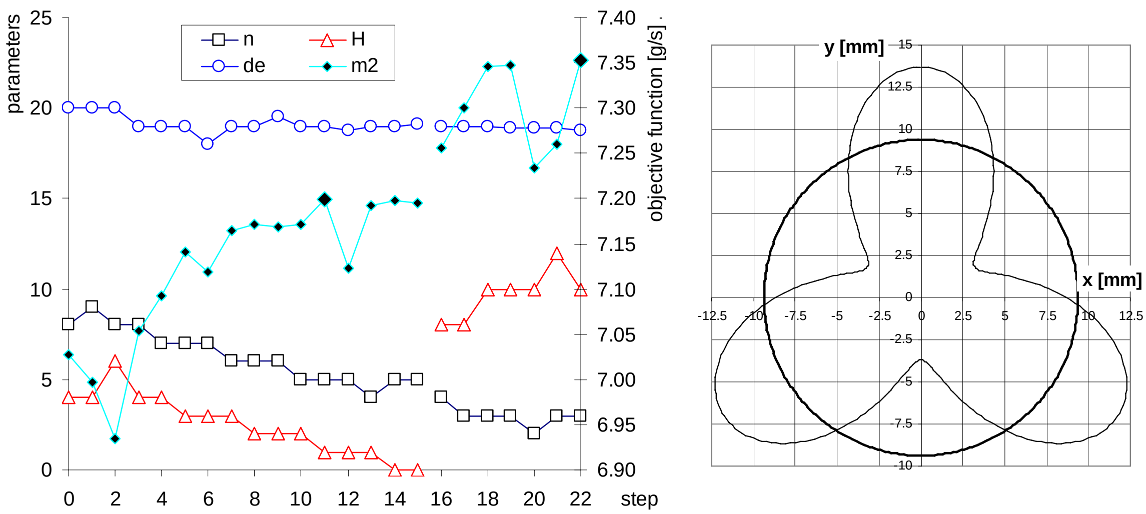


*Fig. 2: a – process of optimization parameters and objective function during optimization; b – resulting shapes of the primary nozzle.*

Curves of static pressure distribution and of kinetic energy given by radial and tangential velocity components during mixing are curried out in Fig. 3. Higher mass flow rate while using lobed nozzle yields lower static pressure in the beginning of the mixing chamber. Higher pressure rise than predicates faster and more uniform mixing for optimized lobed nozzle. Transition between initial and main region of mixing with fast change of static pressure gradient and quick growth of lateral kinetic energy is evident for circular nozzle. This transition occurs in point where the free shear layer between primary and secondary stream encounter boundary layer on the mixing chamber wall. Initial peak of the lateral kinetic energy is given by expiring of the wake behind the trailing edge of the primary nozzle. Kinetic energy given by lateral velocity components is higher for lobed nozzle and two peaks are obvious.

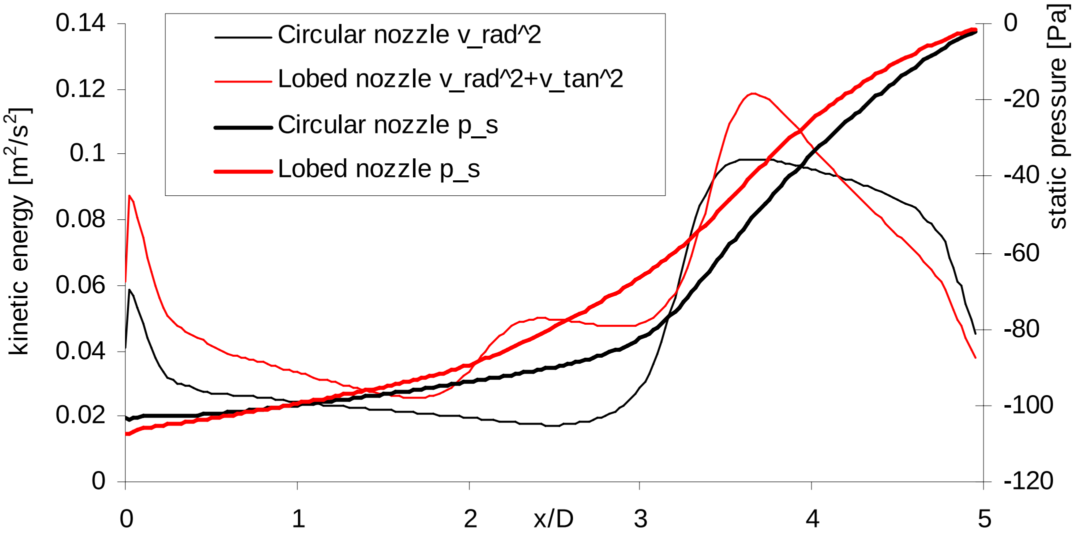


*Fig. 3: Static pressure distribution on the mixing chamber wall and averaged kinetic energy given by radial and tangential velocity components during the mixing.*

Curves of kinetic energy given by radial and tangential velocity components are curried out in Fig. 4. The circular nozzle has zero component of tangential velocity. Lobed nozzle has nonzero component of tangential velocity and two peaks are evident on corresponding kinetic energy. The first maximum matches the place, where the free shear layer rising from tops of lobes encounter the boundary layer on the mixing chamber wall. The second maximum similarly matches the collision of boundary layer with free shear layer rising from the bottom of the lobes. Region between both maximums can be called transition region of mixing and is obvious also on the curve of kinetic energy given by radial velocity component. This transition region is missing while using circular nozzle. The question is, if this transition region with significant lateral kinetic energy is responsible for faster mixing with lobed nozzle.

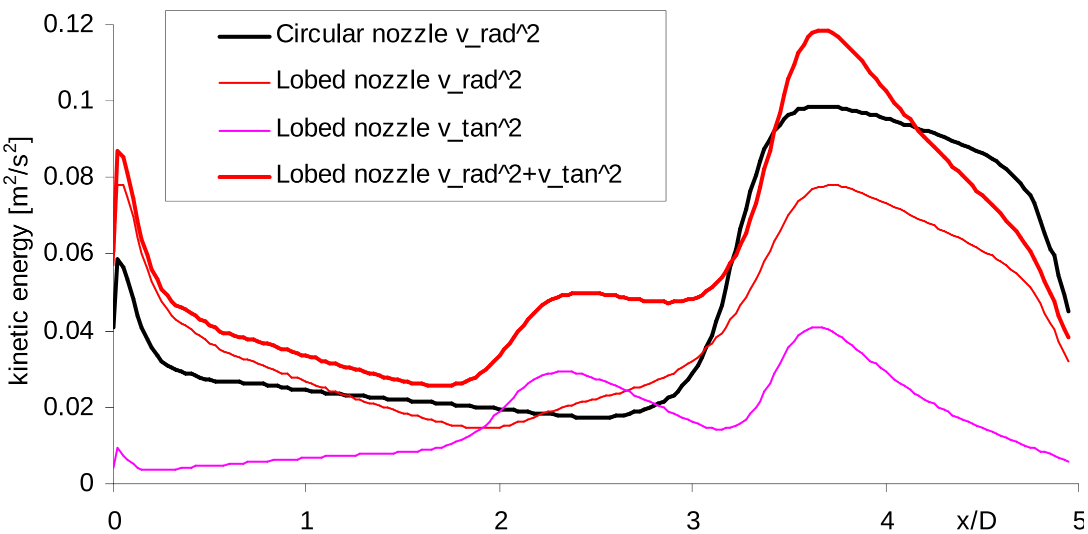


*Fig. 4: Averaged kinetic energy given by radial and tangential velocity components during the mixing.*

The growth of the free shear layer is higher for lobed nozzle because of larger bound between primary and secondary stream. It is well observable on velocity contours in Fig. 5. Notice that velocity is lower in the end of the mixing chamber for lobed nozzle.

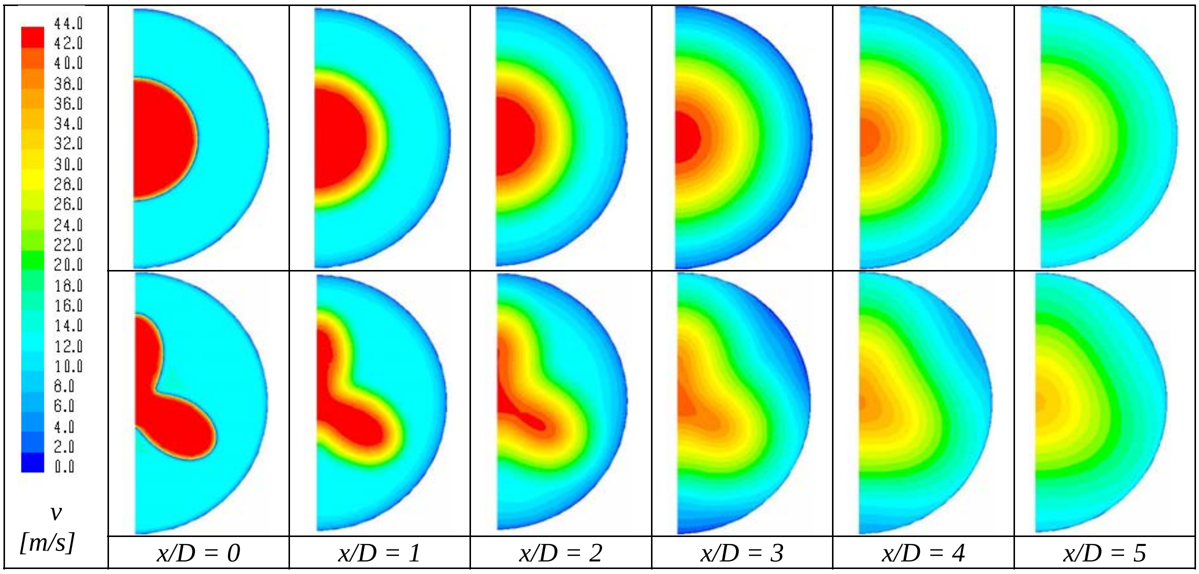


*Fig. 5: Contours of velocity in cross sections for circular and lobed nozzle.*

The area of the shear layer is visible in contours of turbulent kinetic energy in Fig. 6. Lobed nozzle has higher turbulent kinetic energy in the initial region of mixing and this energy grows more uniformly, than it is for circular nozzle, which has higher turbulent kinetic energy in the main region of mixing. The maximum of turbulent kinetic energy is in point of $x/D = 4.2$ for lobed nozzle, but it is $x/D = 5$ for circular nozzle, as we can observe in Fig. 7. So we can consider that the mixing process is faster with the lobed nozzle.

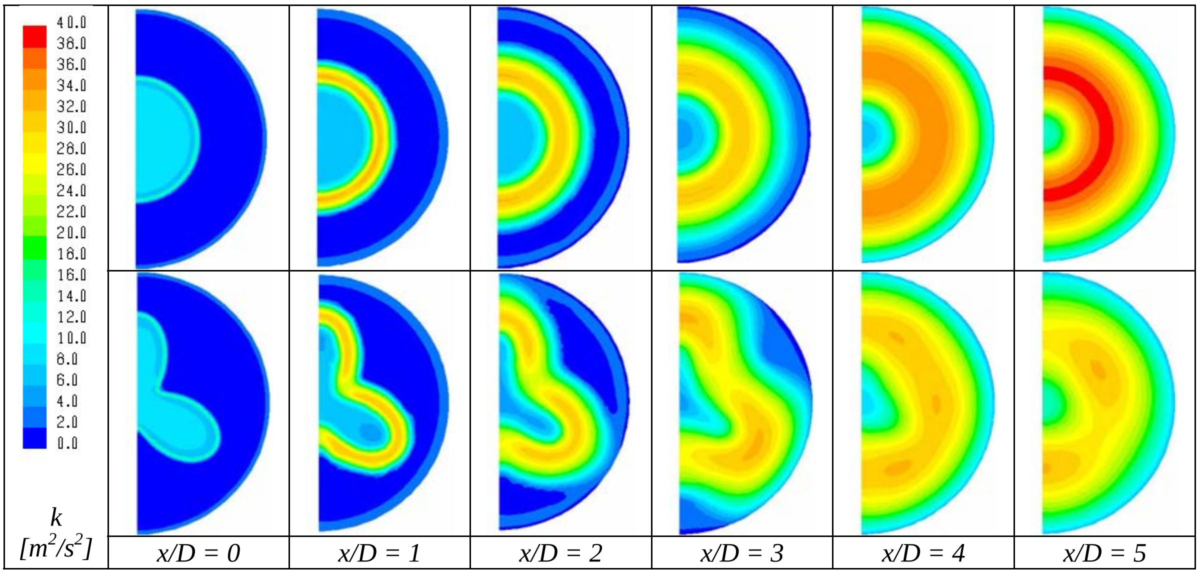


*Fig. 5: Contours of turbulent kinetic energy in cross sections for circular and lobed nozzle.*

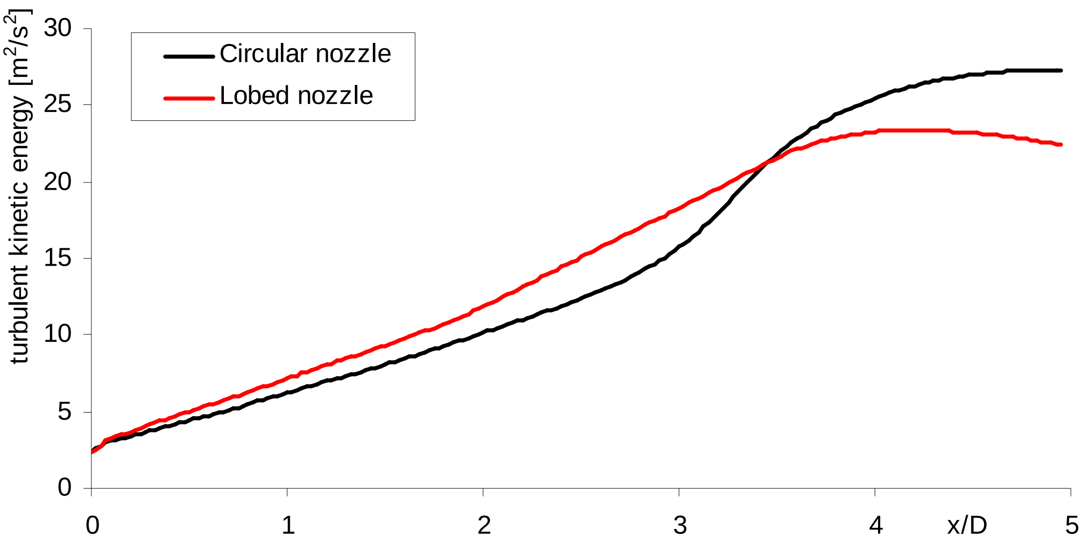


*Fig. 7: Averaged turbulent kinetic energy during the mixing for circular and optimized lobed nozzle.*

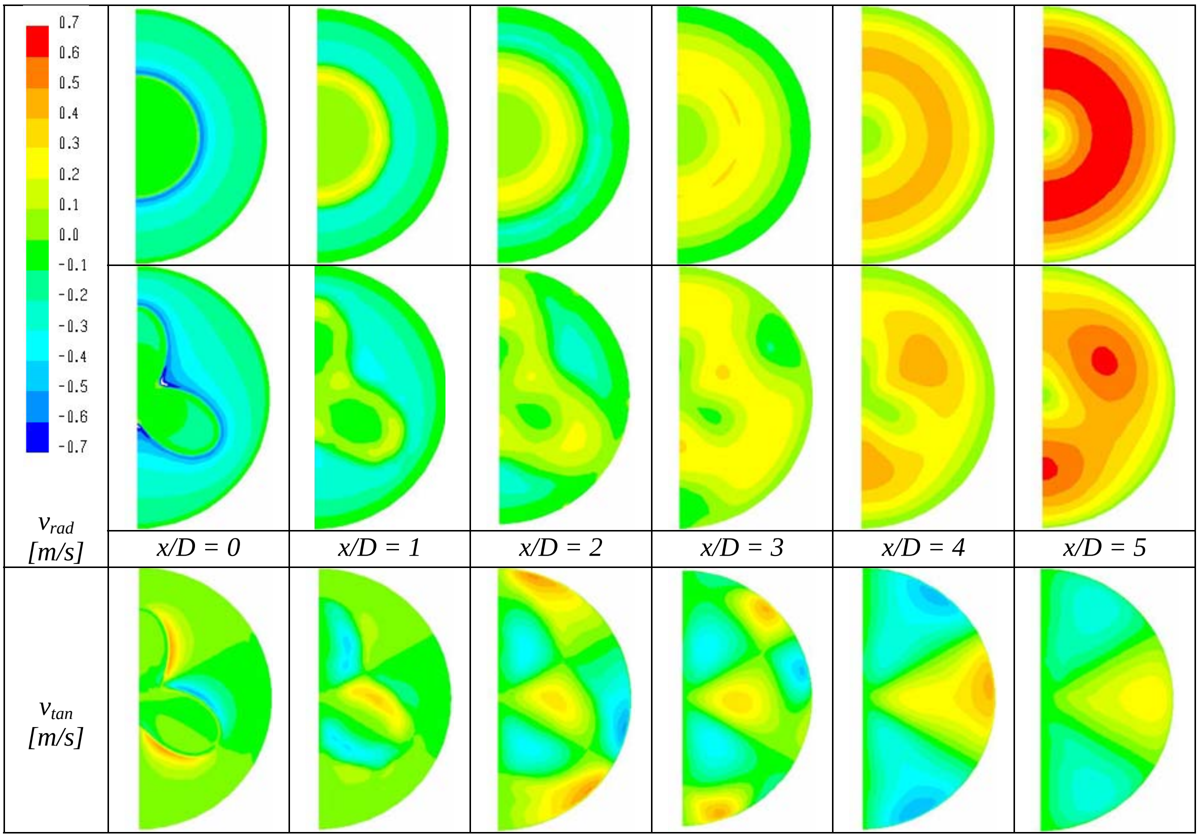


*Fig. 8: Contours of radial velocity for both nozzles and of tangential velocity for optimized lobed nozzle.*

Contours of radial velocity for both nozzles and contours of tangential velocity for optimized lobed nozzle are in Fig. 8. It is obvious that both primary and secondary streams direct to the mutual bound, to the shear layer, while the direction is from the primary stream in the main region of mixing. Thus each lobe generates two longitudinal vortexes [3].

## Conclusion

A simple optimization of lobed nozzle for mixing in an ejector was made. It was found out that the objective function is not unimodal and one of local maximum is close to the circular nozzle without any lobes. It was found out another local maximum with tree lobes of relative high $H/d_e = 0.533$. It was shown that mixing is faster while using lobed nozzle. The turbulent kinetic energy is higher and also kinetic energy given by radial and tangential velocity components is higher for lobed nozzle. Static pressure rises more rapidly. A transition region of mixing was evaluated for using lobed nozzles. This region represents successive encounter of the free shear layer with the boundary layer on the mixing chamber wall. It was found out that maximal value of turbulent kinetic energy is lower for lobed nozzle. The real three-dimensional shape of the nozzle will be solved in next optimization.

## Acknowledgement

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## References

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