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Experimental investigation on multi-vane expander operating conditions in domestic CHP ORC system

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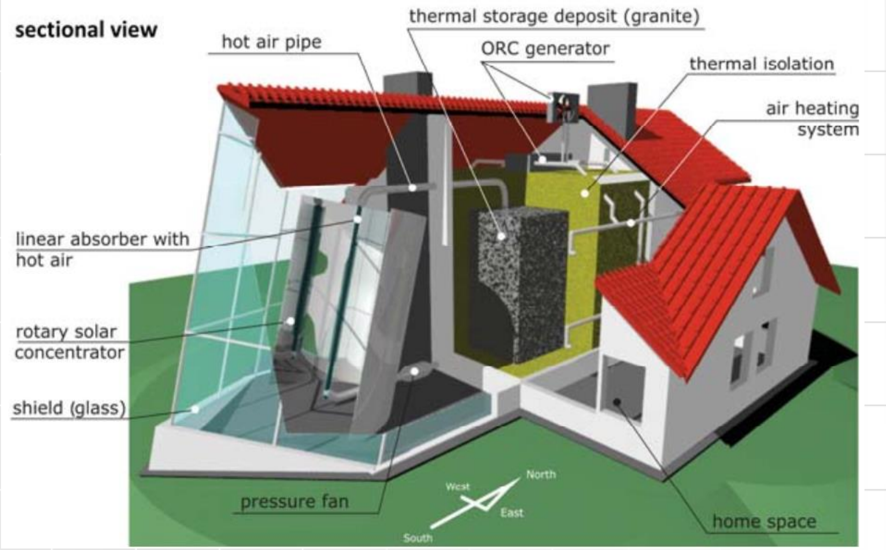
Introduction–micro power (domestic) ORCs

- Micro power (up to 10 kW) CHP ORCs are nowadays considered for domestic usage,
- These systems may utilize different renewable heat sources such as e.g. biomass, solar or geothermal heat,
- Compared to larger systems they feature: smaller dimensions, capacity, working fluid flow, etc.,
- Thus, the design problems are different,



- The research challenges related to these systems include a variety of topics, i.e., working fluid selection as well as system components design (heat exchangers, pumps and expanders design).

Domestic ORCs – applied expanders

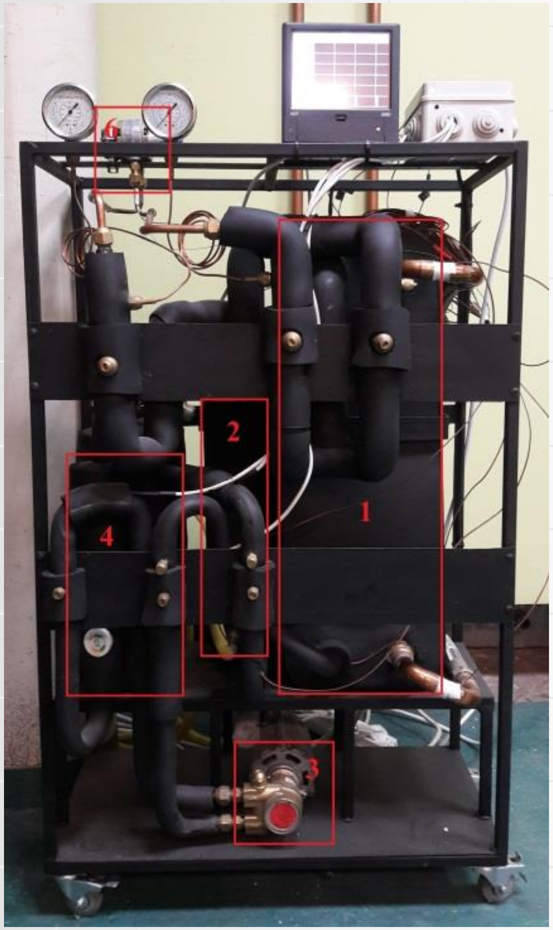
- Domestic ORC systems should be **cheap** and **reliable**, that's why the **expander selection** and its **design** is one of the **key issues** of the domestic ORC **system design** (as the price of heat exchangers and the expander is the main part of the system cost),
- In domestic ORCs mainly **volumetric expanders** are applied e.g. **scroll** or **screw** expanders (also micro turbines are adopted into these systems),
- **Scroll** and **screw** expanders are complicated and expensive,
- The **micro turbine** needs **high gas flow** capacity and its design requires **high precision workmanship** (due to very high rotational speeds) which directly translates into the **high price** of such machines,
- Compared to **micro turbines**, **volumetric expanders** feature a **lower range** of operating **pressure** and **lower gas flow** capacity.

Domestic ORCs – multi-vane expanders

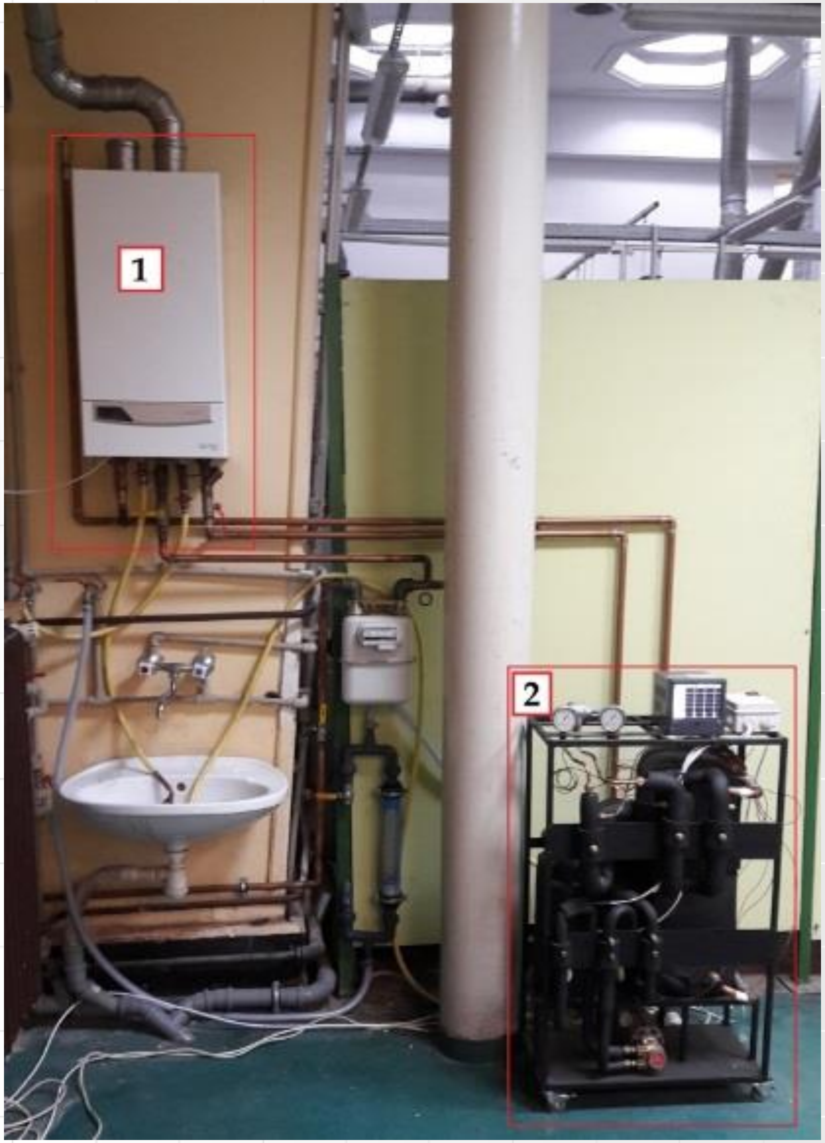
- Compared to other expanders the multi-vane expander features:
  - very simple design (which translates into low production costs),
  - an advantageous range of power (0.5—5 kW),
  - low gas flow capacity,
  - low expansion ratios,
  - an advantageous ratio of the power output to the external dimensions.
- These expanders are insensitive to the negative influence of the gas-liquid mixture expansion,
- The multi-vane expander can be easily hermetically sealed, which is one of the key issues in the ORC system design,
- Internal friction, pressure fluctuation during filling and evacuation, vortices and internal leakages are the main phenomena limiting the efficiency of multi-vane expander.

Experiment

- The experimental investigations were carried out using a prototype of domestic combined heat and power (CHP) ORC,
- The main test-stand components are: a plate evaporator (1), a plate condenser (2), a working fluid pump (3), a reservoir of a working fluid (4), and a micro-vane expander (5).
- The working fluid is R123.



Experiment



- The heat source for the test-stand is hot water (heated in a gas boiler) which temperature can be regulated in the range of 40—95 °C,
- The condenser is cooled by the cold water in the open cycle,
- The experimental series were performed for the values of the heat source temperature ranging between 55 °C and 85 °C and for the working fluid pressure ranging between 2.0 and 5.2 bar.

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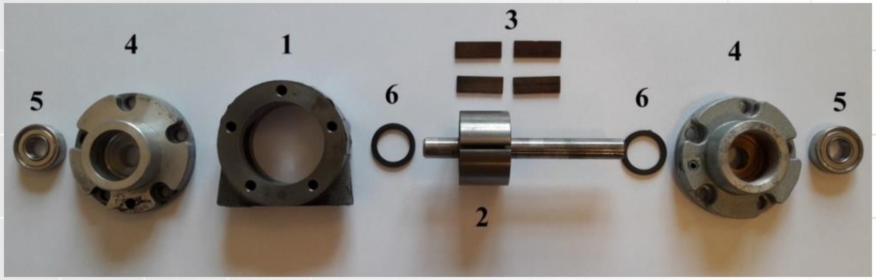
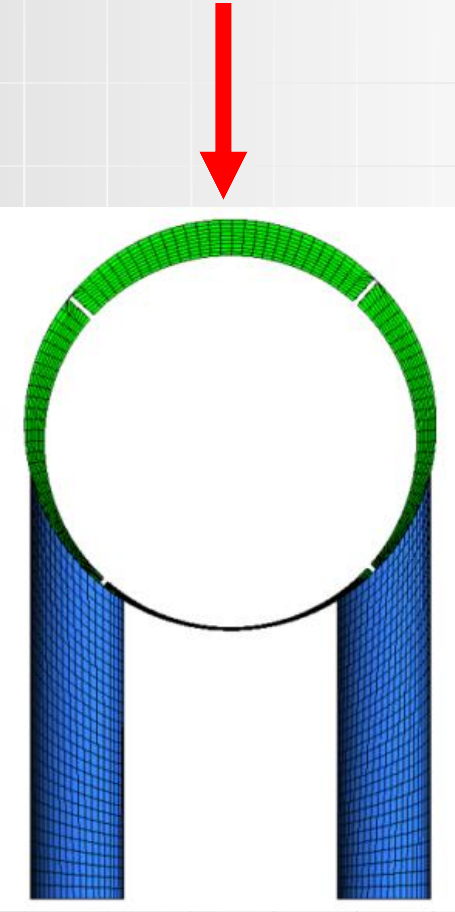
Numerical model

- A transient operation of the multi-vane expander was modeled numerically using transient boundary conditions,
- The model complies the rotational motion of the rotor and the vanes as well as the vanes radial position change during the process,
- This allows for an in-depth calculation of the working medium inside a working chamber including the internal leakages,
- The inlet and the outlet pipes remain stationary and they relate to the rotors domain through the interface.





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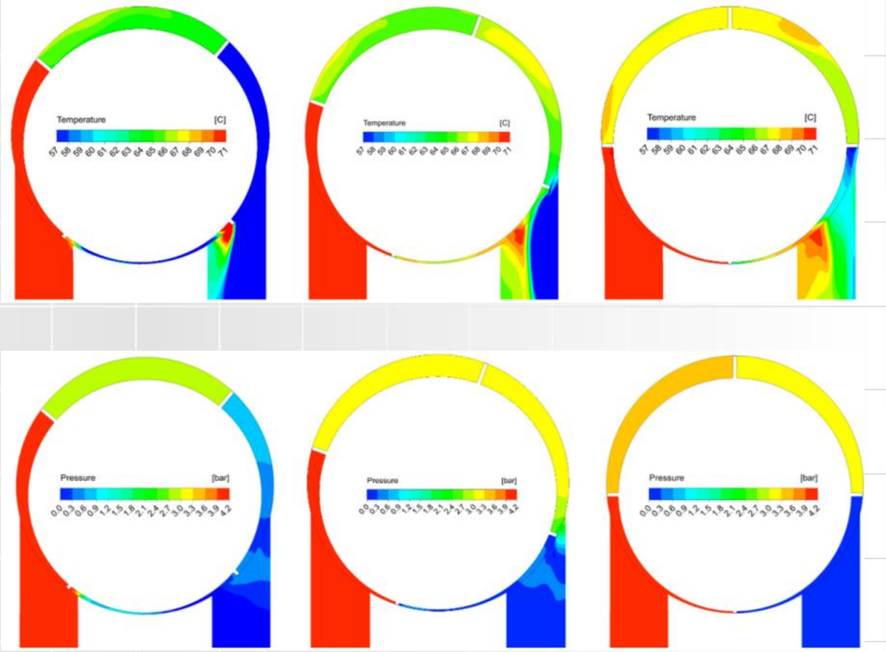
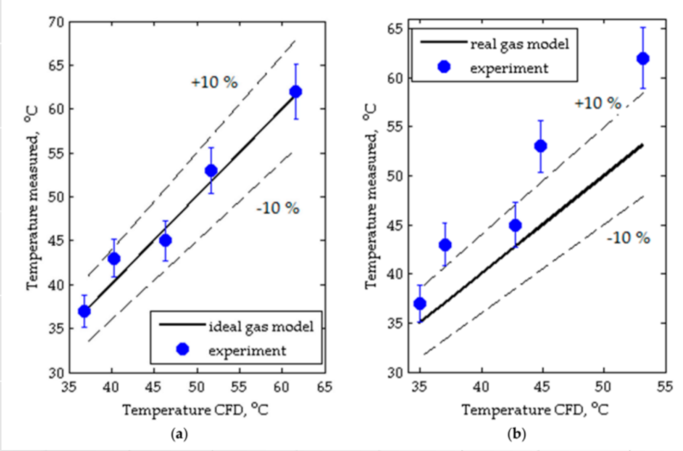
Experimental and modelling results

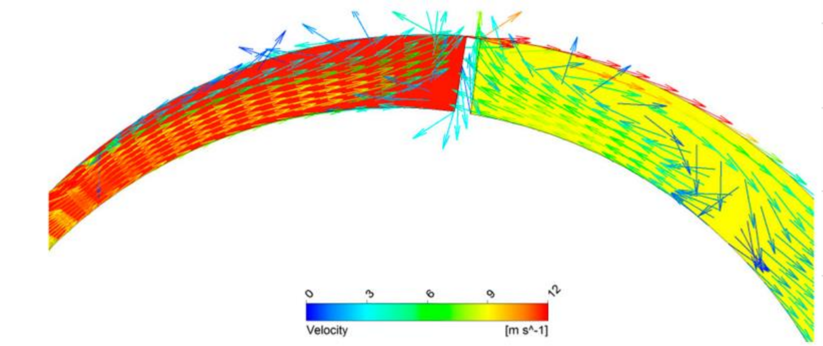
- The experimental results showed that the expander indicated work varies in the range of 0.96—4.18 kJ/kg while its internal efficiency varies in the range of 17.2—58.3 % depending on the experimental conditions,
- It was found that expander features its maximum efficiency for the pressure ratio of $\sigma = 2.0$,
- The numerical model was validated and good agreement between experimental and modelled values were observed.

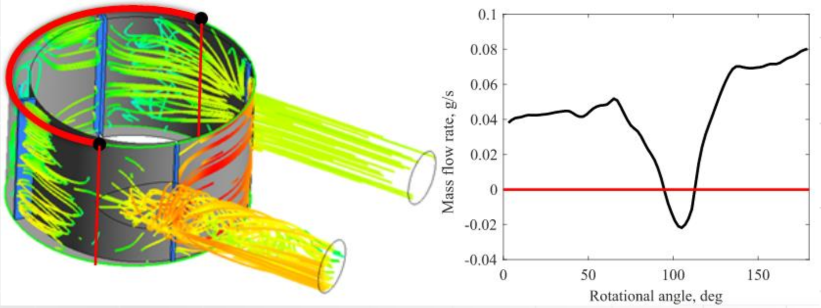




Experimental and modelling results

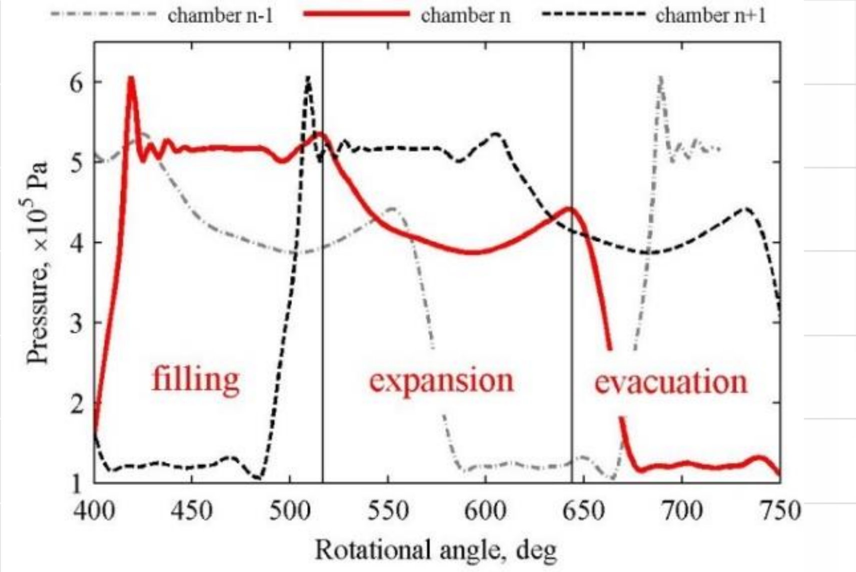
- The numerical results indicated that
  - highly vortex field is present in the whole expander except the inlet tube where the streamlines are straight,
  - In the working chambers, vortex flow cores appear especially near the vanes which impel the working fluid and trigger its rotation,
  - a very complex flow field in the discharge port exists and promotes to decrease of expander efficiency,
  - a large influence of the internal leakages in the expander (especially visible in the area of the inlet and the outlet port, where the working fluid leaks from the inlet to the outlet port between the surfaces composed of two vanes and the rotor).

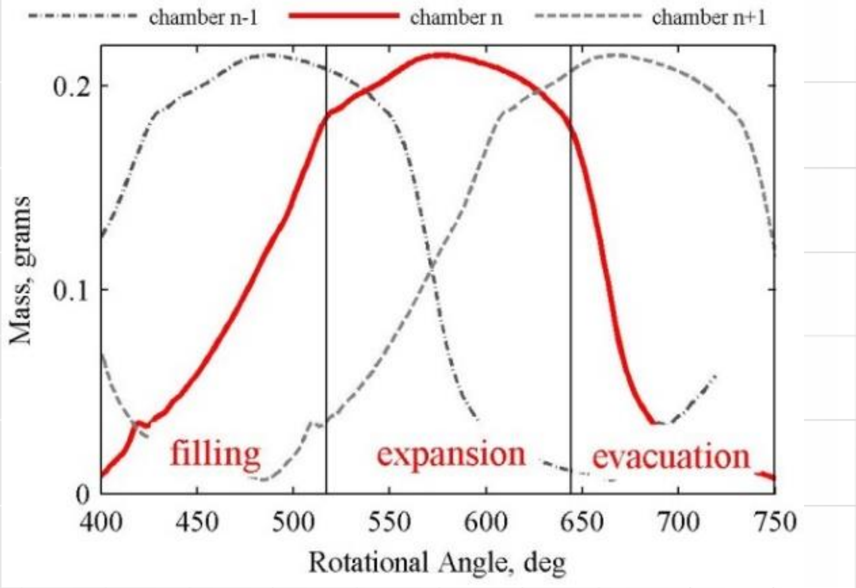




Experimental and modelling results

- The analyses on pressure evolution in different working chambers of the expander indicated that
  - At the beginning of the filling the ripples pressure fluctuations, caused by the internal leakages between the expanders' inlet and outlet ports, are observed,
  - During the following part of the filling stage, the working fluid pressure is nearly constant,
  - At the end of the filling, pressure firstly decreases and then increases due to compression caused by the decrease of the working chamber volume,
  - During the expansion the working fluid pressure firstly decreases and then increases again what is caused by the geometry of the expander which is symmetric relative to the discharge ports,





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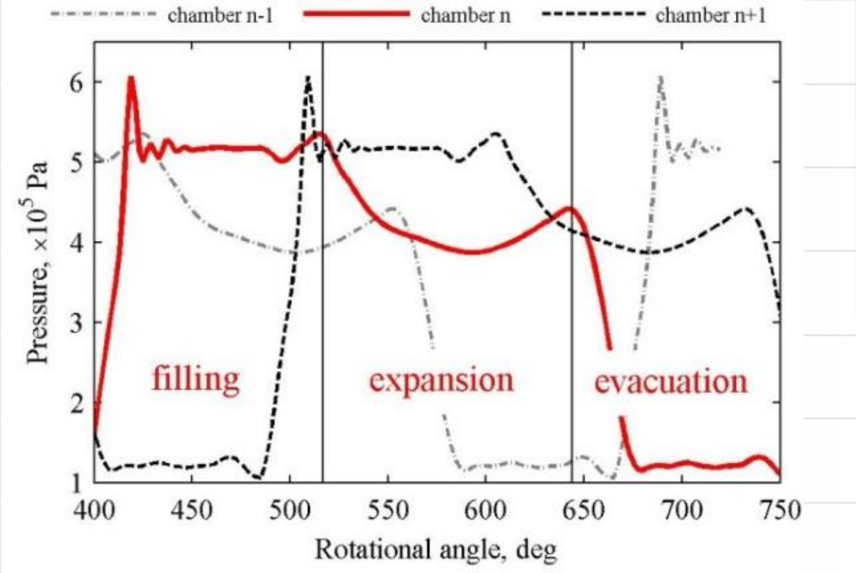
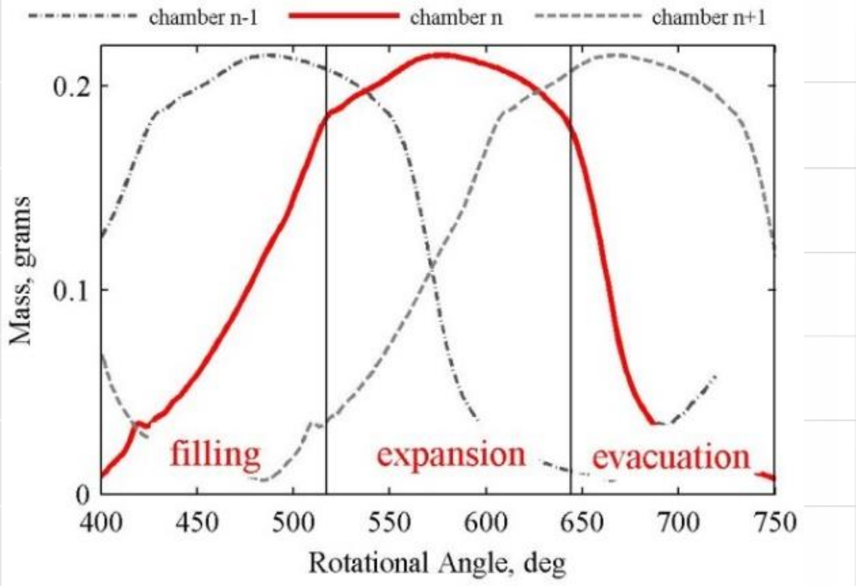
Experimental and modelling results

- During the expansion, the influence of internal leakages is much lower than during the filling as at this stage of the expanders' working cycle, the working chamber is fully separated from the inlet and the outlet port,
- The evacuation of the working fluid from the working chamber begins with a large pressure drop which is caused by the opening of the working chamber to the outlet port,
- During the following stage of evacuation, the pressure fluctuations resulting from the internal leakages between the consecutive chambers and from the inlet to the outlet port are observed.





Summary and conclusions

- The experimental analysis showed that multi-vane expanders are suitable to domestic ORCs,
- The 3D model of the expander was developed and validated using the data obtained from the experiment,
- The results confirmed that there is a large field for the improvements in the machine design, which would increase its efficiency,
- These improvements should include especially:
  - optimizing the geometric dimensions of the expander and shapes of the inlet and the outlet ports edges,
  - minimizing the effect of internal leakages between the working chambers, reducing the pressure difference between the chambers,
  - minimizing the friction between the vanes and the cylinder.

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Thank you very much for your attention

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