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Review of the Doctoral Dissertation

Author:	Paweł Jakończuk
Title of the Thesis:	Investigation of an ejector refrigeration system with flashing in the motive nozzle
Type of Thesis:	Doctoral dissertation
Field of science	Engineering and technology
Discipline of science:	Mechanical engineering
Institution:	Faculty of Mechanical Engineering
Reviewer (Opponent):	prof. Václav Dvořák, Ph.D.

1. Subject and Objectives of the Thesis

The doctoral thesis by mgr inż. Paweł Jakończuk focuses on the study of ejector-based cooling systems in which refrigerant evaporation (flashing) occurs directly in the motive nozzle. This configuration relies on two-phase flow to enhance the efficiency of low-grade heat utilization and represents an environmentally friendly alternative to conventional compressor-based systems.

The research examines the performance of ejectors using modern low-global-warming-potential (GWP) refrigerants and compares two flow models against experimental data obtained from a custom-built test facility.

The main objectives of the thesis can be summarized as follows:

Modelling and Validation:

- To assess the performance of the ejector cycle involving flash evaporation inside the motive nozzle.
- To evaluate the applicability and accuracy of the HEM and Henry-Fauske models by comparing them with experimental data.

Experimental Work:

- To design and construct a test bench capable of precise measurements in two-phase flow conditions with low-GWP refrigerants.

- To experimentally determine entrainment and compression ratios under various operating conditions, especially with different vapour qualities and discharge pressures.

The topic is well aligned with current trends in the development of ejector cooling. The results have practical relevance for the design and optimization of cooling systems powered by renewable or waste heat sources.

2. Structure and Content of the Thesis

The dissertation is clearly structured into eleven chapters, which logically cover the theoretical background, experimental work, and interpretation of results. The thesis begins with introduction, where the author presents the research context, motivation and main objectives.

The theoretical part includes an explanation of the operating principles of ejector-based systems and a review of flow models applicable to two-phase flow, including the Homogeneous Equilibrium Model (HEM) and the Henry-Fauske model. These models are further discussed in terms of their assumptions, advantages, and limitations.

Particular attention is given to the construction of the experimental setup, which the author describes in detail, including measuring equipment, nozzle geometries, and calibration procedures. The measurement results are presented in Chapters 8 to 10.

Chapter 11 concludes the thesis. Overall, the structure of the work is coherent, matching the scientific and engineering nature of the topic. The text is clear and supported by relevant references.

3. Methodology and Results

The methodology of the dissertation is based on a combination of experimental research, analytical modelling, and comparison of theoretical predictions with measured data. The author evaluates the applicability of two models – the Homogeneous Equilibrium Model (HEM) and the Henry-Fauske model – for predicting the behaviour of systems with refrigerant evaporation occurring directly in the motive nozzle.

The experimental part was conducted on a custom-built test bench. The setup allows for the measurement of pressure, temperature, and mass flow rates at various points in the system, under different nozzle configurations and working fluids. Measurements were performed primarily using the refrigerant R123, with supplementary data obtained for R1234ze(E).

The results are presented in the form of graphs and tables and enable a direct comparison between model predictions and experimental data. The author also analyses the influence of key parameters – such as suction pressure, degree of superheat, entrainment ratio, and nozzle geometry – on the ejector's efficiency and operational stability.

The collected data demonstrate that the choice of model significantly affects the predicted performance. While the HEM model shows good agreement under certain operating conditions, the Henry-Fauske model provides a better description in regimes involving intense phase change.

The author’s methodological approach is well considered, the research is systematic, and the results are interpreted with an appropriate level of critical insight.

4. Contribution of the Thesis

The doctoral thesis by mgr inż. Paweł Jakończuk brings contributions on several levels – theoretical, experimental, and applied.

a) Theoretical contribution

- The thesis enhances understanding of the applicability of two commonly used models – the Homogeneous Equilibrium Model (HEM) and the Henry-Fauske model – for calculating two-phase flow in ejectors with refrigerant evaporation occurring in the motive nozzle.
- Based on experimental validation, the author demonstrates under which operating conditions each model yields more accurate results and outlines their limitations when used with less conventional working fluids.
- The contribution lies not in extending or developing new models, but in clarifying the **range of applicability and accuracy** of existing models in practical engineering contexts.

b) Experimental contribution

- The author actively participated in the reconstruction and modification of an existing experimental setup and was responsible for the design of the tested nozzles, measurement calibration, and experimental campaign.
- New measurement data were obtained for the refrigerant R123 and R1234ze(E).

c) Applied contribution

- The findings and conclusions can be applied in the design of environmentally friendly cooling systems, particularly those using waste heat or low-grade thermal sources.
- The thesis offers specific recommendations on the selection of refrigerant, nozzle geometry, and operating parameters with respect to system efficiency.
- The results have potential relevance for industrial use and decentralized energy applications.

5. Comments on the Dissertation

A. Consistency of notation and terminology

- There is inconsistency in the designation of the Henry-Fauske model – in some parts of the thesis it is referred to as "HF," in others as "H-F." I recommend unifying the notation throughout the text.
- Several variables, such as the velocity coefficient φ, are not clearly defined or explained at their first occurrence, which may lead to confusion for the reader.

B. Clarification of physical assumptions

- The explanation of adiabatic mixing may give the impression that dissipative phenomena such as friction, turbulence, or shock waves contradict the assumption of adiabaticity. In fact, adiabaticity refers solely to the absence of heat exchange with the surroundings and is entirely compatible with such internal flow effects. I recommend refining this interpretation.

C. Definition and interpretation of calculation coefficients

- The ejector coefficient is partially defined in terms of the loss coefficient K and the enthalpy ratio. However, it should be noted that the loss coefficient is not a constant but depends on the entrainment ratio – particularly the parameter φ_m depends on velocity ratio.
- The meaning of the parameter K is not entirely clear: in equation (2.12) it appears to represent a product of velocity coefficients, while in equation (2.13) it seems to indicate a product of velocity coefficients squared. This ambiguity should be resolved.

D. Interpretation of flow phenomena and pressure measurements

- Based on the static pressure distribution (p. 136), the author concludes that shock waves do not occur in the mixing chamber. This conclusion is debatable – the flow is clearly non-uniform, and possible shock structures may be oblique.
- Pressure is measured near the wall, i.e. in regions potentially influenced by subsonic boundary layers or even a subsonic core. At higher Mach numbers, the transition from supersonic to subsonic flow may occur not as a discrete shock but as a so-called pseudo-shock train. This possibility is not considered in the thesis.

E. Inconsistency in experimental results – Fig. 9.15

- In Figure 9.15, Series No. 4 exhibits a lower maximum *volumetric entrainment ratio* than Series No. 2, which appears counterintuitive. If this is not due to an error in interpretation or data processing, the phenomenon should be explained or at least briefly discussed.

F. Scope and interpretation of experimental data

- The author relies primarily on integral measurements (pressure, mass flow rate, temperature), which do not allow detailed insight into the internal flow structure. As such, conclusions based on flow stability should be interpreted with caution.
- For example, the claim on p. 129 that higher suction pressure leads to greater flow stability and thus higher ejector efficiency seems overly simplified. In practice, efficiency is governed primarily by mass flow and pressure ratios, while the influence of flow stability is likely to be secondary.

These comments do not affect the overall evaluation of the dissertation, but I recommend that they be at least partially addressed during the defence.

6. Conclusion

The dissertation by mgr inż. Paweł Jakończuk presents a technically competent, and thematically relevant study in the field of ejector-based cooling systems. The author demonstrates a solid understanding of the topic, the ability to conduct independent research, and strong experimental skills.

The thesis is based on a thoughtful combination of analytical modelling and experimental work, resulting in new and practically relevant findings. In particular, the comparison of two-phase flow models and their validation using low-GWP refrigerants adds value both to academic research and potential engineering applications.

The dissertation also meets the requirement of scientific originality, as it explores an unconventional system configuration – evaporation in the motive nozzle – and offers new insights into its behaviour and modelling.

Although I have pointed out several issues that may benefit from clarification or further discussion, these do not affect the overall quality of the thesis.

The overall evaluation of the dissertation is positive.

The dissertation complies with the requirements defined by the applicable Polish legislation, in particular the Act of 20 July 2018 – Law on Higher Education and Science (Journal of Laws of 2024, item 1571, as amended).

I recommend that the dissertation be accepted for public defence, and that mgr inż. Paweł Jakończuk be awarded the academic degree of Ph.D.

In Liberec, 26.5.2025

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