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Prof. Ing. Tomas Jirout,
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Marseille January 31, 2019

Re : Assessment of the Ph.D dissertation 'Thermophysical properties of refrigerants : experiments and simulations' by Martin Doubek
Your ref: 3/12921/O/2019 (your letter of January 8, 2019)

Dear Professor Jirout,

Please let me begin by thanking you for nominating me as one of the reviewers of the Ph.D dissipation of Martin Doubek. Your letter recently arrived at CPPM while I was at CERN. I am able to review the dissertation since the work of Martin Doubek at CERN and at CVUT is well known to me.

As requested, my assessment follows the points you set out in your letter:

1. Achievement of the aims of the thesis;
2. Level of the analysis of the state-of-the-art on the issues dealt with in the dissertation;
3. Contribution of the Ph.D thesis to the theory of the subject elaborated;
4. Contribution of the Ph.D thesis to engineering practice;
5. Relevance of the applied methods;
6. Relevance and approach to the method application;
7. Adequacy of the student's knowledge in the specialized field as demonstrated by the dissertation contents;
8. Formal issues of the Ph.D thesis;
9. Explicit statement whether I recommend/do not recommend the dissertation to a final defence presentation.

1. Achievement of the aims of the thesis

The thesis achieves its aims of measuring sound velocity in the radiation-resistant saturated fluorocarbons R-218 (C_3F_8) & R-116 (C_2F_6) their mixture and a mixture of C_3F_8 with N_2, then using these data to test the predictive power of a number of equations of state. The PC-BACK approach coupled with binary interaction coefficients is identified as the best among those compared, and could represent a significant new way forward in the domain of zeotropic refrigerant blend property prediction.

2. Level of the analysis of the state-of-the-art on the issues dealt with in the dissertation

The level of analysis of the related state-of-the-art in chapter 2 is adequate in that it covers theoretical approaches including a variety of equations of state as well as listing some commercially available instruments. However, I would have also appreciated more detail of the ultrasonic mixture analysis algorithms developed by our CERN-based group (of which Martin Doubek is a member). For example, the work described in our paper: *"A combined ultrasonic flow meter and binary vapour mixture analyzer for the ATLAS silicon tracker"* (R Bates et al, including M. Doubek) https://iopscience.iop.org/article/10.1088/1748-0221/8/02/P02006 is not really mentioned: nor does this paper appear as a reference in the Ph.D thesis. This is unfortunate since Martin Doubek contributed significantly to the ultrasonic gas analyzer developments discussed in the paper. However, I would hope that at least a reference to this important paper could be added in the revised and archived version.

Also in the motivation section of chapter 1, I would have preferred to see more discussion of the advantages of the use of (a) a thermosiphon recirculator and (b) zeotropic C_2F_6/C_3F_8 blends for extending the operating life of silicon tracking detectors in high radiation environments through the reduction of their operating temperature. In this context pressure-enthalpy diagrams of these alternatives would be nice to include. I was surprised not to see at this early stage (rather than in the chapter 8 conclusion) a reference to the paper *"The cooling capabilities of*

C_2F_6/C_3F_8 saturated fluorocarbon blends for the ATLAS silicon tracker" (R Bates et al, including M. Doubek) https://iopscience.iop.org/article/10.1088/1748-0221/10/03/P03027. Martin Doubek contributed significantly to the speed of sound measurements in zeotropic C_2F_6/C_3F_8 blends discussed in the paper. Perhaps these omissions are due to university requirements that only the work performed by the student on his/her own be detailed in the thesis. However, I would hope that a reference to this important paper could be added in the revised chapter 1 of the archived version. These areas should clearly also merit to be covered in the thesis defence presentation

3. Contribution of the Ph.D thesis to the theory of the subject elaborated

The Ph.D thesis contributes indirectly to the theory related to the subject in the sense that sound velocity measurements made in mixtures of C_3F_8/C_2F_6 and C_3F_8/N_2 add to the database from which equations of state and mixing rules can be finessed.

4. Contribution of the Ph.D thesis to engineering practice

The Ph.D thesis contributes to engineering practice related to the subject in the sense that sound velocity measurements are made in mixtures of C_3F_8/C_2F_6, and C_3F_8/N_2 with an apparatus that includes an improved multi-threshold method for finding the leading edge of a received ultrasonic signal. A corrected time-of-flight (rather than resonant) approach is used since the instrument is also intended to operate as a simultaneous gas analyser and flowmeter, in which transit time measurements are necessary. The candidate built the gas mixing station, the ultrasonic analyser tube and the electronics himself, and has demonstrated exceptional expertise.

5. & 6. Relevance of the applied methods & Relevance and approach to the method application

The methods applied (the experimental speed of sound based approach and the use of different equations of state and mixing rules) is conventional and adapted to the aim of the thesis project. The approach to the method application through combination of the PC-BACK formalism with binary correlation coefficients results in good predictive power for sound velocity in zeotropic mixtures of C_3F_8/C_2F_6, and C_3F_8/N_2, which could represent a significant new way forward. Future measurements in further mixtures of these gas pairs could confirm this.

7. Adequacy of student's knowledge in the specialized field as demonstrated in dissertation contents

The student's knowledge of the theory in this specialised field as well as his unusually good technical skills in developing the apparatus used are very well demonstrated in the contents of the dissertation.

8. Formal issues of the Ph.D thesis

In my role as reviewer of the Ph.D dissertation, I see no formal issues or impediments to its progression toward the next step of a final defence presentation. I have identified a number of minor corrections (mainly typographic) and clarifications that can be communicated to the author during or before the thesis defence. (*I ask your clarification on the correct procedure to follow here*). These should be carried out for the final version of the archived copy. I declare no conflict of interest in this matter.

9. Explicit Statement recommending that the Ph.D dissertation of M. Doubek proceed to a final defence presentation.

I formally recommend that the PhD dissertation 'Thermophysical properties of refrigerants: experiments and simulations' by Martin Doubek be allowed to proceed to a final defence presentation.

Marseille: January 31, 2019

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Explicit Statement recommending that the Ph.D dissertation of M. Doubek proceed to a final defence presentation.

As a nominated reviewer of this work, I formally recommend that the PhD dissertation:

'Thermophysical properties of refrigerants: experiments and simulations'

by Martin Doubek

be allowed to proceed to a final defence presentation.

Gregory Hallewell Ph.D

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Marseille: January 31, 2019