Development and Manufacturing of an Interactive Three-Dimensional Phase Diagram of Carbon Dioxide for Teaching Sessions in Thermodynamics

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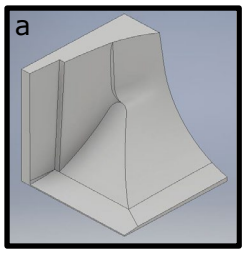
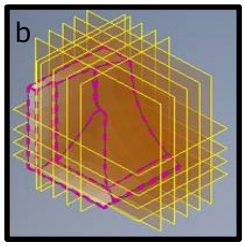
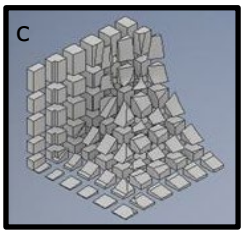
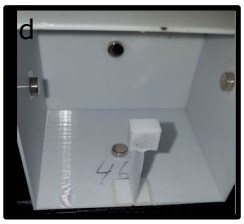
Aims of the project:

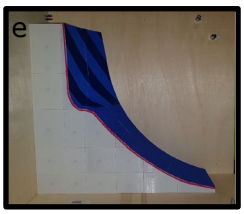
- Improve the students understanding of complex basics in thermodynamics such as the derivation and meaning of the three-dimensional phase diagram and its 2D-projections
- Development of an illustrative model for interactive teaching sessions
- Bachelor-Thesis on this topic. Idea: students invent solutions for next generation of students

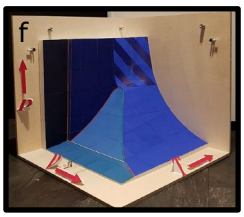


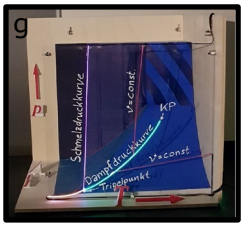












1 Analysis and research on following topics:

- Thermodynamic basics
- Perception of students memory
  - Sensory memory
  - Short-term memory
  - Long-term memory
- Innovative media in teaching sessions
  - Objective media
  - Iconic media
  - Symbolic media
- Information recording and processing
  - Law of proximity
  - Law of closeness
  - Law of similarity
  - Law of experience

2 Defining requirements for the model („wish list"):

- Portability
- Durability
- Costs
- Visibility
- Content
  - similarity to literature
  - 2D-projections shown clearly
  - isolines good visible
  - binodal and phase areas easily recognizable
  - can be broken down into segments for presentation of certain areas/isolines inside

3 Idea generation using creative techniques:

- Brainstorming
- 6-3-5 method
- Disney method
- Imagine method

→ Evaluation of the variants using Morphological Box

Criteria:

- Size
- Material
- Depiction of
  - Phase areas
  - Isolines
  - Binodals
  - 2D-projections
- Detachable cohension of the segments

→ Decision making
→ checking for incompatibilities

4 Modeling:

- determination of the length ratios of the 3D-phase diagram for Carbon dioxide from literature
- Creation of a digital model using the Computer-aided design (CAD) software Autodesk Inventor
- Modeling of the surfaces
- Division into 94 segments
- Generation of thin-walled hollow bodies for each segment
- Generating the three different 2D-projections

5 Manufacturing of the model:

- Converting each of the 94 segments into a printable file format for 3D printing
- 3D printing of all segments
- Polish the edges and surfaces by hand
- installation of magnets for detachable cohension between the segments
- Color design and drawing of the isolines on the inside of every segment
- Casing for transportation
- Design of 2D projections on acrylic glass
- Labeling
- Individually switchable illumination of isolines and binodals in every 2D-projection

6 Advantages in teaching sessions:

- Students easily understand the derivation and meaning of the three-dimensional phase diagram and its 2D-projections
- Teaching sessions become more interactive because students are able to puzzle themselves with the model
- Students are more motivated to acquire knowledge of complex issues like thermodynamics in comparison to usual courses
- Light effects help to highlight certain lines in the diagram
- By turning the 3D- diagram it is easy to understand the 2D-projections
- Exercises can be replicated with this model to underline the explanation of the steps towards the solution
- The model was also successfully used in a selfmade educational film for students homeschooling during the Corona pandemic in 2020

Figures: a: Modeling of the surfaces using CAD b: Generation of some division planes following several isolines c: Generation of thin-walled hollow bodies for each segment d: Inner side of a 3D printed hollow body of a single segment with round magnets for detachable cohension e: critical isotherm on the opened model (pink line) f: three-dimensional p, v, T phase diagram with colored binodals and phase areas g: illuminated and labeled lines of projection on acrylic glass for two-dimensional p, T diagram

Literature:

[1] Kircher, E.: Physikdidaktik; Theorie und Praxis. Springer Spektrum Verlag, 3. Auflage 2013
[2] Jakoby, W.: Projektmanagement für Ingenieure; Ein praxisnahes Lehrbuch für den systematischen Projekterfolg. Springer Vieweg Verlag, 4. Auflage 2019
[3] Cheng, K. T.: Entwicklung und Bau eines interaktiven thermodynamischen CO_2-Phasendiagramms in 3D für Lehrzwecke. Bachelor-Thesis, FH Aachen, 2020