



University of Stuttgart

Institute of Mechanical Process Engineering

Master's Thesis in Chemical- and Bio-Engineering

**Understanding ink formulations for
high temperature polymer electrolyte
membrane fuel cells having ion pair
ionomers**

Klaus Hahn



University of Stuttgart

Institute of Mechanical Process Engineering

Master's Thesis in Chemical- and Bio-Engineering

**Understanding ink formulations for high
temperature polymer electrolyte membrane fuel
cells having ion pair ionomers**

Untersuchungen zu Tintenformulierungen für
Hochtemperatur-Polymerelektrolytmembran-
Brennstoffzellen mit Ionenpaar-Ionomeren

Author:	Klaus Hahn
Supervisor:	Prof. Carsten Mehring
Advisors:	Prof. Iryna Zenyuk, Magnolia Pak, B.Sc.
Start Date:	01.01.2024
Submission Date:	01.01.2024

I confirm that this Master's thesis is my own work and I have documented all sources and material used.

Stuttgart, 01.01.2024

Klaus Hahn

Acknowledgements

Abstract

Note:

1. **paragraph:** What is the motivation of your thesis? Why is it interesting from a scientific point of view? Which main problem do you like to solve?
2. **paragraph:** What is the purpose of the document? What is the main content, the main contribution?
3. **paragraph:** What is your methodology? How do you proceed?

Zusammenfassung

Note: Insert the German translation of the English abstract here.

Contents

1 Introduction	13
1.1 Problem	13
1.2 Motivation	13
1.3 Objectives	13
1.4 Outline	13
2 Background	13
2.1 e.g. User Feedback	13
2.2 e.g. Representational State Transfer	14
2.3 e.g. Scrum	14
3 Related Work	14
4 Requirements Analysis	14
4.1 Overview	14
4.2 Current System	14
4.3 Proposed System	15
4.3.1 Functional Requirements	15
4.3.2 Nonfunctional Requirements	15
4.4 System Models	15
4.4.1 Scenarios	15
4.4.2 Use Case Model	16
4.4.3 Analysis Object Model	16
4.4.4 Dynamic Model	16
4.4.5 User Interface	17
5 System Design	17
5.1 Overview	17
5.2 Design Goals	17
5.3 Subsystem Decomposition	17
5.4 Hardware Software Mapping	18

5.5 Persistent Data Management	18
5.6 Access Control	18
5.7 Global Software Control	18
5.8 Boundry Conditions	19
6 Case Study / Evaluation	19
6.1 Design	19
6.2 Objectives	19
6.3 Results	19
6.4 Findings	19
6.5 Discussion	20
6.6 Limitations	20
7 Summary	20
7.1 Status	20
7.1.1 Realized Goals	20
7.1.2 Open Goals	20
7.2 Conclusion	20
7.3 Future Work	21
List of Figures	22
List of Tables	23
Appendix A: Supplementary Material	24
Bibliography	25

1 Introduction

Introduce the topic of your thesis, e.g. with a little historical overview.

1.1 Problem

Describe the problem that you like to address in your thesis to show the importance of your work. Focus on the negative symptoms of the currently available solution.

1.2 Motivation

Motivate scientifically why solving this problem is necessary. What kind of benefits do we have by solving the problem?

1.3 Objectives

Describe the research goals and/or research questions and how you address them by summarizing what you want to achieve in your thesis, e.g. developing a system and then evaluating it.

1.4 Outline

Describe the outline of your thesis

2 Background

Describe each proven technology / concept shortly that is important to understand your thesis. Point out why it is interesting for your thesis. Make sure to incorporate references to important literature here.

2.1 e.g. User Feedback

This section would summarize the concept User Feedback using definitions, historical overviews and pointing out the most important aspects of User Feedback.

2.2 e.g. Representational State Transfer

This section would summarize the architectural style Representational State Transfer (REST) using definitions, historical overviews and pointing out the most important aspects of the architecture.

2.3 e.g. Scrum

This section would summarize the agile method Scrum using definitions, historical overviews and pointing out the most important aspects of Scrum.

3 Related Work

Describe related work regarding your topic and emphasize your (scientific) contribution in contrast to existing approaches / concepts / workflows. Related work is usually current research by others and you defend yourself against the statement: “Why is your thesis relevant? The problem was already solved by XYZ.” If you have multiple related works, use subsections to separate them.

4 Requirements Analysis

This chapter follows the Requirements Analysis Document Template in [1]. Important: Make sure that the whole chapter is independent of the chosen technology and development platform. The idea is that you illustrate concepts, taxonomies and relationships of the application domain independent of the solution domain! Cite [1] several times in this chapter.

4.1 Overview

Provide a short overview about the purpose, scope, objectives and success criteria of the system that you like to develop.

4.2 Current System

This section is only required if the proposed system (i.e. the system that you develop in the thesis) should replace an existing system.

4.3 Proposed System

If you leave out the section “Current system”, you can rename this section into “Requirements”.

4.3.1 Functional Requirements

List and describe all functional requirements of your system. Also mention requirements that you were not able to realize. The short title should be in the form “verb objective”

- FR1 Short Title: Short Description.
- FR2 Short Title: Short Description.
- FR3 Short Title: Short Description.

4.3.2 Nonfunctional Requirements

List and describe all nonfunctional requirements of your system. Also mention requirements that you were not able to realize. Categorize them using the FURPS+ model described in [1] without the category functionality that was already covered with the functional requirements.

- NFR1 Category: Short Description.
- NFR2 Category: Short Description.
- NFR3 Category: Short Description.

4.4 System Models

This section includes important system models for the requirements analysis.

4.4.1 Scenarios

If you do not distinguish between visionary and demo scenarios, you can remove the two subsections below and list all scenarios here.

Visionary Scenarios Describe 1-2 visionary scenario here, i.e. a scenario that would perfectly solve your problem, even if it might not be realizable. Use free text description.

Demo Scenarios Describe 1-2 demo scenario here, i.e. a scenario that you can implement and demonstrate until the end of your thesis. Use free text description.

4.4.2 Use Case Model

This subsection should contain a UML Use Case Diagram including roles and their use cases. You can use colors to indicate priorities. Think about splitting the diagram into multiple ones if you have more than 10 use cases. **Important:** Make sure to describe the most important use cases using the use case table template (`./tex/use-case-table.tex`). Also describe the rationale of the use case model, i.e. why you modeled it like you show it in the diagram.

4.4.3 Analysis Object Model

This subsection should contain a UML Class Diagram showing the most important objects, attributes, methods and relations of your application domain including taxonomies using specification inheritance (see [1]). Do not insert objects, attributes or methods of the solution domain. **Important:** Make sure to describe the analysis object model thoroughly in the text so that readers are able to understand the diagram. Also write about the rationale how and why you modeled the concepts like this.

4.4.4 Dynamic Model

This subsection should contain dynamic UML diagrams. These can be a UML state diagrams, UML communication diagrams or UML activity diagrams. **Important:** Make sure to describe the diagram and its rationale in the text. **Do not use UML sequence diagrams.**

4.4.5 User Interface

Show mockups of the user interface of the software you develop and their connections / transitions. You can also create a storyboard. **Important:** Describe the mockups and their rationale in the text.

5 System Design

This chapter follows the System Design Document Template in [1]. You describe in this chapter how you map the concepts of the application domain to the solution domain. Some sections are optional, if they do not apply to your problem. Cite [1] several times in this chapter.

5.1 Overview

Provide a brief overview of the software architecture and references to other chapters (e.g. requirements analysis), references to existing systems, constraints impacting the software architecture..

5.2 Design Goals

Derive design goals from your nonfunctional requirements, prioritize them (as they might conflict with each other) and describe the rationale of your prioritization. Any trade-offs between design goals (e.g., build vs. buy, memory space vs. response time), and the rationale behind the specific solution should be described in this section

5.3 Subsystem Decomposition

Describe the architecture of your system by decomposing it into subsystems and the services provided by each subsystem. Use UML class diagrams including packages / components for each subsystem.

5.4 Hardware Software Mapping

This section describes how the subsystems are mapped onto existing hardware and software components. The description is accompanied by a UML deployment diagram. The existing components are often off-the-shelf components. If the components are distributed on different nodes, the network infrastructure and the protocols are also described.

5.5 Persistent Data Management

Optional section that describes how data is saved over the lifetime of the system and which data. Usually this is either done by saving data in structured files or in databases. If this is applicable for the thesis, describe the approach for persisting data here and show a UML class diagram how the entity objects are mapped to persistent storage. It contains a rationale of the selected storage scheme, file system or database, a description of the selected database and database administration issues.

5.6 Access Control

Optional section describing the access control and security issues based on the nonfunctional requirements in the requirements analysis. It also describes the implementation of the access matrix based on capabilities or access control lists, the selection of authentication mechanisms and the use of encryption algorithms.

5.7 Global Software Control

Optional section describing the control flow of the system, in particular, whether a monolithic, event-driven control flow or concurrent processes have been selected, how requests are initiated and specific synchronization issues

5.8 Boundry Conditions

Optional section describing the use cases how to start up the separate components of the system, how to shut them down, and what to do if a component or the system fails.

6 Case Study / Evaluation

If you did an evaluation / case study, describe it here.

6.1 Design

Describe the design / methodology of the evaluation and why you did it like that. e.g. what kind of evaluation have you done (e.g. questionnaire, personal interviews, simulation, quantitative analysis of metrics), what kind of participants, what kind of questions, what was the procedure?

6.2 Objectives

Derive concrete objectives / hypotheses for this evaluation from the general ones in the introduction.

6.3 Results

Summarize the most interesting results of your evaluation (without interpretation). Additional results can be put into the appendix.

6.4 Findings

Interpret the results and conclude interesting findings

6.5 Discussion

Discuss the findings in more detail and also review possible disadvantages that you found

6.6 Limitations

Describe limitations and threats to validity of your evaluation, e.g. reliability, generalizability, selection bias, researcher bias

7 Summary

This chapter includes the status of your thesis, a conclusion and an outlook about future work.

7.1 Status

Describe honestly the achieved goals (e.g. the well implemented and tested use cases) and the open goals here. if you only have achieved goals, you did something wrong in your analysis.

7.1.1 Realized Goals

Summarize the achieved goals by repeating the realized requirements or use cases stating how you realized them.

7.1.2 Open Goals

Summarize the open goals by repeating the open requirements or use cases and explaining why you were not able to achieve them. Important: It might be suspicious, if you do not have open goals. This usually indicates that you did not thoroughly analyze your problems.

7.2 Conclusion

Recap shortly which problem you solved in your thesis and discuss your **contributions** here.

7.3 Future Work

Tell us the next steps (that you would do if you have more time). Be creative, visionary and open-minded here.

List of Figures

List of Tables

Appendix A: Supplementary Material

– Supplementary Material –

Bibliography

- [1] C. Breitkopf and K. Swider-Lyons, “Springer Handbook of Electrochemical Energy.” Accessed: Jun. 18, 2024. [Online]. Available: <https://www.springerprofessional.de/springer-handbook-of-electrochemical-energy/11913608>