PROCESS DESIGN PROJECT
TKP4170 Prosjektering av prosessanlegg

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Contents

1 Introduction

Chemical process technologies are constantly evolving. The reasons for this evolution are many, however, some are given below:

- New catalysts are introduced with higher activity and selectivity. This will have an effect on the process design as reactions can take place at more favorable process conditions. Improved selectivity and conversion will require less post-treatment of products, i.e. less separations and recycling. A new catalyst can have a dramatic impact on the overall process design.
- New raw materials and feed-stocks are utilized. There is a slow transition from petroleum based feed-stocks to gas, biomass and coal [1].
- Energy and material efficiencies are very important aspects when it comes to economy. New process developments require that energy and material are utilized efficiently.
- Micro-channel reactors are being developed where the catalyst is more exposed to the reacting fluid and with better heat transfer. The scale-up is straight forward by adding more channels in parallel.
- Governmental regulations to mitigate environmental impact of human activities are also enforcing new developments of process technologies.

Among technology companies and chemical production companies there are a lot of ongoing activity to improve existing process technologies.

2 Project Work

2.1 Objectives

The objective of the process design project is to carry out a preliminary design and cost estimation for a given process, preferably of the chemical industry type. In this memo a framework of activities that need to be done during the design work is described. The accuracy of the calculations is expected to be within about 15% for the technical data and 30-40% for the cost data. This roughly corresponds to what is called a 'concept study' or a 'concept phase' in industry. The purpose of the concept study is to evaluate different alternative process technologies, and on this basis choose one that is to be further examined in more detail. Here, we normally will look at one process technology, but, depending on the problem definition, alternative processes may also be evaluated here. The purpose of this memo is to give some guidelines on how to do the project work.

2.2 Project groups

Process design is team work. Scientists and engineers work together to develop the best possible process concept. In this course the work is also organized in groups, though we limit the group to three students (project groups). Only exceptionally, there may be more or less than three students in a group, but then the expected amount of work and results will be accordingly.

2.3 The supervisor

The supervisor of the project group is normally the person that has proposed the problem. The same person will also be responsible for evaluating the performance of the work and the final report.

2.4 Project meetings

Each project group should have project meeting about once a week with the supervisor(s). If required, extra meetings may be arranged, or a meeting may be skipped if not needed. The project group should be prepared before meetings with the supervisor. In advance, think about what are the important issues to be discussed, study literature and prepare specific questions for the supervisor. During the meeting someone should take notes, and at the end of the meeting the you should repeat what you have agreed upon. A 'minutes of meeting' should be issued right after the meeting, where decisions are stated and the work is distributed. Do not write an essay. The reason for doing this is to remind everyone who is responsible of doing what, but also to keep a record of decisions that are made during the course of the work.

2.5 Manage your time

The duration of the work is about 10 weeks. The workload is about 12 hours per week per student. Since the time is very limited, it is of great importance that you manage your time well, and to focus on the right aspects of the problem. The project group should make a rough project plan by listing the main activities that need to be done, and allocate time on each activity. You should also distribute tasks among yourself.

2.6 Deadline

The deadline for submitting the report will be announced on the first plenary meeting. The official report is submitted to the department office, but the supervisor(s)

may also have a copy.

2.7 Information platform

All essential information, including this memo, will be uploaded on "it's learning". Also you as a project group may create a "project" within "it's learning", where you may exchange information during the course of the work, such as literature, minutes of meetings, report drafts etc.

3 Activities

The main activities are

1. Synthesis of process flowsheet
2. Equipment sizing
3. Project evaluation
4. Reporting

3.1 Process flowsheet synthesis

Design Basis: One of the first thing you should do is to establish the design basis. A battery limit shall be defined or decided, as well as specifications of the main input and output streams. A feed-stock specification shall be given in a relevant component breakdown. Information about specific trace components and impurities may be included if they are important for the process design. Specification of the product streams shall be given in relevant component breakdown. Information about specific unwanted components should be included. Design capacity shall be given as quantities of feed materials or products. Information about available utilities, off-sites, storage areas and tanks etc shall be given including data like pressures, temperatures or other specifications.

Process flowsheet: Normally only one process flowsheet is evaluated. A description of the process structure shall be given. The process flowsheet may be given by an existing process technology, or you may do a modification of an existing technology, or you may even develop a new process flowsheet. This should describe briefly each of the most relevant process items and their function, and also the technologies applied in the process. A literature search should reveal different and alternative process technologies and reaction paths. For the different process

technologies make an overview of the main chemical reactions taking place, available catalysts, kinetic models, equilibrium relations, energy requirements and feed requirements. You may not find detailed information about all of this.

A process flow diagram shall describe the main process sections and the main process flow lines. If it is necessary for understanding of the process, data like material flow, pressures and temperatures must be stated in the diagram. The process flow diagram shall give the following information:

- Main process equipment
- Equipment identification numbers and letters and a short description of the main capacity describing parameters (diameter, area, volume, heat duties etc.)
- Main process flow lines with identifiers (numbers)
- Relevant flow line properties like flow rate and composition, temperatures and pressures.

Process calculations: Energy and mass balances of the process shall be calculated. These data must include flow rates, compositions, pressures and temperatures for the main streams. The data should, as far as possible, be calculated on a realistic and detailed data input. The use of flowsheeting programs like UNISIM Design, HYSYS or similar are recommended for calculating the streams. Remember to check the quality of the results from these flowsheeting programs. For the system at hand, is a proper fluid package or equation of state applied, is the feed properly modeled, are the reactors reasonably well modeled (e.g. the assumption of equilibrium), are mass and energy conserved and does the calculations look reasonable? You should be aware of these and other issues when you present the results of your calculations. You need not answer all issues explicitly in the report, but you should discuss the most important ones. For some problems it is not possible or necessary to use flowsheeting programs, but rather do shortcut calculations by hand.

Litterature: There are several process design textbooks that are suitable: Sinnott & Towler [2], Peters, Timmerhaus & West [5], Turton et al. [7], Douglas [8], Seider, Seader & Lewin [9] and Biegler, Grossmann & Westerberg [10]. Reaction Engineering textbooks are Levenspiel [4], Froment & Bischoff [6] and Fogler [11]. There are encyclopedia of describing existing process flowsheet structures such as

3.2 Equipment selection and sizing

Selection of construction materials for the equipment and piping should be made on the basis of corrosion evaluations. When the capacity and the steady-state mass and energy balances of the plant are established, the size of the major equipment is to be estimated. Steady-state flowsheeting tools like HYSYS and UNISIM will not necessarily give the size of the equipment[1]. As an example the diameter of a column is calculated based on a required vapor velocity and the actual vapor flow rate from e.g. HYSYS. The required vapor velocity must be below that which cause excessive liquid entrainment. This is described in process design text books, as in Sinnott and Towler [2] chapter 11. The size of a reactor can be calculated based on a given kinetics and assumption about the fluid dispersion.

3.3 Project evaluation

To evaluate a project we need to calculate its profitability. It involves estimatation of the purchase cost of the individual process units delivered at the site. Furthermore, the estimated total investment is based on the cost of the individual process units, corrected using a factorial method. The operating (manufacturing) costs in addition to the production revenues need to be estimated. An economic evaluation of the project (profitability analysis) based on the total investment, sales revenues and operating costs is made. There are several criteria that may be used for estimating the profitability of a project. The economic life time of the project is a parameter that is normally set to 10 years. The most common criteria are net present value, return on investment, pay-off time and internal interest rate. These measures are described in more details in different process design textbooks, as in Sinnott and Towler [2].

3.4 Reporting

The subsequent chapter gives an introduction to writing a report for the process design project.

4 Reporting

4.1 Writing

Write the report with the company management in mind. The report should give the readers a clear view of the problem that is studied, what conclusions

[1] If there are numbers in these tools indicating the size of equipment, you should show how they are calculated.

are drawn, how reliable are the conclusions and what are the recommendations for further work. Please, do not tell us about all the irrelevant problems you had during course of the work. The report should give the reader all relevant information with the use of as little space as possible. The report including the appendices should be paginated. The main report should be concisely formulated, but not so short that the reader feels that important data is left out. Tables and graphs can replace many pages of words. You should agree with your supervisor in what language the report is written. It may be in English or Norwegian.

General rules for writing

- Use your own words, and **do not copy and paste** text from other sources;
- cite the sources when you use results and assertions from others;
- use simple and declarative sentences, avoid long sentences, in which the meaning may be lost by complicated construction;
- be concise, avoid idle words;
- explain all acronyms and abbreviations when they first appear in the text,
- use all units consistently throughout the report.

4.2 Report Structure

The structure of the report should be logical. The following structure is suggested, but deviation from this may be equally good.

FRONT PAGE A standard front page as described in Appendix A.1 should be used. The word file will be available on "it's learning" or you may get the file from the department office.

TABLE OF CONTENTS

SUMMARY Give a short summary of the work, the main conclusions and recommendations. The most important data may be included, as for example project basis, investments, profitability etc. The length of the summary is often less than half a page and should never exceed one page. The summary is not a numbered chapter.

1. INTRODUCTION The background of the project is given. Why is it important to look at this particular process. The problem is put in a wider perspective and what are the applications of the products.

2. **PROJECT BASIS** Basic assumptions such as product specifications, specification of raw material or feed streams, production capacity and any other assumptions. This is not a large chapter and is typically one page or less.

3. **PROCESS DESCRIPTION** A description of the selected process is given in this chapter. The chemistry of the processes and the selected type of equipment are described. Alternative process technologies may also be described. For the sake of readability, the process flow diagram (PFD) may be drawn in a suitable drawing tool. A copy of the HYSYS model graphics may often be too difficult to read. A simple drawing tool can be found in PowerPoint. HYSYS and similar graphics describing the model may be shown in the next chapter or in the Appendix.

4. **FLOWSHEET CALCULATIONS** In this chapter a summary of the calculations and the model are given. Use tables and graphs since they are more easily conceived. Only the most essential figures and numbers related to the mass and energy balances are given here. It is necessary to do a quality check on the calculated data, e.g. check if mass and energy are conserved. Short notes about the methods that are applied and the basic equations are given here. More detail calculations may be put in the Appendix.

5. **COST ESTIMATION** Estimate the total capital investment, composed of fixed and working capital. The basis of fixed capital is the cost of the major equipment. Operating (manufacturing) costs are costs of raw material, utilities, manual labor etc as described in Sinnott and Towler [2] should be estimated.

6. **INVESTMENT ANALYSIS** The profitability of the project is based on the total capital cost, sales revenues and operating costs. There are different profitability measures, but here you may use "net present value". Normally the prices of products and raw materials are not exactly known. Therefore, it may be of interest to do a sensitivity analysis of the investment as function of prices.

7. **DISCUSSION** Discuss your findings on the basis of the chosen process structure and selected equipment. Evaluate the assumptions made and their impact on the process calculations. As for example the selected catalyst type, assumed activity, reaction temperature etc will have a profound effect on the design. The plant may produce more than one product, environmental effects, process safety, are aspects that may need some consideration.

8. **CONCLUSIONS AND RECOMMENDATIONS** State the main conclusions and recommendations (maybe a list) that can be made from this study.

This chapter may also contain suggestions and proposals for further investigations that should be done.

LIST OF SYMBOLS Make an alphabetic list of symbols used in the report with units and description. Latin and Greek symbols are listed in separate groups.

Symbol	Units	Description
A	m^2	Area
a	m^2/m^3	Specific surface area
c_p	kJ/(kg K)	Specific heat capacity
D_e	m^2/s	Effective diffusivity

If the report contains many acronyms, they may also be listed in a separate group here.

REFERENCES There is a standard way that should be used when referring to 1) articles, 2) books, 3) reports and 4) internet addresses. Internet addresses are often temporary and should not be cited if they can be avoided. Often they refer to articles, books or reports and a reference to these are preferred. An article reference is given in [3], a book reference is given in [4] or [2], a report is

APPENDICES The appendices shall be complementary to the main report. The most important data and result shall be in the main report, while all other essential data should be placed in appendices. The appendices contain all the data and calculations that lead to the main tables in the main report. Detailed printouts from flowsheeting systems should not be in the main report, but rather in the appendix. Also lengthy mathematical deductions should be here, while results are in the main report.

4.3 Poster presentation

In addition to the report, the project work will be presented through a poster presentation. The main results of the project work are presented on a poster. Each group shall make a poster with the size 0.7 x 1 meter. On engineering and scientific and conferences it is very common to use posters to communicate results. Compared to an oral presentation, a poster presentation may be an equally effective way of communicating. Since you are present at your stand, you will meet with the people that have interests in your work. A poster should catch the interest of these people in 3-4 seconds; otherwise they will pass your stand. The design of

the poster is therefore very important. Even more important is the content, which should give the impression you have made an investigation of the problem on a relatively high level, and that the results are significant. A separate short memo is issued to show how to make a poster. There will be a price for the best posters.

5 Evaluation of your work

The supervisor(s) will be responsible for evaluating your work and giving a grade. The basis for the evaluation is the report and the work progress during the course of the project. The supervisor will have the following aspect in mind when the work is evaluated:

Disposition (20%) :

- Disposition of the project work: reasonable plan of progress, focus on the relevant issues, reasonable limitations and assumptions.
- Disposition of the report: logical structure, list of symbols, list of references, summary, appendices.
- Formal appearance of the report: language, spelling, clear tables and figures, literature references and citations, consequent use of symbols, acronyms and definitions

The main investigation (60%) :

- Literature study: adequate extent, your own evaluation of literature
- Independent theoretical and/or experimental effort
- Understanding of the problem
- Thoroughness
- Presentation of theory and experiments
- Correctness of presentation of derivations and equations
- Effort and performance

The result presentation/conclusion (20%) :

- Presentation of results: discussion of results, critical assessment of results, explanation of unexpected results, suggestions for further work, documentation of computer programs
- Conclusions: is the conclusion in accordance with the main investigation

References

[1] Diercks, R., Arndt, J-D., Freyer, S., Geier, R., Machhammer, O., Schwartze, J. & Volland, M., Raw meaterial changes in the chemical industry, *Chem. Eng. Technol.*, 31, no. 5, (2008), 631–637.

[2] Sinnott, R. & Towler, G., *Chemical Engineering Design*, Coulson & Richardson's Chemical Engineering Series, Vol. 6, 5th edition, Elsevier, Amsterdam, 2009.

[3] Graaf, G. H., E. J. Stamhuis & A. A. Beenackers, Kinetics of low-pressure methanol synthesis, *Chem. Engng. Sci.*, **43**, (1988), 3185–3195.

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[5] Peters, M.S., Timmerhaus, K. & West, R.E., *Plant Design and Economics for Chemical Engineers*, 5th edition, McGraw-Hill, New York, 2003.

[6] Froment, G.F. & Bischoff, K.B., *Chemical Reaction Analysis and Design*, 2nd edition, Wiley, New York, 1990.

[7] Turton, R., Bailie, R.C., Whiting, W.B. & Shaeiwitz, J.A., *Analysis, Synthesis and Design of Chemical Processes*, 2nd edition, Prentice Hall, New York, 2007.

[8] Douglas, J.M., *Conceptual Design of Chemical Processes*, 1st edition, McGraw-Hill, New York, 1988.

[9] Seider, W.D., Seader, J.D. & Lewin, D.R., *Process Design Principles*, 1st edition, John Wiley & Sons, New York, 1999.

[10] Biegler, L.T., Grossmann, I.E. & Westerberg, A.W., *Systematic Methods of Chemical Process Design*, 1st edition, Prentice Hall, New Jersey, 1997.

[11] Fogler, H.S., *Elements of Chemical Reaction Engineering*, 3rd edition, Prentice Hall, New Jersey, 1999.

A Appendix

A.1 Front Page

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TKP4171 PROCESS DESIGN. PROJECT

Title:	**Keyword (3-4):**
Written by:	**Time of work:**
Supervisor:	**Number of pages:** **Main report:** **Appendix :**
EXTRACT OF WORK AND CONCLUSIONS **Postulations and dimension of work:**	
Conclusions and recommendations:	
Date and signature:	

Figure 1: Front page of the report