EDUCATION IN THERMAL ENGINEERING AT AALBORG UNIVERSITY IN DENMARK

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Abstract. *The Department of Thermal Energy Technology at Aalborg University offers a M.Sc. degree in Energy Engineering and an International M.Sc. Degree in Sustainable Energy Technology is planned to start up in 2001. The Energy Engineering education focuses on the detailed design of thermal components and energy systems, typically with special focus on Computational Fluid Dynamics at component level, and with focus on simulation and optimisation when addressing energy systems in general. The International Master, education focussing on foreign students is planned to be running over three semesters, ending up with a master degree. The objective of this education is to give the students knowledge about and understanding of different types of sustainable energy supply systems and effect on both the overall and the local supply system. The feature that makes both degrees stand out from most engineering degrees is that the whole curriculum in engineering is project-organized (problem-based learning). In every semester the project activities are supported by relevant lectures in the field of thermodynamics, fluid dynamics, combustion, energy systems and optimisation. A general and comprehensive evaluation of the education programme in engineering at Aalborg University has proved the concept to be an effective educational system, which produces readily adaptable graduates with strong qualities in the fields of management, problem-solving, co-operation, and project work.*

Keywords: *Thermal Energy, Problem-oriented, Master, Education, Sustainable Energy*

1. INTRODUCTION

Twenty years ago Aalborg University's project-organised studies were introduced. The experience since then has proved this to be an important innovation in higher education [2]. The curriculum in engineering is project-organised from the day the freshmen arrive until their graduation. The first year is common for all engineering programs, and after that the students choose their field of engineering, with additional possibilities for specialisation later on.

2. EDUCATION AT AALBORG UNIVERSITY

The teaching at Aalborg University (AAU) is based on research, which implies that lecturers' current research ensures that students are continuously provided with the latest up-to-date knowledge (Aalborg University).

2.1 The project

Aalborg University focuses on project work. A project is a major assignment within a given subject-related framework or theme determined for each individual semester of the educational sequence. For most of the semesters a project subject is chosen which has to be approved by a supervisor.

The initial phase of the project work is the formulation of the problem statement. The purpose is to find an explanation for an often complex problem, for which it is subsequently difficult to obtain an overview and understanding.

2.2 Problem statement

In the process of finding a problem statement through courses, literature, co-operation with companies and relevant persons, students will acquire an understanding of the subject which is often more comprehensive than first-hand reading and understanding would imply.

The results of the project work are described in a report, which forms the basis of the evaluation at the end of the semester. Apart from the real academic benefits, this study format encourages the development of very special qualifications, which future employers of the university's graduates highly appreciate: co-operating and negotiating skills, practice in problem management, description, and solution, together with practice in oral and written expression.

2.3 Group work

In connection with the project work many students work part of the time in groups having their own workrooms. Through the co-operation and distribution of work, the group is able to tackle major problems more complex than the individual student can usually handle alone.

The common work hours for group and project work are 8 a.m. to 4 p.m. daily as it is the case for the ordinary workday in Denmark. However, often the group work requires homework as well so the study format of Aalborg University is both challenging and efficient but also quite demanding.

Experiences show that group discussions reap significant academic benefits. In addition, experiences show that discussions with other students are more relaxed and open than those with supervisors. Students discover very quickly that if they cannot argue for their viewpoints they cannot implement them in their project. The ability to debate with clout and on the basis of arguments is a prerequisite for group influence.

A supervisor, who is also a lecturer in the study course, directs all project groups. The supervisor helps the group to get started, continuously evaluates the group's work and steps in if the group needs assistance. Besides, the supervisor ensures that the project complies with the academic requirements for the education.

2.4 Course of Study

A course of study covers an investigation and an examination of a subject area - for instance a topic, a number of methods or a sequence of problems presented by a supervisor. The format may be lectures - especially for large groups – but only when feasible students are involved in the education, for instance in the form of seminars based on written or oral student presentations.

The purpose of such courses is to give an overview and to broaden students' knowledge and understanding of elements beyond project work and to go into depth in terms of prerequisites and background for specific methods in certain subject areas.

Some courses are directly relevant to the subject of the project work and evaluated through the project. Other courses are characterised by contents, which secure an overall academic knowledge of the study chosen. Such courses may be evaluated in groups, but often they will be evaluated through individual written or oral examinations. These courses usually demand significant work outside the classroom.

2.5 Evaluation

The result of the work must, of course, be evaluated. AAU uses both internal and external evaluations. Internal evaluations use the university's own lecturers as examiners. External evaluations use external examiners from other universities and from trade and industry.

2.6 Summary

If there are any drawbacks to such an approach, AAU can only maintain that after many years' successive adjustments of the educational system, all of the growing pains have been overcome.

Since group work is an academic and social process among people with different interests, ambitions, strengths, and weaknesses, problems and conflicts may of course arise in the establishment of groups, choice of subjects, and in the daily group work. Academic disagreements or different perceptions of meeting and work discipline may characterise the group work. If a group member for instance does not want to be a responsible member, such an issue must immediately be addressed, both with regard to the group and to the irresponsible group member. Such conflicts are uncomfortable and time-consuming, but if they are solved - which they usually are - the group members will have been enriched by the experience. Such experiences can be used later in their education and especially in their future jobs. However, if the group members cannot solve their personal conflicts themselves nor can their supervisor, the group must immediately be dissolved.

Another drawback can be that the students themselves sometimes place a great deal of work pressure on one another and, consequently, contribute to creating a "social crisis" in the group. However, Aalborg University offers students a safety valve enabling them to work totally or partially on their own.

3. THE PROGRAMME FOR THERMAL ENERGY ENGINEERING

The education for Master of Science in Energy Engineering is divided into four phases, see “Fig. 1”.

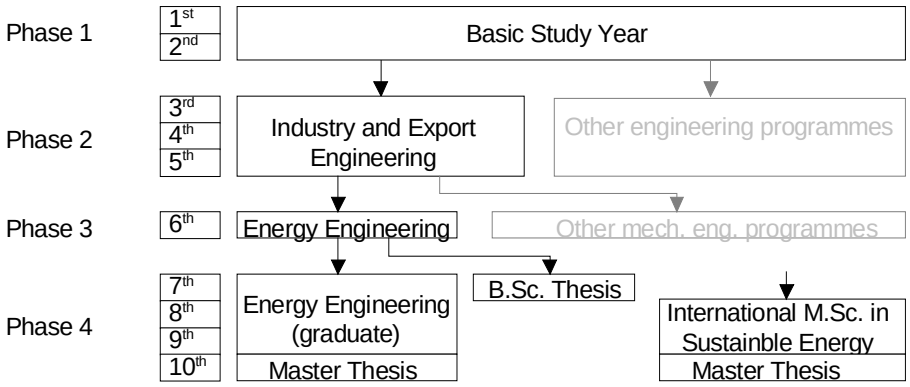

Figure 1 - The structure of the education for Energy Engineering.

- Phase one covers the first year, the freshman year. (1st – 2nd semester)
- Phase two covers the first part of the undergraduate studies (3rd – 5th semester)
- Phase three covers the last semester of the undergraduate studies (6th semester)
- Phase four covers the graduate studies (7th – 9th semester) or alternatively the students can make a thesis and become Bachelor of Science in Energy Engineering (7th semester). At the end of the fourth phase the student write the Master Thesis (10th semester). In section 3.1 you will find a detailed description.
  In year 2000 Aalborg University expects to start up an International Master in Sustainable Energy

A detailed description of the graduated studies and the new International Master is provided in section 3.2

3.1 Energy Engineering (graduate study)

Below you will find a detailed description of the M.Sc. in thermal engineering, as it has been developed until now.

7th semester

The graduate program for the education begins at the 7th semester. To emphasise the more scientific approach at the graduate level, the project at the 7th semester considers scientific work; the students must write an academic paper, instead of the usual project report, make a poster and give a lecture at a conference[1]. The work is typically focused on a simple fluid-dynamic problem. The students must use both analytically, numerically and experimental methods for analysing the problem. Courses within the following areas are offered, in connection with the project work:

- Fundamentals of Fluid Mechanics
- Numerical Fluid Mechanics
- Experimental Fluid Mechanics
- Constitutive Modelling
- Finite Element Methods

[1] The conference is internal at the university, where the students from various studies present their work for each other.

- Turbo Machinery
- Structured Programming
- Theory of Science
- Numerical Methods

Examples of recent projects of the semester includes
- "Analysis of Flow over Backward-facing Step"
- "Analysis of Vortex Shedding from Square Object"

The students implement their own software for solving the flow problem. As the students write their own source code, they acquire a profound knowledge of both the numerical algorithms, the discretization of the governing differential equations and the flow phenomena. Experiments are carried out to compare the numerical solution to actual measurements, which is done using LDA-equipment.

8th semester

At the 8th semester the focus is moved from the very detailed level at the 7th semester to a more overall view of an energy system. The projects focus on the design of an energy system. Simulation of the system and optimisation is central in this work. The students must model all components in the energy system in order to obtain knowledge of the interaction between the components, and the function of the entire plant. During this semester the following courses relating to the curriculum are provided:
- Advanced Thermodynamics
- Simulation and Optimisation of Energy Systems
- Turbo Machinery
- Modern Electrical Drives
- Optimisation of Constructions
- Finite Element Methods

Examples of recent project titles include:
- "Optimisation of Power Plant Operation, with Considerations of Corrosion"
- "Design of Industrial CHP-Plant, using Micro Gas Turbines"

E.g. the project "Optimisation of Power Plants, with considerations of corrosion" was elaborated in cooperation with a Danish CHP plant based on waste incineration. Corrosion is a major problem for these plants, especially in the superheater, where the temperature of the materials is highest.

The project investigated how the economy of the plant was affected by the corrosion and aimed to increase the overall profit of the plant. A detailed model of the boiler and especially the superheater was made, to predict the corrosion as a function of various operational parameters. This model was combined with the overall system simulation, and the operation was optimized, with the contribution margin as object function. The students concluded that the plant would be able to increase their contribution margin by 10% by changing their operational strategy.

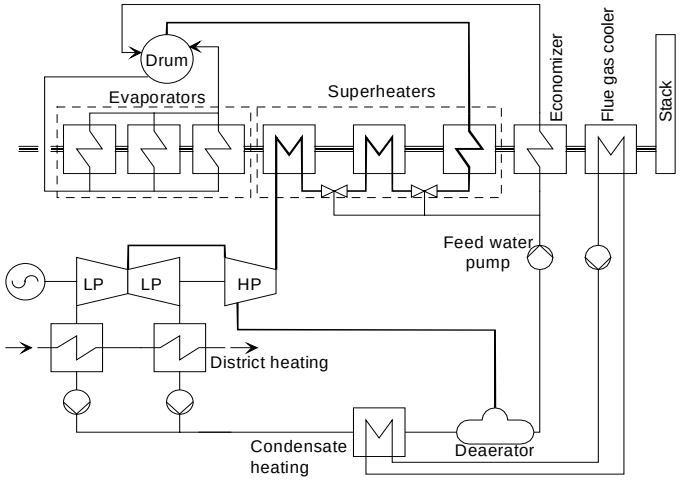

Figure 2 - Overall system diagram of the CHP-plant

9th semester

The 9th semester is typically used to carry out preliminary work for the Master Thesis at the 10th semester. The students are free to choose any project within the area of energy engineering.

During the 9th and 10th semesters the students have access to the departments advanced computer facilities, including CFD-Software (CFX), and very recently heat-balance software has been added (GateCycle and Cycle Tempo). Furthermore, the students are allowed to carry out advanced experiments. The following courses, related to the project work, are offered:

- Applied Numerical Fluid Mechanics
- Two-phase Flow and Non-newtonian Fluids
- Thermal Process Technology
- Noise and Vibrations in Rotating Machinery
- Theory of Decisions and Investment

E.g. a student was a trainee, which is a possibility, at AVL in Austria during his 9th semester. The project aimed at developing a model for a drive system for a car based on fuel cells.

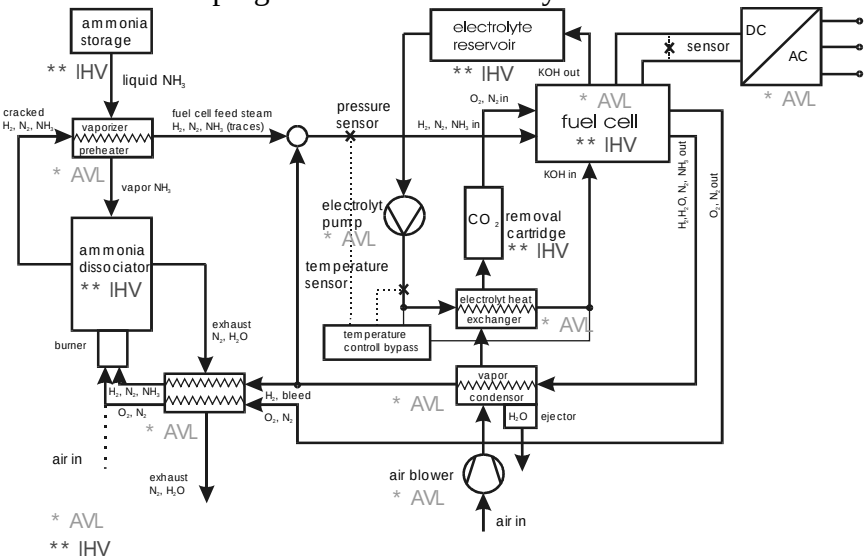

Figure 3 - Fuel cell drive system for a car / train

The chosen fuel cell concept is the alkaline fuel cell. With the development of new electrodes and reformers, this Alkaline fuel cell concept has now come to a point where it might bee considered very competitive (economically) to other fuel cell systems. The system designed for propulsion of a vehicle is shown in “Fig. 3”. In the first project phase a computerized model of the whole system is being made. The requirement or objective of the system model is to make a model of a lab car.

10th semester: Master’s Thesis

On the 10th semester the students do their master thesis. It is typically done in groups of 1-3 persons. Often the Master Thesis is made in corporation with an industrial partner. Recent Master thesis includes:

- Optimum Design of CHP Plant
- Optimum Design of Wings for Wind Turbines
- Numerical Modelling and Investigation of Particle Deposits
- Vortex Pumps, Empirical and Analytical Study
- Numerical Model of Fish Product Freezing Process.

The project “Optimum Design of CHP Plants” aimed at the development of a computer based tool for optimum design and operation of CHP-plants. The task was divided into three sub problems, where the first problem was to make an overall plant design. Given a district heating demand over the year, the choice is made under consideration of the Danish regulations. The second part aimed at optimising the selected overall design, e.g. by using heuristics. The third part dealt with the optimisation of operation. The software was tested on an actual case, and the students found it to be a powerful tool when designing a CHP-plant.

3.2 International master in sustainable energy

As a parallel to the program for Thermal Energy Engineering the Department of Energy at Aalborg University expects to start up an International Master running over three semesters, 8., 9. and 10. and ends up with a master degree. The new education in sustainable energy is more focused on the overall view of the energy systems, though the interaction between components and systems are in focus, while teaching of the detailed construction of the single components are only touched briefly.

Target Group

The education is directed against bachelors, or students with similar level, both from Denmark and abroad, e.g. engineers with a background in electrical or thermal energy, planning, physics, chemistry etc. The education might especially attract students from the East and Central Europe, as the reconstruction of the energy systems in these countries is a very demanding task.

Objective of the International Master

The objective of the education is to give the students knowledge about and understanding of different types of energy supply systems and the placement in and effect on both the overall and the local supply system. The objectives of the education are to:

- impart knowledge to the student about planning, constructions of energy supply systems and selection of renewable and fossil energy sources
- impart the student technical knowledge about placement and optimal operation of energy supply systems in existing electrical and thermal systems
- enable the student to execute life cycle analysis for plants and systems
- impart the student technical knowledge about renewable and fossil sources, e.g. biomass, wind power, solar and geothermal energy, natural gas and wastes

The education is aiming to enable the student to estimate/evaluate a demand of energy; to plan an overall energy supply system, to construct energy supply plants and estimate the environmentally consequences of the choice. Altogether making the students able to construct more environmentally sustainable energy systems.

8th semester

This semester focus on thermal components in energy systems. During the semester the student will achieve knowledge about pumps, gas turbines, steam turbines, compressors, reciprocating engines, heat exchangers and windmills.

In the project work the students from a certain number of assumptions shall make a temporary design of a thermal component with the purpose of low cost, optimal utilising of resources, low maintenance cost or a simple construction. Furthermore a life cycle analysis of the designed component should be done. Project titles could be

- Design of Biomass Fuelled Power Plant
- Design of Wind Power Plant

During this semester the following courses relating to the curriculum are provided:

- Combustion Technology
- Energy Resources
- Emission Control Technology
- Wind Power Technology
- Thermal Conversion Technology
- Electric Conversion Technology
- Energy Distribution Technology

9th semester

The 9th semester is mainly used to give the students knowledge of thermal energy systems. During the courses and the project work the students will be able to make calculations of energy systems using commercial simulation programs; and make the students understand how these programs are constructed. The semester will also give students knowledge about control and operation of energy systems, which is an important factor when designing and planning both small and larger energy systems. Project titles could be:

- Redesign of an energy system
- Design of a combined heat and power plant for a town
- Design of a combined heat and power plant in combination with windmills
- Design of a district heating systems based on biomass

The following courses will be offered:

- Design and Operation of Energy Systems
- Socio-economics
- Overall Planning of Energy Systems
- Energy Systems Economics
- Control Systems
- Analysis, Modelling and Simulation Methods in Energy Systems

10th semester Master Thesis

The students will have a high degree of freedom when selecting their thesis work, and the work may extents to fields beyond the ones taught in the courses. Also under this international education programme cooperation with an industrial partner is foreseen. This partner will together with the supervisor at the University provide the students with the necessary information and supervision during the project. The very broad field of subjects for the thesis requires that the supervisors at the university are constantly updated in several fields. E.g. foreign students could work out their Master Thesis considering a particular problem in the country of origin, thus making them able to use their knowledge within the framework provided by their native country. This strategy aims to initiate very different projects as political decisions and local laws and strategies often plays a major role in the design of an energy system.

4. EVALUATION OF THE EDUCATION

The education: Master of Science in Energy Engineering has not been evaluated separately but only as a part of several major evaluation projects which have included all the engineering studies at the university (Kjersdam, 1994).

The educational system is efficient, as 80% if the students pass their examination at the prescribed time. The results and experiences of the research, which are carried out at the university, are easily incorporated in the study program because of its close relationship to problem-solving, and because of its direct integration with the educational system and its program. The graduates achieve great experience in interdisciplinary teamwork, and they will normally possess the latest, scientific and methodological knowledge, which, due to the employment of new graduates, is quickly transferred to both public bodies and industries, free of charge.

The engineering education in Aalborg has been evaluated and compared with traditional engineering education. This was done by two international panels, as well as by external examiners, alumnus and their employers and undergraduate and graduate students. Evaluation assessed that there were no differences in quality or level between engineers graduated from Aalborg University and the other Danish University engineering education institution in Copenhagen. But the evaluation also assessed significant differences between the profiles of the graduates from the two Danish engineering Universities. The engineers from Aalborg were assessed to be stronger in problem solving, communication, cooperation and general technical knowledge, while the traditional engineers were assessed to be stronger in specialist knowledge and technical methodology. Most of the graduate engineers from Aalborg had no difficulties in their first job and felt confident after three months. There was convincing agreement between the composition of the knowledge and experience used in the project-oriented education and in the professional engineering practice. The only difference was slightly more emphasis on theoretical engineering and science at the university and on economy in industry. Surprisingly, computing and foreign language were more important than theoretical science for the graduate engineers in their jobs.

After three years of employment, the main source of the applied professional knowledge still derived from their project work at the university, while only a minor part of the applied knowledge derived from taught courses, colleagues or postgraduate courses.

The students felt enthusiastic about the group work. They preferred the later problem-oriented semesters with their better possibilities of deciding the content and organization of the project work and their better scientific and technological tools to solve the problems. But the formation of groups was found to be a difficult and sometimes painful process.

Also the demands for the curriculum were assessed to be sufficient, but it was judged too diffuse by a minor part of the students. The students assessed the technical coherence in the program as average. There was a good overlap between the supervisors' qualifications and the qualifications the students wished them to possess, such as willingness to advise, engagement in and mastery of the subject, and the ability to provide precise clear explanations. Only at the last point many of the supervisors failed the students grading.

Finally, the examination system with a written project report orally to be presented and defended by the project group was judged good by the students as well as our graduate engineers, external examiners and the international panel.

5. CONCLUSION

To conclude, the combination of problem-oriented and project-organised education in Aalborg has proved to be an effective educational system, which produces readily adaptable graduates with strong qualities in problem solving, communication and general technical knowledge. The weakness of the problem-based education is the students' lower amount of specialist knowledge and methodology.

The problem-oriented and project-organised style of education is indeed a benefit for the Energy Engineering. The field of energy engineering is broad, and the projects help the students to obtain an overview of the field; an important skill, as the interaction between components and phenomena is very significant in this field.

The Department of Energy expects the problem-oriented education to match very well to a general energy education, which is planned to start up in 2001. The problem-oriented education together with the project work will make it easier for the students to obtain a general energy knowledge, mainly because they will be faced with difficult choices. The students will with this education model do a lot of work on their own and not just passively follow lectures.

The graduates have expressed satisfaction with their education, and the skills they had when they were employed. This is very much in agreement with the overall evaluation of the educational system.

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