The Chemical Engineering Ph.D. Program

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Introduction

The Ph.D. represents the last formal stage of academic training for an engineer, and can lead to a variety of careers in industry, government, and academia. The PhD program aims to teach students to conduct research, to develop the maturity of judgment necessary for critical, creative, and independent thinking, and to contribute to scientific and engineering knowledge in a particular area of scholarship. The conduct of this research, as well as the versatility expected of a productive member of the profession, also requires a breadth of knowledge of chemical engineering fundamentals and their application.

The requirements set out below represent the minimum that the department expects every student to satisfy. They are designed to be sufficiently flexible to accommodate differences among students with respect to interests, aptitude, and expected career paths. Students are encouraged to take the initiative in seeking opportunities for formal and informal intellectual exploration beyond the guidelines imposed by the degree requirements. Please also recognize that these guidelines change with time, and that the faculty continue to refine and improve the PhD program in consultation with the graduate students and office of graduate studies. We will certainly keep you informed of any significant changes.

Course Requirements

The aim of the course requirements is to develop a foundation of technical knowledge in chemical engineering. This knowledge should be obtained in a way that develops an understanding of basic principles, while at the same time providing depths in a specific area. An overall GPA of 3.00 or above must be maintained in courses taken toward meeting these requirements.

There are three components to the course requirements:

- the chemical engineering science core (thermodynamics, transport phenomena, and chemical kinetics and reaction engineering)
- advanced mathematics
- chemical engineering technical electives

The core courses and the mathematics sequence should all be taken during the first year (prior to the qualifying exams). Eight credits of chemical engineering electives are required. At least three credits of these must be at the 800-level; the remainder may be at the 600- or

800-level and suitable courses taken outside chemical engineering may be substituted. The chemical engineering electives may be started during the fall semester of the first year and are usually completed during the second year. Nine credits of CHEG 969-xxx Doctoral Dissertation are also required. These credits should be taken after all other course work is completed. A typical schedule for the first year is shown below: The curriculum is reviewed each year and updated often. A typical schedule for the first year is shown below, excerpted from the 2007-2008 AY:

FALL 2007

CHEG 825 Thermodynamics
CHEG 835 Chemical Kinetics
CHEG 831 Chemical Engineering Principles 1
CHEG Tech Elective from list below

Approved Fall 2007 CHEG Elective Courses for First Year Grad Students:

CHEG 600-010 Intro to Polymer Science and Engineering
CHEG 616-010 Chemistry & Physics of Surfaces & Interfaces
CHEG 620-010 Biochemical Engineering
CHEG 667-013 Multidisciplinary Biotechnology (For IGERT or CBI students only)

Approved Fall 2007 Elective Courses from other departments (check course catalog for time and availability):

CHEM 527-010	Introductory Biochemistry
CHEM 641-010	Biochemistry
CHEM 641-011	Biochemistry
CHEM 651-010	Advanced Inorganic Chemistry I
CHEM 671-010	Quantum Chemistry
MATH 512-010	Contemporary Application of Math
MSEG 632-010	Principles of Polymerization
MSEG 667-016	Solid State Nanotechnology

SPRING 2008

CHEG 845 Advanced Transport Phenomena
CHEG 841 Chemical Engineering Principles II
CHEG 6xx/8xx Technical Elective
CHEG 6xx/8xx Technical Elective

Candidates seeking additional recognition for course work may choose to earn a specialization, which consists of four graduate courses in a defined area.

Sample areas of concentration with possible course selections are given below:

1. Applied Polymer Science or Complex Fluid Science

CHEG 867 Advanced Polymer Science
CHEG 867 Transport Phenomena in Polymers
CHEG 867 Polymer Dynamics & Thermodynamics
CHEG 867 Advanced Colloid Science
CHEG 828 Statistical Thermodynamics
CHEG 600 Intro. To Polymer Science & Engineering I
CHEG 602 Polymer Process Analysis and Design
CHEG 617 Colloid Science and Engineering
MSEG 667 Principles of Polymerization
MSEG 667 Biopolymeric Materials
MSEG 667 Polymer Physics

2. Biomolecular or Biochemical Engineering

CHEG 828 Statistical Thermodynamics
CHEG 836 Advanced Chemical Kinetics
CHEG 867 Molecular and Cellular Engineering
CHEG 867 Molecular Biophysics
CHEG 620 Biochemical Engineering
CHEG 650 Biomedical Engineering
CHEG 667 Topics in Biochemical Technology
BISC 604 Recombinant DNA Laboratory
BISC 653 Recent Advances in Molecular Biology
BISC 658 Developmental Genetics
CHEM 527 Introductory Biochemistry
CHEM 641, 642 Biochemistry
CHEM 667 Interface Research: Chemistry / Biology

3. Catalytic Science and Technology

CHEG 836 Advanced Chemical Kinetics (reactions)
CHEG 606 Introduction to Catalysis
CHEG 616 Chemistry and Physics of Surfaces and Interfaces

CHEM 667 Introduction to Industrial Chemistry
CHEM 651, 654 Advanced Inorganic Chemistry I, II
CHEM 652 Organometallic Chemistry
CHEM 671 Quantum Chemistry
CHEM 672 Spectroscopy
CHEM 674 Chemical Dynamics

PHYS 610, 811, 812 Quantum Mechanics
PHYS 803, 839 Solid State Physics, Advanced Solid State Physics

A schematic overview of non-course requirements to progress towards a Ph.D. degree, beginning with the qualifying examinations (see also below), is provided in the Appendix.

Qualifying Procedures

The qualifying procedures serve a number of purposes. They give the faculty an opportunity to evaluate students' analytical skills and their abilities to think critically and generate original ideas. In addition, they give students a chance to practice their communication skills and faculty a chance to evaluate them. The qualifying exams are oral exams given towards the end of the student's first year (after completion of the core courses). This insures that all students have the necessary chemical engineering background to take the exams and also allows students to get involved in their research in a rapid and effective manner. In order to avoid unnecessary delays in formal admission to the Ph.D. program, students are given only a single opportunity to take and pass the qualifying exams. The faculty feel very strongly that we have more than enough information to make an appropriate decision about Ph.D. candidacy after students have spent a full year at Delaware, and that it would be inappropriate for us to delay the decision and interfere with the development of the thesis.

The central formal element of the qualifying procedures is an oral examination that typically takes place near the end of August of the students' first year unless other legitimate activities, such as special graduate training programs, require a later exam. The

oral exam is intended to evaluate students' abilities in several areas: creative thinking, progress in understanding and formulating a research project, mastery of the relevant underlying chemical engineering fundamentals, and effective communication of ideas in both oral and written forms. The specific guidelines for the oral exam vary from year to year as the technology of the oral presentation advances, and as needed to improve the examination process. The most recent procedures (applicable for the August 2009 oral exam) are as follows:

Each oral exam lasts 60 minutes, of which the first 12-15 minutes are reserved for oral presentation and the remaining time is provided for faculty questions. Transparencies or PowerPoint files may be used for the oral presentation; inclusion of a large number of slides (more than 8–10) is discouraged, as this usually results in confusing and incomplete explanations of the content. Each student's exam is administered by a group of at least five faculty, of whom at least two must be members of the student's thesis committee, with the thesis advisor included in this number. It is the student's responsibility to organize the thesis committee prior to scheduling the exam, in consultation with the research advisor. In preparation for the exam, students should also prepare a brief written summary, to be made available to the faculty in both written and electronic form at least a week before the exam, with a common deadline for all students typically set by the department each year. The written document should comprise 6-10 double spaced pages on standard paper in at least 11 pt fonts, including all figures and a bibliography. The written report must include an appendix (beyond the regular page limit) that outlines goals, plans, and a time line for the proposed thesis research, with particular emphasis on the goals for the coming year, as these will form part of the basis for the thesis committee's evaluation of students at the end of their second year.

The exam date and time for each student will be scheduled by the Department's graduate student advisor in consultation with the faculty.

Both the oral and the written presentations should provide succinct and clear descriptions of the concepts underlying the proposed thesis research, the goals of the project, and the methods to be used in achieving those goals. Results obtained to date provide a useful focus to help motivate the discussion. Questions asked by the faculty may address specific details or the broader context of the project presented, the proposed approaches, and associated chemical engineering principles. Clear communication in both the oral and

written presentations and in interpreting and answering questions is essential for successful completion of the process.

In each student's preparations for the exam, his/her advisor is likely to be the principal source of information and guidance. However, since it is expected that both the written and the oral presentations represent the student's own work, advisors do not work with the students on the structure or content of either presentation, e.g., by reading drafts of the written document or the slides, or being present during practice sessions.

In addition to the formal oral exam, student performance in the required first-year courses is also considered in reaching a decision on admission to Ph.D. candidacy. These courses provide perhaps the best view of students' analytical skills. In recognition of the importance of course work in providing a good test of the analytical abilities essential for successful completion of the Ph.D., a 3.00 GPA in approved graduate classes is required before taking the oral exams. The faculty will also consider other information in addition to performance in the formal qualifying procedures in assessing students' suitability for admission to Ph.D. candidacy. Instructors in courses and, most important, each student's advisor will have had a better opportunity than the faculty as a whole for extensive interaction, and their judgment will thus be particularly valuable in evaluating students' performance.

The faculty, as a group, will make their decisions on admission to the Ph.D. program within a week after all the oral presentations have been completed. The decisions will be conveyed to the students in writing by the Department Chair. All of the components considered by the faculty are important. A strong showing in only one area will probably not be sufficient to ensure admission to Ph.D. candidacy, but neither will a weak showing in any one area lead to automatic rejection. It should be emphasized that the department admits students to its graduate program with the expectation that they will be successful in the qualifying procedures and proceed to completion of the Ph.D. degree. The qualifying procedures are thus intended to be a constructive learning experience; they are not intended to eliminate large numbers of students from the Ph.D. program. The faculty member in charge of the thesis committee will provide a written summary of the feedback to the student from the faculty within one week after candidacy decisions are completed. This will include a summary of strengths and weaknesses identified by the committee during the oral exam and through the student's written report, as well as any recommendations regarding the student's goals and time line for the coming year's research efforts. The external member(s)

of each student's thesis committee must also be identified once a student is admitted to Ph.D. candidacy.

Research

The unique feature of graduate education is the development of the skills necessary to conduct and present independent research. The Ph.D. thesis should demonstrate that the student has (1) acquired the skills necessary to conduct high-quality research including the abilities to think creatively and critically, and (2) completed a coherent piece of independent research that makes a solid contribution to the general pool of scholarship. The length of the actual thesis, the number of associated publications, and the time required will necessarily depend upon the abilities and effort of the student, the details of the project, and the philosophy of the thesis advisor. It is impossible for the department to determine, a priori, how long any given student will remain in residence. However, it is important to recognize that the Ph.D. program is a transition period, one that provides students with an opportunity to expand their intellectual horizons, to learn how to conduct research, and to be creative. The transitional nature means that students should move as rapidly as possible towards completion of all of the objectives/requirements associated with the Ph.D. degree. The following sections describe the policies and guidelines that have been established to assist the student in the selection, conduct, and completion of the doctoral thesis.

Thesis topic selection

Since research is such a critical component of the graduate program, students need time to gather information about the available projects, to clarify their own personal research interests, and to think carefully about their own long-term objectives. Thus the Department does not allow students to choose thesis topics or advisors prior to actually arriving at Delaware. Instead, toward the beginning of the Fall semester, a set of written descriptions of available projects (prepared by the faculty offering them) is provided to the students. Over the course of the next few weeks, each faculty member presents his or her projects in a 30 minute talk. Graduate students are expected to attend all of the thesis topic presentations (even if they have no interest in that particular research area). These presentations are an ideal way to meet the faculty and become exposed to the full range of chemical engineering research. Students should then talk individually to faculty members and other graduate students to gain a more thorough understanding of possible research topics. Several meetings may be required to fulfill this objective, and many projects are

negotiable; students are encouraged to work with the faculty to develop projects that match their personal research interests.

Outside the thesis presentations, students should speak to at least 6 faculty members in individual or group appointments. Students are then asked to give a listing of their preferences and a paragraph describing the reasoning behind them to the graduate advisor in late October or early November. **The list must include at least five projects spanning at least four advisors**. The matching of students to topics is a difficult multivariable problem. There are many factors involved in the determination of the final assignments, including current research group sizes, faculty objectives, department objectives, funding, and student preferences. Often the solution does not match everyone's requests and some students may be asked to meet again with the graduate advisor to discuss options.

Thesis committee

Research projects are independent, but they are not isolated. Graduate students are encouraged to involve many faculty, both inside and outside the department. Since students often feel uncomfortable asking other faculty members questions about research, a formal structure for this interaction is provided by the formation of a thesis committee. The committee consists of at least 2 other faculty members chosen by the student in consultation with the thesis advisor; other people with PhD (i.e. working in industry) may also be included, as deemed appropriate. The faculty will usually be from the Chemical Engineering department, but outside faculty may also be included; one outside faculty member is ultimately required to be included in the committee for the final thesis defense. This external member of the committee does not need to be identified prior to qualifying exams, but does need to be included in later committee meetings and decisions once a student has been admitted to Ph.D. candidacy. The departmental committee members are to be chosen before the oral qualifiers are taken. Additional committee members may be added at any time before the thesis defense. However, removal of a committee member requires either that the committee member in question gives written approval to the Graduate Program director for the department, or requires special approval by the Department Chair if the faculty member in question is unable or unwilling to fulfill their role as a committee member within a reasonable time frame.

The thesis committee members make a formal commitment to provide input and feedback throughout the course of the thesis research. This includes feedback on your departmental

seminars and during committee meetings. Students are strongly encouraged to provide the committee written progress reports and copies of all manuscripts/publications. One benefit from frequent communication with the thesis committee is that you help insure that additional people are well qualified to write recommendation letters that can significantly help your post-PhD career placement! There are limited departmental requirements for formal interactions with the thesis committee, as detailed below. This format is intended to encourage flexibility and to ensure that substance, rather than form, prevails. However, a minimal set of required interactions are intended to help assure a reasonable pace for measurable progress towards the degree, without inhibiting creativity and freedom for the evolution of the thesis direction. To this end, each student is required to meet with his/her thesis committee around the end of his/her second year, prior to the start of the third year. This is separate from the 2nd year seminar to the Department as a whole. The purpose of the meeting is for the student to present results and update the committee regarding progress and any changes in direction since the qualifying exam. It is also intended to assure sufficient progress is being made to justify any department commitments regarding funding. An analogous committee meeting is also required around the end of the fourth year, provided that the student has not already graduated. A formal committee meeting is not required in the third year, but students must provide the committee members with a brief written summary as an update between the 2nd-year and 4th-year meetings. The exact format is flexible; current guidelines are for a report of no more than 5 pages, double spaced; plus any necessary appendices such as copies of published or pending manuscripts. Students are encouraged to proactively seek additional informal or formal feedback from individual committee members on an as-needed basis.

Seminars

A necessary complement to good research is good presentation skills, and participation in the departmental seminars gives the student a chance to develop an effective presentation style. Each student is expected to present two seminars during his/her graduate career, one during their 2nd year and one during their 4th. These seminars are given as part of a day-long Departmental Research Review that provides students, faculty, and postdocs an opportunity to learn about different research areas, discuss alternative approaches to research, and provide comments and feedback to colleagues.

The content of the talks will vary with the state of the projects, but suggested content includes: background, experimental approach, results, future plans, etc. The second year seminar typically is primarily a preliminary report and research proposal, while the fourth year seminar is more polished and presents a more coherent picture of results of the project. The student can improve his or her skills by soliciting feedback from faculty members and other students; at a minimum each thesis committee member should be consulted. Students are encouraged to make use of video equipment, which is available for recording and reviewing presentations.

Final thesis defense

The final oral defense is a presentation to the department, the defense committee, and the public research community of a summary of the research. The defense committee may be the same as the thesis committee discussed above, with the addition of one member from outside the department. The student must provide a copy of the thesis to each member of the defense committee at least 2 weeks before the defense. At this time the graduate advisor should also be informed of the date and venue of the defense, and an announcement, including an abstract, should be distributed to the department.

The period leading up to the final defense should involve the close interaction of the student, the advisor, and the thesis committee. Since a good research project is one that is quite open-ended, questions such as which specific goals are to be pursued and which are to be set aside as secondary require substantial discussion. To allow all possible points of view to be brought to bear on these issues, continuous involvement of the thesis committee is recommended to obtain the best advice possible. Such involvement of several faculty also ensures that neither the student nor the faculty advisor will be surprised by the interests and requirements of the other, and that impartial reviews of any divergent interests occur promptly. At a minimum, each student must hold a thesis committee meeting no less than six months prior to the intended defense date. This meeting may preempt the 4th-year committee meeting requirement described above.

Funding

Funding will be available on a continuing basis assuming that the student maintains satisfactory progress towards completion of the degree. A 3.00 GPA must be maintained in course work throughout the program, and this will obviously be the main criterion during

the first year. After the first year, however, progress will be primarily in research, where a clear quantitative measure of performance is infeasible. In general, the thesis advisor is responsible for this progress review but in cases where there is disagreement between advisor and student the thesis committee will provide an independent evaluation to determine if there is "satisfactory progress" for the continuation of funding. In the event that progress is deemed unsatisfactory, the student will be provided at least three months notice that funding is in danger of being discontinued, and will, wherever possible, be given sufficient opportunity to rectify the situation. Although the likelihood of this happening during the early stages of the research is slim, students should be aware that all theses must come to an end and thus the likelihood of funding being discontinued increases as the residence time in the program increases. In particular, funding is not guaranteed beyond four years.

The majority of students in the department are supported on research contracts and grants obtained by their faculty advisors. Students on projects without external funding will be provided support (assuming that their progress is satisfactory) through the use of either departmental funds (e.g., industrial grants) or by appointment as a teaching assistant. No student will be supported by departmental funds for more than five semesters; funds beyond such a commitment must be provided by the thesis advisor or by appointment as a teaching assistant. This policy does not apply to students working with new faculty, where full support may be provided for purposes of initiation of new research.

Teaching Assistants

The ability to communicate ideas, concepts, and factual information in a "teaching" environment is an essential skill for all PhD graduates, even those who have no interest in an academic position. In recognition of this, all PhD students are required to fulfill a teaching requirement, which consists of serving as a TA for either 2 lecture courses or one Junior or Senior laboratory course. Students who serve as a TA for a lab will be considered full-time TAs for that semester, while students who serve as a TA for a lecture will be considered half-time TAs. All TAs are expected to continue to be actively involved in their research while serving as a TA. Although the exact timing of TA appointments is flexible, it is highly desirable to complete all TA responsibilities relatively rapidly (by the end of the 3rd year if possible) to allow students to focus more strongly on their research as they near the end of their graduate studies.

In order to be an effective TA, it is essential that students have adequate command of the English language. Graduate students who are felt to have insufficient language ability will be required to correct this deficiency, e.g., by taking an appropriate "course" through the University's English Language Institute. Identification of any language deficiencies can also be made during the Oral Qualifying Examination. Final decisions on how to resolve these deficiencies are made by the Graduate Program Coordinator in consultation with the student's thesis advisors and the Department Chair.

Teaching Assistant positions are assigned by the Graduate Program Coordinator in November (for the upcoming spring semester) and in May (for the following fall). Students are encouraged to submit their preferences for specific TA positions early to facilitate the process. Although every effort is made to satisfy these requests, students should recognize that this may not be possible in all cases. In addition, the educational needs of the Department may require the Graduate Coordinator to ask students to fill specific TA positions.

Every spring, the Department gives out the Robert L. Pigford Awards for Outstanding Teaching Assistants. These awards are used to recognize and modestly financially reward the contributions of our most outstanding TAs and to thank them for all their efforts on behalf of the Department.

Teaching Fellowship

The Department has established the Teaching Fellowship program for graduate students with particular interest in an academic career. Each Teaching Fellow actually co-teaches one of the Chemical Engineering courses with a faculty mentor, and is involved in all aspects of the course (lecturing, preparation of new material, grading, etc.). Graduate students interested in the Teaching Fellow program should meet with the Graduate Program Coordinator to discuss the various options. Teaching Fellows are chosen by a committee based on their performance in previous TA positions, recommendations from their thesis advisor, and comments from the prospective faculty mentor. It is strongly encouraged that students complete their TA requirements prior to applying for a Teaching Fellowship. A particularly outstanding Teaching Fellow candidate may be awarded the Shirley and Fraser Russell Teaching Fellowship by the committee.

Requirements for the MChE Degree

If you make the decision to obtain a MChE instead of a PhD there are two options for graduate education leading to a Masters in Chemical Engineering (MChE) Degree.

The thesis option requires 6 credit hours of thesis work (CHEG869 Master's Dissertation) and 24 credit hours of course work and is designed for full-time graduate students in residence. Our course option requires 30 credits of course work and is designed for engineers who are studying part-time. The faculty member supervising the thesis research will act as an advisor for students in the thesis option. The Department's graduate student advisor will act as an advisor to all students in the course work option.

Both options require 10 credits (three courses) of core courses in chemical engineering fundamentals: Thermodynamics (CHEG 825, 3 credits), Applied Chemical Kinetics (CHEG 835, 3 credits), and Advanced Transport Phenomena (CHEG 845, 4 credits). Students must also fulfill an advanced mathematics requirement, MEEG 690 (Intermediate Engineering Mathematics) or CHEG 831 (Chemical Engineering Principles), as well as MEEG 891 (Advanced Engineering Mathematics).The Department offers numerous technical electives in all areas of Chemical Engineering, and up to six credits of electives may be taken in suitable courses outside Chemical Engineering.

Continued funding is provided only for MChE students pursuing the thesis option. Students who have been provided support will generally not be allowed to pursue the non-thesis MChE degree. Funding will be available for students performing MChE thesis work on a continuing basis if they maintain satisfactory progress towards the degree. A 3.00 GPA must be maintained throughout the program. Students should be aware that theses must come to an end in a reasonable period of time (typically 18 months). Funding beyond the 18 month period is not guaranteed.

APPENDIX

Overview of formal requirements & milestones for progression of Ph.D. candidacy