January 2012 RAE Schedule and Proposal Format

January 9 (Monday):
Exam questions will be posted at 9 am; question selection by noon of that day (email selection to Ms. Kathy Lopresti: lopresti@umd.edu).

January 19 (Thursday):
Turn in exam (email and hard copy) by noon of that day to Ms. Kathy Lopresti; your responsibility to obtain validation of submitted exam from her.

January 20 (Friday):
Oral exams (8:30 am to 5 pm); schedule will be emailed to you by January 18.

January 24 (Tuesday):
Exam results will be given to students.

Prepare write-up in the form of a proposal:

Format: 1” margins, single-spaced, 12-point font

Total pages (not including references): ≤ 10

Page 1: Title Page: Title, Name, Summary (1 para), University Honor Pledge

Page 2: Checklists: Global, Specific to the problem you choose

Page 3-6: Introduction and Background, including discussion of relevant literature and problem motivation.

Page 7-10: Proposed Research, including plan of work; make sure you have addressed all parts of the problem statement (see Checklist).

References: No page limit, but include only papers or books that you have read.

The exam is an individual effort – do not discuss the exam or your solution with anyone. Please direct all questions to Professor Raghavan (sraghava@umd.edu)

Page 2: Copy the checklist below as well as the checklist specific to your problem. Use the checklists to verify that you are adhering to the right format and also that you have addressed all parts of the problem.

Global Checklist

Format: 1" margins, single-spaced, 12-point font	
Total pages (not including references): ≤ 10	
Title page (pg 1) has **Honor pledge**	
Title page (pg 1) has **Summary** (1 paragraph)	
Checklists (Global, Specific) are provided on pg 2	
Introduction, Background: ≤ 4 pages (pg 3 – 6)	
Proposed Research, Plan of Work ≤ 4 pages (pg 7 – 10)	
References (no page limit), includes only those you have read	
Figures have all been created by you or are appropriately cited	

Problem 1. Piezoelectric Ink-Jet Printing

Piezoelectric drop on demand ink-jet printing has found wide application both in industry as a low cost manufacturing technique and in the laboratory. Not every fluid can be printed using this technique though, and dimensional analysis can provide guidance as to the suitability of various fluids. Important physical parameters are fluid viscosity, density and surface tension. Key dimensionless parameters are the Reynolds number (N_{Re}), the ratio of inertial to viscous forces, and the Weber (N_{We}) number, the ratio between inertial and capillary forces. In 1984, Fromm solved the Navier-Stokes equations for droplet ejection, and he found that stable droplet formation only occurred for N_{Re}/N_{We} ratios greater than 2 (Fromm, 1984). Later reports focus on the dimensionless group called the Ohnesorge number, which is independent of the fluid velocity (see for example Derby, 2011). In this RAE problem:

1. (a) Briefly explain the physical reasoning behind the lower boundary for stable droplet formation.
   (b) Does an upper boundary exist? If so, what is the reason?

2. Briefly explain additional challenges associated with ink-jet printing of **colloidal solutions**, that is, solutions containing nano or micro-scale particles or assemblies.

3. Develop an approach for determining the range of printability for **colloidal solutions of metallic and ceramic nanoparticles**.

4. Your approach should be based upon dimensional analysis and experimental characterization. With regard to the experiments: (a) describe how the physical properties of the fluid would be measured; (b) describe how stable droplet formation would be determined; (c) what would be the criterion for (b).

References:

B. Derby, Journal of the European Ceramic Society 31 (2011) 2543–2550

J. E. Fromm, IBM Journal of Research and Development, 28 (1984) 322-333

Checklist for Problem 1. Piezoelectric Ink-Jet Printing

1. Lower boundary / Upper boundary for droplet formation	
2. Challenges with printing colloidal solutions	
3. Approach for range of printability of colloidal solutions	
4. Details of proposed experiments, dimensional analysis	

Problem 2. Chemotaxis of Rodlike Particles

Chemotaxis refers to the ability of bacteria to move in the direction of food. For this, bacteria use a "temporal sensing" algorithm that tells them whether the current path is taking them in the direction of increasing food concentration. Bacterial motion relies on flagella, which in turn are internally powered by the cell's metabolism, i.e., by ATP.

Recently, researchers [1] have reported an example of chemotaxis that has nothing to do with biological systems. The researchers used platinum-gold (Pt-Au) rods that are 2 μm long and placed them in a gradient of the fuel, which was hydrogen peroxide (H_2O_2). The rods were shown to move in the direction of higher H_2O_2 concentrations by a mechanism called "active diffusion".

(a) Review the referenced paper [1] as well as related papers and **explain** the above mechanism for rod chemotaxis. Will it work for larger (mm-sized) particles? Will it work for particles of a different geometry? Relate your explanation to dimensionless numbers you have learned in your transport classes.

(b) As you know from your transport classes, diffusion usually occurs DOWN a concentration gradient. Here, the rods are diffusing UP the concentration gradient of H_2O_2. Does this **violate** the laws of thermodynamics? That is, does the motion of the rods imply a net increase in free energy of the overall system?

(c) Propose a combined **experimental** and **theoretical (modeling)** approach for studying chemotaxis in the above system. Clearly specify the various equations and components of the model. Identify an unresolved variable or question to focus on for the experiments and explain how the experimental results will be used to verify (or disprove) your model.

[1] Y. Hong et al., *Phys. Rev. Lett.* **99,** 178103 (2007)

Checklist for Problem 2. Chemotaxis of Rodlike Particles

1. Explain mechanism for rod chemotaxis; use dim.less nos.	
2. Thermodynamic analysis of rod chemotaxis	
3. Model for chemotaxis with equations	
4. Experiments to test above model; identify exptal variable	

Problem 3. Advanced Distillation Methods for Bioethanol Production

In a recent paper, Karuppiah et al. [1] present a detailed optimization study of the heat integration of corn-based bioethanol plants. The authors examine the entire ethanol manufacturing process, from corn grinding to molecular sieve dehydration of the fuel-grade ethanol, creating process models for each unit operation and tying the process flowsheet design alternatives together in a superstructure optimization procedure.

Azeotropic ethanol is produced in this study by a pair of conventional distillation columns – one to roughly split most of the ethanol from the fermentor product stream, and a second rectifying column to produce the azeotropic mixture. Both columns in the base-case design operate at atmospheric pressure.

For this Research Aptitude Exam,

1) Review the literature on current separation methods used to produce fuel-grade ethanol from corn and compare those technologies to the one in the cited study.

2) Calculate the minimum amount of energy that is necessary to separate the azeotropic and the fuel-grade ethanol from the fermentor product stream and compare your values to the state-of-the-art.

3) Propose a research program that would investigate design alternatives to the conventional distillation used to produce azeotropic ethanol, focusing specifically on replacing the rectification column with two or more multi-effect distillation columns. Give a detailed plan on how energy integration, column pressures, and other design parameters would be optimized for this design alternative.

[1] R. Karuppiah, A. Peschel, M. Martín, I. E. Grossmann, W. Martinson and L. Zullo "Energy optimization for the design of corn-based ethanol plants," *AIChE J.*, **54**, 1499-1525 (2008)

Checklist for Problem 3. Advanced Distillation Methods for Bioethanol Production

1. Compare separation methods to the one in the paper	
2. Calculate energy requirements	
3. Propose an alternative design	
4. Details of energy integration, optimizn of design parameters	