1SC2292 – Biofilm: a hindrance to electricity production coupled with environmental and health risks

Instructors: François Puel
Department: DOMINANTE - VIVANT, SANTÉ, ENVIRONNEMENT
Language of instruction: FRANCAIS
Campus: CAMPUS DE PARIS - SACLAY
Workload (HEE): 40
On-site hours (HPE): 27,00

Description

Biofouling an obstacle to electricity production coupled with an environmental risk is one of the 4 courses (**EI)** that ends the Thematic Sequence (ST2) **Bioengineering: Produce, Protect, Repair.** This course illustrates how bioengineering may contribute to **Produce energy and Protect a natural ecosystem.**

A problem related to energy production and its health and environmental impact.
Nuclear power plants have three cooling circuits in series. The tertiary circuit is based on the withdrawal of water from the environment (river or sea) of the plant and aims to remove a significant amount of heat from the secondary circuit. Practically it consists of condensing a steam. This water taken from the natural environment returns directly to it, so it should not be modified in a way that is too important from a thermal, physicochemical and biological point of view. Due to its natural origin, this cooling water contains microorganisms. These latter can develop in the condenser tubes and form a biofilm. The problem faced by the operating team are on three levels:
(i) this biofilm will hinder the heat exchange capacity between the secondary and tertiary circuits, thus limiting the productivity of the plant (biofouling phenomenon). There is an operational limitation. The operator must use additional cooling capacities, which has an additional financial cost.
(ii) the water released into the environment must not be allowed to rise too highly its temperature, otherwise it is too harmful for the aquatic ecosystems at the place of release.
(iii) When the biofilm is removed, microorganisms will return to the aquatic environment (open circuit). The pathogens that have developed present a health risk for the surrounding populations. Chemical treatment of this water is possible, but in return there is a chemical discharge into the environment that is detrimental to aquatic ecosystems.
The proposed subject aims at modelling the loss of efficiency of a heat exchanger in the tertiary water circuit, caused by this biofouling

phenomenon (fouling by biofilm, inevitable due to water withdrawal in the natural environment). This modeling will be used to propose operating and investment scenarios according to situations proposed by the electricity plant manufacturer (production capacity, characteristic of the environment where the water intake is carried out, etc.). These scenarios must take into account environmental and health constraints

Modelling of the heat exchanger

- The course focuses on limiting heat exchange due to the biological growth of the biofilm. The proposed approach is in three stages (i) Formulation of the problem, resulting in the writing of the model describing the phenomena involved, without forgetting to clearly define the system under consideration, the initial and boundary conditions (ii) Simulation implementation by coding and its validation. In general, a simple reference case ("Toy problem") is used to validate the simulation code, the calculated results must correspond to the results already established for this configuration. This step allows to have the orders of magnitude of the phenomena (temperature drift, biofilm thickness) and to make a sensitivity study of each of the parameters, to determine which ones are critical for the representation of the phenomena involved (iii) Application of the modeling to the industrial study case. By combining the simulation results with other technical and economic data, it is then possible to design equipment and propose operating strategies depending on the location of the plant on the seashore (Europe or Asia) and according to health and environmental discharge criteria

Quarter number
ST2

Prerequisites (in terms of CS courses)
None

Syllabus

1. **Day 1** : Implementation of the problem formulation. Context of electricity production and its environmental and health impact, reading of the bibliography provided on the subject of heat exchange and biofilm growth; writing of the energy efficiency model (two slides to be returned by 4pm to supervisors)
2. **Day 2** : Performing the simulation : Programming the growth of the biofilm by assuming a temperature profile in the fluid inside the

tube); Programming the temperature profile for a biofilm thickness; Joint programming of the temperature profile and the growth of the biofilm. Validation of the simulation by considering a baseline study. Sensitivity study of the parameters; discussion of the results. Writing a written note of no more than 2.5 pages (1st part of the final technical note)

3. **Day 3 a.m** : Travel to the EDF research center in Chatou (78). Visit of the experimental biofouling study systems; Discussion of the results already obtained; Presentation of the methodology for calculating investment costs (CAPEX) and operating costs (OPEX)
4. **Day 3 p.m & Day 4 a.m**: Simulation of the case study supplied by EDF by integrating cost aspects. Establishment of different investment and production management scenari. Finalization of the calculation note, preparation of the oral for the project manager and the oral for the experts
5. **Day 5 morning:** Finalization of the written note, preparation of two orals for the project manager and for the jury of experts
6. **Day 5 p.m** : two oral meetings with the project manager and experts / discussions / self-assessment

Class components (lecture, labs, etc.)

- Biofouling an obstacle to electricity production coupled with an environmental risk is a course dedicated to **Problem solving**. Students will confront the multiphysics and multiscale aspects (heat exchange, biology) of of an industrial problem, by implementing the concepts introduced in the basic courses of **ST2 Bioengineering** and in the common courses of mathematics and computer science. Finally, the student is in the position of a young engineer who must produce a technical simulation note and present his work to technical experts and a project manager as part of an industrial investment.

The course is scheduled over 5 consecutive days. It begins with a half-day project launch (Monday morning) with the client. During the week, students work in groups of 4 to 6 students, supervised by a team of teacher-researchers from the LGPM laboratory. The students visit a research and development laboratory dedicated to this problem at the cclient site to see how to obtain reliable data and thus validate the simulations carried out.
Updates will be held daily: sharing of information, methodological input, additional courses. The week ends with a debriefing session on Friday afternoon in the presence of an expert and a project manager from the client (EDF).

Grading

The evaluation will take into account: individual assiduity, group involvement, model relevance, numerical implementation, programming quality (code), oral presentations and discussions (Q&A), quality of the technical report.

Course support, bibliography

Slides of the various presentations, handout of courses in Thermal Transfer, scientific articles will be provided during the course.

- Client presentation: file "20191203 EI02 Biofouling EDF presentation"
- Extract from the Heat Transfer Course on Exchangers: "TT-Chapter 5-Exchangers Course"
- Techniques de l'ingénieur P. Lemoine, Refroidissement des eaux Techniques de l'Ingénieur, b2480, 1986
- Article Melo et al. 1997 "Biofouling in water system" Experimental Thermal and Fluid Science 1997 ; 14 :375-381
- Article Nebot et al. 2007 "Model for fouling deposition on power plant steam condensers cooled with seawater: Effect of water velocity and tube material" International Journal of Heat and Mass Transfer 50 (2007) 3351-3358
- Article Huang et al. 2011 "Effect of temperature on microbila growth rate-Mathematical analysis : The Arrhenius and Eyring-Polanyi Connections"
- EDF document "“Centrales Nucléaires et Environnement : prélèvements d’eau et rejets « EDP Sciences 2014
- Presentation by Mrs. M. Lorthioy on 02/12/2019 "CS-Centrale nucléaire environnement".
- A first set of data (Figure 1, Nebot et al. 1997) in.txt and Excel files

Resources

- • Teaching staff : F. Puel (Professor, CS, MEP Department, LGPM), V. Pozzobon (Associate Professor, CS, CEBB Industrial Chair of Biotechnology, LGPM), T. Neveux (Research and Development Engineer, EDF Chatou), N. Jourdan (Engineer, PhD student EDF Chatou)

• Maximum enrolment : 24 to 28
• Software tools and number of licenses required: Sypder-Python (free software)

Learning outcomes covered on the course

- At the end of the course, the students will be able to :

1. Identify the different time and space scales taking place in a given process
2. Select the most appropriate scale to solve a given problem;
3. iIentify and keep the predominant phenomena;
4. Reduce the dimensionality and the complexity of a problem;
5. Establish a multiphysics model by aggregating knowledge from different scientific fields (biology, transport phenomena, technical and economic analysis);
6. Write a program to implement a mathematical model ;
7. Keep a critical eye on a model and its limitations.
8. Provide a comprehensive presentation of a modelling approach.

Description of the skills acquired at the end of the course

- **C1.1 :** Examine problems in their entirety and beyond their immediate parameters. Identify, formulate and analyse the scientific, economic and human dimensions of a problem, milestone 1 : learning outcomes 1 et 3

C1.2 : Develop and use appropriate models, choosing the correct modelling scale and simplifying assumptions when addressing a problem, milestone 1: learning outcomes 2, 4 et 5
C1.2, : Develop and use appropriate models, choosing the correct modelling scale and simplifying assumptions when addressing a problem milestone 2: learning outcome 2
C1.2 : Develop and use appropriate models, choosing the correct modelling scale and simplifying assumptions when addressing a problem, milestone 3: learning outcome 5
C1.3, : Apply problem-solving through approximation, simulation and experimentation. milestone 1B: learning outcome 2, 3 et 4
C1.3 : Apply problem-solving through approximation, simulation and experimentation. milestone 2B: learning outcome 7
C6.1 : Identify and use the necessary software for one's work (including collaborative tools) and adapt digital responses according to the context. milestone 1: learning outcome 76
C7.1, Persuade at core value level; to be clear about objectives and expected results. To apply rigour when it comes to assumptions and structured undertakings, and in doing so structure and problematise the ideas themselves. Highlight the added value milestones 1 et 2 : learning outcome 9