Learning Outcomes (Course Topics)
At the end of the course, students will have solid understanding of fundamentals of biological reactions in various wastewater treatment processes. Students will also practice and obtain relevant skills and techniques in evaluating and designing wastewater treatment processes. For detailed learning outcomes and CEAB learning indicators, see Appendices. (Appendices are available on Avenue.) The main course topics are:

- Introduction of biological wastewater treatment
- Characterization of wastewater: Suspended solid, oxygen demand, nitrogen and phosphorus
- Kinetics of microbial growth and substrate utilization: Monod equation and its applications
- Conventional activated sludge and its design
- Estimation of kinetic parameters in biological wastewater treatment: $Y, K_s, k (\mu_m), b$
- Bioreactor operation under aerobic, anoxic or anaerobic conditions
- Activated Sludge Model #1 (ASM1)
- Gas transfer and aeration system design
- Settling and thickening of wastewater sludge
- Membrane bioreactors (MBRs)
- Nutrient removal in wastewater treatment
- Sequencing batch reactors (SBRs)
- Attached growth reactors
- Anaerobic digestion for wastewater sludge treatment
- Optional topics: water reuse; biosolids utilization; micro-pollutants and emerging contaminants

Grading Schemes

<table>
<thead>
<tr>
<th>Component</th>
<th>Percentage</th>
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<tbody>
<tr>
<td>Midterm Exam</td>
<td>25%</td>
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<tr>
<td>Final Exam</td>
<td>30%</td>
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<tr>
<td>Assignments</td>
<td>15%</td>
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<tr>
<td>Term Project</td>
<td>15%</td>
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<tr>
<td>Lab Participation and Reports</td>
<td>15%</td>
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</tbody>
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(2% bonus if you have completed all academic work, including late assignments i.e. you did not use an MSAF)

Attendance: Lecture attendance is expected but will not be reflected in grading. It is strongly recommended that you not miss lectures. Lab attendance is mandatory.

Examinations: The McMaster Standard Calculator may be used during examinations. You may bring one crib sheet (letter size; double sided) in the mid-term exam and 2 pieces to the final exam.

- Crib sheets must be hand-written.
- Photocopied or printed information of any size is NOT allowed.
- Photocopy of your own handwriting (including homework assignments and class note) is NOT allowed.

Assignments: 3-4 assignments will be posted on Avenue. Late assignments will be assessed a penalty of 20% per academic day. Late assignments may or may not be accepted depending on course schedule. It is your responsibility to communicate with the instructor / lab supervisor on how you submit late assignments and reports.

Term project: The term project consists of two separate parts: (1) Model development; and (2) Report preparation
using the model. The first part should be done individually while you work in a group (as assigned for laboratory works) for the second part. Everyone in a group is equally responsible for preparing project reports (i.e., no leader assigned in the term project). Graduate students enrolled in CIV ENG 6V04 must work individually both in the first and second parts of the term project. The term project topic will be given later on Avenue.

**Laboratory experiments:** Each student must participate in mandatory laboratory sessions, which will provide supplemental exposure to several important concepts we will be covering over the course in this term. We will have four regular lab sessions in addition to a preliminary lab. The dates for lab sessions will be announced on the Avenue calendar. Lab experiments will be conducted in groups of four students. All group members must participate in all labs. Each group is responsible for submitting a report. All group members are expected to take part in report preparation. A formal report structure is expected for each laboratory write-up. Suppose that you are working as a professional engineer and prepare your reports accordingly. Clear expectations for report structure are posted under the link on Avenue. A late penalty of 20% per academic day will be applied. All group members must read the lab handout prior to a lab session. There may be pre-lab quizzes to ensure that you have read the lab handouts and understand experimental steps and materials. Both of the lab report and quiz will be included in your lab evaluation. During the preliminary lab session, we will have a safety presentation and group assignment. Attendance at this preliminary lab is also mandatory.

**Tutorials**
Prerequisite materials and design examples will be covered in tutorials. We will also learn to use commercial simulation tools. We do not have tutorials every week and the tutorial dates will be announced on Avenue.

**Laboratory Safety: The lab space can be a dangerous place if you do not follow safety rules!**
The Faculty of Engineering is committed to McMaster's University Workplace and Environmental Health and Safety Policy which states: "Students are required by University policy to comply with all University health, safety and environmental programs". It is your responsibility to understand McMaster University Workplace and Environmental Health and Safety programs and policies. For information on these programs and policies please refer to McMaster University Environmental and Health Support Services Occupational Safety Risk Management Manual at (suggested reading: Sections 10 through 16):
(You can also find this lab safety handbook on Avenue under the Content tab of this course.)

It is also your responsibility to follow any specific Standard Operating Procedures (SOPs) provided for some of the experiments and the laboratory equipment.
The safety requirements for JHE 220 are listed below. Students not abiding by these safety requirements will be given one warning. Second offences will result in the student being asked to vacate the laboratory, and receiving a grade of zero for that particular lab.

- **Glasses or safety glasses/goggles must be worn in the lab at all times!!!**
- Contact lenses are not to be worn in the lab.
- No short (i.e., above the knee) pants or skirts are permitted in the lab – lab coats must be worn over top of your clothing in these instances.
- Closed-toe shoes must be worn at all times.
- No loose clothing allowed.
- Long hair must be tied back.
- Gloves must be worn when working with hazardous chemicals (as indicated by the laboratory instructor).

**Academic Integrity:** You are expected to exhibit honesty and use ethical behaviour in all aspects of the learning process. Academic credentials you earn are rooted in principles of honesty and academic integrity.

Academic dishonesty is to knowingly act or fail to act in a way that results or could result in unearned academic credit or advantage. This behaviour can result in serious consequences, e.g. the grade of zero on an assignment, loss of credit with a notation on the transcript (notation reads: “Grade of F assigned for academic dishonesty”), and/or suspension or expulsion from the university.

It is your responsibility to understand what constitutes academic dishonesty. For information on the various types of academic dishonesty please refer to the Academic Integrity Policy, located at www.mcmaster.ca/academicintegrity.
The following illustrates only three forms of academic dishonesty:

- Plagiarism, e.g. the submission of work that is not one’s own or for which other credit has been obtained.
- Improper collaboration in group work.
- Copying or using unauthorized aids in tests and examinations.

**Academic Accommodation for Students with Disabilities**: Students with disabilities who require academic accommodation must contact Student Accessibility Services (SAS) to make arrangements with a Program Coordinator. Student Accessibility Services can be contacted by phone 905-525-9140 ext. 28652 or e-mail sas@mcmaster.ca. For further information, consult McMaster University’s *Academic Accommodation of Students with Disabilities* policy.

**Requests for Relief for Missed Academic Term Work**: When a self-reporting relief is submitted, the portion of the missed academic work will be automatically transferred to the final examination. It is still your responsibility to notify the instructor of your MSAF submission. MSAF will not be accepted for missed exams or group work (lab reports and term projects).

**Academic Accommodation for Religious, Indigenous or Spiritual Observances**: Students requiring academic accommodation based on religious, indigenous or spiritual observances should follow the procedures set out in the RISO policy. Students requiring a RISO accommodation should submit their request to their Faculty Office normally within 10 working days of the beginning of term in which they anticipate a need for accommodation or to the Registrar's Office prior to their examinations. Students should also contact their instructors as soon as possible to make alternative arrangements for classes, assignments, and tests.

**Extreme Circumstances**: The University reserves the right to change the dates and deadlines for any or all courses in extreme circumstances (e.g., severe weather, labour disruptions, etc.). Changes will be communicated through regular McMaster communication channels, such as McMaster Daily News, A2L and/or McMaster email.

**Appendix A: CEAB Learning Indicators Measured in This Course**

1.1 Competence in Mathematics
1.2 Competence in Natural Sciences
1.3 Competence in Engineering Fundamentals
1.4 Competence in Specialized Engineering knowledge (I, D, A--both)

2.2 Demonstrates an ability to identify a range of suitable engineering fundamentals (including mathematical techniques) that would be potentially useful for analyzing a technical problem.

2.3 Obtains substantiated conclusions as a result of a problem solution including recognizing the limitations of the solutions.

3.2 Selects appropriate model and methods and identifies assumptions and constraints.

3.3 Estimates outcomes, uncertainties and determines appropriate data to collect.

4.1 Recognizes and follows an engineering design process. (This means an iterative activity that might include recognizing the goal, specifying the constraints and desired outcomes, proposing solutions, evaluating alternatives, deciding on a solution, and implementing.)

4.2 Recognizes and follows engineering design principles including appropriate consideration of environmental, social and economic aspects as well as health and safety issues.

4.3 Proposes solutions to open-ended problems.

4.5 Includes appropriate health and safety considerations

5.1 Evaluates and selects appropriate modern tools.

5.2 Demonstrates an ability to use modern/state of the art tools.

6.3 Works in a group, taking a leadership role as appropriate and relinquishing the leadership role as appropriate. (Lab experiments and report preparation; term project)

7.3 Constructs effective oral or written arguments as appropriate to the circumstances (Report preparation)
Appendix B: Learning Outcomes (Corresponding Graduate Attributes in Parenthesis)

1. Introduction
   - Know the two main objectives of wastewater treatment. (1.4)
   - Be able to explain how to remove particulate organic compounds. (1.3)
   - Be able to explain why we need to remove nutrients in WWT. (1.2)
   - Be able to explain how to remove dissolved (and colloidal) organic compounds. (1.3)
   - Know the wastewater treatment trains with individual unit processes (1.4)
   - Know the sludge (biosolids) treatment trains with individual unit processes. (1.4)

2. Wastewater Analysis
   - Know the solids categorization based on size and volatility. (1.4)
   - Know the definition of TS, TFS, FFS, VFS, TSS, FSS, and VSS. (1.4)
   - Know how to measure TSS and VSS. (1.4)
   - Know the meaning of TSS and VSS for the microorganism concentration. (1.4)
   - Can calculate ThOD for a given chemical composition. (1.2)
   - Know the definition of NOD. (1.4)
   - Know the definition of COD and can measure COD for a water sample. (1.4)
   - Know the definition of BOD and can measure BOD for a water sample. (1.4)
   - Plot “measured BOD vs. time” with and without nitrification. (1.4)
   - Know how to find BOD$_L$ from measured BOD$_S$. (1.4)
   - Know the definition of TOC. (1.4)
   - Know the nitrogen compounds in wastewater. (1.4)
   - Know the phosphorus compounds in wastewater. (1.4)

3. Microbial kinetics
   - Know the definition of catabolism, anabolism, and metabolism. (1.2)
   - Know the definition of microbial yield coefficient. (1.4)
   - Can correlate $dS/dt$ and $dX/dt$ using $Y$. (1.4)
   - Know the rate expression for microbial growth. (1.4)
   - Know the Monod equation and can plot $\mu$ as a function of $S$. (1.4)
   - Know the rate expression for substrate utilization. (1.4)
   - Know the rate expression for microbial decay and net growth rate. (1.4)
   - Know the five kinetic parameters: $Y$, $K_s$, $k(\mu_m/Y)$, and $b$. (1.4)
   - Know the definition of specific substrate utilization, $U$. (1.4)
   - Know the definition of food-to-microorganism ratio, F/M ratio. (1.4)

4. Activated Sludge Process
   - Know the difference between chemostat and activated sludge systems. (3.2)
   - Be able to draw the activate sludge process and know the assumptions. (3.2)
   - Know the definition of solids retention time both in verbal and mathematical expressions (1.4)
   - Be able to perform mass balance on X across the entire system and derive the S expression. (1.1; 1.4)
   - Be able to perform mass balance on S across the entire system and derive the X expression. (1.1; 1.4)
   - Know that $1/\theta_c$ is equivalent to the net cell growth rate (1.4)
   - Know the physical meaning of $\theta_c$ (1.4)
   - Know the following correlations between $\theta_c$ and microbial composition in AS (1.2; 1.4)
     - Short $\theta_c$: we will have only fast-growing microorganisms in AS.
     - Long $\theta_c$: we will have both fast- and slow-growing microorganisms in AS.
     - Nitrifying bacteria are slow-growing microorganisms; thus, nitrification will occur for long $\theta_c$.
   - Can do mass balance on X across clarifier to find the expression for $Qr/Q$. (1.3; 1.4)
   - Can find the equation for waste sludge production: $QwXr$ (1.4)
   - Can find minimum solids retention time ($\theta_c^{min}$) by assuming washout (1.4)
   - Know the combine sewer and separate sewer systems (1.4)
   - Know how $\theta_c$ controls the following AS operation factors. (1.4)
     - $\theta_c \uparrow$: $S \downarrow$ (if $\theta_c > 5d$, $S$ is already sufficiently small and thus rather independent on $\theta_c$.)
     - $\theta_c \uparrow$: amount of waste sludge $\downarrow$ (by which eqn?) $\$ $\downarrow$ for sludge (biosolids) management
     - $\theta_c \uparrow$: $X \downarrow$ (by which eqn?) $O_2$ requirement $\uparrow$ $\$ $\uparrow$ for aeration
     - $\theta_c \uparrow$: $X \uparrow$ $Qr \uparrow$ (by which eqn?) $\$ $\uparrow$ for RAS pumping
     - $\theta_c \uparrow$: activation of nitrifying bacteria $\$ $\downarrow$ NH$_3$ removal $\uparrow$
0 $\theta$ “may” cause sludge bulking problem
- Can explain the following operation factors and their effects. (1.4)
- Can use the Arrhenius equation for temperature correction of kinetic coefficients. (1.2)
- Know the two types of microorganisms in WWT: heterotrophs and autotrophs (1.2)
- Know how heterotrophs grow under aerobic and anoxic conditions (1.2; 1.4)
- Know how autotrophs grow under aerobic conditions (1.2; 1.4)
- Know the effect of pH on microbial growth and can include the effect in the model equation (1.4; 3.2)

5. Estimation of Microbial Kinetics
- Can use the equation for $1/U$ to find $K_s$ and $k$ (3.3)
- Can use the Arrhenius equation for temperature correction of kinetic coefficients. (1.2)
- Know the model for multiple substrates and inhibitors (1.4; 3.2)
- Know the distribution of decayed cell materials. (1.4)
- Be able to sketch the reaction charts in ASM1 (1.4)
- Be able to write a mass balance equation on each component (1.3)
- Be able to solve the 10 mass balance equation using a numerical method (Term Project) (1.1)
- Can use ASM No.1 to better understand how CAS works (Term Project) (5.2)
- Know the benefits and limitations of ASM No.1 (2.3; 3.3; 5.1)
- Attempt to expand ASM No.1 for an emerging contaminant (Term Project) (4.3)
- Can use commercial software (e.g., BioWin) (5.2)

6. Activated Sludge Models
- Know the 10 components in Activated Sludge Model No.1 (1.4)
- Be able to explain hydrolysis of particulate substances (1.4)
- Be able to explain ammonification of soluble organic nitrogen compounds (1.2; 1.4)
- Know two mechanisms of ammonia consumption in activated sludge processes (1.2; 1.4)
- Be able to plot the $G_b$ curve vs. particle concentration from settling column tests (4.1)
- Can determine the clarifier size based on the found limiting flux (4.1)
- Know the state point and its physical meaning (1.4)
- Know factors to be considered in designing secondary clarifiers (4.1)
- Know the design trade-off among clarifier, aeration tank and return sludge pump (2.2; 4.2)
- Know sludge volume index (1.4)
- Know the definition of sludge bulking
- Know what cause sludge bulking and how to control it (1.4; 4.2)
- Know the definition of rising sludge and how to control it (1.4)

9. Nutrient removal in wastewater treatment
- Know that nutrient is removed as WAS (1.4)
- Can explain nitrification (1.2; 1.4)
- Can explain denitrification (1.2; 1.4)
- Know the three types of reactor conditions and resulting redox reactions (1.2; 1.3; 1.4)
- Know how phosphorus accumulating organisms (PAOs) remove phosphorus (1.2; 1.4)
• Know various BNR processes (1.4; 5.1)
• Know the benefits and limitations of the individual BNR processes (1.4; 5.1)
• Know the fate of excessively uptaken P in later sludge treatment processes (4.3)
• Know the chemical phosphorus removal method (1.2; 1.4)

10. Sequential batch reactors (SBRs)
• Know the operation steps of SBRs (1.4)
• Can analyze SBR performance by doing mass balance during the React step (1.1; 1.4; 3.2)
• Know the benefits of SBRs compared to continuous flow systems (4.2)

11. Membrane bioreactors (MBRs)
• Know the advantages and disadvantages of MBRs compared to CAS (1.4; 4.2)
• Two types of MBRs: External side-stream MBRs; Submerged MBRs (1.4; 4.2)

12. Attached growth reactors
• Know the four types of attached growth reactors (1.4)
• Know the advantages and disadvantages of attached growth systems (1.4)
• Know three distinct regions in the biofilm system (1.4)
• Can drive the micro-scale mass balance equation and set up the boundary conditions (1.1; 1.3)
• Know the equation for mass flux in the liquid film. (1.4)
• Know the definition of the shallow and deep biofilms. (1.4)
• Know the kinetic expression for S removal in biofilm depending on the rate-limiting component. (1.4)
• Can set up the macro-scale mass balance equation depending on the type of attached growth reactors (3.2)
• Can find the effluent quality from a numerical grid by equating the micro- and macro-scale mass balance equations (1.1)

13. Anaerobic Digestion
• Know the objective of anaerobic digestion (1.4)
• Know the four macro nutrients and their monomers (1.2)
• Be able to sketch the anaerobic reaction chart (1.4)
• Can explain hydrotrropic methanogenesis (1.2; 1.4)
• Can explain acetoclastic methanogenesis (1.2; 1.4)
• Can explain anaerobic oxidation (β-oxidation) (1.2; 1.4)
• Can explain fermentation (1.2; 1.4)
• Can explain hydrolysis (1.2; 1.4)
• Be able to find out the rate-limiting reaction from multiple chain reactions. (1.4)
• Know the effect of pH on anaerobic digestion (1.4)
• Know the effect of temperature on anaerobic digestion (1.4)
• Know the consequences of having sulfate in wastewater (1.3; 1.4)
• Know the role of ammonia (NH₃) in pH buffering and toxic effects (1.2; 1.4)
• Know the two (three) types of reactors (1.4; 4.2)
• Know the benefits of anaerobic digestion (1.4)
• Can find the rate of CH₄ production (1.4)
• Know the design factors of anaerobic digesters (4.2)
• Know the important operation and monitoring factors (1.4)

14. Wastewater reuse, biosolids utilization and micro-pollutant removal
• Know the challenges of treated wastewater reclamation (4.2; 4.3; 4.5)
• Know the current trends in wastewater treatment (e.g., source-separate urine) (4.3)
• Know the challenges in treating emerging contaminants in wastewater treatment (4.2; 4.3; 4.5)
• Know the challenges in utilizing wastewater biosolids as land fertilizers (4.2; 4.3; 4.5)