The Reverse Flow Reactor

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Outline

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Background

- Global warming is one of the major environmental issues causing severe climate changes. One of the causes of global warming is the release of the green house gases into the atmosphere.
- A greenhouse gas is a gas that traps heat into the earths atmosphere (e.g Carbon dioxide, Methane, Nitrous Oxide and Ozone).
- While we can not reduce global warming overnight, there are some steps that have been taken to reduce it, such as, to reduce heating and encouraging people to buy energy efficient appliances.

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Introduction

Methane as a greenhouse gas has a warming potential twenty five times greater than carbon dioxide, it is released from wetlands, landfills or decaying vegetation.

It is a valuable source of energy in

- Food processors
- Petroleum refineries
- To dry and dehumidify products

For practical use a catalyst is required to accelerate the conversion of methane/oxygen mixture.

The Objective :

- To convert methane into a less harmful gas.
- To maximize the heat produced by the reaction for other uses such as heating water.
- To optimize the water cooling rate.

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The Reverse Flow Reactor

$$CH_4 + 2O_2 + Catalyst \longrightarrow CO_2 + 2H_2O + Catalyst$$

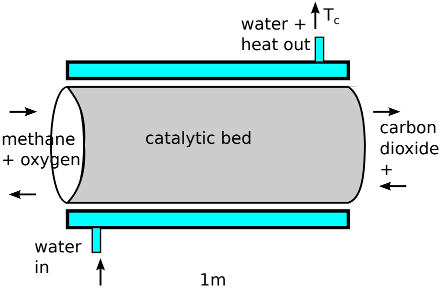

Figure: The Reactor

Typical Solution Profiles

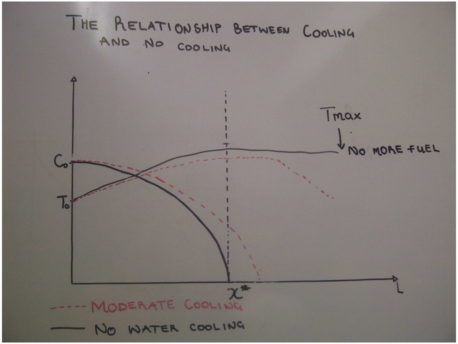

Figure: The Reactor

Typical Solution Profiles

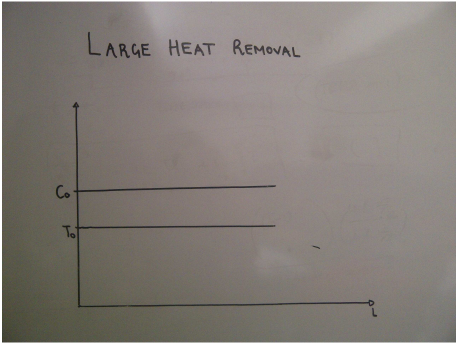

Figure: The Reactor

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Governing Equations

The governing equations for the considered model can be written as:

$$(\rho\alpha)_m \frac{\partial T}{\partial t} + (\rho c_p)_g U \frac{\partial T}{\partial x} = k_m \frac{\partial^2 T}{\partial x^2} + q_m - \lambda(T - T_c), \tag{1}$$

$$\frac{\partial c}{\partial t} + U \frac{\partial c}{\partial x} = r(T)(c_0 - c) + k_g \frac{\partial^2 c}{\partial x^2}, \tag{2}$$

where ρ is density, c is specific heat, k_m conductivity, U is the velocity, $q_m = r(T)(c_0 - c)$ is the reaction heat, λ is the heat transfer coefficient, T is temperature, r(T) is the reaction rate and k_g is diffusion.

This problem is a bit challenging because of the chemistry involved.

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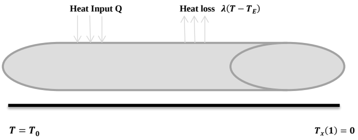
An analogous situation

- So now we consider a much simpler case where a rod of length L is heated using an external heat source, for example electric current, a flame, etc.
- The concept here is similar to the one above, except in this case we are only trying to optimize the amount of energy produced.



From this problem we expect to get the following equation:

$$(\rho c)\frac{\partial T}{\partial t} = k\frac{\partial^2 T}{\partial x^2} + Q - \lambda(T - T_E), \tag{3}$$

with

$$T(0,t) = T_0, \qquad T_x(L,t) = 0 \tag{4}$$

where ρ is density, c is specific heat, k is conduction, Q is the heat input per unit length, λ is the heat transfer coefficient, T is temperature, T_E is the environmental temperature.

To solve this we scale the PDE in order to reduce the number of unknowns After scaling we get:

$$T^{'}_{t} = \epsilon T^{'}_{xx} + 1 - T^{'} \tag{5}$$

with the following boundary condition

$$T^{'}(0, t^{'}) = T^{'}_{0}, \qquad T^{'}_{x^{'}}(1, t^{'}) = 0 \tag{6}$$

where $\epsilon << 1$, $T' \to 1$ as $t' \to \infty$ and $\epsilon \approx \frac{k}{\rho c L^2}$ for a 1m long metal rod.

Assuming steady state we obtain this solution :

$$T = 1 + \frac{T_0 - 1}{cosh(\frac{1}{\sqrt{\epsilon}})} cosh\left(\frac{x-1}{\sqrt{\epsilon}}\right).$$

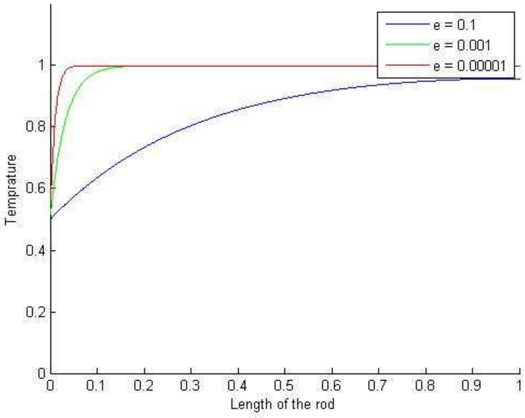


Figure: Temperature profile

For small values of ϵ the desired maximum temperature is reached quickly.

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Having obtained a solution to the scaled PDE, we go back to the original problem(RFR) given by the following equations

$$(\rho\alpha)_m \frac{\partial T}{\partial t} + (\rho c_p)_g U \frac{\partial T}{\partial x} = k_m \frac{\partial^2 T}{\partial x^2} + q_m - \lambda(T - T_c),$$

$$\frac{\partial c}{\partial t} + U \frac{\partial c}{\partial x} = r(T)(c_0 - c) + k_g \frac{\partial^2 c}{\partial x^2}.$$

With our experience of the rod problem we now assume a steady state and provided we are not concerned with what happens at the boundary, we can drop the diffusion term in order to obtain solutions to the equations (1) and (2).
In view of aforementioned assumptions our RCR problem reduces to the following first order equations

$$(\rho c_p)_g U \frac{dT}{dx} = q_m - \lambda(T - T_c), \tag{7}$$

$$U \frac{dc}{dx} = r(T)(c_0 - c), \tag{8}$$

- Now that our equations are in first order,they are easier to solve. So one can then deduce an efficient way to maximize the energy output while reducing the amount of methane present in the air.
- Due to lack of time, we weren't able to obtain the solution.

Thanks for your attention