

CM3215
Fundamentals of Chemical Engineering Laboratory

MichiganTech

RTD Dynamics
*Also, Identifying Empirical Models
 for Laboratory Data*

Professor Faith Morrison
 Department of Chemical Engineering
 Michigan Technological University

© Faith A. Morrison, Michigan Tech U.

CM3215 Fundamentals of Chemical Engineering Laboratory

We often need to fit a model to data:

Functions are easier to deal with than discrete data:

- Compact
- Smooth
- Easy to program

Faith Morrison, *An Introduction to Fluid Mechanics*, Cambridge University Press, 2013

© Faith A. Morrison, Michigan Tech U.

CM3215 Fundamentals of Chemical Engineering Laboratory

Carreau-Yasuda Model for Shear Viscosity of Polymer Solutions

$$\eta = \eta_{\infty} + (\eta_0 - \eta_{\infty})[1 + (\dot{\gamma}\lambda)^a]^{\frac{n-1}{a}}$$

If we know the functional form, it's easy to find the parameters with **Excel Solver**
 (www.chem.mtu.edu/~fmorriso/cm4650/Using_Solver_in_Excel.pdf)

1. Plot data
2. Plot model
3. Construct error vector
4. Use Solver to minimize sum of error (*first guess must be reasonably close*)

© Faith A. Morrison, Michigan Tech U.

CM3215 Fundamentals of Chemical Engineering Laboratory

Carreau-Yasuda Model for Shear Viscosity of Polymer Solutions

$$\eta = \eta_{\infty} + (\eta_0 - \eta_{\infty})[1 + (\dot{\gamma}\lambda)^a]^{\frac{n-1}{a}}$$

It's easy to find the parameters with **Excel Solver**
 (www.chem.mtu.edu/~fmorriso/cm4650/Using_Solver_in_Excel.pdf)

1. Plot data
2. Plot model
3. Construct error vector
4. Use Solver to minimize sum of error (*first guess must be reasonably close*)

Let's try.

www.chem.mtu.edu/~fmorriso/cm3215/fittingCarreau2010blank.xlsx

© Faith A. Morrison, Michigan Tech U.

CM3215 Fundamentals of Chemical Engineering Laboratory

Fitting data to a model with Excel

- Need a model (an equation) whose shape mimics the data (see Table 2 for some ideas).
www.chem.mtu.edu/~fmorriso/cm3215/AnalyticalFunctionsTable2.pdf
- Play with the model's parameters to see what they do to the shape of the model.
- *Solver* can determine the parameters; the first guess of parameters must be reasonably close, however.

This Lab:

- Find a model and parameters that best represent two sets of time-dependent data

© Faith A. Morrison, Michigan Tech U.

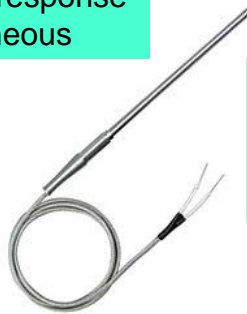
CM3215 Fundamentals of Chemical Engineering Laboratory

CM3215 Assignment 7: Resistance Temperature Detectors (RTDs)

Definition: devices that measure temperature based on the positive temperature coefficient of electrical resistance of metals. The hotter they become, the larger or higher the value of their electrical resistance.

But: Temperature response is not instantaneous

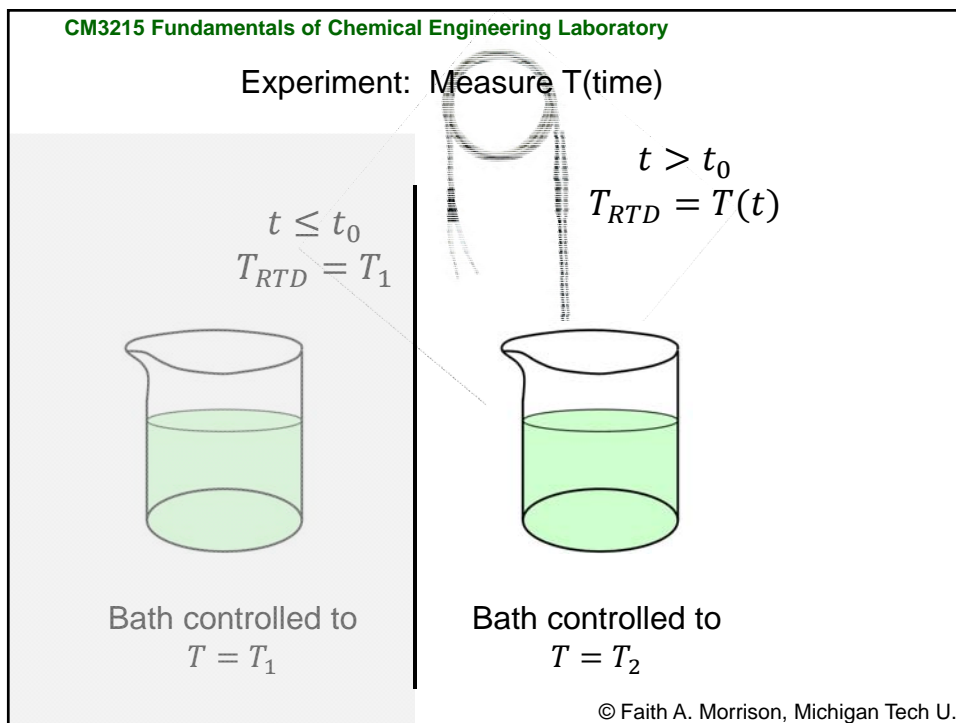
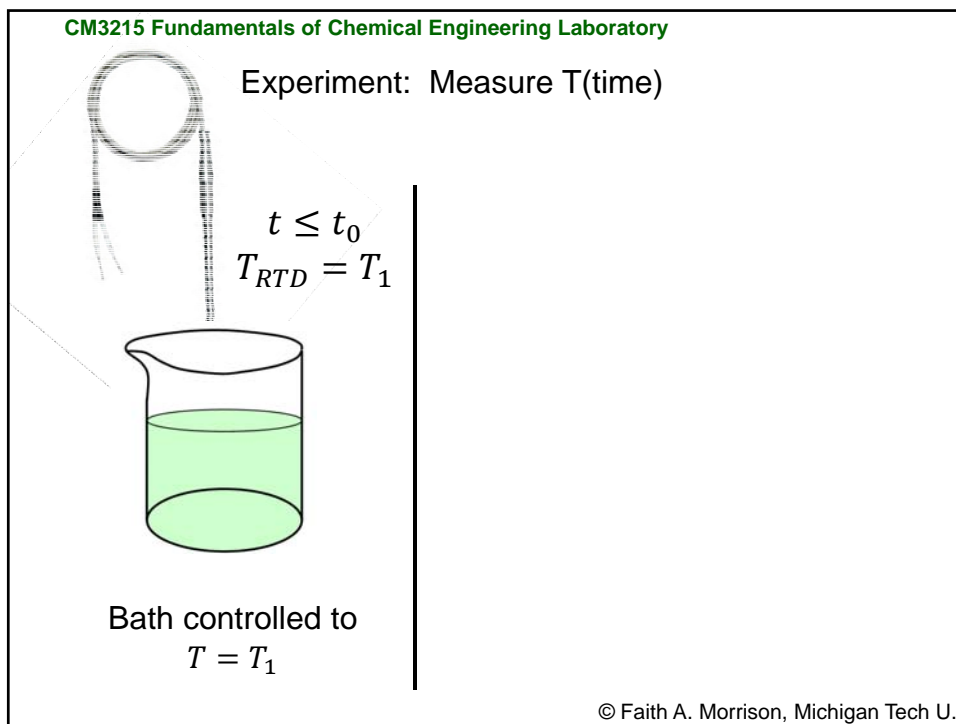
www.temperatures.com/rtds.html



"They are among the most precise temperature sensors available with resolution and measurement uncertainties or ± 0.1 °C or better possible in special [situations]."

www.indiamart.com/thermechinstruments/products.html


© Faith A. Morrison, Michigan Tech U.



CM3215 Fundamentals of Chemical Engineering Laboratory

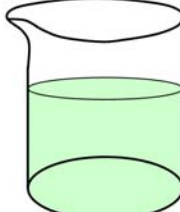
Experiment: Measure T(time) (already done for you)

$t \leq t_0$
 $T_{RTD} = T_1$



Bath controlled to
 $T = T_1$

$t > t_0$
 $T_{RTD} = T(t)$



Bath controlled to
 $T = T_2$

Excel:

t(s)	T(°C)
9.50E-02	7.46E+00
2.11E-01	7.44E+00
3.09E-01	7.44E+00
4.09E-01	7.57E+00
5.24E-01	7.46E+00
6.23E-01	7.49E+00
7.39E-01	7.53E+00
8.37E-01	7.46E+00
9.54E-01	7.59E+00
1.05E+00	7.53E+00
1.15E+00	7.58E+00
1.27E+00	7.48E+00
1.37E+00	7.57E+00
...	...

© Faith A. Morrison, Michigan Tech U.

CM3215 Fundamentals of Chemical Engineering Laboratory

**Assignment 7: RTD Dynamics –
Choosing Empirical Models for Representing Lab Data**

**CM3215 Assignment 7:
System Identification for RTD Response Data**

Complete the assignment described below; this is a team assignment. The assignment is due 1:00pm Friday, 1 December 2014 to Intranet Box A. Both team members must sign the submission.

References: See documents at the links on the class website or handed out in lecture.

Mission: Faith A. "Model Identification for Laboratory Data," CM3215 Fundamentals of Chemical Engineering Laboratory, Department of Chemical Engineering, Michigan Technological University, Houghton, MI, 50 November 2014, on the web at www.dcm.umt.edu/~fa-morrison/cm3215/HandoutofInterest7.pdf

Mission: Faith A. "Using the Solver Add-in as a Model of Excel," CM3215 Fundamentals of Chemical Engineering Laboratory, Department of Chemical Engineering, Michigan Technological University, Houghton, MI, 27 April 2014, on the web at www.dcm.umt.edu/~fa-morrison/cm3215/Using_Solver_in_Excel.pdf

Assignment: Determine empirical models that fit the two supplied data sets for the temperature-time response of an RTD (see the general for experimental details related to obtaining the supplied data). A complete report is not required or expected. Describe in the same the strategy you followed as sufficient detail to allow others to perform the same calculations. Provide plots for each fit that shows how well the model (with the parameters you determined) fits the data. Point out differences between the two data sets in terms of the model parameters you find.

Instructions:

- Submit your results in the form of a paper of reasonable size that use page of text is expected; explaining your results with supporting plots, attached and explained. All plots must have proper numbers and explanatory captions. Put your name on each page. There will be no appendix.
- Provide a plot for each fit that shows how well the model (with the parameters you determined) fits the data. This is a group assignment. Both authors must sign the submission on the lecture.

Background: The data for the system identification for RTD Assignment comes in the form of temperature readings from a resistance temperature detector (RTD) as a function of time.

An RTD is a sensor that uses electrical resistance to follow temperature. Most RTD elements are constructed of wire wrapped around a ceramic or glass core. The metal from which the wire is made has a resistance as a function of temperature that is known. The device is designed to measure the resistance of the wire, and from that signal a temperature is determined.

In Data Set 1 (see website for Excel spreadsheet link), the RTD was moved from being at equilibrium in an ice-water bath to being submerged into a bucket of boiling water (the same, on the reverse side of the spectrum). In Data Set 2, the initial and final conditions were different, but again we are looking at the RTD signal as a function of time.

One task for this assignment is to find functions that closely match the shape of the data and to determine the parameters of the model that provide a best fit to the data. The range of the data that we wish to fit from the moment the RTD signal begins to change up to the final steady state response. This type of time response data is very common in process monitoring and control in the chemical process industries. Your model results will be presented something like this (parameters were made up in MS Excel with a table of 4 columns):

Case 1:	$0 \leq t \leq 23.8s$	$T = T_1 = 0.71^\circ C$
	$23.8s < t \leq 2300s$	$T = \text{function you find}$

Case 2:	$0 \leq t \leq 48.8s$	$T = T_1 = 0.71^\circ C$
	$48.8s < t \leq 2320s$	$T = \text{function you find}$

Measure RTD Time Dependence

Pre-laboratory Assignment
Read the handouts on the class website and be prepared to participate in an in-class discussion of how to design an Excel spreadsheet to address the assigned objectives.

Introduction
An RTD (resistance temperature detector) is a sensor that uses electrical resistance to follow temperature. Most RTD elements are constructed of wire wrapped around a ceramic or glass core. The metal from which the wire is made exhibits a resistance $R(T)$ as a function of temperature; this function, $R(T)$ is known. The RTD device is designed to measure the resistance of the wire, and from that signal a temperature is determined.

An RTD will not respond automatically to a temperature change. In this experiment, we work with data that show the characteristic time response of an RTD moving from one steady temperature to another.

In this laboratory we follow the procedure two model identification exercises, that is, we fit appropriate models to two sets of data, and we report the model parameters that provide the best fit.

Theory: See lecture.

Overall Objectives and Strategy:
Determine the model that best describes the time-dependent data of an RTD subjected to a step change in temperature. The data collection has been done by a colleague, but you must analyze the data. Address all other objectives as discussed in the Assignment 7 handout.

30 November 2014 page 2

Data Collection Procedure

The data collection has been performed by a colleague. Your colleague followed the following procedure. The date of temperature versus time are available on the class website.

Prepare the vessel as follows:

- Fill two 4-l liter beakers with distilled water. Add a second connecting temperature control unit to each beaker. Set each to the desired temperature. The two temperatures are called T_1 and T_2 .
- Wait for both beakers to come to thermal equilibrium.
- Set up a data acquisition system to record the temperature versus time registered by an RTD.
- Submerge the RTD into the first beaker and record the temperature as a function of time until "steady state" is achieved when the RTD temperature does not vary by more than 0.1°C for 5 minutes.
- Working quickly, move the RTD from the first beaker to the second beaker.
- Record temperature as a function of elapsed time using the data acquisition setup and wait for steady state; steady state is achieved when the RTD temperature does not vary by more than 0.1°C for 5 minutes. Save the data by transfer to Excel.

Share Data Procedure

- Shut off the temperature controllers.
- Discard water and clean all equipment.
- Dry off any wet surfaces with paper towels.

Data Analysis

- Fit the data to a model and address objectives in the Assignment 7 handout.

© Faith A. Morrison, Michigan Tech U.

CM3215 Fundamentals of Chemical Engineering Laboratory**Assignment 7: RTD Dynamics –
Choosing Empirical Models for Representing Lab Data**

- Team assignment—both must sign the submission.
- Obtain data from Dr. Morrison
- Fit an appropriate model to the $T(t)$ data; for models, see:
www.chem.mtu.edu/~fmorriso/cm3215/CM3215HandoutonFunctionFitting.pdf
www.chem.mtu.edu/~fmorriso/cm3215/AnalyticalFunctionsTable2.pdf
- Report the parameters of the fit
- Show plots of “goodness of fit”
- As always, consider uncertainty and express uncertainty along with answers
- Write cover memo to transmit your plots and fit; address all objectives
- **Due 2:05pm Wednesday 6 April 2016, Homework Box A**

© Faith A. Morrison, Michigan Tech U.