### CHEMICAL COMPOUNDS

Making chemical compounds or formulations often requires that a mixture is stirred and heated or cooled. It is usually quite easy to do this in the laboratory, but it becomes an increasing problem as a process is scaled up from bench to pilot to full-scale manufacture.

Industrial mixing or reaction vessels come in various sizes. They are usually fitted with a mechanical stirrer and are 'jacketed'. This means there is a jacket around the outside of the vessel where heat transfer fluid (htf) can be passed. The htf is passed around the jacket either to provide heat or to take heat away.

In this activity you will explore the scale-up challenges for a process engineer.

### EQUIPMENT

- 50 $cm^3$ beaker
- 250 $cm^3$ beaker
- 600 $cm^3$ beaker
- datalogger with temperature sensor (alternatively, 0 to 110 °C thermometer)
- electric kettle or Bunsen burner, tripod and gauze to heat water

### SAFETY NOTES

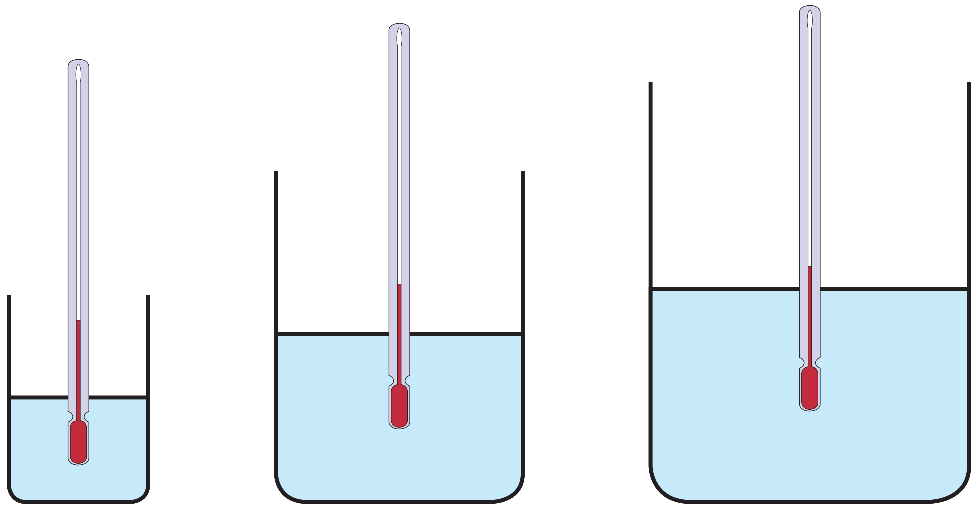
Take care not to splash boiling water on yourself or people working near you.

## METHOD: MAKING A PREDICTION

You are given three glass beakers:

| | |
|---|---|
| 50 $cm^3$ | height 6 cm, diameter 4 cm |
| 250 $cm^3$ | height 9.5 cm, diameter 7 cm |
| 600 $cm^3$ | height 12 cm, diameter 9 cm |

Imagine each is half-filled with boiling water.
A thermometer is placed at the middle of the water in each beaker.



1. Sketch graphs of temperature against time to show how you think the rate at which the water cools differs between the three beakers.
2. Imagine the water in each beaker was stirred slowly, gently and continuously as it cooled down. Sketch cooling curves to show how stirring might affect the rate of cooling in each of the three beakers.
3. Now imagine the water in each beaker was stirred more quickly and continuously as it cooled down. Sketch cooling curves to show how stirring might affect the rate of cooling in each of the three beakers.

Note: You might find it useful to use a mini-whiteboard to make rough sketches. These can be easily erased or modified if your ideas change. When you are happy with the graphs you have drawn, copy them into your notebook.

## METHOD: TESTING THE PREDICTION

Design and carry out carry out experiments to test your predictions.

Show your plan to your teacher before starting.

### Health and safety

Boiling water can scald. Be very careful when pouring it from one container to another. A risk assessment must be done before starting practical work.

## RESULTS

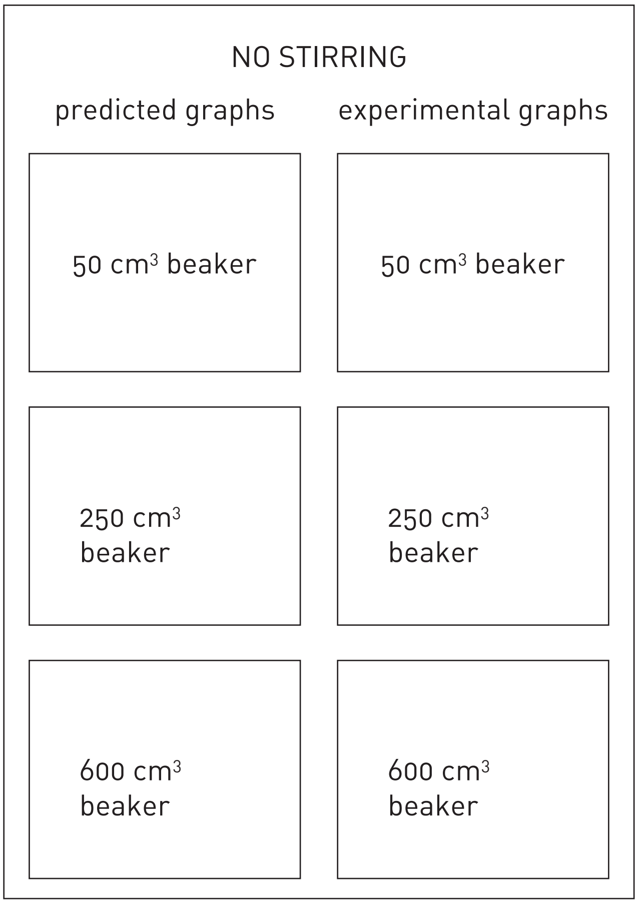
Tabulate your results.

Plot cooling curves by hand or you could use an Excel spreadsheet and the *Chart Wizard* and the *XY (Scatter)* option. If you use a datalogger there may be software to convert your data to a suitable graph.

Present your results on three single sheets of paper. The layout for each piece of paper is shown in the picture, right.

The three pieces of paper should be headed:

- NO STIRRING
- SLOW STIRRING
- FAST STIRRING




## EXPLANATIONS

1. Give your reasons for drawing the ‘predicted graphs’ the way you did.
2. Compare the ‘predicted graphs’ with your ‘experimental graphs’. Do your experiments support the reasons you drew the ‘predicted graphs’ the way you did?
3. In chemical reactors or mixing vessels, why is it necessary to:
   - increase the temperature of some chemical reactions
   - decrease the temperature of some chemical reactions?
4. How could the contents of a jacketed chemical reactor or mixing vessel be cooled more quickly?

## HEALTH AND SAFETY

Water should be boiled in an electric kettle and carefully poured into the beaker. Alternatively, a beaker could be half filled with water and brought to the boil on a tripod and gauze, using a Bunsen burner.

It is essential that students do NOT sit down so that, in the event of a spill, it is much easier to jump out of the way.

A risk assessment must be made before starting any practical work.

## THE INVESTIGATION

In the video, students will have seen a pilot plant mixing vessel and a manufacturing-scale vessel. Similar vessels are used to carry out chemical reactions on a large scale.
Making chemical compounds or formulations often requires that a mixture is stirred and heated or cooled.

Students might think about how reaction mixtures are heated or cooled in the laboratory, e.g. heating - Bunsen burner, electric hotplate, steam bath; cooling – ice bath, refrigerator. They might then discuss how this could be done on a much larger scale. Suitable vessels for this are usually fitted with a mechanical stirrer and jacket. Heat transfer fluid (htf) is passed through the jacket, either to provide heat or to take heat away. Industrial plants usually have a heat transfer fluid available at three temperatures, two above room temperature for heating and one below room temperature for cooling.

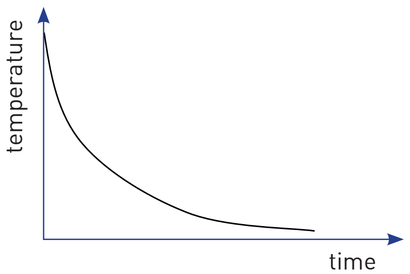
In this activity students investigate one of the challenges faced by process engineers who design and build chemical plant – heating and cooling mixtures. They are asked to predict how cooling curves for water depend on:

- its volume and the size of the glass beaker (in other words, the surface area to volume ratio)
- whether or not the water is stirred and, if it is, how quickly it is stirred.

Having made their predictions, they carry out a practical investigation to verify (or not) their predictions.

Before asking students to make their predictions, they should be reminded of the ways heat energy is transferred (conduction, convection and radiation).

Students may have learned about cooling curves at an earlier stage and, perhaps, carried out a simple experiment to investigate. They should be reminded of this, using appropriate questioning to draw the ideas from the class. Make sure all students understand the shape of a typical cooling curve:




The steeper the gradient of the tangent to the curve at is a given time, the faster the rate of cooling.

The flattening curve shows that the rate of heat loss is lower as the temperature falls.

You might ask students to work in small groups (3-4) to discuss how hot water cools down in a glass beaker and how the temperature of the water changes with time. Provide each group with a mini-whiteboard to make rough sketches (these can be erased or modified easily as discussion progresses). Students can copy the 'final' graphs on to their recording sheet.

The practical investigation could be done using thermometers. However, using datalogging is a good way to illustrate the usefulness of this technique:

- the display is easier to read than normal thermometers
- readings can be taken more often
- less chance of making errors when recording data.

## RESULTS

The rate of cooling depends on the surface area of the container. The rates of cooling will be:

50 $cm^3$ beaker faster than 250 $cm^3$ beaker faster than 600 $cm^3$ beaker

→ decreasing rate of cooling

It will also be seen that stirring increases the rate of cooling. The rate of heat transfer depends on the temperature gradient across the heat exchange interface.

## SUGGESTED SEQUENCE

Students might work in a team of six.

The team divides into three pairs:

- to make their predictions about the cooling curves
- to carry out the practical work, sharing the tasks between them.

The team comes together to share and compare results.

The team produces three summary recording sheets which they display and answer questions about them. The questions might come from other students in the class or the teacher. Alternatively, each member or pair in the team might be asked to produce their own summary.

It is expected that this is carried out by all students in the class. If it is, the hazard posed by boiling water is greatly increased.

### Time required

About 15-20 minutes to remind students about cooling curves.

About 20 minutes to make their predictions.

About 20-30 minutes for each rate of cooling experiment.

## TECHNICIAN EQUIPMENT LIST

- 50 $cm^3$ beaker
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- electric kettle or Bunsen burner, tripod and gauze to heat water