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## Method Article

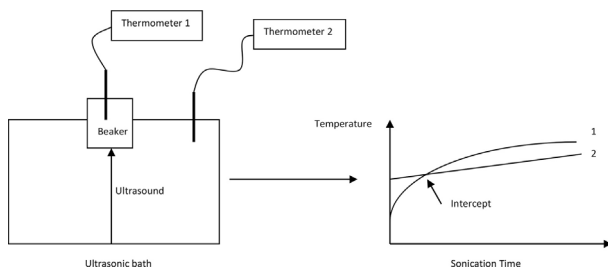
# Disequilibrium calorimetry for determination of ultrasonic power in sonochemistry



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## GRAPHICAL ABSTRACT



## ABSTRACT

The two most characteristic properties of an ultrasonic wave are the frequency and the power. It is therefore important to determine the power in a given reactor. This can be done by calorimetry, i.e. by measuring the temperature rise in the vessel during sonication starting at thermal equilibrium with the surroundings (classic calorimetry) [1–3]. However, the classic ultrasonic calorimetry has drawbacks. In particular it is difficult to evaluate the temperature rise at thermal equilibrium, because the relevant initial time and temperature intervals are small and measurement errors in the temperature readings are large. Also the initial temperature response of the probe is complex [4]. The authors propose to start the calorimetric measurement at thermal disequilibrium, i.e. with a lower temperature in the reaction vessel. During sonication the temperature in the reaction vessel rises faster than in the surrounding and passes thermal equilibrium. The acoustic power transferred to the vessel at thermal equilibrium can then be calculated. The method consists of:

- Setting up the reaction vessel at lower temperature than the surroundings (ultrasonic bath or air).
- Measuring temperature rise in the reaction vessel and the surroundings during sonication.
- Determine the temperature rise at intercept by interpolation and calculate the ultrasonic power in the reaction vessel.

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## Methods detail

A glass beaker (100 ml) was filled with 40 ml deionized water with a temperature lower than the temperature of the ultrasonic bath (VWR Ultrasonic Cleaner USC-TH, 45 kHz, 180 W). The beaker was then placed in the ultrasonic bath and the bath was switched on. The temperature rise in the beaker and the bath was recorded using two thermocouple type thermometers that had a precision of 0.1 °C (VWR Traceable Monitoring Thermometer). The experiment was repeated 5 times. A typical result is shown as example in Fig. 1.

It can be seen that the temperature rise in the beaker is curved and that it fits a polynomial of 2nd order. The temperature rise in the ultrasonic bath was linear and a straight line could be fitted to the data. The temperature rise in the beaker was faster than in the bath. The temperature in the beaker and the temperature in the ultrasonic bath intercepted at 20 °C after 250 s sonication. Note that it will take longer to reach thermal equilibrium if the initial temperature in the beaker is smaller, i.e. below 12 °C.

The slope of the temperature rise in the beaker was determined at intercept by interpolation and the power was calculated according to equation 1, where  $P$  is the power,  $c_p$  is the heat capacity of water

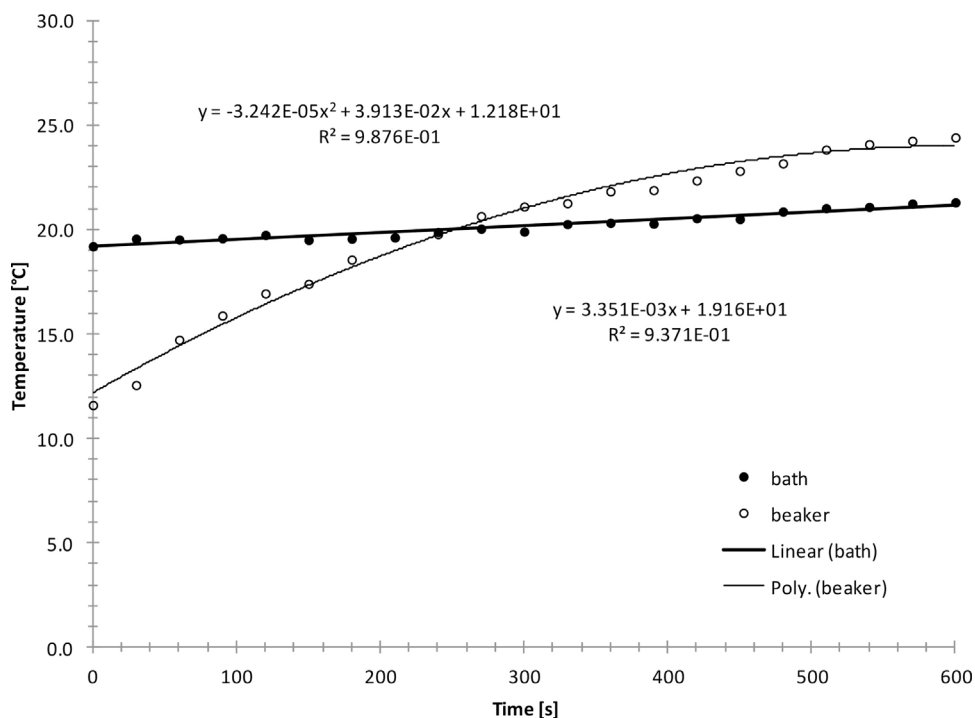


Fig. 1. Typical temperature rises in the beaker and the ultrasonic bath during disequilibrium calorimetry.

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