New controlled rapid quench technique in a 1 atm infrared image furnace

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ABSTRACT

We describe a new quench technique that allows for controlled and reproducible constant quench rates exceeding 100 °C/s in the temperature range of 1400–700 °C and ~10 °C/s in the range 1400–200 °C at 1 atm total pressure. Our technique uses a 1 atm infrared image furnace and a blower unit capable of discharging cooling air through the infrared furnace at speeds approaching 100 m/s. The control protocol consists of operating the furnace at a constant power setting, sufficient to reach the highest desired temperature, and modulating the blower output continuously; blower output is controlled via a silicon-controlled rectifier (SCR) using a proportional-integral-derivative (PID) algorithm on a personal computer (PC). A special autotuning procedure was used that enables the fine-tuning of PID parameters necessary for precise temperature control. Temperatures are controlled to ±1 °C over the entire temperature range under isothermal conditions and to within 10 °C of the setpoint during quench. The range of accessible quench rates using our technique opens up new temperature-time paths for quantitative study. Potential applications include detailed studies on chemical diffusion and the kinetics of bubble and crystal formation under conditions of rapid temperature changes. Such studies have direct relevance to the crystallization, degassing, and structural relaxation of silicate melts during rapid temperature changes such as those encountered during volcanic eruptions.

INTRODUCTION

Virtually all thermodynamic and kinetic properties of Earth materials are significantly affected by changes in temperature. A thorough understanding of the effect of temperature on various physical properties is an essential first step toward predicting the response of minerals, glasses, and melts to temperature-time (T-t) paths found in nature. For example, detailed knowledge of how temperature affects kinetic properties of silicate melts better enables Earth scientists to (1) understand the physical processes that occur during rapidly changing T-t paths, such as those encountered during explosive volcanism; (2) estimate and even predict the amount of re-equilibration that occurs during quenches from high P-T experimental conditions, an important step toward successful interpretation of run results; and (3) achieve a deeper understanding of liquid dynamics through elucidation of structural changes caused by temperature changes of varying magnitude. Thus, a method for quenching experimental charges from high temperature at controlled rates would be a valuable addition to the range of techniques currently available to experimental petrologists. Current quench techniques for 1 atm furnaces, for example, generally produce either (1) controlled, but slow quench rates (<5 °C/s); or (2) uncontrolled, fast rates (up to 10 °C/s). We describe herein a 1 atm experimental setup capable of controlled and highly reproducible constant quench rates exceeding 100 °C/s from temperatures as high as 1400 °C down to 700 °C; 50 °C/s quench rates can be maintained from 1400 to 400 °C. This enables experimentalists to quantitatively and reproducibly access a portion of T-t space previously unavailable.

EXPERIMENTAL METHODS

The experimental setup used in this study is illustrated in Figures 1a and 1b. A Sinku-Riko infrared (IR) image furnace (model no. RHL-E45P) was used as the heat source. This furnace consists of four ~20 cm long “quartz”-tungsten lamps (actually silica glass, not quartz), each capable of producing 80 watts/cm² (W/cm²). The lamps are situated within gold-plated, parabolic reflecting surfaces machined into a water-cooled aluminum block. A 5 cm diameter fused silica tube (2 mm wall) was inserted into the furnace to protect the furnace lamps and reflective surfaces, as well as to provide for gas-mixing capabilities or operation under vacuum. Fused silica absorbs some of the energy emitted in the infrared, particularly for wavelengths longer than ~2.5 μm. However, since the radiative energy emitted by the hot tungsten element within the lamps must first pass through the silica tube that encloses each element, little additional energy is absorbed by the large silica tube used to protect the furnace. In addition, the IR energy is focused at the centerline of the furnace, not at the radial position of the large silica tube. Consequently, the large silica tube reaches temperatures considerably less than that of the sample.