Influence of intensive parameters and assemblies on friction evolution during piston-cylinder experiments

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Abstract

Piston-cylinder assemblies exhibit inhomogeneous pressure distributions and biases compared to the theoretical pressure applied to the hydraulic press because of the thermal and mechanical properties of the assembly components. Whereas these effects can partially be corrected by conventional calibration, systematic quantification of friction values remain very sparse and results vary greatly among previous studies. We performed an experimental study to investigate the behavior of the most common cell assemblies, i.e., talc [Mg3Si4O10(OH)2], NaCl, and BaCO3, during piston-cylinder experiments to estimate the effects of pressure, temperature, run duration, assembly size, and assembly materials on friction values. Our study demonstrates that friction decreases with time and also partially depends on temperature but does not depend on pressure. We determined that friction decreases from 24 to 17% as temperature increases from 900 to 1300 °C when using t alc cells, indicating a friction decrease of ~2% per 100 °C increase for 24 h experiments. In contrast, friction becomes independent of time above 1300 °C. Moreover, at a fixed temperature of 900 °C, friction decreases from 29% in 6 h runs to 21% in 48 h runs, corresponding to a decrease of friction of 0.2% per hour. Similar results obtained with NaCl cell assemblies suggest that friction is constant within error, from 8% in 9 h runs to 5% in 24 h runs. At 900 °C, possible steady-state friction values are only reached after at least 48 h, indicating that friction should be considered a variable for shorter experiments. We establish that assembly materials (and their associated thermomechanical properties) influence the friction correction more than the dimensions of the assembly parts. Finally, we show that the use of polytetrafluoroethylene film instead of conventional Pb foil does not modify friction but significantly reduces the force required for sample extraction, thus increasing the lifetime of the carbide core, which in turn enhances experimental reproducibility.

Keywords: Experimental petrology, piston-cylinder, friction, assembly, calibration

Introduction

The piston-cylinder apparatus (Boyd and England 1960) is well established in experimental petrology and mineralogy for the synthesis of high-pressure and high-temperature geomaticals. Typical setups can attain pressures of 0.5–4 GPa and temperatures of 600–2000 °C, and special setups extend these ranges down to 0.3 GPa (e.g., Mirwald et al. 1975; Moore et al. 2008) and up to 2500 °C (Cottrell and Walker 2006). Piston cylinders are thus particularly well suited to investigate material properties at crustal to upper mantle conditions on Earth and even at core conditions on smaller planetary bodies. Furthermore, many thermodynamic models concerning the properties of the mantle and their evolution through geological time rely on experimental databases. It is thus critical to provide accurate experimental data with minimal uncertainties.

During high-pressure and high-temperature (HP-HT) piston-cylinder experiments, multiple factors can lead to important biases on the pressure applied to the sample. Laboratories world-wide employ various pressurization and heating procedures to reach the P-T conditions of interest, such as the commonly used hot piston-in and piston-out techniques, leading to noticeably different applied pressures (Johannes et al. 1971; Shimizu and Kushiro 1984; McDade et al. 2002). It has also been suggested that a fraction of the hydraulic pressure is not transmitted to the sample due to heterogeneous pressure distributions and/or frictional strain between the carbide core and the cell assembly (Tamayama and Eyring 1967; Edmond and Paterson 1971). These pressure losses can be characterized by the friction value \( F \) (in %), defined as the difference between the applied hydraulic pressure \( \frac{P_{app}}{P_{eff}} \) and the effective pressure on the sample \( \frac{P}{P_{eff}} \):

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F = \left( \frac{P_{app}}{P_{eff}} - 1 \right) \times 100
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The materials used in piston-cylinder cell assemblies vary widely depending on the purpose of the experiments (see Dunn...