Tidelines: Too Hot to Handle?
Thermal Observations of the Wet/Dry Interface

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INTRODUCTION: Thermal imaging, or image capture between 3000 and 5000 nanometers (nm), has mostly been used in the field of conservation in a static nature to record the differences in temperature between materials. It has been especially useful in analyzing historic structures (Bisegna 2014) and in documenting the presence of blind cleavage in paint films (Gavrilov 2014). In this study, the authors used this traditionally static technology to investigate and observe the dynamic nature of tideline formation in Whatman filter paper. The formation of the wet/dry boundary in localized stains, known to paper conservators as tidelines, have been studied extensively in the field of paper conservation, primarily due to their tenacious disfiguration of works on paper. Previous research has identified furanic compounds (Sladkevich 2016), hydroperoxides and hydroxyl radicals (Jeong 2014), organic acids (Souguir 2008 and Dupont 2009), and peroxides and carboxylic acids (Eusman 1995) as playing a role in tideline formation. Other studies have pointed to potential mechanical effects of tideline formation either through physical stress on the cellulose chains (Whitmore 2011) or the migration and build-up of water-soluble compounds at this boundary (Pedersoli 2001). This study presents for the first time the consideration of the thermal nature of the reaction between solvent and paper as another element that contributes to tideline formation.

EXPERIMENTAL DESIGN: For this study, two tests were conducted to investigate the thermal nature of the reaction between paper and solvents. For the first test, nine solvents commonly used in paper conservation were introduced to Whatman No. 1 qualitative filter paper, 98% alpha cellulose (Whatman filter paper). For the second test, deionized water was adjusted to a bracketed set of pH values to determine whether pH would affect the thermal reaction of water and Whatman filter paper. The pH was measured using a Horiba L'Acqua pH meter calibrated at two points: pH 4 and pH 7. Neutral pH table salt was added to each solution before measuring to increase conductivity of the solution (Novak 2015).

Figure 1: Experimental Setup

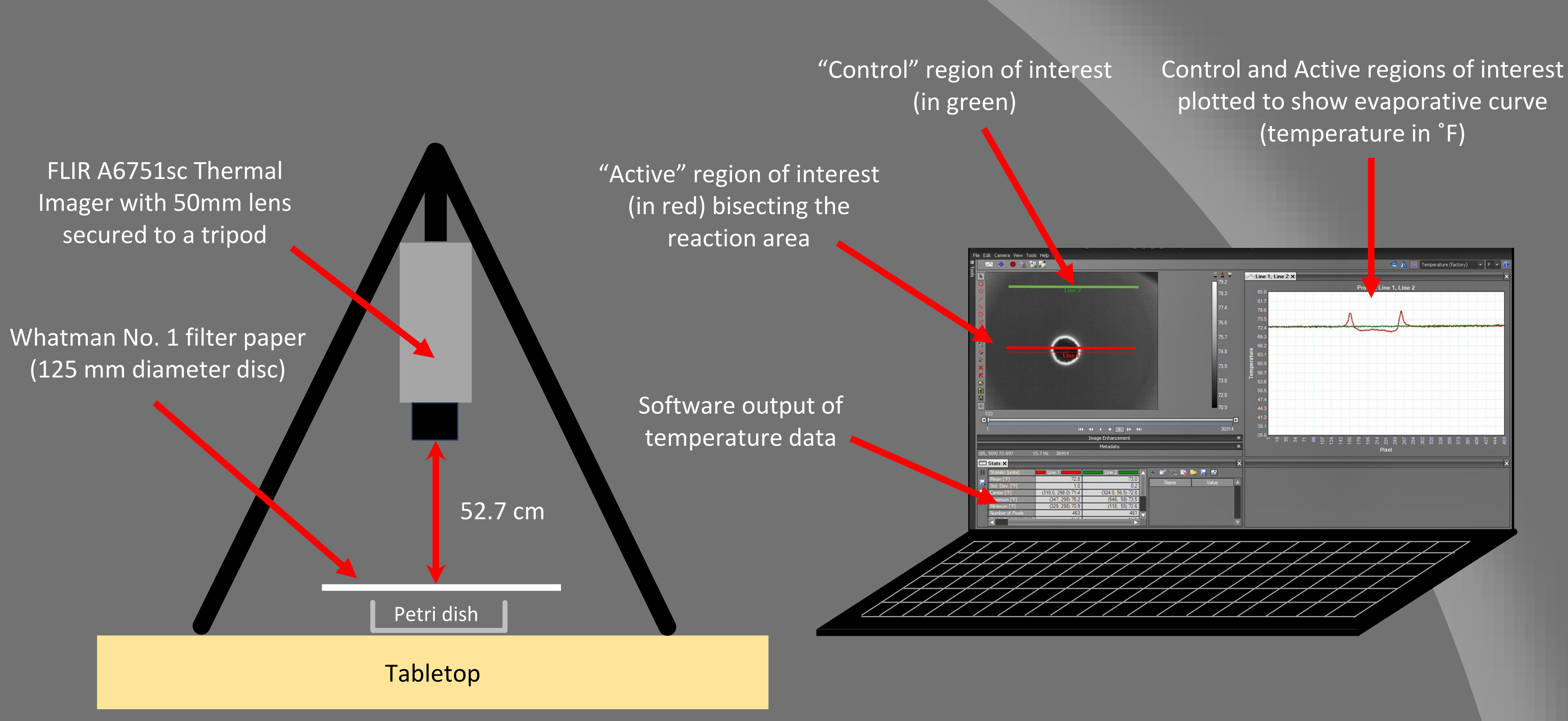
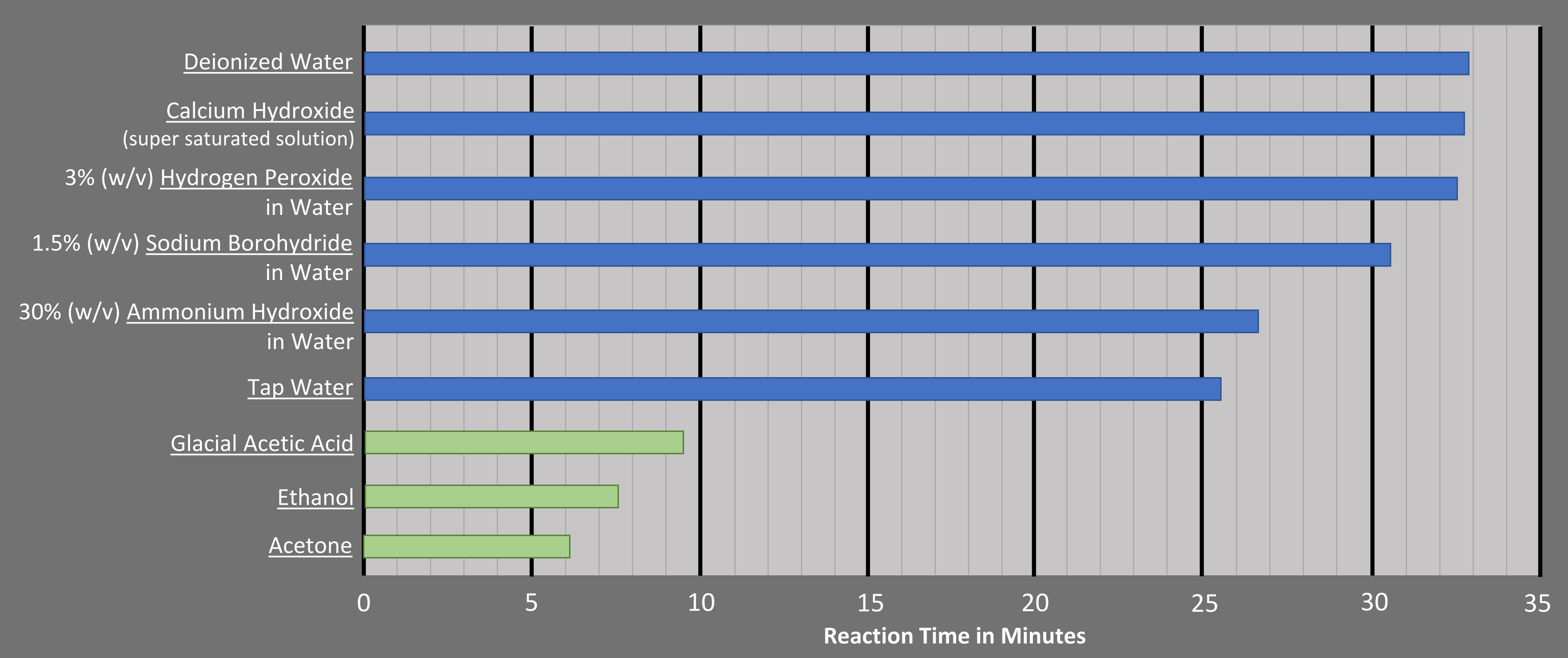


Figure 2: Time to Complete Evaporation



METHODOLOGY: Both tests employed the same testing methodology and environment (Fig. 1). All tests were performed in the same dark room at 72.4 °F and 41.1% RH. An extraction trunk was running continuously for each test, regardless of solvent volatility, to ensure continuity of air flow across tests. All images were captured using a FLIR A6751sc MWIR Thermal Imager with an attached 50 mm f/2.5 lens. This imager has a cooled indium antimonide (InSb) sensor that captures wavelengths between 3000 to 5000 nm. A 125 mm-diameter disc of Whatman filter paper was rested on a petri dish so the test area was not in contact with anything and to encourage air flow beneath the paper. All filter papers were positioned so that the grain direction of the sheet ran parallel with the left and right sides of the image capture screen. With the camera running, one drop of each solvent was manually dispensed from a 1mL graduated polyethylene pipette. The reactions were filmed to completion and the videos were captured using FLIR ResearchIR Max software with high-speed data recording (HSDR) at a rate of 15 frames per second (fps) with a frame size of 640 x 512 pixels. The length of the reaction in minutes was calculated by recording the frame number at the beginning and end of the reaction and calculating the time based on a playback rate of 15 fps. Figure 2 shows the time until complete evaporation, which for the purposes of this study, was determined as the point when the standard deviation of the two regions of interest returned to 0.1, as they were at the beginning of the experiment. Figure 3 and Figure 4 show the character of the evaporative curves of the solvents tested.

Figure 3: Evaporative Curves of Aqueous Solvents

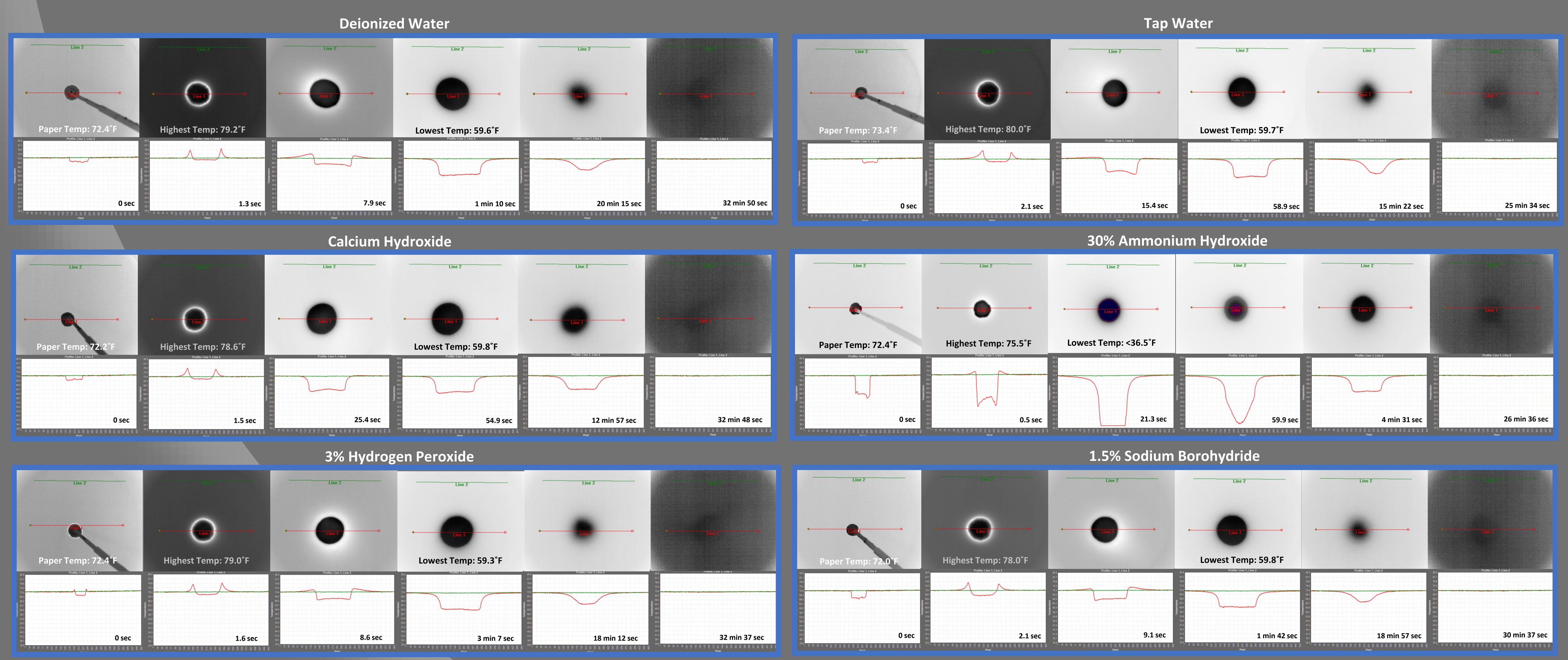
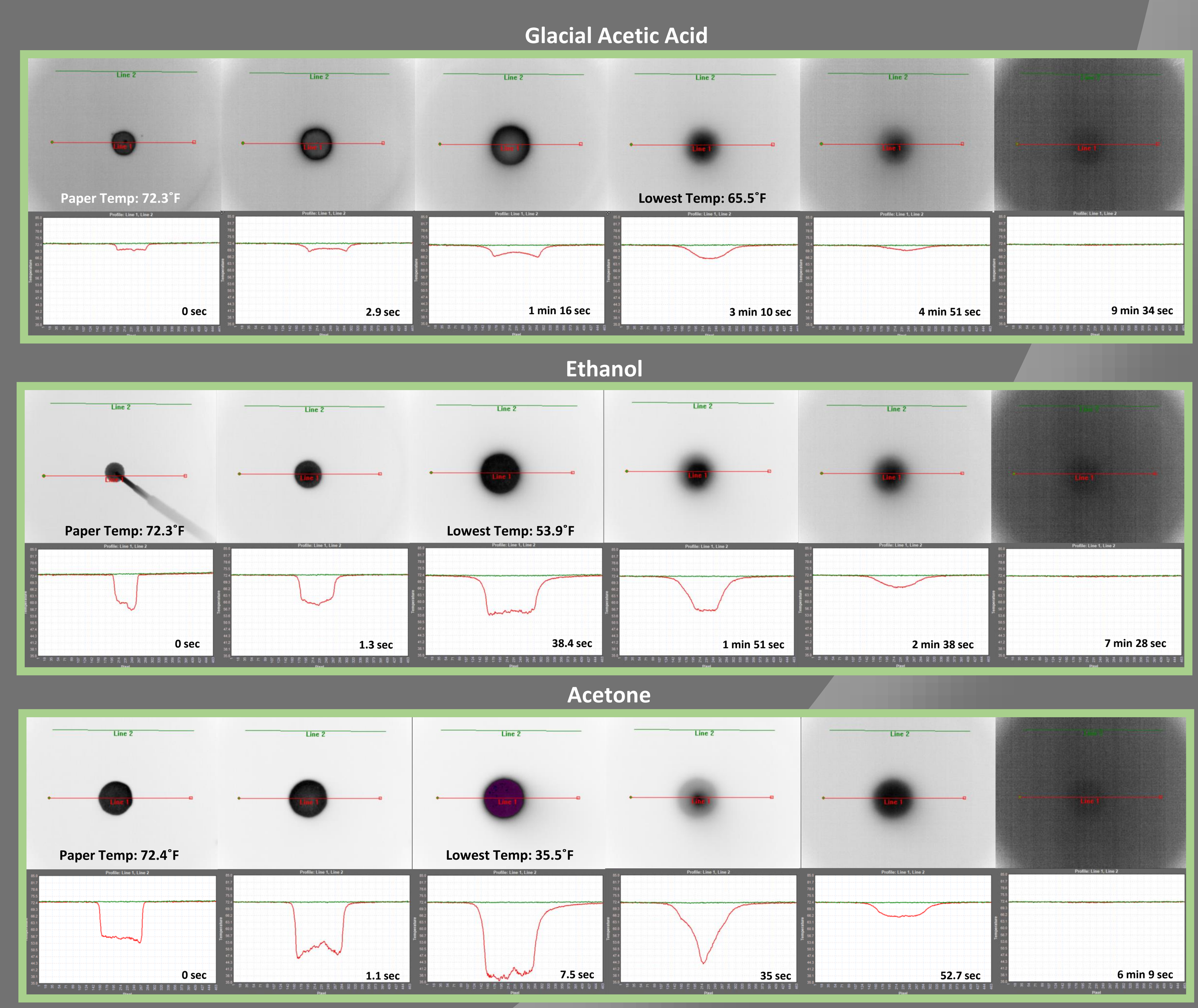


Figure 4: Evaporative Curves of Non-Aqueous Solvents



RESULTS: An exothermic reaction occurred at the wet/dry boundary for all solvents that contained water: deionized water, calcium hydroxide, tap water, hydrogen peroxide, sodium borohydride, and ammonium hydroxide. In general, the temperature of the reaction was about 7°F above the mean temperature of the paper (avg: 72.4 °F). pH did not have a significant effect on the thermal reaction of deionized water and Whatman filter paper.

CONCLUSIONS: While the specific role that heat plays in the formation of tidelines is still unknown, it is a significant observation that heat is generated when water is introduced to Whatman filter paper. This study marks the first time that thermal imaging is used to observe the interaction of cellulose and solvents. This new application of thermal technology could be a useful tool to evaluate the efficacy of conservation treatments in the future, especially local aqueous treatments. Future research could investigate the effect of paper size, fillers, and media on the reaction, as well as adjusted conductivity and gel treatments, among others.

ACKNOWLEDGMENTS: The authors would like to acknowledge the FLIR camera company, and specifically **Jeff Steele** and **Mikala Shremshock**, for loaning the thermal imager, which made this study possible. The primary author, Grace Walters, would like to acknowledge the institutional support she received to continue pursuing this project at the Library of Congress, especially **Elmer Eusman**, **Yasmeen Khan**, and **Susan Peckham**, and at the Amon Carter Museum of American Art, especially **Jodie Utter**, **Fernanda Valverde**, and **Ariadna Rodriguez Corte**. This project could not have been completed without the generous financial support of Walters' conservation education through graduate fellowships and scholarships and without the support of her coauthors: **Jiuan Jiuan Chen** and **Theresa J. Smith**.

REFERENCES