

Once K_v was measured, cake resistance was measured experimentally. A conservative cycle was performed with a target product temperature of $-32\text{ }^\circ\text{C}$, which was below the collapse temperature. Thermocouples were used to obtain the product temperature, which is in turn used to obtain the cake resistance. R_p is represented by the following equation:

$$R_p = 1.15 + \frac{8.58H}{1 + 0.319H}, \tag{7}$$

where H represents the product dry layer.

Once K_v and R_p were measured, a primary drying calculator was then used to predict the primary drying conditions. Figure 4 shows the calculated product temperature profiles during the primary drying stage when different shelf temperatures were employed at 100 mTorr chamber pressure.

The duration of the primary drying step was also estimated based on the time to completely remove the ice. When executing the recommended primary drying conditions, it is very important to verify the end point of primary drying using conventional methods such as a Pirani gauge. In this case, the Pirani gauge was used to verify the end point and this may be examined in Fig. 5. As observed from the predictions in Fig. 4, the $-25\text{ }^\circ\text{C}$ shelf temperature was expected to result in a product temperature below $-33\text{ }^\circ\text{C}$ with primary drying duration of approximately 45 h for the primary drying. The $-20\text{ }^\circ\text{C}$ shelf temperature set point was estimated to have a predicted product temperature of $-30\text{ }^\circ\text{C}$ and the primary drying length can decrease significantly to about 32 h. At a higher shelf temperature of $-18\text{ }^\circ\text{C}$, the

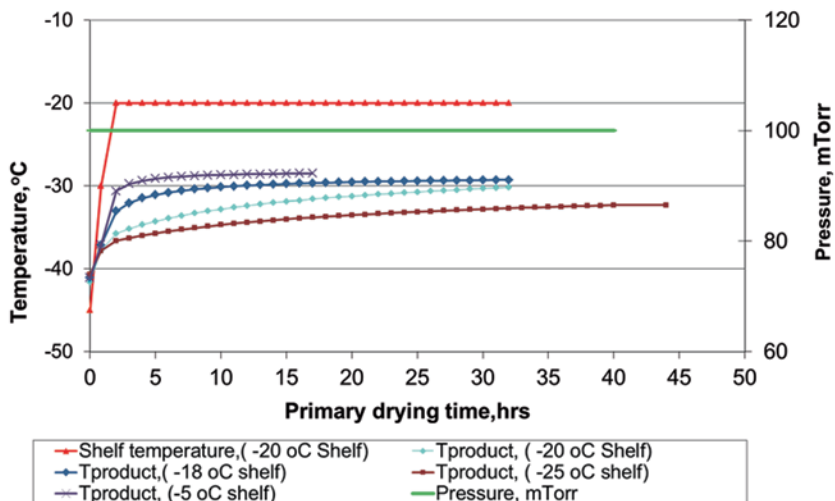


Fig. 4 Prediction of product temperature profiles for various shelf temperatures at a chamber pressure of 100 mTorr