Influence of Flow Rate, Fluid Temperature, and Extension Line on Hotline and S-Line Heating Capability: an in Vitro Study

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Abstract

Background A fluid warmer can prevent hypothermia during the perioperative period. This study evaluated the heating capabilities of Hotline and Barkey S-line under different flow rates and initial fluid temperatures, as well as after the extension line installation.

Methods We measured the temperature of a 0.9% sodium chloride solution at the fluid warmer outlet (T_{Prox}) and the extension line end (T_{Distal}) with three different initial fluid temperatures (room, warm, and cold) and two flow rates (250 ml/hr and 100 mL/hr).

Results At a 250 ml/hr flow rate, the T_{Prox} and T_{Distal} values were observed to be higher in Hotline than in S-line when using a room-temperature fluid; similar results were observed for the cold fluid. Administration of the warm fluid was observed to significantly increase the T_{Prox} and T_{Distal} values in S-line at rates of 250 ml/hr more than the administration of the cold and room-temperature fluids. At flow rates of 100 ml/hr, T_{Distal} values were significantly lower than T_{Prox} values in both devices regardless of the initial fluid temperature.

Conclusions Hotline outperformed S-line for warming fluids at a high flow rate with cold or room-temperature fluids. The administration of the initially warm fluid prevented a decrease in the fluid temperature at a high flow rate in S-line. However, at a low flow rate, the fluid temperature significantly decreased in both devices after passing through an extension line.

Background

Inadvertent perioperative hypothermia commonly occurs in patients undergoing surgery on account of a cold operating room, anesthetic agents that weaken thermoregulatory control, and administration of un-warmed fluid [1–8]. Even mild hypothermia, defined as a core body temperature ranging from 34–36 °C, is associated with complications, such as an increased need for a blood transfusion, increased length of hospitalization, a higher incidence of postoperative myocardial infarction, and the risk of developing a surgical wound infection [7–10]. Preventing perioperative hypothermia is therefore critical.

It is recommended that physicians assess the risk factors associated with perioperative hypothermia to reduce hypothermia-related complications [3, 11]. After assessing these risk factors, physicians should employ interventions that are appropriately designed for the specific patient population and type of operation [1–3, 10]. The use of cold intravenous fluids is one of the most potentially modifiable risk factors [5, 12]. The National Institute for Health and Care Excellence (NICE) published clinical guidelines in 2008 that support the use of intravenous fluid warmers to prevent perioperative hypothermia [13]. Using such a device to warm intravenous fluids before administering it to the patient has been shown to prevent inadvertent hypothermia [4, 5, 12]. However, there are various conditions during fluid administration that must be considered, such as the fluid warmer type, flow rate, fluid temperature, and the IV line length, because the conditions may affect the actual temperature of the administered fluid. Therefore, it is critical to investigate the performance of a fluid warmer in different circumstances.

Numerous commercially available fluid warmers, such as Ranger, ThermoSens, Mega Acer Kit, FT800, and Hotline HL-90, have been investigated under different flow rates and room temperatures [12, 14–16]. However, previous studies mainly focused on changing the flow rate [12, 14, 15]. To determine the clinical effectiveness, various clinical factors such as the initial fluid temperature and the use of extension lines should also be considered.

Barkey S-line is a portable and easy-to-use fluid-warming device wherein the heating profile covers the standard infusion set and warms fluids to a fixed temperature. However, Barkey S-line has rarely been assessed for its heating capability. The Hotline HL-90 fluid-warmer, which depends on a REF L-70 disposable tubing system, uses a counter-current water bath in its disposable administration system to warm the infused fluid.

The purpose of this study was to evaluate the fluid heating capabilities of Barkey S-line and Hotline HL-90 according to different flow rates, fluid temperatures, and the presence of an extension line.

Methods

This study was performed in the designated spot next to the nursing station in the post-anesthesia care unit (PACU). The PACU room temperature was maintained at 23 °C, and the humidity level was maintained at approximately 20%. Normal saline fluid (0.9% sodium chloride solution, CJ, Seoul, Republic of Korea) was used for all the experiments in this study. The fluid temperature was measured using a two-channel thermometer (ThermaQ; ThermoWorks, London, UK). For Barkey S-line (Barkey GmbH & Co. KG, Leopoldshöhe, Germany), the operating temperature was maintained at 39.5 °C throughout the experiments. A standard infusion set was inserted in the 1.5-m heating profile of S-line according to the manufacturer instructions. For Hotline HL-90 (Smiths Medical, Minneapolis, MN), the operating temperature was set to 40 °C. The REF L-70 disposable tubing system (length 2.4 m, volume load 20 ml; Level 1 Technologies Inc., MA, USA) was installed according to the manufacturer instructions.

We evaluated the efficacy of the two fluid warmers under several conditions. Three different conditions were set for the initial fluid temperature: room temperature (22–23 °C), cold (9–10 °C), and warm (46–47 °C.) The normal saline solutions were respectively maintained for 12 h in the operating room, in a refrigerator, and in a heating cabinet for each of the three different conditions. Two distinct flow rates were tested in this study: 100 ml/hr and 250 ml/hr. The roller clamp was fully open, and the flow rate was adjusted using a micro-flow regulator (I.V. Flow Control Line, Insung Medical Co., Seoul, Republic of Korea) attached to the infusion set at a flow rate of 100 or 250 ml/hr. The regulator tolerance ranged from − 10–20% according to the manufacturer instructions. The height of the infusion bag was the same in all experiments (1.8 m.) One unit of a non-insulated extension set (DEHP-free Extension Plus, SBD Medical, Republic of Korea), which was 90 cm in length, was connected to the fluid warmer outlet. The fluid temperature was measured at two points, first at the fluid warmer outlet (T_{Prox}) and then at the end of the non-insulated extension line (T_{Distal}.) After starting each trial, the temperatures at the two positions (T_{Prox} and T_{Distal}) were recorded every minute until the end of the trial (Fig. 1).

T_{Prox} and T_{Distal} were carefully evaluated for the presence of a plateau in each trial. The plateau in each trial was defined as the time point at which the measured temperatures were the most stable without a noted fluctuation for 3 min. In each trial, only the T_{Prox} and T_{Distal} values from the middle time point of the plateau were used for the subsequent statistical analysis. Five trials were performed for an individual experimental condition to obtain five data points for T_{Prox} and T_{Distal}, respectively.

Statistical analysis was performed using SPSS v.20.0 for Windows (IBM SPSS, Inc., Armonk, NY) and R software version 3.4.4 (R Foundation for Statistical Computing, Austria). A data chart was produced using Microsoft Excel 2007. All fluid temperatures were reported as a median (interquartile [IQR] range). The Wilcoxon signed-rank test was used to test for a statistical difference between T_{Prox} and T_{Distal} values. The Hodges–Lehmann estimator was utilized to create the 95% confidence interval for the median difference between T_{Prox} and T_{Distal}. The Mann–Whitney U test was employed to compare T_{Prox} or T_{Distal} values under different flow rates using the same fluid warmer or between Hotline and S-line at the same flow rate. The bootstrap method was applied to form the 95% confidence interval for the analyses performed using the Mann–Whitney U test. Statistical significance was defined as a $p\text{-value} < 0.05$.

Results

Room-temperature fluid

The room-temperature fluid was maintained at 21–23 °C. The median T_{Prox} and T_{Distal} values measured in Hotline and S-line, according to the flow rates are shown in Table 1. T_{Prox} was higher in Hotline than in S-line based on the median difference of 10.5 °C (95% CI 9.6–12.3) at the flow rate of 250 ml/hr and 1.6 °C (95% CI 1.4–2.1) at the flow rate of 100 ml/hr. T_{Distal} measured higher in Hotline than in S-line based on the median difference of 9.8 °C (95% CI 7.6–11.5) at the flow rate of 250 ml/hr. However, the T_{Distal} values were not significantly different in the two devices at 100 ml/hr.

Table 1
Measured fluid temperature in the room-temperature fluid group

	250 ml per hour		100 ml per hour	
	Hotline	S-line	Hotline	S-line
T_{Prox}	38.7 [38.7–38.8]*†‡	28.2 [27.6–28.4]†‡	40.3 [40.1–40.4]*‡	38.7 [38.6–38.7]‡
T_{Distal}	37.6 [37.6–37.9]*†	27.8 [27.0-27.9]†	25.6 [25.3–26.0]	23.4 [23.4–23.5]
* vs. S-line P-value < 0.05				
† vs. 100 ml/hr P-value < 0.05				
‡ vs. T_{Distal} P-value < 0.05				
T_{Prox}: fluid warmer point, T_{Distal}: the extension line point				

T_{Prox} in Hotline was slightly higher at 100 ml/hr than at 250 ml/hr based on the median difference of 1.6 °C (95% CI 1.3–1.9). However, T_{Prox} in S-line was much higher at 100 ml/hr than at 250 ml/hr based on the median difference of 10.5 °C (95% CI 9.6–12.3).

Furthermore, T_{Distal} in Hotline was higher at 250 ml/hr than at 100 ml/hr by 12.0 °C (95% CI 9.8–14.2). T_{Distal} in S-line was higher at 250 ml/hr than at 100 ml/hr by 4.4 °C (95% CI 2.6–5.3.) The T_{Distal} values were lower at 100 ml/hr than at 250 ml/hr. In addition, T_{Prox} was higher than T_{Distal} in both devices regardless of the flow rate. However, the differences were more substantial at 100 ml/hr. At a flow rate of 250 ml/hr, the median differences between T_{Prox} and T_{Distal} were 1.1 °C (95% CI 0.9–2.2) in Hotline and 0.4 °C (95% CI 0.3–0.6) in S-line. At 100 ml/hr, the median differences were 14.7 °C (95% CI 14.3–16.7) in Hotline and 15.1 °C (95% CI 13.9–16.0) in S-line.

Cold fluid

The initial temperature of the starting solution was maintained at 9–11 °C in this group. The median T_{Prox} and T_{Distal} values measured in S-line and Hotline in accordance with the flow rates are shown in Table 2. T_{Prox} was higher in Hotline than in S-line by the median difference of 19.0 °C (95% CI 16.7–20.2) at 250 ml/hr. However, the difference was 1.4 °C (95% CI 0.3–4.3) at 100 ml/hr. T_{Distal} at 250 ml/hr was also higher in Hotline than in S-line based on the median difference of 17.1 °C (95% CI 15.4–18.2). However, the T_{Distal} values from Hotline and S-line were not statistically different at 100 ml/hr.

Table 2
Measured fluid temperature in the cold fluid group

	250 ml per hour		100 ml per hour	
	Hotline	S-line	Hotline	S-line
T_{Prox}	37.2 [36.3–37.4]*†‡	18.2 [17.6–19.5]†‡	40.0 [39.8–40.0]*‡	38.6 [38.5–38.6]‡
T_{Distal}	36.2 [35.6–36.3]*†	19.1 [18.5–20.0]†	23.5 [23.3–24.1]	24.5 [24.1–24.7]
* vs. S-line P-value < 0.05				
† vs. 100 ml/hr P-value < 0.05				
‡ vs. T_{Distal} P-value < 0.05				
T_{Prox}: fluid warmer point, T_{Distal}: the extension line point				

T_{Prox} measured in Hotline was slightly higher at 100 ml/hr than at 250 ml/hr by 2.8 °C (95% CI 1.7–3.8). In S-line, the T_{Prox} value was significantly higher at 100 ml/hr than at 250 ml/hr by 20.4 °C (95% CI 17.5–21.4). For T_{Distal} in Hotline, the temperature at 250 ml/hr was higher than at 100 ml/hr, and the median difference was 12.7 °C (95% CI 11.4–13.6). In contrast, T_{Distal} at 100 ml/hr was higher than at 250 ml/hr in S-line, and the median difference was 5.4 °C (95% CI 4.0–6.4). In both devices, the T_{Distal} values at 100 ml/hr were similar to the ambient temperature. As shown in the table, T_{Prox} was higher than T_{Distal} in both devices regardless of the flow rate. The only exception was observed in S-line at 250 ml/hr; T_{Prox} is 18.2 °C and T_{Distal} is 19.1 °C. The difference between T_{Prox} and T_{Distal} was greater at 100 ml/hr than at 250 ml/hr. At 250 ml/hr, the median differences between T_{Prox} and T_{Distal} were 0.9 °C (95% CI 0.6–1.2) in Hotline and 0.7 °C (95% CI 0.5–0.9) in S-line. At 100 ml/hr, the median differences were 16.3 °C (95% CI 15.8–16.6) in Hotline and 13.9 °C (95% CI 11.2–14.6) in S-line. At 100 ml/hr, the extension line reversed most of the warming and substantially cooled the fluid as it traveled from T_{Prox} to T_{Distal}.

Warm fluid

The initial fluid temperature was maintained at 46–49 °C in the warm temperature group. The median T_{Prox} and T_{Distal} values measured in S-line and Hotline according to the flow rates are shown in Table 3. In this temperature group, the temperature of the initial fluid was higher than the operating temperatures of the fluid warmers themselves. The T_{Prox} value at 250 ml/hr in S-line was higher than in Hotline according to the median difference of 2.7 °C (95% CI 2.4–3.8). At 100 ml/hr, the T_{Prox} value was higher in Hotline according to the median difference of 2.7 °C (95% CI 1.6–3.7). T_{Distal} in S-line at 250 ml/hr was 43.9 °C, and it was higher than in Hotline according to the median difference of 2.7 °C (95% CI 2.2–3.2). At 100 ml/hr, no statistical difference existed between the T_{Distal} values in the two devices.

Table 3
Measured fluid temperature in the warm fluid group

	250 ml per hour		**100 ml per hour**	
	Hotline	**S-line**	**Hotline**	**S-line**
T_{Prox}	42.1 [42.1–42.1]*†‡	44.8 [44.7–45.4]†‡	40.5 [40.5–40.5]*‡	37.8 [37.8–37.9]‡
T_{Distal}	41.2 [41.0-41.2]*†	43.9 [43.5–44.2]†	27.6 [27.4–27.9]	26.6 [26.5–26.8]
* vs. S-line P-value < 0.05				
† vs. 100 ml/hr P-value < 0.05				
‡ vs. T_{Distal} P-value < 0.05				
T_{Prox}: fluid warmer point, T_{Distal}: the extension line point				

In Hotline, the T_{Prox} value was higher at 250 ml/hr than at 100 ml/hr, and the median difference was 1.6 °C (95% CI 1.5–1.7). For the T_{Distal} value, the temperature measured at 250 ml/hr was again higher, and the median difference was 13.6 °C (95% CI 13.1–14.9). Similarly, the T_{Prox} value in S-line was higher at 250 ml/hr than at 100 ml/hr; the median difference was 7.0 °C (95% CI 5.9–8.1). For the T_{Distal} value, the measurement at 250 ml/hr was higher than at 100 ml/hr based on the median difference of 17.3 °C (95% CI 16.7–18.6). T_{Prox} was higher than T_{Distal} at the two flow rates in both Hotline and S-line. A flow rate of 100 ml/hr produced larger differences between T_{Prox} and T_{Distal}. At 250 ml/hr, the median differences between T_{Prox} and T_{Distal} were 1.0 °C (95% CI 0.9–1.1) in Hotline and 1.2 °C (95% CI 0.8–1.5) in S-line. At 100 ml/hr, the median differences were 12.9 °C (95% CI 12.5–14.2) in Hotline and 11.3 °C (95% CI 11.1–12.1) in S-line. The slower flow rate correlated with a more substantial difference in the median values.

Discussion

This study evaluated the warming capabilities of Hotline and S-line under the conditions of two different flow rates and three starting fluid temperatures, as well as before and after the use of an extension line. At the faster fluid administration rate, Hotline was superior to S-line for warming with regard to both T_{Prox} and T_{Distal} by approximately 10 °C and 20 °C in the room-temperature and cold saline groups, respectively. However, at 100 ml/hr, there was no statistical difference between the T_{Distal} obtained with Hotline and S-line. The fluid lost a significant amount of heat as it traveled an additional 90 cm at 100 ml/hr. Thus, Hotline would be more effective in preventing hypothermia during rapid fluid administration. Furthermore, at 100 ml/hr, the delivery of warmed fluids would be more effective without the extension line in both Hotline and S-line.

T_{Prox} in S-line was significantly higher at 100 ml/hr than at 250 ml/hr when using cold or room-temperature fluid, which suggests that a certain amount of time was required to sufficiently warm the fluid. In contrast, T_{Prox} in Hotline was warmed to approximately 40 °C at both rates (100 and 250 ml/hr) using either cold or room-temperature fluids. The difference in heating capacity between these devices was likely due to the differences in their respective heating mechanisms, i.e., a coaxial circulating water bath (Hotline) versus a dry heating profile (S-line). The dry-heating system is expected to incur greater heat losses on account of the exposed portion of the extension line in ambient temperature. Thus, the

Hotline coaxial warming system is apparently more effective than S-line in preventing hypothermia during rapid fluid administration.

In this study, three different temperature groups were used to investigate the influence of the initial fluid temperature on T_{Prox}. At 100 ml/hr, the T_{Prox} values in both Hotline and S-line were less affected by changing the initial fluid temperature than at 250 ml/hr. However, changing the initial fluid temperature notably affected T_{Prox} at 250 ml/hr in S-line: 28.2 °C (27.6–28.4), 18.2 °C (17.6–19.5), and 44.8 °C (44.7–45.4) in room-temperature, cold, and warm saline groups respectively. The corresponding T_{Distal} values were 27.8 °C (27.0–27.9), 19.1 °C (18.5–20.0), and 43.9 °C (43.5–44.2), respectively. Adjusting the initial temperature affected T_{Prox} in S-line, and pre-warming the fluid helped increased the fluid temperature. Careful calibration of the initial fluid temperature should maximize the delivery of an appropriately warmed fluid in S-line. At the same time, precautionary measures should be taken against the preparation of fluid that is too hot.

It is clinically important to determine whether warmed fluids can be delivered to the patient without heat loss as they pass through a non-insulated extension line. Interestingly, in this study, a statistically significant change in fluid temperature was observed after the extension line in every experimental condition regardless of the fluid warmer type, initial fluid temperature, or flow rate. The change in fluid temperature was more pronounced at the low flow rate than at the high one. The fluid lost a significant amount of heat as it traveled an additional 90 cm at a rate of 100 ml/hr. This finding warrants the utilization of additional measures for hypothermia prevention when using an extension at the low flow rate, especially when administering fluids to patients with a high risk of developing hypothermia such as neonatal and older patients [17]. Furthermore, it is essential to minimize heat loss as the fluid travels down the extension line, which can be achieved by an extension line innovation or by applying supplemental measures against hypothermia.

Several limitations of this study should be noted. In an actual clinical setting, the fluid administration rate, initial fluid temperature, and extension line length may differ from the conditions used in this study. For example, during rapid fluid resuscitation, the infusion rate can be as high as 60 to 80 mL/kg per hour [18]. Also, in this study, the fluid temperature in the warm temperature group was greater than 45 °C, which can be problematic because the proteins in red blood cells can degenerate at a temperature higher than 45 °C [19]. Moreover, precautionary measures should be taken against preparing fluids that are excessively hot for clinical practice. Finally, extension lines longer than 90 cm can be employed in certain clinical scenarios. Longer extension lines could affect the fluid temperature more markedly than the line length employed in this study.

Conclusions

In summary, Hotline outperformed S-line in increasing the fluid temperature at 250 ml/hr regardless of the starting fluid temperature. At the flow rate of 100 ml/hr, the respective heating capabilities of Hotline and S-line do not appear to significantly differ. When rapidly administered, S-line is more affected by the adjustment of the starting fluid temperature. Accordingly, careful calibration of the initial fluid temperature in S-line at the faster administration rate could help prevent hypothermia, depending on the clinical circumstance. Finally, using an extension line of 90 cm in length can influence the final fluid temperature delivered to the patient at a flow rate of 100 ml/hr. Applying an extension line to patients that are at high risk of developing hypothermia, such as geriatric or neonatal patients, warrants the utilization of additional protective measures against hypothermia.

List Of Abbreviations

T_{Prox}
temperature at the fluid warmer point
T_{Distal}
temperature at the extension line point
PACU
post-anesthesia care unit

Declarations

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request

Competing interests

The authors declare that they have no competing interests

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Authors' contributions

HK and TKK collected and analyzed the study data. SY and J-TK designed the study and interpreted the study data. HK and TKK was a major contributor in writing the manuscript. All authors read and approved the final manuscript.

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Figures

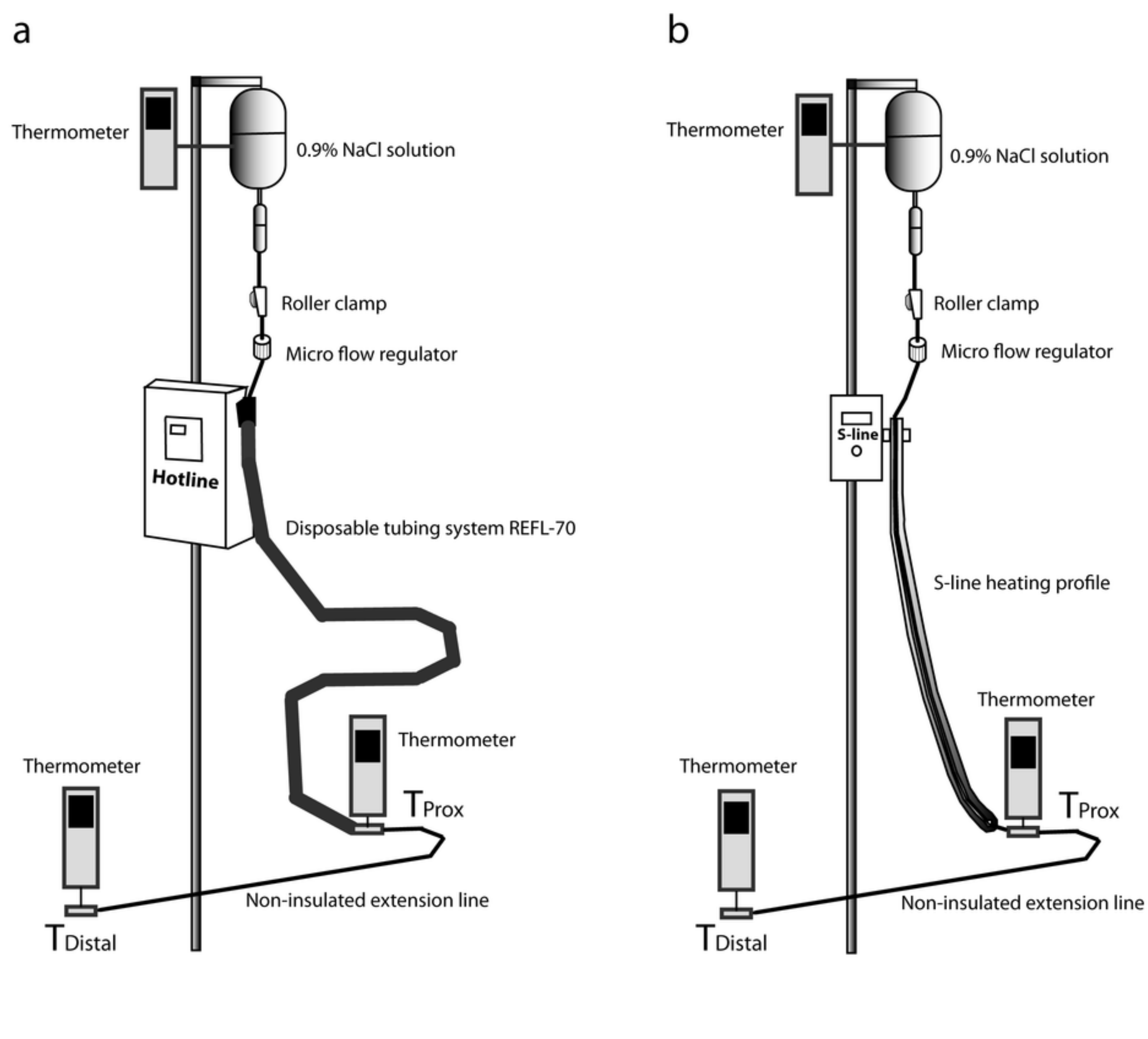

Figure 1

The figure shows an overview of the experimental setup. 0.9 % NaCl solution is warmed as it travels down the fluid warmer. After fluid exits the warmer, it goes further down through the non-insulated extension line. The temperatures at the outlet of the warmer (TProx) and the outlet of the extension line (TDistal) were measured using thermometers. a and b in the left and right show the setups for Hotline and S-line, respectively.