

Executive Summary

Pediatric patients (specifically neonates) at Cook Children's CICU are mechanically ventilated with a heated and humidified respiratory circuit that is prone to excess condensation (rainout) when the patient undergoes nitric oxide therapy. Multiple factors are contributing to the excess condensation such as the cold ambient air in the CICU, the unheated tubing extension for nitric oxide, and the introduction of more airflow from the NOxBOX machine. The rainout risks falling into the patient's lungs when they are being moved and the nurses must suction the water out, risking damage to sensitive tissue. Because these are patients in the CICU, suctioning can negatively affect cardiovascular activity which can lead to the patient going into cardiac arrest. This project focuses on minimizing the risk of condensation buildup in the respiratory circuit which can lead to harmful complications for pediatric patients.

Background

Doctors and nurses at Cook Children's CICU use nitric oxide therapy supplied through NOxBOX, which helps improve oxygenation of the patient. Condensation accumulation, rainout, is a common issue in neonatal ventilator circuits caused by the temperature gradients especially across the unheated circuit attachment.

In NICU settings, excess condensate may:

- Obstruct airflow and breath resistance
- Frequent manual drainage from clinicians
- May cause the neonate to inhale the excess condensate and drown the patient

During Nitric Oxide therapies, the stable ventilators conditions are critical and ensures that condensation management is important. With current solutions such as commercially available circuit covers do not fully eliminate the build up of condensation. A low-cost and passive device is needed without altering the ventilator performance.



Figure 1. Simulation Setup with Prototype

Experimental Setup

The objective of this study is to quantify the condensation accumulation over a 4-hour period and evaluate the effectiveness of the insulation prototype in reducing condensate formation within the ventilator circuit.

An experimental system was developed to replicate the NICU ventilator conditions including the AVEA ventilator, Fisher & Paykel respiratory circuit and humidifier. The temperature gradient between the heated and unheated portions of the tubing was evaluated.

Key Specs:

- Test duration of 4 hours
- Measurements every hour
- Avea Ventilator/ Fisher and Paykel Humidifier
- Inclusion of 1 ft unheated tubing
- Nitric Oxide excluded

Controlled Variables:

- Ventilator settings constant
- Humidifier temperature (37°C)
- Circuit geometry and length
- Ambient conditions
- Measurement method

Table 1. Experimental Conditions

Configuration	Description	Purpose
Baseline	No insulation	Establish reference condensation
Prototype	Designed Insulation	Evaluate performance improvement

Experimental Test Plan

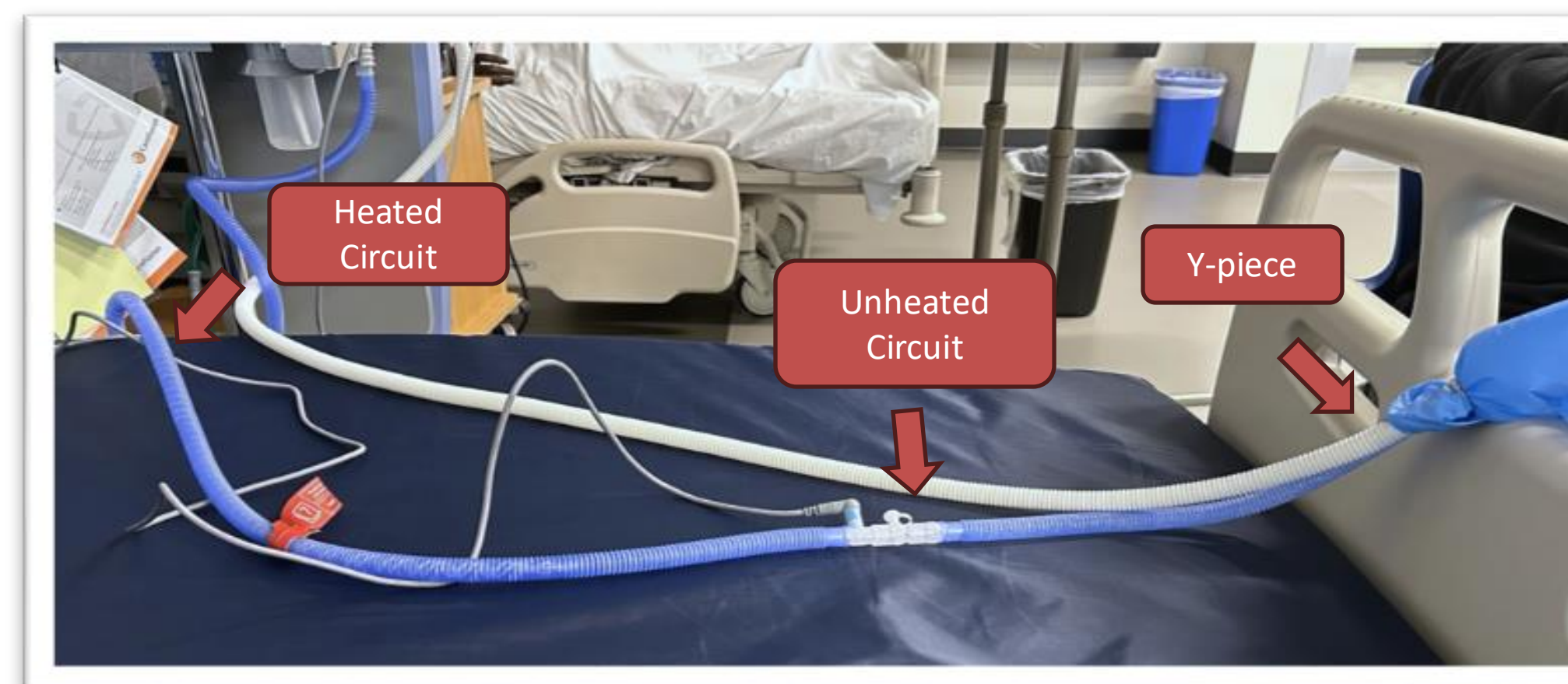


Figure 2. Points measured on the inspiratory circuit

- 3D printed t-line pieces are inserted in the red arrow regions to integrate the iMonnit temperature and humidity sensors, while the ambient and temperature taken at the beginning of the circuit will use an IR Temperature Gun
- Before running the ventilator, the inspiratory circuit, t-pieces, and Y-piece is weighed using a scale
- Within the 4-hours of the test, each hour will have the temperature readings of the ambient temperature, heated circuit, unheated circuit, and y-piece. In addition, a humidity readings of the unheated circuit and y-piece.
- After the 4-hour period the inspiratory circuit, t-pieces, and y-piece will be weighed making sure no excess condensate spills from the circuit

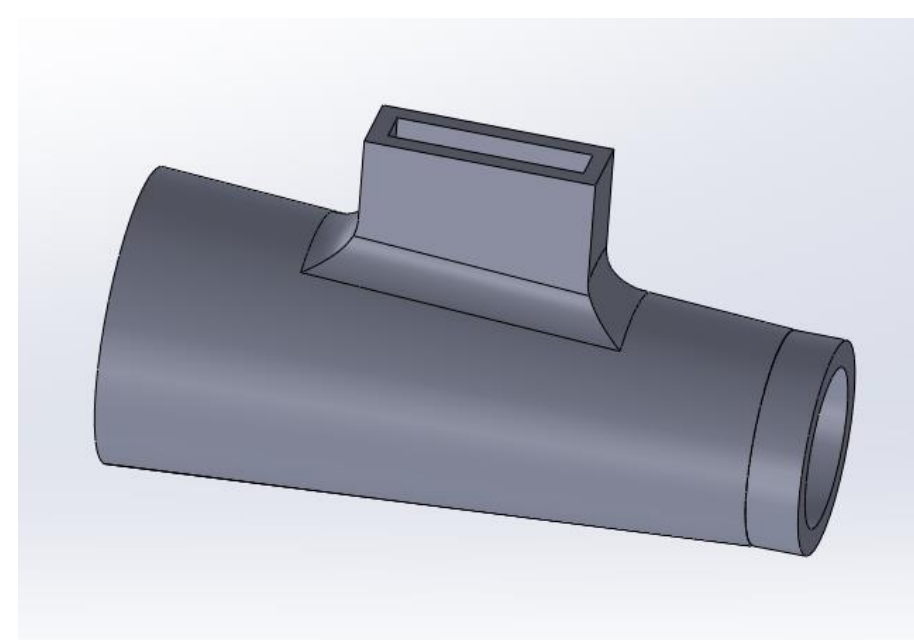


Figure 3. 3D printed T-piece

Experimental Results

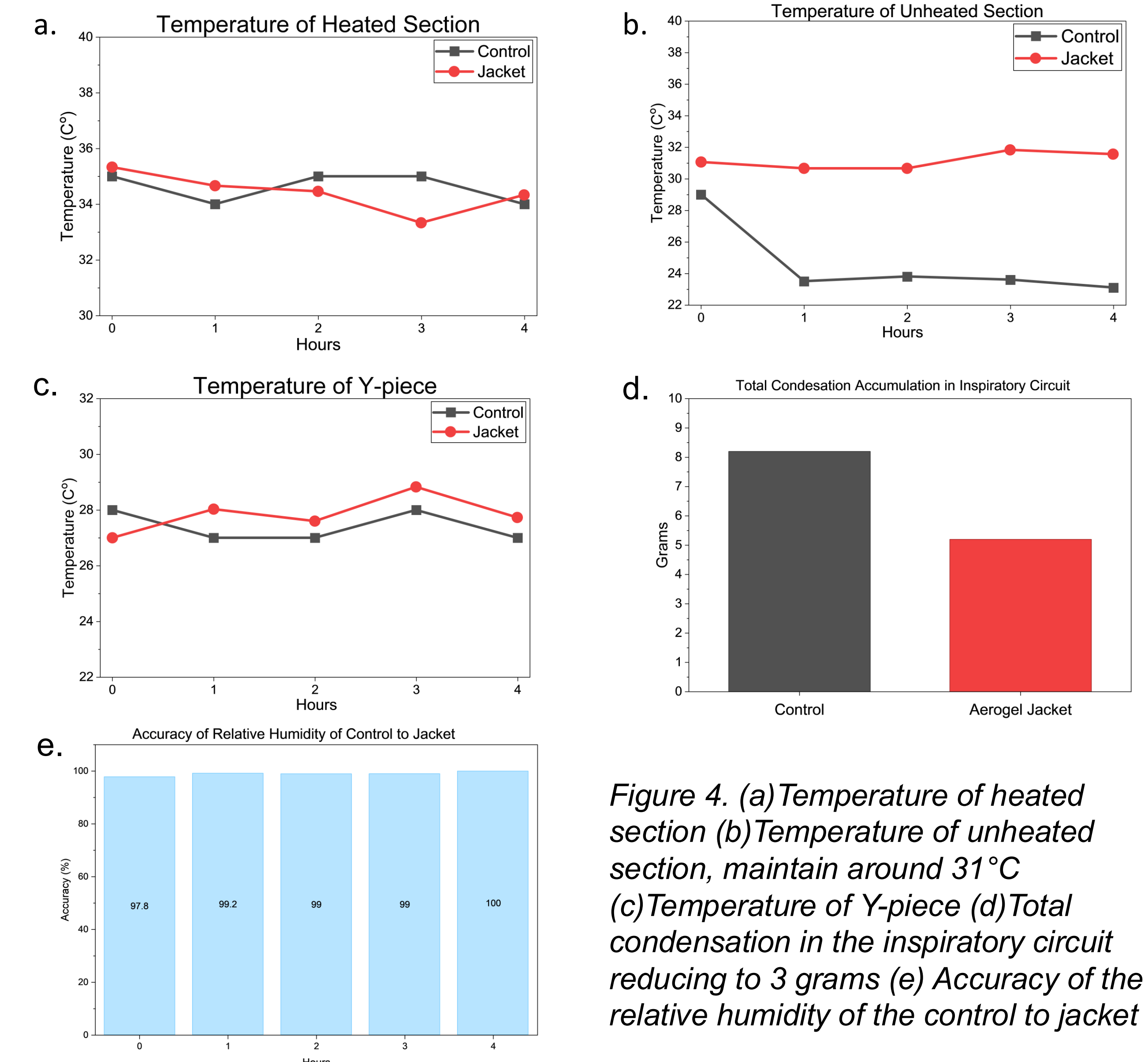


Figure 4. (a) Temperature of heated section (b) Temperature of unheated section, maintain around 31°C (c) Temperature of Y-piece (d) Total condensation in the inspiratory circuit reducing to 3 grams (e) Accuracy of the relative humidity of the control to jacket

Conclusions and Future Works

- The prototype insulation sleeve successfully reduced condensation accumulation within the ventilator circuit.
- There was a 39% reduction in condensate mass within the circuit over a 4-hour period. The mass accumulated without the sleeve was 8.2 g to 5.2 g.
- The sleeve increased the unheated tubing from 23°C to 31°C which reduces the temperature gradient that creates the condensation formation
- The results also confirm that the temperature gradient difference is the primary driver of condensation within the circuit
- The solution is passive, low-cost and compatible with existing ventilator systems

Future Work

- Test over longer time durations to simulate full clinical use
- Evaluate performance under varying conditions and compare the design against commercial insulation designs

References and Acknowledgements

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