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Exhaust process of cryogenic nitrogen gas from a cryogenic wind tunnel with an inclined exit

Jingfeng LI, Kai WANG, Chenjie GU, Limin QIU

Institute of Refrigeration and Cryogenics, Zhejiang University
Baima Lake Laboratory

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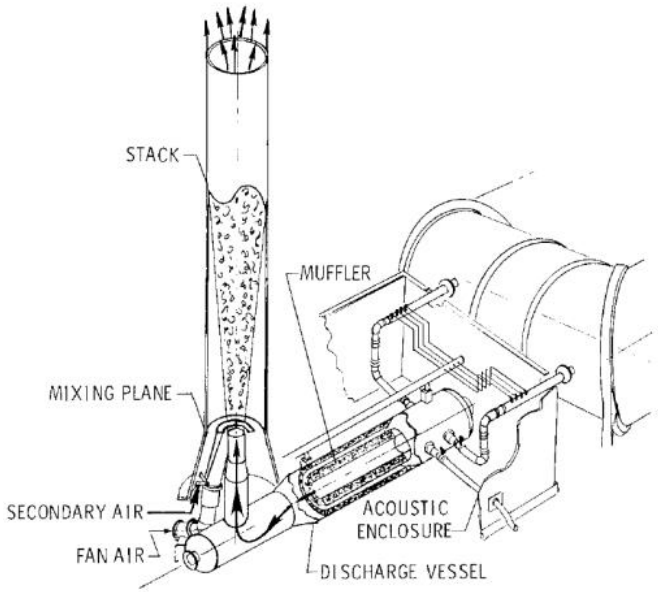
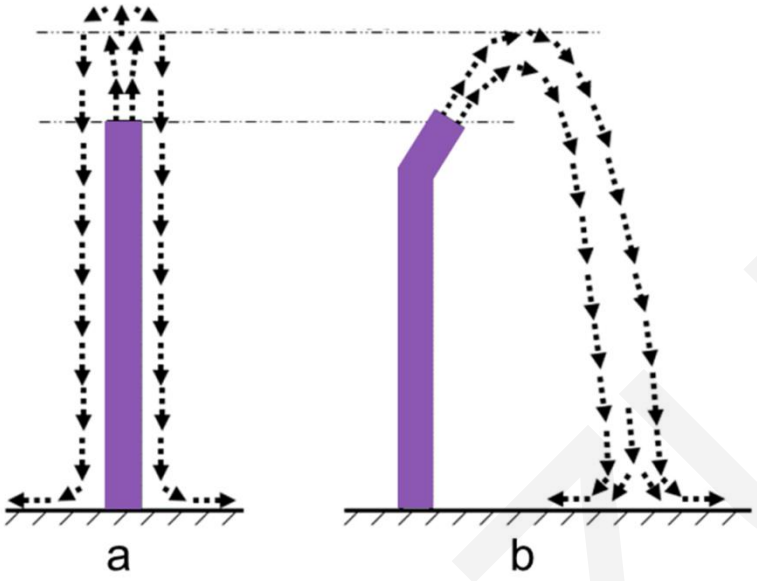
During operation of a cryogenic wind tunnel, gravity settlement of large amounts of exhausted cryogenic nitrogen gas can endanger public safety because of the low temperature of the gas and its potential to cause oxygen deficiency.

Measures to reduce hazard

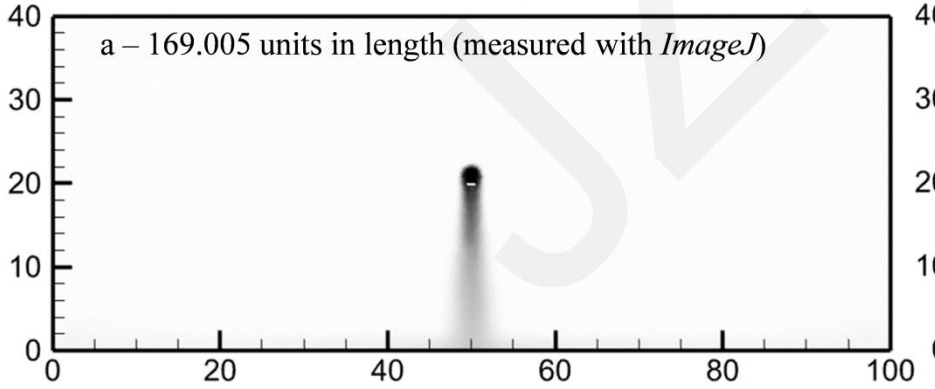
- Ejector → Without energy consumption
- Fan → With significant energy consumption
- Burner → With significant energy consumption

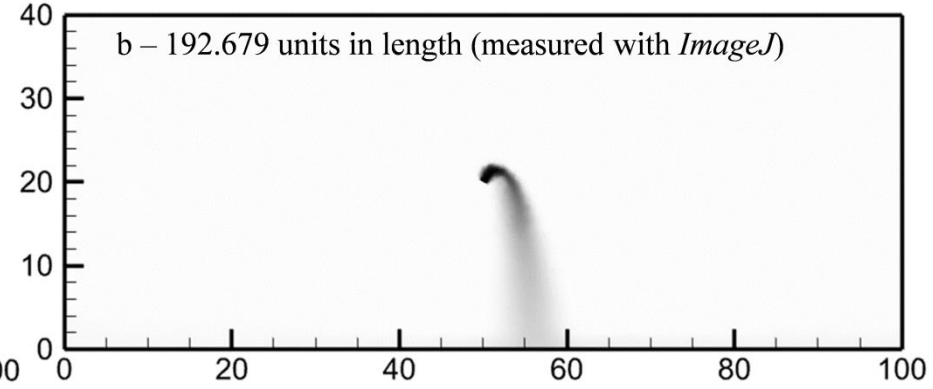


For gases that exhibit gravity settlement, extending the settlement trajectory can reduce potential harm to the public. In the new exhaust method with an inclined exit proposed here, the effect of extending the plume trajectory can be obtained by simple structural improvement.

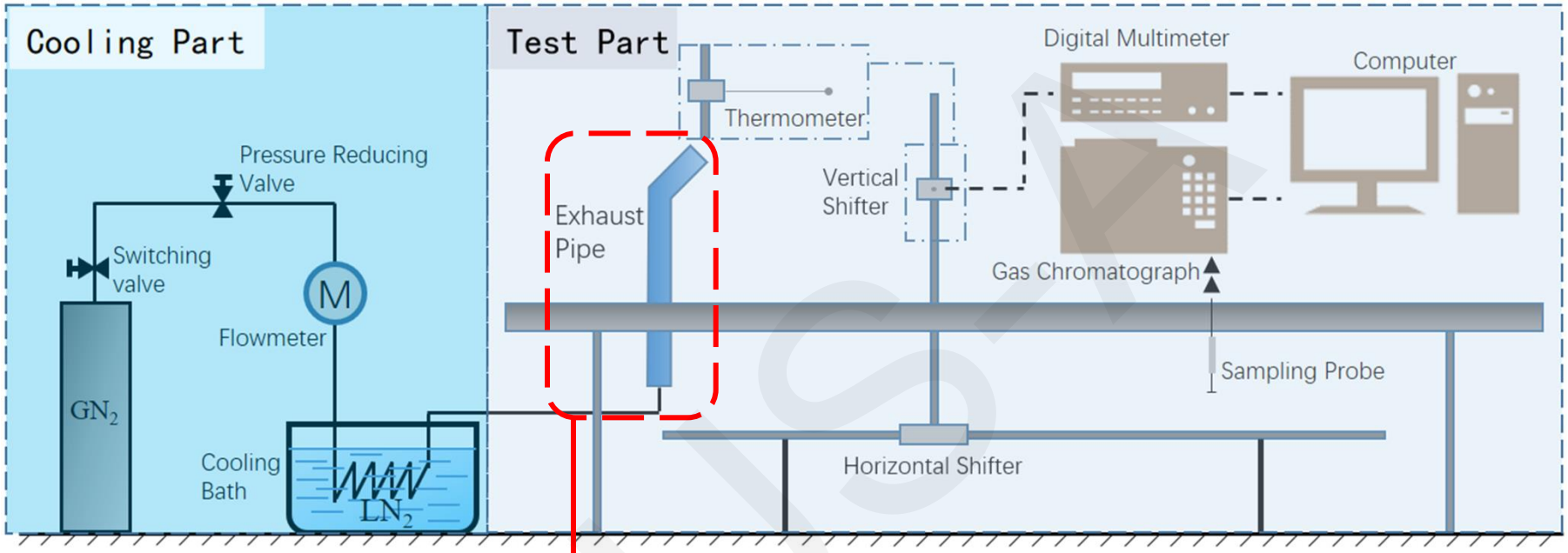


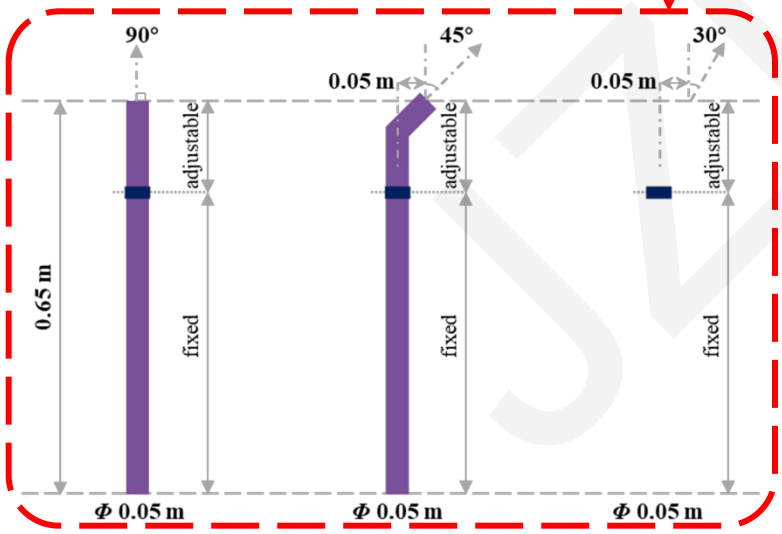
The extended trajectory means that the heat and mass transfer between the gas group in the plume and the atmospheric air can be more effective throughout the dispersion process before settling to the ground; both the temperature and the oxygen concentration of the plume near the ground increased.



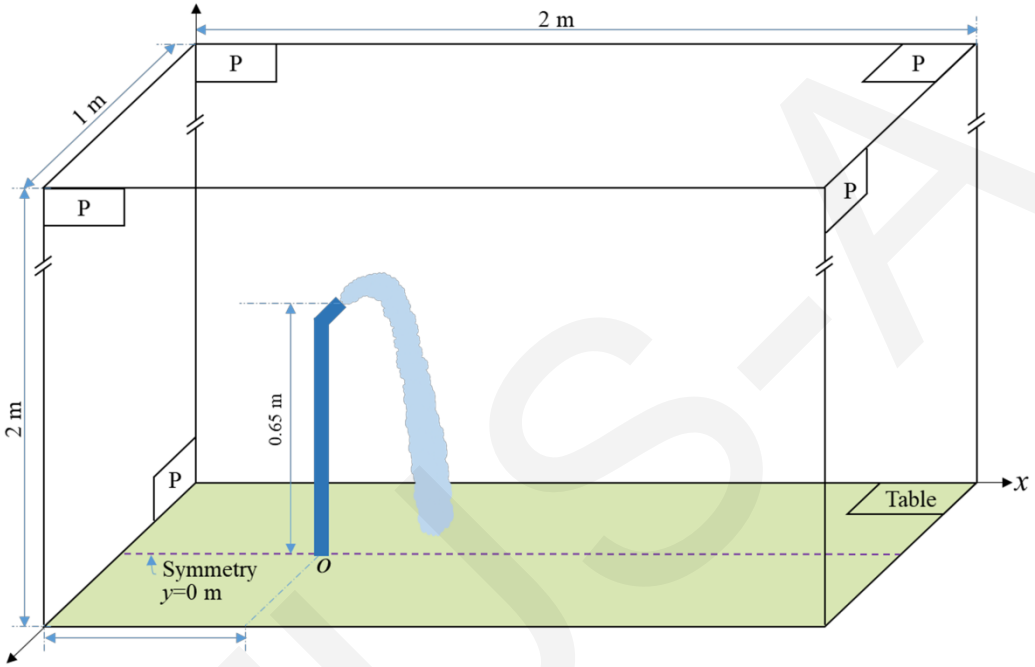


Experimental methodology



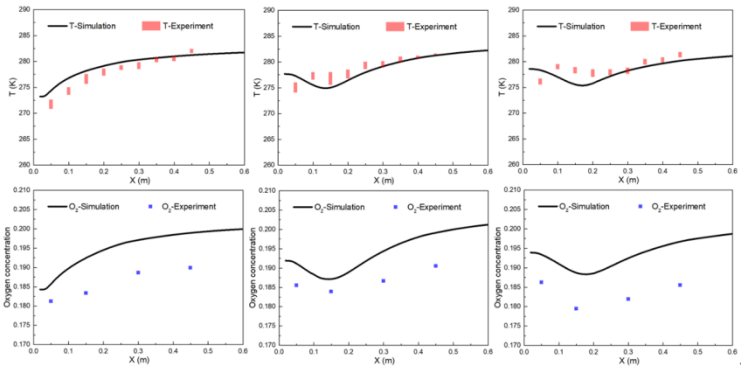


Volume flowrate of GN_2 at room temperature, V_r (L/min)	Exhaust velocity, U_e (m/s)	Exhaust temperature, T_e (K)
30	0.285	180
50	0.421	155
70	0.514	135
155 (simulation)	0.885 (simulation)	110 (simulation)

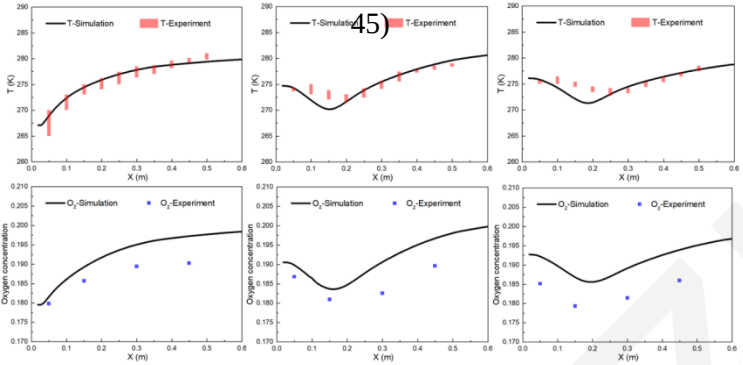


Boundary location	Boundary type
N_2-exhaust (outlet of the exhaust pipe)	Velocity-inlet
Left surface (x=−0.5 m)	Pressure-outlet
Right surface (x=1.5 m)	Pressure-outlet
Front surface (y=0.5 m)	Pressure-outlet
Rear surface (y=−0.5 m)	Pressure-outlet
Top surface (z=2 m)	Pressure-outlet
Bottom surface (table, z=0 m)	Wall

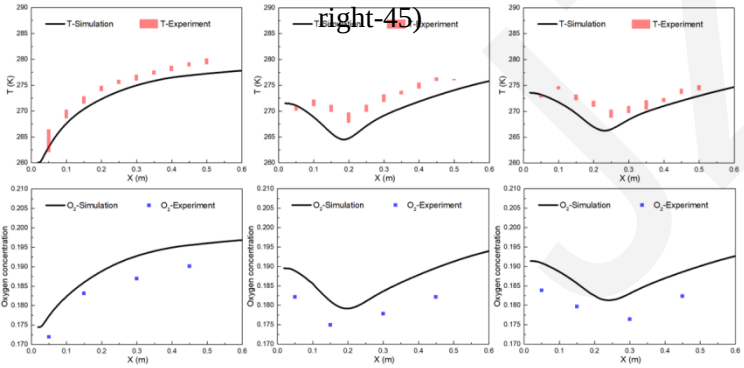
Results and analyses



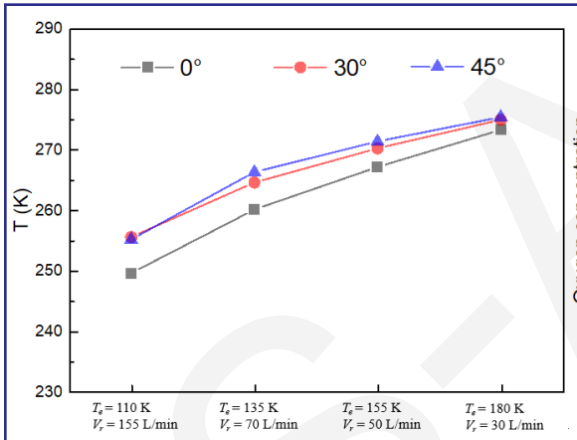
Group A: V_r =30 L/min, T_e=180 K (left-0°, mid-30°, right-45)



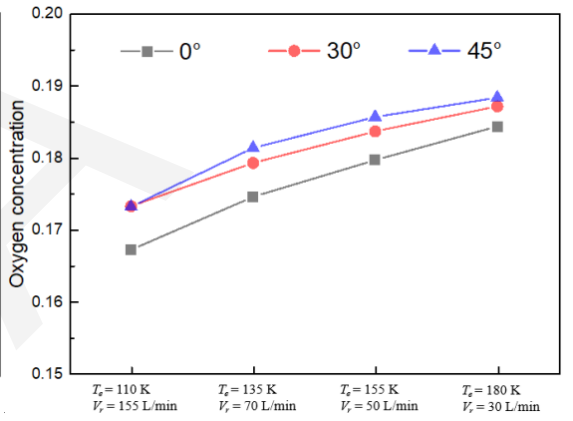
Group B: V_r =50 L/min, T_e=155 K (left-0°, mid-30°, right-45)



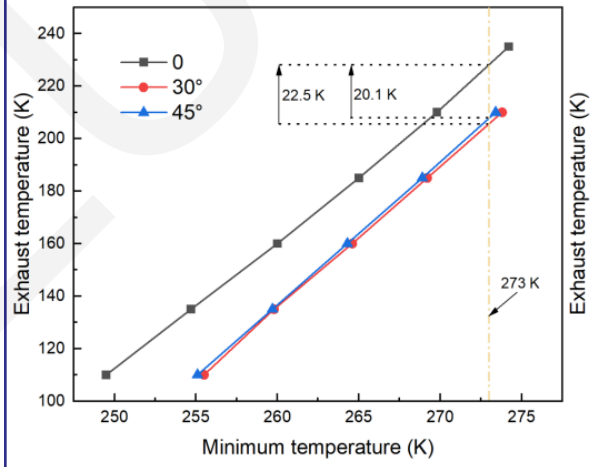
Group C: V_r =70 L/min, T_e=135 K (left-0°, mid-30°, right-45)

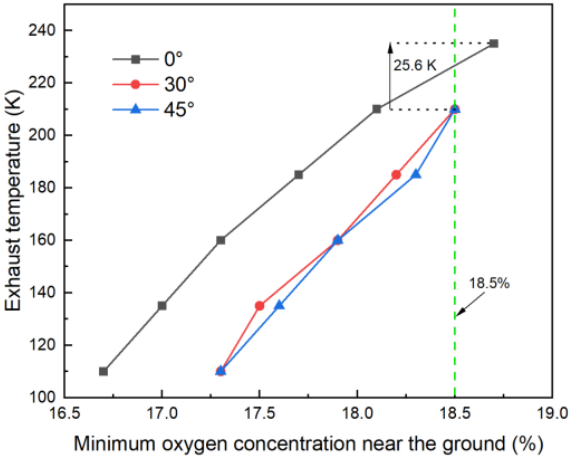


Simulated minimum T at z=1 mm with different angles of inclination



Simulated minimum O_2 vol% at z=1 mm with different angles of inclination





Simulated plume dispersion results at z=1 mm with different inclined-angle exits with different exhaust temperature

The comparative analysis based on the experimental and further simulation results shows that the new exhaust method with the inclined exit of 30° or 45° can effectively reduce the settlement hazard of the cryogenic plume, compared with the conventional vertical exhaust method, and the more severe the exhaust conditions (V_r↑, T_e↓), the better the effect.

The theoretical energy-saving potential of the new exhaust method with an inclined exit is calculated by taking the extreme exhaust case of the 0.3-m cryogenic wind tunnel as an example. Compared with a burner, this energy-free structural optimization with a 30° or 45° inclined exit can save up to 15.9% of heating energy consumption under windless conditions, while meeting the same emission safety standards. In addition, the new exhaust method with an inclined exit can raise the safe lower limit of the exhaust system.

In future studies, further consideration should be given to the influence of environmental wind speed and direction on the exhaust process of cryogenic nitrogen gas based on an inclined wind-tunnel exit. Finally, the optimal angle of inclination and horizontal angle between exit and wind should be obtained, with different weather and exhaust parameters.