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Abstract

Fluid flow systems for delivery of oxygen and nutrition, as well as removal of waste, can be found in all natural living systems. Respiratory and blood circulation systems in animals, trophic fluid systems in sponges, and veins in plants are examples of optimal transportation systems with minimum energy losses [1]. The nasal cavity in reindeers gives an example of efficient heat and mass exchange, able to quickly heat up the ambient air from -30°C to 38°C and to moisturize it from ~20% to 100% 2. An equivalent 1D model based on measured data of perimeters, cross-section areas and distribution of blood vessels along the nasal airway of the reindeer showed better performance during respiration, than a simple cylindrical shaped reference nose [2, 3]. Moreover, while the fully developed reindeer's nasal geometry is more efficient at lower temperatures, the reindeer calf's nasal geometry showed an opposite trend. In both cases, performance was quantified in terms of entropy production.
opportunities, challenges and literature is presented. Key aspects are illustrated by simple examples while smaller case studies indicate potentials for industrial applications.

Natural designs of efficient heat and mass exchangers

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Fluid flow systems for delivery of oxygen and nutrition, as well as removal of waste, can be found in all natural living systems. Respiratory and blood circulation systems in animals, trophic fluid systems in sponges, and veins in plants are examples of optimal transportation systems with minimum energy losses [1]. The nasal cavity in reindeers gives an example of efficient heat and mass exchange, able to quickly heat up the ambient air from -30°C to 38°C and to moisturize it from ~20% to 100% 2. An equivalent 1D model based on measured data of perimeters, cross-section areas and distribution of blood vessels along the nasal airway of the reindeer showed better performance during respiration, than a simple cylindrical shaped reference nose [2, 3]. Moreover, while the fully developed reindeer's nasal geometry is more efficient at lower temperatures, the reindeer calf's nasal geometry showed an opposite trend. In both cases, performance was quantified in terms of entropy production.

In this work, we use the equivalent 1D model to study the influence that nasal geometries of polar and non-polar animals have on heat and mass transfer. In addition, we estimate their efficiency as air heaters and moisturizers. We show that the use of the equivalent tube hydraulic diameter Dh does not properly describe the influence of the complex non-convex cross sections on heat and mass transport. Thus, a new parameter accounting for the tortuosity Td of the different cross sections is proposed. The nasal airways of the juvenile reindeer, reindeer calf, and a white-tailed deer are classified in terms of Td, and the entropy production during respiration is computed taking this new parameter into account. The geometry of these efficient natural systems can be used as inspiration for the design of energy-efficient mass- and heat-exchange processes.

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