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Review

A review of heat transfer between concentric rotating cylinders with or without axial flow

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ABSTRACT

Heat transfer in flow between concentric rotating cylinders, also known as Taylor–Couette flows, constitutes a long-existing academic and industrial subject (in particular for electric motors cooling). Heat transfer characteristics of those flows are reviewed. Investigations of previous works for different gap thickness, axial and radial ratio, rotational velocity are compared. Configurations with axial flow and/or with slots on the cylinders are also considered. For each case, different correlations are presented. Finally, unresolved issues are mentioned for further research.

1. Introduction

Flow dynamics between two concentric rotating cylinders constitutes an old academic subject since Couette [1] and Taylor [2], whose names are recalled in the term Taylor–Couette flow, which has become a reference in stability studies due to the gradual destabilizing of a flow lending itself to a rigorous mathematical approach. Moreover, this kind of flow has many industrial applications, particularly in the fields of mechanical or chemical mixing equipment. It has consequently been the subject of several bibliographic reviews by Di Prima and Swinney [3], Cognet [4], and Maron and Cohen [5].

The heat transfer in this flow and the impact of flow structures on heat transfer were more recently studied (Gazley [6]); there already existed numerous industrial applications of the rotating elements (rotation, outer wall of the rotating heat pipes, cooling of the lower extremities of the turbojet turbine…), especially in electric motors. Indeed, different studies [7,8] on the heat transfer of electric motors have demonstrated the importance of convective heat transfer within the cylindrical gap (area separating the rotor from the stator). In fact, the rotor is the locus for large-scale dissipations of electromagnetic origin, and its cooling is ensured principally by the air flow of the cylindrical gap. Two main families of rotating electric machines may be distinguished; closed machines (rotor rotation without axial air flow: Taylor–Couette flow), and open machines (axial flow combined with rotor rotation: Taylor–Couette–Poiseuille flow). Moreover, as regards some motor technologies, the existence of grooves on the rotor (where copper threads, for example, may be coiled) is liable to significantly modify the dynamic and the thermal flow behavior.

Excepted a short part of the bibliographic review by Maron and Cohen [5], no very detailed analysis of heat transfer in a rotating annular gap has ever been carried out. This bibliographic review is focused on the heat transfer of Taylor–Couette flow patterns. The kind of thermal behavior to be studied is obviously linked to the dynamics of these kinds of flow. We shall present in detail the different forms of flow already encountered, but our survey is not exhaustive.

2. The fundamentals of Taylor–Couette flow

Let us first look at the different parameters of influence. We shall consider a basic system composed of two concentric cylinders (Fig. 1). Its geometry is characterized by two radii, the outer radius of the inner cylinder R_1 and the inner radius of the outer cylinder R_2, as well as their length L. The flow is then characterized by the following geometric parameters: hydraulic diameter: $D_h = (4S_p/P_m) = (2[\pi(R_2^2 - R_1^2)]/\pi(R_2 + R_1))$, annular gap thickness (also known as cylindrical gap): $e = R_2 - R_1$, radial ratio $\eta = R_1/R_2$, and axial ratio: $\Gamma = L/R_2 - R_1$.

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