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A heat transfer correlation for the suction and compression chambers of scroll compressors

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ABSTRACT

Heat transfer in the suction and compression chambers of scroll compressors has not been sufficiently studied and typical correlations available in the literature are based on simplified flow conditions. This paper presents the results of a model developed to predict fluid flow and heat transfer inside the suction and compression chambers of scroll compressors. Due to the particular geometry of scroll compressors, an algorithm was developed to adapt the computational mesh automatically for each orbiting angle. Convective heat transfer is strongly affected by the flow in the near-wall region and for this reason a low-Reynolds-number turbulence model was adopted in the simulations. The study covered a wide range of operating conditions and geometric parameters, allowing the proposal of a characteristic velocity for the flow inside the suction and compression chambers and a new heat transfer correlation for scroll compressors, which is compared with other correlations adopted in the literature.

Corrélation du transfert de chaleur pour les chambres d'aspiration et de compression des compresseurs à spirale

Mots clés : Compresseur à spirale ; Transfert de chaleur ; Modélisation du compresseur ; Analyse numérique

1. Introduction

Scroll compressors are positive displacement machines of orbital motion that compress a gas by means of two conjugated spiral-shaped members. Such compressors are widely employed in air conditioning, refrigeration and water heating due to their high reliability, low noise levels and high efficiency. In the suction process of scroll compressors, the refrigerant is heated as it comes into contact with hot components, such as the electric motor, bearings, and compressor housing. Some of the heat is rejected to the outside environment through the compressor housing, and the remainder heats the refrigerant admitted into the suction line. Fig. 1 outlines the interactions between the sources and the heat paths in a typical low-pressure-housing scroll compressor. Some gas superheating in the suction process is necessary, primarily to cool the electrical motor but also to avoid the presence of liquid

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Nomenclature

a	radius of the basic circle of the scroll [m]
A_s	surface area of the control volume [m^2]
c_p	specific heat at constant pressure [J kg^{-1} K^{-1}]
c_v	specific heat at constant volume (J kg^{-1} K^{-1})
C^*	chamber dimensionless curvature [–]
D_h	hydraulic diameter [m]
h	wrap height of scroll [m]
h_c	convective heat transfer coefficient [W m^{-2} K^{-1}]
k_f	fluid thermal conductivity [W m^{-1} K^{-1}]
L_i	length of the inner involute [m]
L_o	length of the outer involute [m]
$L_{w;int}$	length of the inner lateral wall [m]
$L_{w;ext}$	length of the outer lateral wall [m]
f_c	compressor operating frequency [s^{-1}]
N	number of compression chambers [–]
Nu	Nusselt number [–]
Nu_{DB}	Nusselt number given by correlation of Dittus–Boelter [–]
Pr	Prandtl number [–]
Pr_t	turbulent Prandtl number [–]
q_w	heat flux at the wall [W m^{-2}]
r_0	orbiting radius of the rotating scroll [m]
Re	Reynolds number [–]
R_c	average curvature radius [m]
S_t	Strouhal number [–]
t	wrap thickness of scroll; time [m; s]
T_{dis}	discharge gas temperature [K]
$\bar{T}_g$	mean gas temperature [K]
T_{suc}	suction gas temperature [K]
$\bar{T}_w$	mean wall temperature [K]
T_w^*	ratio between T_w and T_g [–]
U_s	characteristic velocity [m s^{-1}]
V	volume of the control volume [m^3]

Greek letters

α	initial involute angle [–]
α_i	initial angle of the inner involute [–]
α_o	initial angle of the outer involute [–]
γ	specific heat ratio [–]
μ	fluid dynamic viscosity [Pa·s]
μ_t	turbulent (eddy) viscosity [Pa·s]
ρ	fluid density [kg m^{-3}]
φ	involute angle [–]
φ_e	final involute angle [–]

in the compression chambers. However, suction gas superheating negatively affects the compressor performance. The first effect is a reduction in the volumetric efficiency due to a decrease in the gas density, reducing the cooling capacity of the system. The second consequence is a reduction in the isentropic efficiency brought about by an associated increase in the specific work of compression (Kremer et al., 2012).

Most simulation models for the thermodynamic analysis of scroll compressors adopt integral formulations (Chen et al., 2002; Diniz et al., 2015). The accuracy of such models is dependent on the adequate description of the different processes involved, such as suction and discharge, leakage and heat transfer. However, there are few studies (Jang and Jeong, 2006; Ooi and Zhu, 2004; Sunder, 1997) dedicated to convective heat transfer in scroll compressors, mainly due to the level of complexity imposed by the restricted space for measurement and small time scales. As a consequence, there remains much uncertainty regarding the prediction of heat transfer for operating conditions found in actual applications.

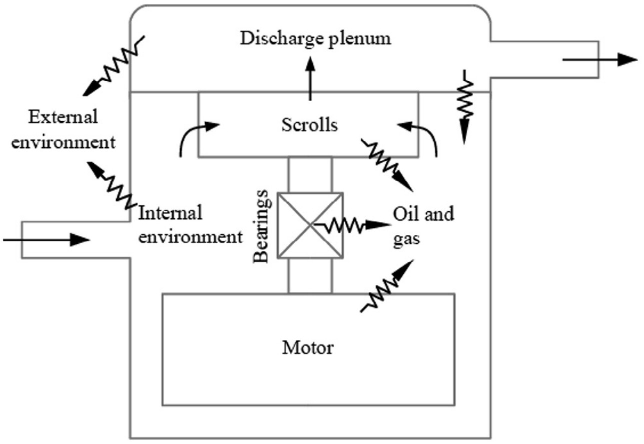

Fig. 1 – Heat sources and pathways in a typical low-pressure-housing scroll compressor.

Based on experimental results and correlations of heat transfer for turbulent pipe flows, Sunder (1997) noted that the physical contact between the stationary and orbiting scrolls would be the primary heat transfer mechanism during the compression process. However, his measurements for the temperature profile of the stationary scroll differ from experimental data obtained in other studies, indicating that this heat transfer mechanism is not always operating.

Ooi and Zhu (2004) developed a simulation model for the study of flow and heat transfer in the compression chamber of a scroll compressor. They adopted the standard k–ε turbulence model and wall-functions, in addition to specifying a turbulent Prandtl number of 0.6, based on empirical results for Wankel engines. For some operating conditions, their predicted values for the heat transfer coefficient were much higher than those reported by Sunder (1997).

Jang and Jeong (2006) made a comprehensive experimental thermal analysis of scroll compressors and measured the temperature distribution in the stationary scroll. The authors also analyzed heat transfer for specific conditions using the simplified geometry of an oscillating plate to simulate the orbiting scroll and proposed a correction factor for the Nusselt number based on the Strouhal number to include the effect of the oscillating motion. Jang and Jeong (2006) pointed out that their correlation was able to predict the discharge temperature better than other correlations, including that for spiral heat exchangers adopted by Chen et al. (2002).