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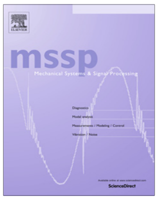

External gear pumps operating with non-Newtonian fluids: Modelling and experimental validation

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A R T I C L E I N F O

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External Gear Pumps are used in various industries to pump non-Newtonian viscoelastic fluids like plastics, paints, inks, etc. For both design and analysis purposes, it is often a matter of interest to understand the features of the displacing action realized by meshing of the gears and the description of the behavior of the leakages for this kind of pumps. However, very limited work can be found in literature about methodologies suitable to model such phenomena. This article describes the technique of modelling external gear pumps that operate with non-Newtonian fluids. In particular, it explains how the displacing action of the unit can be modelled using a lumped parameter approach which involves dividing fluid domain into several control volumes and internal flow connections. This work is built upon the HYGESim simulation tool, conceived by the authors' research team in the last decade, which is for the first time extended for the simulation of non-Newtonian fluids. The article also describes several comparisons between simulation results and experimental data obtained from numerous experiments performed for validation of the presented methodology. Finally, operation of external gear pump with fluids having different viscosity characteristics is discussed.

1. Introduction

External gear pumps are among the simplest and most inexpensive positive displacement machines available in the market. They are also very compact, robust and have high power to weight ratios. Fig. 1 shows the exploded view of the external gear pump taken as reference in this work. The pump consists of two meshed gears. The volumes between the gear teeth (called tooth space volumes) form the displacement chambers. The tooth space volumes are sealed on the radial side by the inner surface of the casing and on lateral side by front and end covers. It is to be noted that in the reference unit, there is no lateral gap compensation like in units used for high pressure applications [1]. Fig. 2 shows the working principle of an external gear pump. As the gears rotate, the set of tooth spaces coming out of the meshing zone increase in volume thereby sucking fluid from the inlet. At the same time, other set of tooth spaces go into the meshing zone decreasing in volume thereby displacing the fluid to the delivery. In order to realize the fluid displacement also in the regions where the tooth spaces are trapped between the points of contact of the gears, lateral relief grooves are provided on the front and end covers. These grooves thus realize a connection between the tooth space volumes and the suction/delivery ports. A proper profile of such grooves permits a smooth transition for the displacement chambers from high pressure to low pressure during the meshing region, and avoids the occurrence of internal pressure peaks or localized cavitation [2,3].

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Nomenclature

A	area
A_{ref}	reference area (maximum area of the orifice HV/LV)
b	gap width
d	orifice diameter
Eu	Euler number
C_d	discharge coefficient
H	gap height
H_{ref}	reference gap height (nominal clearance between the gear tooth and the pump casing)
I	interaxis
k	power law flow consistency index
l	thickness of orifice
L	length of the plate
L_h	length of the circular hole
$\dot{m}$	mass flow rate
n	power law flow behavior index
n_{ref}	reference flow behavior index
p, P	pressure
P_{ref}	reference pressure (maximum differential pressure across the pump in experiments and simulations)
q, Q	flow rate
Q_{ref}	reference flow rate (Kinematic flow rate at reference pump speed).
R	radius of circular hole
Re	Reynolds number
t	time
U	surface velocity
V	volume
V_{ref}	reference volume (maximum volume of a TSV)
v	plate/moving wall velocity
Wi	Weissenberg number
x, y	coordinate directions
x_1	x coordinate position of drive gear
y_1	y coordinate position of drive gear
x_2	x coordinate position of free gear
y_2	y coordinate position of free gear
z	direction of flow

Greek letters

β	orifice diameter ratio i.e. ratio of orifice diameter to pipe diameter
$\dot{\gamma}$	shear rate
$\dot{\gamma}_{ref}$	reference shear rate
$\dot{\gamma}_{cr,high}$	high critical shear rate (a shear rate above which the fluid becomes Newtonian and below which the fluid follows power law of viscosity)
$\dot{\gamma}_{cr,low}$	low critical shear rate (a shear rate below which the fluid becomes Newtonian and above which the fluid follows power law of viscosity)
λ	relaxation time
μ	viscosity
μ_0	zero shear rate viscosity
μ_∞	infinite shear rate viscosity
μ_{ref}	reference viscosity
ρ	density
Ω	area

Subscripts

i, j	index of volume
var	variable
x, y	coordinate system
z	direction of pressure gradient

Abbreviations

CV	Control Volume