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Observations of acoustically generated cavitation bubbles within typical fluids applied to a scroll expander lubrication system

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ABSTRACT

An experimental study to evaluate the dynamic performance of three different types of cavitation bubbles is conducted. An ultrasonic transducer submerged into the working fluids of a scroll expander is utilised to produce cavitation bubbles and a high speed camera device is used to capture their behaviour. Three critical regions around the ultrasonic source, between the source and the solid boundary, and across the solid boundary were observed. Experimental results revealed that refrigerant bubbles sustain a continuous oscillatory movement, referenced as "wobbling effect", without regularly collapsing. Analytical results indicate the influence of several factors such as surface tension/viscosity ratio, Reynolds number and Weber number which interpret that particular behaviour of the refrigerant bubbles. Within the refrigerant environment the bubbles obtain large Reynolds numbers and low Weber numbers. In contrast, within the lubricant and the water environment Weber number is significantly higher and Reynolds number substantially lower. The bubble radius and velocity alterations are accurately calculated during the cavitation process. Lubricant bubbles achieve the highest jet velocity while refrigerant bubbles having the lowest jet velocity are not considered as a destructive mean of cavitation for scroll expander systems.

1. Introduction

Scroll expanders have been a key component of many industrial systems over the last 20 years (CHP systems, air-conditions, pumps, etc.). A specific scroll expander was tested for 1000 h as a part of a small domestic combined heat and power (CHP) system. Cavitation was identified as a wear mechanism during the investigation of the scroll's components [1]. The cavitation mechanism developed inside the scroll is caused by the operational fluid environment [2]. This environment includes two fluids; a high molecular organic refrigerant and a synthetic lubricant. The refrigerant, as a gas form, drives the scroll while the lubricant protects the parts of the scroll from excessive wear. Thus the present study focuses on these two scroll fluids and in the dynamic behaviour of their cavitation bubbles investigating their engineering implications to scroll expander systems or similar automotive industrial units. Limited experimental information concerning lubricant and refrigerant bubble formation and their dynamic behaviour [2–6] is available within the published literature.

The influence of viscosity and surface tension upon cavitation threshold has led to some debate within published literature, with claims of increased or decreased cavitation activity arising from different studies of similar environments. Brujan et al. [7] in polymer aqueous solutions has shown that higher levels of viscosity can substantially mitigate the tendency of cavitational activity to damage. Popinet and Zaleski [8] in his study has found that the amplitude of the oscillations decreases due to viscous damping, while the jet impact velocity decreases as viscosity increases. Williams et al. [9] and Berker et al. [10], reported a mitigating effect of viscosity in the jet propulsion by the bubbles collapse of various fluids. Karunamurthy et al. [11] presents the viscosity influence of various lubricants on erosion rate, showing that as the viscosity increases the erosion decreases. In contrast, Meged et al. [4] after a series of experiments using 20 different types of liquid lubricants, has found that there is no direct correlation between the viscosity of a liquid and the cavitation erosion mechanism. In regards to surface tension in a micro-scale level, the bubble growth and the elongation are influenced by the surface tension forces which are dominant at this scale [12]. According to Iwai and Li [13], experiments conducted in various water solutions with different surface tensions, showed that surface tension increases the liquid-jet impact and the bubble size. In contrast Liu et al. [14] has shown that in a cavitation environment higher surface tension values leads to smaller sized bubbles reducing the collapse duration.

In the present study cavitation tests were utilised to analyse and evaluate the dynamic behaviour of the cavitation bubbles generated within the refrigerant and the lubricant environment of a scroll expander system. Distilled water was also used as a

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