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Experimental evidence of the thermal effect of lubricating oil sprayed in sliding-vane air compressors

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ABSTRACT

A way to increase the efficiency of positive-displacement air compressor is spraying the lube oil to exploit it not only as lubricating and sealing agent but also as thermal ballast. This work seeks the experimental evidence in sliding-vane compressors by measuring the air standard volume flow rate and the electrical power input of three diverse configurations. The first configuration, taken as the reference, employs a conventional injection system comprising calibrated straight orifices. The other two, referred to as advanced, adopt smaller orifices and pressure-swirl full-cone nozzles designed for the purpose; the third configuration utilizes a pump to boost the oil pressure. The laser imagining technique shows that the nozzles generate sprays that break-up within a short distance into spherical droplets, ligaments, ramifications and undefined structures. Tests on the packaged compressors reveal that the advanced configurations provide almost the same air flow rate while utilizing half of the oil because the sprays generate a good sealing. Moreover, the sprayed oil is acting as a thermal ballast because the electrical input is reduced by 3.5% and 3.0%, respectively, if the pump is present or not , while the specific energy requirement, accounting for the slightly reduced air flow, by 2.4% and 2.9%, respectively.

1. Introduction

Positive-displacement machines are used widely for air compression in commercial and industrial applications. As in many other fields, the efficient utilization of energy has become a major goal. A way to increase the efficiency is spraying the lube oil into the gas as small droplets in order to exploit it not only as lubricating and sealing agents, but also as a thermal ballast with a great thermal capacity (thanks to its high density and heat capacity) and large exchange surface. In the past, Singh and Bowman [1] and Stosic et al. [2] analyzed numerically and verified experimentally the positive effect of sprayed oil on the shaft power of screw compressors, which was reduced by 2.8–8.3%. Over the years, other scientists achieved the same conclusions, despite a very few like De Paepe et al. [3] estimated benefits lower than 1%.

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This work seeks for the experimental evidence of the thermal effect of lubricating oil sprayed in sliding-vane air compressors, starting from the positive indications of a previous study [4]. Due to their cylindrical shape, sliding-vane compressors are particularly adequate because oil can be sprayed axially from the end plates. The compressors investigated here are electrically driven and packaged. Thus, the experimental evidence is sought by measuring the air standard volume flow rate and the electrical power input and by reconstructing the pressure-angle diagram (known as the indicator diagram) in a compressor equipped with either a conventional injection or an advanced spraying system. The advanced system is implemented in two configurations, depending whether an external pump is employed to boost the oil pressure.

2. Compressor configurations

The reference compressor is a large-size sliding-vane rotary compressor in which lubricating oil is inserted into the chambers with a conventional system comprising a number of calibrated straight orifices drilled on the stator.[1] Considering the compressor stator is a cylinder, the orifices are placed on the lateral surface, aligned along the axis, and positioned relatively close to the discharge port. Consequently, in the reference compressor oil is injected radially inward onto the rotor in a chamber in which air has already reached a high temperature due to the compression process. A pump is not required for this injection because the pressure of the oil after separation from the air is sufficient to sustain the injection.

The advanced compressors differ from the conventional by the way oil is inserted into the chambers. The diameter of the calibrated straight orifices is halved so that the flow rate through the orifices is roughly a quarter of the conventional. A number of pressure-swirl full-cone nozzles, specifically designed for the scope of generating small droplets at quite large flow rates,[2] are employed in addition to the calibrated orifices. A pressure-swirl nozzle is an atomizer that generates liquid droplets imparting a swirl motion to the fluid prior to entering an orifice so that the centrifugal forces break the fluid as soon as it leaves the orifice [5, Chapter 10]; the generated cone of droplets may be full (also said solid) or hollow.

The nozzles are mounted on the end plates and are distributed from the suction to the discharge port. Consequently, the oil through the nozzles is inserted axially in chambers in which air is increasingly reaching higher temperatures. Given the relatively large size of the nozzles, only up to four of them can be mounted on one end plate and none on the lateral surface where the calibrated orifices are. Two configurations of the advanced compressor are implemented: one configuration does not employ a pump, whereas the second uses a pump to boost the oil pressure exclusively for those nozzles positioned close the discharge port, where the air temperature and pressure are the highest. The flow rate of the oil through the nozzles is slightly less than a quarter of the conventional in the configuration without the pump, and slightly more with the pump. Briefly, the advanced configurations have an overall oil flow rate that is half of conventional; moreover, this flow rate is split almost equally between the calibrated orifices and the pressure-swirl nozzles.[3] The advanced compressor during the final stages of manufacturing are pictured in Fig. 1, whereas a schematic of the position on one end plate of the pressure-swirl full-cone nozzles (as well as of the piezoelectric pressure transducers, see below) is reported in Fig. 2.

3. Experimentation

Two different experimental campaigns are conducted. First, the nozzle sprays in an atmospheric reservoir are characterized at diverse oil pressures and temperatures with the laser imaging technique. A solid-state laser generates a monochromatic green light beam for the very short period of 5 μs that is directed into the spray. A camera captures the resulting scattering in photos that highlight the spray structure.

In the second campaign, the reference and the advanced compressors are tested on a rig that allows measuring:

- temperature, pressure and humidity of air at ambient conditions;
- temperature and pressure of air and oil along the process;
- pressure drop across an ISA 1932 nozzle;
- volume flow rate of oil through the external pump;
- rotational speed of the compressor;
- electrical power input to the package.

From the data, the actual delivered flow rate of air is computed accordingly to standard ISO 5167. Subsequently, the standard volume flow rate of air and the specific energy requirement of the packaged compressors are calculated accordingly to standard ISO 1217. The combined measurement uncertainty on the standard volume flow rate is in the 4.5–5.5% range (computed with the practical working formula of ISO 5167), the measurement uncertainty on the electrical

[1] The reference compressor is not a commercial unit because it employs modified inlet valve, suction port, discharge port and air–oil separator (see Fig. 1) that allow altogether an increase of air standard volume flow rate by 3.6%.

[2] The nozzles adopted here are different from the commercial ones analyzed in the previous investigation, [4], because they are tailored for the advanced compressor.

[3] A previous experience on a small-size compressor with calibrated straight nozzle and halved oil flow rate indicated that the performance decreased, so that this case is not investigated here on this larger unit.