Performance improvement of an industrial Stirling engine heat pump

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Abstract:
After widespread use for refrigeration and cooling, heat pumps (HPs) are also becoming mainstream for private and public building heating. Driving forces are the need to reduce greenhouse gas emissions and the increased availability of renewable electricity. Nowadays, HPs find use in industry, choosing for low temperature (waste) heat and cheap (renewable) electricity rather than a combustion system for the production of process heat. However, temperatures above 150°C still present challenges for HP systems based on a vapour-compression process, being limited by compressor technology and availability of suitable refrigerants. So-called very high temperature heat pumps (VHTHPs) based on alternative processes using renewable electricity are an attractive "green" route to producing ~200 °C steam. This paper describes work aiming at improving the performance, reliability and efficiency of an industrial Stirling engine-based heat pump system in operation at a pharmaceutical research facility. It is funded by the EU Horizon 2020 FTI programme, targeting reduced greenhouse gas emissions, efficient use of energy and increased use of renewable energy resources. In short, heat output shall increase from 500 kW to 750 kW closer to 200°C rather than 180°C with input heat of ~ 30°C while efficiency expressed as coefficient of performance (COPHP) increases from 1.4 – 1.5 to 1.8 –1.9. The approach is to increase the pressure of the (helium) medium, while changes to the hardware would involve new designs for the internal heat exchanger, regenerator, piston rod seal, piston rings and other seals. CFD and structural mechanics models were used to simulate existing and future designs for heat exchangers, regenerator and seals while process dynamics simulations showed the response to, for example, small leaks and the effect of dissimilar temperature gradients in the heat exchangers or regenerator porosity. The results show how the existing system could be improved to obtain the enhanced performance aimed at.

Keywords:
Heat pump system, Stirling engine, increased output, efficiency, system dynamics

1. Introduction

The first decades of the 21st century have shown transitions and changes towards energy systems that have a higher efficiency, lower or zero emissions of greenhouse gases and a smaller environmental footprint in general. In today's world, the increased availability of electricity from renewable sources may on one hand be intermittent but on the other hand is more predictable than the pricing levels for natural gas. Heat pumps (HPs) have a long history with consumer products for refrigeration and air conditioning and can in principle use a cheap renewable source for both input heat and electricity. System purchases by users are nonetheless often motivated by an attractive coefficient of performance (COP). Industry is increasingly implementing HP technology that circumvents the formation of CO_2 when producing heat, although reaching sufficiently high temperatures > 150°C may be challenging (being limited by compressor technology and availability of suitable refrigerants). So-called very high temperature heat pumps (VHTHPs) [1] based on alternative processes using renewable electricity are an attractive "green" route to ~200 °C steam.