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Model of the expansion process for R245fa in an Organic Rankine Cycle (ORC)

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ABSTRACT

An Organic Rankine Cycle (ORC) is considered as one of the most environmental-friendly ways to convert different kinds of low temperature energies, i.e. solar, geothermal, biomass and thermal energy of exhaust gases into electrical energy. Two important facts about the ORC must be considered: An organic fluid is selected as the working fluid and a high expansion ratio is usually presented in the machinery due to thermodynamic and efficiency factors. In the past, the pre-design of turbomachinery has been based on the usage of ideal fluid laws, but the real gas effects have a significant influence in the ORC working condition, due to its proximity to the saturation vapor line. In this article, the Equations of State (EoS) (Ideal gas, Redlich-Kwong-Soave and Peng–Robinson) have been evaluated in a typical ORC expansion in order to observe the inaccuracies of the ideal gas model with different thermodynamic variables. Finally an isothermal process followed by an isochoric process is proposed to reproduce the thermodynamic process of the organic fluid expansion by means of simpler equations. In the last point of this paper, several examples of this expansion process have been calculated, in order to analyze the proposed methodologies. It has been concluded that in typical expansion process of ORC (2.5 MPa-0.1 MPa and 1.6MPa-0.1 MPa), the PR and RKS equations show deviations between 6% and 8% in specific energy. These deviations are very low compared with the ideal gas equation whose deviations are above 100%.

1. Introduction

The trends of rising fuel costs and the necessity of reducing CO_2 emissions is forcing governments and industries to focus on the development of low temperature heat energy recovery systems.

Many solutions have been proposed to generate electricity form waste thermal energy produced by industrial processes and power plants. Generally, the conventional methods for energy recovery in industrial process are economically infeasible due to the low temperature of the heat source (less than 500 K). Among the proposed solutions, the Organic Rankine Cycle (ORC) is the most widely used [1]. The ORC consists of the classical steam generation in a Rankine cycle using an organic working fluid instead of water. The organic fluid is usually characterized by low saturation temperatures and by a saturated vapor line with positive slope in the *T*–*s* diagram [2,3]. This positive slope prevents the formation of a two-phase mixture during the expansion process through the turbine.

R245fa, also known as 1,1,1,3,3-Pentafluoropropane, is usually selected as the working fluid in ORC with low temperatures of heat sources due to different factors like its critical temperature, critical pressure and its pressure at 298 K (near atmospheric conditions). The ORC working conditions are usually between 300 K (condensation process) and 450 K (evaporation process) due to the low temperatures of the heat sources. The pressures associated to these temperatures are about 0.1 MPa and 2.5 MPa. These working conditions with high pressures near the saturated vapor line cause a deviation between the real and ideal gas behavior. This deviation is generated by neglecting molecular volume and intermolecular forces of the gas when the ideal gas model is considered. It is well known that when these organic fluids are studied, the ideal gas hypothesis can be regarded only under low temperature and low pressure conditions [4].

In these technologies for the recovering of waste energy, the design and the evaluation of expander machines are two of the most important aspects to achieve high efficiencies in the cycle. Typically, calculations with steam turbines using the ideal gas law are leading to acceptable results. But in this kind of technology, when organic fluids are considered, the differences between the ideal fluid model and the real thermodynamic behavior are quite important. In addition, if high expansion ratio is required, the supersonic impulse turbine (Laval Turbine) is the best choice as results of its easy regulation and cheap maintenance. A supersonic Laval nozzle in the stator is used to accelerate the flow to

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