Vapor Compression Refrigeration System Data-Based Comprehensive Model

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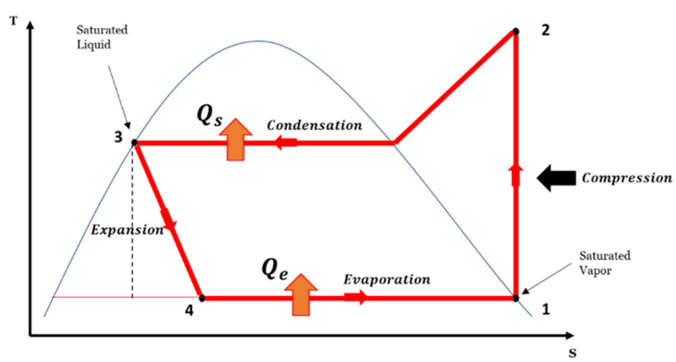
INTRODUCTION

VCRS are the most used cold production method worldwide. Approximately 30% of the energy is consumed in applications related to air conditioning (Jahangeer et al., 2011). VCRS integrate elements from multiple energy domains using the reverse Rankine cycle to subtract heat from a lower temperature tank to a higher temperature tank, figure 1. Much energy is required for such tasks. Energy comes from the power injection of an external source of electromechanical work (Wcomp) to compress and circulate a refrigerant, which undergoes phase changes as it absorbs and delivers heat. The refrigeration cycle to obtain the desired temperature inside a chamber begins when the refrigerant enters the compressor as saturated vapor (state 1) to be isentropically compressed until reaching a certain pressure and temperature in the superheated region (state 2). The compressed refrigerant enters the condenser to transfer heat (Qs) to the environment. The refrigerant leaves the condenser as saturated liquid (state 3). To low the refrigerant temperature, an expansion valve applies adiabatic throttling. in state 4, so it absorbs heat (Qe) in the evaporator space. The refrigerant is heated to recover its saturated vapor state repeating the cycle. Figure 1 represents the heat transfer in case of reversible processes. The area under the curve for process 4-1 represents the heat absorbed (Qe) by the refrigerant in the evaporator and the area under the curve for process 2-3 represents the heat rejected (Qs) in the condenser.

Figure 1. Temperature-entropy for the thermal cycle of a VCSR



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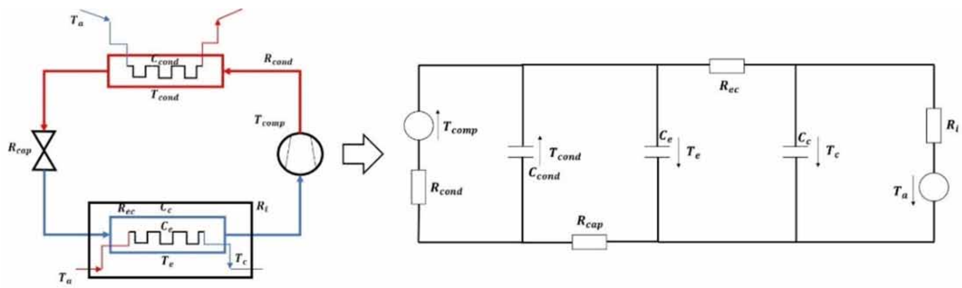
There is a growing interest in improving the energy efficiency of VCRS. Refrigerators accounts for a substantial portion of the annual energy consumption in the average home. The report (United Nations Environment Programme, 2018) on potentials to improve energy efficiency of refrigeration, air conditioning and heat pumps, highlights among the main measures with the greatest impact on energy saving: 1.- minimize the load of cooling, 2.- minimize temperature rise, 3.- consider variable operating conditions, 4.- select the most efficient refrigeration cycle and components, and, 5.- design effective control systems and verify operational performance correcting faults in existing systems. Given the need to improve the design, operation and use of energy in cold production, are necessary models that characterize in the most approximate way the real behavior of the installation (Belman Flores, 2008). A VCRS is a machine that from the electrical domain (motor) makes a conversion to the rotational mechanical domain (torque and RPM) acting on the hydraulic domain (pressure and flow) to finally reach the thermal domain, figure 2.

Figure 2. a) Diagram of a VCRS, b) Elements in a domestic fridge



This chapter illustrates the multidomain modeling of a VCRS to offer a holistic and unified representation that facilitates energy saving strategies and behaviors characterization of its components. The VCRS modeling starts from experimental data in the thermal domain on a commercial fridge (Schné et al., 2015) and is complemented with catalog data from other domains. This VCRS multi-domain model is not limited to the current state but includes recent advances in variable-speed compressors and adjustable-expansion valves. This approach allows exploring into the impact the new technologies that are projected as future solutions in intelligent control that affect the dynamics of the VCRS process. There are difficulties in achieving *a priori* a comprehensive visualization of the coupled behavior of a multidomain system. In VCRS, the thermal part has been studied in-depth but if the aim is to increase energy efficiency, the electromechanical excitation that drives the internal dynamics of the compressor must be considered.

The VCRS holistic model is made up of electrical, rotational mechanical, hydraulic, and thermal submodels. The Bond Graph (BG) method was applied. BG is based on the exchange and preservation of energy among elements; it applies equally to any energy domain. BG represents in a unified way with a minimum number of symbols the different elements of a system and their energetic interactions as well as the cause-effect relationships. The BG resulting model is a coupled differential equations system in state variables corresponding to the existing energy domains. In this chapter, the dynamic relationships among the various variables of each energy domain that make up the VCRS are modeled. The VCRS holistic model serves to identify the potential for energy savings in different behavior routes resulting from the intervention within the dynamics of the system. In the thermal dynamics, a model found ex-

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