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Research Paper

Using a multiple response optimization approach to optimize the coefficient of performance

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HIGHLIGHTS

- A statistical approach to optimize the refrigeration cycle's efficiency is illustrated.
- A multiresponse problem was formulated and solved under the RSM.
- The relationship between each response and control factors is modeled.
- Simultaneous optimization of refrigeration and electric powers is illustrated.
- Variable settings to maximize cycle's efficiency were identified.

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ABSTRACT

Response surface methodology was employed to optimize the efficiency of a refrigeration cycle demonstration unit using a multiresponse optimization approach. Statistically designed experiments were conducted to simultaneously minimize energy consumption and maximize the refrigeration effect of a compression refrigeration cycle. Regression models were fitted to refrigeration and electrical powers and optimal variable settings were identified using an easy-to-use optimization criterion. Results give confidence to apply the illustrated approach in academic and industrial settings, namely for optimizing equipment operation.

1. Introduction

Statistical design and analysis of experiments have enjoyed increased exposure and success across industries over the past three decades, and among their most often use are the design and development of processes and products. However, running experiments in real settings are not always possible, because it can be time-consuming, too expensive, technically difficult or even dangerous to be performed. Other reasons like resistance to change and low commitment of the management, among other business, educational and technical barriers, have also been reported in literature, as for instance, by Owen et al. [1] and Tanco et al. [2]. In this context, simulated or computer experiments and experimentation with prototypes (laboratory models) play an important role in the industry and the academy in designing and developing medical devices [3], biotechnological processes [4], military applications [5], and mechanical components [6], to cite only a few. Here, the focus is a refrigeration cycle, namely the one stage refrigeration compression cycle (hereafter denoted as RC).

The RC is a thermodynamic cycle incorporated in a diversity of equipments used, for example, in domestic and public rooms for air conditioning purposes, in food and pharmaceutical industries for refrigeration and conservation as well as in health services to maintain some medicines at low temperature. Its efficiency is usually assessed through the coefficient of performance [7,8], which is defined as the ratio between refrigeration power (heat-extraction capacity per unit time from the refrigerated medium), denoted by $\dot{Q}_{evap}$, and electric power (electric energy consumption per unit

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time), denoted by $\dot{W}_{elect}$. Therefore, simultaneous maximization of $\dot{Q}_{evap}$ and minimization of $\dot{W}_{elect}$ is an appropriate approach to optimize RC's efficiency. For this purpose, statistically designed experiments were performed as alternatives to the current practice of trial-and-error method or changing one-control factor-at-a-time, which works well only in specific conditions [9] and so must be avoided or discouraged. Then, $\dot{Q}_{evap}$ and $\dot{W}_{elect}$ were modeled and their models aggregated in a composite function followed by its optimization.

2. Experimental installation

A didactic refrigeration cycle installation, complemented with two auxiliary devices, was used to run experiments designed with the objective of optimizing the RC's efficiency. The didactic unit is a one stage refrigeration compression cycle produced by P.A. Hilton Ltd (see Fig. 1). It includes a hermetic compressor EMBRACO Asprea NEK6214Z (power = 0.5 HP), a condenser constructed from a thick-walled glass cylinder with machined brass end plates and a coil of copper tube inside (through which heating water flows), an evaporator constructed from a thick-walled glass cylinder with machined brass end plates and a coil of copper tube inside (through which cooling water flows), and an expansion valve (a float operated needle valve situated in the bottom of the condenser). The refrigeration fluid is R141b and the unit integrates analogical devices for measuring the pressures and water mass flow rates in both the condenser and the evaporator. Inlet and outlet temperatures in both the condenser and the evaporator were measured with digital thermometers. A verification procedure to validate the device outputs (the readings made with the devices) was performed. The estimated maximum error in the water mass flow rate readings was equal to ± 1 g/s while in the pressure readings the estimated maximum error was equal to ± 2.5 kN/m^2. In the temperature readings we estimate an uncertainty equal to $\pm\left(0.05/\sqrt{3}\right)$°C, assuming a rectangular distribution. These errors and uncertainties are too small so they were ignored in this study.

Two auxiliary apparatus were built for heating and cooling water in order to set the temperature in the inlet and outlet of both the evaporator and condenser at planned values. Hot water was produced by a gas burner, stored in a thermo-accumulator tank SOLCAP (capacity = 200 liters; electric heating power = 8 kW) to stabilize the temperature at specified values, and then pumped to the condenser (see Fig. 2). Cold water was obtained by introducing ice water in a tank where current water was stored, and then pumped to the evaporator at the desired temperature (see Fig. 3). The pump used in the water evaporator circuit was a Stuert Turner 1E100340X, with

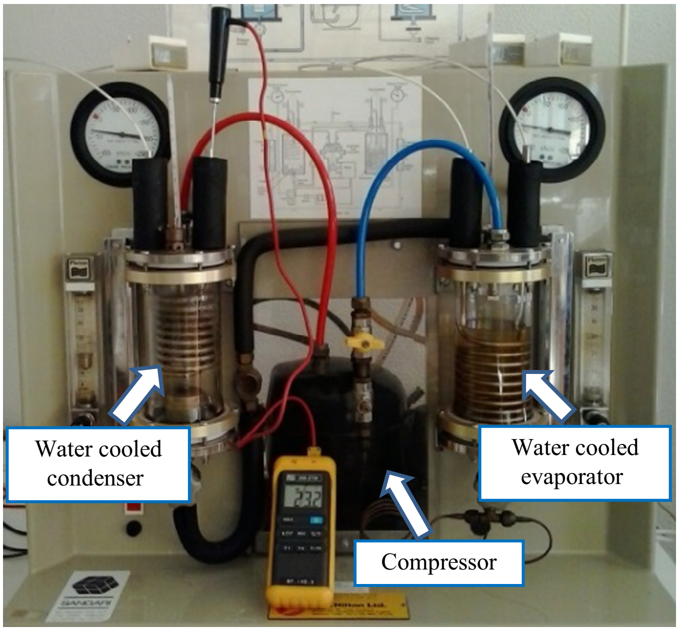

Fig. 1. Didactic unit.

Fig. 2. Heating water system.

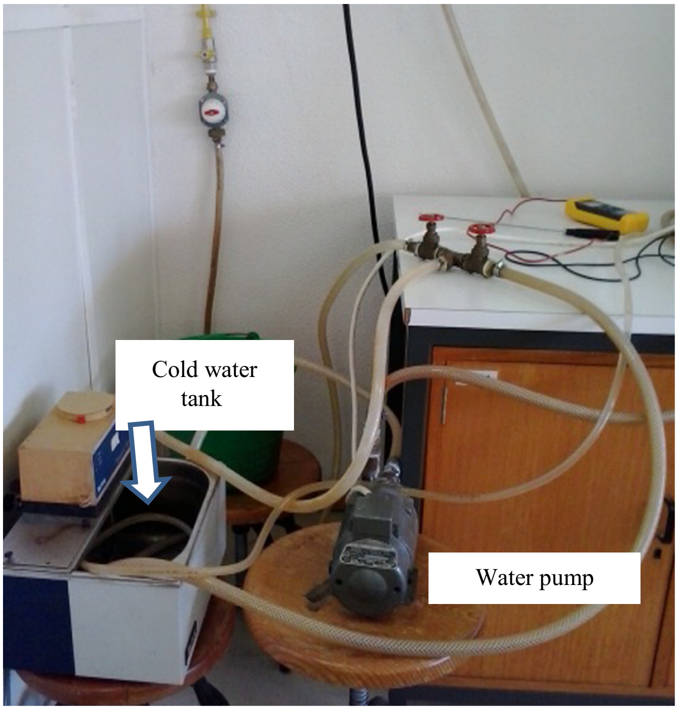

Fig. 3. Cooling water system.