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Comparative analysis of performance and techno-economics for a H_2O–NH_3–H_2 absorption refrigerator driven by different energy sources

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ABSTRACT

The objectives of the present work are of two-folds. First, it evaluates the transient temperature performance of the H_2O–NH_3–H_2 absorption cooling machine system's components under two types of energy sources, i.e. the conventional electric energy from grid (electric) and fuel energy from liquid petroleum gas (LPG). Results obtained have shown that performance of various components under different type of energy sources is almost coherent. For the evaporator, the system with electric supply has shorter starting time, around 6 min earlier than the system run with LPG. Meanwhile, the system powered by LPG produced a lower cooling temperature around −9 °C, compared to the system run with electric which produced temperature at around −7 °C. Economical study had been carried out subsequently, for three different energy sources, i.e. electric, LPG and solar energy (photovoltaic). From the techno-economical analyzes, it was found that the conventional electric from grid is still the best form of energy source for short-term application, as far as the present location and conditions are concerned. LPG is the next attractive energy source, especially at locations with constant LPG supply; the photovoltaic energy from solar is attractive for long term consideration since it has zero fuel cost and environmentally-friendly, but with the highest initial cost.

1. Introduction

Energy sources, system performance and economics are all interrelated and very much dependent in an energy-dependant system, such as that of air-conditioning system. The use of air-conditioning technology for cooling is not new; however, air-conditioning technology is required to evolve due to many environmental regulations, such as Montreal protocol in 1987, Kyoto Protocol and European Commission Regulation 2037/2000. These regulations or policy instruments are concerning the depletion of the ozone layer and global warming, which decided to phase-out CFCs and to be followed by HCFCs in conventional compression air-conditioning. As a result, this has lead to a strong demand for alternative air-conditioning technology. Absorption refrigeration is one of the alternative technologies that uses heat energy to produce desired cooling; as compared to the common refrigeration technique which uses electrical compressor to accomplish the same cooling effect. Unlike vapor compression refrigerator, absorption refrigerator could be driven by various energy sources and methods, e.g. (1) It can be powered by conventional electric energy, by means of a heating coil, to heat the solution mixture in the generator; (2) It can be driven by low heat source energy, such as waste heat, to heat the solution mixture in the generator; and (3) It can be driven by external heating of fossil fuel, by means of a gas burner, such as LPG.

The absorption cycle can be powered by waste heat. The ability to use unwanted heat causes such system to gain popular in the commercial cooling for energy recycle applications. Absolute low noise also is one of the added advantages of the absorption refrigerator, as pointed out by Horuz and Callander [1]. Moreover, it had been reported to cause zero or minimum ozone depletion by Misra et al. [2], etc., because it does not use any CFC or HFCs refrigerant as the working fluids.

Afif et al. [3] had conducted a study on the first and second law analysis of a power and refrigeration thermodynamic cycle using a solar heat source. In 2004, Horuz and Callander [1] had conducted an experimental investigation of a 10 kW vapor-absorption refrigeration system powered by natural gas to produce chilled water. In both papers, only the COP of the system under different energy sources was found. No detail techno-economical study is given in the papers.

In 2005, Misra et al. [2] have conducted the thermoeconomic evaluation and optimization of aqua-ammonia vapor-absorption refrigeration system. The objective was to use the thermoeconomic concept to minimize its overall production cost. In 2001, Ajib [4] from Germany has conducted the research on the profitability

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Nomenclature

A	ampere
C	capital cost
C_m	cost of machine
C_{se}	cost of supplying energy
F_m	annual fuel cost of the machine
C_{LS}	life cycle cost
C_F	cost of fuel
C_{OP}	annual operating cost
C_M	cost of maintenance
F	fuel cost
F_e	fuel cost of the electrical grid system
V	volt
RT	running tools
P	present value
I	interest rate earned at the end of each inters period
N	number of interest period
S	future value
R	uniform future value
RRI	real rate of interest
IRR	internal rate of return
ARR	accounting rate of return

Abbreviation

COP	coefficient of performance
NPV	net present value
LPG	liquid petroleum gas
NAT	net annual saving
ANAT	average net annual saving

Greek symbol

ρ	density, kg/m^3

Subscripts

e	evaporator
c	condenser
g	generator
a	absorber

study of using solar energy for refrigeration and air-conditioning application. The objective was to analyze the use of solar thermal energy to operate the absorption refrigeration machines for refrigeration. Both papers had provided analysis on the costing of refrigeration systems but without detail comparison between different energy sources. Recently, Desider et al. [5] had conducted a technical and economical analysis of the solar-powered cooling systems on industrial refrigeration and air-conditioning application. A comparison on the net present value and fuel cost estimation were done between the 100% electrical driving plant with hybrid tri-generation and solar cooling plants. The result showed that the hybrid plant is superior from both technical and economical standpoint. Gebreslassie et al. [6] conducted the design of environmentally conscious absorption cooling systems via multi-objective optimization and life cycle assessment in 2009. They concluded that the reduction of absorption cooling system's operating cost can reduce the energy consumption which indirectly decrease the environmental impact.

Most text books, e.g. Cengal and Boles [7] and available journals, e.g. [8–10], deal with either water–ammonia (H_2O–NH_3) or lithium bromide–water (LiBr–H_2O) working pairs for absorption cooling. In the present study, a H_2O–NH_3–H_2 absorption cooling machine is considered. Here, the H_2O–NH_3–H_2 absorption cooling machine, which uses ammonia (NH_3) as refrigerant, water as absorbent and hydrogen as equalizer for pressure, had been employed. The transient temperature of the system's components under two types of energy sources, i.e. electric form grid and LPG were first accessed and compared. Subsequently, the economical analysis was done to investigate the system run under three feasible energy scenarios, viz. electric, LPG and photovoltaic.

2. Experimental set-up and procedure

Two types of energy sources considered in this study for experimental investigations are electric energy from conventional grid and LPG. The typical properties of LPG used in the current study are given in Table 1. LPG is made up of hydrocarbon gases, comprising mainly of propane (C_3H_8) and butane (C_4H_{10}). In this study, LPG was used as a fuel in the LPG burner in the generator; the LPG consumption for the system is 0.02 kg/h. When electrically tested, the cooler was powered at 10.25 A and 12 V, which equal to a power capacity of around 123 W. The resistance was set at one (1) Ohm.

An absorption cooler, as shown schematically in Fig. 1, was employed [11] for all the experimental tests. The measurement points 1–6 are indicated in the diagram. The experiments were conducted under the ambient condition of around 27 ± 0.5 °C in the laboratory of the Mechanical Workshop Building, University Malaysia Sarawak, Kota Samarahan, East Malaysia (Lat: 01°20′E, long.: 110°20′E, height above mean sea level: 21.73 m). The thermometer used is ACEZ 328 Type K Thermometer (accuracy: ±0.3%). The power input for electric heater is 123 W and LPG is 0.02 kg/h. The data was recorded every minute in 2 h period. Five sets of data were collected and analyzed with standard deviation. The mean of data was calculated and plotted with Microsoft Excel. The comparison study is categorized into three types. First, transient temperature of main components such as generator, condenser, evaporator and absorber were analyzed. Next, the relationship between the transient temperature and humidity of cooling space with generator and evaporator was found and established. Subsequently, comparison between the systems with different energy sources, viz. electric, LPG and photovoltaic, was carried out.

3. Economical analysis

To conduct cost comparison investigation and energy economy analysis, few methods are adopted here based on Keown et al. [12], Thumann and Mehta [13] and Anon [14]. In the current study, the economical analysis was categorized into two parts, i.e. *without* time effect, and, *with* time effect, presented in Sections 3.1 and 3.2, respectively.

3.1. Economical analysis without time effect consideration

The economical analysis (without time effect) carried out includes the capital cost, life cycle cost, cash flow diagram, account-

Table 1
Properties of LPG (50/50 propane/butane).

Physical and chemical properties	Value
Specific gravity of liquid at 15 °C	0.54
Specific gravity of vapor at 15 °C	1.75
Vapor pressure at 38 °C	8.0
Latent heat of vaporization	175