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Review

A review of recent research on the use of zeotropic mixtures in power generation systems

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ABSTRACT

The use of zeotropic fluid mixtures in refrigeration cycles and heat pumps has been widely studied in the last three decades or so. However it is only in the past few years that the use of zeotropic mixtures in power generation applications has been analysed in a large number of studies, mostly with low grade heat as the energy source. This paper presents a review of the recent research on power cycles with zeotropic mixtures as the working fluid. The available literature primarily discusses the thermodynamic performance of the mixture power cycles through energy and exergy analyses but there are some studies which also consider the economic aspects through the investigation of capital investment costs or through a thermoeconomic analysis. The reviewed literature in this paper is divided based on the various applications such as solar energy based power systems, geothermal heat based power systems, waste heat recovery power systems, or generic studies. The fluid mixtures used in the various studies are listed along with the key operation parameters and the scale of the power plant. In order to limit the scope of the review, only the studies with system level analysis of various power cycles are considered. An overview of the key trends and general conclusions from the various studies and some possible directions for future research are also presented.

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Nomenclature

CNG	compressed natural gas
CO_2	carbon dioxide
LCOE	levelized cost of electricity
LNG	liquefied natural gas
MD_2M	decamethyltetrasiloxane
MDM	octamethyltrisiloxane
MM	hexamethyldisiloxane
ORC	organic Rankine cycle
OTEC	ocean thermal energy conversion
SF_6	sulphur hexafluoride
T_{cd}	condensation temperature, °C
T_{cs}	cooling medium temperature, °C
T_{ev}	evaporation temperature, °C
T_{hs}	heat source temperature, °C
WHR	waste/exhaust heat recovery

1. Introduction

Fluid mixtures have been widely studied for their use in refrigeration systems and heat pumps in the past few decades [1]. These include mixtures of natural as well as artificial refrigerants and could either be azeotropic or zeotropic. For an azeotropic mixture, the compositions of the liquid and the vapour phases are the same for a certain combination of temperature and pressure [1]. The state where this happens is called the *azeotropic point*. This point is highlighted in Fig. 1 for a binary azeotropic mixture with the azeotropic point boiling temperature lower than the boiling temperatures of both the pure fluid constituents of the mixture.

For a zeotropic mixture, on the other hand, the compositions of the liquid and the vapour phases are always different in the two-phase region. These mixtures have sometimes also been referred to as *non-azeotropic mixtures*. The temperature-composition diagram for a binary zeotropic mixture is shown in Fig. 2. In the figure, for any bulk fluid composition x at a state k in the two-phase region, the points ‘A’ and ‘B’ represent respectively the dew point and the bubble point temperatures for the mixture. The points ‘C’ and ‘D’ represent the liquid and the vapour saturation points for the equilibrium liquid and vapour phase compositions at that state, respectively. The temperature difference ΔT on the vertical axis of the figure represents the *temperature glide* for the mixture, i.e. the difference between the bubble and dew points for a particular mixture composition at a specified evaporation pressure. The composition here could either be the mole or the mass fraction with respect to one of the components. This temperature glide occurs during evaporation because of the evaporation of the more volatile component of the mixture first, thereby resulting in different compositions in the liquid and the vapour phases, and thus the continuously changing evaporation temperature at the same pressure until the entire mixture is evaporated. The same phenomenon is observed during condensation because of the condensation of the less volatile component of the mixture first.

In recent years, the use of fluid mixtures in power cycles has attracted increased interest because of the possibility to reduce the irreversibility during a two-phase heat transfer process, enabling to increase the average temperature of heat supply and/or decrease the average temperature of heat rejection, thereby resulting in better thermodynamic performance in terms of improved cycle efficiency. This reduction comes through the matching of the temperature profiles of the fluid mixture with those of the heat source and sink during evaporation and condensation, respectively, because of the occurrence of non-isothermal phase change.

This paper presents a review of the recent literature on the use of zeotropic mixture in power generation applications. The key conclusions drawn from the state-of-the-art along with guidelines for future research are also presented. The reviewed literature is

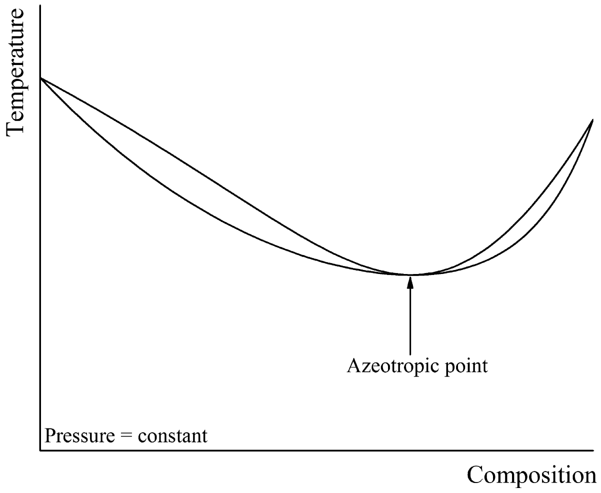

Fig. 1. Schematic temperature-composition diagram for a binary azeotropic mixture at a constant pressure.

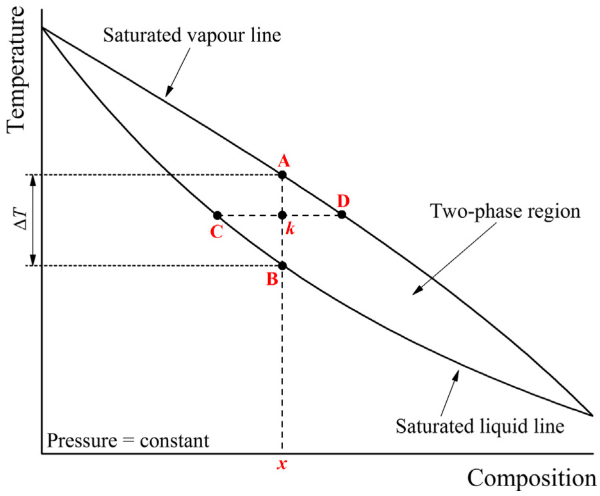

Fig. 2. Schematic temperature-composition diagram for a binary zeotropic mixture at a constant pressure.