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Optimal fan speed and compression ratio of an air-condensed vapor-compression ammonia recycling system

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A B S T R A C T

In the technology of liquid ammonia modification, the ammonia is recycled by compression and condensation. To minimize the energy-consumption of ammonia recycling system, compression ratio and fan speed are optimized. Thermodynamic models for the compressor and evaporative condenser are developed respectively. Mathematical equations are given to determine the optimal compression ratio and the corresponding fan speed ratio. To solve the equations, a numerical algorithm is proposed. By controlling the fan speed, the matching of ammonia mass flow rate and air flow rate can be optimized, which brings about the minimal energy-consumption. When the wet-bulb temperature is 22 °C, the system energy-consumption could be saved by 10.8–12.9% under optimal compression ratio and fan speed.

Vitesse optimale de ventilateur et taux de compression d'un système à compression de vapeur à l'ammoniac à condensation par air

Mots clés : Condensation par air ; Compression de vapeur ; Taux de compression ; Vitesse de ventilateur ; Système de recyclage d'ammoniac ; Consommation énergétique

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Nomenclature

A	correction coefficient affected by water film temperature
A_1	actual overall mass transfer coefficient of evaporative condenser [kg s^{-1}]
A_{1e}	overall mass transfer coefficient of evaporative condenser if operating at rated fan speed [kg s^{-1}]
C	coefficient [0.35]
c_{pwa}	specific heat capacity of air [1.02×10^3 J kg^{-1} K^{-1}]
d_0	external diameter of tubes in the evaporative condenser [m]
F_o	external surface area of tubes of evaporative condenser [m^2]
F_w	contact area between water film and air [m^2]
h_1	specific enthalpy of the superheated ammonia at the compressor suction [J kg^{-1}]
h_2	specific enthalpy of the superheated ammonia at the compressor discharge [J kg^{-1}]
h_3	specific enthalpy of ammonia at saturated state [J kg^{-1}]
h_4	specific enthalpy of liquid ammonia at saturated state [J kg^{-1}]
$h_{air,in}$	enthalpy of air at the inlet of evaporative condenser [J kg^{-1}]
$h_{air,out}$	enthalpy of air at the outlet of evaporative condenser [J kg^{-1}]
h_{ave}	average enthalpy of air [J kg^{-1}]
h_{sat}	enthalpy of saturated air at condensing temperature [J kg^{-1}]
i	number of compressor cylinder
J	cost function [J kg^{-1}]
k	isentropic index of compression, for ammonia [1.3]
M	molar mass of ammonia [17×10^{-3} kg mol^{-1}]
$\dot{m}_a$	ammonia mass flow rate [kg s^{-1}]
$\dot{m}_{air}$	actual air mass flow rate [kg s^{-1}]
$\dot{m}_{aire}$	air mass flow rate if operating at rated fan speed [kg s^{-1}]
m'	polytropic index of compression, for ammonia [1.28]
n_1	speed of compressor [r s^{-1}]
n_2	actual speed of fan [r s^{-1}]
n_{2e}	rated speed of fan [r s^{-1}]
P_f	actual power of condenser fan [W]
P_{fe}	rated power of condenser fan [W]
P_p	rated power of condenser pump [W]
Pr_f	Prandtl number of air [0.721]
P_t	actual power input of compressor [W]
p_{dk}	discharge pressure of compressor [Pa]
p_{int}	suction pressure of compressor [Pa]
Q	heat rejection of evaporative condenser [W]
q_{va}	airflow provided by evaporative condenser fan if operating at rated fan speed [m^3 s^{-1}]
R	ideal gas constant [8.314 J mol^{-1} K^{-1}]
Re_f	Reynolds number of air
T_1	suction temperature of compressor [K]
T_2	condensing temperature of ammonia [K]
T_{db}	dry-bulb temperature of the inlet air in the condenser [°C]
T_{wb}	wet-bulb temperature of the inlet air in the condenser [°C]
u_2	fan speed ratio $u_2 \in [0,1]$
v_{int}	specific volume of ammonia at compressor suction [m^3 kg^{-1}]
v_m	coefficient of kinematic viscosity of air [15.8×10^{-6} m^2 s^{-1}]
v_p	cylinder volume of compressor [m^3]
$\dot{v}$	theoretical volumetric displacement of compressor [m^3 s^{-1}]
W_{ts}	isentropic compressor work per unit mass of ammonia [J kg^{-1}]
w_{max}	actual air velocity at the narrowest section in the evaporative condenser [m s^{-1}]
w_{maxe}	air velocity at the narrowest section in the evaporative condenser if operating at rated fan speed [m s^{-1}]
Δh	heat rejection per unit mass of ammonia during condensing process [J kg^{-1}]
Δh_{air}	increment enthalpy of air in the evaporative condenser [J kg^{-1}]

Abbreviations

COP	coefficient of performance
CTC	condensing temperature control
HPC	head pressure control
RH	relative humidity

Greek symbols

α_c	sensible heat transfer coefficient [W m^{-2} K^{-1}]
β_w	correction coefficient of contact area between water film and air affected by water splashing and waving [1.5]
η	overall electrical efficiency of compressor
η_{isen}	isentropic efficiency of compressor
η_m	combined motor and transmission efficiency of compressor
η_v	volumetric efficiency of compressor
ε	compression ratio
λ_f	heat conductivity of air under average temperature [2.61×10^{-2} W m^{-1} K^{-1}]
ρ_a	average density of air [1.16 kg m^{-3}]

1. Introduction

Liquid ammonia modification is a novel process for dyeing, printing and finishing. Liquid ammonia medium is used to modify cotton and linen, which could improve the performance of cotton and linen. As liquid ammonia is easy to volatilize and ammonia gas is a toxic gas, liquid ammonia and ammonia gas must be recycled in the technology of liquid ammonia modification.

Ammonia gas is recycled by compression and condensation. The recycling process leads to considerable energy-