Applied Energy 195 (2017) 453–477

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

A novel study of using oil refinery plants waste gases for thermal desalination and electric power generation: Energy, exergy & cost evaluations

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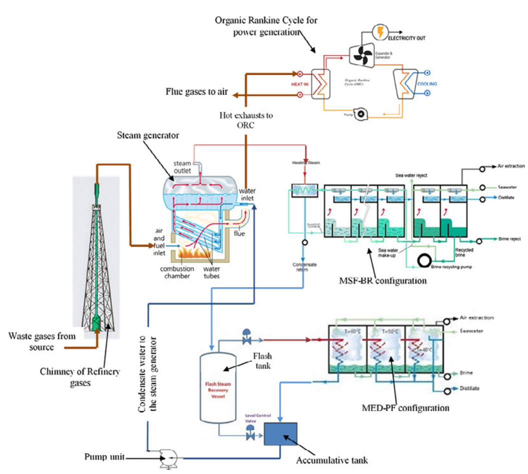
HIGHLIGHTS

- Waste gases from oil refinery plants are burned for thermal desalination and electric power generation.
- Heat from waste gases powered on ORC and gas turbine cycle.
- Hybrid MSF and MED is used in the performed work.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 24 December 2016
Received in revised form 15 February 2017
Accepted 10 March 2017

Keywords:
Oil refinery waste gases
Desalination
Hybrid MSF-MED
Design analyses
Organic Rankine Cycle (ORC)
Gas Turbine Cycle (GTC)

ABSTRACT

Thermal desalination plants need large amounts of fuel to desalinate large quantities of seawater. At the same time, burning non-beneficial gases in the oil refineries is considered a huge waste of energy instead of using it. In this paper, a novel study on the possibility of operating the thermal desalination plants by waste gases that emerged from oil refineries rather than burning these gases in the air is performed. Hybrid MSF-MED thermal desalination processes are utilized in this study to produce a total range of 100–40,000 m^3/day. Three scenarios are performed utilizing the waste gases with MSF-MED. The comparison brings out that using waste gases would save roughly 1136 $/h (UHC-unit hourly costs, $/h) while comparing against the conventional natural gas operation. Moreover; 5 m^3/h of waste gases would produce an amount of 58–60 MW of electric power combined with a production of 100 m^3/d of fresh water (gas turbine cycle scenario) and 4.5–5 MW combined with a production of 40,000 m^3/d in case of organic Rankine cycle operation. Based on energy and exergy balances, the 3rd scenario gives remarkable results.
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http://dx.doi.org/10.1016/j.apenergy.2017.03.052
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Nomenclature

A	cross-sectional area, m^2
BH	brine heater unit
BPR	boiling point ratio, °C
Cp	specific heat capacity, kJ/kg°C
CC	combustion chamber unit
$Comp$	compressor unit
CV	calorific value, kJ/kg
D	diameter, m
Ex	exergy rate, kW
GR	gain ratio = M_d/M_s
H_L	head losses, m
$H.P.T$	high pressure turbine unit
h	enthalpy, kJ/kg
Iex	exergy destruction rate, kW
L	latent heat of vaporization, kJ/kg
$L.P.T$	low pressure turbine unit
M	mass flow rate, kg/s
MED	multi effect distillation
MSF	multi stage flash
N	number of stages, or effects
NEA	non-equilibrium allowance, °C
ORC	Organic Rankine cycle
P	pressure, bar
PR	performance ratio
Pr	pressure ratio, bar
Q	thermal power, kW
Re	reynolds number
S	salinity ratio, g/kg
SFC	specific fuel consumption, kg/h/kW
T	temperature, °C
TBT	top brine temperature, °C
U	overall heat transfer coefficient, kW/m^2 °C
UHC	unit hourly costs, $Z_{unit}^{IC\&OM}$, \$/h
V	velocity, m/s
W	work, kW
WGC	Waste Gas Chimney
Z	level, m

Subscripts

a	air
b	brine
cc	combustion chamber
$comp$	compressor
$cond$	condenser unit
cw	cooling water
d	distillate
ex	exhaust, exergy
evp	evaporator unit
f	feed
fsh	flash tank
g	generator
$H.P.T$	high pressure turbine
i	inlet
$L.P.T$	low pressure turbine
m	mechanical
MED	multi effect distillation
MSF	multi stage flash
N_{stg}	number of stages in MSF
N_{eff}	number of effects in MED
n	last stage
o	out
orc	Organic Rankine cycle
p	pump
r	recycle stream
rec	recuperator
s	steam, isentropic
sea	tend to sea
sg	steam generator
t	turbine, tube
v	vapor
w	exergy work, kW
wg	waste gases

Greek

ρ	density, kg/m^3
ε	effectiveness
η	efficiency
γ	isentropic index

1. Introduction

Water shortfalls in the Arab countries are one of the problems that hamper growth in these, especially in the states of North Africa countries. Desalination of saline (sea/brackish) water is one of the most promising techniques to overcome water shortages in a considerable number of states. Multi stage flash (MSF) and multi effect distillation (MED) are considered a vital option to solve the water shortage problem from the perspective of thermal power. MSF-BR and MED-PF configurations have a gain ratio ranged as 11.5 and 20 respectively with a share capacity around 95,000 m^3/d with specific power consumption ranged between 1_{med}-4_{msf} kW h/m^3 [1]. To produce such large quantities of fresh water, large amounts of thermal power that conventionally represented by the fossil fuel are urgently needed which are already available in abundance. Entirely the same; with the volatility of fossil fuel prices and the continued high prices, fossil fuels remains a problem for thermal desalination plants. At the same time, the oil refining plants produces large amounts of waste gas which is burning around the clock in the air so enormous thermal energy waste. It is calculated that an amount of 960 m^3/d of waste gases would be fired in the air (Egypt case study, 5 m^3/h per each plant [2]). Burning waste gases cause many severe problems, including, for example:

- They contain large quantities of sulfur.
- Air pollution is constantly, especially when flame failure generated hydrogen sulfide.
- Produce large amounts of carbon monoxide and nitrate compounds.
- Produce large amounts of heat energy when incinerated.

Thus, it gets more urgent for the use and recycling of these waste gases in the propagation of thermal energy that will run thermal desalination plants and create electricity. The average flow rate of flue gases is about 5 m^3/h [2] which contains hydrogen sulfide (H_2S), Hydrogen (H_2), Methane (CH_4), Ethane (C_2H_6), Ethylene (C_2H_4), Propane (C_3H_8), Propene (C_3H_6), Butane (C_4H_{10}), Butene (C_4H_8), Pentane (C_5H_{12}), and Pentene (C_5H_{10}). Other than the gas hydrogen sulfate, the rest of the gas has a high calorific value. The norm of the calorific value is about 45,000 kJ/kg, meaning of this a huge amount of thermal energy is completely misplaced and in addition increasing the pollutant contents to the surroundings. Regain-

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