



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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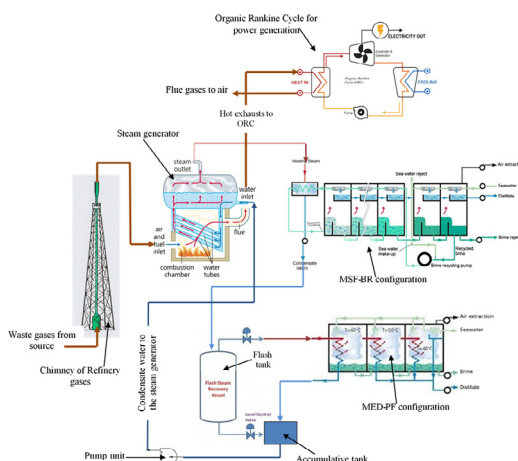
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HIGHLIGHTS

- 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



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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 m³/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 m³/h of waste gases would produce an amount of 58–60 MW of electric power combined with a production of 100 m³/d of fresh water (gas turbine cycle scenario) and 4.5–5 MW combined with a production of 40,000 m³/d in case of organic Rankine cycle operation. Based on energy and exergy balances, the 3rd scenario gives remarkable results.

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Nomenclature

<i>A</i>	cross-sectional area, m ²	<i>cc</i>	combustion chamber
<i>BH</i>	brine heater unit	<i>comp</i>	compressor
<i>BPR</i>	boiling point ratio, °C	<i>cond</i>	condenser unit
<i>C_p</i>	specific heat capacity, kJ/kg°C	<i>cw</i>	cooling water
<i>CC</i>	combustion chamber unit	<i>d</i>	distillate
<i>Comp</i>	compressor unit	<i>ex</i>	exhaust, exergy
<i>CV</i>	calorific value, kJ/kg	<i>evp</i>	evaporator unit
<i>D</i>	diameter, m	<i>f</i>	feed
<i>Ex</i>	exergy rate, kW	<i>fsh</i>	flash tank
<i>GR</i>	gain ratio = M_d/M_s	<i>g</i>	generator
<i>H_L</i>	head losses, m	<i>H.P.T</i>	high pressure turbine
<i>H.P.T</i>	high pressure turbine unit	<i>i</i>	inlet
<i>h</i>	enthalpy, kJ/kg	<i>L.P.T</i>	low pressure turbine
<i>I_{ex}</i>	exergy destruction rate, kW	<i>m</i>	mechanical
<i>L</i>	latent heat of vaporization, kJ/kg	<i>MED</i>	multi effect distillation
<i>L.P.T</i>	low pressure turbine unit	<i>MSF</i>	multi stage flash
<i>M</i>	mass flow rate, kg/s	<i>N_{stg}</i>	number of stages in MSF
<i>MED</i>	multi effect distillation	<i>N_{eff}</i>	number of effects in MED
<i>MSF</i>	multi stage flash	<i>n</i>	last stage
<i>N</i>	number of stages, or effects	<i>o</i>	out
<i>NEA</i>	non-equilibrium allowance, °C	<i>orc</i>	Organic Rankine cycle
<i>ORC</i>	Organic Rankine cycle	<i>p</i>	pump
<i>P</i>	pressure, bar	<i>r</i>	recycle stream
<i>PR</i>	performance ratio	<i>rec</i>	recuperator
<i>Pr</i>	pressure ratio, bar	<i>s</i>	steam, isentropic
<i>Q</i>	thermal power, kW	<i>sea</i>	tend to sea
<i>Re</i>	reynolds number	<i>sg</i>	steam generator
<i>S</i>	salinity ratio, g/kg	<i>t</i>	turbine, tube
<i>SFC</i>	specific fuel consumption, kg/h/kW	<i>v</i>	vapor
<i>T</i>	temperature, °C	<i>w</i>	exergy work, kW
<i>TBT</i>	top brine temperature, °C	<i>wg</i>	waste gases
<i>U</i>	overall heat transfer coefficient, kW/m ² °C		
<i>UHC</i>	unit hourly costs, $Z_{unit}^{IC&OM}$, \$/h	<i>Greek</i>	
<i>V</i>	velocity, m/s	ρ	density, kg/m ³
<i>W</i>	work, kW	ε	effectiveness
<i>WGC</i>	Waste Gas Chimney	η	efficiency
<i>Z</i>	level, m	γ	isentropic index
Subscripts			
<i>a</i>	air		
<i>b</i>	brine		

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 m³/d with specific power consumption ranged between 1_{med}–4_{msf} kW h/m³ [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 m³/d of waste gases would be fired in the air (Egypt

case study, 5 m³/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 m³/h [2] which contains hydrogen sulfide (H₂S), Hydrogen (H₂), Methane (CH₄), Ethane (C₂H₆), Ethylene (C₂H₄), Propane (C₃H₈), Propene (C₃H₆), Butane (C₄H₁₀), Butene (C₄H₈), Pentane (C₅H₁₂), and Pentene (C₅H₁₀). 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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