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Concepts for lifetime efficient supply of power and heat to offshore installations in the North Sea

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ABSTRACT

This paper assesses different concepts for efficient supply of power and heat to specific offshore installations in the North Sea, with the objective of cutting carbon dioxide emissions. The concepts analyzed include solutions with on-site power generation, full plant electrification, and hybrid solutions where power can be either generated locally or taken from the onshore grid. A detailed modeling of the power generation system was carried out, enabling design and off-design simulations. Plant power and heat demand profiles were used to evaluate the various concepts throughout the entire field's life. A first analysis of the common on-site power generation systems revealed the possibility of cutting carbon dioxide emissions simply by optimizing the operating strategy. Overall, the assessment of the different concepts showed that full plant electrification and the implementation of an offshore combined cycle have the potential to substantially reduce cumulative carbon dioxide emissions. A sensitivity analysis of the carbon dioxide emission factor, associated with the grid power, stressed how this parameter has a strong influence on the analysis outputs and, thus, needs to be thoroughly assessed. Similarly, the impact of increased plant heat demand was evaluated, showing that advantages connected to the plant electrification tend to diminish with the increase in heat requirements.

1. Introduction

The offshore processing of oil and gas is an energy-intensive sector, where natural gas is widely used to fuel equipment in the production, gathering and processing of gas and conventional crude oil. It has been estimated that petroleum extraction is the main contributor to greenhouse gas emissions in Norway, making up 28% of the total emissions in 2015 [1]. In 1991 Norway became one of the first countries in the world to introduce a CO_2 tax; this tax reached 1.02 NOK (0.12 $) per liter of petroleum or standard cubic meter of gas in 2016 [2]. In addition, Norway joined in 2008 the EU Emissions Trading System (EU ETS). It is becoming clear that improving the energy management of offshore installations opens up significant opportunities with regard to both cost savings and reduction of the environmental impact. In recent years, comprehensive thermodynamic analyses have been carried out on offshore facilities, pinpointing thermodynamic inefficiencies and estimating the potential for reducing energy and exergy losses. Some analyses were based on installations in the Norwegian Continental Shelf region. Different scenarios with respect to gas-to-oil and water-to-oil ratios were studied [3]. The variability of feed composition showed to have little influence on the breakdown of the thermodynamic irreversibilities. In order to assess potential differences in comparison to a field at the production peak, the situation on a mature field was analyzed in a following paper [4]. The operation on a real production day [5] was also investigated. The largest exergy destruction was noted in the processes involving pressure changes (compressors, pressure reduction valves and recycling), albeit the power generation unit was not taken into account. In another work, the same analysis framework was used to analyze and compare the oil and gas processing plants of four different North Sea offshore platforms [6]. Similar analyses were conducted for an offshore platform in the Brazilian Basin [7]. Despite the fact that the wide range of characteristics of offshore installations located in different areas (e.g. North Sea or Brazilian Basin) led to different conclusions, some common guidelines emerged. For instance, one of the main energy losses was the exhaust gases from simple gas turbines cycle. Several studies have investigated the feasibility of offshore combined cycles to exploit that energy, starting from the practical challenges related to the installation of a bottoming cycle [8]. Kloster [9] argued for the technical and economic feasibility of offshore combined cycles using steam by reporting three successful offshore projects. The benefits of steam cycles (SCs) were further showed by Nord and Bolland [10], where process simulations showed a possible CO_2

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Nomenclature

a	pressure drop acceleration loss term
A	heat transfer area, m^2
A_d	cross sectional flow area of the duct enclosing the bundle, m^2
A_n	net free area in a tube row, m^2
A_{nz}	the nozzle area at the steam turbine group inlet, m^2
C	dimensional constant
$C_{1\text{-}6}$	correction factors
C_f	friction factor
d_i	inner tube diameter, m
d_f	outside fins diameter, m
d_o	outside tube diameter, m
f	Fanning friction factor
G_n	mass velocity based on the net free area in a tube row, kg/s/m^2
h	convective heat transfer coefficient, W/m^2/K
H_f	fin height, W/m^2/K
HR_{plant}	plant heat rate, kJ/kWh
L	tube length, m
LHV_f	natural gas lower heating value, kJ/kg
$load_{GT}$	gas turbine load
$\dot{m}_f$	mass flow rate of natural gas used as fuel in the gas turbine, kg/s
$\dot{m}_s$	mass flow rate of steam in the steam turbine, kg/s
N_r	number of tube rows in the direction of flow
Nu	Nusselt number
p	pressure, Pa
p_{cond}	condenser pressure, bar
p_e	pressure at the steam turbine group outlet, Pa
p_i	pressure at the steam turbine group inlet, Pa
p_{steam}	steam evaporation pressure, bar
Pr	Prandtl number
R	steam turbine group pressure ratio correction factor (Stodola factor)
Re	Reynolds number
R_f''	fouling factor
R_{rad}	radiation resistance, K/W
R_{wall}	wall conduction resistance, K/W
T_f	fin temperature, K
T_g	gas temperature, K
T_{steam}	superheated steam temperature, °C
u	average flow velocity, m/s
U	overall heat transfer coefficient, W/m^2/K
v_i	specific volume at the steam turbine group inlet, m_3/kg
$\dot{W}_{aux}$	plant auxiliary power requirement, kW
$\dot{W}_{GT}$	gas turbine gross power output at generator terminals, kW
$\dot{W}_{GT,design}$	gas turbine gross power output at generator terminals at design conditions, kW
$\dot{W}_{net,plant}$	net plant power output, kW
$\dot{W}_{ST}$	steam turbine gross power output at generator terminals, kW
x_m	mean step quality

Greek letters

β	Baumann coefficient
Δp	gas-side pressure drop per pass, mbar
Δp_w	water-side pressure drop, mbar
ΔT_{cw}	condenser cooling water temperature difference, °C
ΔT_{OTSG}	pinch point temperature difference in the OTSG, °C
$\Delta \eta$	user-defined efficiency degradation
η_{dry}	dry step efficiency at design point
$\eta_{net,plant}$	net plant efficiency
η_{od}	dry step efficiency at off-design
η_{step}	corrected step efficiency
η_0	overall surface efficiency of a finned surface
ρ	fluid density, kg/m^3
ρ_b	average outside fluid density, kg/m^3
ρ_1	outside fluid inlet density, kg/m^3
ρ_2	outside fluid outlet density, kg/m^3
ϕ	flow function at off-design
ϕ_0	flow function at design
χ_{CO2}	CO_2 emission factor, kg/kWh

Acronyms

AC	alternating current
GA	genetic algorithm
GB	gas burner
GT	gas turbine
HR	heat rate
OTSG	once-through heat recovery steam generator
PFS	power from shore
SC	steam cycle
ST	steam turbine
WHRU	waste heat recovery unit

emissions reduction of 20–25% in comparison to a simple gas turbine cycle. The possibility to use SCs for cogeneration of heat and power was also studied [11], resulting in potential cuts of CO_2 emissions between 9% and 22% depending on the heat requirements. Organic Rankine cycles (ORCs) were also thoroughly analyzed in the literature. The optimal design was studied by Pierobon et al. [12] through a multi-objective optimization process. Barrera et al. assessed the exergy performance [13] for offshore ORCs. Different ORC configurations were evaluated by Bhargava et al. [14], in connection with the gas turbines commonly used in offshore applications. A comparative analysis highlighted that SCs and ORCs are both attractive technologies for offshore applications [15]. The high working pressure typical of a CO_2 cycle leads to an increased compactness and makes these cycles interesting as well [16]. Another possible approach to improve energy efficiency involves electrification of the offshore facilities. Electrification has received strong political support recently. The Oil and Gas Department of the Norwegian Ministry of Petroleum and Energy instructs operators to look into the possibility of electrification of future offshore installations with power from shore. Electrification can be achieved with a connection to the onshore electric grid [17]. The integration of offshore wind power facilities with oil and gas installation and to the onshore grid was also proposed [18]. The grid integration did not show to be an issue, as the system demonstrated to withstand large disturbances [19]. Within certain conditions, offshore electrification has the potential to be beneficial both from a thermodynamic and environmental perspective, at the expense of high investment costs [20]. Projects involving the electrification of offshore installations have already been developed on the Norwegian continental shelf. The fields Ormen Lange, Snøhvit, Troll 1, Gjøa, Valhall and Goliat are supplied with power from shore [2]. An additional option is to integrate renewable energy sources to local power generation. Korpås et al. [21] discussed the possibility of operating an offshore wind farm in parallel with gas turbines, concluding that offshore wind is an economic and environmentally attractive option. Analyses could also be made by considering offshore areas as microgrids, to which apply advanced energy management systems for optimal operations [22].