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Trigeneration scheme for a natural gas liquids extraction plant in the Middle East

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ABSTRACT

Natural gas processing plants in the Persian Gulf face extreme climatic conditions that constrain their gas turbine (GT) power generation and cooling capacities. However, due to a past history of low hydrocarbon prices, such plants have not fully exploited their waste heat recovery potential to date. The techno-economic performance of a combined cooling, heating and power (CCHP) scheme designed to enhance the energy efficiency of a major natural gas liquids extraction plant in the Persian Gulf is assessed. The trigeneration scheme utilizes double-effect water–lithium bromide absorption refrigeration powered by steam generated from GT exhaust gas waste heat to provide both GT compressor inlet air- and process gas cooling. Part of the generated steam is also used for process gas heating. Thermodynamic modeling reveals that recovery of 82 MW of GT waste heat would provide additional cooling and heating capacities of 75 MW and 24 MW to the plant, respectively, thereby permitting elimination of a 28 MW GT, and existing cooling and heating equipment. GT compressor inlet air cooling alone yields approximately 151 GW h of additional electric power annually, highlighting the effectiveness of absorption refrigeration in meeting compressor inlet air cooling loads throughout the year in the Gulf climate. The overall net annual operating expenditure savings contributed by the CCHP system would average approximately 14.6 million US$ over its lifespan, which corresponds to average yearly savings of 190 MMSCM of natural gas. The CCHP scheme economic payback period is conservatively estimated at 2.7 years based on current utility and domestic gas prices. The net present value of the CCHP system is estimated at 158 million USD, with an internal rate of return of 39%.

1. Introduction

The natural gas (NG) industry is an energy-intensive sector, which consumes as much as 10% of its gross production to sustain its operations [1]. NG production in the Middle East is forecasted to increase by 16 trillion cubic feet from 2007 to 2035 [2]. To meet rising production targets resulting from increased global demand, maintain profit margins affected by the increased intensity of gas extraction [1], and reduce environmental impact, the NG industry in the Middle East is under increasing pressure to improve its energy efficiency throughout the production chain of NG, from extraction, purification, liquefaction and re-gasification, to distribution. In the gas processing sector, which is the focus of this work, energy efficiency improvements to date have been accomplished through integration of operations and introduction of more efficient components (e.g., pumps, compressors). Although more efficient components will continue to be integrated, this can require significant modification of existing licensed processes. In the foreseeable future, plant efficiency improvements are likely to be essentially obtained through waste energy utilization, which can often be implemented with little modification of existing facilities. NG plants generate large amounts of waste heat in the form of process streams at temperatures sufficiently high above ambient to offer significant recovery opportunities [3]. Although waste energy recovery has been introduced in many plants outside the Middle East to date, generally through conventional cogeneration,[1] published studies in this area have either been restricted to a limited section of the plant, or did not consider the entire range of waste energy recovery technologies available. In the Middle East, industry practices have placed low priority on waste heat recovery (WHR). This may be attributable to (i) the fact that most facilities rely on processes and equipment developed prior to the commercialization of waste energy recovery technologies, (ii) a past history of affordable hydrocarbon prices, combined with insufficient financial incentives to reduce plant energy consumption, (iii) a lack of strict environmental regulations, (iv) a high reliance on licensed process technologies, which

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[1] Approximately 72% of all NG plant capacity added in 2009 was based on combined-cycle units [3].

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Nomenclature

COP	coefficient of performance (–)
h	enthalpy (J/kg)
HR	heat rate (kJ/MW h)
K	superheating and sub-cooling correction factor (–)
i	real discount rate (%)
IRR	Internal rate of return (%)
k	investment period (year)
LHV	lower heating value
M	molar mass (kg/mol)
$\dot{m}$	mass flow rate (kg/s)
NPV	net present value (million USD)
P	pressure (kPa)
Q	heat transfer rate (W)
R	net cash inflow (million USD)
SPB	simple payback period
T	temperature (°C)
V	molar volume (m^3/mol)
$\dot{v}$	specific volume (m^3/kg)
w	specific humidity (kg water vapor/kg dry air)
W	work done (kW)
x	concentration of LiBr (%)
χ	dryness fraction of steam (–)

Subscripts

abs	absorber
amb	ambient
ARS	absorption refrigeration system
cond	condenser
c	cooling
e	electrical
evap	evaporator
exh	exhaust
f	furnace
high, des	high temperature desorber
high, cond	high temperature condenser
low, des	low temperature desorber
low, cond	low temperature condenser
net	net
steam	steam
turb	turbine

often prevent process modification due to vendor technical support issues, and confines recovery applications to utilities rather than main plant processes, and (v) perceived safety issues associated with recovery of certain waste energy sources. As a result, there is still insufficient awareness of the waste energy recovery potential of regional NG facilities, of the potential techno-economic benefits of waste energy recovery, and of the spectrum of technologies available. However, the emergence of NG as an abundant, affordable and clean source of energy, combined with growing environmental concerns and global energy shortages, may place increasing pressure on NG plants to integrate WHR. Furthermore, the energy needs of process industries vary widely according to local circumstances and operational conditions [1]. NGPPs in the Persian Gulf face unique, extreme climatic conditions, (i.e., elevated temperature and relative humidity (RH) over a major part of the year),[2] that constrain their cooling and gas turbine (GT) power generation [4] capacities. Typically, GT output power decreases by 0.5% to 0.9% per °C rise in inlet air temperature [5]. Both process cooling and GT power generation could therefore significantly benefit from waste heat-activated cooling technologies. An objective of this study is to highlight and evaluate the potential of such technologies to enhance the energy efficiency of NGPPs, with emphasis placed on those located in the Middle East or exposed to hot, tropical climatic conditions. A waste-heat powered, absorption cooling based trigeneration (i.e., combined cooling, heating and power (CCHP)) scheme tailored to a major NGPP in the Persian Gulf is developed in this study and techno-economically assessed.

The plant considered is a major natural gas liquids (NGLs) extraction facility constructed in the early 1980's in the Persian Gulf. This facility processes over 300 million standard cubic feet per day (MMSCFD) of associated gas. NGL recovery involves cooling the gas to −80 °C using energy-intensive electrically-driven air-coolers and propane vapor compression chillers, followed by dehydration and demethanisation of both the extracted liquid hydrocarbon and remaining (i.e., lean or residue) gas. The NGL produced is subsequently fractionated into C2 (Ethane), C3 (Propane), C4 (Butane) and C5+(Paraffinic Naphtha) at another processing facility. The lean gas is regenerated using direct heating furnaces fueled by natural gas. The WHR applications targeted in the present phase of plant energy efficiency enhancement focus on utilities, i.e. enhancement of GT electrical power generation, process gas cooling, and steam production for process gas heating and lean gas regeneration.

2. Proposed strategy for efficiency enhancement of NGPPs in hot or tropical regions

2.1. Waste heat auditing of NGPP facilities

Each NGPP being unique, in terms of local raw gas composition, hence refining process, the design, thermodynamic and economic evaluation of an effective WHR strategy tailored to a given facility requires a detailed plant energy audit, to quantify potential waste heat sources. Examples of comprehensive energy audits for NGPPS are however difficult to find in the published literature. Although such audits are routinely conducted in most major facilities, the information compiled is generally either (i) limited to a fraction of the plant or selected processes being targeted for waste heat recovery, (ii) incomplete due to a lack of incentives to accurately and comprehensively monitor processes for the design of a potential WHR system, or (iii) not shared in the public domain due to potential commercial sensitivity issues associated with plant energy efficiency and its associated environmental impact. In addition, the waste heat data that could be extracted from published WHR studies is limited, as few analyzes have been conducted for actual NG plants, with the majority of analyzes being industry- or application-generic. By contrast, waste heat recovery is more advanced and documented in oil refineries, chemical/petrochemical facilities and power generation plants than in the gas sector. This may be attributable to the past dominance of oil as fossil fuel, and the larger power generation requirements of petrochemical and power plants, which have placed greater incentives on energy efficiency than in the natural gas processing industry to date.

The sources of waste heat identified in the plant and their characteristics are summarized in Table 1, in terms of grade (i.e., temperature), amount (i.e., production rate), accessibility (i.e., proximity to potential waste heat utilization applications), and

[2] Ambient air temperatures in for example Abu Dhabi, United Arab Emirates, average 29 °C yearly, with typical daily maximum and monthly average temperatures of 51 °C and 36 °C, respectively [6]. Relative humidity averages 52% yearly, with daily maximum and monthly average RH levels peaking at 90% and 57%, respectively [7].