Exergy analysis of an LNG boil-off gas reliquefaction system

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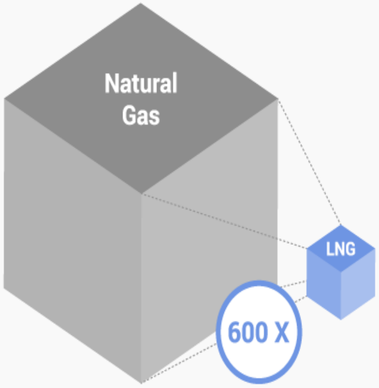
Introduction

- LNG (Liquefied Natural Gas) is mainly produced for transportation purposes.
- LNG is at atmospheric pressure and normal boiling point (111 K) during its storage and transportation.
- Heat in-leak into the storage tanks and pipelines generates boil-off gas (BOG).
- BOG is reliquefied because of economic, environment and safety reasons.
- In LNG carrier ship reverse Brayton cycle (RBC) is used to reliquefy BOG.
- RBC is compact and safe for offshore applications.



Dahej LNG Terminal, Gujarat, India

Dahej LNG regasification terminal

LNG carrier ship at Dahej Terminal

Literature review

Author/Company	Refrig. Cycle	Pressure range of Refrigeration cycle (bar (a))	BOG Compress or Exit pressure	No. of HX (excluding intercoolers & aftercoolers)
Tractebel Gas Eng.	RBC	--	6	1
Mark 1. Hamworthy Gas System [9]	RBC	58 – 14.5	4.5	1
Ecorel, Cryostar [2]	RBC	47 – 9.5	4.8	2
Sayyandi et al. [15]	Claude cycle	81-14	--	4
Shin et al. [18]	RBC	46 - 13	7.2	3

Technological gaps

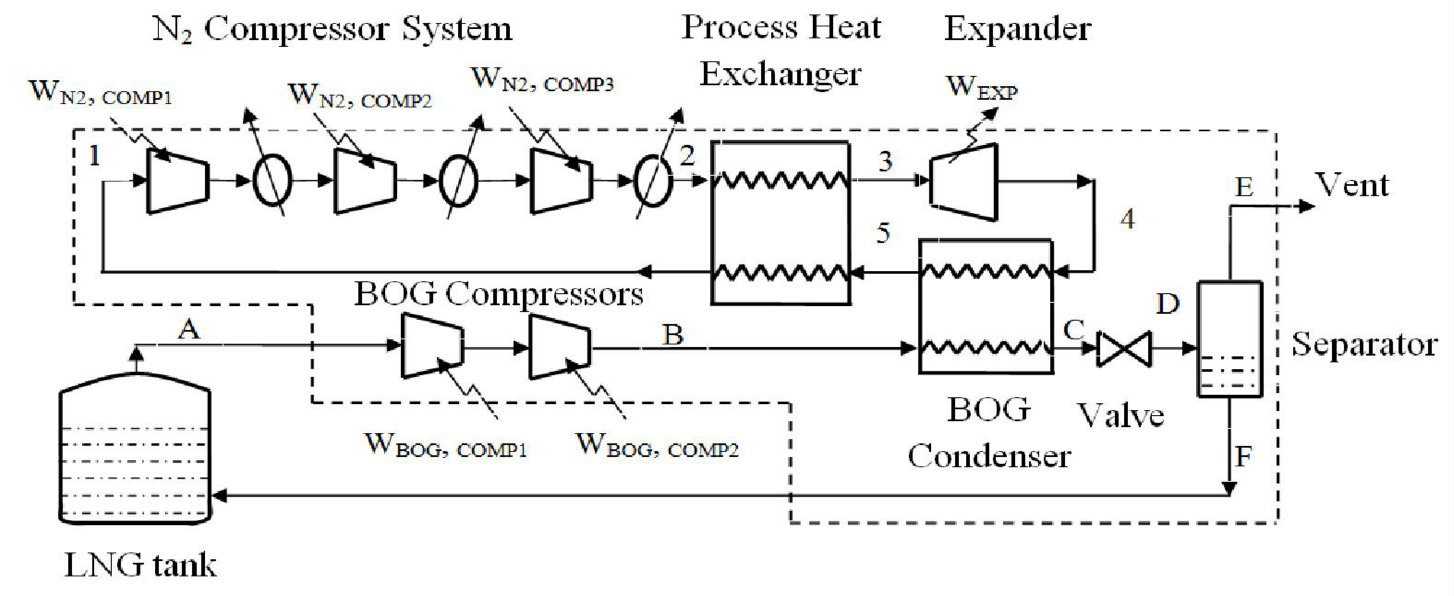
- Complete reliquefaction of BOG (91 % methane, 9 % nitrogen by mole fraction)
  - Higher power requirement
- Partial reliquefaction with nitrogen removal
  - Lesser power requirement
  - Methods for minimization of both quantity of vent gas as well as the quantity of methane in vent gas needs to be done.
- The configurations and process parameters practiced by companies are different.
- General guidelines backed by thermodynamics are needed for choice of appropriate configuration and operating and geometric parameters of reliquefaction systems.

Objective

- An efficient reliquefaction system implies
  - reduction of power input,
  - maximisation of reliquefaction output and,
  - minimisation of methane in the vent gas
- The objective of this work is to perform exergy analysis on a simple reverse Brayton cycle based LNG boil-off gas reliquefaction system to understand the effects of geometric parameters of heat exchanger and BOG compressor exit pressure on its performance.

Methodology

Thermodynamic cycle



Fixed simulation conditions	
N_2 cycle high pressure	50 bar(a)
N_2 cycle low pressure	10 bar(a)
Mass flow rate of nitrogen	36 kg/s
Condition of BOG vapour from tank	133 K; 1.073 bar(a); 91 % methane, 9 % nitrogen (mol %)
Mass flow rate of BOG	2 kg/s

Methodology (contd.)

- *Nondimensionalisation of UA of heat exchangers*

$$\text{Nondimensional UA} = \frac{(UA)_{eff}}{\dot{m}_{BOG} c_{p,\ BOG}}$$

$$(UA)_{eff} = F \times (UA)_{design}$$

$$(UA)_{design} = \frac{1}{(hA)_h} + \frac{x}{kA} + \frac{1}{(hA)_c}$$

$$\dot{Q} = (UA)_{eff}\,(LMTD)$$

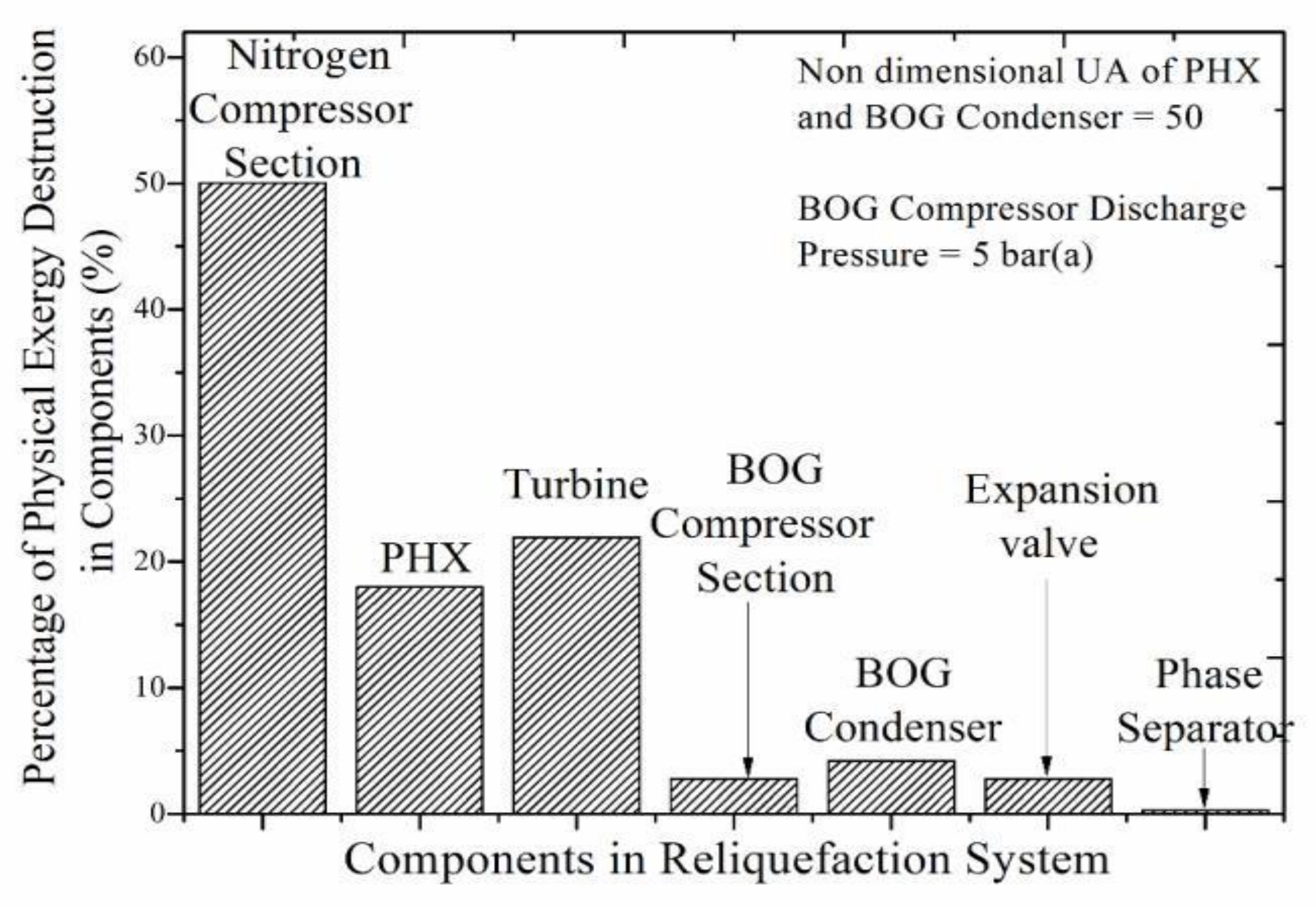
- Process simulator: Aspen Hysys 8.6®
- Fluid package for generating thermo-physical properties of fluids: The Peng-Robinson equation of state.

Methodology (contd.)

- The exergy efficiency of the system is calculated by considering only physical exergy
  - Net exergy output: $Ex_{output} = \dot{m}_F ex_F - \dot{m}_A ex_A$
  - Net exergy input: $Ex_{input} = \dot{W}_{NET} = \dot{W}_{N_2,COMP} - \dot{W}_{EXP} + \dot{W}_{BOG,COMP}$
  - Exergy efficiency: $\eta_{ex} = \dfrac{Ex_{ouput}}{Ex_{input}} = \dfrac{\dot{m}_F ex_F - \dot{m}_A ex_A}{\dot{W}_{NET}}$
- Loss of chemical exergy at the vent represents less methane content
- The specific chemical exergy (kJ/mole) $ex_{ch} = \sum x_k ex_{ch}^0 + \sum x_k \ln(x_k)$
- The total chemical exergy at a point $Ex_{ch} = ex_{ch} \times MF$

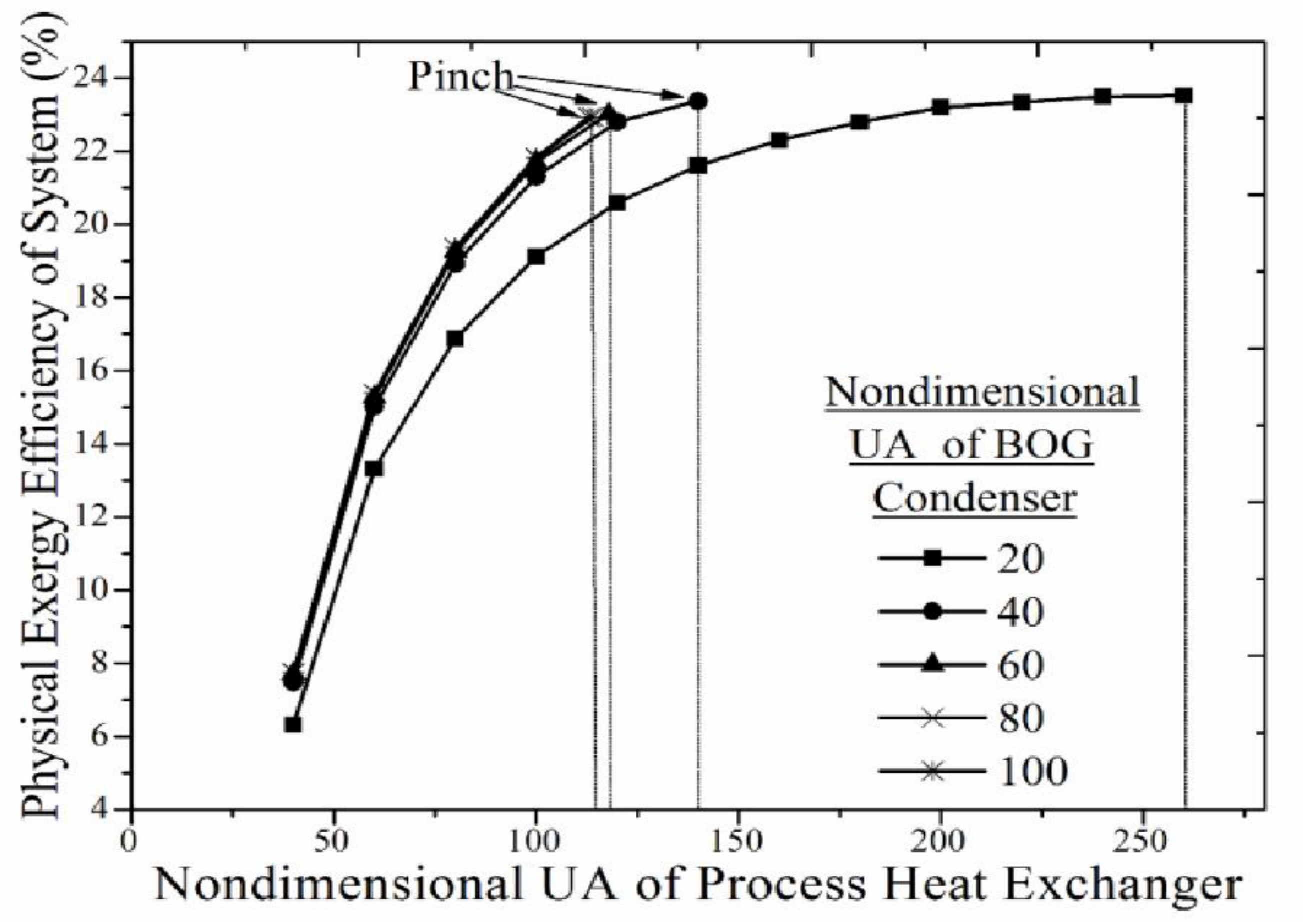
RESULTS AND DISCUSSIONS

Physical exergy destruction in components of system



RESULTS AND DISCUSSIONS (contd.)

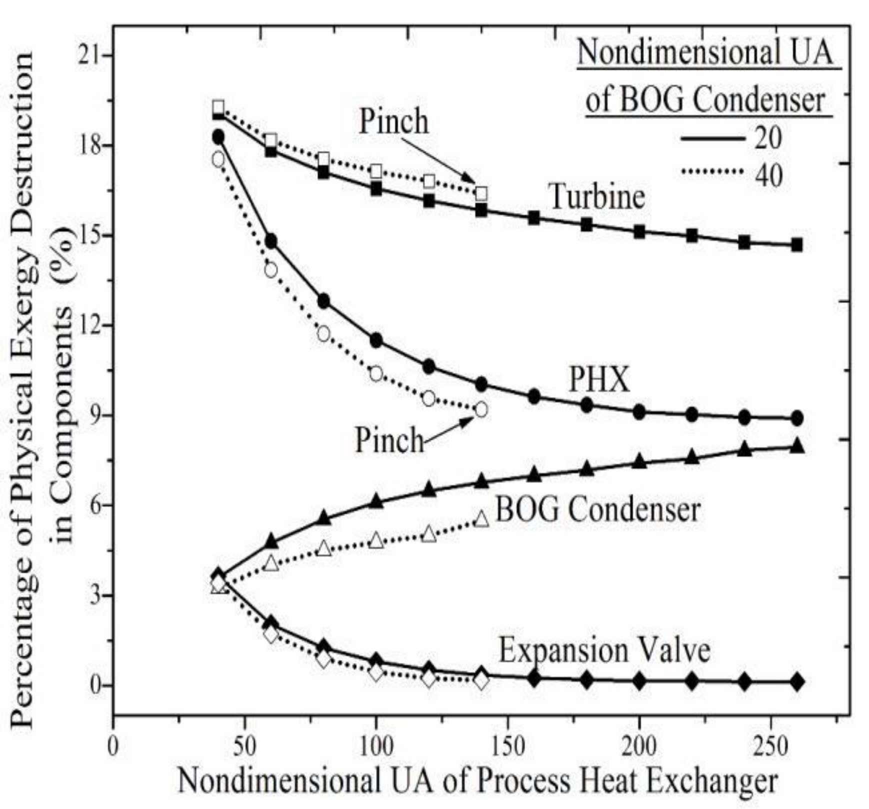
Effect of heat transfer area of heat exchangers on reliquefaction system performance



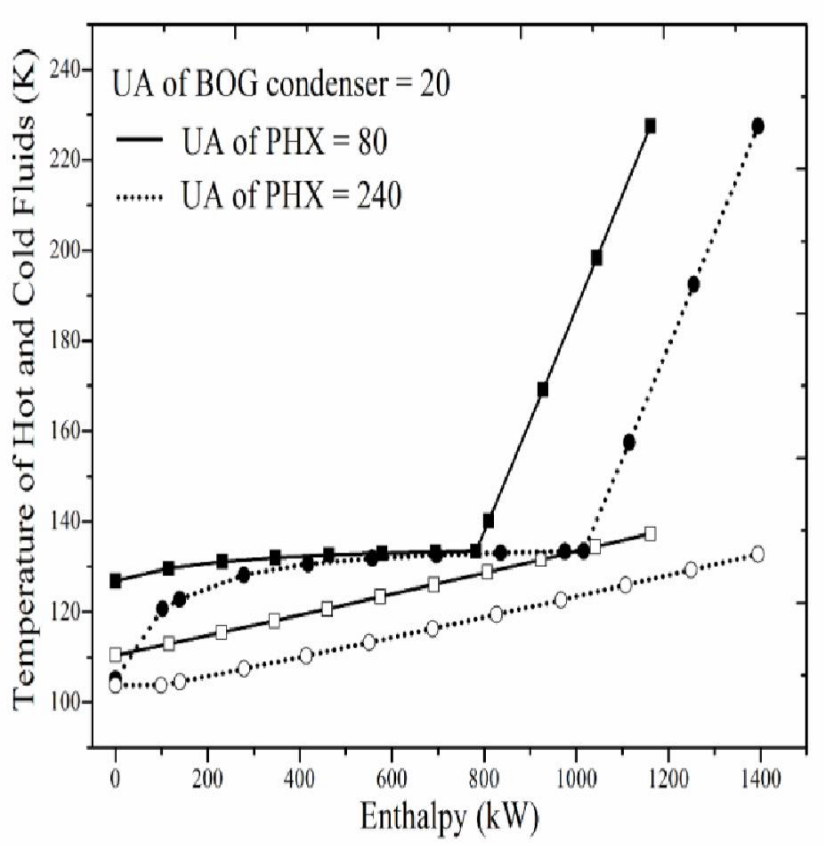
RESULTS AND DISCUSSIONS (contd.)

Effect of heat transfer area of heat exchangers on performance of system

Exergy destruction in components

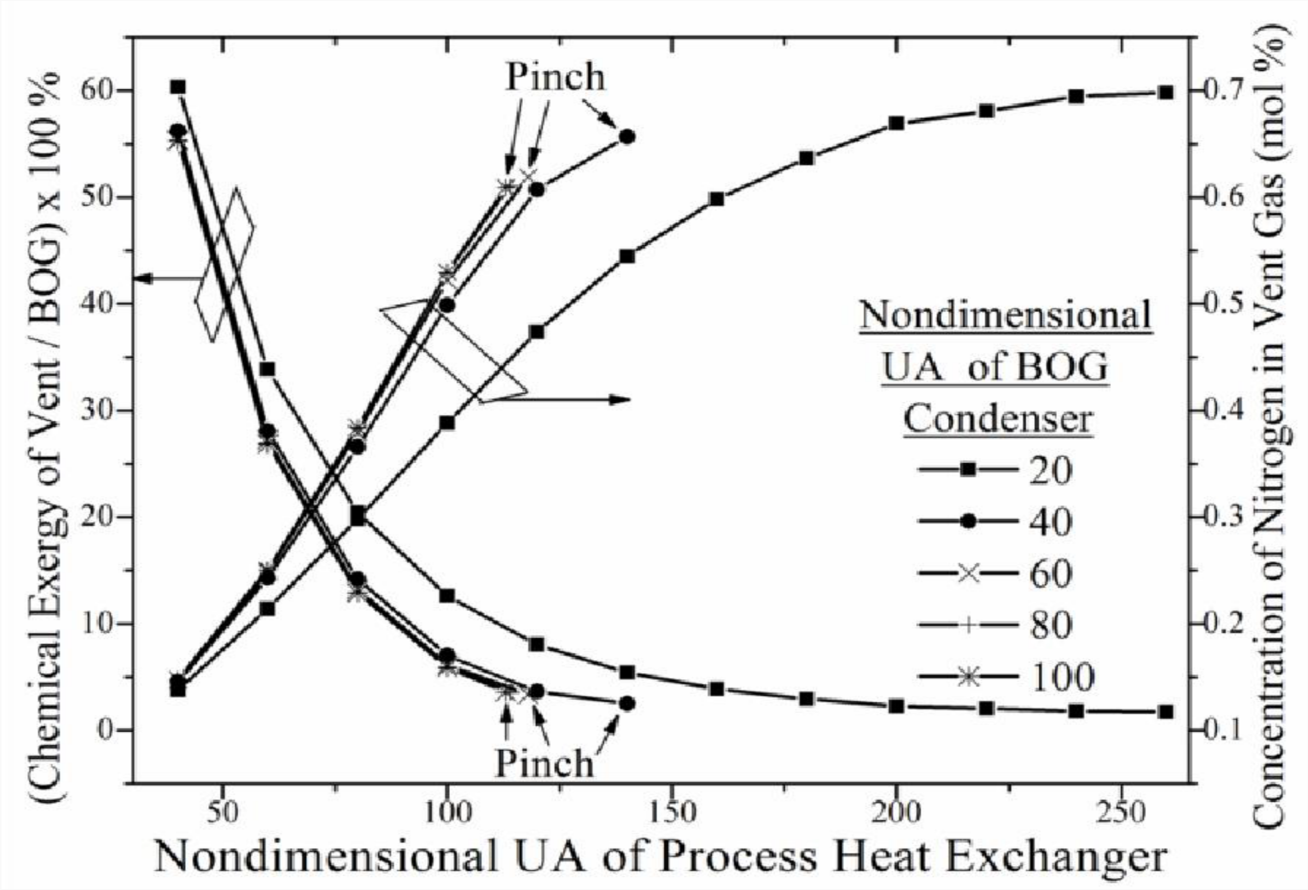


Temperature profile of BOG condenser



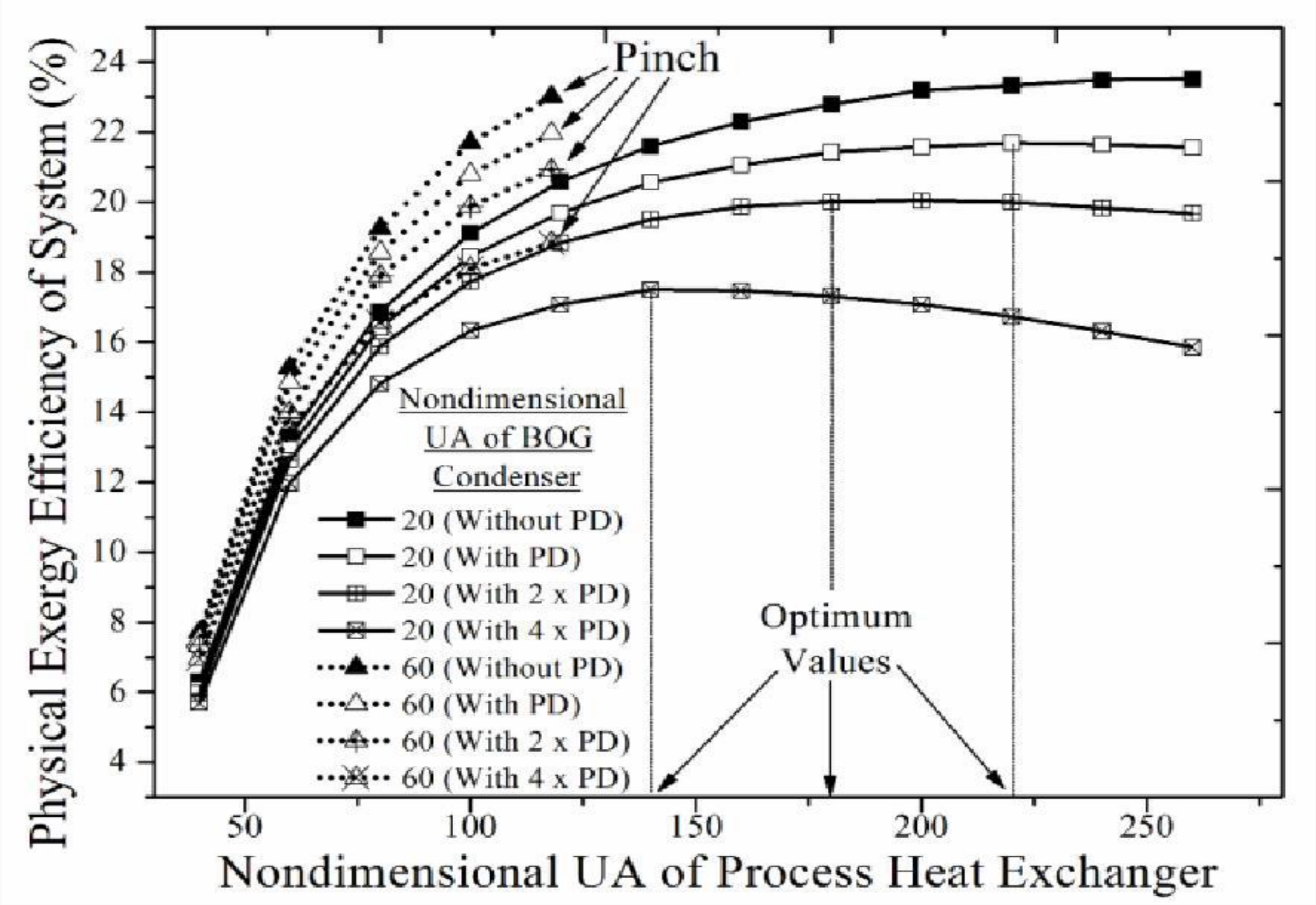
RESULTS AND DISCUSSIONS (contd.)

Effect of heat transfer area of heat exchangers on vent gas conditions



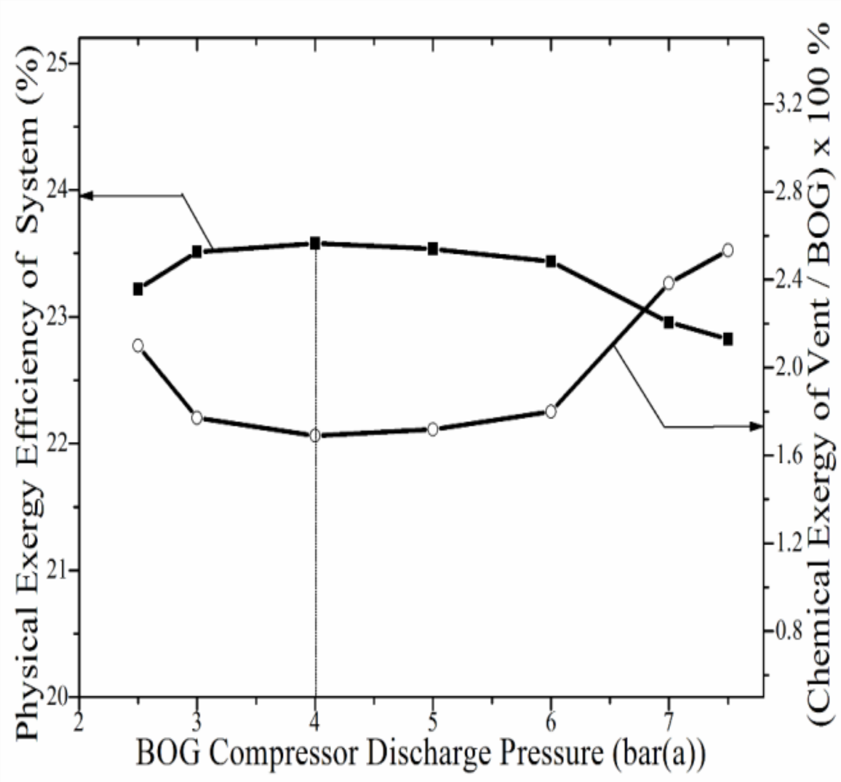
RESULTS AND DISCUSSIONS (contd.)

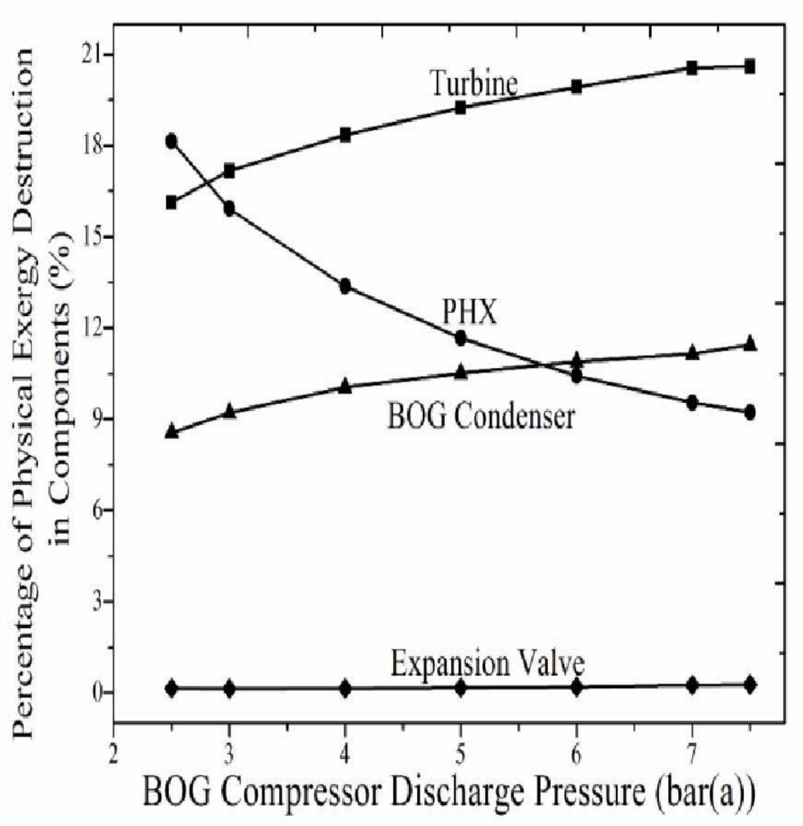
Effect of pressure drop in heat exchangers on system performance



RESULTS AND DISCUSSIONS (contd.)

Effect of BOG compressor exit pressure on system performance





CONCLUSIONS

- Process heat exchanger has to be significantly bigger than the BOG condenser.
- UA of PHX above 140 minimizes the vent gas and its methane content.
- System is more sensitive to pressure drop when the UA of PHX is greater than 100
- With increasing pressure drops system performance deteriorates and the optimum UA of PHX reduces.
- For fixed UAs of heat exchangers, an optimum discharge pressure of BOG compressor gives maximum physical exergy efficiency.

Thank You