Energy 123 (2017) 198–217

Contents lists available at ScienceDirect

Energy

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

The choice between turbine expanders and variable speed pumps as replacement for throttling devices in non-thermal process applications

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ARTICLE INFO

Article history:
Received 23 November 2015
Received in revised form
9 January 2017
Accepted 23 January 2017
Available online 25 January 2017

Keywords:
Energy recovery
Throttle
Turbine expander
Variable speed pump
Part-flow
Process applications
Pump as turbine

ABSTRACT

The choice of energy recovery technology in process industries is still a matter of debate despite the two state-of-art methods, namely turbine expanders and variable speed pumps, available in the market.

The paper enables a theoretical model to define different performances indices for both techniques. A heat exchanger problem operating with incompressible fluids is selected as the general process application and simplified to single and multiple processes for clearer interpretation.

The investigation finds the need for the two expanders, one across the throttle (traditional) and the other across the combined throttle-process unit (novel) for enhanced recovery potential. Variable speed pumps would be better than twin expanders in single processes, but not in multiple processes that form backbone of process industries.

The decisive outcome particularly for multiple process application revealed the need to innovate by combining both the technologies where the throttle expander for each elemental process is hybridized with the variable speed feed pump.

The study concludes that the use of two recovery technologies would be inevitable in industrial processes and proposes a series of recommendations for its realization, which include better knowledge of load duration of processes, using throttle-expander units, carrying out cost-benefit analysis and developing favorable policies.

1. Introduction

1.1. Background

There is a significant benefit to recover excess energy in modern day industrial process applications, which even though gaining some attention is not being treated with the importance it deserves. In addition, the implementation of recovery technologies is not being propelled in a similar way as other renewable energy programs. One of the reasons for this is that the subject of energy recovery has not been clearly understood from the technological as well as philosophical perspectives by engineers, industrialists and even policy makers.

There is a need to assess the realistic recovery potential available in various process applications that are themselves highly complex catering to challenging operating requirements before an optimistic or pessimistic picture is painted on energy recovery. An unbiased determination of recovery potential will come in a long way to remove any misconception and focus on realistic deliverability of recovery technology and pave way for appropriate policy initiatives.

In particular, throttling operation that necessarily forms the backbone of any industrial process application represents a considerable loss of energy. The use of the first type of energy recovery technology is the conventional ‘reaction turbine’ expanders, but only a few industries have implemented them with success. There have been a host of researchers who have contributed to turbine expanders whose application can be classified into two categories.

The first category covers the application in throttling processes, which is of direct interest to the current research problem. Apfelbacher and Etzold [1] put an Energy Recovery Turbine (ERT) across a throttling device of a drinking water supply network, while Cho et al. [2] used such a recovery turbine across expansion valves in air conditioning systems. Both showed reasonable success in the

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http://dx.doi.org/10.1016/j.energy.2017.01.124
0360-5442/

Nomenclature

Full Scripts

c	flow velocity, m/s
D	characteristic internal diameter, m
f	pipe friction factor
g	acceleration due to gravity, m/s^2
h	normalized head
H	head/enthalpy parameter, m
K	effectiveness factor
L	characteristic pipe length
N	speed, rpm
p	pressure, N/m^2
P	power, kW
q	normalized discharge
Q	discharge, l/s
u	blade velocity, m/s
U	Internal energy, J/kg
v	mean velocity, m/s

Greek symbols

η	efficiency, %
ρ	density, kg/m^3

Subscripts

fl	full-load
g	generator
m	motor
N	speed parameter
P	pump
pf	part-flow

Superscripts

*	dimensionless form

AbbreviationS

ERT	Energy Recovery Turbine
VSP	Variable Speed Pumps
PAT	Pump as Turbine
BEP	Best Efficiency Point
RPF	Recovery Potential Factor
GF	Gain Factor

recovery of useful shaft power.

The second category encompasses the use of ERT directly in series with a process (thermal or non-thermal) application. Hirschberger and Kuhlmann [3], Gülich [4], Antwerphen and Greyvenstein [5] and Bansal and Marshall [6] are some of the prominent researchers who have attempted to integrate such ERT systems, which were mainly thermal in nature. Most of them have mechanically coupled the output of the ERT to the feed process pump, which reduces the active shaft power required and hence decreasing the input energy supply from the motor.

To add up Lueneberg and Nelson [7] and some of the above [1,3,4,5and6] have recommended the use of 'pumps as turbines' for the purpose of recovery. On the other hand Reisser [8] dedicated his study on evaluating various system design options for ERTs including conventional turbines. However, despite these studies, the turbomachinery design of ERT technology has not been optimized enough to cover all processes and the range of their operating loads, which in itself is quite complex.

With the advent of power electronics in recent years there has been a talk of a second type of recovery technology known as variable speed pumps for better energy management in different process industries. Lingireddy and Wood [9] were few of the early contributors to this study and found advantages of using VSP in water supply networks. Marquand et al. [10] also showed that when a heat pump is coupled to a motor operating under different speeds it would lead to lower energy consumption without compromising on the performance. However, Yongzheng et al. [11] in a comprehensive study cautioned that one must be careful while investing in the VSP technology and called for a prudent study of the characteristics of the intended application so as to accurately determine the benefits of using this technology.

In recent years there is more focus on proving advantages of variable speed pumps in praxis over centralized single speed pumping systems without any explicit mention or comparison with recovery turbines. While Yan et al. [12] showed improvements in district heating system, Çalişkan et al. [13] achieved valve-less operation of hydraulic piston cylinders with variable speed pumps. Other examples include 14% reduction of energy consumption in sea water cooling circuits reported by Xia et al. [14] and a model's validation of VSP gains through measurements in water distribution network by Georegecu et al. [15].

In spite of all these contributions on the two recovery technologies, there has been so far no comprehensive study on evaluation of these technologies (recovery turbine expanders and variable speed pumps) on identical process applications covering all the operating conditions. In the quest of finding out whether expanders or variable speed pumps are more efficient replacements to throttling devices, a real-time and holistic study of various process applications will be required, since the suitability of recovery technology is closely related to physics of these processes. This study should also include an economic evaluation and guide the industry to focus on a particular recovery technology for specific category of process applications. This effort would eventually revive the subject of energy recovery/efficiency and bring it to the forefront of clean energy reforms.

1.2. Objectives and problem outline

The background of the problem discussed leads to the following objectives that this study would like to achieve.

i. Firstly, there is a need for a holistic treatment and understanding of all non-thermal process applications involving throttling.
ii. Secondly, it is vital to define a numerical parameter that specifies the actual recovery potential of a process with respect to some standards. This parameter should also serve as a judging tool from the perspective of physics as well as economics. It will be required to develop a universal theoretical model to evaluate the two recovery technologies under scrutiny, i.e. VSP and ERT, on identical process applications.
iii. Thirdly, the study should also propose innovative designs that bring out the maximum value of recovered energy in process applications.