Applied Energy 87 (2010) 1048–1053

Contents lists available at ScienceDirect

Applied Energy

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

Short Communication

Feasibility of hydraulic power recovery from waste energy in bio-gas scrubbing processes

Pradeep Bansal *, Nick Marshall

Department of Mechanical Engineering, The University of Auckland, Private Bag – 92019, Auckland, New Zealand

ARTICLE INFO

Article history:
Received 29 June 2009
Received in revised form 5 September 2009
Accepted 16 September 2009
Available online 13 October 2009

Keywords:
Waste energy recovery
Bio-gas scrubbing
Hydraulic system

ABSTRACT

This paper investigates the feasibility of recovering waste energy from typical bio-gas upgrading facilities by means of a hydraulic turbine, and presents analysis of different types of hydraulic power recovery turbines. A selection method and analysis is developed which can be applied to an existing process to determine the effectiveness and energy savings of such a system for its economic viability. A practical testing rig was designed and constructed to verify the reliability and consistency of data for the both selection and optimization techniques. It was found that a centrifugal pump operating in reverse flow, essentially as a turbine, could be a possible option for waste energy recovery.

1. Introduction

In many industries, it is often necessary for a high pressure fluid to be throttled to a lower pressure state, where some of the flow energy gets converted to heat through friction. Such a process is totally irreversible, where useful energy is essentially wasted. This process is typical in the oil and gas industry, where large amounts of energy are consumed. The energy from a high pressure fluid can be recovered by using a hydraulic power recovery turbine (HPRT) in place of the usual throttling device. If sized properly, this device can essentially convert the wasted energy [1–5] into a useful mechanical energy output, while still providing the same reduction in pressure. There are several such processes in various industries where such an operation can be potentially utilised for improved energy efficiency.

A world leading company that markets bio-gas as an automobile fuel has three bio-gas generation systems. These systems use high pressure water to allow effective scrubbing to purify the stream of 'raw' un-purified bio-gas from a landfill or waste-water site and remove all unwanted impurities without the use of any chemicals, and essentially upgrading the gas to the vehicle fuel standard. Feedstock of raw bio-gas is normally supplied to the plant (see Fig. 1) at just above atmospheric pressure and water saturation (RH 100%). Moisture and particulates are removed at the inlet through a separator, and the gas is compressed in two stages up to 9 bar(g) and cooled. This raw gas at high pressure enters the scrubber at the bottom and mixes with a stream of equally high pressure process water in counter-flow in a high pressure scrubber vessel. The impurities, such as CO_2 and H_2S, are scrubbed out of the bio-gas and are absorbed into the water, leaving only the desirable methane (CH_4) with 97–98% purity at 100% RH. The scrubbed waste water is throttled to a lower pressure, while the purified gas is dried in a twin column PSAITSA drier. If the process does not meet the quality criteria for vehicle fuel, it is recycled back to the compressor inlet for reprocessing. Inevitably the process water absorbs some CH_4 during the scrubbing process; this CH_4 is recovered at intermediate pressure in the flashing tank and is returned to the compressor to minimise CH_4 losses. The process water then enters the stripping system, where CO_2 is removed at atmospheric pressure, and clean water is pumped from the stripper back into the scrubber process. There seems to be a good potential of 'recovering this waste energy' by expanding this high pressure fluid in a hydraulic power turbine (in the form of rotational work output) instead of using a throttling device. The schematic diagram of such a proposed system is shown later in Fig. 7.

Literature search reveals that the concept of HPRT was studied in the reverse osmosis industry as early as 1980s [1,2], where these devices were assessed to be reliable and efficient, saving up to 50% energy. Also, small centrifugal pumps have been proposed to be used as hydraulic turbines in micro-hydro power systems [3]. These systems have a number of advantages including the use of integral pump and motor as a turbine and generator set, having wide range of heads and flows, range of sizes and easy installation. However, the disadvantage of such a system is that it is difficult to evaluate the turbine characteristics to select the correct pump. Sharma [6] suggested that the performance of a standard centrifugal pump in a turbine mode should be based on the pump

* Corresponding author. Tel.: +64 9 373 599x88176; fax: +64 9 373 7479.
E-mail address: p.bansal@auckland.ac.nz (P. Bansal).

0306-2619/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.apenergy.2009.09.010

Nomenclature

$\dot{W}$	useful work output (kW)
$\dot{Q}$	rate of energy flow (kW)
SG	specific gravity
η	efficiency
H	pressure head (m)
Ns	specific speed
RH	relative humidity
$\dot{\forall}$	volume flow rate ($m^3\ s^{-1}$)
$\dot{m}$	mass flow rate ($kg\ s^{-1}$)
h	enthalpy ($kJ\ kg^{-1}$)
V	velocity ($m\ s^{-1}$)
g	acceleration due to gravity ($m\ s^{-1}$)
z	elevation (m)

best efficiency data to enable the calculation of predicted flow and head of the turbine at the same speed. Williams [7,8] found this method to work satisfactorily and subsequently, published a practical manual for selecting a pump for micro-hydro site. In 2005, Drablos [4] tested Danfoss pumps as reverse running water hydraulic turbines for energy recovery in smaller reverse osmosis desalination plants, where energy savings between 6% and 9% were realized. It was noted that high energy recoveries were impractical for such small systems, while the tested system was smooth and stable in operation. Another small scale reverse osmosis system [5] with an energy recovery unit was tested at Agriculture University of Athens, where energy savings of up to 80% were realized. The proposed system was found to be attractive for coupling it with the renewable energy systems such as photovoltaic and wind turbines.

Although hydraulic power recovery devices are readily available, there seems to be some apprehension in using them in industry. Therefore, this paper presents a procedure that can be applied for selecting effective hydraulic recovery devices for a given set of conditions. The investigation begins with research into existing applications currently in use and theoretical analysis. This is followed by the design, construction and testing of a practical prototype to verify the reliability and consistency of data for the both selection and optimization techniques. The practical testing verifies the selection of a suitable hydraulic power recovery turbine (HPRT) and the accuracy of initial theoretical analysis in order to make an informed decision on the effectiveness of the process.

2. Hydraulic power recovery devices

Hydraulic power recovery turbines are often used in large scale applications and tend to have different operating requirements and characteristics. A Pelton wheel type turbine is best suited for high flow application, where high pressure fluid is throttled down to almost atmospheric pressure. A Francis Vane type turbine operates at low pressures and high flow rates, and is often used in large scale hydro power stations. A commercial water turbine is suited to any application but has limited availability and to perform effectively, requires a large initial capital investment. A more economical and effective approach involves the use of a radial flow centrifugal pump in reverse to act as a hydraulic power recovery turbine, that creates a rotational work output. These are readily available, substantially cheaper than an equivalent water turbine [9–11] and offer comparable performance and efficiency.

The complication with a reverse flow pump, however, is to predict its performance due to its internals being optimized for operation in the direction of flow [12,13]. This means that if this mechanism were to be reversed, the impact on the overall efficiency would be detrimental to its performance. The best efficiency point (BEP) of a turbine, when operating in reverse will be at

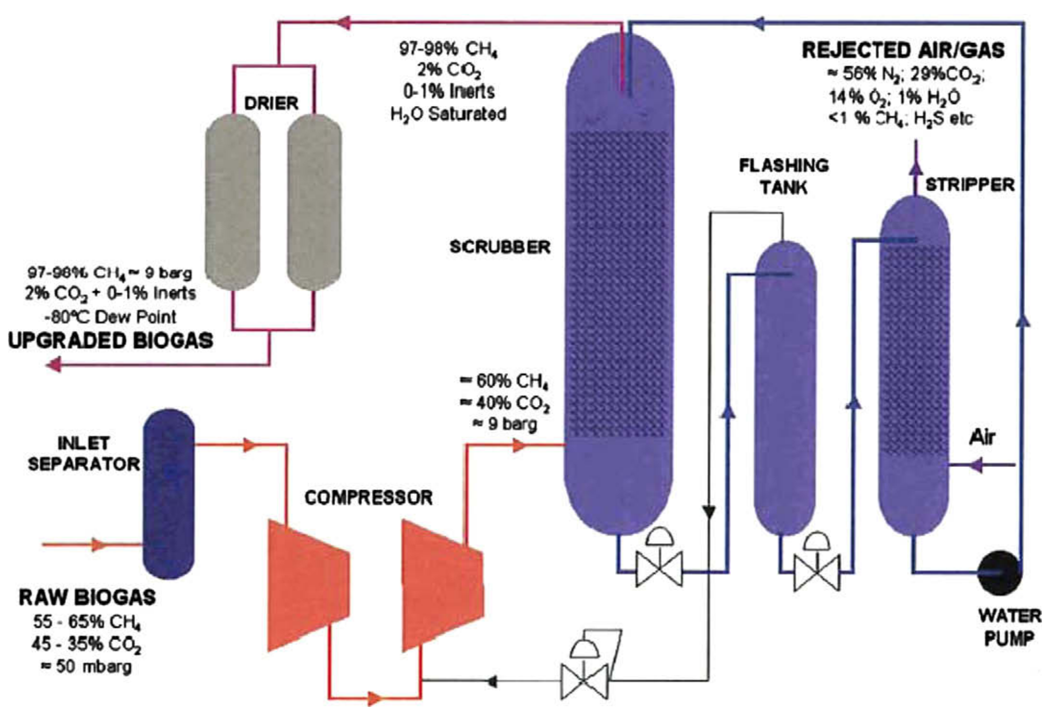

Fig. 1. Schematic of a typical throttling process in the bio-gas scrubbing process.