Renewable Energy 81 (2015) 239–250

Contents lists available at ScienceDirect

Renewable Energy

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

A new design for natural gas pressure reduction points by employing a turbo expander and a solar heating set

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ARTICLE INFO

Article history:
Received 19 March 2014
Accepted 16 March 2015
Available online 1 April 2015

Keywords:
CGS
NG
Turbo expander
Solar heating system
NPV

ABSTRACT

Natural gas pressure reduction station (CGS) is one of the most important pieces in natural gas transmission system. In a CGS, the high inlet natural gas (NG) pressure has to be reduced down to a much lower value. Pressure reduction is usually implemented by utilizing throttling valves. Due to the positive Joule–Thompson coefficient of NG, this pressure drop causes significant temperature fall and consequently hydrate forming in the NG stream. The hydrates may prevent stable NG flow through the pipeline. To prevent hydrate forming, the NG should be preheated by some heaters which burn huge amount of fuel. In this work, firstly, adding a solar heating system aiming to reduce the heater fuel consumption and secondly, replacing the throttling valve by a turbo expander in order to utilize the NG stream exergy are proposed. The proposed configuration is simulated for Birjand CGS as a case study. For the simulation, the locally available solar irradiation is estimated by employing solar engineering formulations and the NG availability is calculated by thermodynamics correlations. Net present value (NPV) method is also employed to analyze the proposed system effectiveness economically, resulting to only 3.5 years of pay back ratio.

1. Introduction

The NG extracted and refined in refineries is mostly transmitted to consuming points by transmission pipelines. Considering the long distance that the NG has to pass from the refinery to the consuming points, it must overcome friction losses along the path. That's why, firstly, the NG stream is pumped into the pipeline at much higher pressure than consumption values and secondly, numerous attenuator and booster pressure stations work out along this way. CGSs which are usually located close to the consumption points are mainly used to regulate the NG pressure [1]. Through a CGS, the NG pressure is dropped from nearly 70 bar g to almost 17 bar g. There are also two further pressure reduction steps. The first step is carried out at Town Border Station (TBS) in which the NG pressure decreases from 17 bar g to 4 bar g and the last step is done by a small regulator at consumption points which converts the NG pressure from 4 bar g to almost 0.02 bar g [2].

Due to the high mass flow rate and the high pressure of NG stream, it has high exergy value. This makes the implementation of various optimizations in the CGS an interesting subject. On the other hand, due to the positive Joule–Thompson coefficient, the pressure reduction process leads to considerable temperature drop in the NG. If the amount of temperature drop exceeds the maximum allowable value, it could result in hydrate forming in the NG stream. In fact, hydration point is a temperature in which suspended water droplets in the NG stream start to freeze, obstructing the transmission pipeline. Hydration point range varies for various NG mixtures because of being a functional of the NG compositions [3]. For this reason, the NG stream should be preheated before the pressure reduction in the CGS to prevent gas hydrate forming. Line heaters are mostly used for doing this task by burning a remarkable portion of the passing NG [4]. Fig. 1 illustrates the conventional configuration of the CGS.

In this study, two proposals are simultaneously presented to improve the energy efficiency of CGS conventional configuration.

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http://dx.doi.org/10.1016/j.renene.2015.03.043
0960-1481/

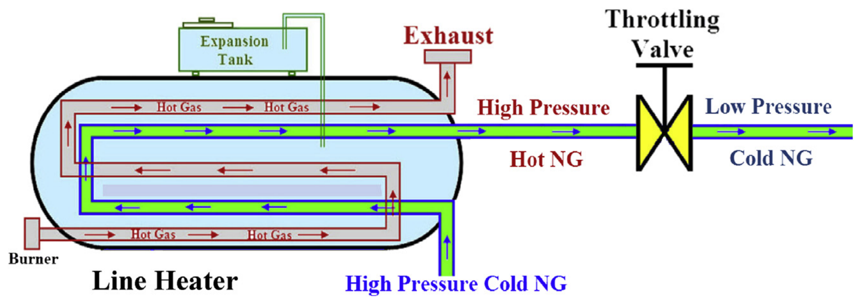

Fig. 1. The conventional configuration of the CGS.

The first proposal is adding a solar heating system to the CGS in order to decrease the fuel consumption of the heater. It is not the first time that employing a renewable energy source system is proposed to decrease the amount of consuming fuel in a part of industry. In fact, numerous studies have been addressed in the literature on how to hire renewable and sustainable energy source systems for either domestic or industrial applications. Among all sources of renewable energy, the free and endless energy of the sun has attracted more attention over the last decades. In this regard, Norton has presented a thorough research about the most common solar energy utilization for providing required heat for various applications [5]. The research consists of a comprehensive background about agricultural and industrial solar energy applications and some practical examples as well. Spate et al. have introduced a solar heater system taking advantage of non-concentrator collectors suitable for both big bakeries and kitchens in developing countries [6]. Benz et al. introduced two different solar systems for operating in a dairy factory in Germany [7]. They also did a thorough study on non-concentrator collectors' applications for using in food production industry in Germany [8]. In another work, Li and Young have analyzed Hong Kong's potential for providing solar heat [9]. The aforementioned references are only a few out of many studies accomplished in this area. As low temperature heat is required in the CGS, therefore, employing low temperature solar heat system (including flat plate solar collectors) is proposed in this work. Low temperature solar heat systems may not be that much appropriate for big industries as there is always extra heat available in these places; however, the utilization of solar energy to generate the required heat where surplus heat is not available seems a very sensible idea [10]. The other advantage of low temperature solar heat systems is employing non-concentrator collectors which are simpler and cheaper.

The second proposal in this work is substituting the throttling valve in the conventional configuration by a turbo expander and an electricity generator to produce power. In this case, not only the fuel consumption of the heater is reduced by the solar heating system, but also the exergy of the NG stream is utilized by the power production unit. The evaluation of the NG stream exergy through the transmission pipeline has been of interest for many years. Bisio employed a mechanical air compressor to utilize the exergy of the NG flow in the transmission pipeline for air compressor [11]. Greeff et al. implemented a study on feasibility of using turbo expanders in exothermic chemical mixing procedures leading to considerable energy providence in the processes [12]. Hinderink et al. introduced a method to calculate the existing exergy in multi-component liquids and two-phase flows [13]. Pozivil studied feasibility of employing turbo expanders in the CGSs using HYSIS software and assessed the effects of the isentropic efficiency of these turbines on temperature and pressure drop of the NG as well as electricity generation [14]. Farzaneh-Gord and Magrebi analyzed exergy destruction in Iran's CGSs and found out that the total of 4200 MW electricity could be generated in these stations [15]. Farzaneh-Gord et al. studied the methods of utilizing the existing pressure exergy in the CGS of Bandar Abbas refinery [16]. They also implemented a comprehensive research on enhancing the output energy of CGSs by employing turbo expanders and presented some useful suggestions [17]. It should be mentioned that there are various turbo expander models which operate in the range of 75–130 kW and have isentropic efficiency between 84 and 86% [18].

2. The improved configuration

In order to assess the improved configuration effectiveness, Birjand station with 60,000 m^3/hr maximum capacity has been chosen as a case study. Birjand is the capital city of South Khorasan province in Iran with the latitude and longitude angles of 32° and 59° respectively. As Birjand is located in Dashte-Lut desert (as one of the best places in the world in terms of the total annual received solar irradiation), in comparison with other cities of Iran, it has a high potential to lodge solar heating systems. Fig. 2 illustrates the schematic diagram of the improved configuration proposed to be implemented in Birjand station.

According to Fig. 2, the first step of modification is adding a solar water heating unit including a water bath solar heat exchanger and flat plate collector modules to the conventional configuration in order to decrease the fuel consumption of the heater, while the throttling valve is still used for expanding the NG stream. In this state, during the daily times if there is solar irradiation available, the valve number 2 is totally closed and the NG stream goes through the solar heat exchanger to be warmed up to possible temperatures. Clearly, the hot water in the solar heat exchanger is supported by the flat plate collector modules. In this case, a remarkable portion of the heat required for preheating the NG stream before the expansion process is provided by the solar heating unit. The second case is for nightly hours or the times during which there is no solar irradiation available. In this case, the valve number 2 is opened and the valve number 1 is closed. Naturally, the solar heating system contribution in the NG stream heating process for this case is zero and all the required heat should be provided by the line heater.

On the other hand, the second step of modification is substituting the throttling valve by a power production unit including a turbo expander and an electricity generator. Naturally, in the presence of the turbo-expander, the required temperature before the expansion process is much more than what is needed for throttling valve. Therefore, the amount of heat required for preheating the NG stream in the improved configuration is also much more comparing to the conventional configuration.

As a result, in the improved configuration of the CGS, not only the exergy along with the NG stream, which was totally wasted in