

Integration of vertical ground-coupled heat pump into a conventional natural gas pressure drop station: Energy, economic and CO₂ emission assessment



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ABSTRACT

City gate stations receive high pressure natural gas and decrease the pressure by throttle valves. Concurrent with the natural gas pressure reduction, the temperature also drops. Thus, to prevent blocking of the downstream pipeline by the liquid and solid particles, natural gas must be preheated before pressure reduction. Heaters utilized for preheating task, have a low thermal efficiency and consume a large amount of fuel. In addition to the high fuel consumption, they release a huge amount of CO₂ into the atmosphere. Therefore, the present study proposes a new system for in-situ fuel consumption elimination at these stations. It utilizes vertical ground-coupled heat pump system as a renewable source of energy to preheat natural gas stream. The system performance was studied at two different climatic conditions of Iran which have also two different natural gas compositions. Results show that the system is completely capable to eliminate in-situ fuel consumption of city gate stations; however, by considering indirect fuel consumption of electrical heat pumps, the system fuel consumption reduction potential was calculated over 65%. It is also able to reduce CO₂ emission up to 79%. The discounted payback period is computed around two years, which proves the suitability of offered system.

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1. Introduction

Natural gas (NG) has become the primary energy source in Iran after the change in country's energy consumption policy from oil to gas over the past 25 years. Currently, Iran is the second largest producer of NG in the world with a yearly amount of 166.6 billion cubic meters (bcm), 4.9% share of the world, and one of the largest consumers of NG in the world with a yearly amount of 162.2 bcm, 4.8% share of the world. The most of extracted NG is consumed at the domestic and industrial sectors [1]. Furthermore, the share of NG in Iran's CO₂ emission is 53%. Over 295 million ton CO₂ annually is released to the atmosphere by burning the NG. Therefore, to promote sustainable development and reduce energy consumption, improving thermal efficiency of equipment or finding an alternative energy sources are essential. NG pressure drop stations, known as CGSs (City Gate Stations) have attracted more attention due to considerable amount of fuel consumption and utilizing

renewable energy sources could decrease fuel consumption and CO₂ emission.

Delivering NG to end consumer is an energy consuming process as well as cost consuming. Iran's NG pipeline delivery network has been expanded over 34,000 km. NG is transported from a production point via pipeline with pressure as high as 5–7 MPa. The pressure must be reduced in several steps to make it usable for end consumers. One major pressure drop occurs in CGSs. The pressure is reduced through a throttling valve placed in CGSs to the 1.5–2 MPa. As the pressure reduces via throttling process, the temperature is also reduced (Joule-Thomson phenomena). After pressure drop process, low temperature and high pressure state of NG, cause gas hydrates (ice like compounds) appear in downstream. The undesirable gas hydrate formation may damage NG transmission pipeline [2]. For avoiding the gas hydrate formation, the inlet NG must be heated up. Indirect water bath heaters (line heaters) are used to preheat NG stream in Iran, which utilize the available NG at the station as fuel source. The standard temperature of preheated gas is in the range of 30–55 °C [3]. The exact value depends on the inlet pressure and the NG compositions. A schematic of a typical line heater is also shown in Fig. 1. Heat is produced

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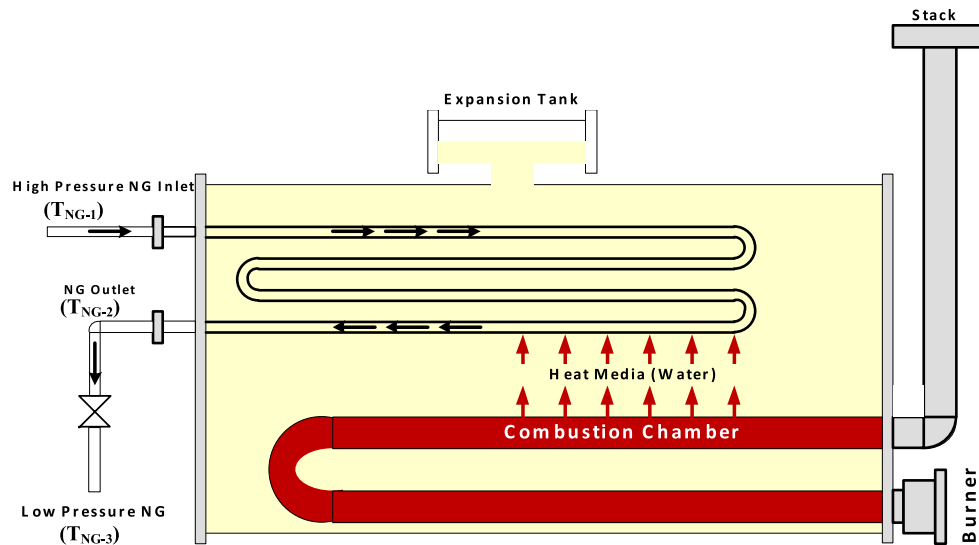


Fig. 1. A schematic of NG pressure drop station.

by burning NG in fire tube, and then it is transferred to heat transfer medium fluid (water). Finally, heat is delivered to NG passing through the line heater.

To reduce energy consumption in CGSs, a few studies have been conducted. Farzaneh-Gord and Kargaran [4] proposed the possibility of using vortex tube instead of throttling valves in CGSs. They have studied vortex tube performance with low pressure NG stream experimentally. Farzaneh-Gord et al. [3] proposed a solar system to provide a part of heat demand in the Akand CGS. The study was carried out by assuming an uncontrolled line heater. Economic analysis shown the system net benefit is coming back after 11 years. Recent study by Farzaneh-Gord et al. [5] revealed that using solar heat with controllable heater at the Akand CGS gives annual benefit of 27,011 USD with capital cost equal to 144,000 USD. The simple and discounted payback period were also determined to be 5.5 and 8 years respectively. Lately, in another work, Farzaneh-Gord et al. [6] proposed and studied using of vertical ground heat exchangers in CGSs to reduce fuel consumption in Gonbad Kavooos CGS. Comprehensive thermo-economic analysis showed that a system comprising 8 boreholes with 150 m depth and 0.15 m diameter each is the most efficient configuration for Gonbad Kavooos station. The discounted payback period and IRR of the system was computed to be about 5 years and 15.5% respectively. In comparison to utilizing solar systems, the offered system showed good economic performance. Ghezelbash et al. [7] investigated employing GCHP (Ground-Coupled Heat Pump) system in the modern type of NG pressure drop station which uses turbo-expander instead of throttle valve. In the proposed system, initially, the vertical GCHP system preheats the NG stream up to medium temperatures, then; gas stream passes through station heater and reaches the desired temperature. They concluded the fuel saving potential of the system is 45.80% annually. Economically, the discounted payback period was also calculated about 6 years. In the recent study by Ghezelbash et al. [8], they offered a new system based on vortex tube and vertical ground heat exchangers in order to minimize energy consumption. The proposed system reduced energy consumption up to 88%, and the discounted payback period was always less than 4.5 years.

For this purpose, heat pumps are connected to the ground heat exchangers, which are installed either vertically or horizontally, and heat or cool the building space. Compared to Horizontal GCHP, vertical GCHP uses less land area [9] and less pumping energy.

Moreover, heat exchange rate per unit length of the straight horizontal heat exchanger pipe is mainly lower than those obtained from vertical GHXs [10]. Although the installation cost of the vertical GCHP is higher than the horizontal one, it has attracted more attentions due to mentioned advantages [11–16]. It uses relatively constant temperature of earth for heating and cooling purposes [17,18] which is approximately constant below the 15 m depth [19]. It also has proved better thermal performance than other conventional heating and cooling devices such as air source heat pumps [20–24].

Utilization of free geothermal heat for providing process heat in industrial applications is not common, especially for low temperature cases. It may be due to available low temperature waste heat in most big industries. However, for industrial sectors or places with no waste heat, the utilization of geothermal energy has the potential for substantial economization of primary energy resources. As low temperature NG stream (less than 55 °C) required at CGS, it has the good opportunity of using geothermal heat at CGSs.

The NG price is high and consequently its export could enhance the earnings of Iran. Thus, wasting this reliable energy source in the CGSs is undesirable. Moreover, utilizing of NG as a heat source especially in low thermal efficiency heaters could release considerable amount of CO₂ into atmosphere. Consequently, in the present study an innovative system based on vertical GCHP is proposed to be integrated into the line heater of the conventional CGS in order to eliminate in-situ fuel consumption of the medium flow and partly high flow CGSs. The system capability in eliminating in-situ fuel consumption is studied. The energy and economic performance is studied as well as the CO₂ emission reduction potential of the proposed system. In order to show the possibility of using geothermal heat pump at different climatic condition of the Iran, two mega cities at north of the Iran is selected as case studies. The cities experience cold days in winter and have different undisturbed ground temperature and NG chemical composition. The mentioned parameters directly or indirectly affect the viability of the proposed system.

2. Description of proposed system

The proposed system employs the vertical GCHP for transferring the ground heat to a pressurized NG in a pipeline before the pressure reduction process. As it was claimed, the proposed system

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