Reducing energy consumption in Natural Gas Pressure Drop Stations by Employing Solar Heat

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Abstract: In Iran (and probably in most countries) natural gas is transported through transmission pipeline at high pressures (5-7 Mpa) from production locations to consuming points. At consumption points, or when crossing into a lower pressure pipeline, the pressure of the gas must be reduced. This pressure reduction takes place in CGSs. At CGSs, the pressure is reduced from (5-7 Mpa) to (1.5-2.0 Mpa) (typically 1.7 Mpa) in high-pressure intrastate pipelines. Currently, gas pressure reduction is accomplished by using throttle-valves in all of Iran's CGSs, where the constant-enthalpy expansion takes place and a considerable amount of energy is wasted. The gas must be heated before it enters throttle valves to ensure that it remains above the hydrate-formation zone and dew point, so that no liquid or solid phase condenses at the station exit. The heaters are consuming a considerable amount of natural gas flowing though the CGS as fuel to provide the required heat for preheating the natural gas stream. As the low temperature heat is required for preheating the natural gas in a CGS, this makes a CGS as perfect place to utilize solar energy and to meet low temperature heat demand. As the low temperature heat is required for preheating the natural gas in a CGS, A solar collector array is proposed to be utilized in the CGS in order to displace heating duty of the heater and to reduce amount of fuel consumption. The proposition includes a modified design of an in-use CGS to take advantage of freely available solar heat.
The proposed system has been applied to study the thermal behaviour of a CGS within Iran. The results show that the cost effectiveness of the proposed method with an array of 450 collector modules is resulted in fuel saving with variation between 0 to 20 USD/hr. The annual fuel saving is about 10678 USD and as the capital cost is about 76500 USD, the payback ratio is calculated to be around 9 years. The number of collector modules has been determined based on cost analysis.

Keywords: *Natural gas pressure drop station, Line Heater, Solar energy, Solar thermal storage*

Nomenclature

CGS City Gate Stations, ...
T_{NG-1} *Natural gas temperature before heater* ^0C
T_{NG-2} *Natural gas temperature after heater..* ^0C
T_{NG-2} *Natural gas temperature after valve .* ^0C
$\dot{m}_{NG}$ *mass flow rate*.................................. $kg.s^{-1}$
$\dot{m}_{NG}$ *mass flow rate of fuel heater*............ $kg.s^{-1}$
$\dot{Q}_{solar}$ *Heat transfer rate produced by solar KW*
$\dot{Q}_{heater}$ *Heat transfer rate produced by heater KW*
h_{NG-1} *Enthalpy of Natural gas before heater W/kg*
h_{NG-2} *Enthalpy of Natural gas after heater W/kg*
T_W *Temperature of water in the tank*............. ^0C
static pressure Pa
LHV Lowering heating value of fuel .... $kj.kg^{-1}$
η_h *Heater efficiency*
$\dot{m}_f$ *mass flow rate consumed heater* $kg.s^{-1}$

1. Introduction

Solar thermal technologies utilise the heat from the sun to offset the heating demand for many applications. The main component of any solar thermal technology is the solar collector. The device absorbs heat form solar radiation and transfers this heat to a circulating fluid (usually water). The heat absorbed by collectors then utilized in many applications. Kalogirou1 presented a survey of the various types of solar thermal collectors and applications. These includes Solar water heating systems, Solar space heating and cooling, Solar refrigeration, Industrial process heat, Solar desalination systems, Solar thermal power systems, Solar furnaces and Solar chemistry applications[1].

The utilization of solar energy for providing process heat in industrial applications is not common especially for low temperature cases and a few researches have been carried out in this subject. Norton [2] presented the most common applications of industrial process heat. The history of solar industrials and agricultural applications are presented and practical examples are explained. A system for solar process heat for decentralised applications in developing countries is presented by Spate et al. [3] The system is suitable for community kitchen, bakeries and post-harvest treatment.

In Iran (and probably in most countries) natural gas is transported through transmission pipeline at high pressures (5-7)MPa from production locations to consuming points. At consumption points, or when crossing into a lower pressure pipeline, the pressure of the gas must be reduced. This pressure reduction takes place in CGSs. At CGSs, the pressure is reduced from (5-7)MPa to 1.5-2.0 MPa (typically1.7 MPa) in high-pressure intrastate pipelines. Currently, gas pressure reduction is accomplished by using throttle-valves in all of Iran's CGSs, where the constant-enthalpy expansion takes place and a considerable amount of energy is wasted (Farzaneh-Gord et al. [4]). The gas must be heated before it enters throttle valves to ensure that it remains above the hydrate-formation zone and dew point, so that no liquid or solid phase condenses at the station exit. Indirect Water Bath Gas Heaters (known as line heater) are employed in the CGS to preheat the natural gas. The heaters are consuming a considerable amount of natural gas flowing though the CGS as fuel to provide the required heat for preheating the natural gas stream. As the low temperature heat is required for preheating the natural gas in a CGS, this makes a CGS as a perfect place to utilize solar energy and to meet low temperature heat demand.

In this study, the objective is to reduce amount of the heater fuel consumption in the CGS by utilizing solar energy. A solar collector array is proposed to be utilized in order to displace heating duty of the line heater. The proposition includes a modified design of an in-use CGS to take advantage of freely available solar heat. The modification has been done in line to minimize the CGS design alteration and availability of the CGS to continue its tasks with or without additional solar system.

2. Methodology

When a natural gas pipeline approaches a city, the high-pressure gas has to be reduced to a distribution level. A city gate station (CGS) is a. Inlet Gas has a high temperature (T_{NG-1}) which is typically related to the ambient temperature (T_{am}). The gas must be heated before it passes through throttle valves to ensure that it remains above the hydrate-formation zone and dew point, so that no liquid or solid phase condenses at the output temperature (T_{NG-3}). The standard preheated gas temperature (T_{NG-2}) is in range of 30-55^{o}C but its value highly depended on inlet pressure and temperature. The heaters are comprised of four basic components, the heater shell, the fire tube, the gas coil and the water expansion section.

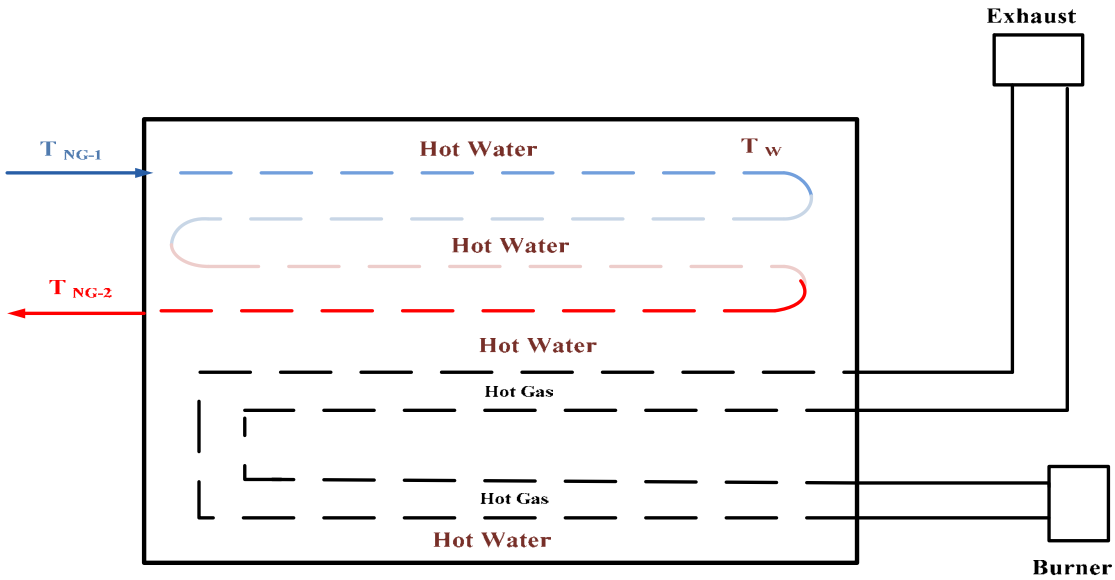

Fig. 1. A schematic diagram of an Indirect Water Bath Gas Heater (Line heater) employed in a CGS for preheating the gas

The heating duty of the heater and the water bath temperature could be estimated by knowing the station inlet and outlet gas temperature and pressure as discussed as follow.

Based on the standard outlet station gas pressure (250 psig or 17 barg) and the natural gas compositions, the hydrate gas temperature (T_{hyd}) could be calculated from thermodynamics models. The outlet station gas stream temperature (T_{NG-3}) is then selected 5 ^{o}C above the hydrate temperature [5]. By knowing the outlet station gas stream temperature, the gas temperature at the heater exit could be calculated as below:

$$T_{NG-2} = \overbrace{T_{hyd} + 5}^{T_{NG-3}} + \Delta T_{tv} \tag{1}$$

In which, $\Delta T_{tv} (= T_{NG-2} - T_{NG-3})$, is temperature drop due to pressure drop though the throttling valves. The amount of temperature drop is affected by the station inlet pressure and the natural gas compositions. Once, the gas temperature (and pressure) at the heater exit is known, the heater heating duty could be calculated as below:

$$\dot{Q}_{gh} = \dot{m}_{NG} (h_{NG-2} - h_{NG-1}) \tag{2}$$

As the gas travels a long distance before reaching to the station trough a buried pipeline at depth of 1.2 m, the gas temperature assumed to be equal to the surrounding soil temperature (Edalata and Mansoori,[6]). The soil temperature varies with environment temperature and locations. Najafi-mod et al.11 proposed an empirical correlation for a simple and rational relationship between ambient temperature and soil temperature at different depths. The soil temperature for depth higher than 1 m for Iran could be simplified as follow (Najafi-mod et al.[7]) :

$$T_{NG-1}(^{o}C) = T_{soil} = 0.0084 T_{am}^{\ 2} + 0.3182 T_{am} + 11.403 \tag{3}$$

The heating duty of the heater is provided by burning natural gas as fuel. Considering a value for thermal efficiency, η_h, of the heater, the fuel mass flow rate, $\dot{m}_f$, could be calculated as below:

$$\dot{m}_f = \dot{Q}_{gh} / (\eta_h LHV) \tag{4}$$

In which, LHV, is lowering heating value of the fuel (here Natural gas). It should be pointed out that the heater heat lost to ambient is considered through the heater thermal efficiency. The current thermal efficiency of conventional heaters are low and in range of 0.35 to 0.55. In this research, thermal efficiency of the heater is assumed to be 0.45.

As the water bath temperature wouldn't need to be higher than 70°C and the line heater are most needed during winter, in this study an array of flat plate solar collector are proposed to be installed parallel to the heater as shown in Fig.2. The solar flat plat collectors received the water, heated it up and finally returned it to the heater. As it could be realized, a current CGS could be easily modified to take advantages of solar thermal energy as proposed in the Fig.3. The heater is able to continue its normal take with or without solar collectors.

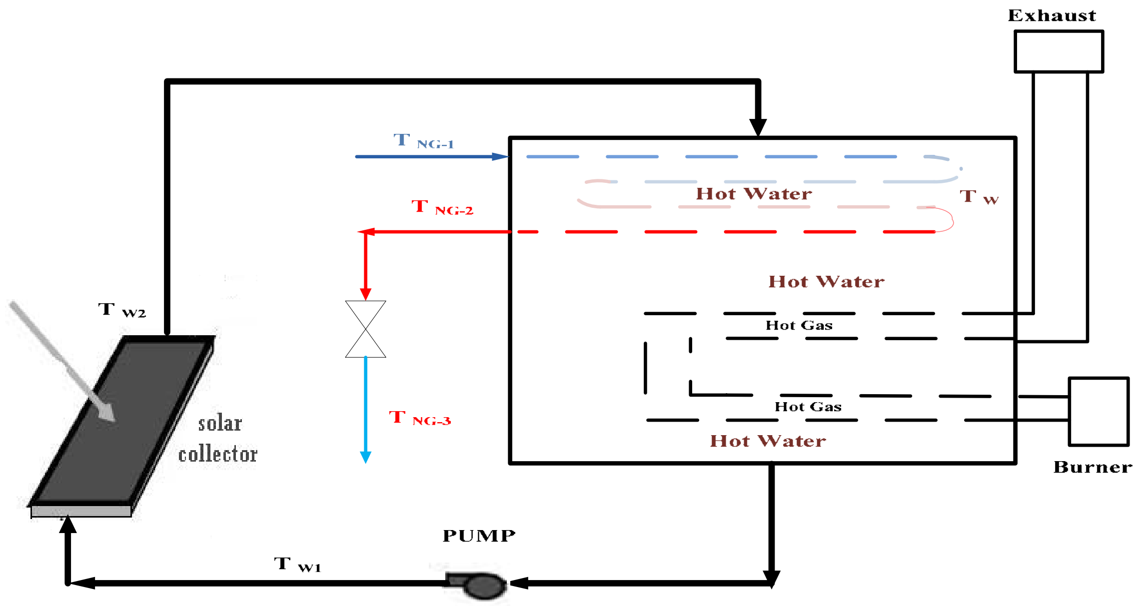

Fig. 2. A schematic diagram of the proposed system to utilize solar energy in the pressure drop stations

The governing equation for a perfectly mixed storage tank could be written as:

$$m_w C_{pw} \frac{dT_w}{dt} = \dot{Q}_{solar} + \underbrace{\dot{m}_f LHV \eta_h}_{\dot{Q}_{heater}} - \dot{Q}_{gh} \tag{5}$$

In which, $m_w C_{pw}$, is the system thermal capacity, T_w, is bath temperature and $\dot{Q}_{solar}$ is rate of useful solar energy which is absorbed by the solar collector array and transferred into circulated water. $\dot{Q}_{gh}$ is heating duty of the heater or solar load in the system.

$\dot{Q}_{heater}$ is the rate of thermal energy provided by burning fuel. It should be noted that heat lost from the heater is considered in this term by introducing heater thermal efficiency. There are possibility of two scenarios at this point as a)a heater with automatic controllable $\dot{Q}_{heater}$ b) a heater with fixed $\dot{Q}_{heater}$. It should be pointed out that although all line heaters (within Iran) could be controlled and the rate of $\dot{Q}_{heater}$ could be varied, but these heaters are not equipped with automatic control unit. Here it is assumed that the heaters are equipped with automatic control unit and scenario a (a heater with automatic controllable $\dot{Q}_{heater}$) has been applied. In this scenario, the gas temperature at heater exit is fixed.

Fixed gas outlet temperature could be achieved by controlling rate of $\dot{Q}_{heater}$. $\dot{Q}_{heater}$ could be estimated by making some simple assumptions and applying a "Euler" integration technique. For this, it will be assumed that the values of $\dot{Q}_{gh}$ and $\dot{Q}_{solar}$ are only a function of storage tank temperature at the start of the hour and that (m_w C_{pw}) of the storage is fixed. Therefore, assuming one hour time period (i.e. 3600 seconds), $\dot{Q}_{heater}$ could be estimated by integrating both sides of equation(5). The final equation will be as below:

$$\dot{Q}_{heater} = m_w.C_{pw}(T_{w(i+1)} - T_{w(i)})/3600 + (\dot{Q}_{gh} - \dot{Q}_{solar})_{(i)} \qquad (6)$$

The above equation could be employed to find altered value of the heater fuel mass flow rate as below:

$$\dot{m}_f = (m_w.C_{pw}(T_{w(i+1)} - T_{w(i)})/3600 + (\dot{Q}_{gh} - \dot{Q}_{solar})_{(i)})/LHV\eta_h \qquad (7)$$

Equation (6) or (7) could be rearranged to estimate the hourly variation in water bath temperature as below:

$$T_{w(i+1)} = T_{w(i)} + \frac{(\dot{Q}_{solar} + \dot{Q}_{heater} - \dot{Q}_{gh})_{(i)} \times 3600}{m_w \cdot C_{pw}} \qquad (8)$$

3. Results

The heating duty should be supplied by heater either completely by fuel energy or by combination of solar and fuel energy. As discussed previously, the heater burns natural gas as fuel to preheat the gas. The rate of burning fuel would be useful for studying feasibility of the proposed solar system. Fig 3 shows the averagely daily rate of fuel (natural gas) burned in the heater for months of 2009.

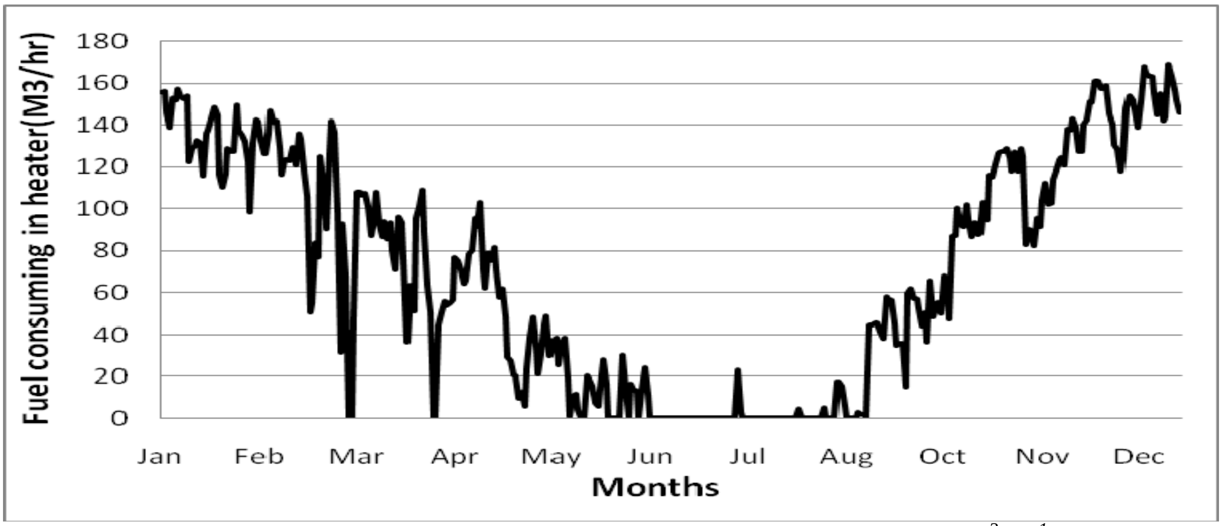

Fig. 3. The averagely daily rate of heater fuel (natural gas) consumption in 2009 ($m^3.hr^{-1}$)

As discussed previously, some part of required preheat energy in the heater is proposed to be replaced by energy gained in solar collector array. The average monthly of absorbed solar energy that gained in Akand Station area shown in Fig 4. It could be realized that the maximum absorbed solar energy is reached in Jun and The lowest value is in October.

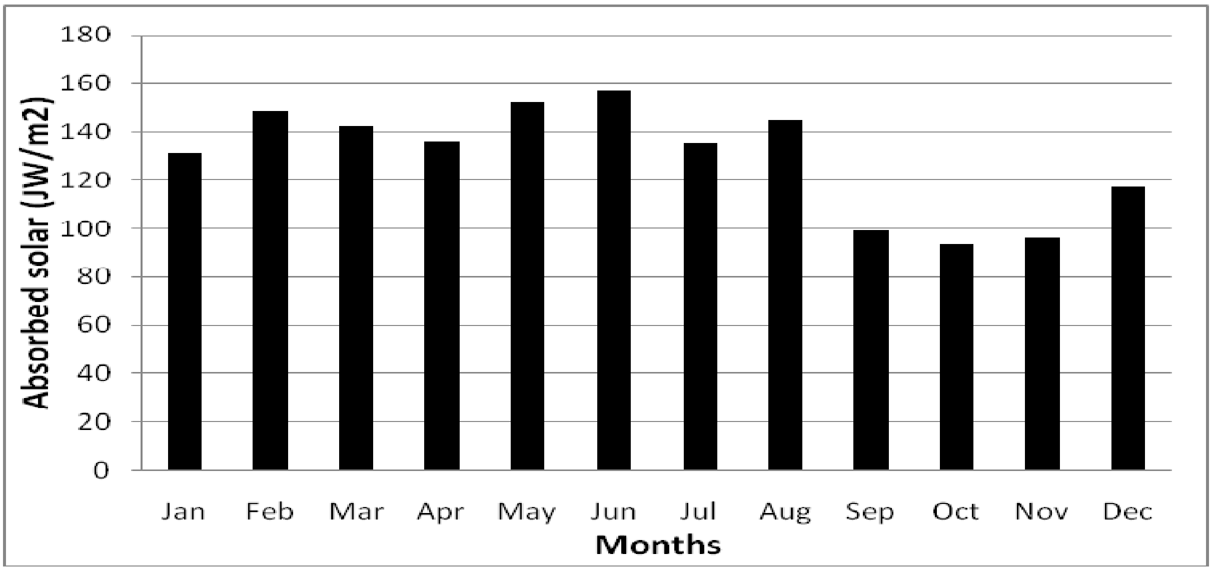

Fig. 4. Average monthly of absorbed solar energy in 2009

The capital cost of the proposed solar system or the array of collector modules could be actually calculated by multiplying the number of collector modules and cost of one module. The cost of one flat plate collector module is about 230 USD in Iran. As number of collector modules in the array increases, the capital cost increases but the heater fuel cost decreases. The variation of annual fuel cost of the heater and solar energy system capital cost against number of collectors modules are displayed in Fig.5. Considering the figure, one could select 450 as an optimum value for the number of collector modules.

It should be noted that the fuel cost calculation is based on current natural gas price which is 0.28 USD for each cubic meter.

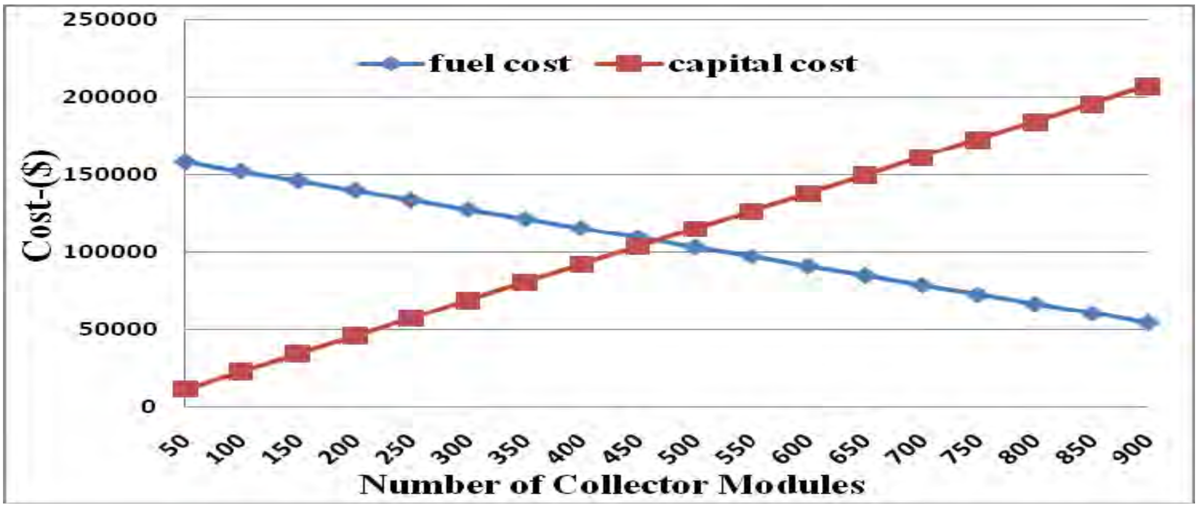

Fig. 5. Variation of solar system capital cost and fuel cost for against number of collector modules

To evaluate the desirability and to investigate the cost effectiveness of the proposed method with an array of 450 collector modules, Fig.6 shows the daily average heater fuel consumption required for preheating gas in 2009 in case of utilizing solar system or without solar system. The distinction between fuel consumptions, shows saving in fuel ($m^3.hr^{-1}$). Annually fuel cost saving can calculate by multiply this amount in 0.28 USD.

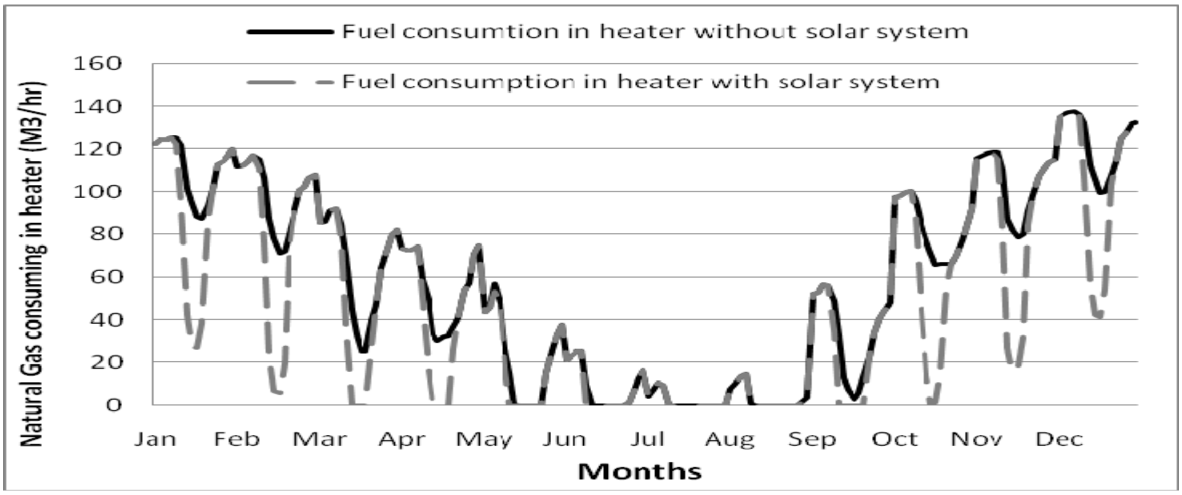

Fig. 6. The heater fuel (natural gas) consumption required for preheating gas in 2009

The annual fuel saving is about 10678 USD and as the capital cost is about 76500 USD, the payback ratio could be calculated as below:

$$Payback\ Ratio = (Capital\ \cos t)/(Benefit) = 9.2\ years \quad (9)$$

4. Discussion

The natural gas pressure must be reduced to distribution pressure when reaches its end users. The gas must be heated before it enters throttle valves to ensure that it remains above the hydrate-formation zone and dew point, so that no liquid or solid phase condenses at the station exit when pressure and temperature reduced. Currently in all Iran's CGSs, the gas is preheated through a bath type heat exchangers (known as line heater) which burns a portion of the gas for providing heating duty to warm up the natural gas. As the low temperature heat is required for preheating the natural gas in a CGS, A solar collector array is proposed to be utilized in the CGS in order to displace heating duty of the heater and to reduce amount of fuel consumption. The proposition includes a modified design of an in-use CGS to take advantage of freely available solar heat. The proposed system has been applied to study the thermal behaviour of a CGS within Iran (Akand City Gate Station). The results show that the cost effectiveness of the proposed method with an array of 450 collector modules is resulted in fuel saving with variation between 0 to 20 USD.hr^{-1}. The annual fuel saving is about 10678 USD and as the capital cost is about 76500 USD, the payback ratio is calculated to be around 9 years. The number of collector modules has been determined based on cost analysis.

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