Bath heaters using alternative heat transfer medium: a thermo-economic analysis

Amiri Delouei, Amin; Karimnejad, Sajjad; Gharajeh, Ayoub; Sajjadi, Hasan; Atashafrooz, Meysam; Xie, Gongnan; Arabkoohsar, Ahmad

Published in:
Journal of the Brazilian Society of Mechanical Sciences and Engineering

Link to article, DOI:
10.1007/s40430-022-03989-8

Publication date:
2023

Document Version
Peer reviewed version

Citation (APA):
Amiri Delouei, A., Karimnejad, S., Gharajeh, A., Sajjadi, H., Atashafrooz, M., Xie, G., & Arabkoohsar, A. (2023). Bath heaters using alternative heat transfer medium: a thermo-economic analysis. *Journal of the Brazilian Society of Mechanical Sciences and Engineering*, *45*(2), Article 73. https://doi.org/10.1007/s40430-022-03989-8

Bath Heaters Using Alternative Heat Transfer Medium: A Thermo-economic Analysis

Amin Amiri Delouei[1*], Sajjad Karimnejad[2], Ayoub Gharajeh[3], Hassan Sajjadi[1], Meysam Atashafrooz[4], Gongnan Xie[5], Ahmad Arabkoohsar[6,7]

[1] Department of Mechanical Engineering, University of Bojnord, Bojnord 945 3155111, Iran

[2] Mechanical Engineering Department, Shahrood University of Technology, Shahrood, 361 9995161, Iran

[3] North Khorasan Gas Company (NKGC), Bojnord, Iran

[4] Department of Mechanical Engineering, Sirjan University of Technology, Sirjan, Iran

[5]Department of Mechanical and Power Engineering, Northwestern Polytechnical University, Xi'an, 710072, China

[6]Department of Mechanical Engineering, Technical University of Denmark, Lyngby, Denmark

[7]Department of Energy Technology, Aalborg University, Denmark

Abstract

In this paper, the performance enhancement of a particular type of heater, i.e. Water Bath Heater, with a wide range of industrial applications is proposed and assessed. The idea is centered around using an alternative working fluid with better heat transfer characteristics (heat transfer oil – HTO) to quantify the impacts not only from a technical point of view but also from an economic perspective. The indirect heater of Arkan CGS (located in North Khorasan province of Iran) is selected as the case study, and its laboratory model is constructed by dimensional analysis. The thermal analysis is done at different fluid flow rates in the heating coil of the experimental setup. The results are verified by both numerical simulation and available empirical correlation. The results show that using HTO as the heating medium leads to heater efficiency improvement by up to 158%, and it will also lead to energy savings of up to 36.5%. A comprehensive economic analysis is carried out based on the technical results. It is found that the internal rate of return and dynamic payback period are in the ranges of 42%-67%, and 1.53-2.17 years, respectively.

Keywords: Passive Energy Enhancement; Energy Systems; Experimental Techniques; Heat and Mass Transfer; Heat Exchangers.

---

* Corresponding Author, a.amiri@ub.ac.ir ; a.a.delouei@gmail.com

1. Introduction

Although the world is tending toward renewable and sustainable energy systems, natural gas is to stay the primary source of energy for the next decade [1]. Industrial countries like the United States and China have had (and will have) the most gas demand growth in recent years. The Asia Pacific is also projected to account for approximately 60% of the total consumption in 2024 and China will be the main driver of gas demand [2]. Iran is one of the main producers of natural gas in the world. However, due to the incorrect consumption pattern of consumers and also energy waste in distribution networks, a large amount of natural gas produced inside the country is wasted. Considering the increasing demand for natural gas resources, it is very important to investigate the methods of reducing natural gas consumption.

From a holistic view, energy efficiency enhancement methods could be categorized as passive and active techniques. The former keeps the system structure as it is and proposes a marginal modification of the system framework or operation method which will normally not cost much and could result in marginal improvements [3]. The latter refers to the cases with a major revision of the system configuration or operating approach to get major modification [4]. Passive techniques are getting quite a lot of attention, as a measure to make conventional energy systems compatible with future smart energy systems [5] via increasing the efficiency and/or sustainability with minor or moderate revisions [6]. Sustainability here does not only mean renewable energy supply but also a true and broader concept considering the efficiency of supply, cost-effectiveness, social and environmental impacts [7]. Some examples of passive energy enhancement techniques are using nanofluids or alternative working fluids in energy systems for better efficiency, waste heat recovery, flue gas condensation, etc. [8].

One of the many energy technologies being widely used in the industry is water bath heaters, also called line haters. These are, to the best of the authors' knowledge, mostly used in gas stations, for preheating the gas flows before being expanded. Gas pressure must be reduced to the desired level in several stages before consumption by major users such as cities, power plants, gas-driven factories, etc. One of the pressure reduction stations is the city gate station (CGS) [9, 10]. CGSs usually use throttling valves for the pressure reduction process [11, 12]. The gas is preheated before expansion because pressure reduction will make a significant temperature drop in it and as a result solid water crystals could be formed at certain temperature levels, potentially blocking the gas pipeline [13]. The temperature and pressure drop relationship is a function of the Joule-Thomson (JT) factor of the gas which may vary from one gas to another depending on their compositions [14, 15]. The preheating process is carried out mostly using an indirect water bath heater burning a portion of the main gas stream as fuel [16]. Like any other conventional energy system, especially those using fossil fuels, the environmental issues and economic considerations have resulted in efforts on the optimization and betterment of such heaters [17-19]. For example, Angelo et al. [20]

recommended designing heaters with the aid of a two-phase closed-loop thermosiphon leading to smaller heaters offering the same heating capacity. A thermo-economic analysis on pressure reduction stations using a system of integrated power generation was done by Li et al. [21] using a multi-objective optimization approach to optimize both technical and economic performance criteria of the system. They claimed that the energy cost is reduced by 42% using their proposal. Farzaneh-Gord et al. [22] suggested a solar system to supply part of the heat demand in CGS. Akand CGS in Iran has been selected as a case study. Simple Payback Ratio and Net Present Value methods are used to examine the economic feasibility of the proposed approach. The payback ratio is reported to be 6.9 years. The cost analysis is a vital parameter in determining the number of collector modules in this scheme. Also, Farzaneh-Gord et al. [23] used a geothermal-driven heat exchanger to be combined with the gas heater and did a detailed thermo-economic analysis on it. They found a promising IRR of about 0.16 for this arrangement.

Furthermore, Farzaneh-Gord et al. [24] investigated a new system to eliminate the gas consumption in CGSs by utilizing a vertical ground-coupled heat pump scheme. the study was done for two different climatic conditions in Iran. They claimed that the proposed method is practical and by considering the energy consumption of heat pumps, the total fuel consumption reduction will be over 65%. Ghezelbash et al. [25] introduced a new fuel reduction technique based on using a vortex tube and vertical ground heat exchanger before the CGS heater. In this technique, the vortex tube is utilized to reduce the gas line pressure, and the throttle valve is eliminated. The study found that the proposed method will reduce fuel consumption by up to 88%. Arabkoohsar et al. [14] proposed a combination of a turbo expander and a solar heating unit to optimize the CGS performance. They claimed that the proposed configuration has a payback ratio of 3.5 years and it is suitable for CGSs located in Iran. Naderi et al. [26] proposed a plan to increase the efficiency of the CGS heaters by recovering a part of the waste energy from the chimney of the heaters. For this purpose, they designed a reheating system with the help of a gas-water heat exchanger. CGS located in Shahrekord city in Iran was considered as the case study. They reported that the proposed plan will reduce energy consumption by 45%.

The literature also brings up a number of research works that have taken a secondary approach, i.e. the passive technique, to enhance the efficiency of the line heaters. Salari and Goudarzi [27] used turbulators in such heaters with circular and elliptical tube cross-sections and they simulated the thermal behavior of the heater in ANSYS CFX 14.5. They studied the Nusselt number, friction, and thermal performance factor of the device. In another study, the arrangement of the gas and fire coils was discussed and the size of coil pitches was investigated [28]. Arabkoohsar et al. [29] numerically studied the thermal and environmental performance of heaters using different twisted-tape designs with various pitch lengths. It was revealed that shorter pitches and a larger number of twists have a positive impact on the line heaters' efficiency. Khosravi et al. [30] also conducted a numerical simulation to investigate the thermal effect by using twisted flow disturbers in the gas coil of CGS heaters. The results show that the flow disturber could increase the Nusselt number by about 20%. Ref. [31] researched the efficiency enhancement of combustion reaction of line heaters by taking advantage of barometric dampers and regulating burners. It was found that adjusting flame length and controlling air/fuel ratio will increase the overall heating efficiency by 30%. A very thorough study on the energy and exergy characteristics in a CGS, by considering seasonal parameters such as natural gas inlet pressure, temperature, and relative humidity of the surrounding, was carried out by Olfati et al. [32]. They emphasized the importance of seasonal variables and claimed the results can be applied to all CGSs.

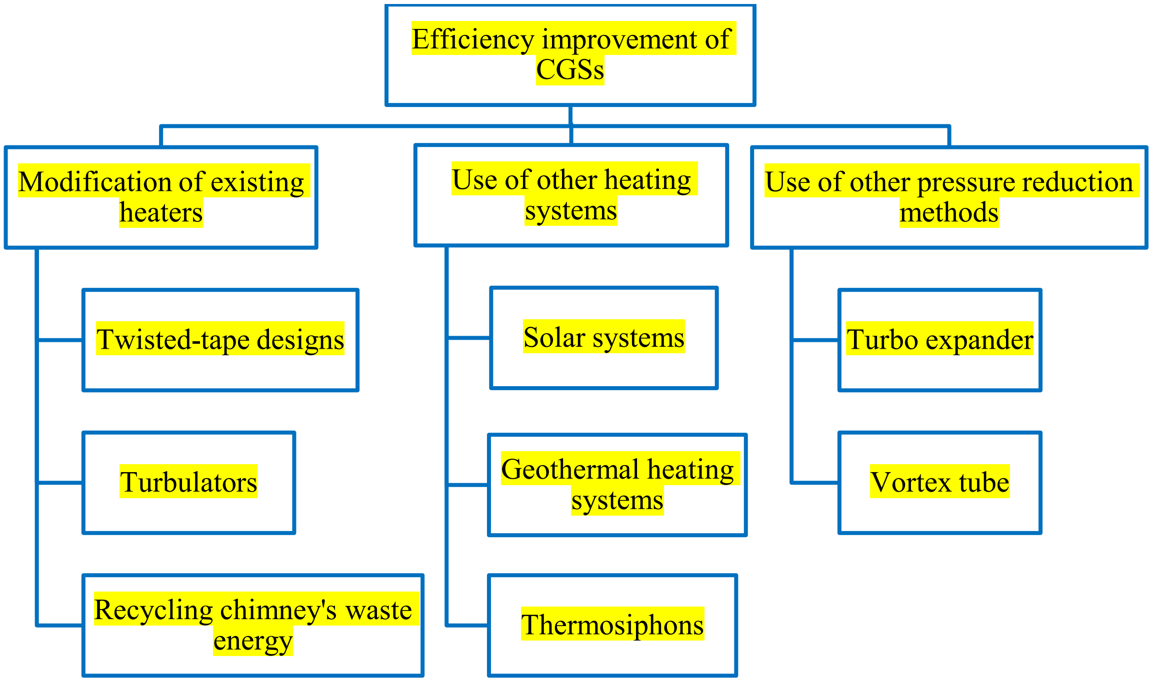

Fig. 1. Suggested solutions to reduce energy waste by indirect heaters in CGSs.

The literature review shows that there are generally three approaches to reduce energy waste by CGS heaters: (1) Modifying the existing heaters, (2) Use of other heating systems, and (3) Use of other pressure reduction methods. **Fig. 1** shows the proposed techniques for each of these three approaches. There are several problems in using the proposed methods in **Fig 1.** (1) In many cases, one needs advanced technologies, and also there is a need for a huge initial investment, which might not be justified considering the low price of natural gas in countries like Iran. (2) Many proposed methods have been presented in theory and their practical implementation has not been proven yet. In fact, they are applicable under certain specific conditions (e.g. geothermal or solar systems). (3) Equipment maintenance in some methods, especially those that require equipment with moving parts (such as turboexpander) is very expensive and timeconsuming. It will also reduce the reliability of the gas line. (4) Performance of some equipment (like vortex tube and turboexpander) are so sensitive to the gas flow characterizes like temperature and flow rate. Due to the changing conditions of the station at different times, the use of these technologies will reduce the reliability of CGSs.

The current study proposes a feasible and effective proposal for tackling this issue. Most of the previous works done on the heat transfer improvement in existing CGS heaters have been either numerical [29, 30, 33] or theoretical [22, 34, 35] studies. Such studies consider many simplifications and assumptions, while a laboratory investigation can make more accurate and robust results. Here, a prototype of the heater using dimensional analysis is constructed and technical tests are carried out experimentally. The study is done on a real case study (Arkan CGS located in North Khorasan of Iran). The main idea is to use an alternative medium (industrial oil) instead of water in the bath to improve heat transfer, which is categorized as a passive heat transfer enhancement approach with a low initial investment requirement in comparison with the other previously proposed approaches in **Fig. 1** and no need to any changes in the configuration of the existing heaters. Using HTO instead of water has also further positive benefits such as preventing algae formation and evaporation in CGS heaters, reducing maintenance costs. Another Argument in favor of this approach is the fact that the new intermediate liquid is rather eco-friendly.

To ensure the reliability of the results, proper validation tests are conducted. To do so, first, the data related to the case with water as the intermediate flow is verified against both numerical simulations and the Dittus-Boelter's empirical correlation. For moving toward practicality, the feasibility of the proposed method is also checked from an economic point of view by performing a series of comprehensive economic studies. This includes Net Present Value (NPV), Internal Rate of Return (IRR), Dynamic Payback Period (DPBP), and Profitability Index (PI), which can provide researchers in this field with an accurate economic view. It is revealed that using this method not only increases efficiency but also there is a considerable reduction in fuel consumption and pollutant emissions. As for the economic perspective, most hired economic analyses show fruitful results, and most importantly the DPBP is around two years.

2. Mathematical formulation

In this section, the governing equation and dimensionless numbers of this study are presented. Considering Reynold–Averaged–Navier–Stokes (RANS), and the Boussinesq hypothesis, the flow motion can be stated as follow [36].

$$\frac{\partial \rho u_i}{\partial x_i} = 0 \tag{1}$$

$$\frac{\partial u_i}{\partial t} + \frac{\partial u_i u_j}{\partial x_j} = -\frac{1}{\rho}\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_i}\left[\ \nu\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} - \frac{2}{3}\delta_{ij}\frac{\partial u_l}{\partial x_l}\right)\right]$$

$$+\frac{\partial}{\partial x}\left[\ \nu_t\left(\frac{\partial \bar{u}_i}{\partial x_j} + \frac{\partial \bar{u}_j}{\partial x_i}\right) - \frac{2}{3}k\delta_{ij}\right] \tag{2}$$

where, u_i, u_j, and u_l are the velocity terms. x_i, x_j and x_l are the Cartesian coordinates in i, j, and l direction, respectively. δ_{ij}, υ, μ and p are the Kronecker delta function, kinematic viscosity, dynamic viscosity, and pressure of the fluid, respectively. Furthermore, ν_t and ρ refer to turbulent viscosity and density, respectively. The realizable k-ε model could be utilized for turbulence effect and this has been reported in [37] or by Khosravi et al.[38]. Regarding this turbulent model, turbulent kinetic energy (k) and dissipation of turbulence energy (ε) are solved by the following equations:

$$\frac{\partial k}{\partial t} + \frac{\partial k u_j}{\partial x_j} = \frac{\partial}{\partial x_j}\left[\ (\nu + \nu_t)\frac{\partial k}{\partial x_j}\right] + \nu_t S^2 + \beta g_i \frac{\nu_t}{Pr_t}\frac{\partial T}{\partial x_i} - \varepsilon \tag{3}$$

$$\frac{\partial \varepsilon}{\partial t} + \frac{\partial \varepsilon u_j}{\partial x_j} = \frac{\partial}{\partial x_j}\left[\ \left(\nu + \frac{\nu_t}{1.2}\right)\frac{\partial \varepsilon}{\partial x_j}\right] + C_1 S\varepsilon + \frac{1.9\ \varepsilon^2}{k + \sqrt{\nu\varepsilon'}} \tag{4}$$

where g_i, β, Pr_t, and T represent the gravity acceleration, thermal expansion coefficient, turbulence Prandtl number, and temperature, respectively. The modulus of the mean rate-of-strain tensor (S) is achieved as follows:

$$S \equiv \sqrt{2S_{ij}S_{ij}}, \quad S_{ij} = 0.5\left(\frac{\partial u_j}{\partial x_i} + \frac{\partial u_i}{\partial x_j}\right) \tag{5}$$

Furthermore, the constant C_1 in Eq. 4 is obtained as follows:

$$C_1 = max\left[\ 0.43, \frac{\eta}{\eta + 5}\right], \quad \eta = S\frac{k}{\varepsilon} \tag{6}$$

For the energy balance, the following equation is available [39]:

$$\frac{\partial \rho E}{\partial t} + \frac{\partial}{\partial x_i}\left[u_i(\rho E + p)\right] = \frac{\partial}{\partial x_j}\left(k_{eff}\frac{\partial T}{\partial x_j}\right) \tag{7}$$

In this equation, E and k_{eff} are the total energy and the effective thermal conductivity, respectively. Nusselt number is a critical dimensionless number used commonly to study the enhancement of convection. Here, Nusselt number for the fluid flow in the heating coil is defined as:

$$Nu = \frac{hD}{k} \tag{8}$$

where h, D and k are the convection coefficient, the diameter of the circular heating coil, and thermal conduction, respectively. The convection coefficient reads as:

$$h = \frac{q}{A\Delta T_{bulk}} \tag{9}$$

here, A is the pipe's surface area and q is the amount of heat transfer achieved via the energy balance equation as:

$$q = \dot{m}c_p(T_o - T_i) \tag{10}$$

$\dot{m}$ and c_p are mass flux and thermal capacity, respectively. Additionally, T_i and T_o are the heating coil's input and output temperature. ΔT_{bulk} is the temperature difference between the tank (T_{tank}) and the bulk fluid flow running in the steel pipe (T_{bulk}). There are two methods to obtain ΔT_{bulk} [40, 41]: mean temperature and log mean temperature difference (LMTD) approach. As for the former, the mean temperature between the input and output of the coil is calculated:

$$\Delta T_{bulk} = T_{Tank} - \left(\frac{T_i + T_o}{2}\right). \tag{11}$$

As for the latter, the following is used

$$\Delta T_{bulk} = \frac{T_o - T_i}{Ln\left(\frac{T_{Tank} - T_i}{T_{Tank} - T_o}\right)} \tag{12}$$

In the current study, both of them are calculated but the difference is insignificant. So, the former is reported.

Reynolds number is defined as:

$$Re = \frac{UD}{\nu} = \frac{4Q}{\pi D \nu} \tag{13}$$

where, U and ν are the velocity and the viscosity of the fluid. It should be noted that the dimensionless parameters are defined for fluid flow inside the heating coil.

3. Experimentation

3.1. The experimental set-up

As mentioned earlier, line heaters are one of the most common devices to preheat NG in CGSs. They are generally in the form of a cylindrical tank which is horizontal and allow the heating coil (designed as inlet-outlet pipelines) to pass NG throw itself and heat the flowing gas. In the current investigation, the bath heater of Arkan CGS in the North Khorasan province of Iran (**Fig. 2**) is selected as the case study.

Fig. 2. Bath heater of Arkan CGS, North Khorasan state, Iran.

These indirect heat exchangers as in **Fig. 2** consist of a cylindrical shell, heating coil, heat-transmitting intermediate fluid, fire tube, and data acquisition system. For carrying out the experiments and calculations, an experimental model of a typical line heater is built by taking advantage of similarity rules and dimensional study [42]. The physical properties of the device are noted in **Table 1**. Like the previous research [43], in this study, water is used instead of gas for safety measures. Two temperature sensors[2] are adjusted at the inlet and outlet of the heating coil.

Also, two same sensors are located inside the heater tank to capture the temperature variation of the intermediate fluid. The heater body is well insulated to prevent energy loss. To supply water at a certain temperature, a refrigerated circulator[3] is used, which is responsible for rotating the water and also cooling it to a certain temperature. Also, a valve with a bypass pipe is used to achieve different amounts of fluid flows. All the sensors are linked with a homemade data acquisition system. As seen in the schematic of **Fig. 3**, a semi-industrial cooling system equipped with a PID controller is installed in the room where the equipment is located so that the ambient temperature is kept the same in different experiments. It is also worth mentioning that conduction and convection are two mechanisms that play an important part in this kind of heat exchanger [43].

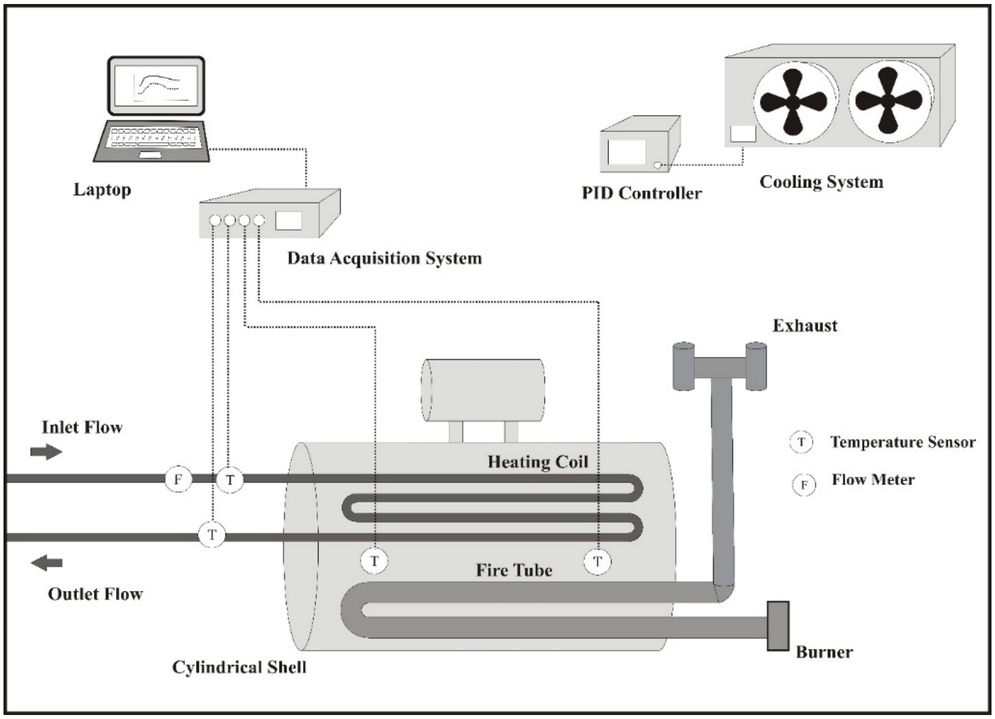

Fig. 3. Schematic illustration of the under-study experimental line heater

3.2. Properties of the under-study heat-transmitting intermediate fluid

---

[2] Maxim Integrated Co. USA) with the sensitivity of ±0.5 °C

[3] LAUDA cooling thermostats Alpha RA, -25 to 100 °C, Temperature stability, ±0.05 K

As mentioned, the main focus of the study is to make a technical and economic comparison between HTO and water as the intermediate fluid in CGSs' indirect heaters. Accordingly, two types of liquids, namely water and heat transfer oil, are used to deal with the problem. In **Tables 2** and **3,** the most important thermo-physical properties of both fluids are stated.

Table 1. The geometry of the modeled indirect CGS heater

Diameter of the heating coil	18 mm
Diameter of U-shape fire tube	40 mm
Length of U-shape fire tube	120 cm
Shell diameter	20.32 cm
Shell length	70 cm
Tank capacity	20 lit

Table 2. Thermo-physical properties of water

Density	999 kg/m^3
Viscosity	0.658 Cst
Heat transfer coefficient	0.588 W/m.K
Specific heat capacity	4190 J/kg.K
Prandtl number	4.495

Table 3. Thermo-physical properties of heat transfer oil

Density	869 kg/m^3
Viscosity	32 Cst
Heat transfer coefficient	0.133 W/m.K
Specific heat capacity	1954 J/kg.K
Flash point	206°C
Pour point	-12°C
Prandtl number	375

3.3. Uncertatinty analysis

Moffat's [44] method is used to calculate the uncertainty of the results. Regarding the technique proposed by Moffat's [44], the uncertainty of the dependent variable (δR) will be as follows:

$$\delta R = \left[\left(\frac{\partial R}{\partial X_1}\ \delta X_1\right)^2 + \left(\frac{\partial R}{\partial X_2}\ \delta X_2\right)^2 + \cdots + \left(\frac{\partial R}{\partial X_n}\ \delta X_n\right)^2\ \right], \tag{14}$$

In this method, the result R of the experiment is considered as a function of the independent variables $(X_1, X_2, \ldots, X_n)$ as:

$$R = R(\ X_1, X_2, \ldots, X_n), \tag{15}$$

Also, δX_1, δX_2, ..., δX_n are the uncertainty of the independent variables which are used in function R. Regarding this method, the maximum uncertainty in calculating heat transfer rate, Reynolds number, and Nusselt number are presented in **Table 4**.

Table 4. Uncertainty values.

Parameter	Uncertainty
Reynolds number	±5.2%
Nusselt number	±3.6%
heat transfer rate	±2.9%

4. Results and discussion

In this section, the validity of the results is discussed first (subsection 4.1). Then, some technical tests regarding the medium in the under-study experimental model are presented (subsection 4.2). In the next part, an economic analysis is done on the case study line heater to show the practicality of the proposed medium financially (subsection 4.3).

4.1. Validation

To ensure the accuracy of the results, the data from laboratory tests for water (as intermediate-fluid) are compared with the results from numerical simulations and the well-known empirical correlation of Dittus Boelter [45]. The Dittus Boelter equation in terms of Reynolds (Re) and Prandtl numbers (Pr) could be written in the following form:

$$Nu = 0.023\ Re^{0.8} Pr^{n}, \begin{cases} n = 0.4\ \ (heating) \\ n = 0.3\ (cooling) \end{cases} \tag{16}$$

This equation is presented for fully developed (hydrodynamically and thermally) turbulent flow in circular tubes [46].

ANSYS FLUENT Software is hired for the numerical simulation of the problem. The purpose of this numerical simulation is to calculate the tank temperature and compare that with the experimental results in different conditions. The finite element method [47] is used to discretize the governing equation. In the current numerical simulation, Least Squares Cell-Based method [48] is employed for calculating the gradient terms. The QUICK scheme is used to discretize energy and momentum equations, and also First Order Upwind method is applied to discretize turbulent kinetic energy and turbulent dissipation rate. Pressure interpolation is done by PRESTO (PREssure STaggering Option) Scheme. Furthermore, the pressure-velocity coupling is done by the SIMPLEC algorithm [49].

The mesh grid study is carried out for four different mesh sketches. The mesh sketches are categorized based on the average elements' size as Very Coarse, Coarse, Normal, Fine, and Very Fine (**Table 5**). Tank temperature (at Re=19000) is calculated using these four mesh sketches. The mesh sensitivity analysis shows that the difference between the results obtained for the mesh sketches of "Fine", and "Very Fine" is so small (about 1.5%). So, to reduce the computational cost, the "fine" mesh sketch is used for the numerical simulation.

Fig. 4 shows the 3D model and the structure of the mesh grids in the numerical domain. Hexahedron elements are employed to disassemble all the computational domain.

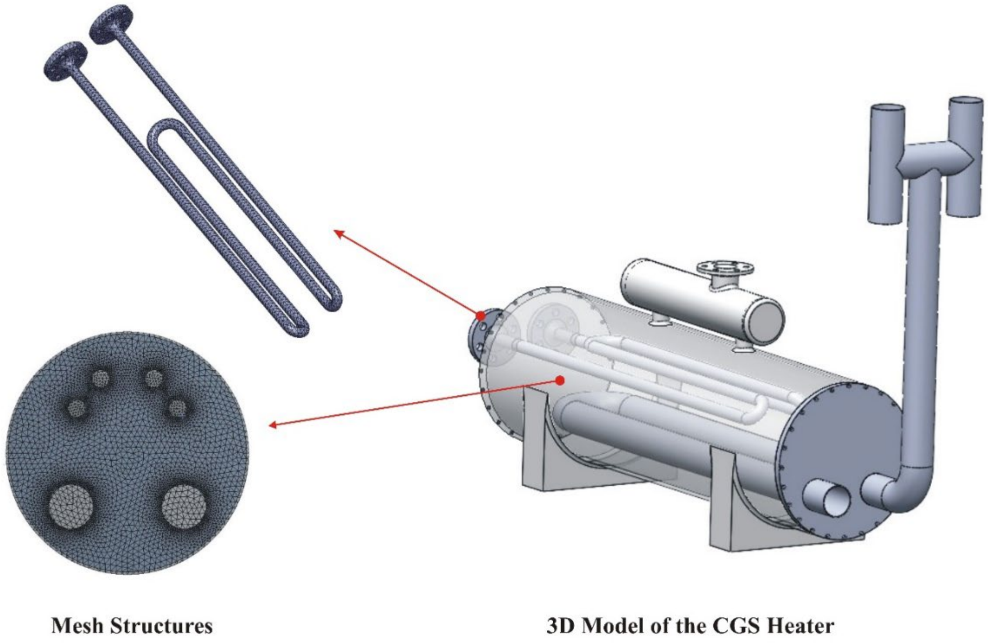

Fig. 4. 3D model of the under-study CGS heater and Structure of the mesh grids on the numerical domain.

Table 5. Mesh grid sizes

Mesh	Very Coarse	Coarse	Normal	Fine	Very Fine
Elements' size	0.01 m	0.0085 m	0.007 m	0.0055 m	0.004 m
Total grids' number	164055	220867	270707	408585	874005

Fig. 5 compares the results of the experiments with the values of the tank temperature, and Nusselt number obtained by numerical simulation and Dittus-Boelter correlation [49], respectively. The difference between the data obtained in both cases was less than 15% which is acceptable for an experimental study.

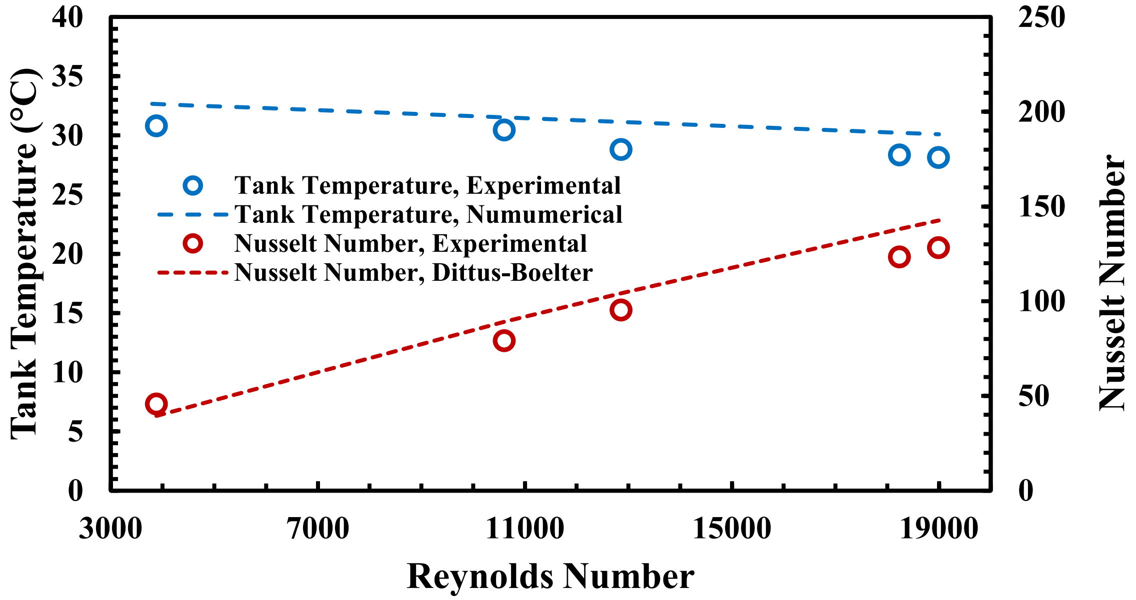

Fig. 5. Comparison of the results from laboratory test with the values of tank temperature and Nusselt number obtained by numerical simulations, and Dittus Boelter equation [49], respectively.

4.2. Thermal analysis

Here, the thermal analysis of the CGS heater in different Reynolds numbers of the fluid flow in the heating coil will be discussed. First of all, For a better comparison of the results, the numerical values of the results obtained from the sensors are shown in **Table 6**.

The variations in the temperature of the medium fluids and heat transfer rate with respect to different Reynolds numbers are shown in **Fig. 6**. As illustrated, for the tank temperature, there is no considerable difference in both cases.

Table 6. The results of the experimental test at different Reynolds numbers.

Flow rate (m3/s)	Reynolds number	Outlet temperature (°C)		Tank temperature (°C)	
		Water	HTO	Water	HTO
0.065	3881.55	17.44	20.25	30.82	61.84
0.18	10604.45	15.75	16.88	30.45	60.53
0.22	12861.74	15.44	16.31	28.82	55.85
0.31	18241.87	15.13	15.56	28.35	55.85
0.32	18994.41	15.09	15.49	28.13	55.63

The inlet temperature is fixed at 12.56 °C. The volume of the liquid inside the tank is large compared to the volume of the fluid passing through the heating coil. So the flow rate variation of the fluid passing through the coil does not have a great effect on the tank temperature. Indeed, the temperature level of HTO is higher than water, which is caused by its lower heat capacity compared to water. For the heat transfer rate, there is a wide disparity between the figures for water and HTO, with the latter ranking first in all tests. The higher temperature of the tank is the main reason for the higher quantity of heat transferred to the fluid flowing in the heating coil when using oil instead of water. Also, there is an upward trend for both cases with a growth in Reynolds number. In fact, at higher Reynolds numbers, and consequently higher mass flow rates in the heating coil, the energy transfer capability will increase.

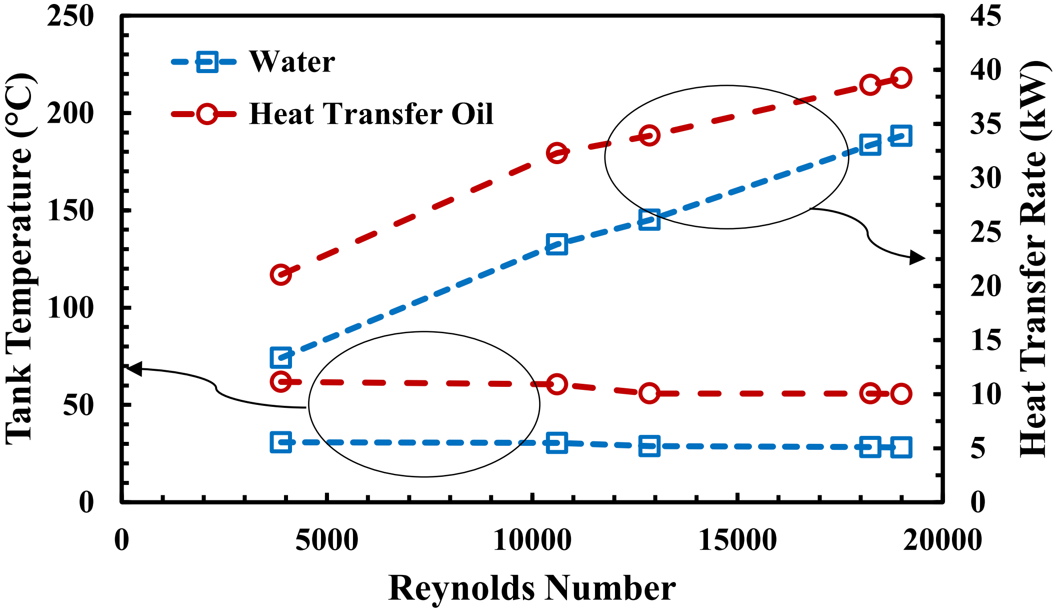

Fig. 6. The variations of the tank temperature and heat transfer rate versus Reynolds number

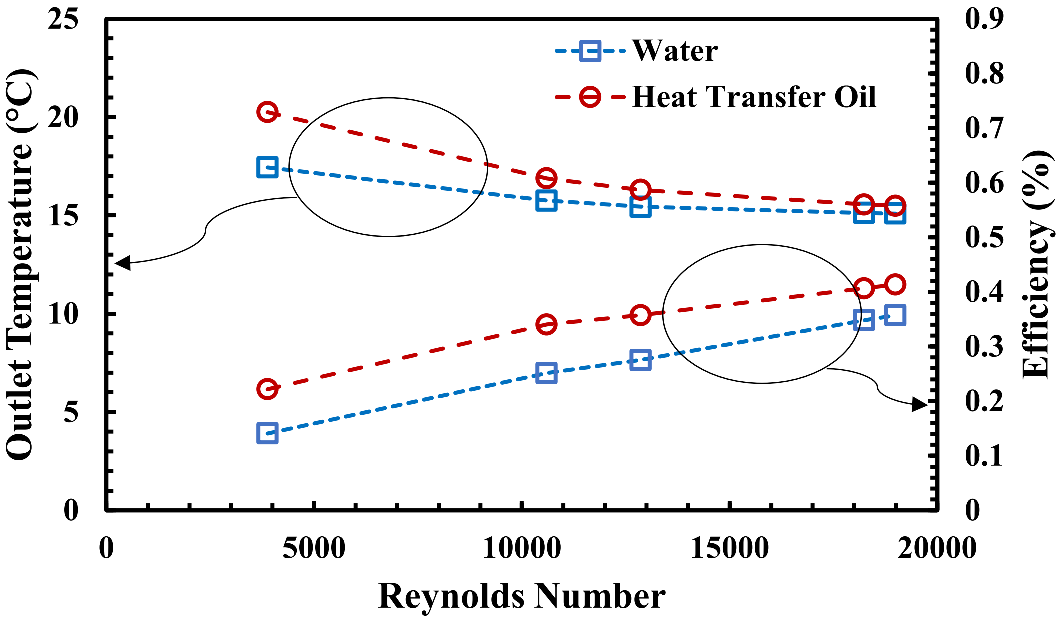

Fig. 7. Efficiency and outlet temperature versus Reynolds number

A comparison between two under-study mediums in terms of outlet temperature of the heating coil and heater's efficiency at different Reynolds numbers while inlet temperature is considered to be fixed (12.56°C) for all tests is depicted in **Fig. 7**. It is seen that with an increase in Reynolds number, the temperature enhancement is reduced for both cases. In the higher Reynolds numbers (with higher flow rates in heating coil), the fluid flow does not have enough time to get energy from the heating medium. Moreover, the outlet temperature of the heating coil for HTO is higher than that of water in all cases, especially in lower Reynolds numbers. Again, higher temperature level of heating medium in the case of using HTO is the main reason for this behavior. To calculate heater efficiency, the following relationship is defined:

$$\eta = \frac{\dot{m}C_p(T_o - T_i)}{\dot{E}_{Gas}} \tag{17}$$

Eq. 17 shows the ratio of transmitted heat to fluid in terms of the total energy expended by gas consumption. In the current study, the rate of gas consumption is fixed at 2.64×10^{-4} m^3/s. Considering the heating value of the consumed gas which is 3.59×10^{7} j/m^3, $\dot{E}_{Gas}$ will be 9.49×10^{3} j/s. **Fig.7** displays the values of the defined efficiency with respect to five different Reynolds numbers. As seen, the efficiency for the case of using HTO instead of water is somewhat higher. **Table 7** gives detailed information in this regard. Accordingly, one can deduce that the efficiency when HTO is used can be up to 1.58 times as high as that of water.

As seen in **Fig. 6**, using HTO increases the tank temperature which will increase the outlet temperature of the fluid flowing in the heating coil. By considering a fixed fluid temperature at the inlet of the heating coil, the increase of the outlet fluid temperature will lead to efficiency improvment of the bath heater (Eq.17). On the other hand, in the higher Reynolds numbers, the temperature difference will be decreased and the amount of efficieny improvment will be less.

The saved energy by using alternative heat transfer medium could be calculated as [15]:

$$Energy\ Saving\ (\%) \cong \frac{\Delta T_2 - \Delta T_1}{\Delta T_2} \times 100 \tag{18}$$

where ΔT_1 and ΔT_2 respectively indicate the temperature difference between inlet and outlet temaperatures of fluid flow in heating coil when using water and HTO as the heating medium, respectively. The values of saved energy by using alternative heat transfer medium are also presented in **Table 7**. As for **Table 7**, the energy saving values experience considerable changes from 13.65% to 36.54% by increasing the Reynolds number. As the Reynolds number increases, the effect of using oil as a heating medium on the inlet fluid temperature of the heating coil decreases, and therefore according to Eq.18, the amount of stored energy will also be lower.

Table 7. Efficiency ratio and stored energy percentage by using alternative heat transfer medium in different Reynolds numbers

Reynolds number	Flow rate (l/s)	Efficiency in case of using HTO (%)	Efficiency in case of using Water (%)	Efficiency ratio for using HTO to water	Energy saving (%)
3881.55	0.065	22.17	14.07	1.58	36.54
10604.45	0.175	34.03	25.13	1.35	26.16
12861.74	0.216	35.74	27.52	1.30	22.99
18241.86	0.307	40.66	34.83	1.17	14.33
18994.41	0.320	41.35	35.71	1.15	13.65

4.3. Economic analysis

In this section, an economic analysis is done on the line heater of Arkan CGS working in North Khorasan (Iran). They are fed by natural gas pipelines of the national gas of the country. Using indirect water bath heaters to preheat gas is a common practice in almost all the CGSs all over the country. These heaters need a proportion of the inlet NG to warm up the gas before reducing pressure. It is officially reported that these heaters burn 32980 m^3 NG in a year. In order for making an initial economic analysis, key economic criteria such as net present value, internal rate of return, dynamic payback period, and profitability index [50-52] are taken into account. These economic indicators are obtained based on a five-year service life assumption.

Fig. 8 illustrates the reduction in fuel consumption per different energy storage percentages. As illustrated, the amount of reduced gas consumption in the best case is over 11688 m^3. Also, **Table 8** is responsible to show the other costs which are saved when removing water as the heat-transmitting intermediate fluid. It is noteworthy to add that some potential costs like cost of inspection, replacing damaged parts (heating coil, shell, fire tube) due to corrosion, and also costs for testing solutions for heaters or overhaul done by contractors (that would be much lesser when using HTO instead of water) are neglected. It should be considered that the amount of saved capital in each year is the sum of fixed costs (**Table 8**) along with saved capital as a result of reduced fuel consumption (**Fig. 8**).

Table 8. Annual Costs for Water intermediate Fluids for the case study of Arkan CGS

	Unite price	Required volume (mass)	Total price
DM water	4 ₵/l	5250 Liter	210 $
Ethylene glycol	133.3 ₵/l	2250 Liter	3,000 $
Nalco	233.3 ₵/kg	75 kg	175 $

4.3.1. Net present value

This index is the difference between the present value of cash inflows and outflows over a period of time. This is generally employed for capital budgeting to analyze the likelihood of a calculated investment or a project [50, 53]. In the current NPV approach, primarily at the time of occurrence, all costs and revenues at an appropriate interest rate are calculated as:

$$NPV = \sum_{t=1}^{t} \frac{C_t}{(1+i)^t} - C_0 \tag{19}$$

here C_t is the net cash flow during the period, and C_0 is the total initial investment costs. Also, i and t are respectively interest rate and the number of time periods. In this study, i=20% and t=5 years. Generally, positive NPV is profitable and vice versa. **Fig. 8** displays net present value versus different energy storage percentages when using HTO rather than water as the medium. As can be seen from the figure, the achievable NPV is more than 10000 $ for the most used amount of consumed energy in only one rather small line heater of Arkan CGS.

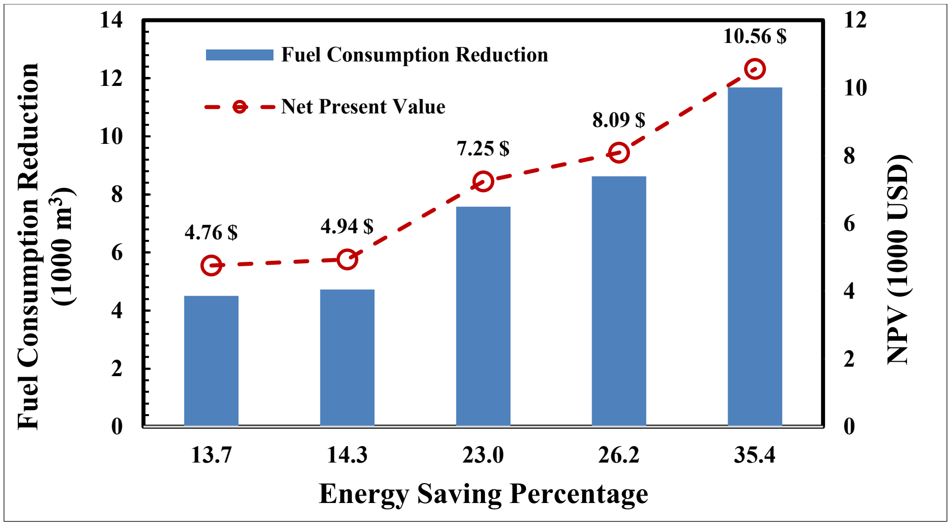

Fig. 8. The comparison of the Fuel consumption reduction, and net present value (NPV) when using HTO instead of water for different energy storage percentages

4.3.2. Internal rate of return

IRR is actually related to NPV and it is obtained when the net cash flow of a particular project equals zero. To calculate IRR, the formula for NPV is used [53]. In most cases, IRR should be solved by means of try and error and an analytical solution is not available. If this amount of IRR is more than the interest rate, then the project can be called profitable and thus practical. On the other hand, if it is less than the real interest rate, the project is fruitless. **Fig. 9** indicates IRR when using HTO instead of water for different energy storage percentages. As can be seen, IRR is in the range of 42% to 67% for the least and most amount of saved energy, respectively.

4.3.3. Dynamic payback period

The payback period (PBP) is a standard economic analysis that is employed by many financial analysts mainly due to its simplicity [53]. This index is defined as the time needed for the initial investment of a project to equal its earnings [53]. The premise behind using this approach is the time length of the returned capital. In other words, the lower the PBP, the better it is. This issue can be helpful when comparing various schemes.

When calculating PBP, the time value of capital is not taken into account and cash flows are assumed to have the same value in different years. Since considering the time value of capital will enhance the accuracy and credibility of the calculations, instead of PBP, the dynamic payback period (DPBP) is defined. In this index, cash flows are aggregated after discounting. **Fig. 9** shows DPBP for using HTO instead of water for different percentages of energy storage. As can be seen, it is estimated that this period ranges from 1.77 to 2.72 years.

4.3.4. Profitability index

PI is the rate that is derived from dividing the present value of cash inflows by the present value of the investment costs. PI in fact expresses the connection between costs of investment and future revenue of the project which is defined as [53]:

$$PI = \frac{PV\ of\ future\ cash\ flows}{Initial\ investment} \tag{20}$$

Fig. 9 illustrates PI when using HTO instead of water for different percentages of energy storage. Accordingly, PI is in the range of 1.53 to 2.17 for different energy storage percentages.

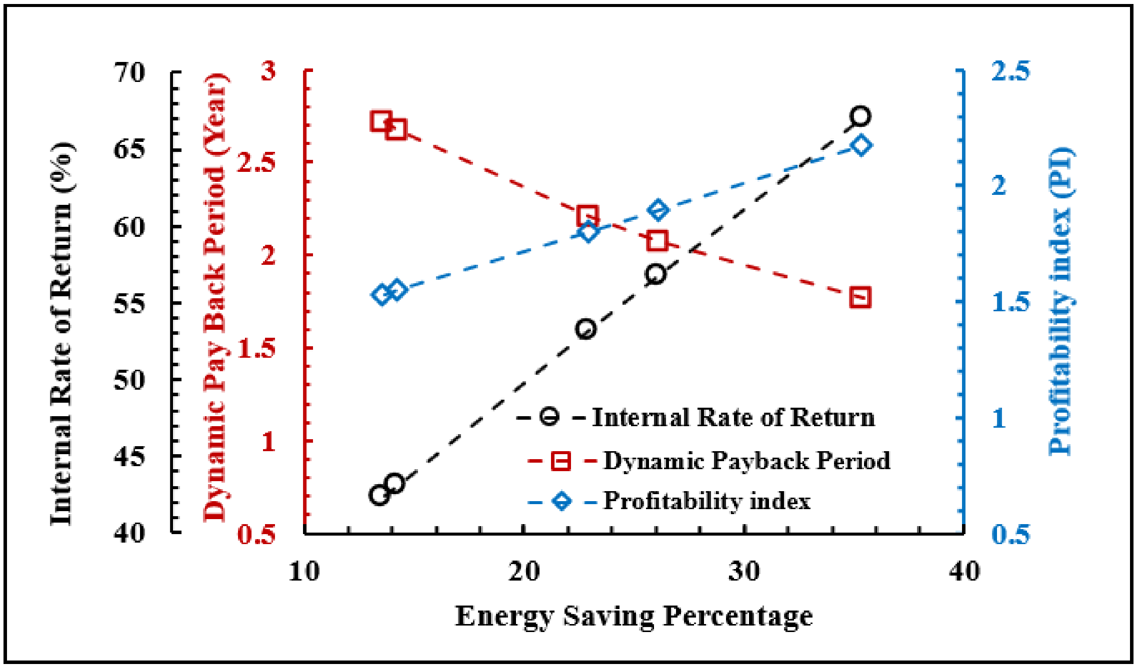

Fig. 9. The comparison of the IRR, DPBP, and PI when using HTO instead of water for different energy storage percentages

To better comparision of the current method with the other available thermo-economic analysis of CGSs, **Table 9** is presented. As it is clear in **Table 9**, the idea of using an the alternative heating medium (i.e. HTO), despite the simplicity of operation and the low initial capital required has an acceptable level of energy saving compared to other relatively complex methods. The payback period is also reasonable.

Table 9. Annual Costs for Water intermediate Fluids for the

Authors	Year	CGS Location	Employing Technology	Energy Saving or fuel consumption Reduction	PBP or DPBP	IRR
Farzaneh-Gord, et al. [22]	2012	Sari, Iran	Solar heating system	11.3%	6.9 years	-
Ashouri et al. [28]	2013	Kermanshah, Iran	Optimization of tube arrangement	5.27%	-	-
Azizi et al. [54]	2014	Mahshahr, Iran	Waste heat recovery	-	1.2 years	14%
Arabkoohsar et al. [14]	2015	Birjand, Iran	Turbo expander, and a solar system	8%-62%	3.5 years	-
Ghezelbash et al. [34]	2015	Kuhdasht, Iran	Vertical ground-coupled heat pump	45.8%	5.87 years	23%
Farzaneh-Gord et al. [24]	2016	Tabriz, Iran Mashad, Iran	Vertical ground-coupled heat pump	65%	-	-
Ghezelbash et al. [25]	2016	Semnan, Iran	Vortex Tube, and vertical ground heat exchanger	88%	4.5 years	20%
Farzaneh-Gord et al. [23]	2016	Gonbad Kavoos, Iran	Geothermal heat exchanger	-	-	15.5 %
Naderi et al. [26]	2018	Shahrekord, Iran	Waste heat recovery	80%	1.3 years	-
Current method	2022	Bojnord, Iran	HTO heating medium	13.65-36.54%	1.77-2.72 years	42-67%

In the end, it should be noted that the fluid used as a heating medium must be tested at certain time period and replaced if necessary. Paying attention to the environmental effects in this process is of particular importance. Fortunately, regarding the replacement of oils in facilities related to the gas and oil industries, there are usually contracts with production companies to refine and reuse oils which can greatly reduce costs. In Iran (where the current tests are conducted), in cases where permanent disposal of these compounds is required, waste management companies licensed by the department of environment are employed.

5. Conclusions

This study presents a thorough experimental test, and case study analysis of a passive energy enhancement technique on conventional water bath heaters for the sake of better energy efficiency pushing the technology towards more sustainability. The idea is mainly to use a more appropriate thermal energy transfer medium in the bath bed, which is a special type of industrial oil here.

Compared to other existing approaches, the proposed idea has features such as low initial cost, no need to change the current equipment, adaptability to different environmental conditions, and low maintenance costs that make its use attractive. Since this type of heater is broadly used for natural gas pressure regulation stations, Arkan CGS's heater is considered as the case study. Unlike most of the previous work done on the modification of CGS heaters which was done numerically, in the present work, laboratory modeling has been used to ensure the reliability of the results. The results of the thermal investigations are also used for the economic analysis of the proposed solution. The comprehensive economic study is enclosed Net Present Value, Internal Rate of Return, Dynamic Payback Period, and Profitability index. The following bullet points present the main findings of the project in a nutshell:

- Using HTO instead of water as the heat-transmitting intermediate fluid can enhance the efficiency of the system and subsequently a considerable reduction in fuel consumption, i.e. from 13.6% to 35.4% in different conditions.
- The proposal leads to remarkable economic benefits based on all the different economic analysis approaches taken here. Just as an example, the IRR varies between 42% and 67%, and the DPBP will be in the range of 1.6-2.8 years, which are really impressive figures.
- The immediate impact of applying the proposed modification method on the design of line heaters is reducing their environmental footprint wherever employed, especially CGSs.
- The presented technical and economic analysis can be useful for designing more efficient heaters with little added costs giving them a broader range of applications in different industries with much less concern about inefficiencies and emissions.

Declarations

Funding: This research is funded by North Khorasan Gas Company (Contract No. 9801).

Conflicts of interest: On behalf of all authors, the corresponding author states that there is no conflict of interest.

Acknowledgments

This research is funded by North Khorasan Gas Company, Iran (Contract No. 9801). The authors appreciated their financial support.

Reference

[1] P. Potočnik, J. Šilc, and G. Papa, "A comparison of models for forecasting the residential natural gas demand of an urban area," *Energy,* vol. 167, pp. 511-522, 2019.

[2] S. A. Mostafavi and M. Shirazi, "Thermal modeling of indirect water heater in city gate station of natural gas to evaluate efficiency and fuel consumption," *Energy,* vol. 212, p. 118390, 2020.

[3] A. Dewan, P. Mahanta, K. S. Raju, and P. S. Kumar, "Review of passive heat transfer augmentation techniques," *Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy,* vol. 218, no. 7, pp. 509-527, 2004.

[4] T. Alam and M.-H. Kim, "A comprehensive review on single phase heat transfer enhancement techniques in heat exchanger applications," *Renewable and Sustainable Energy Reviews,* vol. 81, pp. 813-839, 2018.

[5] H. Lund, P. A. Østergaard, D. Connolly, and B. V. Mathiesen, "Smart energy and smart energy systems," *Energy,* vol. 137, pp. 556-565, 2017.

[6] M. Legay, N. Gondrexon, S. Le Person, P. Boldo, and A. Bontemps, "Enhancement of heat transfer by ultrasound: review and recent advances," *International Journal of Chemical Engineering,* vol. 2011, 2011.

[7] C. H. d. O. Fontes and F. G. M. Freires, "Sustainable and renewable energy supply chain: A system dynamics overview," *Renewable and Sustainable Energy Reviews,* vol. 82, pp. 247-259, 2018.

[8] I. Oropeza-Perez and P. A. Østergaard, "Active and passive cooling methods for dwellings: A review," *Renewable and Sustainable Energy Reviews,* vol. 82, pp. 531-544, 2018.

[9] R. J. Steffensen and R. C. Smith, "The importance of Joule-Thomson heating (or cooling) in temperature log interpretation," in *Fall Meeting of the Society of Petroleum Engineers of AIME*, 1973: OnePetro.

[10] H. Ghaebi, B. Farhang, H. Rostamzadeh, and T. Parikhani, "Energy, exergy, economic and environmental (4E) analysis of using city gate station (CGS) heater waste for power and hydrogen production: A comparative study," *International Journal of Hydrogen Energy,* vol. 43, no. 3, pp. 1855-1874, 2018.

[11] M. Saadat-Targhi and S. Khanmohammadi, "Energy and exergy analysis and multi-criteria optimization of an integrated city gate station with organic Rankine flash cycle and thermoelectric generator," *Applied Thermal Engineering,* vol. 149, pp. 312-324, 2019.

[12] I. Andrei, T. Valentin, T. Cristina, and T. Niculae, "Recovery of wasted mechanical energy from the reduction of natural gas pressure," *Procedia Engineering,* vol. 69, pp. 986-990, 2014.

[13] A. Mohammadzadeh and N. Etemadee, "Design of Heater for City Gate Station Assisted by Solar Energy," *International Review of Mechanical Engineering,* vol. 6, no. 4, pp. 730-735, 2012.

[14] A. Arabkoohsar, M. Farzaneh-Gord, M. Deymi-DashteBayaz, L. Machado, and R. Koury, "A new design for natural gas pressure reduction points by employing a turbo expander and a solar heating set," *Renewable energy,* vol. 81, pp. 239-250, 2015.

[15] E. Ashouri, F. Veysi, E. Shojaeizadeh, and M. Asadi, "The minimum gas temperature at the inlet of regulators in natural gas pressure reduction stations (CGS) for energy saving in water bath heaters," *Journal of Natural Gas Science and Engineering,* vol. 21, pp. 230-240, 2014.

[16] S. M. Romocki, "Indirect fluid heater," ed: Google Patents, 2019.

[17] P. Soleimani, M. Khoshvaght-Aliabadi, H. Rashidi, and H. Bahmanpour, "Performance enhancement of water bath heater at natural gas city gate station using twisted tubes," *Chinese Journal of Chemical Engineering,* 2019.

[18] J. Zhao, L. Wei, H. Dong, and F. Liu, "Research on heat transfer characteristic for hot oil spraying heating process in crude oil tank," *Case studies in thermal engineering,* vol. 7, pp. 109-119, 2016.

[19] S. Koohi-Fayegh and M. Rosen, "A review of energy storage types, applications and recent developments," *Journal of Energy Storage,* vol. 27, p. 101047, 2020.

[20] W. Angelo, M. Mantelli, and F. Milanez, "Design of a heater for natural gas stations assisted by two-phase loop thermosyphon," in *14th International Heat Pipe Conference, Florianopolis*, 2007.

[21] C. Li, S. Zheng, J. Li, and Z. Zeng, "Optimal design and thermo-economic analysis of an integrated power generation system in natural gas pressure reduction stations," *Energy Conversion and Management,* vol. 200, p. 112079, 2019.

[22] M. Farzaneh-Gord, A. Arabkoohsar, M. D. Dasht-bayaz, and V. Farzaneh-Kord, "Feasibility of accompanying uncontrolled linear heater with solar system in natural gas pressure drop stations," *Energy,* vol. 41, no. 1, pp. 420-428, 2012.

[23] M. Farzaneh-Gord, R. Ghezelbash, A. Arabkoohsar, L. Pilevari, L. Machado, and R. Koury, "Employing geothermal heat exchanger in natural gas pressure drop station in order to decrease fuel consumption," *Energy,* vol. 83, pp. 164-176, 2015.

[24] M. Farzaneh-Gord, R. Ghezelbash, M. Sadi, and A. J. Moghadam, "Integration of vertical ground-coupled heat pump into a conventional natural gas pressure drop station: Energy, economic and CO2 emission assessment," *Energy,* vol. 112, pp. 998-1014, 2016.

[25] R. Ghezelbash, M. Farzaneh-Gord, and M. Sadi, "Performance assessment of vortex tube and vertical ground heat exchanger in reducing fuel consumption of conventional pressure drop stations," *Applied Thermal Engineering,* vol. 102, pp. 213-226, 2016.

[26] M. Naderi, G. Ahmadi, M. Zarringhalam, O. Akbari, and E. Khalili, "Application of water reheating system for waste heat recovery in NG pressure reduction stations, with experimental verification," *Energy,* vol. 162, pp. 1183-1192, 2018.

[27] S. Salari and K. Goudarzi, "Heat transfer enhancement and fuel consumption reduction in heaters of CGS gas stations," *Case studies in thermal engineering,* vol. 10, pp. 641-649, 2017.

[28] E. Ashouri, F. Veisy, M. Asadi, H. Azizpour, and A. Sadr, "Influence of tube arrangement on the thermal performance of indirect water bath heaters," *Journal of Chemical and Petroleum Engineering,* vol. 47, no. 2, pp. 69-81, 2013.

[29] A. Arabkoohsar, M. Khosravi, and A. S. Alsagri, "Effect of various twisted-tape designs on the thermal and environmental performance of line-heaters in city gate stations," *International Journal of Heat and Mass Transfer,* vol. 148, p. 119123, 2020.

[30] M. Khosravi, A. Arabkoohsar, A. S. Alsagri, and M. Sheikholeslami, "Improving thermal performance of water bath heaters in natural gas pressure drop stations," *Applied Thermal Engineering,* vol. 159, p. 113829, 2019.

[31] M. Riahi *et al.*, "Optimization of combustion efficiency in indirect water bath heaters of Ardabil city gate stations," in *Seventh Mediterranean Combustion Symposium (MCS-7)*, 2011, pp. 11-15.

[32] M. Olfati, M. Bahiraei, S. Heidari, and F. Veysi, "A comprehensive analysis of energy and exergy characteristics for a natural gas city gate station considering seasonal variations," *Energy,* vol. 155, pp. 721-733, 2018.

[33] M. M. A. Bhutta, N. Hayat, M. H. Bashir, A. R. Khan, K. N. Ahmad, and S. Khan, "CFD applications in various heat exchangers design: A review," *Applied Thermal Engineering,* vol. 32, pp. 1-12, 2012.

[34] R. Ghezelbash, M. Farzaneh-Gord, H. Behi, M. Sadi, and H. S. Khorramabady, "Performance assessment of a natural gas expansion plant integrated with a vertical ground-coupled heat pump," *Energy,* vol. 93, pp. 2503-2517, 2015.

[35] Q. Zhang *et al.*, "Energy-exergy analysis and energy efficiency improvement of coal-fired industrial boilers based on thermal test data," *Applied Thermal Engineering,* vol. 144, pp. 614-627, 2018.

[36] F. M. White, *Fluid mechanics*. Tata McGraw-Hill Education, 1979.

[37] H. Tennekes, J. L. Lumley, and J. L. Lumley, *A first course in turbulence*. MIT press, 1972.

[38] M. Khosravi and A. Arabkoohsar, "Thermal-hydraulic performance analysis of twin-pipes for various future district heating schemes," *Energies,* vol. 12, no. 7, p. 1299, 2019.

[39] K.-C. Chang and M.-J. Shyu, "Revisiting the Reynolds-averaged energy equation in near-wall turbulence models," *International journal of heat and mass transfer,* vol. 43, no. 5, pp. 665-676, 2000.

[40] A. A. Delouei, H. Sajjadi, R. Mohebbi, and M. Izadi, "Experimental study on inlet turbulent flow under ultrasonic vibration: Pressure drop and heat transfer enhancement," *Ultrasonics sonochemistry,* vol. 51, pp. 151-159, 2019.

[41] A. A. Delouei, H. Sajjadi, M. Izadi, and R. Mohebbi, "The simultaneous effects of nanoparticles and ultrasonic vibration on inlet turbulent flow: an experimental study," *Applied Thermal Engineering,* vol. 146, pp. 268-277, 2019.

[42] H. L. Langhaar, *Dimensional analysis and theory of models* (no. BOOK). Robert E. Krieger publishing company, 1980.

[43] A. Rahmati and M. Reiszadeh, "An experimental study on the effects of the use of multi-walled carbon nanotubes in ethylene glycol/water-based fluid with indirect heaters in gas pressure reducing stations," *Applied Thermal Engineering,* vol. 134, pp. 107-117, 2018.

[44] R. J. Moffat, "Describing the uncertainties in experimental results," *Experimental thermal and fluid science,* vol. 1, no. 1, pp. 3-17, 1988.

[45] R. H. Winterton, "Where did the Dittus and Boelter equation come from?," *International journal of heat and mass transfer,* vol. 41, no. 4-5, pp. 809-810, 1998.

[46] F. P. Incropera, D. P. DeWitt, T. L. Bergman, and A. S. Lavine, *Fundamentals of heat and mass transfer*. Wiley New York, 1996.

[47] R. Khademi, D. Mohebbi-Kalhori, and A. Razminia, "Thermal analysis of a tumorous vascular tissue during pulsed-cryosurgery and nano-hyperthermia therapy: Finite element approach," *International Journal of Heat and Mass Transfer,* vol. 137, pp. 1001-1013, 2019.

[48] B. Li, W. Xu, and F. Tong, "Measuring thermal conductivity of soils based on least squares finite element method," *International Journal of Heat and Mass Transfer,* vol. 115, pp. 833-841, 2017.

[49] H. Xiao, J. Wang, Z. Liu, and W. Liu, "A consistent SIMPLE algorithm with extra explicit prediction—SIMPLEPC," *International Journal of Heat and Mass Transfer,* vol. 120, pp. 1255-1265, 2018.

[50] V. Farzaneh-Kord *et al.*, "Defining a technical criterion for economic justification of employing CHP technology in city gate stations," *Energy,* vol. 111, pp. 389-401, 2016.

[51] A. Ebrahimi-Moghadam, A. J. Moghadam, M. Farzaneh-Gord, and K. Aliakbari, "Proposal and assessment of a novel combined heat and power system: Energy, exergy, environmental and economic analysis," *Energy Conversion and Management,* vol. 204, p. 112307, 2020.

[52] A. Ebrahimi-Moghadam, M. Deymi-Dashtebayaz, H. Jafari, and A. Niazmand, "Energetic, exergetic, environmental and economic assessment of a novel control system for indirect heaters in natural gas city gate stations," *Journal of Thermal Analysis and Calorimetry,* pp. 1-16, 2020.

[53] S. A. Ross, R. Westerfield, and B. D. Jordan, *Fundamentals of corporate finance*. Tata McGraw-Hill Education, 2008.

[54] S. Azizi, A. Rashidmardani, and M. Andalibi, "Study of preheating natural gas in gas pressure reduction station by the flue gas of indirect water bath heater," *International Journal of Science and Engineering Investigations,* vol. 3, no. 27, pp. 17-22, 2014.