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Heat Transfer Rate Enhancement in CGS Heaters Using a Tube Insert

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ABSTRACT

In this study, in order to increase the heat transfer rate in the heaters of the City Gas Station(CGS), a classic type of a tube insert was placed into its heating coils. The use of the inserts will lead to increase in the pressure drop that maybe treated as disadvantage of using inserts in some heat exchangers. However, in this case pressure drop is quite favor phenomenon as pressure should be reduced in city gas transfer line. The type of the given insert is spiral, and is made of seamless steel in accordance with the gas pipe production standard. The inserts are embedded in eight coil paths in the heater of Mavian pressure reducing station of in Kamyaran city of Kurdistan Province with capacity of 2500 m^3/h. Heat transfer enhancement up to 47% obtained, which is quite important from energy saving and environmental pollution control point of view.

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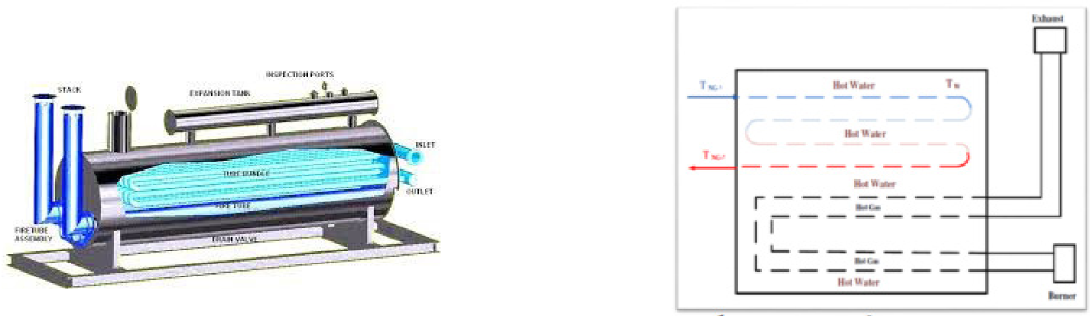
1. Introduction

Pressure reducing stations are located at the entrance to cities to reduce the high pressure of gas that flows from refineries to consumption points. This decrease in pressure is associated with a decrease in the gas temperature due to the Joule-Thomson coefficient, which, in turn, involves numerous problems such as freezing of the water and the blockage of the transmission line. In order to prevent such problems, the temperature of the gas should be increased before the pressure decreases in the station. Nowadays this temperature rise is achieved by thermal heaters using natural gas. A heaters used in the gas stations is a type of heaters in which the gas is placed inside a tube series and hot water around the pipes in a uniformly homogeneous surface with a balanced temperature. In fact, firstly, the water is heated indirectly and the water transmits this heat to the flowing gas. Hence, these heaters are also called as indirect heaters. One of the main problems with the use of this kind of heaters is the high fuel consumption, which in most cases is natural gas, so due to the low efficiency of this type of heaters, finding solutions to increase their efficiency has always been considered.



a) A general view (Farzaneh-Gord et al., 2006) **b) heating mechanism**

Figure 1. A conventional CGS gas heater layout

In a CGS gas heater, the burning of natural gas in the torch generates hot gases, and these gases cause to product the warm water due to passage from the heater. Natural gas flows from one side of the pipe and is surrounded by warm water inside the heater. This tube circulates inside the heater in several steps, and finally the temperature of the gas within it will be extremely desirable. A scheme of a classical heater which is called "linear heater" is shown in the Fig 1.

In the process of reducing pressure in constant volume, any reduction in pressure will lead to the decrease in temperature. Therefore, in gas pressure reduction systems, we will always be faced with a decrease in gas temperature. Therefore, in the gas pressure reduction systems, we will always be faced with a decrease in gas temperature. As a result, when the temperature of the gas approaches the dew point of the gas, the steam of the liquids associated with the gas, such as water and heavier hydrocarbons, is converted to liquid and at low ambient temperature at the facility causing frostbite. Since the gas temperature entering to station is 15 degrees, this pressure drop causes condensation and crystallization. This reduction in pressure causes the condensation and formation of crystals in the path and equipment of the station and ultimately reduces the life of the equipment and damage to the station. As a result, adding a heater unit in the station is essential and inevitable (Cullender, 1955).

One of the main problems with using this kind of heaters is the high fuel consumption, which is usually natural gas. Since the efficiency of this kind of heaters is low, finding solutions to increase their efficiency has always been considered. In this regard, many studies have been done to optimize energy consumption and, consequently, reduce fuels consumption of the heaters.

Heat transfer and friction coefficient of circular spiral- shaped tube with different torsion ratios were investigated by Pathipakka and Sivashanmugam (Pathipakka and Sivashanmugam, 2010) in two complete conditions of these components and short length with regular intervals. They found that these components could be used in a short length, like full length, to increase the heat rate, and only a small amount of pressure drop would increase.

Bhuiya et al. (2013) carried out a lot of laboratory studies on the use of pipes equipped with double spiral with different angles and concluded that the Nussselt number and the friction coefficient increase by decreasing the helical angle in the same conditions. Sarma et al. (2005) have also presented a series of equations for predicting friction coefficients and heat transfer coefficients in tubes equipped with twisted tapes for a wide range of Reynolds and Prandtl Numbers. There is a good agreement between laboratory data and the presented equations.

In a study, the effects of twisted tape insert with square-shaped wings containing several holes in the fluid flow and heat transfer in heat exchangers were investigated by Suri et al. (2017). Hence, under the same operating conditions in exchangers having tube insert with square-shaped wings and numerous holes, the thermal performance coefficient was higher than that of a tube insert without wing.

Rahimi et al. (2009) showed that among the various types of twist strips, including the classic twisted tape, perforated twisted tape, notched twisted tape, Jagged twisted tape; Nusselt number, and thermal performance coefficient for this serrated insert is more than other cases. Thianpong et al. (2012) studied the effects of a simple spiral tape in the tube with a fixed heat flux in a laboratory and indicated that by decreasing the twist ratio of the tape, heat transfer and pressure drop are increased. The effect of twisted tapes in the form of the regular and quadruple arrangement in thermal exchangers was examined by Samruaisin et al. (2018.) In the mode in which tapes were placed in the form of the regular and quadruple strips, the heat transfer rate and the coefficient of friction were less than that mode in which the tapes had occupied the entire space of the tube in the form of the quadruple.

2. The studied heater characteristics

The capacity of the aforementioned heater is 3000 standard cubic meter per hour (SCMH) which was built by Aria Petro Jam Company in 2008. The inside of the heater chamber is consists of the mixture of the distilled water and antifreeze, in which 8 coil paths with a diameter of 2 inches pass through the mixture. The thickness of each coil is 5 mm and the weight of each coil is considered to be 200 kg. Due to the fact that the work pressure of the heater is PSI 1050, high pressure equipment should be used. In order to prevent heat loss in the outlet of the heater, the outlet should be insulated. If the shell is full of distilled water, it's weight is 5000 kg and if shell is empty, it's weight is 1000 kg. It is obvious that the temperature increases due to increasing the capacity of the heater. To increase the temperature of the mixture inside heater chamber, the warming pan is used, which it's feed is supplied from the outlet gas of the station with a diameter of 1 inches. The amount of this feed is very significant therefore, before entering the feed into the heater, a turbine meter is installed on the heater for measuring the consumption of this energy.

Figure 2. A real photograph of heating coil

Figure3. A real photograph of station's warming pan

3. Tube insert implementation

In the construction of the station's heater mentioned above, the coil pipes with a diameter of 2 inches have been used. Due to the fact that the length of the coil is 170 cm, it should use an insert that covers enough the pipe surface. Considering the above, the dimensions of these inserts were selected according to the figure below, as the length of these tube inserts is 160 cm and their steps and the diameters for given tubes are 4 cm.

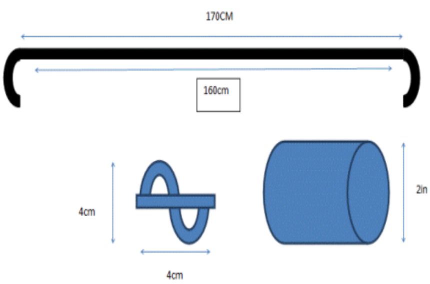


Figure 4. the geometry of the employed insert

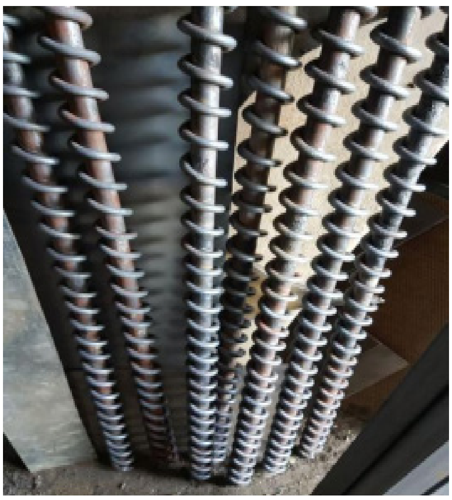


Figure 5. A real photograph of the inserts

3.1. Destruction test

The corrosion parameter is a necessary factor that should be measured during the process. As far as using an insert in tube cause a rotational fluid motion on the lateral tube wall, it can cause erosion corrosion For this purpose, before the test, the thickness is measured by the thickness gauge device. and then after the installation of the insert, the intended number is re-measured, which is considered as the difference of the corrosion criterion. The device is based on the Multigauge 5700 Datalogger model of the Trichtex company in the United Kingdom. This works on ultrasonic wave transmission. A transmitted ultrasound pulse travels though both the coating and the metal and reflects from the back wall. The returned echo then reverberates within the metal, with only a small portion of the echo travelling back through the coating each time. The timing between the small echoes gives us the timing of the echoes within the metal, which relate to the metal thickness.

3.2. Test procedure

At the first stage, necessary tests are carried out for heaters in which the insert has not been used, and the results related to the parameters of temperature, pressure and consumable flow rate are be measured and then the structure of the desired inserts are used. Finally, the results are compared. The measuring points are illustrated in Fig.6.

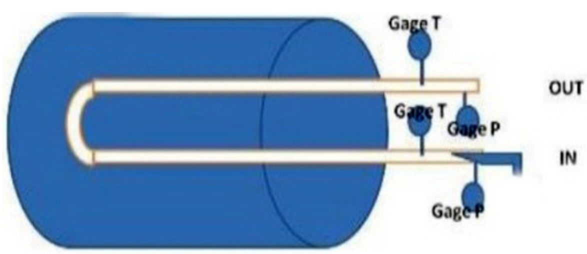


Figure 6. the schematic of how to measure the parameters

In the measurement, before installation of the insert, the input and output data related to temperature and pressure were recorded. The average time interval for each test is approximately one hour in order to reach to steady state condition. The pressure and temperature values measured at different water temperatures of 35, 40, 45, 50, 55 and 60 ºC. Also, in order to obtain more accurate results, and calculating fluid properties including viscosity, density, and thermal conductivity of fluid, as well as specific heat, the average fluid temperature was used.

3.3 Measurement results

According to the heater temperature setting, the results of inlet and outlet temperatures as well as measured pressure drop are listed in Table 1.

Table 1. Range of parameters

Heater temp (ºC)		Ti (ºC)	To (ºC)	ΔP(bar)
35	Without insert	19	36	0.15
	With insert	13	38	0.47
40	Without insert	20	41	0.13
	With insert	17	44	0.51
45	Without insert	21	45	0.1
	With insert	19	49	0.40
50	Without insert	20	47	0.1
	With insert	21	53	0.38
55	Without insert	22	49	0.09
	With insert	23	54	0.37
60	Without insert	25	50	0.88
	With insert	26	53	0.34

3.4. Data Reduction

to use laboratory results optimally, the measured data is reducible as follows: in the first step, the heat transforming rate is calculated as below (Shabanian et al., 2011):

$$Q = mC_p\,(T_0 - T_i) \tag{1}$$

On the other hand, the amount of heat transfer which conveys from the fluids to the ambient condition is calculated as below

$$Q = hA\,(\widetilde{T_W} - T_b) \tag{2}$$

$\widetilde{T_W}$ indicates the pipes' surface temperature and in under study industrial sample, is a water temperature of the heater and T_b indicates the fluids mass temperature, which is obtained from the following relationship:

$$T_0 = (T_i + T_0)/2 \tag{3}$$

The equation to calculate the average heat transfer rate and NASLET is as follows

$$h = mc_p(T_0 - T_i)\,/\,A(\widetilde{T_W} - T_i) \tag{4}$$

$$Nu_m = (hD_h)/k \tag{5}$$

Furthermore, the Reynolds's number and average friction rate is specified through the following equations:

$$Re = (puD_h)/\mu \tag{6}$$

$$f = (2D\Delta P)/(pLu^2) \tag{7}$$

One of the most important factors in the comparison of heat transfer using the structure of inserts is the parameter of the percentage of improvement in heat transfer, which is visible in the form of increase at the heat transfer in the embedded insert mode relative to the non-embedded -insert mode.

$$\%\Delta T_e = \frac{\Delta T_{with\ insert} - \Delta T_{without\ insert}}{\Delta T_{without\ insert}} \times 100 \tag{8}$$

4. Discussuion

4.1 Heat Transfer enhancement evaluation

According to measured results and by using data reduction procedure, the following results are listed for heat transfer parameters in Table2.

Table .2 Comprehensive results at various temperatures

Heater temp (°C)		Measured value				Calculated value				
		Ti (°C)	To (°C)	ΔP(bar)	u(m/s)	Re	f	h (w/m².k)	Nu	% increase in h
35	Without insert	19	36	0.15	22.16	50651.4	0.28	5.85	61.54	47
	With insert	13	38	0.47	24.5	57431	0.72	61.12	71.91	
40	Without insert	20	41	0.13	22.16	50809	0.25	52.01	59	28.51
	With insert	17	44	0.51	24.51	56205	0.78	66.88	76.85	
45	Without insert	21	45	0.1	22.16	50651	0.18	47.24	53	25
	With insert	19	49	0.4	24.51	56030	0.61	64.13	72.87	
50	Without insert	20	47	0.1	22.16	50651	0.18	38.65	43.9	18.51
	With insert	21	53	0.38	24.3	50630	0.58	57.88	65.77	
55	Without insert	22	49	0.09	22.16	50651	0.17	32.59	36.99	14.81
	With insert	23	54	0.37	24.51	50631	0.57	44.17	50.2	
60	Without insert	25	50	0.88	22.16	50651	0.16	26.58	30.2	8
	With insert	26	53	0.34	24.51	56031	0.52	29.11	33.08	

From Table 2, it can be concluded that the use of insert inside the heater improves heat transfer. Hence, increasing the Nusselt parameters and the heat transfer coefficient.

The main mechanism of increasing the temperature in a canal which has a screwed tape is creating a secondary flow due to the presence of a tangential component of velocity and increasing velocity near the wall of the tube. The fluid passing around it cause to move a part of the fluid flow perpendicular to the direction of the primary flow. This flow is known as the rotational flow. This increases the temperature gradient across the cross-section and leads to an increase in the heat transfer rate. In other words, the rotational flow generated by the strip, which leads to an increase in the heat transfer of the centrifugal displacement, plays an important role in the heat transfer of the rotational flow (Jacobi and Shah, 1995).

As expected from the studies in literature, the use of these inserts has led to an increase in pressure drop and, consequently, a friction coefficient. Considering that the increase in pressure occur before the regulator, hence it improves the demanding pressure drop reduction.

From the results of Table 2, it is found that at low water temperatures due to the difference in the driving force of the temperature, the use of inserts is very effective. Hence, the highest efficiency of use of the inserts is at temperatures of 35 and 40°C. At 35°C, improved heat-transfer of 47%was obtained. Also, at high water temperatures, Nusselt number has less variation than low temperatures, so that use of the inserts could not be effective at a water temperature of 60°C in heater. A slight increase in speed and, consequently, the Reynolds-number are of cases considered in the gas supply facilities. This can be an effective point in the issues of corrosion.

4.2. Economical and energy saving evaluation

Considering the importance of the role of energy and the conservation of non-renewable energy sources, and considering the high energy consumption of pre-heating gas in gas pressure reduction stations, it is important to check and calculate the amount of energy. To achieve this goal, the amount of fuel intended for heating which is natural gas is measured by turbine meters at different temperatures of the reservoir. By considering the recent parameter, you can calculate the efficiency of the heater and the amount of savings resulting from the use of this insert.

$$V^{\bullet} = Q^{\bullet}_{Heater} / \mu \times LHV \tag{9}$$

LHV is a low heat value of the fuel, which is 34129 kj/m^3 by using the region's gas analysis, and also, μ is the efficiency of the heater, which can be changed using the insert.

$$\dot{Q}_{Heater}\,(\frac{Kj}{h}) = \dot{m}\,(\frac{Kg}{h}) \times \mathrm{CP}(\frac{\mathrm{KJ}}{\mathrm{Kg^{\circ}k}}) \times \Delta \mathrm{T} \quad (10)$$

The following results are adapted by using the above equations.

Table 3. Checking the consumption of heaters by using insert

	Different heater temperatures	Consumption rate without insert (cubic meter per hour)	Efficiency without insert	Consumption rate with insert (cubic meter per hour)	Efficiency with insert
1	35	0.3	0.23	0.15	0.7
2	40	0.35	0.25	0.16	0.71
3	45	0.43	0.23	0.18	0.68
4	50	0.49	0.23	0.2	0.65
5	55	0.51	0.22	0.2	0.63

From Table 3, it can be concluded that the use of insert in addition to saving energy, also increases the efficiency of the heater. After ensuring that the energy consumption is reduced according to the above table, in this section the amount of savings resulted from the insert will be estimated by Rial. Given that the cost per cubic meter of gas is about fifty cents equal to half a dollar, and the dollar is set at 100000 Rials, it should be noted that the use of heaters in most areas is considered to be about 8 months, Therefore, the basis of calculation is considered to be 8 months during the year.

Table 4. Estimated costs by using insert

	Heater temperatures (degrees Celsius)	amount of energy savings (cubic meter per hour)	Energy saving cost per hour (Rials)	Energy price per day (Rials)	Energy price per month (Rials)	Energy price per year (Rials)
1	35	0.15	7500	180000	5400000	4320000
2	40	0.19	9500	228000	6840000	5472000
3	45	0.25	12500	300000	9000000	7200000
4	50	0.29	14500	348000	1044000	8352000
5	55	0.31	15500	372000	11160000	8920000
6	60	0.29	14500	348000	10440000	8352000

The average savings resulting from the use of inserts in a heater with a capacity of 2500 Cubic meters per hour, according to the current table, are about seventy million Rials. It is worth noting that this amount will be significant in high capacity heaters. On the other hand, the cost of making this inserts in eight coil direction is 20,000,000 Rials. On the of construction of this unit in eight coils is 20,000,000 Rials, which is estimated at 30,000,000 Rials by calculation of installation costs, including welding and controlling at the station.

According to the National Gas Company's program, heater repairs are planned for a period of 8 years. At best, the inserts may be used for at least 5 years, in other words, the depreciation of use of inserts is about 5 years, which is equivalent to ten million Rials each year. Considering all of the above, as well as taking into account the costs of building and installing these inserts at the Mavian Station, it will be possible to save 60 million Rials each year.

5.Conclusion

The present study focuses on the heat transfer and pressure drop on the heater in pressure reducing station through the helicoid spiral insert. The increase in the Nusselt number indicates that the heat transfer rate has been increased, and as it was shown, the highest Nusselt number was reported to be 76.85. The percentage of heat transfer improvement of 47% indicates that the increase at heat transfer rate is optimal. Due to the amount of energy savings and ease the manufacturing process of the inserts, the use of the inserts intended have increased the efficiency of the heater. As already mentioned, the use of Insert in the structure of the heaters due to the desirability of pressure drop can be a good alternative to other methods for increasing the heat transfer.

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ارتقاء سرعت انتقال حرارت توسط قطعه تعبیه شده در گرم‌کن ایستگاه گاز شهری

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چکیـــــــده

در این تحقیق به‌منظور افزایش سرعت انتقال حرارت در یک گرم‌کن ایستگاه گاز شهری (CGS) نوع کلاسیک قطعه تعبیه‌شده در داخل کویل‌های حرارتی قرارگرفته است. استفاده از این قطعات باعث افزایش افت فشار می‌شود که استفاده از آن در اکثر مبدل‌های حرارتی یک عیب به‌حساب می‌آید. آما در این مورد پدیده کاملاً مطلوب است فشار در خط انتقال شهری بایستی کاهش یابد. نوع بکار گرفته قطعه موردنظر از نوع مارپیچی است از استیل بدون درز بر طبق استاندارد شرکت گاز ساخته‌شده است. قطعات در هر هشت مسیر مارپیچ ایستگاه تقلیل فشار ماویان شهر کامیاران استان کردستان با ظرفیت ۲۵۰۰ مترمکعب بر ساعت نصب‌شده است. ارتقاء سرعت انتقال حرارت تا ۷۴٪ به دست آمد که ازنظر صرفه‌جویی در انرژی و کنترل آلودگی کاملاً مهم است.

واژگان کلیدی: قطعه تعبیه‌شده در لوله، ایستگاه تقلیل فشار، گرم‌کن، رگلاتور، ایستگاه گاز شهری