ENERGY REGENERATION IN NATURAL GAS PRESSURE REDUCTION STATIONS BY USE OF GAS TURBO EXPANDER; EVALUATION OF AVAILABLE POTENTIAL IN IRAN

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Introduction

Iran has the second rank of owning natural gas reservoir in the world. Natural gas is transported for longer distances through transit pipeline at high nominal pressure 1000 psi. In a place of consumption or at passing into a lower pressure pipeline the pressure of the gas must be reduced. In the city gate stations (CGS) the pressure must be reduced from 1000psi to 250psi. Standardly, gas pressure reduction is accomplished in throttle-valves, where the isenthalpic expansion takes place without producing any energy. A non-negligible amount of pressure energy is wasted in that irreversible process and throttling of natural gas lowers its potential energy. Most gases cool during the expansion (Joule-Thompson effect). The temperature drop in natural gas is approximately 1ºF per 15Psi, depending on gas composition and state. The replacement of the gas-throttling process by the process of its expansion in turbo expanders (TE) makes it possible to convert the pressure of the natural gas into the mechanical energy, which can be transmitted to a loading device, for example, an electric generator.
In this paper we have evaluated this work. One computer simulation was developed to study and calculate the exact values of some parameters when an expansion turbine driving a generator is used in place of the throttle valve. The energy in the gas can be used to produce electricity. The work the gas performs is gained from its enthalpy and the gas cools rapidly in the turbine. From thermodynamics relations involving enthalpy, entropy and also by using the first law of thermodynamic, Supposing that the expansion turbine undergeos an isentropic process, the work can be achieved, $w=\int c_P dT$.

To calculate the exact and precise value of the c_P we determined the volumetric anlysis of the natural gas compositions. As a case study, we have evaluated one City Gate Station with the maximum capacity of 120,000 SCMH[1] in Shahrekord city in Iran. The statistical records from log sheets taken from the station, show that the average pressure and temperature of the inlet gas during the year 2008, varies from 694-780 PSIG and 8-19.4 ºC respectively. The outlet pressure of the station is reduced to 250 PSIG through the regulator valves. The temperature of the natural gas decreases averagely 18ºC as it expands through the control valve.
When the turboexpander is used, the temperature drop is much greater, as the gas is doing work in the expansion. This means the gas must be pre-heated before it enters the TE to temperatures higher than when using throttle valves. The desirable outlet gas temperature from TE to sustain above hydrocarbon dew point and also water dew point temperatures was considered to be 3ºC. In this way, the gas needs to be preheated averagely 83ºC, so it would be necessary to consume a small portion of main gas as a fuel gas for preheating.
Calculations related to the case study show that the TE can produce 1.8 Mw power (maximum power) and the total electricity produced in one year is nearby 6000 Mw-hr.
Economical analysis show that for initial plant outlay (Turbo expansion with electrical switch gear) and operation & Maintenance costs, the payback period, supposing rate percent of 2%, will be less than 3 years.
Also an estimation was performed to determine the available potential of using gas pipeline pressure in Iran to produce energy, electricity, via expansion turbines. Statistical reports of consumptions in Iran show that since 2004, domestic consumption has one-third of total consumption. In year 2008, domestic consumption was about 70,000 MMSCM (Million Standard Cubic Meter) in Iran. A rule of thumb indication in all pressure reduction stations in Iran simply show that replacing of throttle valve with turbo expansions, would acquire more than 160 million $ each year!

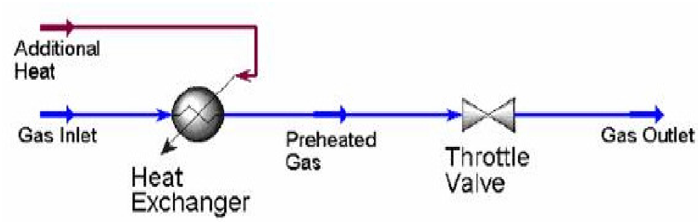
[1] Standard Cubic Meter per Hour

Regeneration from gas pressure reduction station

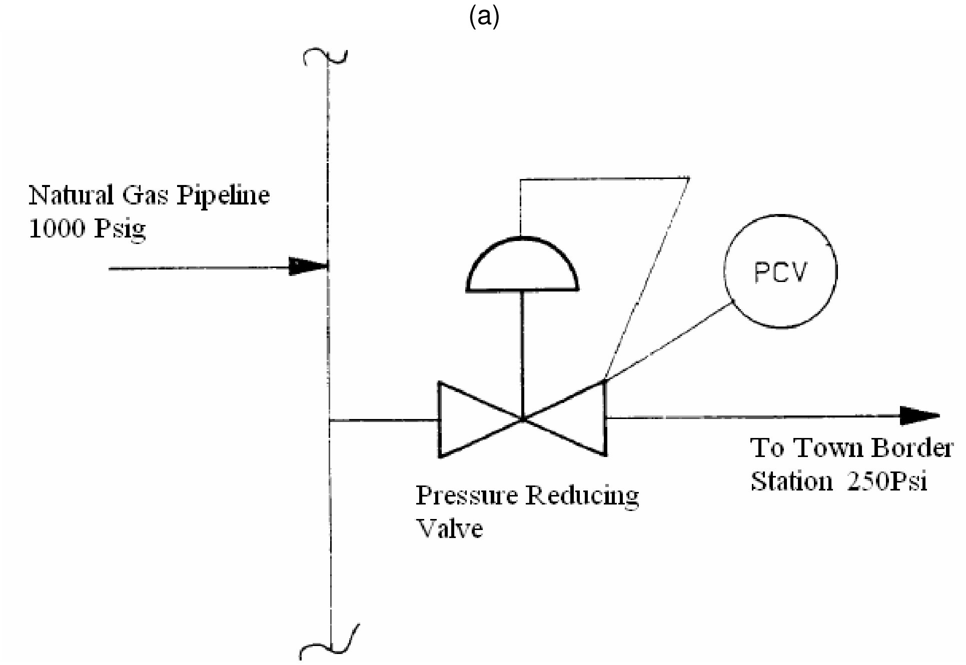
Gas transmission pipeline has the nominal pressure of 1000 psi. To provide safe and applicable usage of natural gas in domestic divisions, the pressure of the gas must be reduced. In the city gate stations (CGS) the pressure must be reduced from 1000psi to 250 psi and then at the Town Break Station (TBS) the pressure reduces from 250psi to approximately 60psi. In addition, at the most power plants in Iran the outlet gas pressure from reducion stations, varies from 100 to 400psi, depending on type of the gas turbines, to provide fuel gas for combustion chambers.

Standardly, gas pressure reduction is accomplished in throttle-valves. In the ideal case, throttling of gas occurs on the basis of isoenthalpy from the initial gas pressure P_1 to the terminal pressure P_2. In that case, throttling from P_1 and T_1 to the terminal pressure P_2 leads to a drop in the temperature of the natural gas isoenthalpy. The Joule-Thompson coefficient $\mu_J = \partial T/\partial P$ at the condition h=const requires adiabatic occurrence of the throttling process.

According to the figure 1, the gas must be preheated before the expansion to ensure that no liquid or solid phase condenses at the output temperature.



(a)



(b)

Fig.1: Schematic of gas pressure reduction station (Part: a) with throttle valve (regulator valve) (Part:b)

Throttling of natural gas lowers its potential energy. The replacement of the gas-throttling process by the process of its expansion in turbo expanders (TE) makes it possible to convert the pressure of the natural gas into the mechanical energy, which can be transmitted to a loading device, for example, an electric generator. Moreover, a significant amount of cold is generated as the gas expands to low pressures. When an expansion turbine driving a generator is used in place of the throttle valve, the energy in the gas can be used to produce electricity. The work the gas performs is gained from its enthalpy and the gas cools rapidly in the turbine. When using an expansion turbine, gas outlet temperature must remain above hydrocarbon dew point and also water dew point temperatures.

Reliability of the pressure regulating and reduction stations must be assured, and therefore the expansion turbines are installed parallel to existing conventional pressure reducing valves.

There are many applications of turbines where the working fluid is not steam. There are other gases, however, at ambient temperature and high pressure that can be expanded through a turboexpander to

produce work. There are existing installations utilizing natural gas as the working fluid to drive a turboexpander.
From thermodynamics relations involving enthalpy, entropy and also by using the first law of thermodynamic, Supposing that the expansion turbine undergeos an isentropic process, the work can be achieved as $w=\int c_P dT$. To calculate the exact and precise value of the c_P we need to know the volumetric analysis of the natural gas composition. Since our case study is Shahrekord reduction station, then we evaluated its components as shown in Table 1.
Natural gas is a complex multicomponent mixture of a number of saturated hydrocarbons: methane, ethane, propane, and butane and its isomers. Nitrogen, hydrogen sulfide, helium, argon, water vapor, and other components are contained in small amounts in natural gases.

Table 1: Volumetric Analayis Of Natural Gas [Shahrekord Station-Iran]

Constituent	Percent by volume
Methane (CH_4)	89%
Ethane (C_2H_6)	4.1%
Propane (C_3H_8)	1.2%
Nitrogen (N_2)	5%
Carbon dioxide CO_2	0.7%

By thermodynamical calculations we determined the exact value of the constant-pressure specific heat of natural gas, $c_P\,(kj/kg.^\circ K)$, as a function of temperature, $c_P=1.133+3.206\times10^{-3}T+5.69\times10^{-7}T^2-6.3\times10^{-10}T^3$, where T varies from $250^\circ K<T<1200^\circ K$.

Simulation Results and Conclusions
In this paper, as a case study for a turboexpander application, we have evaluated one City Gate Station with the capacity of 120,000 SCMH in Shahrekord city in Iran. The monthly domestic consumption of this station is shown in figure 2. The statistical records from log sheets taken from the station, show that the average pressure and temperature of the inlet gas during different months, varies from 694 to 780 PSIG and 8 to 19.4 ºC respectively. The outlet pressure of the station is reduced to 250 PSIG through the regulator valves and The temperature of the natural gas decreases averagely 18ºC as it expands.

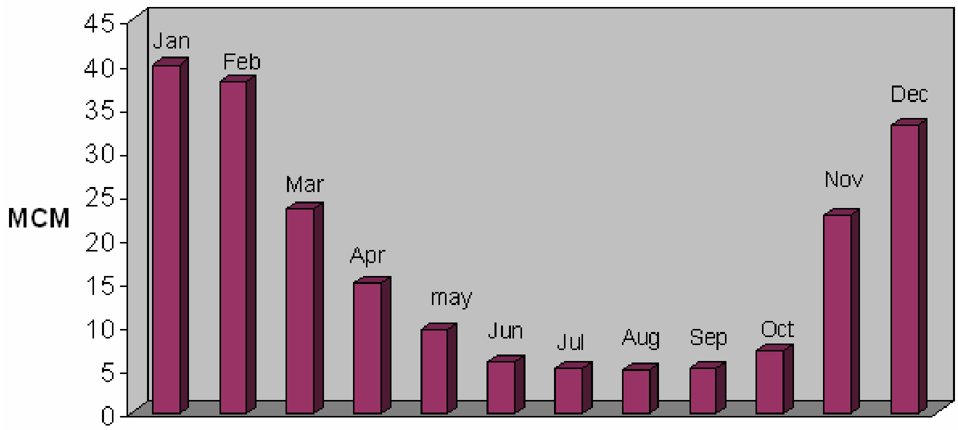
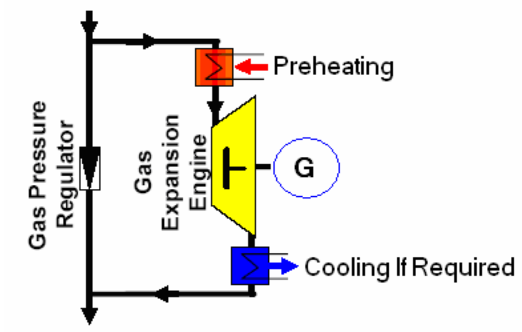
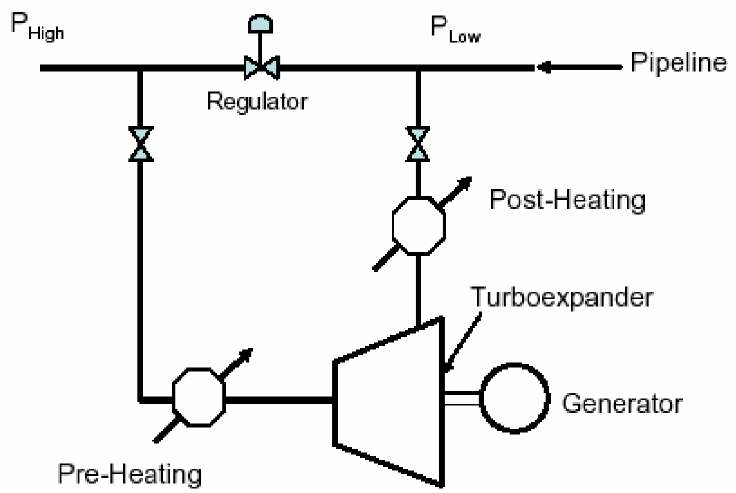


Fig 2: Monthly gas flow in Shahrekord Reduction Station (MCM= Million Cubic Meter)

The turboexpander would be installed in parallel with the existing pressure reducing station (figure 3). With the turboexpander, the temperature drop is much greater, as the gas is doing work in the expansion. The gas is therefore heated prior to entering the turbine, to a temperature sufficiently high to maintain approximately above 3ºC at the turbine outlet. This temperature is greater than the dew point temperature and hydrate formation temperature. We supposed that this temperature has the constant value of 3ºC during the simulation. In this way, the gas needs to be heated averagely 83ºC, so it would be necessary to consume a small portion of main gas as a fuel gas for preheating.



Part a: with Cooling if required



Part b: with post Heating if required

Fig 3: Energy recovering in gas pressure reduction station by use of TE (Parts a & b)

One computer simulation was developed to calculate all parameters as shown in table 2. The system was analyzed. In each steps, knowing the mean temperature and pressure of the inlet gas to the station and using the gas flow rate in each months, the required temperature for TE inlet was calculated. Then required gas, m^3, for preheating and preheating load determined. The net heating value of the natural gas (Table 1) is about 8400kcal/sm^3. Finally the produced power in each month and its benefit was obtained. The turboexpander with isentropic efficiency of 85% can produce approximately 1.8 Mw power. The economical analysys was done using the price of electricity (7.7 cents/kwh) and the price of natural gas as a fuel for preheating gas in station (7cents/m^3).
The simulation results show that total annual benefit of producing electricity in the station is $463,000 (by including O&M cost). The estimated capital cost of the turboexpander installation is $730,000 and supposing rate percent of 2%, i=0.02, the payback period, n, is approximately 3 years which was driven from $n=(\mathrm{Log}\frac{A}{A\text{-}iP})/\mathrm{Log}(1+i)$, where A represents for annual benefit and the parameter P stands for initial capital cost.

Table 2: Results of turbo expander installation in Shahrekord City Station

Month	Gas Flow Through Station (m^3)	Avg. Gas Inlet Temperature (ºC)	Avg. Gas Inlet pressure (psi)	Total Preheat (Gj)	T(ºC) at TE Inlet	Fuel Gas for preheating (m^3)	Electricity Produced Kw-h
Jan	39,720,000	8	702	4442	79.4	126517	1,118,716
Feb	37,800,000	6.8	694	4240	78.5	120756	1,051,364
Mar	23,142,000	7.1	707	2644	80	75306	657,163
Apr	14,880,000	11	718	1646	81.3	46878	430,151
May	9,393,000	15	725	995	82.1	28338	274,477
Jun	5,889,000	18.2	728	600	82.5	17088	173,000
Jul	5,068,500	17.3	731	528	82.8	15043	149,485
Aug	4,929,000	19.4	737	501	83.5	14268	146,740
Sep	5,053,000	19.4	780	554	88.3	15778	160,000
Oct	7,110,000	14	763	816	86.5	23240	220,068
Nov	22,560,000	12	740	2555	83.8	72767	674,290
Dec	32,850,000	10	720	3693	81.5	105178	952,201

Also an estimation was performed to determine the available potential of using gas pipeline pressure in Iran to produce energy, electricity, via expansion turbines. Statistical reports of consumptions in Iran show that since 2004, domestic consumption has one-third of total consumption. The power plants consumption share is also one-third. Since there is a good source of extra heat in power plants (outlet temperature of gas turbines is approximately 500ºC), using of TE can be more profitable. In year 2008, domestic consumption was about 70,000 MMSCM (Million Standard Cubic Meter) in Iran. A rule of thumb indication in all pressure reduction stations in Iran (only in domestic consumptions divisions) simply show that replacing of throttle valve with turbo expansions, would acquire more than 160 million $ each year!

Turboexpanders represent an opportunity to recover pipeline energy that would otherwise be lost. The investment in transmission lines is a relatively small fraction of the investment in the construction of power stations.

Some Limitations to Application of Turbo Expanders

It has been identified that a number of key hurdles to economic application of turboexpanders to pipelines. The most important of which are the high capital cost of the systems themselves, and the recoverable value of the electricity generated.

Other key variables include the gas flowrate and pressure drop, which together determine the power generation potential, and the hourly, daily and seasonal variability in flow.

• Capital Costs – The total costs for a turboexpander system include the equipment costs for the expander, gearbox, generator, pre- or post-heaters, utility interconnect and controls, and pipeline connection, as well as the overall engineering and installation costs. The costs ranged from $600 to $2,300/kW. The lowest cost per kW was on the largest system indicating that some economies of scale do exist. In general, however, experience has shown that the installations are very site specific and require significant custom engineering design, and do not lend themselves easily to the economies of prepackaged designs or standard configurations that might lower costs.

• Operating Costs – Turboexpander installations generating electricity at city gates will have significantly higher operating costs than regulator stations. The highest cost will be in the fuel required for pre- or post-heating of the gas. Along with this are maintenance costs for the turboexpander equipment itself. A 1987 study by AGA estimated the annual non-fuel operating and maintenance (O&M) costs at two percent of capital costs.

• Pressure Ratio – The power recovery potential is roughly proportional to of the pressure ratio (ratio of inlet pressure to outlet pressure). Higher pressure ratios result in higher power production. While normal pipeline operating pressures are well below maximum turboexpander pressure ratios, there is also a minimum pressure ratio that must be maintained below which the turboexpander will not function.

• Flow Rate – Power output is also a function of flow rate. Variability in flow rate is an important consideration in project economics, and gas flow rates, particularly at city gate stations, will vary over a wide range due to seasonal, daily and hourly demand fluctuations. Turboexpanders can generally operate between 50 and 140 percent of design flow,although exact capabilities will vary from manufacturer to manufacturer. This can make optimum sizing for an installation difficult to estimate. Size the system too large and there may be significant periods of the year where flow (and pressure) are below the minimum requirements and the system will remain idle. Size the system too small and capital cost economies are lost and there may be extended periods where a significant portion of the flow will need to bypass the turboexpander.

Turboexpanders have been successfully used in LNG and natural gas processing plants because many of the limiting factors discussed above are absent. Flow rates and pressure drops in these facilities are constant or predictable. Process integration allows waste heat to be used for gas heating, and in many cases the cooling effect of the gas expansion can be used elsewhere in the process.
It should be noted that despite limited success, elements of the industry continue to periodically re-evaluate the economics and potential applicability of turboexpanders to the pipeline system. The most recent examples are demonstration projects underway in Canada and the United States incorporating fuel cell and turboexpander technologies. In these applications, waste heat from the fuel cell generator provides the preheat to the turboexpander system.

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