Using gas pipeline pressure to liquefy natural gas or generate electricity

This novel approach can save money and improve energy usage efficiency

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Gas pipelines transport processed natural gas (NG) from plants usually located near producing regions to consumption centers. It is common to have a pipeline crossing states or provinces within a country and even international borders. Along a gas pipeline, local distribution companies have a pipeline network of smaller diameter pipe, working at a lower pressure, connected to the main transmission pipeline at stations known as city gates.

In those stations, high pressure NG undergoes an irreversible throttling process to drop its pressure to distribution pressure. At extreme conditions up to 100 bar is dropped to a few bars. This wastes useful process work energy. This problem was analyzed from a thermodynamic standpoint, giving estimations for energy utilization potential using a turbo-expander (TE) expanding NG in place of a conventional throttling valve. Electrical energy may be generated and even a small scale liquefied natural gas (LNG) plant may run using this available pressure energy.

Available energy from pipeline pressure. Transmission pipelines transport NG over long distances from a processing plant to consumption centers. Placed along the pipeline are compression stations ensuring gas flows at desired rates as well as overcoming losses due to friction. Transmission pipelines work at a high pressure (up to 100 bar). At the city gates the pressure is dropped down to local distribution pressure (as low as 1 bar, but can go up to 20 bar) depending on the particular distribution network.

The pressure-reducing process is usually carried out through a throttling device, such as a valve. A non-negligible amount of pressure energy is wasted in that irreversible process. The amount of available specific work can be estimated by substituting the throttling process by an ideal expansion, in the following equation:

$$w = \int_{P_2}^{P_1} \frac{dP}{\rho}$$

where P_1 = transmission pressure
P_2 = distribution pressures
ρ = NG density
w = available specific work in kJ/kg or kW/kg/s.

If an equation of state is available for the NG, then the amount of specific lost work can be readily obtained by solving

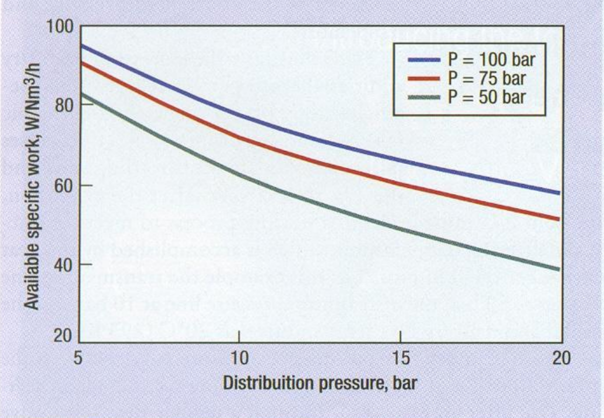

FIG. 1 Specific available work as a function of transmission and distribution pressure.

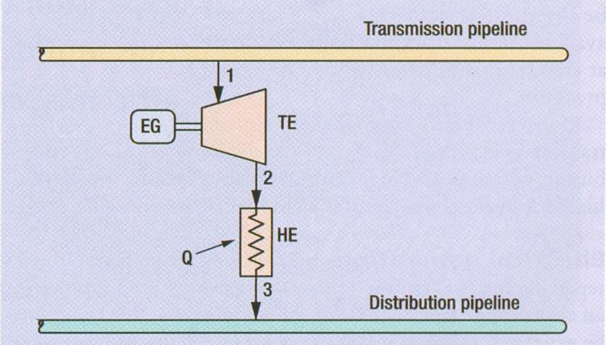

FIG. 2 A turbo-expander system for electricity generation.

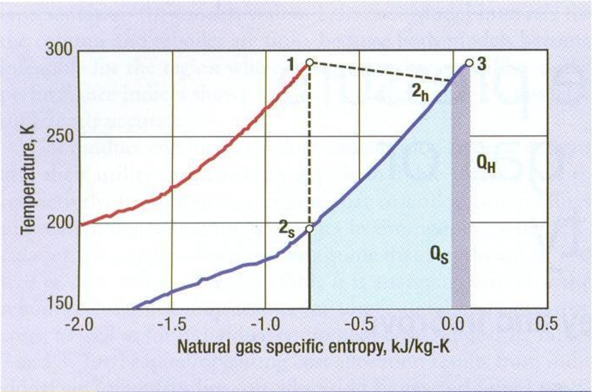

FIG. 3 Temperature-specific entropy and the throttling and isentropic expansion processes. *Areas under the curves are proportional to the minimum heating amount necessary for NG to meet delivery temperatures. Actual heating calculations require low temperature limit set to 0K.

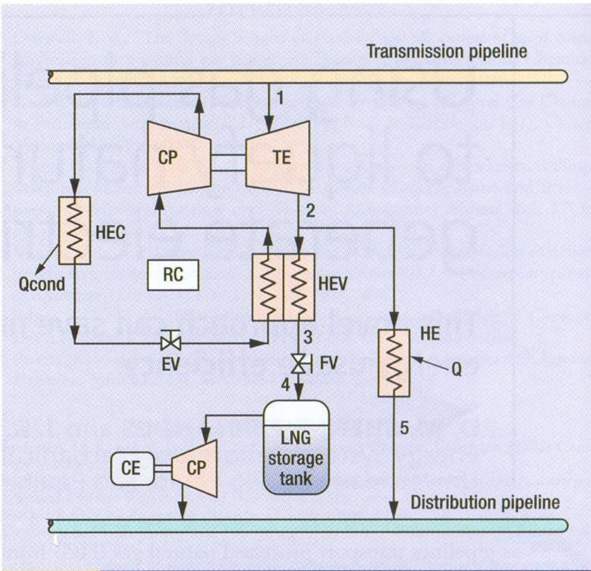

FIG. 4 Small scale LNG plant.

the above equation. A very simple case of ideal behavior yields a plain working equation easily obtained in any thermodynamic textbook:

$$w = \frac{kR}{k-1}(T_1 - T_2)$$

where T_1 and T_2 = initial e final temperatures, respectively
k = heat capacities ratio
R = NG constant.

The above equation does not provide a precise calculation. To obtain a more realistic result, the expression for specific work should be integrated numerically, by imposing an isentropic solution, i.e., final and initial states have the same specific entropy. In this case an NG sample that was 90% methane, 8% ethane and 2% nitrogen (N_2) was analyzed. Specific work calculations were done for three transmission pressures, 50, 75 and 100 bar, and for distribution pressures between 5 bar and 20 bar (Fig. 1). The specific available work is in Watt per normal cubic meter per hour (W/Nm^3/h), which can be interpreted as the mechanical power available per unit of NG hourly flowrate at standard conditions (0°C and normal pressure).

■ Energy normally lost when NG is depressurized at city gates can be conserved using turbo expansion technology, thus improving energy efficiency and costs.

Curves in Fig. 1 show that for a given transmission pressure the lower the distribution pressure, the higher the available specific work. Also, higher transmission pressures yield higher specific work.

Electrical generation. Electricity can be generated by replacing the conventional throttling valve with a TE powering an electrical generator (EG) as shown in Fig. 2. Electricity may be generated for local use at the city gate facility or exported to other demanding areas. The implantation cost is mostly related to capital investment. As an example, consider a 100 Nm^3/h NG flowrate, a transmission pipeline pressure at 75 bar and a 10 bar distribution working pressure. Using the central curve in Fig. 1, the maximum electrical power is:

$$\dot{W}_E^{max} = 71.5 \times 100 = 7{,}150 \text{ W} = 7.15 \text{ kW}$$

Considering that there are some overall losses, say, 20%, then the actual electrical power would result in (1 – 0.2) × 7.15 = 5.7 kW, which is enough to run electrical instrumentation and other supporting electrical devices in the city gate facility.

The main disadvantage of expanding NG through a TE is that a much lower NG final temperature is obtained. Consequently, a higher demand for heating is necessary in order to meet delivery conditions. Transfer of custody from transmission to distribution lines are made by commercial contracts between two or more companies and the NG should be delivered at the contracted pressure and temperature.

Fig. 3 illustrates the increase of necessary additional heating in the temperature-specific entropy plane, where the isenthalpic ($1 \rightarrow 2_H$) and isentropic ($1 \rightarrow 2_S$) processes fairly approximate the throttling valve and the TE, respectively. After the expansion, the cold NG must undergo a heating process to meet contractual delivering temperatures, which is accomplished by the heat exchanger (HE) in Fig. 2. In this example the transmission line was set at 50 bar, the distribution pressure line at 10 bar and the initial and delivery NG temperature was 20°C (293 K).

The area under the transmission pressure curve between the points 2_H to 3 is proportional to the minimum required gas heating, Q_H, after an expansion through a regular throttling valve necessary to reach delivery temperature. The area under the same curve, between points 2S to 3, provides the minimum heating,

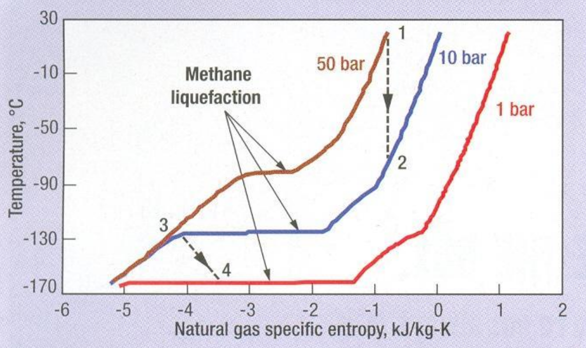

FIG. 5 Liquefaction process in a SSLNG plant in the temperature-specific entropy. *Marked points are those indicated in Fig. 4.

Q_S, necessary, which is significantly higher. Also, the actual heating demands are higher than minimum ones indicated due to irreversible processes.

Finally, a more practical and straightforward way to look at the heating issue is to calculate the final temperature for each expansion process: 5°C (268 K) for throttling and –76°C (197 K) for the isentropic TE (Fig. 3). In practice, the TE is only nearly isentropic and the NG final temperature reaches a higher value than that of the equivalent isentropic process, thus favoring its use.

Small scale liquefied natural gas plant. In this second application a small scale liquefaction plant (SSLNG) is analyzed. The schematic cycle is shown in Fig. 4. As before, the NG from the high pressure transmission pipeline expands in a TE. As a result, the temperature drops considerably but not enough to get into the liquefaction range.

To liquefy methane, its temperature should be decreased to –163°C for LNG to be stored at standard atmospheric pressure. Fig. 4 shows that after the initial expansion the NG is split into two streams. The first one (r.h.s.) is driven to the HE for heating to reach contractual transfer of custody temperature (20°C in this example).

The other stream is directed to a special heat exchanger (HEV) boosting the cooling process to liquefaction conditions. HEV is a heat exchanger formed by the evaporator of a cryogenic refrigeration circuit (RC), which is mechanically powered by a compressor driven by the TE (Fig. 4).

RC is a low temperature refrigeration circuit whose working fluid can be methane or N_2, for example. It works as a regular vapor compression cycle, which means that it requires an expansion valve (EV) and a condenser (HEC). As LNG is produced, some of the non-condensing vapors such as N_2 should be removed. To remove the non-condensing vapors, a small internal combustion engine (CE) can be used to compress the non-condensing vapor from the LNG storage tank to the distribution pipeline.

The amount of LNG being produced depends on the refrigeration cycle's cooling capacity. The mechanical power ($\dot{W}$) obtained from TE is thoroughly used to drive the refrigeration compressor (CP) and the refrigeration load ($\dot{Q}_R$) is directly proportional to that mechanical power:

$$\dot{Q}_R = COP \times \dot{W}$$

where *COP* is the performance coefficient.

Estimations show that in general, the available mechanical power and, therefore, the refrigeration load is not enough to liquefy the entire NG flow that expands in TE for an auto-sustaining process. That is the reason why the schematics in Fig. 4 has the NG divided into two streams: one goes to the HEV to cool it down to liquefaction conditions and the other follows the regular path to be heated and injected into the distribution line.

Fig. 5 is a temperature-specific entropy diagram for the LNG plant in Fig. 4 for the gas stream that is liquefied (processes 1→2→3→4). Only ideal processes are considered, i.e., isentropic expansion, TE and reversible heat rejection in the HEV. A detailed study[1] showed that about 20% to 30%, depending on the transmission and distribution pressures as well as the NG composition, can be liquefied. Finally, the SSLNG proposed is mostly schematic, as there are other issues that should be taken into account such as carbon dioxide and water vapor removal, prior to any expansion.

The future. Transfer of custody takes place when NG from a transmission pipeline is conveyed to a local distribution pipeline. This process is mostly done by a simple throttling valve. Two systems have been proposed that use pressure energy for electricity generation and LNG production.

These principles apply to other situations where mechanical power available from a TE can be used, such as driving any other machine. The main costs associated are capital. However, one must also take into account that additional NG will be consumed for heating in order to meet contractual delivery temperature requirements. **HP**

LITERATURE CITED

1 Shen, D., F. Fernandes, and J. R. Simões-Moreira, "Technical and economical study of natural liquefaction processes from high pressure pipelines," Petrobras Internal Report, 2005 (in Portuguese).

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