TECHNOLOGY

Natural gas supply cut-off in gas distribution networks

Natural gas supply cut off is a chronic operational problem in gas distribution networks during periods of peak consumption. This is due to the high pressure drop in the network mainly caused by excess consumption for space heating purposes.

The rate of heat loss from buildings is a crucial factor in space heating determination. Space heating appliances operate only when the inside temperature becomes low enough (outdoor temperature less than 65-70 °F) to make the consumers uncomfortable. In order to estimate the space heating demands of individual customers or the whole distribution system, an index of the intensity and the duration of cold weather, the so called degree-day index, is defined as the difference between the average temperature for a specific time period and the base temperature. Typically, 65 °F is taken as the temperature at which the space heating load begins [1].

To ensure an adequate gas supply for peak consumption periods, factors such as population growth rate, daily and hourly peaks in the demand and the degree-day index for each month of the year should be considered in the preliminary design phase of distribution networks. Occasionally, during hourly or daily peaks in demand, the pressure of some parts of the distribution network decreases considerably in spite the fact that there is excess gas at the City Gate Station (CGS) entrance. This means that the distribution system cannot deliver excess natural gas flow due to large pressure drop in the network. In addition to unexpected cold weather, the neglecting of significant factors, e.g. elevation profile of pipes in the network design can often lead to unexpected pressure drop.

The steady state momentum balance around a differential control volume of a pipe segment is formulated as follows [2]:

$$\frac{dP}{dL} = -\rho\frac{g}{g_c}\sin\theta - \frac{24\rho f u^2}{g_c D_i} - \rho u\frac{du}{dL} \qquad (1)$$

Wherein f is calculated by Colebrook equation [3]:

$$f^{-0.5} = -4\log\left(\frac{\varepsilon}{3.71 D_i} + \frac{1.255}{f^{0.5}\,\mathrm{Re}}\right) \qquad (2)$$

Assuming that the accelerative pressure drop is negligible, the ratio of the gravitational pressure drop and the total pressure drop is defined as:

$$\beta = \frac{-\rho g \sin\theta}{\frac{dP}{dL}} = \frac{1}{1 + \frac{24 f u^2}{g_c D_i \sin\theta}} \qquad (3)$$

Wherein an increase in the pipe elevation or a decrease in the gas velocity results in higher values of β.

Elevation profile

For design purposes, the net elevation change between two nodes of a network system is often considered, whereas the exact elevation profile between the nodes is neglected. It is self-evident that due to the renewable nature of static pressure, such simplification does not affect the pressure of the end node; however, critical low pressure conditions between the nodes may remain unforeseeable. The significance of static pressure drop is further illustrated in the following example. The specification of a network branch is given in Table 1. The static pressure drop and frictional pressure drop of a natural gas flow, under the conditions given in Table 2, are 2.896 psi and 0.257 psi respectively. Accordingly, the ratio of the static pressure gradient and the frictional pressure gradient is 10.84. It is, therefore, clear that neglecting the elevation profile of a distribution system located on inclined terrain can result in dramatic errors in the pressure drop calculations. The natural gas supply cut off during peak seasons in northern Tehran with steep slopes is mostly attributed to the elevation profile neglect in the preliminary design phase of the distribution network.

Table 1 Specification of a typical network branch.

L	3280 ft
θ	+ 30°
D_i	7.981 in.
Schedule Number	40
Nominal diameter	8 in.
ε	750 μin.

Table 2 Specification of natural gas flow in the pipe.

Natural Gas Composition Percent	C_1=88, C_2=4.5, C_3=1.4, i-C_4=0.24, n-C_4=0.35, i-C_5=0.23, N_2=5, CO_2=0.2
Q	19.62 scf/s
T	520 R
P_{inlet}	60 psia

At typical temperature of 520 R and pressure of 60 psia, the density [4] and the viscosity [5] of a gas mixture, with composition given in Table 2, would be 0.19 lb/ft^3 and 7.32 x 10^{-6} lb/ft.s, respectively. Assuming absolute roughness of 750 μin. and pipe diameter of 8 in., the variation of β with respect to gas flow rate, Q, in different inclinations can be calculated on the basis of Colebrook equation for fanning friction factor:

$$\beta = \frac{1}{1+\left(\frac{24f}{g_c D_i \sin\theta}\right)\left(\frac{4Q\rho_{sc}}{\pi\rho D_i^2}\right)^2} = \frac{1}{1+\left(\frac{38.9071\rho_{sc}^2}{g_c\rho^2 \sin\theta}\right)\left(\frac{fQ^2}{D^5}\right)} \quad (4)$$

Where ρ_{sc} represents the gas mixture density at standard condition (14.7 psia and 520 R). Figure 1 reveals that the contribution of static pressure drop to the total pressure drop in the low pressure distribution networks (60 psi) at ambient temperature (520 R) and typical flow rates of 0-10 MMscf/D is not negligible. Clearly, for smaller pipe diameters this range will be tightened.

Increase in the natural gas consumption in response to population growth and urban developments are also an essential factor to be considered in distribution network design. The distribution systems are often designed on the basis of hourly and daily peaks in demand, as well as consumption growth for the next fifteen years. Therefore, the capacity of the distribution network should always be realized in civil construction works and urban developments.

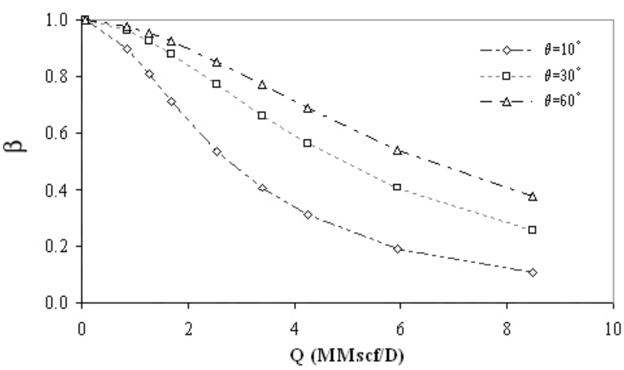

Figure 1 The variation of the ratio of static pressure drop and total pressure drop versus gas flow rate in different inclinations.

Solutions to tackle gas supply cut-off

Here, two solutions are proposed to tackle the natural gas supply cut off in the distribution systems:

- Short-term solution: Critical low pressure blocks can be identified with the aid of distribution network simulations. Then, by providing the suitable installations in these blocks, portable CNG units can be utilized to inject natural gas during the peak consumption periods.
- Long-term solution: To eliminate these deficiencies, fundamental changes, i.e. pipe size, should be implemented in specific network branches. Switching natural gas input grids is also a way of overcoming high pressure drop. If the distribution system is able to afford higher flows, natural gas can be injected from CGS or underground storage facilities.

In Tehran, portable CNG units are to be used at hourly peaks in consumption as a temporary solution to the natural gas supply cut off. Furthermore, underground natural gas storage was chosen as the permanent solution to this deficiency. However, the distribution network spread over the large city of Tehran is not capable of delivering excess gas at hourly peaks. Some mechanical restructuring of the distribution network is, therefore, required.

NOMENCLATURE

D_i	pipe internal diameter, (in.)
f	Fanning friction factor
g	gravitational acceleration, (ft/s^2)
g_c	conversion factor, 32.174
L	pipe length, (ft)
T	Temperature, (R)
P	pressure, (psi)
Q	gas flow rate, (scm/h)
u	gas velocity, (ft/s)
ε	absolute pipe roughness, (μin)
θ	inclination angle with horizontal
ρ	gas density, (lb/ft^3)
Re	Reynolds number ($\rho u D_i / \mu$)
_	Viscosity, (lb/ft.s)

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