Ensuring the Safety of Gas Distribution Stations When Increasing Capacity

E Fomina¹, M Guskov¹, S Mitichkin² and S Shishkin³
¹Department of Industrial Safety and Environment Protection, Gubkin Russian State University of Oil and Gas (National Research University), 65-1 Leninsky prospect, Moscow, 119991, Russian Federation
²Department of Gas and Oil Pipelines Engineering and Operation, Gubkin Russian State University of Oil and Gas (National Research University), 65-1 Leninsky prospect, Moscow, 119991, Russian Federation
³Department of Computer-Aided Design of Oil and Gas Industry Facilities, Gubkin Russian State University of Oil and Gas (National Research University), 65-1 Leninsky prospect, Moscow, 119991, Russian Federation

E-mail: ka72@bk.ru

Abstract. The paper shows the dynamics of accidents and industrial fatality injuries at the Main Pipeline Transport of Hydrocarbons in the Russian Federation. The features of operation of a Gas Distribution Station (GDS) as one of the Hazardous Production Facilities of Main Pipeline Transport of Natural Gas are considered. The main technological units and systems for ensuring the complex safety of automated low-performance GDS are presented. The main factors contributing to the occurrence and development of accidents at the GDS are listed. To increase gas supplies to the consumer, the calculation of the technically possible throughput capacity of the existing GDS with a design capacity of 20 thousand m³/hour was carried out. Using a software complex "Vesta-GDS" we built process flow diagram that under the given constraints (pressure, temperature, gas velocity in the pipeline and the degree of opening of the gas pressure regulator valve) determined that the technically possible throughput capacity of GDS is 16.37 thousand m³/hour more than design capacity. With technically possible increased productivity, a qualitative and quantitative assessment of the risk of an accident at the GDS II class of danger was made, as a result of which the risk was assessed as "low" and not exceeding the background indicators of the oil and gas industry of the Russian Federation.

1. Introduction

Global gas consumption, which accounts for 23% of all types of energy (oil, coal, biomass, electricity, and heat), continues to grow steadily [1]. And according to forecasts [2], the decline is not expected until 2040. Currently, there is a problem with gas transport facilities reaching their maximum loads. This is especially acute for the GDS.

GDS belong to the system of Main Pipeline Transportation of Natural Gas and, depending on the gas productivity, are classified into [3]:

1) mini GDS with a capacity of less than 1.0 thousand m³/hour,
2) automated GDS of low-capacity 1.0–50.0 thousand m³/hour,
3) GDS of average capacity 50.0–160.0 thousand m³/hour.
4) high-capacity GDS 160.0–1000.0 thousand m³/hour.

The GDS is a complex technical structure. The main features of the GDS operation are:
- high capacity and constant technological connection with gas supply pipelines,
- high density of placement of technological equipment, buildings, structures (according to [3] class of clutter surrounding space – III),
- saturation of the GDS site with electrical equipment, power supply lines, remote control and communication devices, which causes an increased probability of gas ignition in the event of an accident,
- presence of hazardous substances on the production site necessary for maintaining technological processes,
- direct contact of a significant part of the equipment with the natural environment,
- connecting industrial enterprises.

According to Federal Service for Environmental, Technological and Nuclear Supervision of Russia (Rostekhnadzor) data [5], the average annual number of accidents in Russia over the past 5 years at Hazardous Production Facilities (HPF) of Main Pipeline Transportation of Gas (MPTG) is 10 (table 1). At the same time, there are 7 incidents per accident according to 2018 data, and 15 incidents per accident according to 2016 data [6].

| Year | 2014 | 2015 | 2016 | 2017 | 2018 |
|------|------|------|------|------|------|
| The number of HPF | 4301 | 4479 | 4522 | 4310 | 4273 |
| The number of accidents at the HPF of MPTH: | | | | | |
| - of them at the MPTG | | | | | |
| The number of industrial fatality injuries at the HPF of MPTH: | | | | | |
| - of them at the MPTG | | | | | |

In most cases, accidents are associated with a gas leak, which carries with it the probability of a fire, explosion, or poisoning people [7, 8].

The main causes and factors contributing to the occurrence and development of accidents at the GDS are [9, 10]:
- handling of high and medium pressure explosive gas in pipelines and equipment,
- availability of a large number of fittings, tees, adapters, shaped details, i.e. the places with a high concentration of strain,
- the presence of transitions of underground pipelines to aboveground ones, which are places of increased corrosion activity and strain concentration,
- the complex spatial design of aboveground gas pipelines,
- manufacturing defects of the equipment (valves, pipes),
- high wear of the GDS equipment with insufficient quality diagnostic control and untimely performance of repair work to ensure the tightness of pipelines, tanks, fittings,
- project errors,
- violation of the rules of technical operation and work safety by the employees, errors of the employees due to inattentiveness or incompetence,
- external causes of natural (for example, a lightning strike) or anthropogenic nature (terrorist attack).

Secondary typical causes of accidents can be failures of safety valves, pressure regulators, shut-off valves, protective automation, the formation of hydrates in pipelines, failures of ejectors in the filling line of odorant flow tanks.
All these factors dictate the need for thorough risk analysis of accidents at the GDS in conditions of increased productivity, deviations from the project.

2. Object of exploration
The object of the exploration is a low-capacity GDS, hazard class II HPF. GDS was commissioned in 1981. In 2006 the GDS was overhauled, after which the maximum achieved capacity of the GDS was 26.7 thousand m³/hour. The form of GDS service is home-based by two operators. The technical characteristics of the GDS are shown in table 2.

Table 2. Technical characteristics of the GDS.

| The Technical Characteristic                              | Value   |
|----------------------------------------------------------|---------|
| The design capacity, $Q_d$, thousand m³/hour              | 20      |
| Maximum (design) gas pressure at the GDS inlet, MPa       | 5.4     |
| Maximum (guaranteed) gas pressure at the GDS inlet, MPa   | 4.39    |
| Minimum (guaranteed) gas pressure at the GDS inlet, MPa   | 3.69    |
| Maximum (design) gas pressure at the GDS outlet, MPa      | 0.6     |
| Diameter of the pipeline (above ground) at the GDS inlet, mm | 325     |
| Length of the pipeline (above ground) at the GDS inlet, m | 5       |
| Diameter of the pipeline (underground) at the GDS inlet, mm | 273     |
| Length of the pipeline (underground) at the GDS inlet, m  | 3840    |
| Average winter gas temperature in the process gas pipeline, K | 278.15  |
| Enclosure area of the GDS, m²                              | 1963.5  |

The GDS consists of technological units and systems, the main of which are (figure 1) [11]:
1) the Switching Unit, the purpose of which is to change the direction of high-pressure gas flow from the main reduction line to the bypass line,
2) the Gas Purification Unit is used to remove solid substances and moisture from the gas and bring its quality to the level that meets the requirements [12]. For this purpose, dust and moisture collecting devices should be used,
3) the Gas Reduction Unit is designed to reduce and automatically maintain the set gas pressure supplied to the consumer,
4) the Gas Accounting Unit – commercial accounting of gas supplied to the consumer, as well as accounting for their own needs,
5) the Gas Odorization Unit is designed to give a characteristic smell of gas supplied to the consumer for early detection of its leaks by smell.
3. Methods and results of exploration

To increase the capacity of the GDS, the Vesta-GDS software and computing system was used [13, 14]. It allowed to build a mathematical model and technological scheme of the GDS (figure 2) and determine the Technically Possible Capacity (TPC) – the calculated natural gas capacity ($Q_c = 36.37$ thousand m$^3$/hour) of the GDS, which is 181.9% of the design capacity. Calculations have been made according to the requirements [15].

The technical condition of pipelines was determined taking into account the results of technical diagnostics and the values of Hydraulic Efficiency Coefficients and Heat Transfer Coefficients from gas to the environment. The technical condition of filters, narrowing devices, shut-off and control valves was determined taking into account the results of technical diagnostics and Local Resistance Coefficients. The main controlled technological restrictions are: maximum operating gas pressures in pipelines and maximum speed of gas movement in pipelines, filters, and gas pressure regulators. The task was to determine the optimal control parameters on the gas pressure regulators (the position of the control elements), which will ensure the maximum technically permissible capacity of the GDS, at the same time, the balance of flows would be maintained in all nodes of the calculation scheme, technological limitations would be observed for all objects, and set points of regulation would be observed for gas pressure regulators.

This method of increasing capacity is low-cost [16, 17].
The deviation in the direction of increase from the design capacity of the GDS is accompanied by several hazards, the identification of which is performed using qualitative methods of risk analysis “What if ...?”, HAZOP [18]. Increase TPC leads to an increase in the degree of opening of the valve of the pressure regulator; to increase the gas velocity in the pipelines, and as a consequence, to the possible increase in the level of noise and erosive effects on the walls of pipelines; to lower the gas temperature in the pipelines and, consequently, to the possible hydrate formation. The results of a qualitative assessment of the accident risk are presented in table 3. The verbal description of the risk levels is given in table 4.

To maintain the safe operation of the GDS, it is sufficient to comply with all safety requirements in the field of labor protection, industrial, fire and environmental safety. Of course, the continuous monitoring of all integrated safety systems of the GDS remains an important point [19].

According to [20, table 6-3], the hazard category of the HPF GDS by the level of accident risk is "Small".

The value of the background risk of accidents at oil and gas facilities in accordance with [6, 21] is assumed to be equal to $2.4 \times 10^{-3}$ accidents/year.

The background risk of death in the Russian Industrial Complex of Oil and Gas (the average annual number of deaths from accidents per 1 million risk takers) in 2018 is $8.2 \times 10^{-5}$ people/year [6].

As a result of the quantitative assessment of the accident risk performed in accordance with the requirements [9, 10, 20], the following indicators were obtained at the GDS, which do not exceed the background ones:

- frequency of implementation of all accident scenarios at the GDS $f = 1.0 \times 10^{-4}$ accidents/year,
- the maximum individual risk of personnel death $R = 2.21 \times 10^{-6}$ people/year.
Table 3. Qualitative risk assessment of the accident at the GDS.

| Possible Deviation | Consequence | Exceeding the Maximum Allowed Level | Additional Measure | Risk Level |
|--------------------|-------------|-------------------------------------|--------------------|------------|
| Increasing the gas capacity, $Q_c = 36.37$ thousand m³/hour | 1. Increasing the gas velocity in the pipelines ($V = 24.99$ m/s – maximum) | Does not exceed the allowed level (25 m/s) | No need | Low |
| | 2. Increasing the degree of opening of the gas pressure regulator valve (56.8%) | Does not exceed the allowed level (80%) | No need | Low |
| Lowering the gas temperature at the outlet of GDS, $T_{out,1} = -9.49 \degree C$ | Possible hydrate formation | The temperature is not lower than the allowed level ($-10\degree C$) | No need | Low |
| Increasing the gas pressure at the inlet of GDS, $P_{in} = 4.39$ MPa | Increase in the amount of gas involved in the accident | The pressure does not exceed the design pressure (5.4 MPa) | No need | Low |
| Increasing the gas velocity in the pipelines of GDS, $V = 24.99$ m/s | 1. Increase in noise and vibration in process piping | Does not exceed the allowed level (80 dB). | No need | Low |
| | 2. Increasing the erosive effect of the gas flow on the walls of gas pipelines (bends) | | No need | |

Table 4. Verbal description of the risk levels.

| Risk Level | Risk Management Activities |
|------------|---------------------------|
| Low        | No additional risk management measures are required. Risks must be maintained at the current level |
| Medium     | Risks require attention and detailed study. It is necessary to define additional measures for risk management in case of insufficiency of existing measures and expediency of additional measures |
| High       | Significant improvements are needed in risk management tools. Production activities should be halted until risk management tools are put in place, making the risk level at least medium |

4. Conclusion

The conducted researches of the operated GDS allowed to determine that the Technically Possible Capacity is greater than the design capacity by 16.37 thousand m³/hour, while the risk of an accident at the GDS does not exceed the background risk indicators for the Russian Oil and Gas Industrial.
5. References

[1] Global Energy Statistical Yearbook [Internet] 2019 [Cited 24 February 2020] Available from: https://clck.ru/NY7kQ

[2] U.S. Energy Information Administration International Energy Outlook [Internet] 2016 pp 37-60 [Cited 24 February 2020] Available from: https://clck.ru/NY7sK

[3] 39-1.8-022-2001 from 03 January 2001 Departmental Guidance Document Nomenclature List of Gas Distribution Stations of Main Gas Pipelines [Internet] 2001 [Cited 24 February 2020] Available from: https://clck.ru/NY7tQ

[4] GOST R 12.3.047–2012 Fire Safety of Technological Processes. General Requirements. Control Methods Application E [Internet] 2012 [Cited 24 February 2020] Available from: https://clck.ru/NY7ud

[5] Annual Report on Activities of the Federal Environmental, Industrial and Nuclear Supervision Service of Russia in 2018 p 160 [Internet] 2019 [Cited 24 February 2020] Available from: https://clck.ru/NNWaU

[6] Background Indicators of Accidents at Hazardous Production Facilities of Russian Oil and Gas Industry [Internet] 2019 [Cited 24 February 2020] Available from: https://clck.ru/NY7wj

[7] Hemmatian B, Abdolhamidzadeh B, Darbra R M, Casal J 2014 The Significance of Domino effect in Chemical Accidents J. Loss Prev. Process Ind. 29 pp 30–38

[8] Chmielowski K, Bugajski P, Maziarz J 2017 Analysis of Failure Events Occurring in the Gas Networks Based on the Example of the Gas Company in Jaslo Gas Water San. Tech. 4 pp 136–139

[9] STO Gazprom 2-2-3-351-2009 Guidelines for Conducting Risk Analysis for Hazardous Production Facilities of JSC "Gazprom" [Internet] 2009 [Cited 24 February 2020] Available from: https://clck.ru/NY8RG

[10] Order of Rostechnadzor of 26 December 2018 N 647 Methodology for Assessing the Risk of Accidents at Hazardous Production Facilities of Main Pipeline Transportation of Gas [Internet] 2018 [Cited 24 February 2020] Available from: https://clck.ru/NY8SB

[11] VRD 39-1.10-069-2002 Departmental Guidance Document Regulations on Technical Operation of Gas Distribution Stations of Main Gas Pipelines [Internet] 2002 [Cited 24 February 2020] Available from: https://clck.ru/NY8Tg

[12] GOST 5542-87 Natural Combustible Gases for Industrial and Municipal Use. Technical Conditions [Internet] 1988 [Cited 24 February 2020] Available from: https://clck.ru/NY8cM

[13] The Register of Programs for Electronic Computing Machines. The ICR of “Vesta–GDS” [Internet] 2014 [Cited 24 February 2020] Available from: https://clck.ru/NY8eF

[14] Sardanashvili S A, Mitichkin S K, Leonov D G, Shvechkov V A 2015 Software solution for control of gas distribution system operation modes Gaz Rossi 3 pp 78-84

[15] STO Gazprom Gas Distribution 12.2.2-1-2013 Processes. The Process of Working with Data. Determination of Throughput Capacity. Calculation of Free Capacities of Gas Pipelines [Internet] 2013 [Cited 24 February 2020] Available from: https://clck.ru/NY8gZ

[16] Belinsky A V, Rebrow O I, Rechinsky S N 2018 Low-cost Ways to Increase the Production Capacity of Operated Gas Distribution Stations Vestni Gazovoi Nauki M: Gazprom VNIIgaz: LLC “Gazprom VNIIgaz” 2 pp 88-100

[17] Belinsky A V, Rebrow O I 2016 Development of a Methodological Approach to Substantiating Measures for Low-cost Technical Re-equipment of Gas Distribution Stations Territory of Neftegaz 12 pp 54-61

[18] GOST R 51901.11–2005 Risk Management. Hazard and Performance Studies. Application Guide [Internet] 2005 [Cited 24 February 2020] Available from: https://clck.ru/NY8iK

[19] Augusto Bianchini, Filippo Donini, Alessandro Guzzini, Marco Pellegrini, Cesare Saccani 2015 Natural Gas Pipelines Distribution: Analysis of Risk, Design and Maintenance to Improve the Safety Performance. XX Summer School "Francesco Turco" - Industrial Systems Engineering [Internet] pp 243-247 [Cited 24 February 2020] Available from: https://clck.ru/NY8jN
[20] Order of Rostechnadzor of 11 April 2016 N 144 *Methodological Bases for Conducting Hazard Analysis and Risk Assessment of Accidents at Hazardous Production Facilities* [Internet] 2016 [Cited 24 February 2020] Available from: https://clck.ru/NY8kP

[21] Order of Rostechnadzor of 23 August 2016 N 349 *Procedure for Determining the Permissible Accident Risk when Justifying the Safety of Hazardous Production Facilities of Russian Oil and Gas Industry* [Internet] 2016 [Cited 24 February 2020] Available from: https://clck.ru/NY8mC