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ANALYSIS OF THE METHODS FOR GAS DEMAND FORECASTING**

1. INTRODUCTION

Natural gas is a very important and strategic raw material. On the World's scale its participation as a primary energy source totals to 25% and is predicted to increase, to finally exceed the share of coal in 2030.

In Poland, where the coal reserves are considerable and energy industry is oriented to this kind of fuel, the participation of natural gas is only about 10%. The common use of solid fuels results in a considerable air pollution, especially in big cities [1].

The environmental issues in the EU are treated very seriously. Poland, as a member country, declared to lower greenhouse gases emissions and improve air quality in big cities, especially in Kraków.

The transition to gaseous fuel in big cities is an efficient tool for lowering the hazardous emissions, but at the same time generates technical issues, especially the necessity to precisely diagnose the gas demand in cities in new conditions, and design new gas distribution networks.

Designing gas distribution networks is performed on the basis of predicted gas demands for a predefined group of customers in peak hours. On this basis the diameters of the gas pipelines are selected.

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The gas demand is conditioned by the following factors:

- characteristic conditions for a given network system, i.e. magnitude of the city, social and economic structure of the population, standard gas devices and equipment, dominating mode of space heating, local industry, etc.;
- assumptions of economic and spatial development of the analyzed area;
- gas prices;
- data about gas consumption so far, etc. [2].

There are various methods of predicting gas demands, which are based on various assumptions. The problem lies in the fact that the methods bring about different results for the same input data, which speaks for the lack of coherence in the gas planning issue.

Therefore, the most efficient way of planning gas deliveries in the cities, which already make use of gas, are analyses of actual gas consumption.

The successive subchapters are devoted to the principles of predicting gas deliveries on the basis of existing methods and with the use of the proposed method.

2. REVIEW OF APPLIED METHODS FOR PREDICTING GAS CONSUMPTION

One of the most complicated problems relating to the calculation of gas networks is planning maximum hourly gas consumption by the customers as on this basis the diameters of gas pipelines and hydraulic calculations can be efficiently selected.

Gas consumption is not constant in a function of time. It varies in time in hourly cycles, daily, weekly, monthly or even in seasons. The variability of gas consumption is closely connected with the type of demand of gas consumers.

The gas users do not make use of gas appliances at the same time, therefore the actual consumption is much lower than suggested by the summary of nominal gas consumption.

Maximum hourly consumption of the network can be defined with two methods:

1) as part of the annual gas demand of all customers using the network, divided by ‘number of gas-using hours’ over a year;
2) as a sum of nominal load of consumption of all customers using the network gas, taking int account the coefficient of simultaneous gas consumption.

Method of ‘annual gas-consumption hours’ bases on coefficients of hourly, daily and monthly minimum/maximum demand ratios [2, 3].

The maximum gas consumption oscillations in time are used for determining gas demand for customers consuming large amounts of gas, e.g. industrial institutions, communal institutions, services or space heating.

The following minimum/maximum demand ratios of gas consumption are defined. They are calculated as maximum to average gas consumption and they assume the below values:

- monthly minimum/maximum demand ratio in an annual cycle, k_m = 1.25–1.30;
- daily minimum/maximum demand ratio in a monthly cycle, k_d = 1.10–1.15;
- hourly minimum/maximum demand ratio in a daily cycle, k_g = 1.70–1.80.

Annual minimum/maximum demand ratio is defined as a product of coefficients:

$$K_r = k_m k_d k_g \tag{1}$$

The annual number of consumption-hours to cover the peak demand for gas is a ratio of total hours in the years (8760) to annual minimum/maximum demand ratio, which can be presented as:

$$h_r = \frac{8760}{K_r} \tag{2}$$

Maximum hourly gas consumption:

$$Q_{\max} = \frac{Q_r}{h_r} n \tag{3}$$

where:

Q_r – average annual gas demand per one customer,

n – number of gas customers.

This method has an index character and is applicable for solving perspective tasks and when designing large gas networks and systems.

The second group of methods is based on the simultaneity of gas consumption and is used for calculating distribution networks, local gas pipeline systems and internal conduits, when the number of customers and the installed gas appliances are.

Determining the maximum hourly intensity of gas flow for particular groups of customers generally depends on three basic parameters:

- coefficient of simultaneity of gas consumption in a function of number of customers,
- average gas consumption per customer,
- number of customers.

$$Q_{est} = \sum_j p_j q_j n_j \tag{4}$$

where:

n_j – number of increases in j-th group,

p_j – simultaneity coefficient for the j-th group of gas appliances,

q_j – nominal gas consumption of a gas appliance of j-th group.

The simultaneity coefficient value depends on:

- unit gas consumption by the installed appliances,
- number of installed appliances,
- number of customers.

This coefficient equals to or is smaller than unity; it decreases with the increasing number of installed appliances or clients.

A few methods can be used for determining the hourly load in the network. They were worked out by various authors in Poland (e.g., Milewski method, Zajda method, KOZG in Tarnów), and abroad (German method TDWG-TRGI-86, French method, Russian method). They differ in the application range and in constrains [1, 3].

For instance, the simultaneity coefficient of gas consumption can be calculated with **Milewski method.** It is based on the measuring points, i.e. households equipped with gas appliances with maximum gas consumption of 4.25 m^3/h, and which are calculated from the formula:

$$p = \frac{1}{\sqrt[n]{N}} \tag{5}$$

where:

N – number of calculation points,

n – exponent, assumed value from 1.8 to 2.0.

Zajda method was worked out for a distribution network where customers use gas for communal and household purposes $n_1 < 25\,000$ and the number of customers using gas for space heating $n_2 < 5000$.

The input form of the equation for determining maximum hourly gas consumption assumes two categories of customers:

$$Q_{\max} = Q_1 n_1 p_1 \beta_1 + Q_2 n_2 p_2 \beta_2 \tag{6}$$

where:

n – number of customers of a given category,

p – simultaneity coefficient of gas consumption in a given category, which depends on the urbanization level and number of customers,

Q – average consumption by a given category of users,
β – correction coefficient for gas consumption (non-communal purposes and individual space heating); it depends on the urbanization level of the gasificated area.

In the German **DVGW method** the gas demand is not presented as gas consumption in units of volume, but demand for a heat quantity required for a given process. This method is an example of a different approach to the accurate definition of gas demand. This has its advantages, because the result of calculations can be recalculated for gas quantity with calorific value in view [3].

Analogous approach can be seen in the **Russian SNiP method**, which is based on the calculation of heat demand, which can be recalculated for the gas volume with the use of the calorific value.

These methods abound in suppositions and constrains. What is more, the results of predictions made with the use of various methods considerably differ for the same entry conditions.

A good example, representing the incoherence of approaches to predicting gas demands, is the work by Konrad Bąkowski [1], who calculated GZ-50 gas demand for cooking meals and preparation of warm water for a population of 50 customers. The obtained results are as follows:

– in Zajda method – 24.2 m^3/h,
– tables of Leipzig Energy Institute – 24.5 m^3/h,
– in Russian SNiP method – 31.5 m^3/h,
– in German DVGW method – 17.1 m^3/h.

The difference between minimum and maximum significance equaled to about 85%. This proves that there is no uniform approach to predicting gas demands and a new approach is needed to create bases for more precise planning of gas consumption and correct selection of pipeline diameters – a warranty of safe and reliable realization of gas deliveries.

3. PREDICTING GAS DEMANDS ON THE BASIS OF ACTUAL CONSUMPTION

One of the most complicated problems relating to the calculation of gas networks is planning maximum hourly gas consumption by communal and household users.

In this type of clients, who use gas for space heating or communal purposes, the volume of consumed gas significantly depends on weather conditions, thermal characteristics of the buildings' walls, type of gas appliances, etc. whereas gas consumption in industrial clients can be defined precisely through contracts and on the basis of technological processes.

The purpose of the proposed method is to define an approach to establishing a mathematical equation for predicting hourly gas consumption by communal and household customers, depending on the entry factors.

One of the most reliable ways of planning gas consumption in a city, where gas was already used for heating as well as communal and household purposes, is the analysis of actual consumption.

The reliable **sources of information** for analysis are:

1) data, regularly collected and stored by a gas distribution company;
2) diagrams of gas consumption in gas regulation stations [4].

Usually gas is sampled in the gas regulation stations for a period of time: 1 min, 15 min, 1 hrs, etc.

The diagrams registered on gas regulation stations revealed that gas consumption of communal and household customers can be determined as a difference between total consumed gas and gas consumed by industry [5].

Measurement data frequently have many deficiencies, e.g. rapid changes of values, zero or constant value of stream for a period of time. Such deficiencies may stem from a failure in the system or measuring equipment, operator's error or error in data processing. The making use of such data caused that fictitious profiles are generated and the predictions are burdened with a bigger error. Therefore it is crucial to remove these shortcomings. One of the effective way of handling such type of data is using neural networks which can be taught and then define how to handle data. This will be discussed later [6].

For the sake of creating the final data sample, and defining a mathematical formula, statistical tools can be used, especially **low-pass and high-pass filters,** for the elimination of extremely high or zero gas consumption [4, 7].

The created filter may use its constant boundary value (y_{max}, y_{min}) for 24 hrs or may account for the shape of function characterizing the daily gas consumption.

Another mechanism of deficiency detection lies in **filtering data for the rate of changes**. Based on the existing database of profiles one can determine the admissible increase gradients, i.e. rapid changes of neighboring values $|y_i - y_{i+1}| < \Delta$. Filtered data can be analyzed for establishing the dependence [3].

Numerous studies prove that gas consumption in summer months practically does not depend on ambient temperature because no heating is involved. Moreover, gas network is designed for maximum hourly consumption which can be observed only in the heating period at minimum temperatures of the air [2].

Hence a conclusion that **for establishing a relation between gas consumption and predicted maximum hourly gas consumption it is enough to analyze gas consumption in the gas regulation station only in the heating period**.

For establishing a dependence of gas consumption on entry data conditioning its value, one should analyze the following factors and determine their impact and purposefulness:

1) Weather conditions:
   – average temperature of air,
   – gradient of air temperature over a day,
   – direction and speed of wind,
   – humidity of air.
2) Calendar factors – time of the day, day of the week, holidays and preceding days.
3) Gas composition – calorific value changes and consumption increases till the moment the required quantity of energy is obtained.
4) Population per unit of living space and heating space, type of development.
5) Heat characteristic of buildings' walls.
6) Type of gas equipment and its efficiency [3].

A mathematical formula for predicting maximum hourly consumption for city quarters with identical characteristics (development type, type of installed gas equipment, etc.) can be obtained, e.g. by multiparametric regression analysis method in the form [7, 8]:

$$Q = a_0 + a_1 x_1 + a_2 x_2 + \ldots + a_n x_n \qquad (7)$$

where:

a_i – constant coefficients in mathematical equation,
x_i – arguments of function.

A mathematical formula has to be established for various entry parameters. **For doing so, a mathematical model has to be worked out with highest coefficient of determination**. Then the model should be tested for significance of the correlation coefficient. This can be done on the basis of typical mathematical statistics algorithms and no further explanation of this will be presented herein.

Based on the analysis of actual gas consumption by customers and the established function one may predict the gas consumption for the city quarters which are to be using gas fuel, and who are characterized by similar entry data, i.e. thermal characteristic of buildings, characteristic of gas equipment, etc.

After conducting regression analysis the coefficient of determination, which is a measure of fit of the model, may turn out to have a low value for the linear model and does not defined a dependence between gas consumption and function arguments.

In this case neural networks can be used for approximating a given function. Neural networks are applicable in the following situations:

- data reveal considerable non-linearity;
- data are chaotic and noises are involved.

Moreover, after learning, the network may show ability to select parameters, which are worth incorporating in the model, by itself. In the planning of gas consumption this ability is very valuable because we do not exactly know which parameters have an influence of gas consumption by customers [6].

Numerous scientific works confirm that a standard three-layer one-direction network has high approximation abilities. The architecture of a neural network, number of entries, the development of the learning set and cross-validation set is a question of entry data and cannot be precisely predefined.

The establishing the mathematical formula for determining hourly gas consumption in a city quarter is followed by the calculation of summaric gas consumption in the city and participation of each quarter in the gas consumption balance:

$$Q_{sum} = \sum Q(x_1, x_2, ..., x_n)_i \tag{8}$$

$$a_i = \frac{Q(x_1, x_2, ..., x_n)_i}{Q_{sum}} \tag{9}$$

This algorithm is only based on the analysis of data from the consumption diagram in the gas reduction station. How can the data collected by gas-supplying companies be used? Gas companies usually have data on gas consumption on a monthly basis. These data can be used for determining actual gas consumption in a city quarter as compared to the actual gas consumption in the whole city:

$$b_i = \frac{Q_i}{Q} \tag{10}$$

where:

Q_i – gas consumption in a city quarter, where the entry characteristics were identical, for which a mathematical formula is defined,

Q – total gas consumption in the city.

The comparison of coefficients a_i and b_i can be an additional indicator that establishing mathematical formulae for Q was done correctly as these coefficients represent the actual distribution of gas consumption in the city:

$$a_i \cong b_i \tag{11}$$

The maximum hourly gas consumption in a city quarter asa well as the existing or planned gas network of predefined configuration can be used for predicting needed passability of gas pipeline sections supplying gas to a given group of customers. The following approach can be used.

1. Define unit gas consumption in the network with the formula:

$$q = \frac{Q(x_1, x_2, ..., x_n)}{\sum l_i} \tag{12}$$

   where l_i – length of i-th section of analyzed city quarter.
2. Then, based on the obtained parameter q, make a configuration of gas network and calculate gas consumption for each section of the network using the Kirchhoff law, with the formula:

$$Q_{est\ i} = q \cdot l_i \tag{13}$$

As a result we obtain a set of desired capacity $\{Q_i\}$ of all sections of the gas network, creating bases for further exploitation calculations, designing new gas distribution pipelines and optimization of the existing gas supply system.

4. CONCLUSIONS

Switching to a gaseous fuel in big cities is en efficient tool for lowering noxious emissions, but at the same time generates complex technological issues, especially the necessity to precisely predict gas demands for a city in a new situation, and design new gas distribution networks.

Predicting maximum hourly gas demand is very complicated. There are many methods available and they are based on various assumptions.

The magnitude of the hourly gas consumption can be defined with two methods:

1) as a part of annual gas demand for all customers using a given network divided by the number of consumption hours over the year,
2) as a sum of nominal gas consumption of all users of the network, taking into account the simultaneity coefficient of gas consumption.

The problem lies in the fact that these methods bring about different results for identical input data (error up to 85%), which speaks for the incoherence of approach to the gas planning issue.

The method based on the analysis of the actual gas consumption better fits the condition of the city, for which the calculations have been made.

The proposed method lies in the analysis of actual gas consumption in a city; the source of information could be data collected by gas distribution companies and diagrams in the gas regulation stations.

This method lies in working out of a mathematical model (multi parametric regression or neural network, when data are considerably non-linear) from parameters which determine gas consumption, e.g. weather data, calendar data, characteristics of buildings and gas devices in these buildings.

The comparison of participation of gas consumption in various city quarters to the total consumption, calculated on the basis of mathematical formulae and actual consumption, can be used as an additional indicator that the fit models truly represent the gas consumption distribution in the city.

Based on the calculated maximum gas consumption for a city quarter and accounting for the configuration of gas network and the calculated values per pipeline section creating bases for further exploitation calculations, designing and optimization of the gas supply system.

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