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MATHEMATICAL PROGRAMMING AS A METHOD OF OPTIMIZATION OF OPERATION OF CALDRON BOILER

Lebedeva Irina Leonidovna, Ph.D., associate professor,

Simon Kuznets Kharkiv National University of Economics, Kharkov, Ukraine

Abstract — **In this paper we demonstrated possibility to decide an economic task in relation to optimization of work of low-power caldron aggregates as a task of the linear programming. An objective function is an income of enterprise from realization of heat without the cost of fuel, which is outlaid on the production of heat, and payments of taxes, for contamination of atmosphere by harmful questions.**

Keywords — **efficiency of the use of energy, harmful emissions, linear programming, optimization.**

One of major constituents of welfare in the civilized states is providing of citizens and companies necessary resources of energy. The important influence has development of energy for economy of the state and standard of living of population of country. On the modern stage of development of society efficiency of the use of energy is the key element of economic and national security. It is an issue of the day not only for Ukraine but also for all humanity. Namely, European policy makers introduced targets for the year 2020 in a number of different sectors. Program 20-20-20 supposes to realize the next projects [3]. Till 2020 the energy targets are to have a 20 % reduction in CO_2 emissions compared to 1990 levels, 20 % of the energy, on the basis of consumption, coming from renewables and a 20 % increase in energy efficiency.

It should be noted that the problem of reducing emissions is relevant for all mankind. The World Meteorological Organization (WMO) is a specialized agency of the United Nations, which implements monitoring the composition of the earth's atmosphere. The most dangerous in this regard is carbon dioxide, but also methane and nitrous oxide. According to WMO on a global scale, the amount of CO_2 in the atmosphere has increased to 396.0 parts per million in 2013. For the period from 2012 to 2013 the rate of increase of CO2 in the atmosphere reached 2.9. It should be noted that this is the largest annual increase for the period 1984 – 2013 [4].

The main type of effects of industrial and other facilities on the state of the air basin is the pollution of air pollutant emissions, heat, water vapor and aerosols. The highest quantity of nitrogen oxides, sulphur dioxide and dust emissions came from stationary sources of enterprises of electricity production and the gas and water sectors (respectively, 56 %, 70 % and 52 %). The main sources of emissions of harmful substances are stationary sources.

Before the society of the countries with high level industry sharply raises the problem of reducing the harmful impacts of industrial activity on the environment. The state imposes economic leverage to force companies to comply with environmental regulations. The energy crisis in Ukraine has aggravated the problem of providing energy. Individual companies are trying to reduce the economic burden, so they build small boilers, which use their own resources. The target of this article is to optimize the operation of boiler units of low power on the basis of application of modern algorithms for solving economic problems. Optimization of the modes of operation of boiler units can be regarded as a mathematical programming problem. For this purpose we used the method of linear programming.

The objective function Z will be considered as profit S, which will get the company from the sale of heat that is produced, less the cost of fuel D, spent on the production of heat, taxes for pollution of atmospheric air of harmful substances in emissions $k_t \cdot \sum c_i x_i$, and certain expenses, denote by the constant Z_0 (deductions for depreciation, mandatory payments, and so on). Therefore, the objective function has the form:

$$Z = S - (D + k_t \cdot \sum_{i=1}^{n} c_i x_i + Z_0), \qquad (1)$$

where k_t – a coefficient that takes into account the territorial-environmental features (this coefficient depends on the population in areas where the company is located, and the value of the territory); c_i – normative payment for emissions into the atmospheric air one ton i-th harmful substances within normal limits MPE (Maximum Permissible Emissions); x_i – the total mass emission of the i-th substance (for all objects of the company), if it does not exceed the standard MPE. It is clear that the objective function is explored to the maximum.

For all objects that pollute the atmosphere, calculate and set the maximum allowable emissions. They are defined as the number of harmful substances, which should not be exceeded during ejection into the air per unit of time that the concentration of pollutants at the border of sanitary zone is not higher than the maximum permissible concentration, which has virtually no effect on human health. For small and medium boilers demand for natural gas (or other fuel, for example coal or oil) can be met, the market of heat determines the number of objects running concurrently, and their workload. Therefore, ceteris paribus, the main constraint system this objective mathematical programming related to the amount of harmful substances emitted in atmospheric air during the control period (within one year). Let's write a basic system of constraints as follows:

$$\begin{gathered} \sum_{j=1}^{m} x_{ij} = x_i \le x_{io} \quad (i = \overline{1,n}), \\ S = q \cdot s, \quad D = p \cdot d, \quad \eta \approx d / q. \end{gathered} \qquad (2)$$

Accordingly, x_{ij} – the annual mass emission of the i-th harmful substances, selects the j-th object of the company; x_{i0} – the maximum mass of the i-th hazardous substances that complies with MPE; q – the cost of one ton of steam; s – the number of tons of steam that produces the company; p – the value of 1 m^3 of natural gas; d – number of thousand m^3 of natural gas consumed in production of heat; η – the coefficient of performance boiler unit.

In addition, variables that are contained in the mathematical models have limitations:

$$x_{ij} \ge 0. \qquad (3)$$

Because of the violation of technological process at the enterprise there may be circumstances when one or more of the inequalities in the system of constraints (2) are violated, i.e. the emission of harmful substances exceeds the norm MPE. So, you should consider another component of the objective function. This is a payment of fines for exceeding of maximum permissible emissions standards. Therefore, in the General case, the target function has another negative component:

$$\sum_{i=1}^{n} c_i^* (x_i - x_{i0}), \qquad (4)$$

where c_i^* – the fine, which the company must pay if the emissions of the i-th harmful substances exceed the MPE for 1 ton. It must be emphasized that the magnitude of this penalty c_i^* may exceed the cost c_i with several times. The following relation takes place: $c_i^* = k_i \cdot c_i$, where k_i is the coefficient of expansion that is determined by local Councils. Because payment of fines is introduced with a payroll company, the excess of the MPE significantly affects the income of workers.

In the result, the objective function has the form:

$$\begin{gathered} Z = S - (D + k_t \cdot (\sum_{i=1}^{n} c_i x_i + \\ + \sum_{i=1}^{n} c_i^* (x_i - x_{i0})) + Z_0) \;\to\; \max \end{gathered} \qquad (1^1)$$

For saturated or superheated steam, running on the technological needs of industrial enterprises in the system of heating, ventilation and hot water, are widely used steam boilers DKVR. These boilers can run on various fuels. If the boiler uses natural gas for heat production, emissions into the air contain such harmful substances, for which the company pays taxes (and penalties): carbon monoxide (CO), nitrogen oxide (NO) and nitrogen dioxide

(NO_2). In the model the independent variables are the amount of emissions and boiler efficiency. Since the objective function and the system of the constraints are linear with respect to these variables, equations (1^1) – (3) represent the mathematical model of linear programming.

If we consider equations of the basic system of constraints (2), the components S and D of the objective function are some functions from technological factors. It is known that the technological factors which determine the mode of operation of the boiler is the power of the steam flow capacity ($P_к$) and the coefficient of excess air (α). In addition, all x_i are dependent on $P_к$ and α . Because these functions cannot be predicted theoretically, we performed experiments to determine it.

It should be emphasized that demand for heat varies significantly during the year. In accordance with the needs, the performance of the CHP (Combined Heat and Power) is governed by the number of boilers that work together and load each of them. For each level in the steam flow capacity of the boiler (50 %, 75 %, 100 % and 125 % of the nominal value) is determined optimum mode that provides the highest efficiency with the lowest emissions of all controlled hazardous substances. Control of an operation mode of the boiler for a given value of the steam flow capacity is due to the change of the coefficient of excess air in the combustion zone. For each levels of the steam flow capacity carried out the measurement of the performance of the boiler when the change of the coefficient of excess air α was in the range of 1.2 to 2.5 (or more), but $\Delta\alpha$ did not exceed 0.1. For each level of the production consisted of regime card of the boiler equipment in optimal mode (which contains 23 characteristics) with the definition of the ranges of these characteristics depending on the temperature, which escapes through the chimney, the excess air coefficient and heat of combustion of irrigation within which the mode of operation of the boiler can still be considered optimal.

Experimental data, which are necessary for carrying out calculations in accordance with the mathematical model, were obtained during the conduct environmental thermal test boilers DKVR-20-13. An important advantage of boilers DKVR-20-13 is a wide range of regulation of their performance (from 40 % to 150 % of the nominal value), which allows use of the boiler with maximum efficiency and saves costs for the production of heat and electricity. Their efficiency is becoming 91 %. The measurements were carried out by representatives of the enterprises of JSC "Kotloenergoprom" technique [1; 2].

The application of optimal performance in production 100 % of the nominal saves costs of conventional fuel 1.4 kg per 1 Gcal, which gives the company an annual saving of conventional fuel 52.9 t/year. In terms of the cost of fuel oil M100, which is 3000 UAH/t, the annual savings of enterprises per one boiler is 158700 UAH (price 2014). The emissions of all hazardous substances are within the limits stipulated by the MPE for the enterprise JSC "Heat center Rohan industrial zone".

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Author

Lebedeva Irina Leonidovna, Ph.D., associate professor of department of higher mathematics and ekonomiko-mathematical methods, Simon Kuznets Kharkiv National University of Economics, Kharkov, Ukraine (Irina_L_lebedeva@mail.ru).

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