A R C H I V E S O F M E T A L L U R G Y A N D M A T E R I A L S
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MAXIMAL ACCEPTED COST OF WASTE FUEL BURNED IN HEAT AND POWER PLANTS, INCLUDING PROFITABILITY OF CO_2 EMISSION TRADING

GRANICZNY KOSZT PALIW ODPADOWYCH SPALANYCH W ELEKTROCIEPŁOWNI PRZEMYSŁOWEJ PRZY UWZGLĘDNIENIU EFEKTYWNOŚCI HANDLU UPRAWNIENIAMI DO EMISJI CO_2

This paper presents the method of setting the maximal accepted cost of waste fuel burned in heat industry power plant with the regard of trading effects of CO_2 allowances. In effected analysis, the entrance parameters are specified by the uncertain (heuristic) data or by probabilistic data (trough statistical distributions of given parameters). The research has accomplished for industrial power plant using waste gases from steelworks. The method proposed in this paper has been illustrated in 5-years period perspective of power plant operating. Economical effect was described as an object function, expressed as net present value (NPV).

Keywords: maximal accepted cost, CO_2 emissions, uncertain data, probabilistic data, waste gases

W pracy przedstawiono metodę wyznaczania granicznego kosztu paliw odpadowych spalanych w elektrociepłowni przemysłowej, uwzględniającą skutki handlu uprawnieniami do emisji CO_2. Parametry wejściowe w przeprowadzonej analizie określone są przez dane o charakterze niepewnym (heurystycznym) lub probabilistycznym (przez rozkłady statystyczne rozpatrywanych parametrów). Badania zostały przeprowadzone dla elektrociepłowni przemysłowej, wykorzystującej odpadowe gazy palne z zakładu hutniczego. Zaproponowaną metodę zilustrowano w perspektywie 5-letniego okresu eksploatacji elektrociepłowni. Efekt ekonomiczny został opisany za pomocą funkcji celu, wyrażonej przez wartość bieżącą netto (NPV).

1. Introduction

There is a new challenge that power sector has to face – CO_2 emissions trading. Participation in the system gives new impulses for action and should be considered when taking operational and investment decisions in industrial plants including heat and power plants. Implementation of the system for CO_2 emissions trading first of all makes obligations to monitor and to control CO_2 emissions levels. Obligations resulting from emission allowances can be so tough that company has to look for new solutions in reduction of CO_2 emission.

Discussed heat and power plant is equipped with five OPG-230 steam boilers. The heat and power plant cooperates with neighboring steelworks. The heat and power plant is characterized by utilization of high volumes of gas fuels, which are generated by steel works as by-products during production of pig iron (blast-furnace gas) and production of steel (converter gas) as well as generated during coke production (coke gas) in the neighboring coking plant. These gases are burnt in the heat and power plant together with coal.

Determination of maximal accepted costs of waste fuel burned in heat and power stations including profitability of CO_2 emission trading was the Project objective.

2. Analysis of supply of chemical energy from gas fuels

Supply of chemical energy from blast-furnace gas, converter gas and coke gas were the main data that were covered by the statistical analyses. The stream of chemical energy delivered to the heat and power plant depends on main parameters of these gases – steam volume and caloric value. The gas stream volumes are of high variability, especially in the case of blast-furnace gases,

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which share in chemical energy of gases, burnt in heat and power plant, is 50% and share of gases deliver to the plant is above 90%. Consumption of blast-furnace gas by heat and power plant is presented in Fig.1.

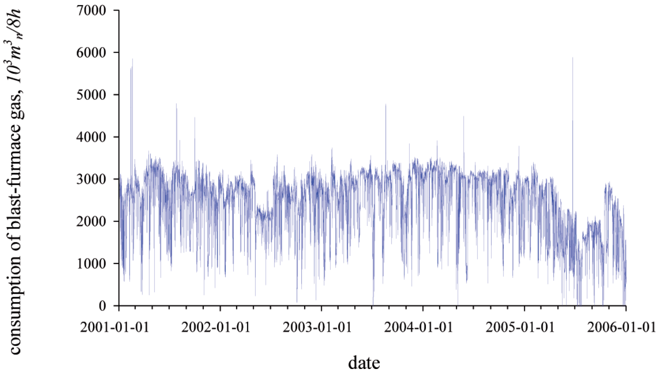

Fig. 1. Consumption of blast-furnace gases from 01. 01. 2001 r. to 31. 12. 2005 r. (data per shift)

Blast-furnace gas delivered by steelworks is often enriched due to its low caloric value. That is why heat and power plant uses it as a mixture with a converter gas and coke gas. Blast-furnace gas is first of all used for technological purposes of the steelworks like heating of blast, supply of rolling mill furnaces and heating sinter belts [8]. Heat and power plant as a buffer receiver of that gas uses only surplus volume of the gas and as production of blast-furnace gas varies significantly the gas collection is not even. Consumption of converter gas and coke gas varies significantly as well. Thus, streams of these gases are treated as random values. Collection of blast-furnace gas by heat and power plant, which is situated in close vicinity of the steelworks, is important for steelworks. Transport of the gas for further distances is not economically justified due to its very low caloric value [9]. At the same time burning of blast-furnace gas with coal is important for the burning process in the boiler itself, first of all as regards temperatures obtained during burning as well as conditions of heat transfer. During burning of blast-furnace gas with coal dust we can observe lower burning temperature. Mean caloric value of blast-furnace gas is 3 673 kJ/m^3_n, and gas composition varied within the ranges given in Table 1.

TABLE 1

Characteristics of blast-furnace gas

blast-furnace gas	volume share		
	min	max	average
CO_2, %	16.2	21.2	19
O_2, %	0.6	1	0.8
CO, %	22.1	36.7	25.3
H_2, %	1.1	6.2	3.1
CH_4, %	0.3	0.7	0.5
N_2, %	42.8	54.9	51.4
W_d, kJ/m^3_n	3 227	4 053	3 673

Converter gas is fed as a mixture with blast-furnace gas to increase caloric value of the mixture. Caloric value of the mixture is maintained in the range 3 400 – 4 400 kJ/m^3_n. Range of converter gas content is given in Table 2.

TABLE 2

Characteristics of converter gas

converter gas	volume share		
	min	max	average
CO_2, %	10.6	17.6	14.8
O_2, %	0	1.2	0.8
CO, %	45.8	68.8	61.4
H_2, %	0	0.4	0
CH_4, %	0.4	0.6	0.4
N_2, %	10.6	36.8	22.6
W_d, kJ/m^3_n	6 767	8 713	7 904

Coke gas is used to light the boilers and it is a high caloric gas and its caloric value is about 17 500 kJ/m^3_n. Range of coke gas content is given in Table 3.

TABLE 3

Characteristics of coke gas

coke gas	volume share		
	min	max	average
CO_2, %	18.8	2.6	2.1
C_xH_y, %	2	2.4	2.2
O_2, %	0.4	1.2	0.8
CO, %	6.4	8.8	7.5
H_2, %	55.7	600.1	60.8
CH_4, %	22	26	23.1
N_2, %	0.7	7.9	4.2
H_2S, $g/100\ m^3_n$	0.1	31.5	1.1
W_d, kJ/m^3_n	16 832	18 322	17 437

3. Data accepted for calculations

In the analysis the following has been distinguished:
a) uncertain input data like:
– set limit for the amount of emission,
– demand for heat,
– price of emission credits.
b) data determined by mean values (caloric values of used fuel),
c) input information, which is determined by known statistic distributions of each parameter.

Statistic analysis of input data [2] enabled to accept the following parameters of known statistic distribution as the independent input data: ambient temperature, streams of blast-furnace, converter and coke gases used in heat and power plant as well as generated streams of blast and compressed air.

Additionally correlation of some variables has been confirmed. Dependence of heat generation $\dot{Q}_{CO}$, production of medium pressure steam as well as production of electric power $\dot{E}_{el}$on ambient temperature and also dependence of production of high pressure steam on blast, compressed air and heat $\dot{Q}_{CO}$, medium pressure stem volume and amount of electric energy result from the calculations.

The characteristics were determined on the basis of studies of the boiler balances. The relationships concerned: power efficiency of the boiler and the steams of CO emission, CO_2 emission NO_x emission, SO_2 emission, dust emission as well as coal chemical energy.

4. Assumptions for the calculation methodology

Uncertain input data were included when solving the discussed problem. The uncertain data concern expected scenarios: limit of amount of CO_2 emission allowance for heat and power plant (3440 thousand, 2900 thousand, 2500 thousand t CO_2/year), heat demand (coefficient: 0.7; 1; 1.3 in relation to the present annual production) and the price for CO_2 emission allowance (10, 25, 40 EUR/t).

In the case of each scenario three variants, determined by a characteristic level of probability were discussed.

Besides the maximal stream of blast-furnace gas burnt in heat and power plant boilers was differentiated. It was assumed that acceptable variants of operation vary from 0 to 100% of the present maximal stream of blast-furnace gas which is 5230 thousand m_n^3 per shift with a skip of 20%. Also the following additional assumptions were made:

1. The analysis concerns the five-years period from 2008 to 2012.
2. 5% discount rate was accepted (interest rate in the case of long term bank deposits
3. Income tax rate is 39%.
4. As in the heat and power plant 5 identical boilers are installed, it was assumed that balance measurements for one OPG-230 boiler are representative for all other boilers.
5. Caloric value of fuels burnt in heat and power plant are constant and their values are as follows:
   a) for coal: W_d = 28 800 kJ/kg,
   b) for blast-furnace gas: W_d = 3 690 kJ/m_n^3,
   c) for converter gas: W_d = 7 890 kJ/m_n^3,
   d) for coke gas: W_d = 17 440 kJ/m_n^3.
6. In the case of shortage of CO_2 emission credits it is assumed that the heat and power plant will buy lacking credits on the market by an assumed price for the emission credit.
7. Additionally the current coal price, cost of coal transportation, price of blast-furnace, converter and coke gases, price of blast, price of compressed air, price of medium-pressure steam, price of heat, price of electric power as well as constant and variable costs of high-pressure steam production were included .
8. To assess the costs of using and protection of environment the following fees for using environment were assumed [6]:
   – for CO emission – 0.11 PLN/kg,
   – for NO_x emission – 0.43 PLN/kg,
   – for SO_2 emission – 0.43 PLN/kg,
   – for dust emission – 0.29 PLN/kg.

5. Target function

Target function was determined using the current NPV (*Net Present Value*). The current NPV is a sum of discounted net cash flow, i.e. differences between incomes and expenses, separately for each year of project realization [3, 5, 7, 10]. From the heat and power plant point of view, as a decision maker, it was agreed that determination of limit prices of blast-furnace gas, converter gas and coke gas, i.e. the price at which costs associated with using these gases would be equal to income reached when including the CO_2 emission trading aspect, is purposeful.

$$NPV = \sum_{t=1}^{n} \frac{CF_t}{(1+r)^t} = 0, \tag{1}$$

where:

NPV – Net Present Value, *PLN*,
CF_t – cash flow in year t, *PLN/year*,
r – discount rate, *1/year*,
n – calculation period, *years*,
t – the following year of calculation period.

During estimation of limit price of gases their mean values were calculated, weighted by probabilities of occurrence of each input condition (scenario). Calculation results were given in Figures 2, 3 and 4.

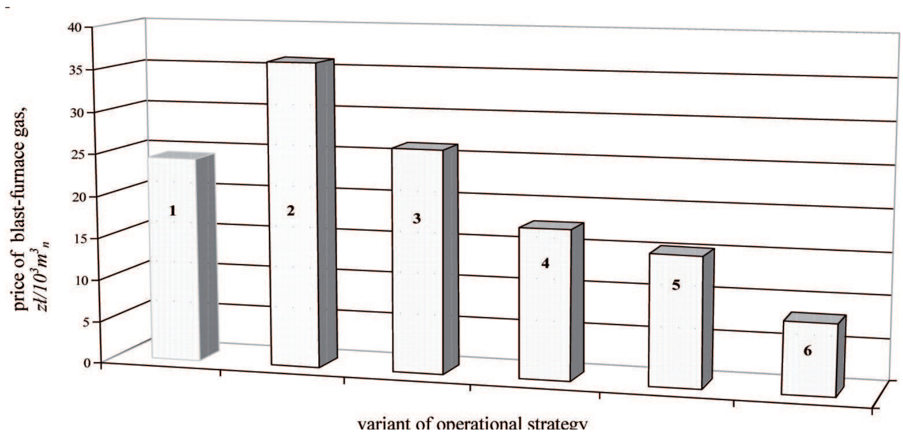

Fig. 2. Limit prices of blast-furnace gas for the discussed operational conditions
Assumed marking: 1– base price of blast-furnace gas, 2 – limit price for strategy: gas 20%, 3 – limit price for strategy: gas 40%, 4 – limit price for strategy: gas 60%, 5 – limit price for strategy: gas 80%, 6 – limit price for strategy: gas 100%.

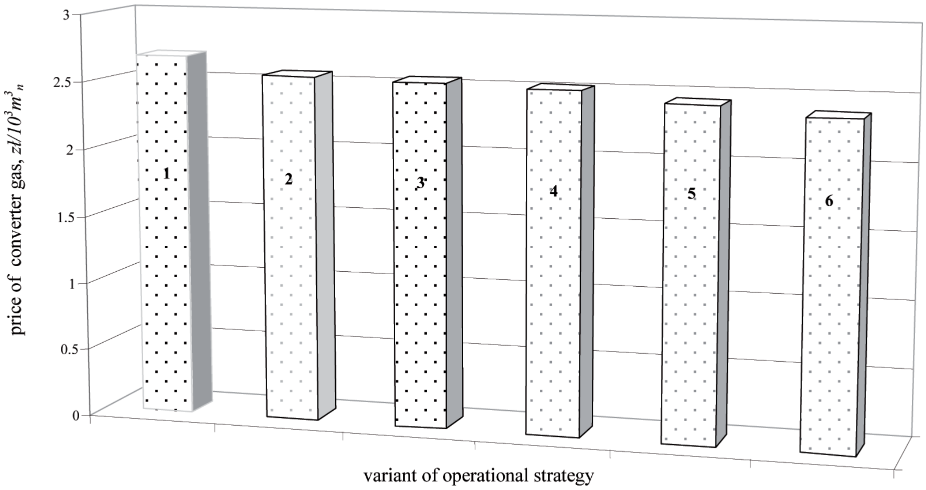

Fig. 3. Limit prices of converter gas for the discussed operational conditions
Assumed marking: 1– base price of converter gas, 2 – limit price for strategy: gas 20%, 3 – limit price for strategy: gas 40%, 4 – limit price for strategy: gas 60%, 5 – limit price for strategy: gas 80%, 6 – limit price for strategy: gas 100%.

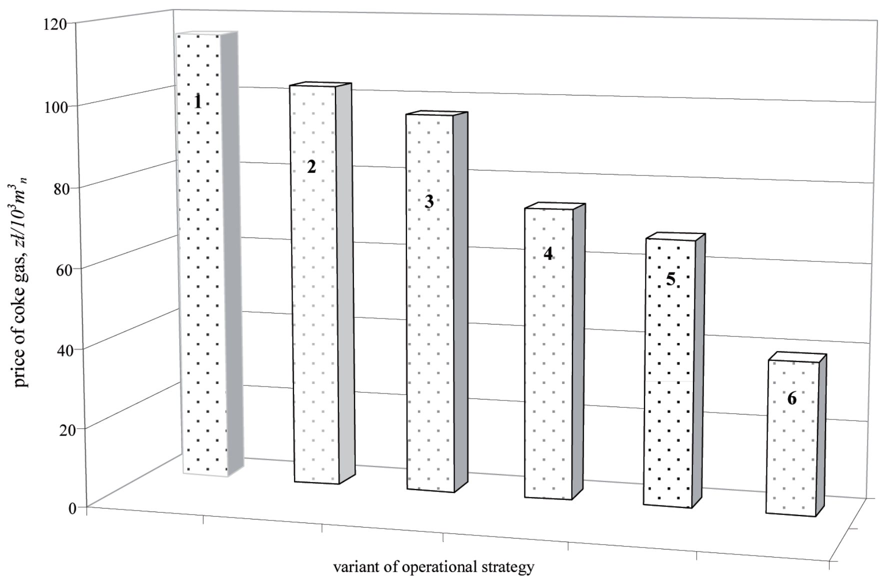

Fig. 4. Limit prices of coke gas for the discussed operational conditions
Assumed marking: 1 – base price of coke gas, 2 – limit price for strategy: gas 20%, 3 – limit price for strategy: gas 40%, 4 – limit price for strategy: gas 60%, 5 – limit price for strategy: gas 80%, 6 – limit price for strategy: gas 100%.

6. Conclusions

From Figures No. 2÷4, presenting the limit prices of waste gases, it results that blast-furnace gas stream volume has the strongest impact on their values. Economic analysis has shown that as the share of that gas in chemical energy of fuels burnt in heat and power plant increases the finance effect decreases. Thus, increasing a share of this gas the heat and power plant should aim at limiting its price. Converter gas and coke gas have no significant impact on value of target function.

This article presents a different approach to assess the effectiveness of energy industrial processes than the proposed in [1, 4]. Its advantage is the use of monetary units in the conducted analyzes. This allows the direct use of the obtained results in practice.

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