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Vacuum boilers developed heating surfaces technic and economic efficiency evaluation

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Abstract. The vacuum boilers as manufacturing proto types application analysis was carried out, the possible directions for the heating surfaces development are identified with a view to improving the energy efficiency. Economic characteristics to evaluate the vacuum boilers application efficiency (Net Discounted Income (NDI), Internal Rate of Return (IRR), Profitability Index (PI) and Payback Period) are represented. The given type boilers application technic and economic efficiency criteria were established. NDI changing curves depending on the finning coefficient and operating pressure were obtained as a result of the conducted calculation studies.

1. Introduction
As part of Russia’s Energy Strategy implementation for the period until 2020, there is a need for the energy-saving technologies development and high efficiency equipment manufacturing in order to reduce the unit production costs and energy resources usage.
The application of the vacuum fire tube boiler with the developed heat exchange surfaces in a volume including the vacuum heat carrier as a manufacturing prototype for the independent heat supply systems is a heat power engineering development promising area.
The chosen method of the fire tube boiler operation efficiency improvement by means of the heat exchange intensification at boiling and condensing in vacuum by using the finning is not well known, there is no published information on the practical application. It demonstrates the relevance of the scientific research chosen direction.

2. The Problem Statement
One of the main principles of the investment projects efficiency evaluation requires the comparison of the related to the project results and costs throughout its duration.
The project is considered to be effective if the return of the original investments and required return are provided for the investors furnished the capital [1].
The decisions on the investment project implementation expediency, on choosing the optimal investment alternative cannot be adopted intuitively. For minimizing risks of malinvestment, the following complex of key evaluation parameters discussed below is applied:

- Net Discounted Income (NDI)
- Internal Rate of Return (IRR),
- Profitability Index (PI),
- Payback Period.
3. Theory
The main investment project efficiency parameter is the net discounted income. The net discounted income (integral effect, net present value) is the accumulated discounted income over the whole accounting period is defined according to the following formula:

\[ \text{NDI} = \sum_{t=0}^{T}(R_t - Ex_t)\alpha_t - I \]

where NDI is the net discounted income, 
\( R_t \) is the annual revenue from heat energy sales, 
\( Ex_t \) is the costs of goods sold 
\( I \) is the investments, 
\( \alpha_t \) is the discount coefficient defined by the formula:

\[ \alpha_t = (1 + E)^{-t}, \]

where \( E \) is the discount rate.
The investment project is effective if the net discounted income is not negative (NDI \( \geq 0 \)), i.e. if the discounted income value (at the defined discount rate value) is not less than the discounted costs value, it is reasonable to prefer the investment project with NDI maximum values [1-3].
The internal rate of return (IRR) is the discount rate (E) value at which the net discounted income equals zero. Therefore, IRR is often referred to as a verification discount as it makes possible to define the discount rate boundary value dividing the investments into acceptable and unprofitable. If the discount rate \( E \) is positive and less than IRR, then the project is effective. If the discount rate \( E \) is greater than IRR, then the project is in effective. The comparison of IRR with the discount rate makes possible to evaluate the project safety margin. A great difference between these values testifies the project sustainability.
The best project is selected upon NDI criterion and the resolution on participation in such a project is made on the basis of IRR.
The profitability index is the accumulated discounted inflow and real money outflow ratio. The profitability index is calculated by the formula:

\[ \text{PI} = \frac{\sum_{t=0}^{T}(R_t - Ex_t)\alpha_t}{I} \]

One of the advantages of this parameter is the possibility of using as a project static stability. The higher the profitability index, the significantly greater the project safety margin. The profitability index is associated with the net discounted income, if the net discounted income is positive (NDI>0), then \( \text{PI}>1 \), the project is effective. For unprofitable projects, NDI<0, then the profitability index is less than 1 (\( \text{PI}<1 \)) [3, 4].
The payback period is the duration of the shortest period after which the net discounted income becomes positive and subsequently remains non-negative.

\[ \sum_{t=0}^{T_{pp}}K_t/(1+E)^t \leq \sum_{t=0}^{T_{pp}}(R_t - C_t)/(1+E)^t, \]

where \( T_{pp} \) is the payback period parameter for the branch. 
Taking into account the above, it is possible to conclude that the efficiency parameters shared use optimality conditions are required to be fulfilled for the maximum economic efficiency of investment projects.
In this regard, in the first stage, it is necessary to calculate the costs emerged during the project implementation.
The annual costs are defined by the formula:

\[ C_a = C_f + C_{ee} + C_w + C_d + C_m + C_{wg} + C_s \]

Where \( C_f \) are the fuel costs, \( C_{ee} \) are the electric energy costs, \( C_w \) are the water costs, \( C_d \) are the depreciation costs, \( C_m \) are the equipment maintenance costs, \( C_{wg} \) are the wage costs, \( C_s \) are the social needs costs.
The annual fuel costs:

\[ C_f = B \cdot P_{\text{gas}} \]

Where \( P_{\text{gas}} \) is the gas price, \( B \) is the fire tube boiler fuel consumption.

For the annual electric energy costs defining it is necessary to calculate the annual energy consumption by the formula:

\[ N_{\text{annual}} = \sum N_{\text{con}} \cdot n \cdot h_{\text{max}}, \]

where \( N_{\text{con}} \) is the fire tube boiler capacity, \( n \) is the number of consumers, pcs – 1 ea, \( h_{\text{max}} \) is the number of active load claimed maximum using hours.

The annual electric energy costs:

\[ C_{ee} = N_{\text{annual}} \cdot T_e, \]

where \( T_e \) is the electricity tariff (according to the enterprise’s data).

The annual water costs:

\[ C_w = G_w^b \cdot P_w \]

where \( G_w^b \) is the fire tube boiler annual water consumption, \( P_w \) is the chemically purified water price.

The annual depreciation costs:

\[ C_d = \alpha_d \cdot I \]

where \( \alpha_d \) is the depreciation deductions rate for the stationary hot water boiler.

The annual maintenance costs:

\[ C_m = \alpha_m \cdot I_a \]

where \( \alpha_m \) is the maintenance deductions rate.

The annual wage costs:

\[ C_{wg} = \left( \sum c_{wg}^p n_p + W_{wg}^e n_e \right) \]

Where \( n \) is the number of operating personnel, persons.

The annual social needs costs:

\[ C_s = \alpha_s \cdot C_{wg} \]

where \( \alpha_s \) is the social needs deductions rate.

The production cost of heat energy generated by the boiler room is calculated by the formula:

\[ S = \frac{C_d}{Q_d^b} \]

where \( Q_d^b \) is the annual heat generation by the boiler room.

The project profit is formed by the fact that fire tube boiler modernization will make possible to reduce gas consumption and water treatment costs:

\[ PP = C_{fb} - C_{d,a,r} - C_w. \]

The net discounted income (NDI), profitability index (PI) and investments payback period is calculated according to the formula as the integral efficiency parameters:

\[ n = \frac{1}{NP} \leq T_s \]

4. Experiment results

The cost of the acquired and upgraded equipment, installation work is represented in tables 1 and 2:
Table 1. The fire tube boiler modernizing capital costs estimate.

| The name of the acquire dequipment, construction and installation works | No. | The cost per item, RUB | The total cost, RUB |
|---|---|---|---|
| Fire tube boiler having the capacity of 500 kW | 1 | 382600 | 382600 |
| Equipment costs for the fire tube boiler furnace modernization | 1 | 133910 | 133910 |
| Installation work cost | | | 46870 |
| Total estimated cost(I) | | | 563380 |

Table 2. The fire tube boiler operating costs.

| The parameter name | UM | The parameter value |
|---|---|---|
| The installed capacity | kW | 400 |
| The construction project investments | RUB | 563380 |
| The heat energy generation full costs, including: | Rubles per year | 2286550 |
| Fuel costs | Rubles per year | 1897345 |
| Electric energy costs | Rubles per year | 4112 |
| Water costs | Rubles per year | 236856 |
| Maintenance costs | Rubles per year | 901 |
| Labor costs | Rubles per year | 96000 |
| Social needs deductions | Rubles per year | 28800 |
| Heat energy production unit cost | RUB/GJ | 115 |

\[ P_{gas} = \text{RUB}5000 \text{ thousand per 1000 m}^{3}\text{ofgas}, \text{VAT} \text{included}; C_{ee} = 3.56 \text{ RUB/kW h} \text{is the electricity tariff (according to the enterprise’s data)}; P_{w} = 27.15 \text{ RUB/m}^{3} \text{is the chemically purified water price; } \alpha_d = 4 \% \text{ is the depreciation deductions rate for the stationary hot water boiler; } \alpha_m = 4 \% \text{ is the maintenance deductions rate; } \alpha_s = 30 \% \text{ is the social needs deductions rate.} \]

5. Results discussion
The net discounted income (NDI) graph of the boiler modernization possible variations at the different finning coefficients (Ψ) in the pressure range from 60.80 to 101.33 kPa is represented in figure 1.
Figure 1. The net discounted income of the boiler modernization possible variations.

The nature of the NDI change is complicated and consequently a large scale optimization is required. Integral efficiency parameters calculations made possible to determine boiler operation areas not only technologically, but also economically profitable. Figure 2 shows three-dimensional graphical dependence of the net discounted income on the finning coefficient and boiler operating pressure.

Figure 2. The net discounted income dependence on the finning coefficient and saturated vapors pressure.

6. Conclusions
Analyzing the received data it is possible to define the optimization parameters rational values at which the maximum technical and economic effect can be achieved. The highest NDI is observed at the saturated vapors pressure of $p = 60.80 \text{ kPa}$, finning coefficient of $\Psi = 3.66$ and is defined by the graphical method.

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