The beneficial using the heat of the exhaust gases of the furnaces of the technological unit for the ethylene oxide production

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Abstract. The solution to the issues of increasing energy efficiency and optimizing the work of enterprises in the petrochemical industry is due to the constant increase in prices for primary energy resources. In this article, the technological site for the production of ethylene oxide, which is characterized by high energy intensity, is considered as an object of study. The largest consumer of energy in this area are technologically furnaces. In the framework of the study, an analysis of the operation of the furnaces was carried out, a balance of the heat-technological flows of the site was compiled, the potential for energy conservation in the utilization of the exhaust gases of the process furnaces was calculated, and the possibility of the beneficial use of the obtained heat was calculated. The economic efficiency and payback period of the proposed method of utilization of flue gases is determined.

1. Introduction
Modern competitive market conditions motivate industrial facilities to change approaches to the use of energy resources in technological processes. The petrochemical industry is one of the major consumers of energy resources. One of the promising directions of energy saving policy at the petrochemical plants is the development of energy technological combination methods, allowing to reduce the consumption of fuel and energy resources without significant change of the entire processing line and to provide the specified indicators of output product [1-3]. Considering that the enterprises of basic organic synthesis is one of the leading ones in terms of production volumes in the petrochemical industry, the production of ethylene oxide is considered as the object of research. Ethylene oxide and its derivatives are the largest petrochemical synthesis products [4-9]. The working purpose is to increase the efficiency of this production.
2. Methods
Consumers of fuel gas of the process section are furnaces H-1, H-2, H-3. Data on operating parameters of furnaces H-1, H-2 are given in table 1.

Table 1. Technical and operational data of furnaces H-1, H-2.

| №  | Parameter name                          | Furnace H-1            | Furnace H-2            |
|----|----------------------------------------|------------------------|------------------------|
| 1  | Heat generated by burning               | 4.0 Gcal/h             | 5.65 Gcal/h            |
|    | Product temperature:                   |                        |                        |
| 2  | - at the input to the furnace          | 177 °C                 | 209 °C                 |
|    | - at the output of the furnace         | 385 °C                 | 380 °C                 |
| 3  | Stack gas temperature at the output of the furnace | 345 °C | 365 °C |
| 4  | Heat coming out of the furnace with the product | 2.85 Gcal | 3.62 Gcal |
| 5  | Heat leaving with stack gases          | 0.95 Gcal/h            | 1.75 Gcal/h            |
| 6  | Heat loss through furnace envelope and thermal insulation of gas pipes | 0.2 Gcal/h | 0.28 Gcal/h |

All expenditure data of the balance scheme (figure 1) are accepted according to the process regulations of furnace operation.

Calculation of the amount of heat produced in furnaces by burning fuel is made taking into account the chemical composition of fuel gas corresponding to the calorie coefficient of 1.814. Heat losses to the environment are taken equal to 5%.

The heat coming out of the furnace with combustion products is calculated on the composition and volume of contact gases and vapor RES (renewable energy resources) [10].

![Figure 1: Balance scheme of work of furnaces H-1, H-2: 1 is supply line of fuel gas from a shared network; 2 is supply of fuel gas to the furnace H-1; 3 is supply line of fuel gas to the furnace H-2; 4 is supply line of compressed air from the air compressor K-1; 5 is supply line of contact gas; 6 is discharge line of furnace air mixture to afterburning reactor R-1; 7,11 are discharge lines of flue gas from furnaces in atmosphere; 8 is supply line of water steam from the boiler-utilizer B-4; 9 is discharge line of the overheated water steam to the steam turbine K-12; 10 is supply line of the water steam from the shared network.]

The average caloric value of fuel \( Q_p \) can be determined by the following formula:

\[
Q_p = \left( q_T \cdot G_{ok.et} \cdot Q_{y.t} \right) / GT_1
\]
where \( G_{\text{et},i} \) that is equal to 4800 tons per month (6670 t/h) is ethylene oxide production; \( G_{T1} \) that equals 760 kg/h is fuel consumption for ethylene oxide production; \( q_1 \) that is equal to 206.85 kgce/ton of ethylene oxide is specific fuel consumption per ton of ethylene oxide; \( Q_{3,1} \) that equals 7000 kcal/kg is the amount of heat released during burning 1 kgce.

### 3. Results

It is proposed to use heat of stack gases to obtain 2.16 t/h steam with pressure that is possible to use in heat point [11-13].

Calculation of the theoretically required amount of air for the combustion of 1 m³ fuel, taking into account the composition of the fuel gas, is carried out according to the expression:

\[
V_0 = 0.01 \cdot (2.38 \cdot 24.23 + 9.52 \cdot 73.77 + 16.66 \cdot 0.01 + 14.28 \cdot 1.42 + 23.80 \cdot 0.05 + 21.42 \cdot 0.5) = 7.92 \text{ m}^3/\text{m}^3 \text{ of fuel or 17.86 kg of air/kg of fuel.}
\]

The number of combustion products, \( \text{CO}_2, \text{H}_2\text{O}, \text{N}_2 \) is calculated:

\[
V_{\text{CO}_2} = 0.01 \cdot (1 \cdot \text{CH}_4 + 2 \cdot \text{C}_2\text{H}_6 + 2 \cdot \text{C}_2\text{H}_4 + 3 \cdot \text{C}_3\text{H}_6 + 3 \cdot \text{C}_4\text{H}_6) = 0.01 \cdot (1 \cdot 73.77 + 2 \cdot 0.01 + 2 \cdot 1.42 + 3 \cdot 0.05 + 3 \cdot 0.5) = 0.78 \text{ m}^3/\text{m}^3 \text{ of fuel or fuel or 17.86 kg of air/kg of fuel.}
\]

\[
V_{\text{N}_2} = 0.01 \cdot (1.8 \cdot \text{H}_2 + 7.52 \cdot \text{CH}_4 + 13.16 \cdot \text{C}_2\text{H}_6 + 11.28 \cdot \text{C}_2\text{H}_4 + 18.8 \cdot \text{C}_3\text{H}_6 + 16.92 \cdot \text{C}_4\text{H}_6) = 0.01 \cdot (1.8 \cdot 24.23 + 7.52 \cdot 73.77 + 13.16 \cdot 0.01 + 11.28 \cdot 1.42 + 18.8 \cdot 0.05 + 16.92 \cdot 0.5) = 6.24 \text{ m}^3 \text{ of N}_2\text{kg} \text{ of fuel or 13.6 kg of N}_2\text{kg} \text{ of fuel.}
\]

\[
V_{\text{H}_2\text{O}} = 0.01 \cdot (1 \cdot \text{H}_2 + 2 \cdot \text{CH}_4 + 3 \cdot \text{C}_2\text{H}_6 + 2 \cdot \text{C}_2\text{H}_4 + 4 \cdot \text{C}_3\text{H}_6 + 3 \cdot \text{C}_4\text{H}_6) = 0.01 \cdot (1 \cdot 24.23 + 2 \cdot 73.77 + 3 \cdot 0.01 + 2 \cdot 1.42 + 4 \cdot 0.05 + 3 \cdot 0.5) = 1.76 \text{ m}^3 \text{ of } \text{H}_2\text{O/m}^3 \text{ of fuel or 2.36 kg of H}_2\text{O/kg of fuel.}
\]

\( V_{\text{stack gases}} \) is 8.78 m³ of stack gas/m³ of fuel or 18.66 kg of stack gas/kg of fuel.

Stack gas consumption \( G_{SG} \) per 1 kg of fuel with excess air coefficient \( \alpha = 1.0 \) is 18.66 kg of stack gas/kg of fuel.

Taking the excess air coefficient for furnaces \( \alpha = 1.2 \), the values are changed:

\[
V_{\text{stack gases}} = 10.36 \text{ m}^3 \text{ of stack gas/m}^3 \text{ of fuel}
\]

\( G_{SG} = 22.26 \text{ kg of stack gas/kg of fuel.} \)

\( G = G_0 \cdot G_{SG} = 16918 \text{ kg/h} \)

where \( G_0 \) that equals 760 kg/h is total fuel consumption at the furnaces H-1 and H-2.

\( G_{SG} \) that is equal to 22.26 kg is stack gas consumption per 1 kg of fuel.

To determine the potential of heat utilization, it is taken the temperature of the exhaust gases equal to 150°C (it is limit value to which the stack gases can be cooled from sulfuric acid corrosion conditions [14,15]), then:

\[
Q_{dp} = G \cdot (c_{150} \cdot t_{150} - c_{150} \cdot t_{150}) = 0.974 \text{ Gcal/h}
\]

where \( G = 16918 \text{ kg/h} \) is stack gas flow rate; \( c_{150} = 0.285 \text{ kcal/kg·°C} \) is stack gas heat capacity at 350 °C; \( c_{150} = 0.285 \text{ kcal/kg·°C} \) is stack gas heat capacity at 350 °C.

The amount of generated steam \( G_{steam} \) is calculated by the following formula:

\[
G_{steam} = (Q_{d,p} / (i_1 - i_2)) \cdot \eta_{bu} = 1556 \text{ kg/h,}
\]

where \( \eta = 0.9 \) is an efficiency of the boiler-utilizer; \( i_1 = 663 \text{ kcal/kg} \) is steam enthalpy at \( P = 10 \text{ kgf/cm}^2 \); \( i_2 = 99.8 \text{ kcal/kg} \) is enthalpy of feed water at \( t = 98 \text{ °C} \).

Annual savings of thermal energy is:

\[
Q = Q_{bu} \cdot T = 0.974 \cdot 8040 = 7831 \text{ Gcal/year or 17409.8 tons/year}
\]

where \( T \) that is 8040 h is the operating time of the equipment per year.
Annual economic effect of implementation:
\[ \Delta C = 7831 \cdot (460 - 110) = 2740.85 \text{ thousand rubles /year} \]
where 460 rub./Gcal and 120 rub./Gcal are cost of steam 13 from the external heat source and steam secondary energy.

Estimated costs for equipment and construction and construction and installation works is 12.6 million rubles. Thus, the payback period of the event is:
\[ T = \frac{12\ 600}{2740.85} = 4.6 \text{ years} \]

4. Discussion
The technical and economic analysis of the efficiency of the proposed event showed that technological steam with total energy potential of 7831 Gcal/year is produced as a result of the boiler-utilizer operation.

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