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Research Article

EMISSION AND TRENDS IN RECLAIMING WASTE HEAT IN INDUSTRIAL INSTALATIONS

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ABSTRACT

The article presents the analysis of waste heat emission in a typical industrial installation. On the basis of the process monitoring system, periodic analyses of fumes composition, installation process manual and the conducted measurements of the heat fluxes from individual sources emitting heat on the way of natural convection from the devices' coats and forced convection in the fumes flux were calculated. According to the authors the heat of temperature 140–155 °C and surface power density 860–970 W/m^2 emitted by devices' covers can be reclaimed in ORC techniques, Peltier's modules and the systems realising Stirling cycle. Part of the waste heat included in fumes, which makes c.a. 76% of the total emission from the installation, should be returned to the process of fuel oxidation, what will reduce the emission by c.a. 18% and the volume of consumed fuel by c.a. 25 m^3 CH_4/h, according to the presented calculations.

Keywords: heat emission, waste heat, heat waste reclaim, distributed generation.

INTRODUCTION

The depletion of energetic resources as well as increasing prices of emission allowances generate high interest of industrial actors in the methods of reducing the energy consumption of fuel oxidation, heat and greenhouse gases emission to the atmosphere. Moreover, increased energy efficiency of industrial processes is one of the key factors influencing energy security and stimulating the development of economy [2].

Heat emission to atmosphere is realised by means of natural and forced convection, infrared radiation of machines and appliances, heat emission from hidden phase transitions of materials in the processes of transportation and storage and also results from incomplete combustion and chimney heat losses [1].

Classifying waste heat, one must take not only its amount and heat dispersion but also its quality into consideration. One of qualitative criteria is the temperature of the heat, including high-, medium- and low temperature heat. High temperature heat at the temperature over 500 °C is related to metallurgical processes, fuel conversion, oxidation and pyrolysis, radiation, gas and electric heating.

Medium temperature heat in the range between 150 °C and 500 °C is most frequently encountered in fumes, whereas, low temperature heat under 150 °C in liquids, waste gases from technological processes and in materials, resources and products [5]. It is estimated that waste heat from vehicles, air conditioning and industrial systems cooling circulating water constitute 78% of anthropogenic emission, whereas the rest comes from technological processes [1].

The aim of the work is to analyse the emission of waste heat from industrial installation of methane conversion including low-temperature sources and to indicate the trends of managing heat fluxes of the highest energetic potency.

The characteristics of installation as a source of heat emission

The installation of methane conversion is a part of the system for preparing synthetic gas in nitrogen processing plant. In the installation there are processes of heating materials such as steam, methane, oxygen and air, processes of methane semi-combustion, endothermic conversion of carbohydrates with steam in the presence of nickel catalyst and non-diaphragm cooling of the products with the extraction of water steam [3]. Figure 1 presents a general scheme of the installation.

As a result of oxidation of the mixture of combustible methane, waste and return gases the steam and technological methane are heated to the temperature 540–550 °C. In heater 2 the process of heating the air enriched with oxygen to the temperature 420–460 °C is realised with the use of heat from oxidation of fuel methane. In cracking reactor Kr the process of catalytic conversion of methane with water steam is conducted, whereas in the injection chamber the process of non-diaphragm cooling of the products with the extraction of water steam at 2.9 MPa is realised. The sources of waste heat in the analysed installation include:

- heater 1 with the mixture of methane with water steam,
- heater 2 with the mixture of oxygen and air
- cracking reactor
- injection chamber of the non-diaphragm cooler.

The emission of heat from installation elements is realised mainly in the natural convection from the device covers and the walls of exhaust stacks and forced convection with the fumes of heaters 1 and 2. Table 1 presents the basic construction data of heat emitters in the analysed installation.

HEAT EMISSION IN NATURAL CONVECTION

The analysis of heat emission in natural convection was conducted on the basis of the measurements and meteorological data from the period between May 2009 and April 2010. The temperatures of coats and exhaust stacks of heaters, cracking reactor and injection chamber were measured. The amount of waste energy calculated with Péclet's equation for the thermal diffusivity coefficient α calculated from the criteria equation of natural convection.

$$Nu = C \cdot (Gr \cdot Pr)^n$$

$$Q' = \alpha \cdot \Delta t \cdot F$$

where: Nu – Nusselt's number, $Nu = \alpha{\cdot}l/\lambda$; Gr – Grashof's number; Pr – Prandtl's number; C – for vertical pipes and walls, $C = 0{,}13$; n – for vertical pipes and walls $n = 0{,}33$; Q' – heat flux [W]; α – thermal diffusivity coefficient [$W/m^2{\cdot}K$]; λ – thermal diffusivity coefficient of the surrounding air [$W/m{\cdot}K$]; l – characteristic measurement [m]; Δt – temperature difference between the wall and surrounding [K]; F – heat emitting surface [m^2];

Figure 2 presents a diagram of the distribution of heat in natural convection from individual

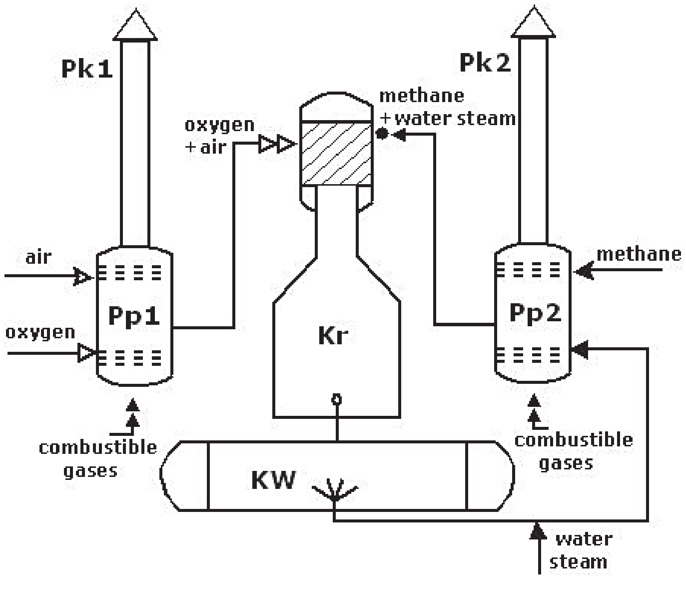

Fig. 1. General scheme of methane conversion installation: Pp1 – heater jacket 1, Pp2 – heater jacket 2, Pk1 – heater exhaust stack 1, Pk2 – heater exhaust stack 2, KW – injection chamber, Kr – cracking reactor

Table 1. Selected construction parameters of heat emitters

Item	Name of emitter	Height of exhaust stack [m]	Exhaust stack diameter [m]	Outer surface of the exhaust stack [m²]	External jacket surface [m²]
1.	Heater 1	7.9	1.5	37	179
2.	Heater 2	15.8	0.9	45	68
3.	Cracking reactor	–	–	–	262
4.	Injection chamber	–	–	–	70

heat emitters in the analysed installation in the period from May 2009 to April 2010.

The coat of cracking reactor was the source of the highest heat emission in natural convection. Its maximum heat flux equal to 296.8 KW was recorded in January at average coat temperature 155 °C and average monthly temperature of the surrounding -8 °C. The lowest amounts of heat were emitted by exhaust stack walls, 7.8 kW and 15.3 kW respectively, on 1st and 2nd July 2009, when average temperature of the surrounding was19 °C. Average values of heat flux from the heater coats 1 and 2 in the analysed period were 39.6 kW and 43.4 kW respectively, from heater exhaust stacks: 7.8 kW and 15.3 kW on average. The cracking reactor emitted 254.5 kW of heat, whereas the injection chamber emitted on 60.1 kW on average at average coat temperature 140 °C. Considering the average values of the emitted heat flux in the examined period, Pareto-Lorentz analysis was conducted. Its results are presented in Figure 3.

Cumulative average heat flux in natural convection in all the installation components was 420.6 kW. Cumulative average heat flux emitted to the surrounding from the injection chamber and the cracking reactor was 314.5 kW, what made 74.8% of the average emission from all the elements.

EMISSION OF HEAT IN THE FUMES

In order to analyse the emission of the heat from installation fumes the authors used theoretical data of components and voluminal fluxes of fumes available in the installation process manual, real amounts of major fumes' components, i.e. CO_2, N_2, O_2 samples from the periodic fume analyses and mean temperatures of fumes in heater 1

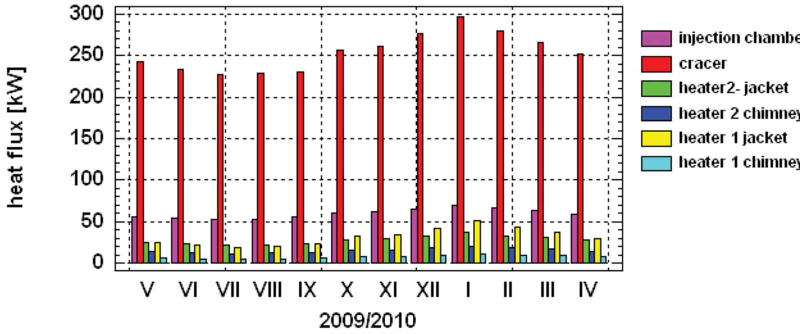

Fig. 2. Diagram of heat emission on the way natural convection in the analysed period

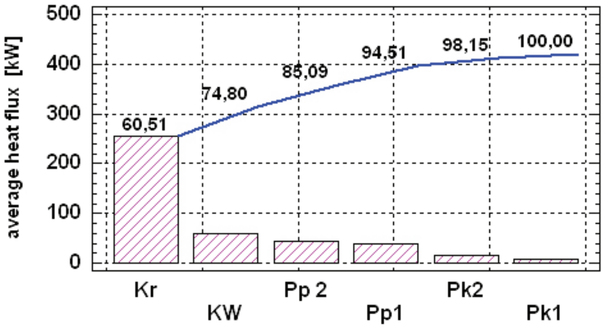

Fig. 3. Pareto histogram and Lorentz's curve for the analysed case

and 2 exhaust stacks, obtained from the installation monitoring system.

The amounts of waste energy in fumes were calculated from the following correlations:

$$Q'_{sp} = \dot{m}_{CO2} \cdot I_{CO2} + \dot{m}_{N2} \cdot I_{N2} + \dot{m}_{O2} \cdot I_{O2}$$

where: Q'_{sp} – heat flux [kW]; $\dot{m}$ – mass flux of a given fume's component [kg/s]; I – enthalpy of a given component at given temperature [kJ/kg].

The data used for calculations and the obtained results for the assumed 95% load of the installation and mean fume temperatures for heater 1 and 2 of 238 °C and 312 °C respectively were presented in table 2.

On the basis of the calculations, the authors stated that in the analysed period the waste heat flux emitted with the fumes of heaters 1 and 2 was 1308.3 kW, with heater 1 emitting 906.7 kW, and heater 2 – 401.6 kW. Comparing the emission of the heat from walls and exhaust stacks with the amount of heat emitted with the fumes it was concluded that c.a. 6.3% of the total heat emission from the heaters comes from coats and exhaust stacks' walls, and 93.7% is emitted with fumes. Heat emission in natural convection manner from all the elements of the installation was c.a. 24% of the total heat emission, the rest was the heat of fumes.

TRENDS IN RECLAIMING HEAT FLUX OF THE HIGHEST ENERGETIC POTENTIAL

The sources of waste heat in the analysed installation that have high energetic potential are the coats of cracking reactor and injection chamber emitting heat by means of natural convection and the fume streams from exhaust stacks from heater 1 and 2.

Average surface heat flux densities from the coats of cracking reactor and injection chambers are 970 W/m^2 and 860 W/m^2 respectively for mean coats' surface temperatures of 155 °C and 140 °C. The graphs of both surface power density and temperature correspond to the ranges of modern intercepting, processing and storing devices such as Stirling engines, ORC modules, Peltier's modules, heat pipe accumulators or heat pumps.

The above-mentioned techniques are more and more commonly used in distributed generation, e.g. solar or geothermal energy, yet only few examples of their use can be found in industrial installations [1, 5]. According to the authors, there is a need to undertake research and development works on the implementation of the technologies in distributed generation of heat waste energy emitted by the devices in industrial installations by means of radiation and natural convection.

The largest flux of heat energy of c.a. 1310 kW is emitted from the analysed installation to the atmosphere with the fumes from heaters 1 and 2. According to the authors, part of this heat should be returned to the process of fuel mixture oxidation by heating the air for the burners. For this purpose a highly efficient "heat pipe" recuperator. Along with ecological effect, this solution will bring savings in fuel amounts used for heating the fuel mixture up to the temperature necessary for ignition. Due to the presence of sulphur in the fuel the temperature of fumes can be reduced only to the level at which the included water steam does not condense.

The energetic effect of the proposed method was estimated under the assumption of the fumes' temperature of 120 °C and stechiometric masses of CO_2 i H_2O in fumes from the fuel composed according to installation process manual according to the following formula:

$$Q'_{r} = \dot{m}_{co2} \cdot (I_{1\,CO2} - I_{2CO2}) + \dot{m}_{H2O} \cdot (I_{1H2O} - I_{2H2O})$$

where: Q'_r – heat flux [kJ/s]; I_1 – enthalpy of CO_2 or H_2O at 238 °C (heater 1) or 312 °C (heater 2) [kJ/kg]; I_2 – enthalpy of CO_2 or H_2O at 120 °C [kJ/kg]; $\dot{m}$ – mass flow of CO_2 or H_2O in the stream of fumes [kg/s].

Table 2. The data and results of calculations of heat flux in heater 1 and 2

Item	Fume component	Component enthalpy [kJ/kg]		Mass intensity of flow [kg/s]		Heat from the fume components [kW]	
		Heater 1 $T_{śr}$ = 238 °C	Heater 2 $T_{śr}$ = 312 °C	Heater 1 $T_{śr}$ = 238 °C	Heater 2 $T_{śr}$ = 312 °C	Heater 1 $T_{śr}$ = 238 °C	Heater 2 $T_{śr}$ = 312 °C
1.	CO_2	223.1	295.5	0.73	0.19	162.9	56.1
2.	N_2	251.1	325.1	2.8	1.03	703.1	334.9
3.	O_2	226.2	259.1	0.18	0.041	40.7	10.6
Total [kW]						906.7	401.6

Table 3. Estimated effects of returning part of fumes' heat to the process

Item	Emitter	Energetic effect	
		Heat flux [kW]	Equivalent flux of fuel methane [m^3/h]
1.	Heater 1	135,0	13,8
2.	Heater 2	109,6	11,2

Energetic effect was also expressed with the volumetric stream of the saved fuel methane assuming its energetic value equal to 35 MJ/m^3. the obtained results were presented in Table 3.

SUMMARY

The installation of methane conversion analysed in terms of waste heat emission is a typical example of industrial installation, with the sources emitting heat mainly by means of natural and forced convection. The conducted analysis based on the data from the installation manual, direct measurements of temperatures, results of periodic analyses of fumes and monitoring process parameters generated the following conclusions:

1. The sources of heat emission in the installation are the isolated surfaces of the heaters, cracking reactor and injection chambers of non-diaphragm condenser, non-isolated exhaust stack walls and the fumes from fuel gases. The installation emits c.a. 1730 kW of heat energy, including c.a. 24% of natural convection energy and c.a. 76% forced convection in fumes.
2. The highest share of natural emission comes from the coats of cracking reactor (60.51%) and injection chamber (14.29%). According to the authors, due to surface heat flux densities from above mentioned elements reaching 970 W/m^2 and 860 W/m^2 at temperatures of 155 °C and 140 °C, one should consider the possibility to utilise the lost heat by using the techniques of intercepting and utilising heat, known and tested in distributed generation based on the systems using Stirling engines (efficiency up to 30%), ORC modules (efficiency 40–60%), Peltier's modules (efficiency 10–15%) or hear pipe accumulators.
3. Together with the fumes from heaters a heat flux of c.a. 1310 kW is emitted to the atmosphere. Simultaneously, it was stated that due to relatively high temperatures of fumes reaching 238 °C and 312 °C it is possible to limit the emission. According to the authors, the use of recuperation techniques in gas-gas system with the use of "heat-pipe" exchanger to retrieve part of heat from fumes and heat the air provided for burners of fuel gases is going to limit the heat emission and fuel consumption. The conducted calculations suggest that in case of lowering the heat temperatures to 120 °C, the emission will be limited to c.a. 18% and the savings in fuel gas will reach c.a. 25 Nm^3CH_4/h.

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