Flue gas moisture capacity calculation at the outlet of the condensation heat recovery unit

Nikolay Galashov[1,*], *Svyatoslav* Tsibulskiy[1], *Denis* Mel'nikov[1], *Alexandr* Kiselev[1], and *Al'bina* Gabdullina[1]

[1]National Research Tomsk Polytechnic University, 634050 Tomsk, Russia

Abstract. As a result, study equation has been obtained which determine the flue gas moisture capacity at the outlet of the condensation heat recovery unit with an error of less than 1%. It possible to at the temperature of the flue gas below the dew point and the known air-fuel ratio efficient. The equation can be used to calculate plants operating on products of gas combustion without Use of tables and programs for calculating the water-vapor saturation pressure.

1 Introduction

The ways to increase gas turbine unit's efficiency are an application of the condensation heat recovery unit (CHE) [1-5]. The condensation heat recovery unit is applied in regions with low air temperature, where air can be used to cool flue gas more efficiency [6]. If the CHE is applied in installations operating on the Rankine Organic Cycle [7-9], the efficiency will be increased due to using the outlet of flue gas. At the same time, by decrease the flue gas temperature and application the heat of condensation of moisture from them, increase of the boiler efficiency can by 10-15%. The most effective is application of CHE in gas burning units because condensed water liberated from flue gas almost does not contain harmful substances except dissolved CO_2 and O_2, which can be easily deaerated. Therefore, the condensate can be useful for both the installation itself and for other purposes.

2 Moisture capacity calculation at the input and output of the CHE

To determine the flue gas moisture content at the input and output of the installation is necessary for calculating CHE. Considering that moisture content determination by calculation is very time-consuming, Seminuk's equations are used for estimative computation of natural gas combustion [8]. It is assumed that at the entrance to the CHE, water vapor in gases has a temperature above the dew point, and at the outlet it is lower. The moisture content is determined in *kg* or *g* of moisture ratiu to 1 *kg* of dry gases.

The moisture content at entrance to the CHE was calculated from the equation

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[*] Corresponding author : gal@tpu.ru

$$d_n = (0.13 - d_{nv} \, \alpha_{yx})/(\alpha_{fg} - 0.058), \tag{1}$$

where α_{fg} is the air-fuel ratio in the flue gas; d_{nv} - the air moisture content before burning, kg / kg (cg).

The moisture content at flue gas to the CHE when it is cooled below the dew point was calculated from the equation

$$d_{fg} = P_{wv} /(P_g - P_{wv}) \, R_{dg} / R_{wv}, \tag{2}$$

where P_g static pressure in the gas boiler pass, P_{wv} - water vapor saturation partial pressure in Pa, is determined by tables [11] on the temperature of flue gas behind the CHE (t_{fg}) ; R_{dg} / R_{wv} is the ratio of the gas constant of dry gases to the gas constant of water vapor, for natural gas depending on α_{fg} was calculated from the equation [8]

$$R_{dg} / R_{wv} = (0.09924 + 0.622\alpha_{fg})/(0.199 + \alpha_{fg}). \tag{3}$$

The values of R_{dg}/R_{wv} are given in Table 1.

Table 1. Dependence of the ratio R_{dg}/R_{wv} to a α_{fg}.

α_{fg}	1	1.5	2	2.5	3	3.5	4
R_{dg} / R_{wv}	0.6015	0.6076	0.6108	0.6129	0.6143	0.6154	0.6162

In table 2 are presented the calculations of d_{fg} according to equation (2) as a function of α_{fg} and t_{fg} at P_g = 100000 Pa.

Table 2. d_{fg} value, g/kg(dry) was calculated from the equation (2).

Parameters		α_{fg}						
		1	1.5	2	2.5	3	3.5	4
t_{fg},°C	10	7.48	7.55	7.60	7.62	7.64	7.65	7.66
	20	14.41	14.55	14.63	14.68	14.71	14.74	14.76
	30	26.68	26.95	27.09	27.18	27.25	27.29	27.33
	40	47.96	48.44	48.70	48.87	48.98	49.06	49.13
	50	84.77	85.62	86.08	86.37	86.57	86.72	86.83
	60	149.87	151.38	152.19	152.71	153.06	153.32	153.52

These equations are derived on the basis of reduced fuel characteristic.

Seminuk [8] has suggested equation for moisture content calculation that does not require saturated vapor pressure determination and is widely-used in scientific literature, kg/kg(dry)

$$d_{fg} = (0.0006382 + 0.004\alpha_{fg})/(0.199 + \alpha_{fg})EXP(0.062t_{fg}). \tag{4}$$

Table 3 shows the results d_{fg} in g/kg(sg) are presented by the equation (4), and table 4 – the ratio error are presented by equation (4) with ratio to (2).

Table 3. d_{fg} value, was calculated from the equation (3).

Parameters		α_{fg}						
		1	1.5	2	2.5	3	3.5	4
t_{fg},°C	10	7.19	7.26	7.30	7.33	7.34	7.36	7.37
	20	13.37	13.50	13.57	13.62	13.65	13.68	13.69
	30	24.85	25.10	25.23	25.32	25.38	25.42	25.45
	40	46.19	46.66	46.91	47.07	47.18	47.26	47.32
	50	85.87	86.73	87.20	87.49	87.70	87.84	87.96
	60	159.63	161.23	162.10	162.65	163.02	163.30	163.51

Table 4. Ratio error value was calculated from the equation (3) ratio to (2), %.

Parameters		α_{fg}						
		1	1.5	2	2.5	3	3.5	4
t_{fg},°C	10	3.86	3.86	3.86	3.86	3.86	3.86	3.86
	20	7.22	7.22	7.22	7.22	7.22	7.22	7.22
	30	6.85	6.85	6.85	6.85	6.85	6.85	6.85
	40	3.69	3.69	3.69	3.69	3.69	3.69	3.69
	50	-1.30	-1.30	-1.30	-1.30	-1.30	-1.30	-1.30
	60	-6.51	-6.51	-6.51	-6.51	-6.51	-6.51	-6.51

Table 4 shows that the ratio error calculation by equation (4) for most points more than 6-7%, so in this research, based on multidimensional approximation of the according table. 2 was receive the equation

$$d_{fg} = (4.287+0.0321\alpha_{fg})\text{EXP}(0.0597t_{fg}). \tag{5}$$

Percentage error of computation using equation (5) relative to data in table 2 does not exceed 5%. However, obvious trend is observed between the difference of calculation according to equations (5) and (2) depending on t_{fg}. This trend was approximated by the third degree polynominal with determination coefficient of 0.9992. The result the equation was obtained.

$$d_{fg} = (4.287+0.0321\alpha_{fg})\text{EXP}(0.0597t_{fg}) + (0.7068–0.208t_{fg}+0.01254t_{fg}^2–0.000175t_{fg}^3) \tag{6}$$

Table 5 show the calculations of d_{fg} by equation (6), and in table. 6 – ratio error of calculation according to equation (6) ratio to (2). The error for all points does not exceed 1%. in calculation by equation (6).

Table 5. d_{fg} the value in g/kg (dry) to (6).

Parameters		α_{fg}						
		1	1.5	2	2.5	3	3.5	4
t_{fg},°C	10	7.55	7.58	7.61	7.64	7.67	7.70	7.73
	20	14.42	14.47	14.52	14.58	14.63	14.68	14.73
	30	26.92	27.02	27.12	27.21	27.31	27.40	27.50
	40	48.29	48.47	48.64	48.82	48.99	49.17	49.34
	50	85.24	85.56	85.88	86.19	86.51	86.83	87.15
	60	150.82	151.40	151.98	152.55	153.13	153.71	154.28

Table 6. Ratio error of calculation by (6) and (2), %.

Parameters		α_{fg}						
		1	1.5	2	2.5	3	3.5	4
t_{fg},°C	10	-0.97	-0.35	-0.20	-0.24	-0.39	-0.60	-0.85
	20	-0.06	0.57	0.74	0.71	0.58	0.39	0.16
	30	-0.92	-0.27	-0.09	-0.11	-0.23	-0.41	-0.63
	40	-0.69	-0.05	0.13	0.10	-0.02	-0.21	-0.44
	50	-0.56	0.07	0.23	0.20	0.07	-0.13	-0.37
	60	-0.63	-0.02	0.14	0.10	-0.04	-0.25	-0.50

3 Conclusion

As a result, study equation has been obtained which determine the flue gas moisture capacity at the outlet of the condensation heat recovery unit with an error of less than 1%. It possible to at the temperature of the flue gas below the dew point and the known air-fuel ratio efficient.

The equation can be used to calculate plants operating on products of gas combustion without Use of tables and programs for calculating the water-vapor saturation pressure.

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