Journal of Thermal Engineering, Vol. 7, No. 2, Special Issue 13, pp. 30-46, February, 2021
Yildiz Technical University Press, Istanbul, Turkey

PREDICTION SULPHURIC ACID AND WATER VAPOUR DEW POINT TEMPERATURES OF FLUE GASES AND COMBUSTION ANALYSIS FOR SOLID FUELS IN TURKEY

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ABSTRACT

In the study, the combustion analysis is examined for the solid fuels in Turkey. The principal aim of the analysis is determined the limits and obstacles in the design heat exchanger to avoid the corrosion risk on the heat exchanger surfaces in the latent heat recovery applications from waste flue gas. To do this, in which regions of the heat exchanger the flue gas temperature reached to the sulphuric acid and water vapour dew point temperatures are required to predict. In order to predict the condensing zone, an air preheater for the coal-fired boiler in a heating system is designed using finite difference method. Designed the air preheater is consists of the counter-cross flow, U-shaped stainless steel tube bundle. The tube is discredited 200 cells to one-dimensional during the flow. The heat transfer rates, the flue gas and air inlet and outlet temperatures, surface temperatures of the tube wall, the mole fractions of water and sulphuric acid vapour, the other non-condensing gases in the flue gas are calculated in each discrete cell. According to the results of the study, while the dew point temperature of the water vapour changes over the range 30-40 °C, the acid dew point temperature waves to 125 °C from 140 °C for the coal types mined in Turkey.

Keywords: *Solid Fuels, Combustion Analysis, Acid Dew Point Temperature, Heat Recovery from Flue Gas, Air Preheater*

INTRODUCTION

The solid fuels contain sulphur, nitrogen and carbon and hydrogen. In the result of fuel combustion in the boiler, the flue gas consists of H_2O, O_2, CO_2, N_2, SO_2 and SO_3. In the heat recovery applications from flue gas, the sulphur dioxide reacts with the water vapour and, sulphuric acid vapour (H_2SO_4) emerges. When water and sulphuric acid vapours in the flue gas are contacted cold surfaces in the heat exchanger, these vapours condense under dew point temperatures. As the condensed solution is further acidic, low-temperature corrosion effects appear on heat exchanger surfaces [1-2]. Thus, predicting the dew point temperatures of the water vapour and sulfuric acid is very important in the design of latent heat recovery units. In the design calculations of the latent heat recovery units for boiler must be examined in detail three important issues. These issues can be classified as the sulphur content of the fuel, excess air ratio and the temperature of the inlet feed water [3].

In the ratio of 1-5%, a small part of SO_2 in flue gas transforms into SO_3. If flue gas temperature is lower than 176 °C, the whole of SO_3 converts into H_2SO_4. Even if the lower existence of 5-50 ppm, the amount of sulphuric acid vapour in flue gas is the most important for acid dew point [1].

When the flue gas temperature is reached their dew points, the condensation of water and sulphuric acid vapour occurs on tube bundles inside the heat exchanger. The dew point of sulphuric acid is higher than water vapour's dew point. Thus, the sulphuric acid vapour in flue gas is firstly condensed. As the flue gas temperature is reduced lower than this point, the condensation of water vapour starts. In the design calculations of the latent heat exchanger, the outside wall temperature of tubes should be calculated each meter length in order to predict the area capable of condensation. If the outside wall temperature of the tube inside the heat exchanger reaches the dew point, the condensation begins there. The condensation causes high speed of corrosion over the exposed area of the heat exchanger tube bundles, which could represent a serious risk of breakdown. For this reason, predicting of dew points is more important for the industrial fields [4]. The waste heat exchanger has played an important role in the industrial process such as chemical, petroleum, medicine and power plants to recover the waste heat from flue gas and save

This paper was recommended for publication in revised form by Regional Editor Ozgen Acikgoz
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Manuscript Received 22 January 2019, Accepted 06 April 2019

fuel and money. The corrosions, emerge on the heat exchanger tubes can be classified as high-temperature corrosion, stress corrosion cracking and dew point corrosion or low-temperature corrosion [5-6].

Han et al. [7] developed a new numerical model to predict the condensation rate of sulphuric acid and condensate acidic solution concentration on the heat exchanger surfaces. According to the results of the study, increasing the flue gas temperature is reduced the corrosion risk by reducing the condensation rate and acid concentration. Vainio et al. [8] conducted a study about low-temperature corrosion in co-combustion of biomass and solid recovered fuels. The cause of low-temperature corrosion was studied in a full-scale boiler firing bank. According to the study, the risk of sulphuric acid dew point corrosion is minimum during combustion of biomass with a low sulphur content (0.3 ppm), and when the moisture concentration in the flue gas was lower (17-18 vol.%.), no corrosion could be observed. Wei et al. [1] studied the theoretical prediction of acid dew point and safe operating temperature of heat exchangers for coal-fired power plants. They examined the impacts of temperature, acid vapour content and water vapour content on the acid solution concentration and condensation rate. As a result of the study, the lowest temperature of the heat exchanger was recommended above 80 °C in the practical application of waste heat recovery in coal-fired boilers considering the low-temperature corrosion. Zarenezhad and Aminian [9] presented a new approach based on using an artificial neural network model to predict the acid dew points. The Levenberg-Marquardt backpropagation algorithm was used for network training. They inferred that the acid dew point is very sensitive to the flue gas SO_3 concentration such that a small increase in SO_3 concentration leads to a significant increase in sulphuric acid dew point at a given H_2O concentration.

Ding et al. [5] analyzed the dew point corrosion on economizer tubes of a waste heat boiler for a company in their study. The necessary of a desulfurizer for the boiler to eliminate the sulphuric acid dew point, monitoring and controlling of sulphur content in flue gas, raising the temperature of flue gas to avoid the dew point corrosion, taking control of the moisture in flue gas and renovating the heavily corroded heat exchanger tubes with 304 stainless steel tubes were recommended the company. Pena and Blanco [4] a new methodology to predict the physical dew point inside an economizer depending on fuel type burned were developed in their study. Only physical dew point (water vapour's dew point) was taken into account. Acid dew point (sulphuric acid vapour's dew point) has not been considered because of natural gas used as fuel. The natural gas has almost undetectable sulphur contents. As a result of the study, the first 3 m of the tube bundle was clearly exposed to fast corrosion because the temperatures in contact with the outside wall of the tube bundle were lower than the dew point temperature calculated there. Besides, as the excess air ratio decreases in the combustion process, the physical dew point temperature increases inside the heat exchanger. Li et al. [10] suggested an updated formula for determining acid dew point temperature of flue gas. The formula was validated with various data obtained the experiments and industrial coal-fired power plants of air and oxy-fuel combustion and also compared to the conventional empirical formulas to confirm its accuracy. In this study, they proved the accuracy much higher than the conventional empirical formula for the air-firing combustion process. Shi et al. [11] conducted the experimental study to investigate the corrosion of the tube heat transfer surface under the ultra-low tube wall temperature circumstance for a waste heat recovery system in the coal-fired boilers. They observed two tuning zones, the first one emerges when the wall temperature is about 32-36 °C lower than the acid dew point, and the second one is about 10 °C higher than the water vapour dew point. Xiang et al. [2] presented the study of the prediction model on the acid dew point temperature in previous studies. By investigating the previous models on the acid dew point prediction, a formula was derived, and a semi-empirical prediction model was proposed in their study.

Blanco and Pena [3] conducted a study about predicting the acid dew point temperature of the baskets on rotating regenerative air pre-heaters by using data obtained in a power plant. In their study, they examined the acid dew point temperature for the two fuel type, called Fuel No: 2 and low sulphur fuel. Experimental values obtained for the power plant was very close to the theoretical values given in this study.

In this study, the combustion analysis is investigated for solid fuels such as various coal and wood types with moist air for different cities in Turkey. For the fuel types, the combustion effects are examined by using different excess air ratio. The dew point temperatures of water vapour (WDT) and sulphuric acid (ADT) are predicted as theoretical for various solid fuels types and the different cities in Turkey. The various factors such as the excess air ratio, relative humidity rate and the altitude of the city affected to the dew point temperatures and the concentration of the water and sulphuric acid vapour in flue gases are studied. In order to predict the condensing, an air pre-heater for the coal-fired boiler is designed using finite difference method. The tube is discredited 200 cells to one-dimensional during the flow. The heat transfer rates, the flue gas and air inlet and outlet temperatures, surface temperatures of the tube wall, the mole fractions of water vapour, sulphuric acid vapour and other non-condensing gases in the flue gas are calculated in each discrete cell.

THEORETICAL ANALYSIS

For combustion analysis of the boilers in the system, the following assumptions are done:

- The mass and energy balances equations at steady state for the material flow in the boiler are obtained with negligible potential and kinetic energy changes.
- The flue gases outside from the boiler are assumed to be ideal gases.
- In the combustion analysis, the reaction of the combustion in the boilers is complete combustion with moist air.

Combustion Analysis of Moist Coal as Fuel in a Boiler

Coal consists of hydrocarbons, sulphur, oxygen, nitrogen, moisture and ash. The stoichiometric combustion reaction of the moist coal with dry air in the boiler's combustor is stated as:

$$C_xH_y\mathrm{O}_z\mathrm{N}_tS_m(\mathrm{H_2O})_n + \mathrm{a}(O_2 + 3.76N_2) \rightarrow xCO_2 + \left(\frac{y}{2} + n\right)H_2O + mSO_2 + \left(\frac{t}{2} + 3.76 \times a\right)N_2 \quad (1)$$

$$a = x + \frac{y}{4} - \frac{n}{2} + m - z \quad (2)$$

$$x = \frac{C\%}{100 \times M_{A-C}} (kmol/kg\ fuel) \quad (3)$$

$$y = \frac{H\%}{100 \times M_{A-H}} (kmol/kg\ fuel) \quad (4)$$

$$z = \frac{O\%}{100 \times M_{A-O}} (kmol/kg\ fuel) \quad (5)$$

$$t = \frac{N\%}{100 \times M_{A-N}} (kmol/kg\ fuel) \quad (6)$$

$$m = \frac{S\%}{100 \times M_{A-S}} (kmol/kg\ fuel) \quad (7)$$

$$n = \frac{(H_2O\%}{100 \times M_{A-H_2O}} \left(\frac{kmol}{kg} fuel\right) \quad (8)$$

In the above formulas, M_A is shown the molecular mass of carbon, hydrogen, nitrogen, oxygen, sulphur and moisture in the coal. The complete combustion reaction with moist air is given as:

$$C_xH_yO_zN_tS_m(H_2O)_n + \lambda a[O_2 + 3.76N_2 + \varepsilon(H_2O)] \rightarrow xCO_2 + \frac{y}{2}H_2O + mSO_2 + \left(\frac{t}{2} + 3.76\lambda a\right)N_2 + \alpha O_2 \quad (9)$$

In Eq. (9), λ is the excess air ratio. As the flue gases (products) are assumed to be ideal gases, ε and α are calculated as [12]:

$$\alpha = \frac{z}{2} + \frac{n}{2} + \lambda.a + \left(\frac{\lambda.a.\varepsilon}{2}\right) - x - \frac{y}{4} - m \quad (10)$$

$$\varepsilon = N_{m,air} = \frac{P_{m,air}}{P_{atm}} \times N_{fg} \quad (11)$$

In Eq. (10) and (11), ε is the mole number of moisture in the air. N_{fg} (the mole number of flue gases) can be calculated the complete combustion reaction in Eq. (9).

$$N_{fg} = x + \frac{y}{2} + m + \left(\frac{t}{2} + 3.76.\lambda.a\right) + \alpha \quad (12)$$

$$P_{total,air} = \phi_{air} \times P_{sat} \quad (13)$$

To find the pressure of the moist air, the relative humidity rate and the saturated pressure at the temperature of the air are required.

Combustion Analysis of Wood as Fuel

Wood consists of hydrocarbons, oxygen, nitrogen, moisture, ash and no sulphur. The complete combustion reaction with moist air is given as:

$$C_xH_yO_zN_t(H_2O)_n + \lambda a[O_2 + 3.76N_2 + \varepsilon(H_2O)] \rightarrow xCO_2 + \frac{y}{2}H_2O + \left(\frac{t}{2} + 3.76\lambda a\right)N_2 + \alpha O_2 \quad (14)$$

$$\alpha = \frac{z}{2} + \frac{n}{2} + \lambda.a + \left(\frac{\lambda.a.\varepsilon}{2}\right) - x - \frac{y}{4} \quad (15)$$

$$N_{fg} = x + \frac{y}{2} + \left(\frac{t}{2} + 3.76.\lambda.a\right) + \alpha \quad (16)$$

Sulphuric and Water Vapour Dew Point Temperatures

As the flue gases (products) are assumed to be ideal gases, the partial pressure of the water vapour in the flue gases and the dew point temperature of water vapour can be calculated by using following equations [12].

$$P_{H_2O} = \frac{N_{H_2O}}{N_{fg}} \times P_{atm} \quad (17)$$

$$T_{WDP} = 0.001173333 \times \left(P_{H_2O}\right)^3 - 0.0942 \times \left(P_{H_2O}\right)^2 + 3.429666667 \times \left(P_{H_2O}\right) + 19.7 \quad (18)$$

In the ratio of 1-5%, a small part of SO_2 in flue gas transforms into SO_3. If flue gas temperature is lower than 176 °C, the whole of SO_3 converts into H_2SO_4. To determine the acid dew point temperature Okkes-B's equation, shown in Equation 20 is used [2].

$$SO_2 + {}^1/_2\, O_2 \rightarrow SO_3 \quad (19)$$

$$T_{ADP} = 203.25 + 27.6 \times lgP_{H_2O} + 10.83 \times lgP_{SO_3} + 1.06 \times \left(lgP_{SO_3} + 8\right)^{2.19} \quad (20)$$

In Equation 20 given the formula, the pressure unit is atm. Because of the no content sulphur in wood, the sulphuric acid vapour doesn't occur.

RESULTS AND DISCUSSION

The combustion reaction of the coal mined from Zonguldak in Turkey is indicated in Equation 21. In the equation, the stoichiometric combustion reaction occurs with dry air.

$$C_{0.5948}H_{0.3611}O_{0.0244}N_{0.0068}S_{0.0024}(H_2O)_{0.0106} + 0.6753(O_2 + 3.76N_2) \rightarrow 0.5948CO_2 + 0.1911H_2O + 2.5424N_2 + 0.0024\, SO_2 \quad (21)$$

According to the types, the mass compositions of coal mined from some regions in Turkey are shown in Table 1 [13].

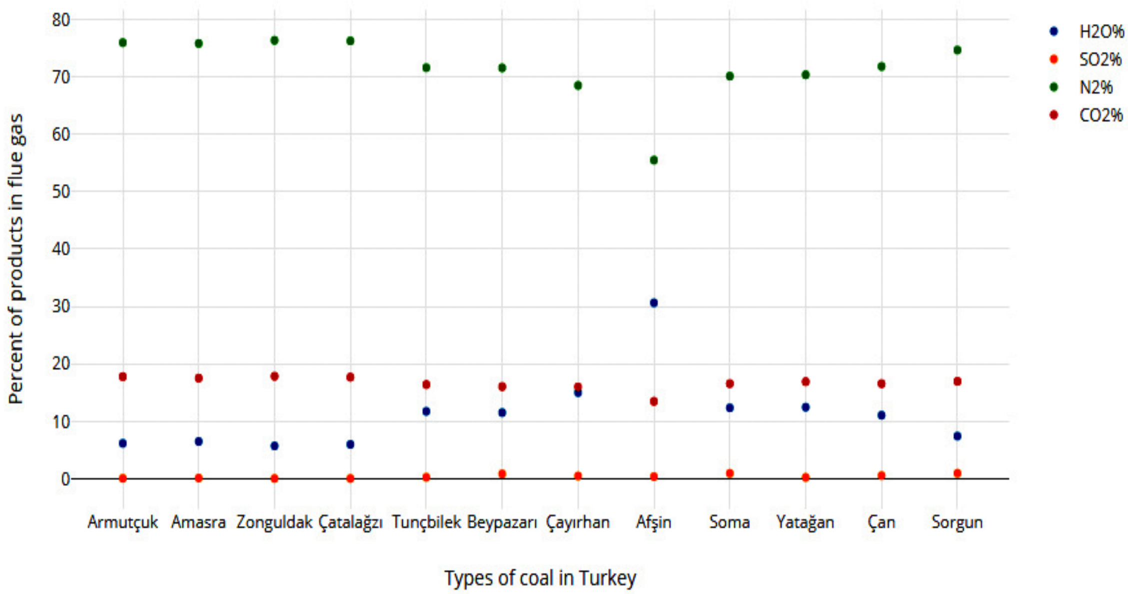

Figure 1. Percent of stoichiometric combustion products with dry air for the coal types

Table 1. The chemical composition of some coals in Turkey

Region	Type	C%	H%	O%	N%	S%	Moisture%
Armutçuk	Anthracite	82.80	4.52	7.94	1.32	0.99	2.43
Amasra		81.61	4.66	7.10	1.40	1.75	3.49
Zonguldak		86.52	4.38	4.72	1.15	0.92	2.30
Çatalağzı		86.31	4.60	4.60	1.15	0.92	2.42
Tunçbilek	Lignite	56.05	4.25	13.20	2.07	2.51	21.92
Beypazarı		52.06	4.38	17.53	1.80	7.60	16.62
Çayırhan		44.71	3.49	15.38	1.08	3.73	31.61
Afşin		22.67	2.42	16.00	1.82	1.70	55.39
Soma		46.48	3.94	23.89	2.03	7.17	16.49
Yatağan		50.93	4.19	21.98	2.21	2.09	18.60
Çan		55.14	4.22	16.86	1.41	5.08	17.30
Sorgun		64.73	3.83	11.60	1.86	9.86	8.12

In the combustion analysis, the values shown in Table 1 of the mass compositions were used. The combustion analysis was firstly done according to dry air and then developed for the moist air of the various cities. The percent of combustion products with dry air are shown in Figure 1 for the types of coal mined from Turkey. In the combustion with the moisture air, the mole number of the moisture air changes with the relative humidity rate. In Table 2, the average relative humidity rates, the altitudes from sea level and the atmospheric pressures of the various cities in Turkey are given.

Table 2. The physical properties of cities used in the analysis

City	Trabzon	Bursa	Ankara	Kayseri	Kars
R. humidity%	69.41	70.34	59.95	61.62	73.48
Altitude (m)	0	201	938	1054	1768
Atmospheric Pressure (kPa)	101.325	98.93	90.56	89.29	81.81

For the city, Ankara has the percent of average relative humidity 59.95 in Turkey; the complete combustion reaction is given the Eq. (22) according to the coal type mined from Zonguldak region. In the equation, the excess air ratio (λ) is taken as 1.3. When the excess air ratio is increased, the percent of the O_2 and N_2 rise, however, the percent of the CO_2, H_2O and the SO_2 decrease in the flue gas. The effect mentioned is given in Tab.3.

$$C_{0.5948}H_{0.3611}\mathrm{O}_{0.0244}\mathrm{N}_{0.0068}S_{0.0024}(\mathrm{H_2O})_{0.0106} + 1.13 \times 0.6753(O_2 + 3.76N_2) \rightarrow 0.5948CO_2 + 0.2569H_2O + 3.3041N_2 + 0.0024\, SO_2 + 0.2026O_2 \quad (22)$$

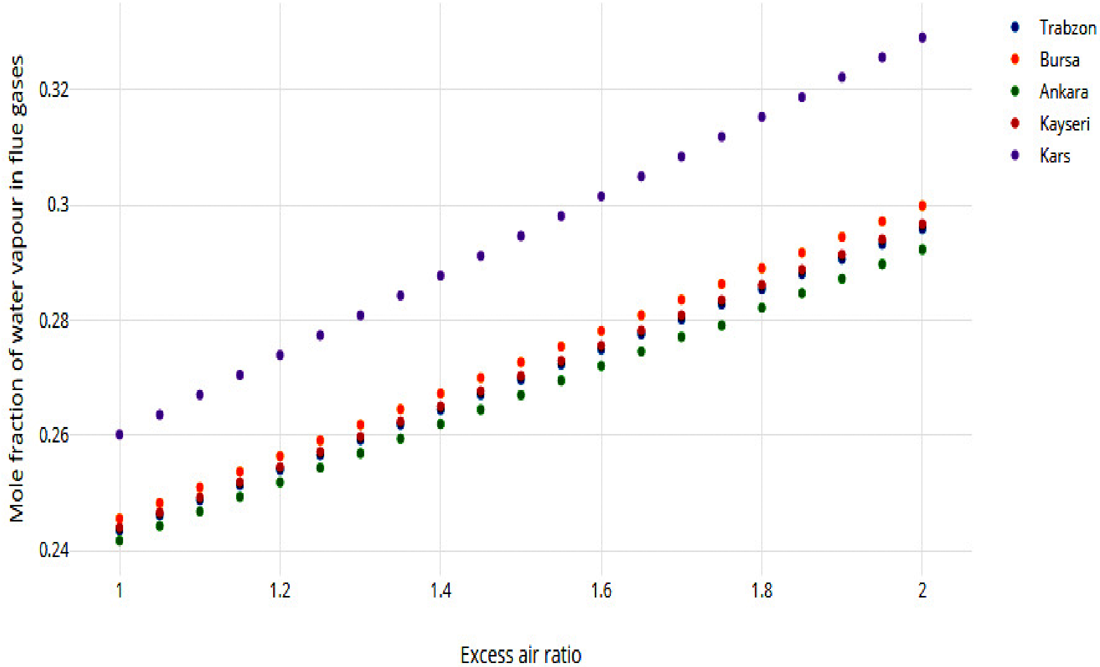

Figure 2. Changes of water vapour mole fraction with the excess air ratio

The mole fraction of water vapour in the flue gas has an important role to predict the dew point temperature of water vapour. The changes of the water vapour mole fraction in the flue gas with the excess air ratio are shown in Figure 2 for the five cities, called Trabzon, Bursa, Ankara, Kayseri and Kars in Turkey.

The dew point temperature of water vapour in flue gas changes with the excess air ratio and the altitude from sea level of the city. When the altitude is higher than sea level, the atmospheric pressure decreases. The lower atmospheric pressure is lead to the lower partial pressure and the dew point temperature of water vapour.

As shown in Figure 3, the dew point temperature of water vapour (DWT) is the highest for Trabzon city, has the altitude at the sea level. The DWT decreases depending on the increase of the excess air ratio. The acid dew point of the sulphuric acid (ADT) has the same effects, too (Figure 4).

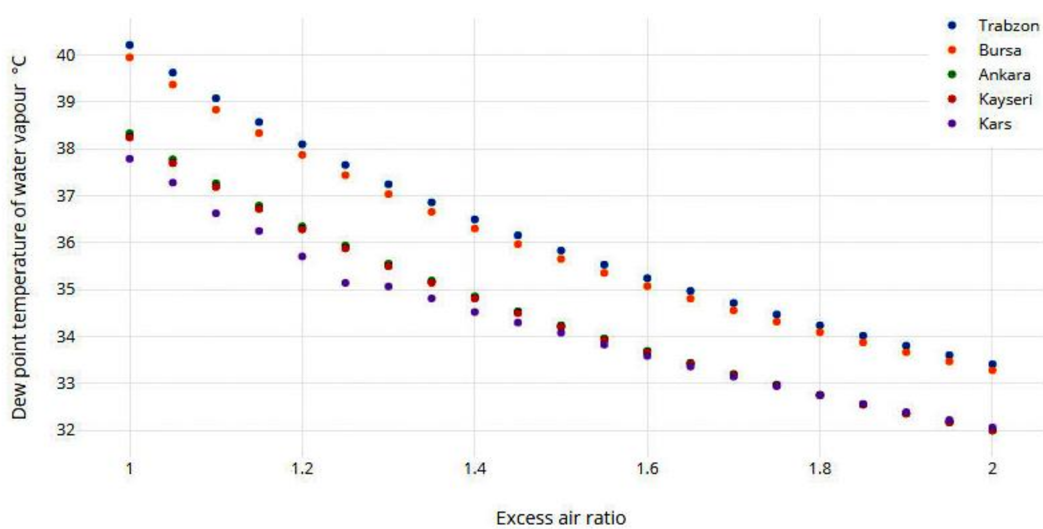

Figure 3. Changes of the DWT with the excess air ratio and the altitude of the city for the coal

Table 3. The complete combustion results for Ankara

λ	O_2%	CO_2%	H_2O%	N_2%	SO_2%
1	0.0	17.5906	7.1479	75.1912	0.0703
1.05	0.9526	16.7805	6.8901	75.3099	0.0670
1.1	1.8212	16.0417	6.6549	75.4181	0.0641
1.15	2.6167	15.3652	6.4396	75.5172	0.0614
1.2	3.3477	14.7434	6.2416	75.6083	0.0589
1.25	4.0219	14.1701	6.0591	75.6923	0.0566
1.3	4.6456	13.6396	5.8903	75.7700	0.0545
1.35	5.2243	13.1474	5.7336	75.8422	0.0525
1.4	5.7627	12.6895	5.5878	75.9092	0.0507
1.45	6.2648	12.2625	5.4519	75.9718	0.0490
1.50	6.7343	11.8632	5.3248	76.0303	0.0474
1.55	7.1741	11.4891	5.2057	76.0851	0.0459
1.6	7.5871	11.1379	5.0939	76.1366	0.0445
1.65	7.9755	10.8076	4.9888	76.1850	0.0432
1.7	8.3416	10.4962	4.8897	76.2306	0.0419
1.75	8.6872	10.2023	4.7961	76.2736	0.0408
1.8	9.0139	9.9244	4.7077	76.3144	0.0396
1.85	9.3233	9.6613	4.6239	76.3529	0.0386
1.9	9.6168	9.4117	4.5445	76.3895	0.0376
1.95	9.8954	9.1747	4.4690	76.4242	0.0367
2	10.1604	8.9494	4.3973	76.4572	0.0357

According to the results, while the DWT changes in the range of 30-40 °C, ADT varies between 140-125 °C. Thus, the predicting of the ADT is more important than DWT in the heat recovery applications for fuels, containing sulphur such as coal. When the flue gas temperature decreases down to the ADT, the H_2SO_4 vapour in the flue gas starts to the condensation.

The condensation liquid has a pH around 3 is very acidic and corrosive for the heat exchanger tube material. Due to these reasons, the more corrosion resistant tube material should use the latent heat exchanger or the flue gas temperature should not decrease down to the ADT.

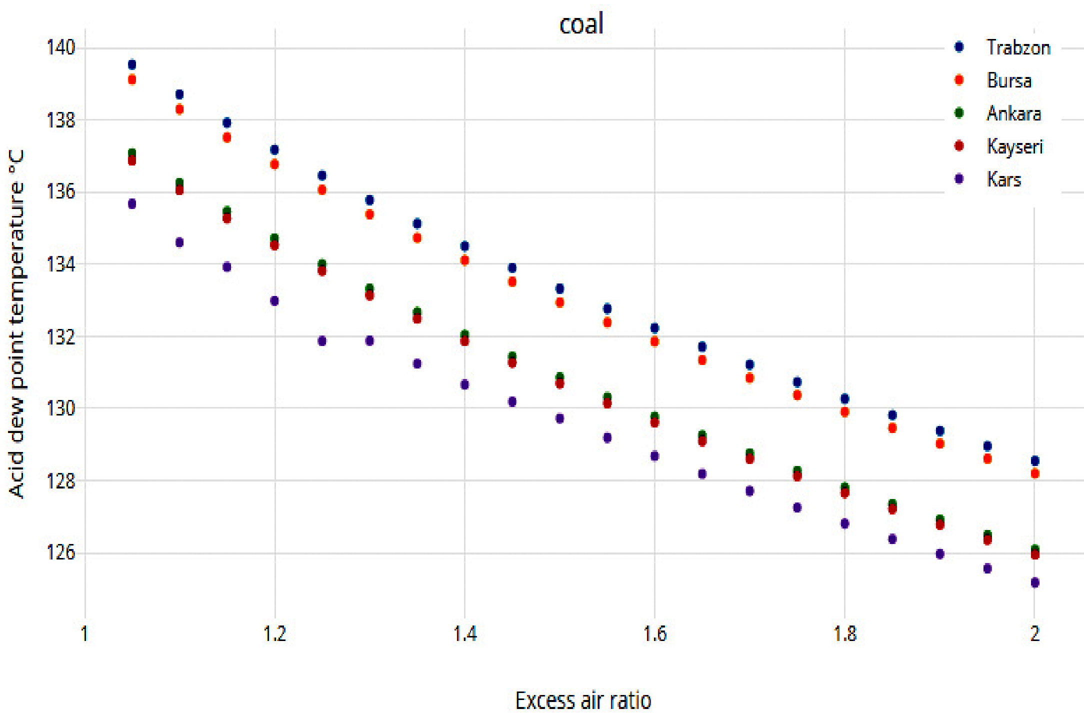

Figure 4. Changes of the ADT with the excess air ratio and the altitude of the city

Depending on the conversion rate, varies between the percent of 1-10 from SO_2 to SO_3 in the flue gas, the ADT increases. For the five cities, the changes with the content (ppm) of SO_3 in the flue gas and the excess air ratio are shown respectively in Figure 5, Figure 6, Figure 7, Figure 8 and Figure 9.

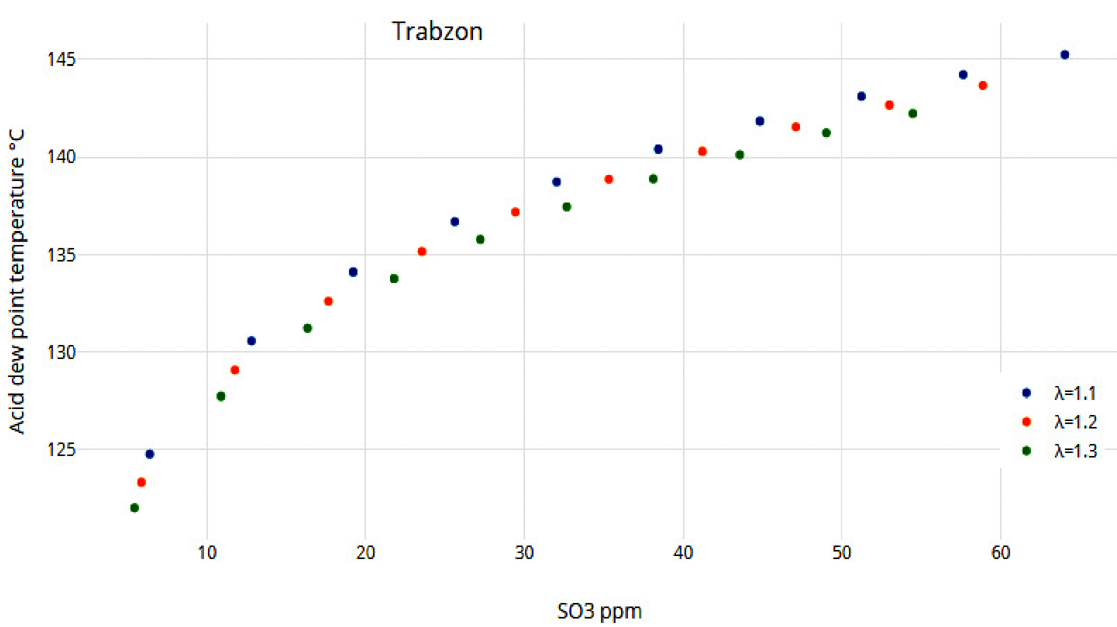

Figure 5. Change of the ADT according to the conversion rate for Trabzon city

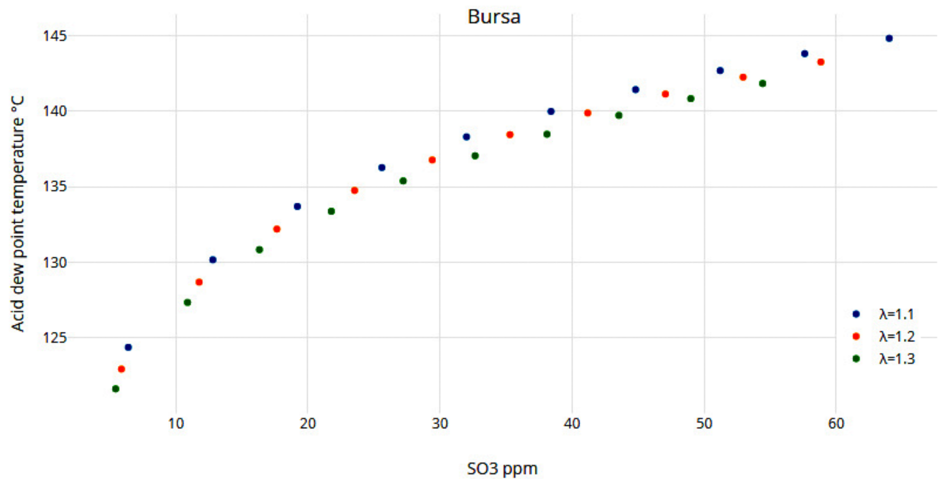

Figure 6. Change of the ADT according to the conversion rate for Bursa city

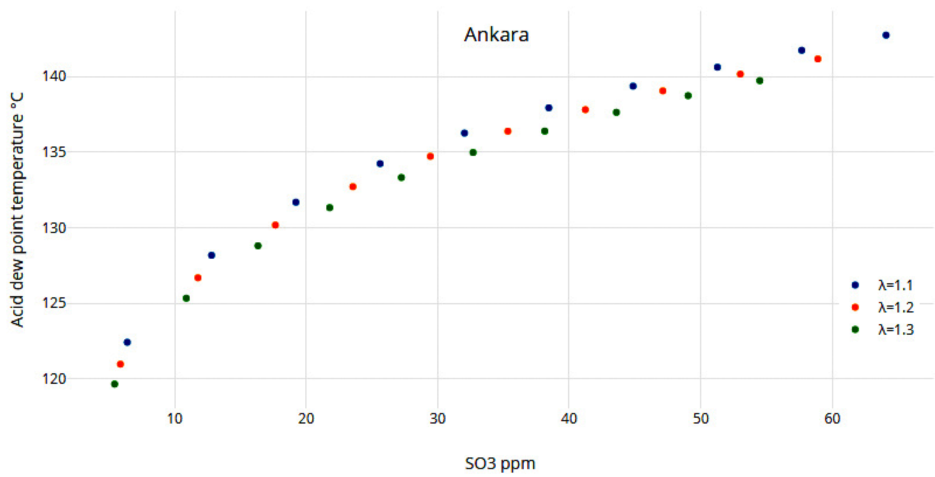

Figure 7. Change of the ADT according to the conversion rate for Ankara city

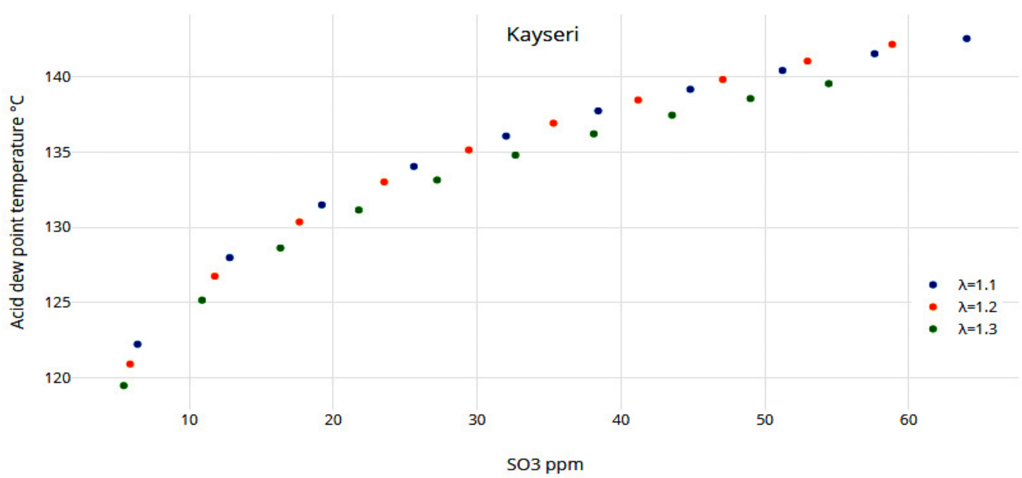

Figure 8. Change of the ADT according to the conversion rate for Kayseri city

As a result of the study, the acid dew point temperature is shown how to change for the excess air ratio λ=1.2 in Table 4. The ADT varies between 120-142 °C depending on the conversion rate of SO_2 to SO_3 for the city, called Kayseri. The ADT increases with the bigger conversion rate of the SO_2 for the constant value of the excess air ratio.

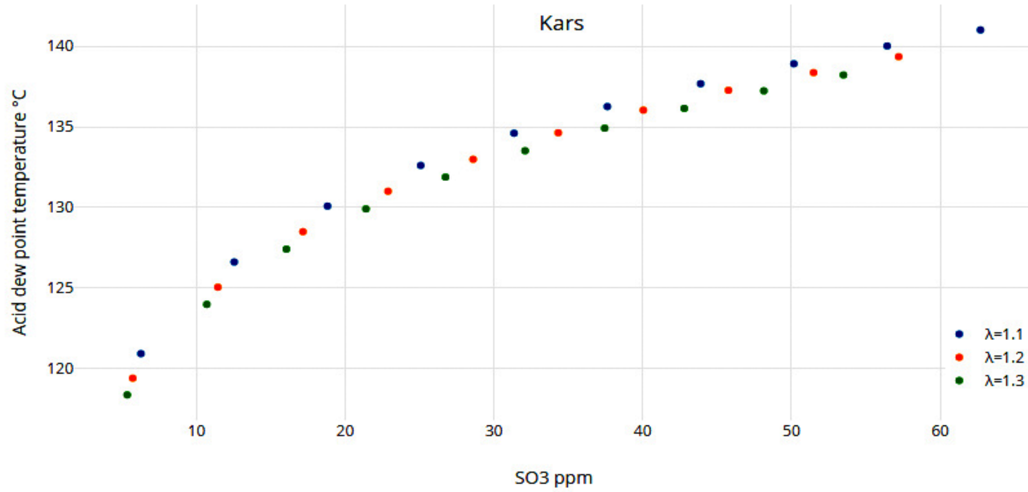

Figure 9. Change of the ADT according to the conversion rate for Kars city

In the combustion analysis of the wood, mass compositions, shown in Table 5 of the wood types were used [12]. The stoichiometric combustion reaction with dry air of the wood type, called hybrid poplar, is given in Eq. (23).

$$C_{0.3097}H_{0.4584}\mathrm{O}_{0.1872}\mathrm{N}_{0.0029}(\mathrm{H_2O})_{0.0418} + 1.13 \times 0.3306(O_2 + 3.76N_2) \rightarrow 0.3097CO_2 + 0.2843H_2O + 1.2447N_2 \quad (23)$$

Table 4. Results of the ADT analysis for λ=1.2 and Kayseri city

N_{SO3} ppm	N_{H2O} kmol	T_{ADT} °C	λ
5.89	0.2570	120.93	1.2
11.77	0.2599	126.76	
17.66	0.2623	130.36	
23.54	0.2649	133.02	
29.43	0.2676	135.14	
35.31	0.2702	136.92	
41.20	0.2729	138.45	
47.09	0.2755	139.81	
52.97	0.2781	141.03	
58.86	0.2809	142.15	

The percent of the stoichiometric combustion products with dry air are shown in Figure 10 for the wood types in Turkey. For the city, Bursa has the percent of average relative humidity 70.34 in Turkey, the complete combustion reaction with moist air is given the Eq. (24) according to the wood type called willow tree. In the equation, the excess air ratio (λ) is taken as 1.25.

$$C_{0.3189}H_{0.4497}\mathrm{O}_{0.2008}\mathrm{N}_{0.0029}(\mathrm{H_2O})_{0.0277} + 1.25 \times 0.3309\big(O_2 + 3.76N_2 + 0.0266(H_2O)\big) \rightarrow 0.3189CO_2 + 0.2858H_2O + 1.5566N_2 + 0.0827O_2 \quad (24)$$

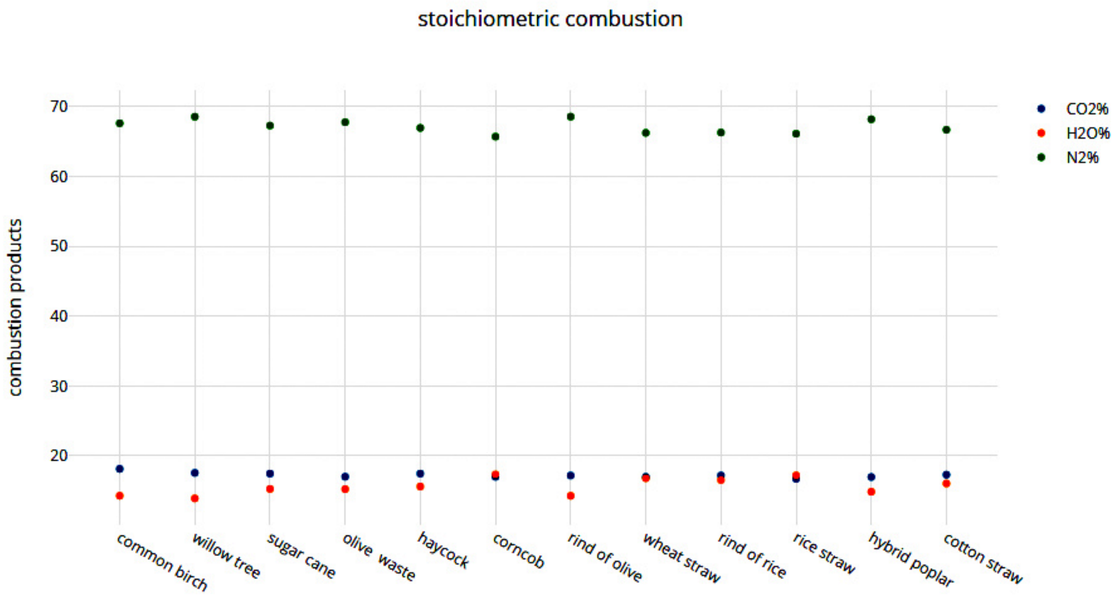

Figure 10. Percent of the stoichiometric combustion products with dry air for the wood types

To analyze the combustion with the moist air, calculating the mole number of water in the moist air needs. In the Figure 11, the mole number of the water in the air for the cities is indicated. As shown in Figure 11, depending on the relative humidity ratio of the cities the mole number of the water in the air changes.

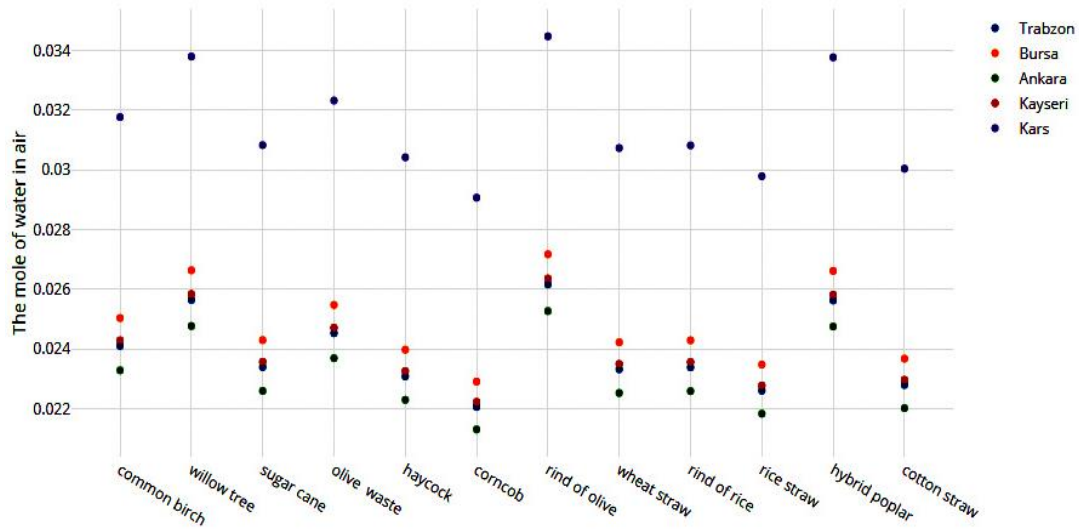

Figure 11. Mole number of water in the air for the cities

The amount of water vapour in the flue gas increases with the moisture of the fuel and the combustion air. In the Figure 12, the percent of H_2O in the flue gas is the lowest in the combustion with dry air, and the highest for the city, Kars because of the high relative humidity rate. Besides when the excess air ratio is increased, the percent of H_2O rises, too. In the combustion corncob, type of wood, the percent of H_2O is highest due to the moisture (0.05509 kmol) of fuel content.

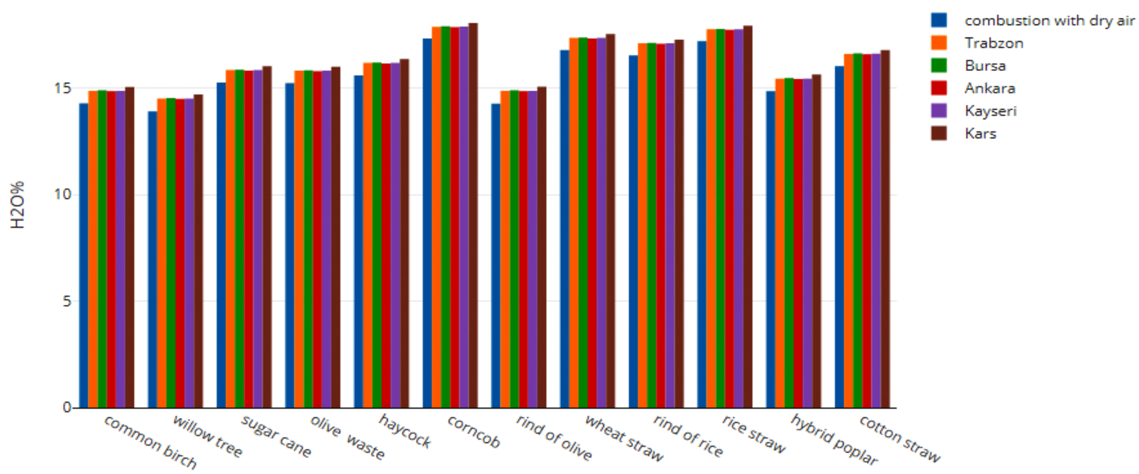

Figure 12. Percent of H_2O in flue gas for the dry and moist air combustion

The dew point temperature changes between the range of 40-55 °C for the wood type, willow tree depending on the excess air ratio and the altitude from the sea level of the city. The change is shown in Figure 13. The DWT decreases by increasing the excess air ratio. The city, Trabzon has the highest DWT because of at the sea level. The results of the dew point temperature are given briefly according to the selected cities for solid fuels in Table 6. According to the results of the study, while the dew point temperature of the water vapour changes over the range 30-40 °C for the coal and 40-50 °C for the wood types, the acid dew point temperature waves to 125 °C from 140 °C for the coal types.

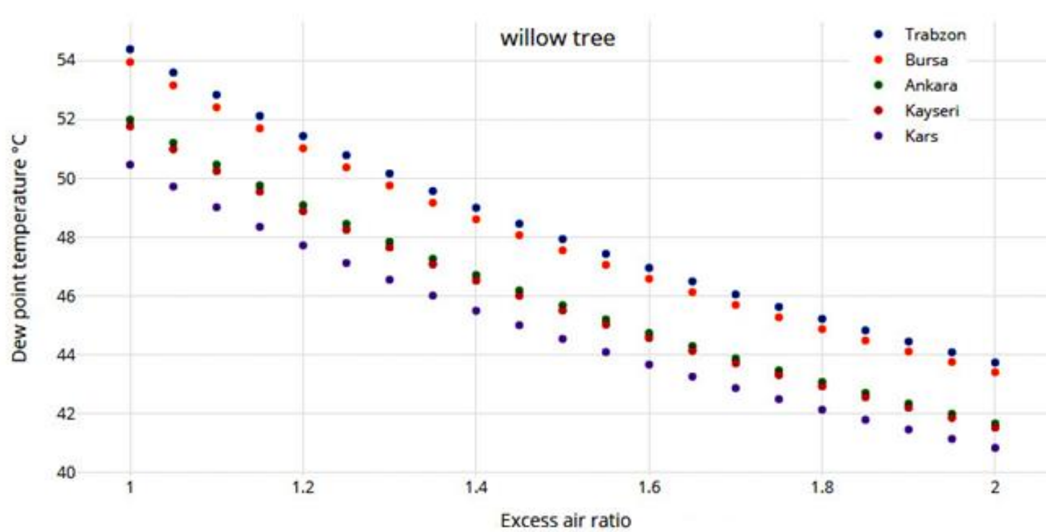

Figure 13. Changes of the DWT with the excess air ratio and the altitude of the city for the willow tree

The results of this study are applied to an air preheater, design in Kars city in Turkey for a coal-fired boiler in a heating system. Required parameters for the design such as the outlet temperature of the flue gas from the boiler, the excess air ratio, the inlet temperature of combustion air to the boiler, the mass flows of the flue gas and the combustion air were taken from the heating system.

Table 6. Results of the dew point analysis for the fuel types and the cities

	T_{WDT}°C		T_{ADT}°C*
	Coal	Wood	Coal
Trabzon	40.21-33.41	54.38-43.73	139.54-128.54
Bursa	39.95-33.28	53.94-43.41	139.12-128.19
Ankara	38.33-31.99	51.99-41.66	137.08-126.08
Kayseri	38.24-31.98	51.76-41.53	136.88-125.95
Kars	37.78-32.06	50.45-40.84	135.67-125.17

*According to the SO_2 of the conversion percent of 5

Designed the air preheater consists of counter-cross flow, U-shaped stainless steel tube bundle. While cold air flows inside the tubes, flue gas flows from up to down on the horizontal tube bundles. In order to predict the condensing, the finite differences method is used and discrete the cells to one-dimensional during the tube flow. So that, the heat transfer rates, the flue gas and air inlet and outlet temperatures, surface temperatures of the tube wall, mole fractions of water vapour, sulphuric acid vapour and other non-condensing gases in the flue gas are calculated in each discrete cell. As the results of the design calculation, the air preheater consists of 25 mm external diameter and 1.2 mm thickness tube bundle.

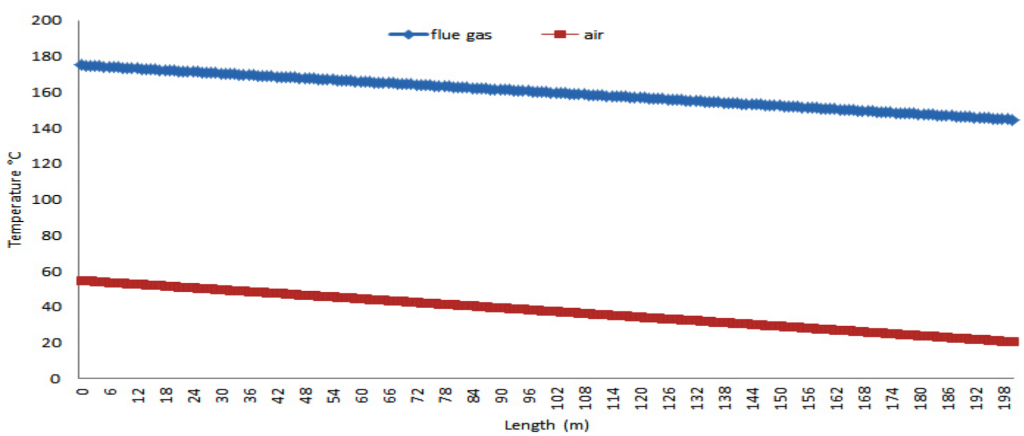

Figure 14. Changes of the flue gas and air temperature by the distance from the inlet air preheater

Table 7. Design results of the heat exchanger

Results and taken data from the heating system		
Tube diameter	mm	25
Total tube length	m	200
Number of tubes	-	204
Total heat surface area	m^2	16.02
Air inlet temperature	°C	20.81
Air outlet temperature	°C	55
Flue gases inlet temperature	°C	175
Flue gases outlet temperature	°C	144.63
Air mass flow inside tubes	kg/s	1.94
Flue gases mass flow outside tubes	kg/s	2.03
Air velocity inside tubes	m/s	9.81
Flue gases velocity outside tubes	m/s	5.71 max. 19.98

Tube material equipment is 316 quality stainless steel, U-shaped tube bundle is surrounded by stainless steel sheet metal, and 10 cm thickness stone wool of a side and metal on the other side equipment. It consists of 12 tubes on y-direction (width) and 17 tubes on z-direction (height), total in-line arrangement 204 tubes. The surface area of the air preheater is about 16.02 m^2 and each tube length is 1 m. Distances between the tubes are S_y and S_z equally 0.035 m in-line. A part of the heat exchanger design results and taken data from the heating system are shown in Table 7.

The calculation results by using finite difference method from the inlet heat exchanger tube to the outlet and changes of air and flue gas temperatures are shown in Figure 14. As seen in the figure, in the almost outlet of the air preheater the flue gas temperature is about 132.83 °C. Under these conditions; Kars city, coal mined from Zonguldak and the combustion 1.25 of excess air ratio with moist air; the acid dew point temperature is predicted as 131.87 °C. Under the temperature, the sulphuric acid vapour in the flue gas starts condensing. To conserve the tube material of the air pre-heater from the low-temperature corrosion the condensing of the sulphuric acid vapour does not wish because of the high corrosion effect. According to the design and analysis calculations, anywhere in the air preheater during tube flow, no dew point corrosion on the tube material can be observed because the flue gas temperature is high from the predicted ADT and DWT.

CONCLUSION

In this study, the combustion analysis is investigated for solid fuels such as various coal and wood types with moist air for different cities in Turkey. For the fuel types, the combustion effects are studied by using different excess air ratio. The dew point temperatures of water vapour (WDT) and sulphuric acid (ADT) are predicted as theoretical for various solid fuel types and the different cities in Turkey. The various factors such as the excess air ratio, relative humidity rate and the altitude of the city affected to the dew point temperatures and the concentration of the water and sulphuric acid vapour in flue gases are examined. In order to predict the condensing, an air preheater for the coal-fired boiler in the heating system is designed by using finite difference method. Designed the air preheater consists of the counter-cross flow U-shaped stainless steel tube bundle. The tube is discredited 200 cells to one-dimensional during the flow.

The heat transfer rates, flue gas and air inlet and outlet temperatures, the surface temperatures of the tube wall, the mole fractions of water vapour, sulphuric acid vapour and other non-condensing gases in the flue gas are calculated in each discrete cell. The results of the study are summarized as:

- According to the results, while the DWT changes in the range of 30-40 °C, ADT varies between 140-125 °C for the coal types in Turkey.
- The dew point temperature of water vapour (DWT) is the highest for Trabzon city, has an altitude at the sea level. The DWT decreases depending on the increase of the excess air ratio. The acid dew point of the sulphuric acid (ADT) has the same effects, too.
- The predicting of the ADT is more important than DWT in the heat recovery applications for fuels, containing sulphur such as coal.
- The dew point temperature changes between the range of 40-55 °C for the wood type, willow tree depending on the excess air ratio and the altitude from the sea level of the city.
- As the results of the design calculation, the air preheater consists of 25 mm external diameter and 1.2 mm thickness tube bundle. Tube material equipment is 316 quality stainless steel, U-shaped tube bundle is surrounded by stainless steel sheet metal, and 10 cm thickness stone wool of a side and metal on the other side equipment. It consists of 12 tubes on y-direction (width) and 17 tubes on z-direction (height), total in-line arrangement 204 tubes.
- The surface area of the air preheater is about 16.02 m^2 and each tube length is 1 m. Distances between the tubes are S_y and S_z equally 0.035 m in-line.

NOMENCLATURE

M_A	Molecular mass, kg / kmol
N	Mole number, kmol
P	Pressure, kPa, atm
T	Temperature, °C

Chemical symbols

C	Carbon
CO_2	Carbon dioxide
H	Hydrogen
H_2O	Water
H_2SO_4	Sulphuric acid
N_2	Nitrogen
O_2	Oxygen
SO_2	Sulphur dioxide
SO_3	Sulphur trioxide

Greek symbols

ε	Mole number of moisture in the air, kmol
λ	Excess air ratio
ϕ	Relative humidity rate, %

Subscripts

a	Coefficient of stoichiometric combustion
air	Combustion air
ADP	Acid dew point
atm	Atmosphere
fg	Flue gases
m	Moisture
sat	Saturated
WDP	Water dew point

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