Chemistry Extended Essay

"The effect of stove chimney cleanliness on CO gas production as a side product of coal combustion reaction in stove"

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Abstract

CO gas is a side product of coal combustion reaction in stove. The newspapers inform that every winter, many people lose their lives from CO gas poisoning. There are many reasons of CO gas poisoning resulting from coal combustion in stoves. Coal quality, cleanness of chimney, coal stove designs, wind effects are common reasons.

This investigation aims to find out and compare the effect of cleanliness of stove chimney on CO gas production in both flue gases and ambient air. The coal which has known chemical properties will be burned in the same coal stove with non-cleaned and cleaned chimney.

In experimentation phase, the coal will be burned in a coal stove used in last winter and its chimneys not cleaned as in case of real situation in both houses. The same coal again will be burned but in this case after cleaning its chimneys.

As a result, it was concluded that stoves with non-cleaned chimney has CO gas amounts almost two times higher value than the stoves with cleaned chimney. When it is analyzed that the CO gas amount and exposure time which may lead to deaths, it is inevitable that those people which are using stoves with non-cleaned chimneys have more risk of CO gas poisoning than others which are using stoves with cleaned chimneys.

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CO Gas Amount in Stoves with Cleaned and Non-Cleaned Chimneys

Finding the CO gas amounts in both flue gases of chimneys and ambient air near stove with cleaned and non-cleaned chimneys.

Introduction

In Turkey, traffic has the greatest ratio of deaths caused by accidents and it is followed by deaths caused by coal stove poisoning.

The main reason of poisoning is the respiration of the CO gas by human beings. The CO gas is a side product of the coal combustion reaction, taking place in the coal stove. Some other products like CO_2, NO_x (causing ozone depletion), and SO_2 (causing acid rain), which are also produced by the burning of coal cause only air pollution, however, CO causes human deaths.

A proper burning of coal is not always achieved and cannot be guaranteed. Coal stove designs, enough supply of air, temperature and cleanness of chimney are directly effective on the full combustion of coal.

On this research, the coal that has known chemical properties will be burned in the same coal stove with non-cleaned and cleaned chimney and the flue gases in chimney and the ambient weather near stove will be examined for their amount of CO resulting from the combustion of coal in stove.

There are many reasons of coal stove poisoning mentioned in literature[1] but in this research, only the cleanliness of the chimney and its relation to the CO gas product[1]ion in chimney and ambient weather will be investigated. By this way, I will try to explain the flue gas poisonings, which ends with death incidents, with the effect of independent variable of chimney cleanliness.

So in order to investigate the introduced issues, research question for the investigation is developed as; **How does the cleanliness of chimney affect the production of CO gas and CO gas poisoning?**

To sum up, the investigation is based upon to see how does the cleanliness of chimney affects the production of CO gas and CO gas poisoning. For this, firstly it was investigated with the non-cleaned chimney. Secondly, it was investigated with the cleaned chimney. I have chosen this topic to show the effect of stove chimney cleanliness on CO gas production as a side product of coal combustion reaction in stove. We are reading from the newspapers that many people lose their lives during winter due to the CO gas poisoning. The reason behind my choice of topic is the deaths of some teenagers at my age.

Carbon Monoxide Gas Poisonings

The scientific explanation for the CO poisoning caused by the burning of coal in a stove is; while breathing CO attaches with the hemoglobin instead of O_2 and as a result, cells cannot get a sufficient amount of O_2 for their living and eventually brain death occurs.

[1]Yılmaz, Ali Osman, Alp, İbrahim and Çavuşoğlu, İbrahim. Coal Stove Poisoning and Precautions to be taken, Proceedings of the 14 th Turkey Coal Congress, June 02-04, 2004, Zonguldak, Turkey.

The Table-1 shows the CO level (ppm) and exposure time that may lead to deaths.[2] "Parts-per" notation is used, especially in science and engineering, to denote relative proportions in measured quantities; particularly in low-value (high-ratio) proportions at the parts-per-million (ppm), parts-per-billion (ppb), and parts-per-trillion (ppt) level.

Carbon Monoxide Level (± 1 ppm)	**Exposure Time (± 1 minute)**
100 ppm	Few hours
200 ppm	Only one hour
600 ppm	40 minutes
1000 ppm	30 minutes
2000 ppm	20 minutes
3000 ppm	15 minutes
6000 ppm	10 minutes
10000 ppm	1-5 minutes

Table 1: Critical CO levels causing deaths

Numbness, dullness and a sense of sleep occurs when someone breathes in CO gas. These symptoms show that the poisoning has begun. When sitting in a room with a coal stove open doors and windows and allow the fresh air into the room if you should feel exhaustion, dullness, headache, dizziness, dormancy, sickness, loss of clear sight. Anyone who is poisoned should be removed from the area immediately and should be breathed with fresh air or with pure oxygen if possible. Person should be taken to the closest hospital immediately.

[2] Yılmaz, Ali Osman, Alp, İbrahim and Çavuşoğlu, İbrahim. Coal Stove Poisoning and Precautions to be taken, Proceedings of the 14 th Turkey Coal Congress, June 02-04, 2004, Zonguldak, Turkey.

On the proceeding levels of poisoning the ability to move will come to a halt, person will be overcome by drowsiness and a wish for sleep occurs. If the person is still affected by CO muscle contractions and the jaw interlocks, eyes become still at one point, body temperature rises, respiration and heartbeat slows down then body temperature starts to fall, person becomes unconscious and death occurs.

As the fossil fuel used in stoves is coal and that it causes the CO production and poisoning, its chemical properties and combustion of coal will be the starting point of this research.

Chemical Properties of Coal

Coal is a fossil fuel formed in ecosystems where plant remains were preserved by water and mud from oxidization and biodegradation, thus sequestering atmospheric carbon. It is composed primarily of carbon and hydrogen along with small quantities of other elements, notably sulfur.

Types of Coal

As geological processes apply pressure to dead biotic matter over time, under suitable conditions it is transformed successively into

- Peat, considered to be a precursor of coal.
- Lignite, also referred to as brown coal, is the lowest rank of coal and used almost exclusively as fuel for electric power generation.
- Sub-bituminous coal, whose properties range from those of lignite to those of bituminous coal.
- Bituminous coal, a dense mineral, black but sometimes dark brown, often with well-defined bands of bright and dull material.

- Anthracite, the highest rank; a harder, glossy, black coal used primarily for residential and commercial space heating.
- Graphite, technically the highest rank, but difficult to ignite and is not so commonly used as fuel: it is mostly used in pencils and, when powdered, as a lubricant.

Picture 1: Coal

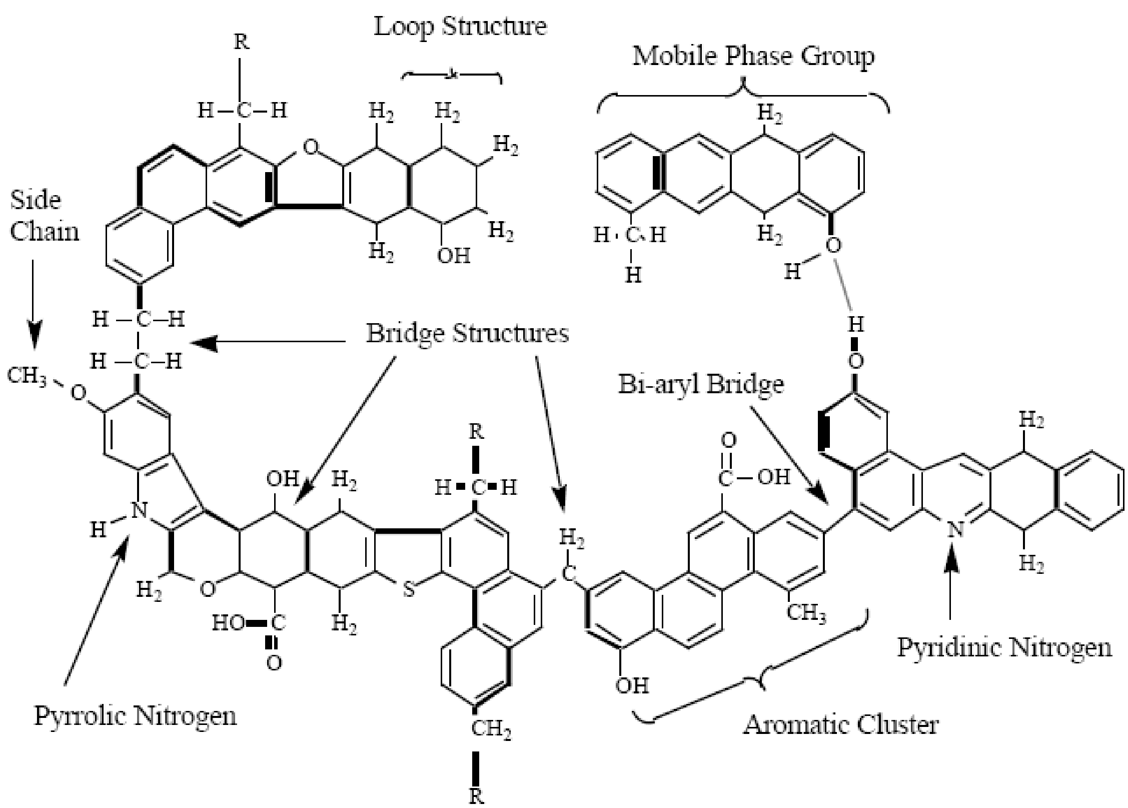

Figure 1: Example chemical structure of coal.[3]

[3] < http://www.et.byu.edu/~tom/Papers/Hambly_Thesis.pdf> 15 Jan 2009

Classification of Coal

The classification of coal is generally based on the physical and chemical properties. There are some standards such as American standard (ASTM D 388), International standard (ISO) and others. According to the German classification, coal is classified as follows:

Coal Name	Volatiles % (±0.1)	C Carbon % (±0.1)	H Hydrogen % (±0.01)	O Oxygen % (±0.1)	S Sulfur % (±0.1)	Heat content kJ/kg (±0.01)
Lignite	45.0-65.0	60.0-75.0	6.00-5.80	34.0-17.0	0.5-3.0	$<2.85x10^4$
Flame coal	40.0-45.0	75.0-82.0	6.00-5.80	>9.8	~1.0	$<3.29x10^4$
Gas flame coal	35.0-40.0	82.0-85.0	5.80-5.60	9.8-7.3	~1.0	$<3.39x10^4$
Gas coal	28.0-35.0	85.0-87.5	5.60-5.00	7.3-4.5	~1.0	$<3.50x10^4$
Fat coal	19.0-28.0	87.5-89.5	5.00-4.50	4.5-3.2	~1.0	$<3.54x10^4$
Forge coal	14.0-19.0	89.5-90.5	4.50-4.00	3.2-2.8	~1.0	$<3.54x10^4$
Non baking coal	10.0-14.0	90.5-91.5	4.00-3.75	2.8-3.5	~1.0	$<3.54x10^4$
Anthracite	7.0-12.0	>91.5	<3.75	<2.5	~1.0	$<3.53x10^4$

Table 2: German Coal Classification Table (Values are given percentage in weights)

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Coal Combustion

Generally, oxygen combining with other elements. Combustion is a special form of oxidation. Oxygen combines rapidly with certain type of fuels, such as coal, oil, gas and wood. Coal as a fuel has two basic elements, hydrogen and carbon. It also has sulfur and some other elements which are called impurities.

Carbon burns this way: Oxygen penetrates the carbon surface to break away atoms, which hook up with the oxygen in a loose type of carbon/oxygen compound that is unstable. It is not a true chemical compound, because proportions of carbon and oxygen atoms are not fixed; nor is it entirely a mixture, since the oxygen cannot be driven off.

$| C^{-1} \Xi O |^{+1}$ 2^{nd} Π bond which is the dative bond is formed by donation of electrons only from one element here its O and empty orbitals is donated by the other element here its C.

Depending on temperature and other conditions, this compound breaks up into carbon dioxide and carbon monoxide. If there is an excess of oxygen, carbon monoxide is oxidized to carbon dioxide. If carbon is in excess, dioxide is reduced to monoxide.

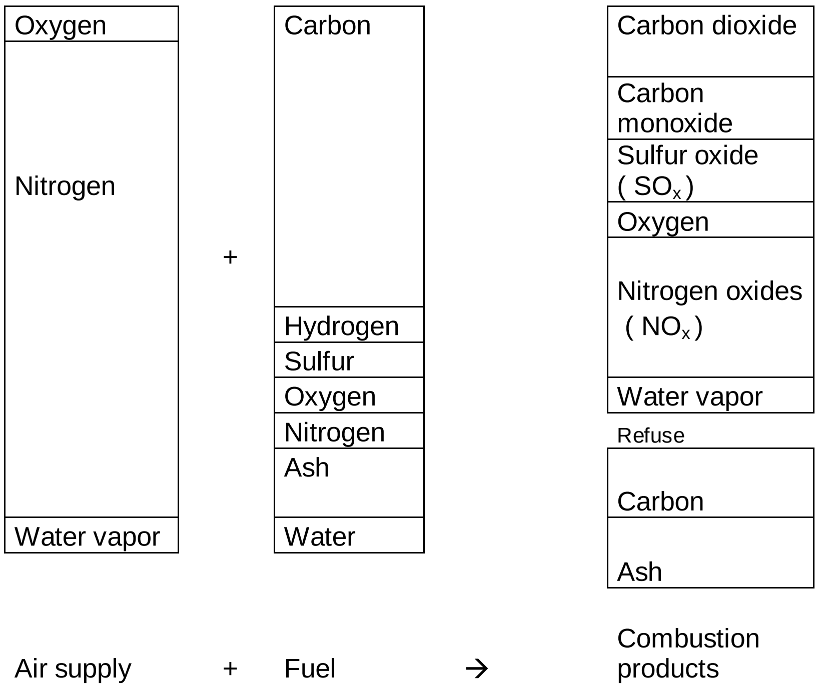

Figure 2: Balance sheet for combustion of coal.

The main chemical reactions that contribute to heat release are oxidation reactions, which convert the constituent elements of coal into their respective oxides, as shown in the Table 3. In the table, the negative signs indicate reactions that release heat (exothermic reactions), whereas the positive sign indicates a reaction that absorbs heat (endothermic reaction).

Principal oxidation reactions in the combustion of coal	
Reaction	Change in heat
$C + O_2 \rightarrow 2\ CO_2$	ΔH = −393.748 kJ/kg-mole
$S + O_2 \rightarrow SO_2$	ΔH = −297.075 kJ/kg-mole
$H_2 + 1/2\ O_2 \rightarrow H_2O$	ΔH = −286.011 kJ/kg-mole
$N_2 + O_2 \rightarrow 2\ NO$	ΔH = +180.857 kJ/kg-mole

Table 3: The reactions that take place while the burning of coal and the heat change they cause.

Flue Gas Emissions from Coal Combustion

Flue gas emissions from fossil fuel combustion refer to the combustion product gas resulting from the burning of fossil fuels. Most fossil fuels are combusted with ambient air (as differentiated from combustion with pure oxygen). Since ambient air contains about 79 volume percent gaseous nitrogen (N2), which is essentially non-combustible, the largest part of the flue gas from most fossil fuel combustion is uncombusted nitrogen. The next largest part of the flue gas is carbon dioxide (CO2) which can be as much as 10 to 15 volume percent or more of the flue gas. This is closely followed in volume by water vapor (H2O) created by the combustion of the hydrogen in the fuel with atmospheric oxygen. Much of the 'smoke' seen pouring from flue gas stacks is this water vapor forming a cloud as it contacts cool air.

1. Determining the CO Gas level in non-cleaned stove chimney

Group Numbers	Mass values of lignite coal (kg±0.0001)
1) 1st trial group for non-cleaned stove	1.2000
2) 2nd trial group for non-cleaned stove	1.1950
3) 3rd trial group for non-cleaned stove	1.1955

Table 4: Mass values of lignite coal groups to be burned in non-cleaned stove.

Group Numbers	Mass values of wood (kg±0.0001)
1) 1st trial group for non-cleaned stove	1.1110
2) 2nd trial group for non-cleaned stove	1.1020
3) 3rd trial group for non-cleaned stove	1.1070

Table 5: Mass values of wood groups to be burned in non-cleaned stove.

Group numbers	Mass values of wood shavings (kg±0.0001)
1) 1st trial group for non-cleaned stove	0.3030
2) 2nd trial group for non-cleaned stove	0.3020
3) 3rd trial group for non-cleaned stove	0.3005

Table 6: Mass values of wood shaving groups to be burned in non-cleaned stove.

The given groups were burned in the non-cleaned stove for constant time of 60 minutes. The CO levels each group produced in the stove and gave out were measured with a stove gas analyzer.

For a detailed method of the experiment, see appendix 1.

Time (minute±0.5)	CO level in air (ppm±1) 1st group	CO level in air (ppm±1) 2nd group	CO level in air (ppm±1) 3rd group
0	0	0	0
5	36	35	22
10	31	27	23
15	72	21	17
20	18	18	20
25	14	19	18
30	17	19	13
35	23	18	14
40	20	16	13
45	26	13	9
50	23	8	11
55	28	5	11
60	18	9	11

Table 7: CO levels observed during the burning of first three groups in the non-cleaned chimney.

For results that are more detailed, see appendix 2.

2. Determining the CO Gas level in cleaned stove chimney

Group Numbers	Mass values of lignite coal (kg±0.0001)
1) 1st trial group for clean stove	1.1990
2) 2nd trial group for clean stove	1.1975
3) 3rd trial group for clean stove	1.1980

Table 8: Mass values of lignite coal groups to be burned in cleaned stove.

Group Numbers	Mass values of wood (kg±0.0001)
1) 1st trial group for clean stove	1.0970
2) 2nd trial group for clean stove	1.1175
3) 3rd trial group for clean stove	1.0950

Table 9: Mass values of wood groups to be burned in cleaned stove.

Group numbers	Mass values of wood shavings (kg±0.0001)
1) 1st trial group for clean stove	0.2955
2) 2nd trial group for clean stove	0.3080
3) 3rd trial group for clean stove	0.2965

Table 10: Mass values of wood shaving groups to be burned in cleaned stove.

The given groups were burned in the cleaned stove for constant time of 60 minutes. The CO levels each group produced in the stove and gave out were measured with a stove gas analyzer.

For a detailed method of the experiment, see appendix 1.

Time (minute±0.5)	CO level in air (ppm±1) 1st group	CO level in air (ppm±1) 2nd group	CO level in air (ppm±1) 3rd group
0.0	1	2	1
5.0	13	12	13
10.0	11	6	3
15.0	7	8	7
20.0	7	3	11
25.0	9	6	12
30.0	8	8	8
35.0	13	9	6
40.0	8	8	4
45.0	9	7	4
50.0	8	8	5
55.0	4	7	6
60.0	8	6	7

Table 11: CO levels observed during the burning of second three groups in the cleaned chimney.

For more detailed data collection, see appendix 2.

Overall Results

	Non-cleaned chimney			**Cleaned chimney**		
Amount of CO level (ppm)	**Mean (ppm ±0.01)**	**Standard Deviation of Trials**	**Standard Error Mean**	**Mean (ppm ±0.01)**	**Standard Deviation of Trials**	**Standard Error Mean**
Ambient air near stove	18.39	9.11	2.53	7.31	2.59	0.72
Flue gases in chimneys	1965.69	720.84	199.93	1097.08	348.23	96.58

Table 12: Overall statistical results of CO level for non-cleaned and cleaned stove chimney.

	Non-cleaned chimney			Cleaned chimney		
Temperature in the stove	**Mean (°C ±0.01)**	**Standard Deviation of Trials**	**Standard Error Mean**	**Mean (°C ±0.01)**	**Standard Deviation of Trials**	**Standard Error Mean**
	250.51	69.20	19.19	244.39	106.81	29.62

Table 13: Mean, standard deviation and error mean for the temperature in both cleaned and non-cleaned chimney.

For detailed data processing and error calculation of all groups, see appendix 3 and 4 respectively.

Conclusion and Evaluation of the Investigation

In my study, I searched the answer of the question whether the cleanliness of the stove chimney effects the CO production and CO gas poisoning or not. In order to test this question, in my first group of measurements a stove is used with a chimney that is not cleaned after the last winter usage. After cleaning the stove chimney, the second group of measurements are done. My first conclusion is that the cleanliness of the stove chimney affects the CO production. The mean values of CO level in the measurements of flue gases are 1965.69±0.01 ppm and 1097.08±0.01 ppm for the first and second group respectively. As you can see there is a 1000 ppm difference between the results which is a huge number. Also the CO level in the ambient air near stove for non-cleaned and cleaned chimney are 18.39±0.01 ppm and 7.31±0.01 ppm respectively. Again, these results show that non-cleaned chimney releases higher amounts of CO into the air that is why the risk of CO poisoning increases when a non-cleaned chimney is used. When a non-cleaned chimney is used the leftovers from the previous usage of the stove surround the circumference of the pipe and block it. Just like a person whose veins are stuffed the area of the pipe decreases therefore flue gas produced during the burning cannot easily move along the pipe and exit through the chimney instead it exit directly from the stove into the room. The second conclusion is that to the end of the coal combustion in the stove, CO level increase is higher with the non-cleaned chimney group. CO level mean values are 2843±1 ppm and 1395±1 ppm. This happens as the heat of the stove decreases and there is not enough energy left for a full combustion of coal. The combustion goes on with a lower energy input so the product of the combustion shifts from CO_2 to CO. This can also be seen in the efficiency values (see appendix 3), which show how well a stove combust the coal. The efficiency of the combustion is decreased through the end of the combustion. Also the lambda values (see appendix 3), which show the excess air in stove, are increasing through the end of the combustion. This also proves that without the necessary energy the system cannot use the ambient air and cannot perform a full combustion. This result clearly shows why people get poisoned mostly during the night and why you shouldn't sleep before stopping the combustion. Because if you go to sleep before putting off the fire, CO levels increase and you cannot notice it during your sleep and get easily poisoned. Therefore, another conclusion that can be made is that when the temperature of flue gases decreases the amount of CO level increase. As can be seen from the third and fourth graph (see appendix 6) there is a negative relationship between them. Temperature values for both non-cleaned and cleaned chimneys are 250.51 ºC±0.01 and 244.39 ºC±0.01 respectively. Although there is not a huge difference between the stove temperatures of the non-cleaned and cleaned stove, CO levels increase in both towards the end of the combustion. Finally, I can conclude that the non-clean chimney has greater possibility to cause CO poisoning deaths then clean chimneys.

An analysis of death news from newspapers shows us that most of the CO poisoning occurs late in nights. The research's results in my study supports this fact. At night, people go to bed and sleep. This means, there is no more charge to stove and combustion slows down and temperature decreases in stove. In my study, there is a negative relationship between temperature and CO gas production. Thus at nights, when the temperature drops to below 200 C the CO gas production goes to peak almost 2000-3000 ppm. However, this is not explanatory to deaths because this value is measured in the chimney. For CO gas poisoning, some amount of CO gas must not leave the chimney but enter the room where people lives. This happens when there are leakages in the stove chimney establishment and as in stated in newspapers there must be a windy weather conditions. This wind creates negative suction pressure in chimneys. Thus, flue gases cannot go through chimney due to the pressure outside, windy air enters through chimney backwards blowing CO gas through the room. This case is even worse because the length of the chimney may be too long giving extra resistance to flue gases trying to go out of chimney. Long chimneys giving resistance to the flow of flue gases thus increase pressure drop through flow.

The measurements are done in this research by the TESTO flue gas analyzer and its probe. The model of the equipment is TESTO 330-2LL. It is calibrated every year for the accuracy of its measurements. The gas sensors of this equipment work electrochemically. In probe (300mm, 08mm), there is a NiCr-Ni thermocouple (up to 500 C). These equipments are quite reliable for their measurements. For detailed information about the equipment see appendix 5.

My experiment was not perfect of course it had a standard error mean of 2.52 and 0.71 for CO level in air, 199.93 and 96.58 for CO level in stove. First of all, the reason why these values are so high is that we are not expecting a stable value of CO during the combustion, as the measured values differ continually this affects the standard deviation and error calculations. However there are still some reasons for this error. First, in the method its said that wait until the coal starts to burn to start your measurements, however it is impossible to be sure about that as you have to look into the stove and see the coals burning but there is also wood and wood shavings burning along with it. Perhaps the coals can be burned with a flamethrower to eliminate this source of error. Second there were other people in room during the experiment and their presence might have affected the measurement of the CO level in the air as they took breaths they probably took some of the CO gas along with it. Maybe with a more advanced analyzer the measurements can be done with no one in the room. And lastly, this experiment was done during one day which means that even tough all the windows and doors was closed temperature of the room fell as it became late and that affected our experiment. To minimize this error the experiment can be done in different days but at the same hours or in a perfectly isolated room.

There are also some limitations to my research. The chemical properties of coal used in this research only represent one region of Turkey coalmines. Further researches may take other coal samples that have different chemical properties and compare the effect of coal quality on CO levels in combustion. Or the effect of type of the stove, place of the stove (near window vs. middle of the room), place of the house (in the city vs. in a village) etc versus the probability of poisoning can be examined in the further researches. Moreover the chimney which was used in my experiment was only filled with leftovers of one year and it is impossible to apply the results of non-cleaned chimney to any other dirty chimney. Also the flue gas analyzer which was used in my experiment was not able to measure the CO_2 level in stove, efficiency and lambda values for the last fifteen minutes. If the tables in appendix 3 are examined carefully it can be seen that these data reached their maximum values and the analyzer was not able to measure any further. In my experiment only one kilogram of coal was used for the combustion. It is obvious that a family who has at least four members would use this little coal to burn. Although, the stove must be provided with a reasonable amount of coal and not over filled with it otherwise the stove flue path narrows and as there will be irregular heat dispersion, chimney draught will decrease. The type of stoves and initiation of combustion from downside or upper side may also affect the CO levels in combustion. The combustion must be started from the upper side so that the poisonous gases can exit through the chimney. To prevent the flue gases from cooling and recoiling the pipes should be isolated. Also for an ideal combustion the chimney height must be between 3.5 and 5 meters. A cowl should be placed on top of the chimney to increase the draught.

Due to the results of my study, I warn people who might be using coal stoves for heating during winter, the possibility of CO gas poisoning decrease if they enter to use their stoves with cleaned chimneys.

Word count:

3785 including tables excluding calculations

2953 excluding both tables and calculations

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Appendix 1: CO level measurement in non-cleaned and cleaned stove chimney experiment planning

Experiment Name: CO level measurement in non-cleaned and cleaned stove chimney

<u>Planning A</u>

Aim of the Experiment: To find how the cleanliness of the chimney affects the level of CO gas emission.

Research Question: How does the cleanliness of chimney affect the production of CO gas and CO gas poisoning?

Hypothesis: When the chimney is stuffed and dirty it will increase the production of CO gas level thus increasing the possibility of poisoning.

Key Variables
Dependent variable: CO level
Independent variables: Cleanliness of the chimney
Controlled variables: Duration of burning.
Mass of coal.
Mass of wood.
Mass of wood shavings.
Type of stove.
Amount of air in the room.
Wind.
Daylight.
Temperature of the room.
Temperature of the stove before the burning process.

Materials (Apparatus)

1. 6.0000 ±0.0001 kilograms of lignite coal.
2. 6.0000 ±0.0001 kilograms of wood.
3. 2.0000 ±0.0001 kilograms of wood shavings.
4. One electronic balance (±0.0001).
5. One adze.
6. One coal stove with stuffed, dirty flue.
7. One coal stove with open, clean flue.
8. One flue gas analyzer. (Testo Model 330-2LL)
9. One lighter.
10. Probe
11. Timer

METHOD

1. Measure the lignite coal with the balance to be six kilograms and divide it into six groups of one kilogram.
2. Measure the wood with the balance to be six kilograms and divide it into six groups of one kilogram.
3. Measure the wood shavings with the balance to be around two kilograms and divide it into six groups of 0.3 kilograms.
4. Put the first group of coal, wood and wood shavings into the stove with stuffed flue.
5. Hold the flue analyzer probe with one-meter distance to the stove. (Picture 3)
6. Start the probe to measure the CO level in air and end it when the value stabilizes.
7. Light the wood shavings in the stove and start the burning.
8. Wait until the coal starts to burn. You check this by looking from the top of the stove.
9. Place the probe into the stove through the exit hole. (Picture 4)
10. Start the measurement and end it in 40 seconds.
11. Then measure the CO level in air by repeating steps 5 and 6.
12. Measure the value of CO gas both in the stove and in the air every 5 minutes until the coal is fully burned out and only ash is left in the bottom of the stove.
13. Repeat steps 4-12 with second and third groups of coal.
14. Repeat steps 4-12 with fourth, fifth and sixth groups of coal using the stove with open flue.
15. During the combustion, do not open any window or door that might cause a change in the volume of air in the room.

Picture 3: Measurement of the CO levels in air with one-meter distance to the stove.

Picture 4: Measurement of the CO level in the stove interior.

Appendix 2: Data of the properties of used coal, experiment groups and the resulting CO level in air.

Properties Lignite coal	
Water (% in weight) (±0.01) kg	11.89
Ash (% in weight) (±0.01) kg	16.90
Volatile substance (% in weight) (±0.01) kg	33.21
Carbon (% in weight) (±0.01) kg	38.00
Total Sulfur (% in weight) (±0.01) kg	1.29
Minimum heat value kcal/kg (±0.001)	5.041×10^3
Maximum heat value kcal/kg (±0.001)	5.316×10^3

Table 1: Properties of lignite coal used in my experiment

Group Numbers	Mass values of lignite coal (kg±0.0001)
1) 1st trial group for dirty stove	1.2000
2) 2nd trial group for dirty stove	1.1950
3) 3rd trial group for dirty stove	1.1955
4) 1st trial group for clean stove	1.1990
5) 2nd trial group for clean stove	1.1975
6) 3rd trial group for clean stove	1.1980

Table 2: Mass values of lignite coal for six groups.

Group Numbers	Mass values of wood (kg ± 0.0001)
1) 1st trial group for dirty stove	1.1110
2) 2nd trial group for dirty stove	1.1020
3) 3rd trial group for dirty stove	1.1070
4) 1st trial group for clean stove	1.0970
5) 2nd trial group for clean stove	1.1175
6) 3rd trial group for clean stove	1.0950

Table 3: Mass values of wood for six groups.

Group numbers	Mass values of wood shavings (kg ± 0.001)
1) 1st trial group for dirty stove	3.030×10^{-1}
2) 2nd trial group for dirty stove	3.020×10^{-1}
3) 3rd trial group for dirty stove	3.005×10^{-1}
4) 1st trial group for clean stove	2.955×10^{-1}
5) 2nd trial group for clean stove	3.080×10^{-1}
6) 3rd trial group for clean stove	2.965×10^{-1}

Table 4: Mass values of wood shavings for six groups.

Time (minute)	CO level in air (ppm ± 1) 1st group	CO level in air (ppm ± 1) 2nd group	CO level in air (ppm ± 1) 3rd group	CO level in air (ppm ± 1) 4th group	CO level in air (ppm ± 1) 5th group	CO level in air (ppm ± 1) 6th group
0	0	0	0	1	2	1
5	36	35	22	13	12	13
10	31	27	23	11	6	3
15	72	21	17	7	8	7
20	18	18	20	7	3	11
25	14	19	18	9	6	12
30	17	19	13	8	8	8
35	23	18	14	13	9	6
40	20	16	13	8	8	4
45	26	13	9	9	7	4
50	23	8	11	8	8	5
55	28	5	11	4	7	6
60	18	9	11	8	6	7

Table 5: CO level in air during the combustion of six groups.

Appendix 3: Data Collection and Processing

Calculating CO_2:

$$CO_2 = \frac{CO_{2max} \times (21 - O_2)}{21}$$

AT: Ambient temperature

21: Oxygen level in air

O_2: O_2 value measured in flue gas

CO_2: Carbon dioxide, calculated using CO_{2max} value and O_2

f: 0.90

CO_{2max}: 19.2

Efficiency of a small burner:

η = 100 % - qA
qA = Flue gas loss (%)

Calculating the flue gas loss for solid fuels:

$$qA = f \times \frac{AT - VT}{CO_2}$$

Time (minute)	0	5	10	15	20	25	30	35	40	45	50	55	60
Stove gas temperature (Cº±0.1)	164.6	170.2	369.9	310.2	248.6	222.7	222.0	217.0	210.7	199.4	182.6	170.0	142.8
O_2 % level in the stove (ppm ±0.1)	1.9	4.1	8.5	13.0	15.4	16.1	16.5	16.8	17.0	17.3	17.6	18.1	18.2
CO level in the stove (ppm ± 1)	1454	3000	1284	1676	2717	2679	2279	2180	2149	2328	2251	2560	2472
CO_2 % level in the stove (ppm ±0.01)	18.01	15.93	11.79	7.54	5.28	4.62	4.24	3.96	3.77	3.49	3.21	2.73	2.64
Lambda (± 0.01)	1.10	1.24	1.68	2.63	3.75	4.29	4.67	5.00	5.25	5.68	6.18	7.24	7.50
Efficiency % (±0.1)	92.9	91.7	73.5	65.7	61.5	61.1	57.8	56.0	55.3	54.6	55.3	51.8	59.3
Room temperature (Cº±0.1)	22.3	22.5	22.8	22.9	23.1	23.3	23.1	23.5	23.5	23.4	23.6	23.6	23.3

Table 6: Flue gas analyzer results for interior of the stove of the first group.

Time (minute)	0	5	10	15	20	25	30	35	40	45	50	55	60
Stove gas temperature (Cº±0.1)	366.5	411.2	376.5	332.8	278.5	268.9	237.2	210.3	194.4	193.2	169.5	169.9	147.7
O_2 % (level in the stove ppm ±0.1)	1.5	5.0	8.2	12.4	14.6	15.5	16.6	17.7	18.3	18.6	19.0	19.2	19.3
CO level in the stove (ppm ± 1)	656	519	367	819	1452	1666	1794	2311	2585	2789	2770	2604	2420
CO_2 % (level in the stove ppm ±0.01)	18.39	15.09	12.07	8.11	6.03	5.19	4.15	3.11	2.55	2.26	1.89	1.70	1.60
Lambda (±0.01)	1.08	1.31	1.64	2.44	3.28	3.82	4.77	6.36	7.78	8.75	10.50	11.67	12.35
Efficiency % (±0.1)	83.2	76.9	73.7	65.7	62.0	57.5	53.8	46.1	39.7	33.0	30.8	22.9	31.0
Room temperature (Cº±0.1)	23.9	23.8	24.1	23.7	24.0	24.2	24.4	24.1	23.8	24.8	24.5	24.7	24.9

Table 7: Flue gas analyzer results for interior of the stove for second group.

Time (minute)	0	5	10	15	20	25	30	35	40	45	50	55	60
Stove gas temperature (C°±0.1)	327.6	384.1	396.7	346.9	354.6	303.3	269.2	238.7	218.4	203.4	189.8	182.0	168.0
O_2 % level in the stove (ppm ±0.1)	1.7	2.2	6.3	9.3	10.3	14.0	15.6	16.8	17.4	17.8	18.3	18.6	18.8
CO level in the stove (ppm ± 1)	973	859	1322	542	324	816	1913	2426	2707	3319	3138	3365	3177
CO_2 % level in the stove (ppm ±0.01)	18.20	17.73	13.86	11.03	10.09	6.60	5.09	3.96	3.39	3.02	2.55	2.26	2.07
Lambda (±0.01)	1.09	1.12	1.43	1.79	1.96	3.00	3.89	5.00	5.83	6.56	7.78	8.75	9.55
Efficiency % (±0.1)	85.0	81.8	75.9	73.8	70.6	62.1	57.0	51.6	49.0	47.1	42.0	38.0	38.5
Room temperature (C°±0.1)	25.1	25.0	25.0	25.6	25.6	25.6	25.9	25.9	26.1	26.0	26.0	26.1	26.3

Table 8: Flue gas analyzer results for interior of the stove for third group.

Time (minute)	0	5	10	15	20	25	30	35	40	45	50	55	60
Stove gas temperature (Cº±0.1)	356.5	389.6	356.2	349.3	299.0	268.6	236.8	216.2	196.2	184.6	176.5	164.0	143.1
O_2 % level in the stove (ppm ±0.1)	7.9	10.9	13.1	12.9	15.4	16.7	17.7	18.3	18.6	19.0	19.0	19.2	19.5
CO level in the stove (ppm ± 1)	776	1757	906	1390	532	789	916	997	1094	1227	1426	1436	1761
CO_2 % level in the stove (ppm ±0.01)	12.35	9.52	7.45	7.64	5.28	4.05	3.11	2.55	2.26	1.89	1.89	1.70	1.41
Lambda (±0.01)	1.60	2.08	2.66	2.59	3.75	4.88	6.36	7.78	8.75	10.50	10.50	11.67	14.00
Efficiency % (±0.1)	75.8	65.5	59.9	61.7	53.2	45.9	38.7	32.4	32.0	23.8	27.7	26.1	24.6
Room temperature (Cº±0.1)	24.2	24.5	24.7	24.8	24.8	24.8	24.9	25.0	25.4	24.9	25.0	24.6	24.7

Table 9: Flue gas analyzer results for interior of the stove for fourth group.

Time (minute)	0	5	10	15	20	25	30	35	40	45	50	55	60
Stove gas temperature (Cº±0.1)	470.9	531.8	350.4	303.1	280.0	247.1	217.8	193.6	172.5	158.7	150.5	142.2	133.6
O_2 % level in the stove (ppm ±0.1)	4.9	6.1	13.7	15.5	16.6	17.5	18.5	19.0	19.2	19.4	19.7	19.9	20.0
CO level in the stove (ppm ± 1)	588	745	171	144	306	690	1216	1625	1738	1780	1760	1635	1600
CO_2 % level in the stove (ppm ±0.01)	15.18	14.05	6.88	5.19	4.15	3.30	2.36	1.89	1.70	1.51	1.23	1.04	0.94
Lambda (±0.01)	1.30	1.41	2.88	3.82	4.77	6.00	8.40	10.50	11.67	13.12	16.15	19.00	21.00
Efficiency % (±0.1)	73.6	67.5	57.5	51.8	44.8	39.6	26.5	19.8	21.9	20.6	8.2	-1.2	-3.4
Room temperature (Cº±0.1)	25.2	25.5	25.7	25.7	25.6	25.7	25.5	25.7	25.4	25.7	25.6	25.6	25.3

Table 10: Flue gas analyzer results for interior of the stove for fifth group.

Time (minute)	0	5	10	15	20	25	30	35	40	45	50	55	60
Stove gas temperature (Cº±0.1)	493.3	379.1	306.7	264.5	235.4	193.1	180.6	159.9	145.2	130.9	126.9	116.3	110.8
O_2 % level in the stove (ppm ±0.1)	5.4	12.1	15.6	17.2	18.2	19.2	19.6	19.8	20.0	20.1	20.2	20.3	20.4
CO level in the stove (ppm ± 1)	885	952	212	750	1130	1410	1408	1318	1192	1157	1140	1113	1116
CO_2 % level in the stove (ppm ±0.01)	14.71	8.39	5.09	3.58	2.64	1.70	1.32	1.13	0.94	x	x	x	x
Lambda (±0.01)	1.35	2.36	3.89	5.53	7.50	11.67	15.00	17.50	21.00	x	x	x	x
Efficiency % (±0.1)	71.3	62.0	50.1	39.7	28.4	10.9	-6.5	-7.5	-15.2	x	x	x	x
Room temperature (Cº±0.1)	24.8	24.7	24.7	24.6	25.4	25.1	24.5	24.9	24.5	25.0	24.4	25.0	27.6

Table 11: Flue gas analyzer results for interior of the stove for sixth group.

Appendix 4: Calculations of flue gas analyzer results for the non-cleaned and cleaned stove chimneys

Time (minute)	0	5	10	15	20	25	30	35	40	45	50	55	60
Stove gas temperature (Cº±0.1)	286.2	321.9	381.0	329.9	293.9	264.9	242.8	222.0	207.8	198.7	180.6	173.9	152.8
O_2 % level in the stove (ppm ±0.1)	1.7	3.8	7.7	11.6	13.4	15.2	16.2	17.1	17.6	17.9	18.3	18.6	18.8
CO level in the stove (ppm ± 1)	1028	1459	991	1012	1498	1720	1995	2306	2480	2812	2720	2843	2690
CO_2 % level in the stove (ppm ±0.01)	18.20	16.25	12.57	8.89	7.13	5.47	4.49	3.68	3.24	2.92	2.55	2.23	2.10
Lambda (±0.01)	1.09	1.22	1.58	2.29	3.00	3.70	4.44	5.45	6.29	7.00	8.15	9.22	9.80
Efficiency % (±0.1)	87.0	83.5	74.4	68.4	64.7	60.2	56.2	51.2	48.0	44.9	42.7	37.6	42.9
Room temperature (Cº±0.1)	23.8	23.8	24.0	24.1	24.2	24.4	24.5	24.5	24.5	24.7	24.7	24.8	24.8

Table 12: Mean values for 1^{st}, 2^{nd}, 3^{rd} groups.

Mean = Sum of all values in each category divided by 3.

Time (minute)	0	5	10	15	20	25	30	35	40	45	50	55	60
Stove gas temperature (C°±0.1)	440.2	433.5	337.8	305.6	271.5	236.3	211.7	189.9	171.3	158.1	151.3	140.8	129.2
O_2 % level in the stove (ppm ±0.1)	6.1	9.7	14.1	15.2	16.7	17.8	18.6	19.0	19.3	19.5	19.6	19.8	20.0
CO level in the stove (ppm ± 1)	750	1151	430	761	656	963	1180	1313	1341	1388	1442	1395	1492
CO_2 % level in the stove (ppm ±0.01)	14.08	10.65	6.47	5.47	4.02	3.02	2.26	1.86	1.63	1.70	1.56	1.37	1.18
Lambda (±0.01)	1.4	2.0	3.1	4.0	5.3	7.5	9.9	11.9	13.8	11.8	13.3	15.3	17.5
Efficiency % (±0.1)	73.6	65.0	55.8	51.1	42.1	32.1	19.6	14.9	12.9	22.2	17.9	12.5	10.6
Room temperature (C°±0.1)	24.7	24.9	25.0	25.0	25.3	25.2	25.0	25.2	25.1	25.2	25.0	25.1	25.9

Table 13: Mean values for 4th, 5th, 6th groups.

Mean = Sum of all values in each category divided by 3.

Standard Deviation SE (Standard Error) = $\frac{SD}{\sqrt{n}}$

$$\sigma = \sqrt{\frac{\Sigma\,(x-\overline{x})^2}{n-1}}$$

σ = **lower case sigma**
Σ = **capital sigma**
$\overline{x}$ = **x bar**

	CO level in air with respect to time				(ppm±1)			
	Dirty stove				Clean stove			
minute	1st trial	2nd trial	3rd trial	**Mean**	1st trial	2nd trial	3rd trial	**Mean**
0	0	0	0	**0**	1	2	1	**1**
5	36	35	22	**31**	13	12	13	**13**
10	31	27	23	**27**	11	6	3	**7**
15	72	21	17	**37**	7	8	7	**7**
20	18	18	20	**19**	7	3	11	**7**
25	14	19	18	**17**	9	6	12	**9**
30	17	19	13	**16**	8	8	8	**8**
35	23	18	14	**18**	13	9	6	**9**
40	20	16	13	**16**	8	8	4	**7**
45	26	13	9	**16**	9	7	4	**7**
50	23	8	11	**14**	8	8	5	**7**
55	28	5	11	**15**	4	7	6	**6**
60	18	9	11	**13**	8	6	7	**7**
		Mean		18.3846				7.3077
		Std. Deviation		9.1154				2.5944
		Std. Error Mean		2.5281				0.7195
95% Confidence Interval of the Difference			**Lower**	12.8763				5.7399
			Upper	23.8930				8.8755

Table 14: Mean, standard deviation, standard error mean and 95% Confidence Interval of the difference values for CO level in air with respect to time for both dirty and clean stove.

Minute	Dirty stove							Clean stove						
	1st trial	2nd trial	3rd trial	**Mean**	**Std. Deviation**	**Std. Error**	**95% CI**	1st trial	2nd trial	3rd trial	**Mean**	**Std. Deviation**	**Std. Error**	**95% CI**
0	1454	656	973	**1028**	**401.79**	**231.97**	**738.12**	776	588	885	**750**	**150.24**	**86.74**	**276.01**
5	3000	519	859	**1459**	**1345.04**	**776.56**	**2471.01**	1757	745	952	**1151**	**534.64**	**308.67**	**982.19**
10	1284	367	1322	**991**	**540.73**	**312.19**	**993.39**	906	171	212	**430**	**413.03**	**238.46**	**758.78**
15	1676	819	542	**1012**	**591.20**	**341.33**	**1086.11**	1390	144	750	**761**	**623.08**	**359.74**	**1144.70**
20	2717	1452	324	**1498**	**1197.15**	**691.17**	**2199.30**	532	306	1130	**656**	**425.77**	**245.82**	**782.20**
25	2679	1666	816	**1720**	**932.69**	**538.49**	**1713.47**	789	690	1410	**963**	**390.27**	**225.32**	**716.97**
30	2279	1794	1913	**1995**	**252.76**	**145.93**	**464.35**	916	1216	1408	**1180**	**247.97**	**143.17**	**455.57**
35	2180	2311	2426	**2306**	**123.09**	**71.07**	**226.14**	997	1625	1318	**1313**	**314.03**	**181.31**	**576.93**
40	2149	2585	2707	**2480**	**293.35**	**169.37**	**538.94**	1094	1738	1192	**1341**	**347.00**	**200.34**	**637.48**
45	2328	2789	3319	**2812**	**495.90**	**286.31**	**911.04**	1227	1780	1157	**1388**	**341.28**	**197.04**	**626.98**
50	2251	2770	3138	**2720**	**445.64**	**257.29**	**818.70**	1426	1760	1140	**1442**	**310.31**	**179.16**	**570.09**
55	2560	2604	3365	**2843**	**452.60**	**261.31**	**831.49**	1436	1635	1113	**1395**	**263.44**	**152.09**	**483.95**
60	2472	2420	3177	**2690**	**422.84**	**244.13**	**776.82**	1761	1600	1116	**1492**	**335.71**	**193.82**	**616.74**

		Dirty stove	Clean stove
	Mean	1965.69	1097.08
	Std. Deviation	720.84	348.23
	Std. Error Mean	199.93	96.58
95% Confidence Interval of the Differance	**Lower**	1530.09	886.64
	Upper	2401.29	1307.51

Table 15: Mean, standard deviation, standard error mean and 95% Confidence Interval of the difference values for CO level in stove chimney with respect to time for both dirty and clean stove.

	Dirty stove				Clean stove			
minute	1st trial	2nd trial	3rd trial	Mean	1st trial	2nd trial	3rd trial	Mean
0	164.60	366.50	327.60	286.23	356.50	470.90	493.30	440.23
5	170.20	411.20	384.10	321.83	389.60	531.80	379.10	433.50
10	369.90	376.50	396.70	381.03	356.20	350.40	306.70	337.77
15	310.20	332.80	346.90	329.97	349.30	303.10	264.50	305.63
20	248.60	278.50	354.60	293.90	299.00	280.00	235.40	271.47
25	222.70	268.90	303.30	264.97	268.60	247.10	193.10	236.27
30	222.00	237.20	269.20	242.80	236.80	217.80	180.60	211.73
35	217.00	210.30	238.70	222.00	216.20	193.60	159.90	189.90
40	210.70	194.40	218.40	207.83	196.20	172.50	145.20	171.30
45	199.40	193.20	203.40	198.67	184.60	158.70	130.90	158.07
50	182.60	169.50	189.80	180.63	176.50	150.50	126.90	151.30
55	170.00	169.90	182.00	173.97	164.00	142.20	116.30	140.83
60	142.80	147.70	168.00	152.83	143,00	133.60	110.80	129.13
		Mean		250.51				244.39
		Std. Deviation		69.20				106.81
		Std. Error Mean		19.19				29.62
95% Confidence Interval of the Difference			Lower	208.69				179.85
			Upper	292.33				308.94

Table 16: Mean, standard deviation, standard error mean and 95% Confidence Interval of the difference values for temperature in stove with respect to time for both dirty and clean stove.

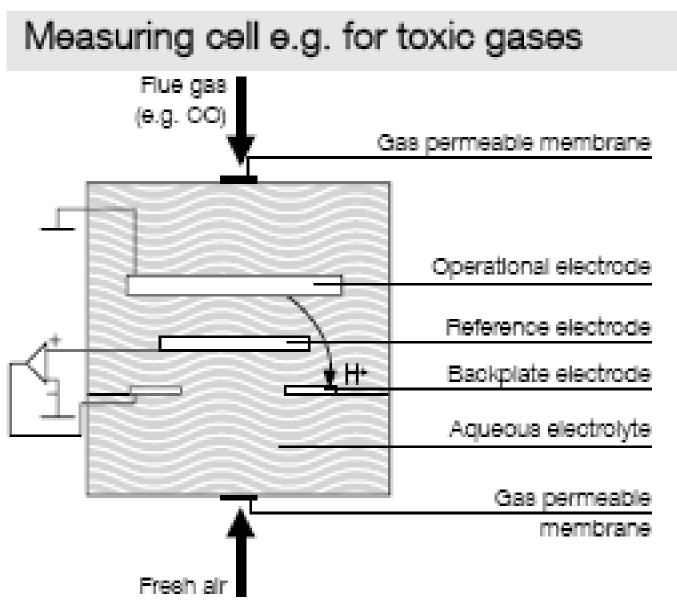
Appendix 5: Information about flue gas analysis

The purpose of flue gas analysis is to ensure environmentally friendly and economic operation of burners. Following formulae and tables can be used to understand flue gas analysis. These information are stored in Testo's flue gas analyzers. All of the calculations are carried out automatically.

Combustion efficiency is calculated by subtracting the flue gas losses from 100% or maximum efficiency.

Measurement principles:

Testo uses electrochemical measuring cells for the O_2, CO, NO, NO_2, H_2S and SO_2 parameters.



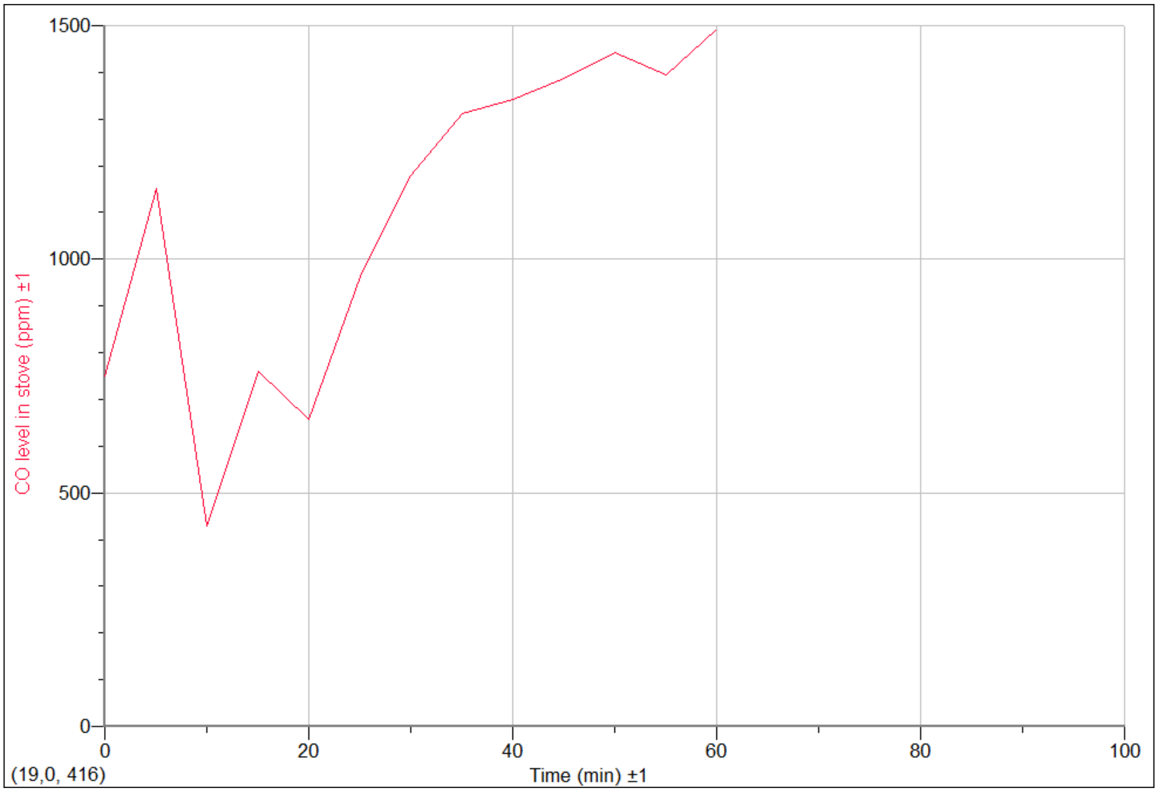
[1]

Figure 1: Figure showing how the Testo flue gas analyzer works.

[1] Flue gas analysers. <www.testo.com.tr>

Appendix 6: Graphs of the results

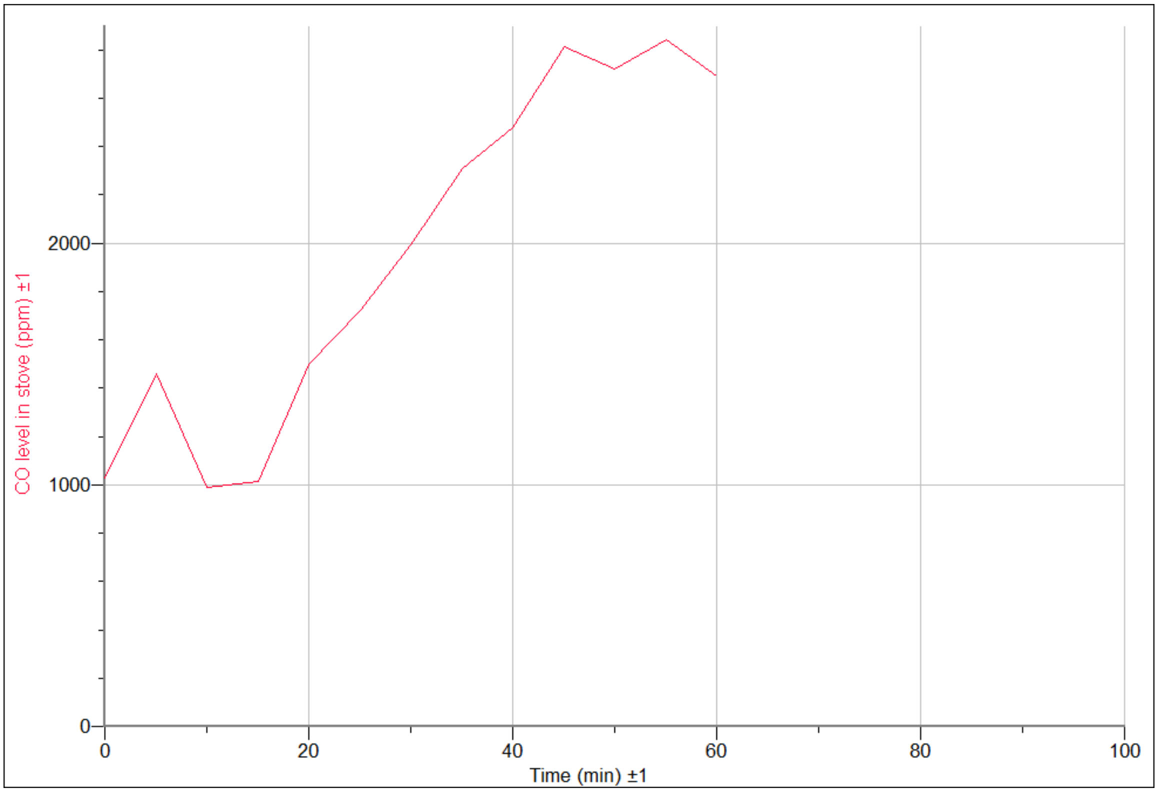
CO level in clean stove (ppm ± 1) versus time (min ± 1)



Graph 1: Mean values of measured CO level in cleaned stove versus time of combustion.

CO level in cleaned stove (ppm ± 1)	Time (min ± 1)
750	0
1151	5
430	10
761	15
656	20
963	25
1180	30
1313	35
1341	40
1388	45
1442	50
1395	55
1492	60

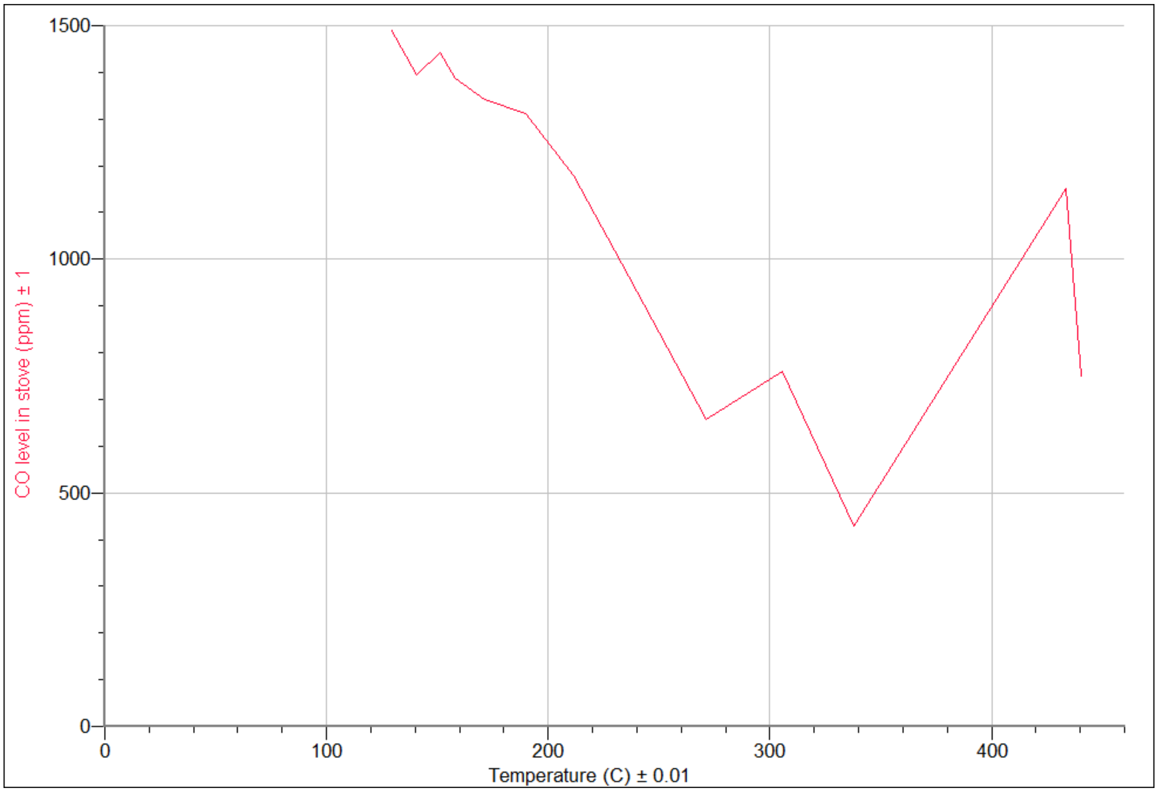
CO level in non-cleaned stove (ppm ± 1) versus time (min ± 1)



Graph 2: Mean values of measured CO level in non-cleaned stove versus time of combustion.

CO level in non-cleaned stove (ppm ± 1)	**Time (min ± 1)**
1028	0
1459	5
991	10
1012	15
1498	20
1720	25
1995	30
2306	35
2480	40
2812	45
2720	50
2843	55
2690	60

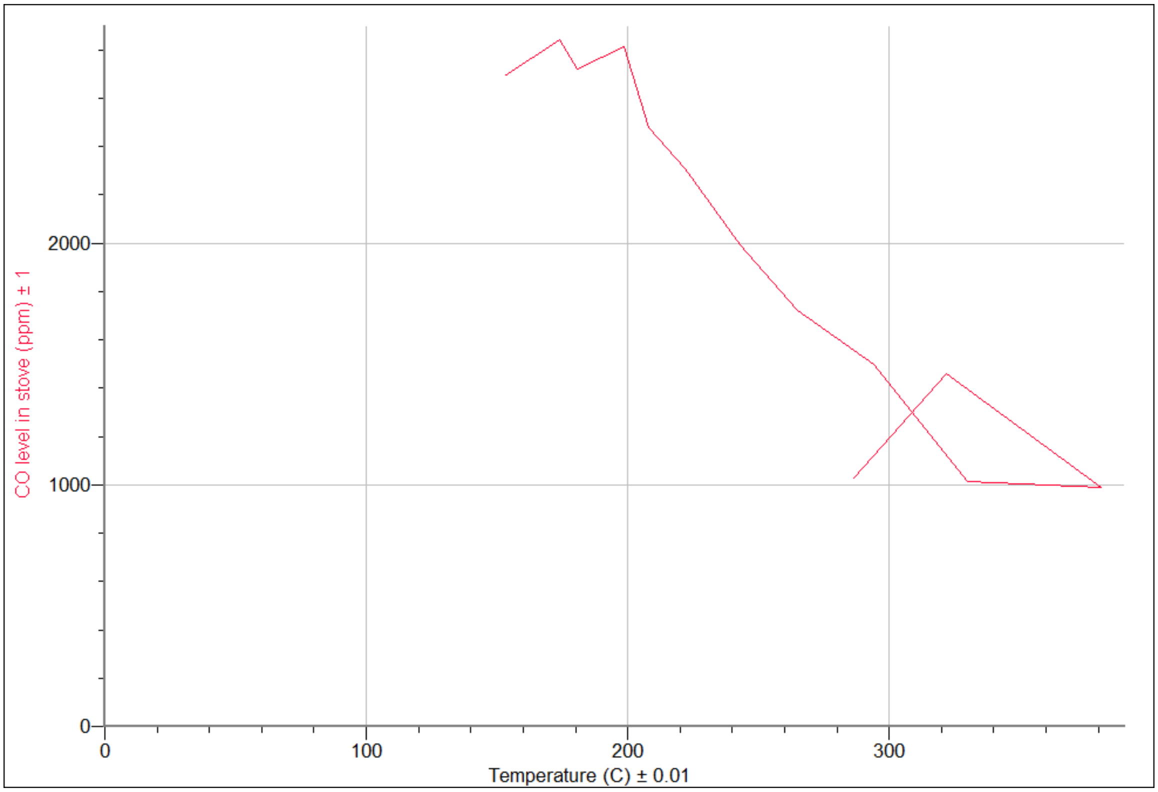
CO level in cleaned stove (ppm ± 1) versus temperature (°C ± 0.01)



Graph 3: Mean values of measured CO level in cleaned stove versus the temperature of the stove during combustion.

CO level in cleaned stove (ppm ± 1)	**Temperature (°C ± 0.01)**
750	440.23
1151	433.50
430	337.77
761	305.63
656	271.47
963	236.27
1180	211.73
1313	189.90
1341	171.30
1388	158.07
1442	151.30
1395	140.83
1492	129.13

CO level in non-cleaned stove (ppm ± 1) versus temperature (°C ± 0.01)



Graph 4: Mean values of measured CO level in non-cleaned stove versus the temperature of the stove during combustion.

CO level in non-cleaned stove (ppm ± 1)	Temperature (°C ± 0.01)
1028	286.23
1459	321.83
991	381.03
1012	329.97
1498	293.90
1720	264.97
1995	242.80
2306	222.00
2480	207.83
2812	198.67
2720	180.63
2843	173.97
2690	152.83