SZENT ISTVÁN UNIVERSITY

Environmental effects on the quantitative and qualitative features of the biogas originated from municipal solid waste

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Géza Tamás Molnár

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Denomination: Mechanical Egineering PhD Scool

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Leader: Prof Dr. István Farkas
Dr. of Technical Sciences
Faculty of Mechanical Engineering
Szent István University, Gödöllő, Hungary

Supervisor: Prof. Dr. István Barótfi
Professor, CSc
Institute for Environmental Engineerig System
Faculty of Mechanical Engineering
Szent István University, Gödöllő, Hungary

…………………………………
Affirmation of head of school

..………………………………
Affirmation of supervisor

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1. INTRODUCTION, OBJECTIVES

In the recent years in Hungary the continuous increase of solid waste, as a result of private consumption, has become a serious issue. In Hungary currently about 23 million m^3 solid urban waste is formed annually. Sixty-two percent (62%) of this waste is household waste and the remaining is waste produced at institutions or service providers which can be treated together with the household waste. Waste management plays a key role in the quality of environment, protecting natural resources and developing environmental security. There can be two basic environmentally harmful effects of waste disposal. One of them is leachate, which percolates through the deposited waste and pollutes ground water, the other is the landfill gas from decomposed organic materials. Landfill sites should have deponia gas discharge duct system in order to comply with the environmental standards. As long as the conditions are established, landfill gas utilization should be worked out. The problem of landfill gas from the decomposition of communal waste got into the focus of attention since it was proved that on the Earth the natural and anthropogen methane and the carbo-dioxide emmission contribute to the so-called glass-house effect. As fossil fuels are finite and are environment pollutants the attention turned to the exploration and exploitation of other alternative energy sources like for instance the bio-gas. The current relevance and significance of the topic is that by the use of modern, state-of-the-art techniques in accordance with EU standards, we could use alternative forms of energy instead of fossil energy sources for both electric and thermal energy production which has both economic and environmental benefits.

The quality and quantity of bio-gas presumably depends on the weather parameters of the refuse dump, the technical parameters of the bio gas recovery system and the organic matter content, typical of the Hodmezovasarhely region. Because of that my objective is to define the the quality and quantity parameters of landfill gas at the refuse dump with regard to the weather parameters, operational factors and the organic matter content. In accordance with the assumption environmental impact can influence directly or indirectly the quality and quantity parameters of the produced landfill gas. Besides the examination of the connection between environmental conditions and gas production it is appropriate to examine the organic matter content of the waste as legal requirements regulate the biodegradable proportion of it. My objectives are the following under the following headings:

1. *Changes of the quality parameters of landfill gas with regard to the vacuum used.* The objective of my examination is to present the effectiveness of the collection system and make the results, gained by statistical methods, usable for everyday life. Based on the measurements I set up rules/coherence about the changes of the qualitative parameters of landfill gas extracted from the refuse dump with regard to the vacuum used, which shows how the extent of aspiration influences the methane content of the landfill gas.

2. *The quality and quantity parameters of landfill gas changes with regard to the average temperature interval, relative humidity, wind speed interval, precipitation and the change in the organic matter content of the waste disposed.* The external characteristics of the refuse dump and its environment were relevant such as weather data between which I looked for connections by mathematical statistical methods. The refuse dump can be considered as a natural bio reactor where not only biological processes but also external conditions have their influence. Because of this it was necessary to examine each external condition and compare them with the measured gas compositions. The results of these examinations can be used at both existing and planned refuse dump sites.

2. MATERIAL AND METHOD

The communal solid waste refuse dump of the *„A·S·A Hódmezővásárhely Köztisztasági Ltd.”* Is located on the outskirts of Hódmezővásárhely on the area No. 01957/1. The refuse dump is situated south of Hodmezovasarhely, west of no. 4414 road, about 5-6 kilometres from the centre. In terms of public service obligation the communal solid waste of Hódmezővásárhely and six other settlements is taken to the refuse dump (Csanytelek, Mindszent, Mártély, Földeák, Békéssámson, Makó, Nagyér), its area of responsibility is 200.000 people. It is operating in accordance with the Waste Management Law of 2000 No. XLIII and the related legislation and the public service contracts signed with the municipalities. The refuse dump and its facilities are built on the basis of an impact assessment of 1994. The refuse dump of Hódmezővásárhely is situated on 20 ha of land and the top height of the landfill is 30m. The refuse dump can store 3,9 million m^3 of refuse and will provide environment friendly storage for the refuse of Hódmezővásárhely and its environs for 50 years. The refuse dump is provided with technical protection, leachate collection system and landfill gas drainage system constructed on the base of Austrian standards. Its cultivation is done by heapmaking technology. Based on the permission of ATIKÖFE the waste that may be delivered to the refuse dump are the following: household waste, not hazardous industrial waste, sewage sludges, debris and soil.

2.1. Technology of landfill gas production at the refuse dump

The elements of landfill gas extracting system are the following: gas wells, gas collecting pipes, gas controller unit, compressor unit, torch, container with gas engine, meteorological station (Figure 1.). The collection of landfill gas is with the help of gas wells. At the beginning there were low drainage gas wells used at the refuse dump but because of their sinking and deformation the effectiveness of gas extraction was impeded. They converted to upper drainage gas wells which are only built after the dump is completely filled or reached a certain height. It does not interfere with the operation and good quality landfill gas is attainable.

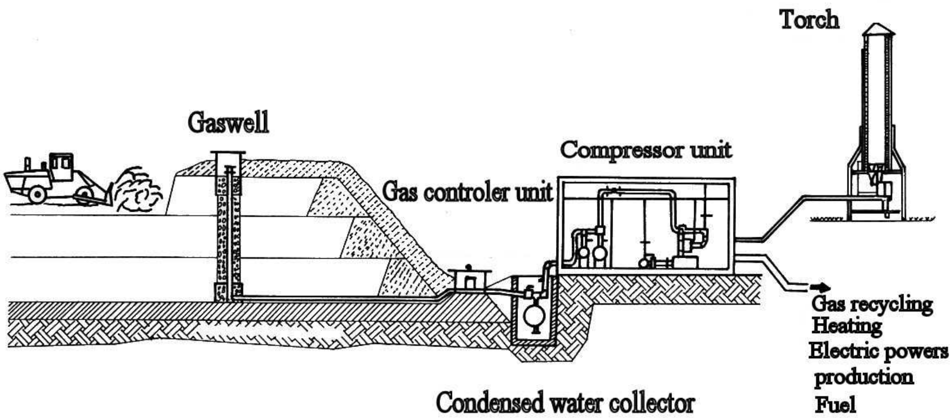

Figure 1. Process figure of gas production

Considering the total amount of waste and the time there would be 60 gas wells to collect landfill gas and the maximum planned production would be 2950m^3/day. At present there are 15 gas wells working on the site the others will be put into service after the dumps are filled. In the gas controller unit every gas pipe of the gas well can be controlled. In the controlling unit It is possible to divide landfill gas into two different quality as usable or torchable. Accordingly, there are two parallel main collecting pipes. Before connecting to the main pipes, the pipes are provided with valves, samplers and flame arrestors. Through the sampler it is possible to measure pressure, temperature and flow rate. The main collecting pipes are structured with a gradient in the direction of the water of condensation isolator pits.

Condensation water is collected through reducers in a pool, insulated by PE-HD concrete lamina. The depth of the pit and the length of the separator will be developed according to the negative pressure in a way that the main collecting pipe would not get wet and the water level could be checked regularly. The vacuum-pump is kept in a container, its parameters were defined by landfill gas prediction. The first vacuum pump installed at the refuse dump has 0-500 m^3/h transport capacity. In order to burn off landfill gas a high-temperature torch is needed, its operation happens through the checking and maintenance of the gas engine unit. The electronic and filter unit are kept in the container of the vacuum pump, sampling is through the measuring pipe. Safety requirements must be strictly obeyed as mix of methane and air, when methane is 5-15 tf% and air is 11.6 tf%, is capable of exploding. For this reason measuring gas concentration is indispensable. For the sake of safe operation the system switches off the compressor when 25tf% CH_4 and 6tf% O_2. This concentration can only appear in the first part of the drainage when the layer of the waste is not very thick. Until the first raising of the layer extraction is not started as the gas well is not able to function well. When the thickness of the waste is 4 metres landfill gas extraction can be started. Due to the quality and quantity of the originating landfill gas on the refuse dump in Hodmezovasarhely, it can be recycled for energy production. This energy can be used in heating social facilities on the premises and burn it in gas engines.

2.2. Planning of the examination

While planning the examination my basic task was to set up my hypothesis. According to my hypothesis the changes of the quality and quantity parameters of landfill gas originating in the refuse dump can be influenced by the environmental characteristics of the region, operational characteristics and the changes of the organic matter content of the waste deposited. Changes in the quality and quantity of landfill gas parameters can be caused by average temperature interval [C°], precipitation [mm/day], wind speed interval [m/s], barometric pressure [hpa] and relative humidity [%]. The quality and quantity parameters can be influenced by the operational characteristics of the gas extracting system, the extent of extraction [mbar] and the concentration of organic matter [%].

2.2.1. The location of the measuring system at the refuse dump

At the communal solid waste refuse dump of the “A.S.A Hódmezővásárhely Köztisztasági Ltd.” a computer data collection system and a measuring system is available to examine the quality and quantity of landfill gas (Figure 2). The vent pipes of the waste unite in a common pipe located in a shaft then, going through the measuring system, they join a gas-motor power plant for the energetic utilization of the landfill gas. During my examinations I measured the following parameters: extraction side vacuum [mbar], operating pressure [mbar], CH_4, O_2 [%], outside temperature [C°], landfill gas temperature [C°], momentary gas production [m^3/h], total gas amount [m^3/day], hazards due to emission of gas indicator [%] and compressor [h].

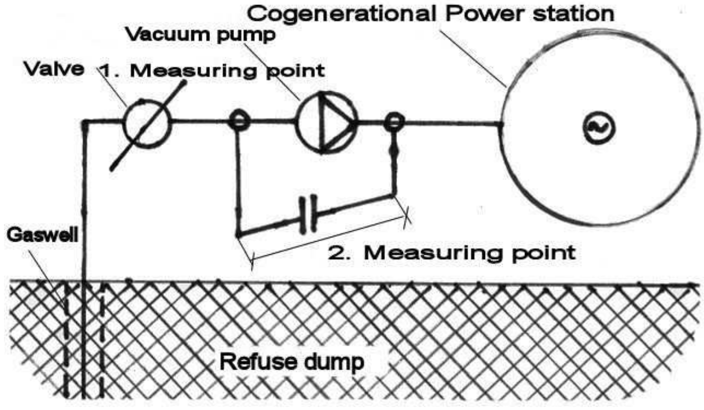

Figure 2. The location of measuring system at the refuse dump

When preparing the measuring system three measuring points were established. Measuring point 1 is the two measuring cones, one for measuring the applied depression [mbar] and the other is for measuring the quality compound of the landfill gas (methane [%], carbon dioxide [%], oxygen [%]) and the opening angle of the sluice valve [°]. Measuring point 2 is situated at the vacuum pump. Pressure values can be measured in front of and behind the pump, and thus the amount of the pressure difference can be calculated. From the pressure difference flow rate of the extracted landfill gas without pipe friction can be calculated and then, with the pipe diameter, the amount of the produced landfill gas. Measuring point 3 is located at the meteorological station of the refuse dump. It provides the weather parameters**:** t_k: external temperature [°C], φ: air humidity [%], v_{sz}: windspeed [m/s], h: rainfall intensity [mm/day]**,** P_h: local atmospheric pressure (QFE).

2.2.2. Evaluating data, statistical methods, measuring instruments

For diagnosing the degradation process in the refuse dump and optimizing energy recovery I used a GA2000 type NDIR (Non Dispersive Infra Red) analyzer, working in the medium infrared region.

The data was statistically processed with SPSS for Windows 11.0 program was used. The data was processed by the method of analysis of variance. Homogeneity was examined with the Levene-test. When comparing the group-couples Tamhane test (in case of heterogeneity), and LSD test (in case of homogeneity) were applied. The tightness between variables was determined by linear regression analysis. In my examinations I calculated the necessary number of data by using a method by [Sváb, 1981]. In order to be able to determine the necessary number of data in a sample you have to be aware of the standard deviation (s), you have to provide the permissible estimation of errors (h), have to give the P% significance level or the likelihood of error. If we know the standard deviation in the unit of measurement of the data and the permissible estimation of errors are given in the same unit of measurement the sample size of the data can be calculated:
:

$$n = \frac{t_{P\%}^2 \cdot s^2}{h^2}$$

n: number of items, $t_{p\%}$: critical element of the „t”test, s: standard deviation, h: estimation of errors

In case standard deviation is known in percentage (coefficient of variation) and the permissible estimation of errors is also given in percentage then the number of necessary elements can be defined by the following formula:

$$n = \frac{t_{P\%}^2 \cdot s\%^2}{h\%^2}$$

n: number of items, $t_{p\%}$: critical element of the „t”test, s%: standard deviation percentage (coefficient of variation) (%), h%: estimation of errors percentage (%)

I made the calculations for a P=3% and P=5% probability level. According to my results in the case of h%=3% estimation of error the sample size for the statistical analysis of the results and drawing the relevant conclusions is n=363 pieces, in the case of h%=5% estimation of error the necessary sample size is n=131 pieces. On this basis I have concluded that the data I collected (n=517) is sufficient to carry out the appropriate statistical examinations and analysis. Even though I carried out the Levene test, by which I concluded which test to use at the comparison of group pairs (Tamhane or LSD) I found it important to calculate the CV% (coefficient of variation) as well. I would like to present the standard deviation within each group by the analysis of coefficient of variation, which was specified by the following formula:

$$s\% = CV = \frac{s}{\overline{\overline{X}}} \cdot 100$$

CV: coefficient of variation [%], s: standard deviation, x: average of dataline

2.2.3. Examinations and the baseline data used during data evaluation

Waste potential generated in the region of Hódmezővásárhely

As the result of the waste analysis by MSZ 21976 standard to determine the biodegradable organic matter content of municipal waste it can be stated that 53% of the total collected amount (19.322.24 tons) of solid municipal waste (EWC 200301), that is 10240.78 tons can be considered biodegradable and it can be considered as biomass potential (Table 1). Usable biomass potential and speculative landfill gas yields produced from municipal waste from Hódmezővásárhely and its region for 2007 are shown in Table 2. Speculative amount of landfill gas produced from municipal waste is 2,244,424 m^3. During my calculations I considered the most favorable yield, which are the following: municipal waste 256m^3/t, sewage sludge 310m^3/t, oily waste 190m^3/t, green wastes 190 m^3/t. The amount of landfill gas produced depends on the composition of the waste and is 40-300m^3/t (by organic content of waste), by practical experience the actual amount of landfill gas that can be produced is 2-3 m^3/t annually. It has to be considered that depending on the gas convey system and its operation only 30-50% of the total amount of landfill gas can be utilized. Differences between theoretical and practical amounts can be because of the changes of the environmental parameters, the organic matter content of waste, the type and composition of the waste and its physical characteristics, degradation conditions and the consistency of waste.
Amount of landfill gas generated in Hódmezővásárhely refuse dump: V_t[m^3/t waste] according to Tabasaran/Rettenberge formula:

$$V_t = 1.868 \cdot C_O \cdot (0{,}014 \cdot T + 0{,}28) \cdot (1 - 10^{kt}) \qquad \text{[Tabasaran/ Rettenberger, 1987]}$$

C_o: proportion of organic carbin of waste [kg/t waste], 1.868: gas production of organic matter [m^3/kg], T: waste temperature [°C], k[-]: degradation constant, t: time [year]

Table 1. Amount of municipal waste by A.S.A. weight data

Year	**Household waste (t)**	**Industrial waste(t)**	**Construction waste (t)**	**Sewage sludge (t)**	**Oily waste(t)**	**All (t)**
2005	31 071,33	13 516,56	11 414,32	3 209,93	11 970,97	71 183,11
2006	28 203,54	14 517,83	19 355,94	4 691,90	10 796,56	77 565,77
2007	**19 322,24**	**21 201,81**	**36 599,36**	**3 396,94**	**10 481,13**	**91 001,48**
2008	19 253,24	20 930,55	14 192,47	2 565,82	10 334,30	67 276,38
2009	20 974,66	17 403,90	12 479,42	2 984,42	6 888,89	60 731,29
2010	36 646,02	21 364,48	12 982,00	2 452,29	11 423,96	84 868,75

Table 2. Produced municipal waste by areas and energy recovery

Area	Biomass potential [t]	Landfill gas recovery [m^3/t]	Landfill gas produced [m^3]	Landfill gas caloric value [MJ/m^3]
Hmvhely	7574,94t	256	1.939.184	21
Mindszent	826,36t	256	211.456	21
Mártély	151,04t	256	38.666	21
Székkutas	188,34t	256	48.215	21
Green waste	1500t	190	285.000	21
Sewage sludge	713,16t	310	221.079	21
Oily waste	524t	190	99.560	21
All	11477,94t		2.843.160	21

Examination of environmental conditions of Hódmezővásárhely region

One of the most important factors of landfill gas generation and composition is the climatic changes of the refuse dump. From the environmental parameters being aware of the external temperature, relative humidity, barometric pressure, level of rainfall and wind conditions is necessary (Table 3).

Table 3. Environmental conditions in the Hódmezővásárhely region

Title	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX	X.	XI.	XII.	Annual
Average temperature [°C]	1,6	0,1	5,7	11,1	16,5	19,7	22,1	21,3	17,3	11,1	5,2	0,5	10,8
Average rainfall [mm/month]	34	34	34	46	62	71	52	48	47	41	50	46	565
Mean evaporation [mm]	5	10	22	48	81	88	85	65	49	27	11	6	500
Wind direction frequency [%]	**É**	**ÉK**	**K**	**DK**	**D**	**DNY**	**NY**	**ÉNY**	**Windstille**				
	15,2	12,9	4,4	6,9	15,5	16	9,4	12,8	6,9				

2.3. Examinations carried out on the refuse dump

I carried out my examinations between 01.01.2007 and 31.12.2007 forty-seven times at eleven gas wells. I determined the necessary number of items needed for the statistical studies and needed to determine significant differences. The number of measurements are n=517 which is sufficient for the minimal number of items needed to carry out appropriate statistical examinations. Measurements were taken daily or weekly, the measured results were recorded. Due to the fact that no data were available about the composition of the waste I did not take the characteristic waste composition values of a particular gas well into account. In order to ensure manageability I created groups and by using statistical examinations I stated significant differences in the cases of all and then each gas well. While creating the group pairs it was crucial to set up a connection between the volume of extraction used, average temperature intervals, relative humidity, barometric pressure, precipitation, wind speed intervals in connection with the quality and quantity parameters of landfill gas created in the refuse dump.

2.3.1. The examination of the composition of waste taken to the refuse dump

The examination was carried out on the A.S.A. Hódmezővásárhely refuse Ltd.'s second and third landfill sites where I analysed the unloaded waste. When laying down the boundaries of the areas for the surveys it had to be taken into consideration where the waste is produced. The areas covered in the examination are the following: Hódmezővásárhely public domain, Hódmezővásárhely downtown, Hódmezővásárhely suburb. This method represents the waste composition for the entire landfill site. During the examination I examined the first loads which arrived each day. On the basis of the entire daily delivery the composition of the total amount of waste can be concluded. Due to this the waste delivered within a day is aggregated by EWC codes. A.S.A. Hódmezővásárhely Ltd. carried out the compulsory winter, sping, summer and autumn monitoring provided in the standard environmental performance permissions by the notice of the Environmental inspectorates (Table 4). Waste composition examination was made by MSZ 21420-28 and MSZ 21420-29 standards where I divided the total waste into 13 fractions and their sub fractions and from these I specified biodegradable proportion in the refuse dump.

Table 4. The amount of waste covered in the examination of waste composition in 2007

		2007.12.18 **winter** *3. site*	**2007.04.06** **spring** *2. site*	**2007.07.10** **summer** *3. site*	**2007.09.05** **autumn** *1. site*
A	Gross mass of the collecting vehicle [kg]	11540 kg	28220 kg	11540 kg	28220 kg
B	Raw nett mass [kg]	1040 kg	11740 kg	1040 kg	11740 kg
C	Mass of average sample [kg]	504,7kg	499,57kg	501,5kg	503,5kg

2.3.2. Volume of extraction and the quality parameter changes of landfill gas

I carried out my examinations in accordance with barometric pressure and the local site-specific pressure conditions. Landfill gas conveys system can be made controllable by using gate valves at gas wells. By changing the opening angle of the gate valves the depression of the waste gets lower or higher and because of this the quality parameters of landfill gas also changes. At landfill sites where landfill gas recovery system works, being aware of the capacity of the recovery system is the most important operation parameter. During the operation we should endeavour that gas wells on the refuse dump always provide 45-50% methane, which is necessary for the operation of gas engines. Pressure groups and their associated gas well methane content numbers were organised. During the statistical process I examined what connection can be found between the volume of extraction and the methane content of landfill gas in the case of all and each gas wells. I processed the data by analysis of variance by using SPSS for Windows 11.0 and I also used the linear regression procedure in the cases of gas wells.

2.3.3. Environmental impacts on the quantitative and qualitative parameters of landfill gas

Data of average temperature [°C], relative humidity [%], barometric pressure [hpa], wind speed [m/s], stand precipitation [mm/day] provided by the meteorological station on the refuse dump were combined with the measured qualitative and quantitative parameters.
During the examinations I created measuring groups, definition of group establishment is in Table 5. I processed the data by analysis of variance by using the SPSS for Windows 11.0 program. During the statistical process I examined what connection can be found between the average temperature interval, relative humidity, barometric pressure, wind speed interval precipitation changes and the quantity and quality parameters of landfill gas in the case of all and each gas well. I found significant differences between group pairs on the basis of the methane content of the pairs. The connection examinations between the variables of the gas wells were made by regression analysis. The results I got through the calculations are presented in charts, graphs and diagrams.

Table 5. Definition of group creating and their operating parameters

	Pressure groups	**Temperature groups**	**Wind speed groups**	**Humidity groups**	**Precipitation groups**	**Barometric pressure groups**
	Extent of extraction [mbar]	**Average temperature interval [°C]**	**Wind speed interval [m/s]**	**Relative humidity [%]**	**Stand precipitation [mm/day]**	**Barometric pressure [hpa]**
1. group	≤ (-3)	≤ 5	v_{sz}<=0,6	50-60	0	1000 - 1010
2. group	(-2,9) - (-2)	5-10	0,6 > v_{sz} <=1	61-70	0,1 - 1	1010 - 1020
3. group	(-1,9) - (-1)	10-15	1 > v_{sz} <=1,3	71-80	1 - 3	>1020
4. group	(-0,9) - 0	15-20	1,3 > v_{sz} <=1,8	81-90	3-5	
5. group	0,1 - 1	20-25	1,8 > v_{sz} <=2,4	>90	>5	
6. group	1,1 - 1,9	25-30	v_{sz} >2,4			
7. group	≥ 2					

3. RESULTS

3.1. Examination results of the organic matter content of the delivered waste

Composition of waste in 2007 winter

The mass of the waste at the primary sorting was 504,7 kg, the weight of waste remaining on the upper sieve (D>100) was 146,2 kg, the weight of biodegradable waste was 5,4 kg (3.7%) and there was 31,5 kg paper (21,5%) (Diagram 1).

At the secondary sorting the mass of waste was 358,5 kg, the weight of waste remaining on the middle sieve (20<D<100) was 42,55 kg, the sample diminution ratio is 8,425. During secondary sorting the weight of biodegradable waste was 22,1 kg (51.9%) and the weight of paper was 1,5 kg (3.5%).

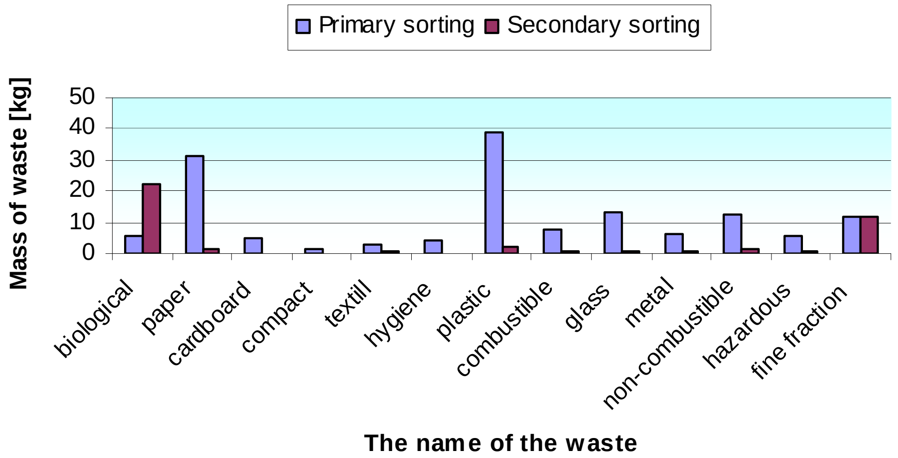

Diagram 1. Composition of remaining waste on the upper and middle sieve examination results

Composition of waste in 2007 spring

The mass of waste at the primary sorting was 499,5 kg, the weight of waste remaining on the upper sieve (D>100) was 196,35 kg, the weight of biodegradable waste was 22,6 kg (11,5%) and there was 48,5 kg paper (24,7%) (Diagram 2).

At the secondary sorting the mass of waste was 303,5 kg, the weight of waste remaining on the middle sieve (20<D<100) was 40,1 kg, the sample diminution ratio is 7,56. During secondary sorting the weight of biodegradable waste was 6,9 kg (17.2%) and the weight of paper was 8,2 kg (20.6%).

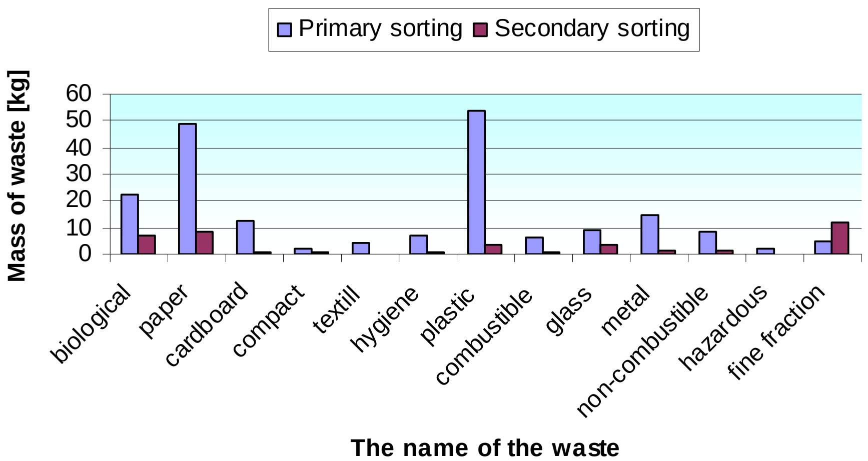

Diagram 2. Composition of remaining waste on the upper and middle sieve examination results

Composition of waste in 2007 summer

The mass of waste at the primary sorting was 501,5 kg, the weight of waste remaining on the upper sieve (D>100) was 160,5 kg, the weight of biodegradable waste was 16,8 kg (10,5%) and there was 36,1 kg paper (22,5%) (Diagram 3). At the secondary sorting the mass of waste was 341 kg, the weight of waste remaining on the middle sieve (20<D<100) was 41,5 kg, the sample diminution ratio is 8,21. During secondary sorting the weight of biodegradable waste was 11,62 kg (28,1%) and the weight of paper was 7,4 kg (18%).

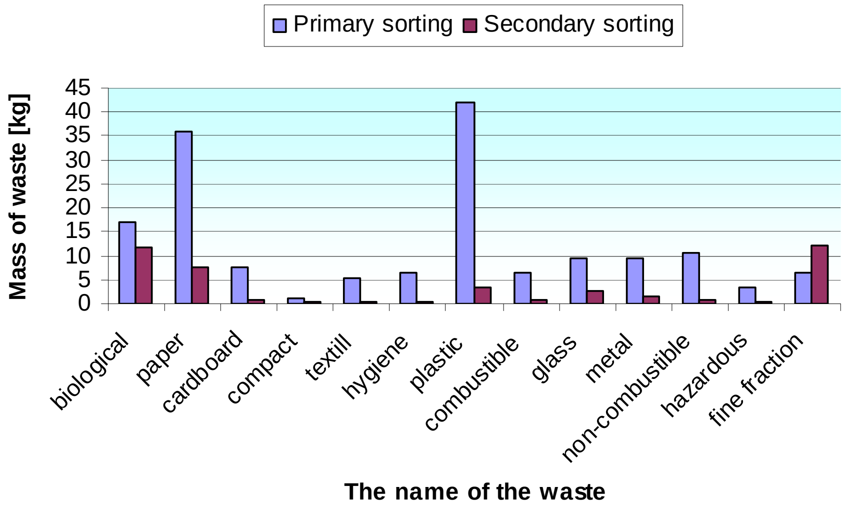

Diagram 3. Composition of remaining waste on the upper and middle sieve examination results

Composition of waste in 2007 autumn

The mass of waste at the primary sorting was 503,5 kg, the weight of waste remaining on the upper sieve (D>100) was 186,5 kg, the weight of biodegradable waste was 22,5 kg (12,1%) and there was 38,24 kg paper (20,5%) (Diagram 4). At the secondary sorting the mass of waste was 317 kg, the weight of waste remaining on the middle sieve (20<D<100) was 40,6 kg, the sample diminution ratio is 7,80. During secondary sorting the weight of biodegradable waste was 19.4 kg (48%) and the weight of paper was 3,37 kg (8,3%).

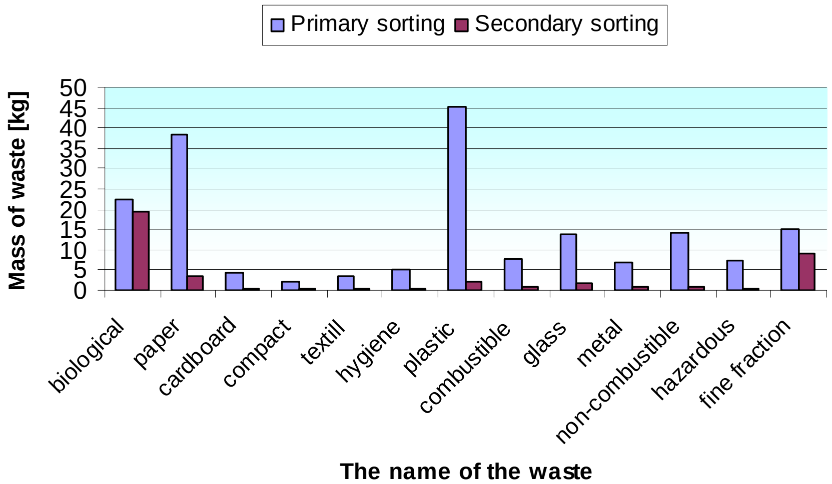

Diagram 4. Composition of remaining waste on the upper and middle sieve examination results

The determining factor of the biodegradable waste is the household waste and the green waste. Sewage sludge contains 30% of degradable organic matter, but municipal waste contains only 3-4% so it does not change significantly the organic matter concentration. Oily waste does not change the organic matter concentration either, as it can cause only about 1.5% concentration rise with the permitted oil concentration by the Environment Performance permission.

3.2. Changes of the quantity parameters of landfill gas with regard to the depression used

In the first part of my examinations I tried to find a connection between the vacuum used and the methane content of landfill gas extracted from the refuse dump. My results can be seen in Table 6. I took my measurements according to the barometric pressure by using a GA2000 landfill gas measuring device with regard to the environmental conditions of pressure. Minimum and maximum data are between the rates of 1-68 CH_4. In the group with the most elements in it ((-0,9)-0) I found 52,44% methane content. The worst rate, 43,34% methane content, was found in the 2nd group ((-2,9)-(-2)), in the 1st group with 45 measurements I found 45,47% methane content. As it can be seen from the results, in the cases of groups 4, 5 and 6 the average methane content is between 51,15-54,11% because of the vacuum used. In this case the applied rate of vacuum was between (-0,9)–1,9 mbar.

Table 6. Results of the connections between the volume of extraction and methane content

Preesure group	Volume of extraction [mbar]	n [pcs]	CH_4 mean [%]	Coefficient of variation CV% [%]	Std. deviation [%]	95%Confidence interval for mean		Minimum [%]	Maximum [%]
						Lower bound	Upper bound		
1. group	≤ (-3)	45	45,47	32,82	14,924	40,99	49,95	6	66
2. group	(-2,9) - (-2)	58	43,34	33,94	19,042	38,33	48,34	6	65
3. group	(-1,9) - (-1)	95	46,15	31,73	14,644	43,16	49,13	13	68
4. group	(-0,9) - 0	180	52,44	21,58	11,317	50,78	54,11	25	66
5. group	0,1 - 1	72	54,11	15,97	8,644	52,07	56,14	31	68
6. group	1,1 - 1,9	41	51,15	34,47	17,635	45,59	56,72	5	66
7. group	≥ 2	18	50,87	39,76	20,226	40,81	60,93	1	67
	Total	517	49,67	28,82	14,319	48,44	50,94	1	68

At gas wells where the extent of aspiration is over (-0,9 mbar) the larger vacuum the methane content lowers so the elements of the gas extraction system have to be under continuous observation (Diagram 5). Standard deviation in the whole test range was s=14,319%, coefficient of variation value was changeable, CV%=28,82%. In the 4th group in the measuring range with the highest number of elements ((-0,9)-0mbar) CV%=21,58% proved to be moderately volatile at 52,44% average methane content. In case of the 5th group in the 0.1-1 range CV%=15,97 because standard deviation is s=8,64% and the changes of minimum and maximum values show 31-68% of methane content.

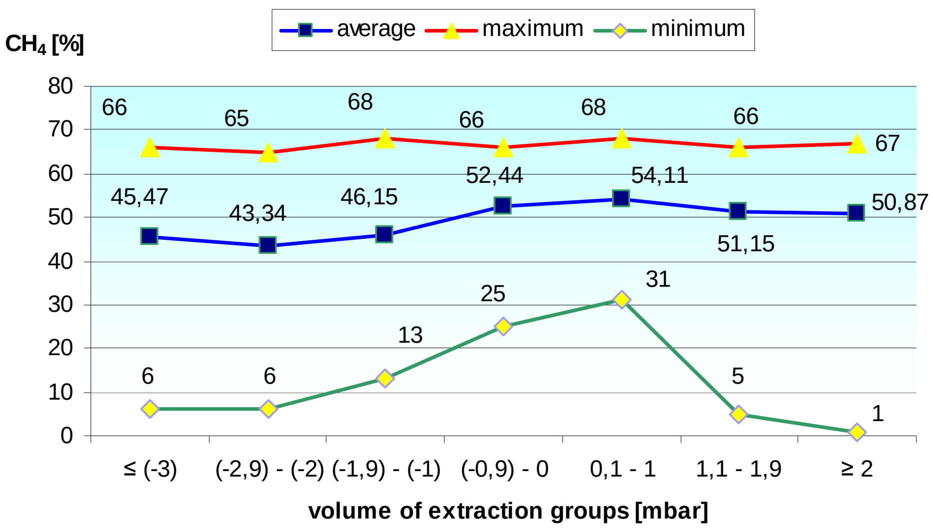

Diagram 5. Results of the connection between aspiration groups and methane content

Analysis of variance proved significant results between the group pairs as the level of significance is P<5% for the examined parameters. In case of the homogeneity tests the samples showed heterogeneity so I use the Tamhane test. Results of the analysis between the groups can be seen in Table 7. The biggest difference is between group 5 (0.1-1) and group 2 ((-0.9)-0) the difference was 10,77% methane content. There was also a big difference between group 4 ((-0.9)-0) and group 2 (-2.9)-(-2) in this case methane content difference was 9,11%.

From the figure you can see that the smallest difference, 0,29% methane content, is between group 6 (1.1-1.9) and group 7 (≥2). There are significant differences between group 4 and group 2, P<5%, and the significant difference between group 3 and group 4 is P<1%. From the processed data we can conclude that under -0.9 mbar pressure there is no significant difference but in case of higher pressure methane content values get worse.

Table 7. Differences in the methane content of the examined groups and group pairs results

Pressure group	Volume of extraction [mbar]	**1. group** ≤ (-3)	**2. group** (-2,9) - (-2)	**3. group** (-1,9) - (-1)	**4. group** (-0,9) - 0	**5. group** 0,1 - 1	**6. group** 1,1 - 1,9	**7. group** ≥ 2
1. group	≤ (-3)	-	ns	ns	ns	*	ns	ns
2. group	(-2,9) - (-2)	2,13	-	ns	*	**	ns	ns
3. group	(-1,9) - (-1)	0,68	2,81	-	**	**	ns	ns
4. group	(-0,9) - 0	6,97	9,11	6,3	-	ns	ns	ns
5. group	0,1 - 1	8,63	10,77	7,96	1,66	-	ns	ns
6. group	1,1 - 1,9	5,68	7,82	5,01	1,29	2,95	-	ns
7. group	≥ 2	5,4	7,53	4,72	1,58	3,24	0,29	-

ns = not significant, * = P<5%, ** = P> 1%

In case of all gas wells I carried out a linear regressive examination taking both methane content and volume of aspiration into account. Its results can be seen in diagram 6. Change of methane content in relation to the vacuum used can be described by the following equation: $y=3,5607x+51,72$, $R^2=0,2644$. Correlation coefficient is r=0,52. The closeness of coherence shows a centralized correlation.

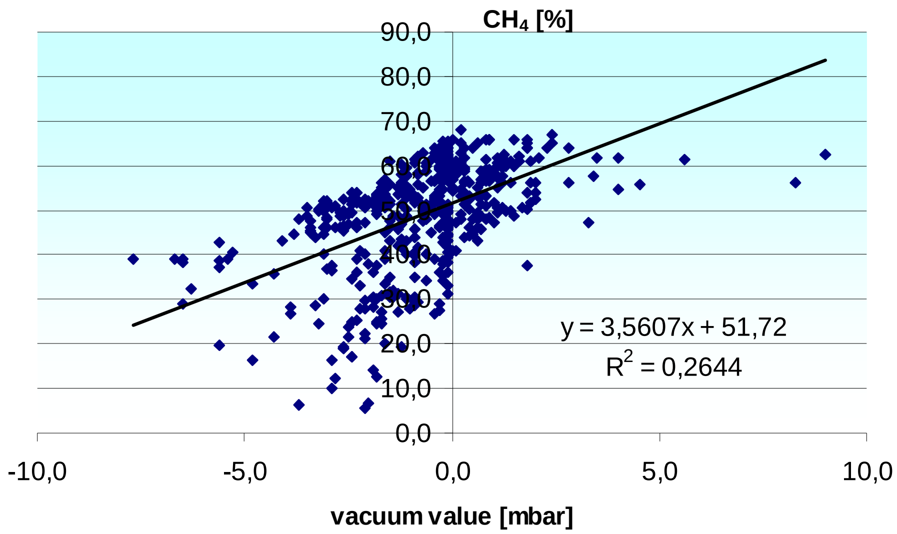

Diagram 6. Changes of methane content in all gas wells in connection with volume of aspiration

4.2.1 Results of the examination by each gas well

During the next part of my examination I looked for relationships about how the vacuum values of the gas wells influence methane contents. For this reason I connected the methane content values and the volume of aspiration values of each gas well and created 1-7 groups. The results can be seen in Table 8.
During data procession I concluded that the average methane content ranged from 32,53 to 61,12%. The least favorable value was found in case of the 2nd gas well where only 10,10% methane content was measured in the 7th group (≥2 mbar) of pressure range. The reason for this is the methane content decrease due to the enormous aspiration on the landfill and the specific biological surroundings of the gas well. The most favorable average methane content value was found in case of the 6th gas well where the fluctuation of methane content within groups ranged from 49,60 to 63,73%. In case of the 3rd, 4th, 5th and 6th gas wells I could not make measurements in the 6th and 7th pressure groups. The change in the volume of aspiration on the landfill influences the methane content of the recoverable landfill gas so we have to pay special attention to that and by controlling the valves the most optimal gas yield and methane content can be accomplished. In case of the gas wells the controlling does not only concentrate on methane content of the local wells but have to make sure that the recovery of the gas from the gas wells provides the necessary quality and quantity parameters of landfill gas for the operation of the gas engines (45m^3/h, 45%).

Table 8. Methane content at each gas well with regard to the volume of extraction

Pressure group	**1. gas well** CH_4 [%]	**2. gas well** CH_4 [%]	**3. gas well** CH_4 [%]	**4. gas well** CH_4 [%]	**5. gas well** CH_4 [%]	**6. gas well** CH_4 [%]	**7. gas well** CH_4 [%]	**8. gas well** CH_4 [%]	**9. gas well** CH_4 [%]	**10. gas well** CH_4 [%]	**11. gas well** CH_4 [%]
1. group	36,21	49,33	48,80	43,50	43,63	49,60	43,85	54,50	41,12	19,80	38,97
2. group	39,07	30,82	36,50	34,50	55,60	60,69	47,60	56,80	40,78	42,75	30,50
3. group	32,23	34,65	37,55	49,12	44,70	55,80	41,30	58,52	43,93	56,84	29,58
4. group	43,02	38,75	38,27	54,35	52,38	61,03	54,56	61,04	42,90	52,89	55,07
5. group	56,55	55,00	48,24	60,25	65,23	63,90	60,60	54,60	50,20	55,78	49,43
6. group	60,95	22,14	-	39,60	50,63	62,93	-	64,00	59,48	59,10	59,91
7. group	57,12	10,10	56,20	-	-	63,73	-	65,00	59,03	56,00	55,70
Total	47,1	32,53	42,47	53,03	51,67	61,12	52,50	58,99	46,63	54,15	45,16

Analysis of variance proved significant results between the group pairs as the level of significance is P<5% for the examined parameters. In case of the homogeneity tests, the homogeneity and heterogeneity of the samples were diagnosed by Levene test and on the basis of the results of the Levene tests I used the Tamhane and LSD tests during the statistical processing (Table 9).
The results of the homogeneity test are the following: gas well no. 1 (sig=0,027), gas well no. 2 (sig=0,051), gas well no. 3 (sig=0,195), gas well no. 4 (sig=0,096), gas well no. 5 (sig=0,398), gas well no. 6 (sig=0,145), gas well no. 7 (sig=0,001), gas well no. 8 (sig=0,006), gas well no. 9 (sig=0,000), gas well no. 10 (sig=0,071) and gas well no.11 (sig=0,008). The amount of data collected for gas wells number 3,4,8 and 10 pressure groups, was not sufficient for the statistical program to find a statistical connection for wells.

At the 1st gas well analysis of variance proved significant results between the group pairs as the level of significance is P<5% for the examined parameters. There are significant differences between group 3 and group 5, P<1%, and the significant difference between group 3 and group 7 is P<5%. In case of the 2nd gas well there are significant differences P<1% between the 7.-5., 6.-1. and 7.-1. group pairs. P<5% significant differences were found between 7.-3., 6.-5. and 7.-4. group pairs.

Table 9. Results of the statistical processes for each gas well

	Results of homogenity examination	Significant differences between group pairs in *P<5% level		Significant differences between group pairs in **P<1% level		Methane content differences CH_4 [%] *P<5%		Methane content differences CH_4 [%] **P<1%	
1. gas well	heterogeneos (Tamhane)	7.-3.		5.-3.		24,86%		24,31%	
2. gas well	homogeneous (LSD)	6.-5. 7.-3.	7.-4. -	6.-1. 7.-1.	7.-5 -	32,86% 24,55%	28,65% -	27,18% 39,22%	44,90% -
3. gas well	heterogeneos (Tamhane)	eh.		eh.		-		-	
4. gas well	heterogeneos (Tamhane)	eh.		eh.		-		-	
5. gas well	homogeneous (LSD)	5.-4.		5.-1.	5.-3.	12,85%		19,60%	20,53%
6. gas well	homogeneous (LSD)	ns.		ns.		-		-	
7. gas well	heterogeneos (Tamhane)	ns.		ns.		-		-	
8. gas well	homogeneous (LSD)	eh.		eh.		-		-	
9. gas well	homogeneous (LSD)	6.-2.		ns.		18,70%		-	
10. gas well	homogeneous (LSD)	eh.		eh.		-		-	
11. gas well	heterogeneos (Tamhane)	6.-3.	6.-5.	-		30,33%	10,47%	-	

ns = not significant, * = P<5%, ** = P< 1%, eh = lack of data

In the 5th gas well analysis of variance proved significant results, in the cases of 5.-3. and 5.-1. group pairs I found P<1% significant differences, in the case of 5.-4. group pair I found P<5% significant difference. In the cases of 6th and 7th gas wells after the statistical procession (SPSS for Windows 11.0) I found no significant differences. In the 9th gas well analysis of variance proved significant differences, P<5%, in the case of 6.-2. group pair. In the 11th gas well analysis of variance proved significant differences in the cases of 6.-3. and 6.-5. group pairs I found P<5% significant difference.

In the cases of the 11 gas wells I combined the methane content values that I measured and the volume of extraction and I carried out a linear regression examination. Results can be seen in Table 10. From the values of the coefficient of correlations it can be seen that methane content of the landfill gas is influenced by the changes of the volume of the vacuum. The closeness of the relationships is either loose or a middle close correlation (r=0,37-0,69). The most favorable correlation relationship was found in case of the 7th gas well, r=0,69. There is positive correlation relationship in case of all the gas wells which means that by increasing vacuum compared to barometric pressure the measurable methane content significantly decreases and the level of oxygen content increases, the change is unidirectional and the correlation is straight. It requires exact regulations in order to recover the most optimal landfill gas yield and avoid fire or explosion.

Table 10. Coefficient of correlation changes by gas wells with regard to methane content and volume of extraction

	Linear equation	R^2	r
1. gas well	y = 2,5852x + 48,628	0,1984	*0,4454*
2. gas well	y = 3,0598x + 29,557	0,1403	*0,3745*
3. gas well	y = 3,0127x + 43,064	0,1473	*0,3837*
4. gas well	y = 3,1633x + 54,149	0,1502	*0,3875*
5. gas well	y = 3,724x + 53,784	0,3762	*0,6113*
6. gas well	y = 1,5363x + 61,158	0,3153	*0,5615*
7. gas well	y = 7,2115x + 56,226	0,4879	*0,6984*
8. gas well	y = 2,6813x + 61,082	0,2951	*0,5432*
9. gas well	y = 5,4264x + 48,139	0,4478	*0,6691*
10. gas well	y = 3,0602x + 55,441	0,2174	*0,4662*
11. gas well	y = 4,7509x + 47,804	0,3626	*0,6021*

3.3. The quality and quantity changes of landfill gas with regard to environmental conditions

3.3.1. The quality and quantity parameter changes of landfill gas produced at the refuse dump with regard to the average temperatures

In the first part of my examinations I tried to find relationships between the changes in average temperature intervals and the methane content of the recovered landfill gas (Table 11, Diagram 7). As the refuse dump can be considered as a large bio-reactor, changes of average temperature do not influence directly the methane content of landfill gas. But it is one of the most important parameter among microbiological conditions. Minimum and maximum values range between 1-68% CH_4 content. I measured an average 48.43% methane content in the 2nd group (5-10°C) interval where the most measurements were taken. The least favorable value, 48,37% methane content was measured in the 3rd group (10-15°C) average temperature interval. The highest value was found in the 5th group (20-25°C) 54,19% methane content with 99 measurements. It can be seen from the results that in the cases of groups number 1, 2, 3 and 4 there are no major differences in methane content between ≤5°C and 25°C average temperature interval. In case of appropriate controlling average methane content was 49,67% which fulfils the minimum conditions of energy recovery. Standard deviation was s=14,319% in the full range of test, coefficient of variation is a volatile result, CV=28,82% since I measured 1% methane content in the 2nd and 4th group. This might be due to operating and microbiological processes in the landfill site which characterize the biological processes of a particular refuse dump. To sum up, we can state that because of the insulation effect of the waste layers methane content of the landfill gas is not influenced directly by external temperature conditions.

Table 11. Results of the examination of the relationship between average temperature interval and methane content

Temperature group	Average temperature interval [°C]	n [pcs]	CH_4 mean [%]	Coefficient of variation CV% [%]	Std. deviation [%]	95%Confidence interval for mean		Minimum [%]	Maximum [%]
						Lower bound	Upper bound		
1. group	≤5 °C	77	48,55	32,44	15,752	44,98	52,13	17	66
2. group	5-10 °C	143	48,43	32,45	15,719	45,83	51,03	1	68
3. group	10-15 °C	88	48,37	28,89	13,978	45,40	51,33	7	65
4. group	15-20 °C	88	48,48	29,78	14,439	45,42	51,54	1	66
5. group	20-25 °C	99	54,19	19,11	10,361	52,12	56,25	22	64
6. group	25-30 °C	22	51,27	25,28	12,965	45,52	57,02	10	65
	Total	517	49,67	28,82	14,319	48,43	50,90	1	68

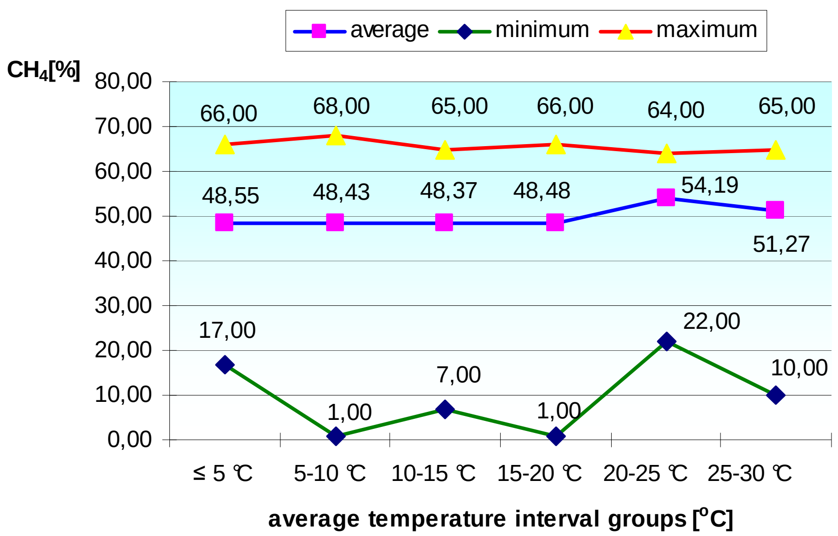

Diagram 7. Results of the examination of the relationships between average temperature and methane content

Between certain group pairs the analysis of variance proved there are significant results as level of significance is P<5% in case of the examined parameters. With regard to the homogeneity test the sample is heterogeneous and I used the Tamhane test. I carried out the analysis between the groups and the results can be seen in Table12.

Table 12. Differences of the methane content of the tested groups and the results of the group pairs

Temperature group	Average temperature interval [C°]	**1. group** ≤5 °C	**2. group** 5-10 °C	**3. group** 10-15 °C	**4. group** 15-20 °C	**5. group** 20-25 °C	**6. group** 25-30 °C
1. group	≤5 °C	-	ns	ns	ns	ns	ns
2. group	5-10 °C	0,124	-	ns	ns	*	ns
3. group	10-15 °C	0,185	0,061	-	ns	*	ns
4. group	15-20 °C	0,074	0,051	0,111	-	*	ns
5. group	20-25 °C	5,635	5,759	5,820	5,709	-	ns
6. group	25-30 °C	2,717	2,842	2,902	2,791	2,918	-

ns = not significant, * = P<5%, ** = P< 1%

The largest difference was measured between the 5th group (20-25°C) and the 3rd group (10-15°C), and the difference was 5,820% methane content. I also noticed large differences between the 5th group (20-25°C) and the values of the 2nd (5-10°C) and the 4th groups (15-20°C), the difference was 5,759% and 5,709% in methane content, respectively. From Table 12 you can see that the smallest difference in methane content, 0,051%, is between the values of the 4th and 2nd groups. There are significant differences between the 5th group (20-25°C) and the 3rd group (10-15°C) (sig=0,024) shows P<5% significant rate. There are also significant differences between the 5th group (20-25 °C) and the 2nd group (5-10°C) (sig=0,010) P<5%. Furthermore significant differences can be found between groups 5 (20-25°C) and 4 (15-20°C) (sig=0,037) P<5%.

For all gas wells I carried out a linear regressive examination taking into consideration both methane content and average temperature rates (Diagram 8). The relationship between the characteristic methane content of the gas well and the average temperature intervals can be calculated by the following equation: $y=0,1948x+47,177$, $R^2=0,0106$. The coefficient of correlation is $r=0,1029$ and from the processed data we can conclude that the external temperature fluctuation influences only the upper few meters of the landfill so it does not influence the inside temperature of the waste dump and the methane content of the landfill gas. On the other hand temperature is an important abiotic environmental factor for the activities of micro-organisms and plays an important role in the recovery of landfill gas.

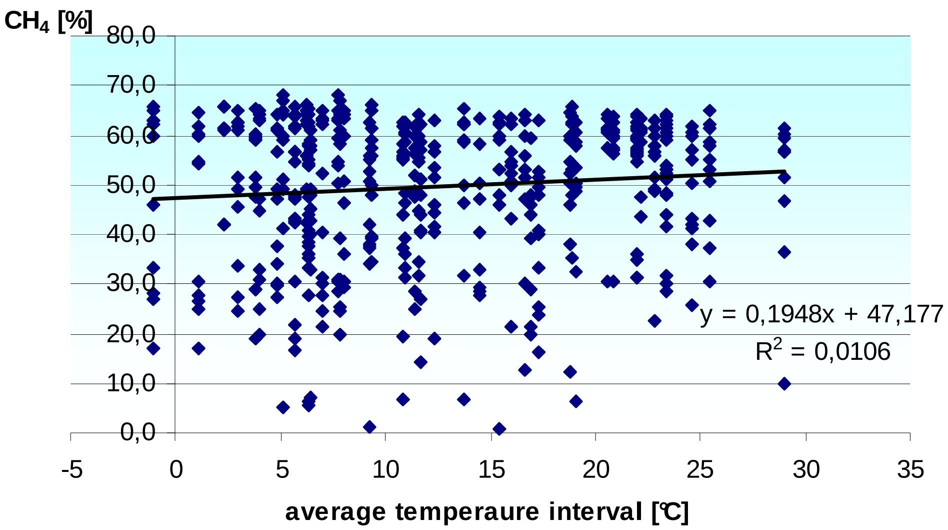

Diagram 8. Changes of methane content in all gas wells in connection with changes in average temperature

The impact of the average temperature intervals on the methane content of gas wells

During the next part of my examination I looked for relationships between the methane content of each gas well and the average temperature intervals. For this reason I connected the methane content values of the 11 gas wells and the adherent average temperature interval groups. The results can be seen in Table 13.

After evaluating the data I concluded that the changes of the average temperature intervals do not influence the methane content of the gas wells. There are no significant differences in methane content between groups 1-4. Between groups 5-6 some tendencies can be seen but it does not change the annual landfill gas yield. On the other hand average temperature intervals influence the methane content of the landfill gas and the characteristic biological surrounding of some gas wells and the location of them in the refuse dump might have some influence on it as well. The least favorable methane content value was measured in the 1st group of the 1st gas well where a 28,83% methane content was measured. The highest methane content, 63,43%, was found in the 1st group of the 6th gas well which proves that despite unfavorable average temperature if there is good biological surroundings and location we can measure higher methane content.

Table 13. Methane content at each gas well with regard to the temperature groups

Temperature group	**1. gas well** CH_4 [%]	**2. gas well** CH_4 [%]	**3. gas well** CH_4 [%]	**4. gas well** CH_4 [%]	**5. gas well** CH_4 [%]	**6. gas well** CH_4 [%]	**7. gas well** CH_4 [%]	**8. gas well** CH_4 [%]	**9. gas well** CH_4 [%]	**10. gas well** CH_4 [%]	**11. gas well** CH_4 [%]
1. group	28,83	31,96	30,80	51,40	47,41	63,43	52,83	59,03	60,10	60,01	48,26
2. group	46,35	25,75	40,15	49,06	50,95	62,35	52,85	58,27	52,22	56,67	38,06
3. group	46,01	29,44	44,10	50,41	49,51	59,53	48,03	60,86	52,51	53,06	38,56
4. group	53,94	34,46	48,11	51,08	53,79	58,10	53,39	59,56	31,69	47,13	42,01
5. group	54,27	38,56	53,00	62,40	56,16	61,51	53,90	60,17	41,98	55,27	58,84
6. group	60,80	56,15	44,85	60,85	51,20	61,70	57,20	48,50	20,30	44,75	57,75
Total	47,10	32,53	43,45	53,03	51,67	61,12	52,50	58,99	46,63	54,15	45,16

Analysis of variance proved significant results between the group pairs, and the level of significance is P<5% for the examined parameters. During homogeneity tests I determined the heterogeneity or homogeneity of the samples by using the Levenne test. On the basis of the results I used the Tamhane or LSD test. The results can be found in Table 14 which are the following: 1st gas well (sig=0,002), 2nd gas well (sig=0,196), 3rd gas well (sig=0,195), 4th gas well (sig=0,000), 5th gas well (sig=0,006), 6th gas well (sig=0,103), 7th gas well (sig=0,218), 8th gas well (sig=0,004), 9th gas well (sig=0,015), 10th gas well (sig=0,015), 11th gas well (sig=0,000).

At the 1st gas well analysis of variance proved significant results between the group pairs as the level of significance is P<5% for the examined parameters. There are significant differences between group pairs 5.-1. and group pairs 4.-1., P<1%, and the significant difference between groups 2.-1. is P<5%. At the 2nd gas well analysis of variance proved significant results between the group pairs 6.-2. Significant difference is P<1%. At the 3rd gas well, as the level of significance is P<5%, analysis of variance proved significant results which are the following: between the group pairs 5.-1., 5.-2., 4.-1., 3.-1. P<1%, between group pairs 5.-3., 6.-1., 4.-2., 2.-1. P<5% is the significant difference. I also examined the groups in case of the 4th, 5th, 6th, 7th and 8th gas wells and concluded that there were no significant differences between the group pairs.
At the 9th gas well the analysis of variance proved significant results, which are the following: in the cases of group pairs 6.-1., 2.-3., and 4.-1., 2.-3., the significant difference is P<1%, in the case of group pair 5.-1. significant difference is P<5%.

At the 10th gas well the analysis of variance proved significant results, which are the following: in the cases of group pairs 6.-1., 4.-1. and 4.-2. significant difference is P<5%. At the 11th gas well I found significant differences in the cases of group pairs 5.-2. and 6.-2., P<5%, by using the SPSS for Windows 11.0 program.

Table 14. The results of the statistical processing of each gas well

	Results of homogenity examination	**Significant differences between group pairs in *P<5% level**		**Significant differences between group pairs in **P<1% level**		**Methane content differences CH_4 [%]**			
						***P<5%**		****P<1%**	
1. gas well	heterogeneous (Tamhane)	2.-1.		5.-1.	4.-1.	17,51%		25,43%	25,10%
2. gas well	homogeneous (LSD)	-		6.-2.		-		30,39%	
3. gas well	homogeneous (LSD)	5.-3. 6.-1.	4.-2. 2.-1.	5.-1. 5.-2.	4.-1. 3.-1.	8,90% 14,50%	7,95% 9,35%	22,20% 12,84%	17,31% 13,30%
4. gas well	heterogeneous (Tamhane)	ns		ns		-		-	
5. gas well	heterogeneous (Tamhane)	ns		ns		-		-	
6. gas well	homogeneous (LSD)	ns		ns		-		-	
7. gas well	homogeneous (LSD))	ns		ns		-		-	
8. gas well	heterogeneous (Tamhane)	eh		eh		-		-	
9. gas well	homogeneous (LSD)	5.-1. - -		6.-1. 6.-2. 6.-3.	4.-1. 4.-2. 4.-3.	18,12% - -		39,80% 31,92% 32,21%	28,41% 20,53% 20,82%
10. gas well	homogeneous (LSD)	4.-1. 4.-2.	6.-1. -	- -		12,88% 9,54%	15,26% -	- -	
11. gas well	heterogeneous (Tamhane)	6.-2.	6.-2.	-		20,78%	19,68%	-	

ns = not significant, * = P<5%, ** = P< 1%, eh= lack of data

In case of the 11 gas wells I carried out a linear regressive examination taking both the methane content of landfill gas and the average temperature rates into account. The results can be seen in Table 15. From the results of the coefficient of correlation we can clearly see that the relationships between the methane content of landfill gas and the changes of the average temperature intervals show a positive correlation in the cases of gas wells 1.-6 and 11. Its value is r=0,18-0,57 so the closeness of the relationships shows loose and middle correlation. Although in the cases of the 7th, 8th, 9th and 10th gas wells we can state that the increase of the average temperature reduces the methane content of landfill gas so there is negative correlation, and its value is between r=0,04-0,52. We can conclude that the results at the gas wells do not affect the methane content of the recovered landfill gas.

Table 15. Coefficient of correlations changes by gas wells with regard to methane content and average temperature intervals

	Linear equation	**R^2**	**r**
1. gas well	y =0,8902x + 35,725	0,2408	0,4907
2. gas well	y =0,7714x + 22,672	0,1043	0,3229
3. gas well	y =0,7512x +33,844	0,3319	0,5761
4. gas well	y =0,489x +46,783	0,1006	0,3174
5. gas well	y =0,3479x 47,223	0,0745,	0,2729
6. gas well	y =0,1243x + 62,706	0,0339,	0,1841
7. gas well	y =-0,0856x +51,411	0,0055	0,0741
8. gas well	y =-0,0329x + 59,412	0,0018	0,0424
9. gas well	y =-1,29x + 63,12	0,3319	0,5761
10. gas well	y =-0,404x + 59,318	0,098	0,3130
11. gas well	y =0,6585x + 36,738	0,0949	0,3080

The quantity changes of landfill gas with regard to the average temperature intervals

During my examinations I observed the quality and quantity changes of landfill gas produced at the refuse dump during the changes of average temperature intervals. In Table 16 I presented the average of the landfill gas methane content, produced in each month of the examination period, and the monthly and hourly distribution of the recovered landfill gas with regard to average temperature parameters. From the figures you can see that there are big differences. In the examination period in 2007 the average methane content of landfill gas was 49,67% which meets the minimum requirements for operating the gas engine, the total amount of landfill gas was 269,991m^3. In contrast with literature data, the expected 20-300 m^3/t landfill gas recovery, depending on the composition of the unloaded waste, we can only count on 2-3 m^3/t landfill gas recovery due to the environmental changes and the characteristic organic matter content of the region. The effectiveness of the gas recovery system was checked monthly for the whole examination periods. The results are the following: total number of working hours is 3913,83 and if we connect it with the total amount of recovered landfill gas we get 69,32 m^3/h landfill gas. The quantity and methane content changes of landfill gas during the examination period can be seen in Diagram 9.

In January, because of the low average temperatures (diagram 11) the amount of recovered landfill gas was 18150,41 m^3/month as the biological processes in the landfill slow down, and the average methane content is 53,91%. The average temperature in February was 5,83°C and due to the favorable amount of precipitation the landfill gas recovery was 24764,41 m^3/month with 53,60% methane content. In March and April the amount of landfill gas recovery was more or less the same (20416,65-21562,23 m^3/month) which might be because of the favourable environmental conditions. Average temperatures change between 9,46-13,41°C and the methane content of landfill gas changes between 47,05-49,12%. The landfill gas recovery system’s top utilization factor is 325,75-332,25h, and the gas recovery per unit time is 62,67-66,91 m^3/h.

May and June are the best operating time as the average temperature is between 18,35-22,17°C and facilitate landfill gas production which means 25998,36-27859,25 m^3/month landfill gas recovery. Due to utilization factors and favourable environmental conditions the amount of the recovered landfill gas can reach 76,63-77,76 m^3/h.

Table 16. Quantity and quality of landfill gas recovered at the refuse dump in 2007

Month	**Landfill gas CH_4 [%]**	**Landfill gas quantity [m^3/month]**	**Peak hours [h]**	**Precipitation [mm/month]**	**Average temperature [°C]**	**Landfill gas quantity [m^3/h]**
January	53,91	18150,41	292,50	26,5	5,65	62,05
February	53,60	24764,41	335,25	35,20	5,83	73,75
March	47,05	20416,65	325,75	48,80	9,46	62,67
April	49,12	21562,23	332,25	10,30	13,41	66,91
May	54,92	27859,25	358,25	98,30	18,35	77,76
June	53,65	25998,36	339,25	111,00	22,17	76,63
July	49,24	22771,35	396,81	32,80	23,58	57,38
August	51,19	23175,18	290,54	52,50	23,09	79,76
September	46,30	16407,71	233,84	68,80	15,14	70,16
October	46,98	22846,56	326,82	51,60	11,38	69,90
November	46,89	22998,25	353,62	66,90	5,11	65,04
December	48,14	22966,35	328,95	23,50	0,82	69,81
Total	49,67	269916,71	3913,8	52,2		69,32

Calorific value of landfill gas *17 MJ/Nm^3*=4,675 kWh/Nm^3=13,06 MJ/kg

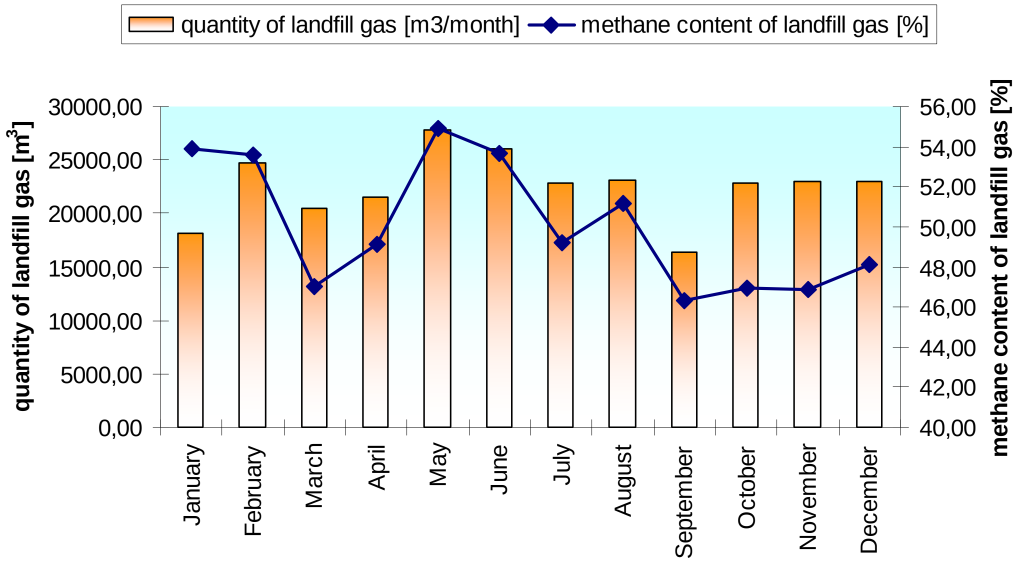

Diagram 9. Change of quantity and methane content of landfill gas during examination period

In July and August landfill gas production decreased, 22771,35-23175,18 m^3/month, due to higher average temperatures (22,17-23,58°C) and the low amount of precipitation. Methane content was between 49,24% and 51,19% which is better in summer months as the organic matter content is higher at this time of the year comparing to other months. The highest landfill gas production was found in August, it was 79,76 m^3/h and 51,19% methane content. The lowest average methane content was measured in September, 46,30%, the amount of recovered landfill gas was 16407,71 m^3/month. Average temperature was around 15,14°C which is quite encouraging but due to the failure of the gas recovery system the utilization factor became the lowest, 233,84h, which resulted in recovering only 70,16 m^3/h. Average temperature decreased to 11,38-5,11-0,82 °C in October, November and December. With the gas recovery system working steadily I measured relatively stable methane content, 46,89-48,14%, and I also measured the necessary amount of landfill gas for the operation of the gas engines, 22846,56-22998,25 m^3/month.
By combining the quantity of landfill gas and average temperature intervals I carried out a linear regression examination. The results can be seen in Diagram 10. The relationship between the quantitative changes of landfill gas and the average temperature intervals can be calculated by the following equation: $y=129{,}91x+21407$, $R^2=0{,}1628$. Coefficient of correlation is $r=0{,}42$, the closeness of the relationships is moderate.

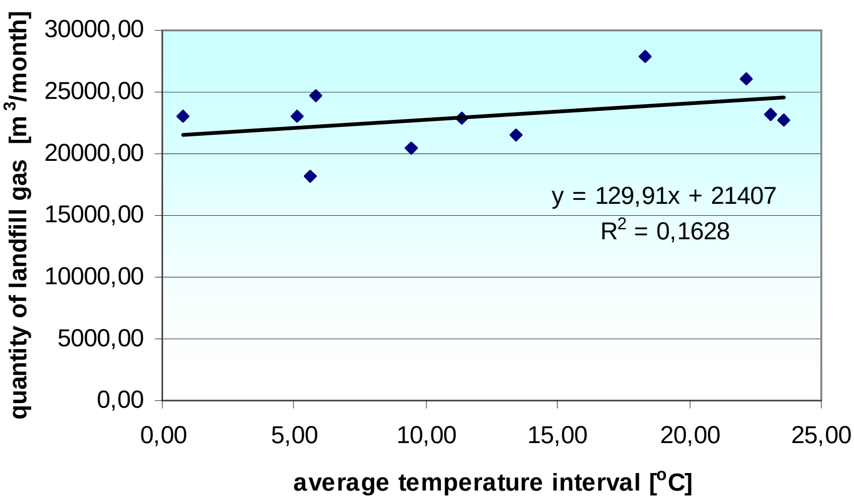

Diagram 10. Relationships between the quantity of landfill gas and changes in the average temperature

3.3.2. The quality parameter changes of landfill gas produced at the refuse dump regarding relative air humidity

During my tests in the cases of all gas wells I looked for relationships between the relative humidity values provided by the meteorological station and the methane content of the landfill gas recovered from the refuse dump. During the evaluation of data I considered it important to analyse the temperature, dew point and relative air humidity values. The values can be seen in Diagram 11.

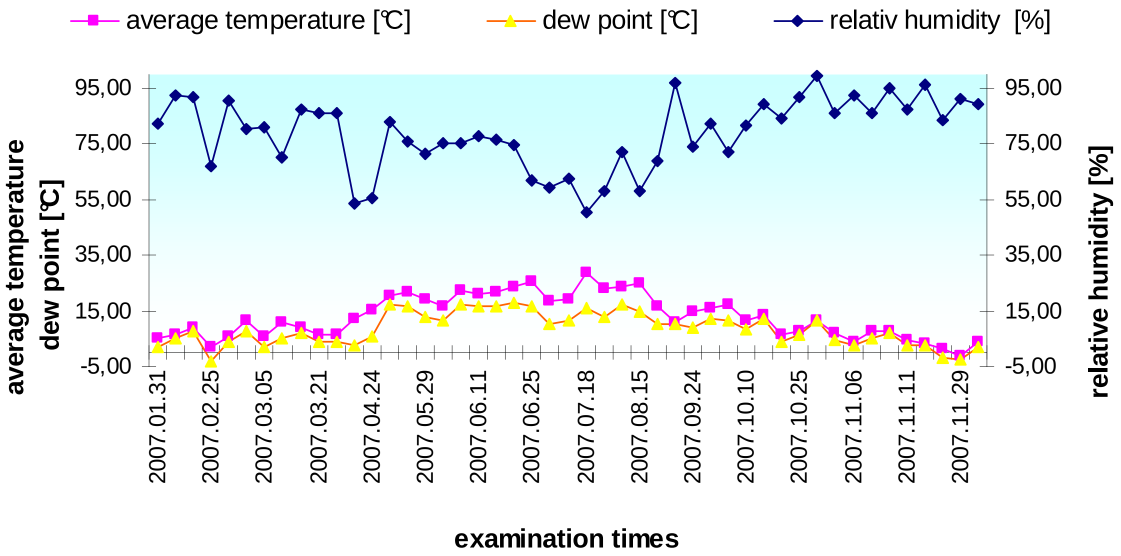

Diagram 11. Average temperatures and relative air humidity values at measuring times

The results of the examination of the changes of relative air humidity and methane content of landfill gas can be found in Table 17 where it can be seen that minimum and maximum values change between 1-68% CH4. The least favourable values were measured at the 2nd group (49,37%) and the most favourable was found at the 3rd group (51,59%). In case of appropriate controlling average methane content was 49,67% which fulfils the conditions of energy recovery regarding the total number of gas wells. From the numbers in Diagram 12 you can see that the in all cases, changes of relative air humidity values do not influence the methane content of landfill gas.
The coefficient of variation in the case of 3rd group was CV%=23,59% as standard deviation was s=12,172% and the minimum and maximum values of methane content were between 13-66%. This can be caused by the most favorable methane content values in group 3 since the minimum and maximum values of group 5 are favorable but the increase of standard deviation and the decrease of average methane content modifies the value of coefficient of variation to CV%=28,64%. In the cases of 1st and 4th groups I measured 1% methane content in the examination period and because of that in the whole test range the value of the coefficient of variation is volatile, CV%=28,82%, and standard deviation is s=14,319%.

Table 17. Results of the relationship between relative humidity and methane content

Humidity group	Relative humidity [%]	n [pcs]	CH_4 mean [%]	Coefficient of variation CV% [%]	Std. deviation [%]	95% Confidence inteval for mean		Minimum [%]	Maximum [%]
						Lower bound	Upper bound		
1. group	50-60%	66	50,13	26,92	13,512	46,82	53,45	1	65
2. group	61-70%	55	49,37	29,72	14,677	45,4	53,33	6	66
3. group	71-80%	110	51,59	23,59	12,172	49,29	53,89	13	66
4. group	81-90%	176	47,85	32,47	15,541	45,54	50,16	1	68
5. group	>90%	110	50,52	28,64	14,469	47,79	53,26	17	68
	Total	517	49,67	28,82	14,319	48,43	50,9	1	68

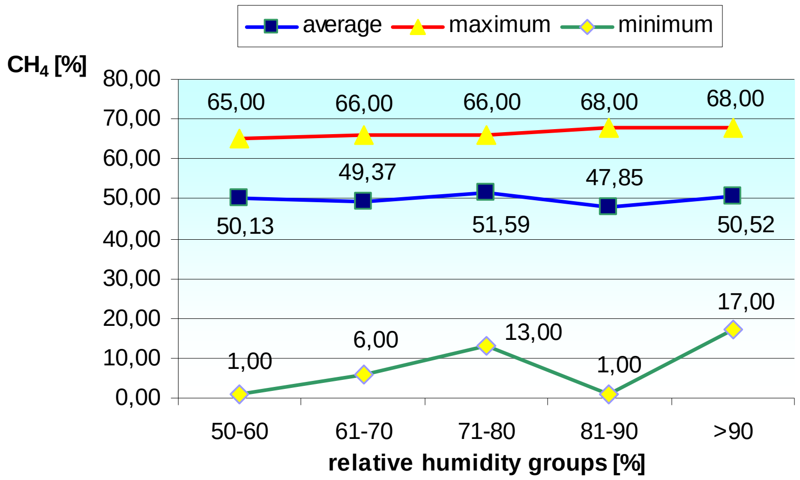

Diagram 12. Relationship between relative humidity and methane content

Analysis of variance proved significant results between the group pairs, the level of significance is P<5% for the examined parameters. On the basis of homogeneity test the sample is homogeneous, I used the LSD test. I also carried out analysis between the groups, the results can be seen in Table 18. During the statistical process of the data between the 4th and 3rd groups I found 3,735% difference in methane content and P<5% significant difference.

Table 18. Results of the methane content difference and the group pairs

Humidity group	Relativ humidity [%]	**1. group** 50-60%	**2. group** 61-70%	**3. group** 71-80%	**4. group** 81-90%	**5. group** >90%
1. group	50-60%	-	ns	ns	ns	ns
2. group	61-70%	0,768	-	ns	ns	ns
3. group	71-80%	1,452	2,219	-	*	ns
4. group	81-90%	2,284	1,516	3,735	-	ns
5. group	>90%	0,388	1,155	1,064	2,671	-

ns = not significants, * = P<5%, ** = P< 1%

For all of the gas wells I carried out a linear regressive examination taking both methane content changes and relative air humidity values into account (Diagram 13). The relationship between the methane content and the relative air humidity can be calculated by the following equation: $y=0,023x+51,478$, and $R^2=0,0004$. Coefficient of correlation is $r=0,002$ so we can conclude that the change of relative air humidity does not influence the methane content of landfill gas.

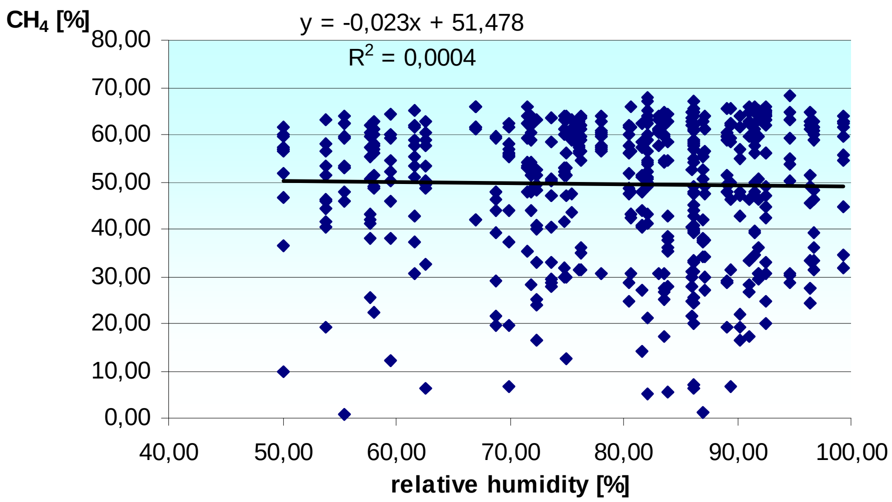

Diagram 13. Change of the methane content with regard to relative air humidity

The effect of relative air humidity on the methane content by gas wells

I looked for relationships between the characteristic methane content of gas wells and relative air humidity. Because of that I combined the 11 gas wells methane content values and their belonging relative air humidity values. Results can be found in Table 19. The average methane content values were between 32,53%-61,12%. 32.53%, the lowest value was found in the case of the 2nd gas well. In the cases of the other gas wells average methane content values are satisfactory with regards of energy recovery.

Table 19. Relative methane content values of gas wells with regard to relative humidity groups

Humidity group	n [db]	**1. gas well** CH_4 [%]	**2. gas well** CH_4 [%]	**3. gas well** CH_4 [%]	**4. gas well** CH_4 [%]	**5. gas well** CH_4 [%]	**6. gas well** CH_4 [%]	**7. gas well** CH_4 [%]	**8. gas well** CH_4 [%]	**9. gas well** CH_4 [%]	**10. gas well** CH_4 [%]	**11. gas well** CH_4 [%]
1. group	6	49,52	36,83	44,32	57,97	54,07	60,77	53,15	58,13	27,08	52,48	57,17
2. group	5	54,66	39,16	49,56	49,84	51,62	60,16	56,58	55,1	35,98	46,62	43,76
3. group	10	52,89	33,25	50,78	58,22	55,07	60,89	51,32	60,59	40,06	52,52	51,86
4. group	16	43,34	22,01	41,54	47,6	48,17	60,23	51,97	58,96	55,62	55,47	41,46
5. group	10	42,12	42,75	35,58	55,19	52,46	63,45	52,12	59,9	55,87	58,45	37,86
Total	47	47,1	32,53	43,45	53,03	51,67	61,12	52,5	58,99	46,63	54,15	45,16

Analysis of variance proved significant results between the group pairs, in the level of significance is P<5% for the examined parameters. I carried out the Levenne homogeneity test and the results can be found in Table 20. At the 1st gas well analysis of variance did not prove significant results. In the case of the 2nd gas well in one case, between groups 5.-4., P<1% I found significant difference. In case of the 3rd gas well I carried out the statistical analysis between the group pairs and the results are the following: analysis of variance showed significant difference between group pairs 5.-3., P<1%, between group pairs 5.-2. And 4.-3. It was P<5%. At the 4th gas well between 4.-3. group pair significant difference is P<5%. At the 5th, 6th, 7th and 8th gas wells analysis of variance between group pairs proved significant results in only one case. At the 9th gas well analysis of variance proved significant results, which are the following: in the cases of group pairs 5.-2. and 5.-3. the significant difference is P<5%, in the case of group pairs 5.-1., 4.-1.,2,3 significant difference is P<1%. In the cases of the 10th and 11th gas wells by analysis of variance I found P<5% significant difference between group pairs 5.-2.

Table 20. Results of the statistical data processing of each gas well

	Results of homogenity examination	**Significant differences between group pairs in *P<5% level**	**Significant differences between group pairs in **P<1% level**		**Methane content differences CH_4 [%]**		
					***P<5%**	****P<1%**	
1. gas well	heterogeneous (Tamhane)	ns	ns		-	-	
2. gas well	homogeneous (LSD)	-	5.-4.		-	20,73%	
3. gas well	homogeneous (LSD)	-	5.-2.	5.-3.		13,98%	15,20%
4. gas well	heterogén (Tamhane)	4.-3.	-		10,62%	-	
5. gas well	homogeneous (LSD)	ns	ns		-	-	
6. gas well	homogeneous (LSD)	ns	ns		-	-	
7. gas well	homogeneous (LSD)	ns	ns		-	-	
8. gas well	homogeneous (LSD)	ns	ns		-	-	
9. gas well	homogeneous (LSD)	5.-2. 5.-3.	5.-1 4.-1	4.-2. 4.-3.	19,89% 15,81%	28,78% 28,53%	19,63% 15,59%
10. gas well	homogeneous (LSD)	5.-2.	-		11,83%	-	
11. gas well	heterogeneous (Tamhane)	5.-2.	-		10,25%	-	

ns = not significant, * = P<5%, ** = P< 1%

3.3.3. Changes of methane contentof landfill gas with regard to barometric pressure

During my examination I tried to find relationships between the average daily barometric pressure values provided by the meteorological station and the methane content values of the landfill gas recovered from the refuse dump. The results are presented in Table 21. Minimum and maximum values range between 1-68% methane content. The highest methane content values were measured in the 1st group between 1000-1010hpa (52,68%). In the 2nd group I measured 50,45% methane content between 1010-1020hpa. The lowest value, 48,47% methane content was measured in the 3rd group, above 1020hpa. Coefficient of variation was CV%=23,74% in the case of the 1st group as standard deviation was s=12,509% and minimum and maximum values ranged between 6-66% methane content values. In the 3rd group I measured 1% methane content in the examination period and because of that coefficient of variation is volatile, CV%=31,72%. On the basis of the graphic representation of data (diagram 14) we can conclude that changes of barometric pressure do not influence the methane content of landfill gas since the insulation function of the external soil layer causes an environmental delay on the material under the surface.

Table 21. Results of the relationship between barometric pressure and methane content

Barometric pressure group	Barometric pressure [hpa]	n [pcs]	CH_4 mean [%]	Coefficient of variation CV% [%]	Std. deviation [%]	95% Confidence interval for mean		Minimum [%]	Maximum [%]
						Lower bound	Upper bound		
1. group	1000-1010	33	52,68	23,74	12,509	48,24	57,11	6	66
2. group	1010-1020	242	50,45	26,47	13,359	48,76	52,14	6	68
3. group	>1020	242	48,47	31,72	15,378	46,53	50,42	1	68
	Total	517	49,67	28,82	14,319	48,43	50,90	1	68

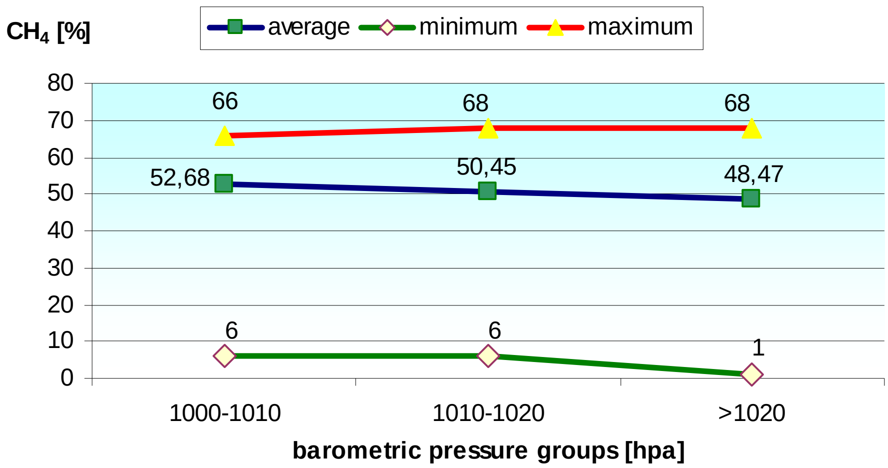

Diagram 14. Results of the relationship between barometric pressure and methane content

During homogeneity test the samples showed a heterogeneous result so during the statistical process I used the Tamhane test. Analysis of variance between group pairs did not prove significant results (Table 22). I did not find significant differences after modifying barometric pressure groups.

Table 22. Methane content differences and results of group pairs

Barometric pressure group	Barometric pressure [hpa]	**1. group** 1000-1010	**2. group** 1010-1020	**3. group** >1020
1. group	1000-1010	-	ns	ns
2. group	1010-1020	2,227	-	ns
3. group	>1020	4,201	1,974	-

ns = not significant, * = P<5%, ** = P< 1%

For all of the gas wells I carried out a linear regressive examination taking both methane content values and average barometric pressure values into account (Diagram 15). The relationship between the methane content changes of a particular gas well and the barometric pressure can be calculated by the following equation: y=-0,223x+277,22, R^2=0,0126. The coefficient of correlation is r=0,11 so we can conclude that the changes of barometric pressure do not influence directly the changes of quantity parameters of the produced landfill gas. On the other hand from the graphic representation you can see the trend that the increase of barometric pressure might decrease the methane content of landfill gas as by the increase of barometric pressure the oxygen content of landfill gas increases and the methane content decreases because of the air diffusing into the landfill.

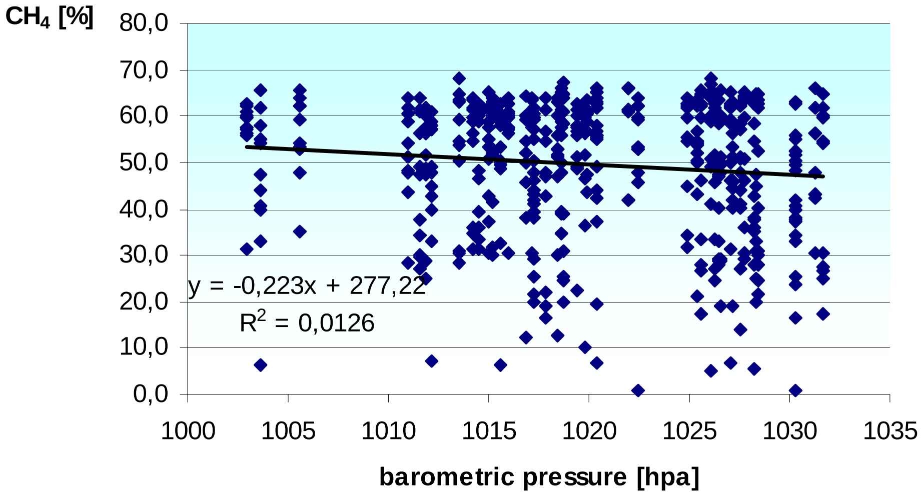

Diagram 15. Changes of methane content of landfill gas with regard to barometric pressure

The effect of average barometric pressure changes on methane content by each gas well

During my examination I was looking for relationships between the characteristic methane content values of each gas well and the average barometric pressure values during test period. So I combined all the 11 gas wells' methane content values and their barometric pressure groups. The results can be found in Table 23. The least favorable value in the 1st group was found in the 2nd group, 24,27% methane content and the most favorable value was found at the 5th gas well, 63,03% methane content. In the 2nd group the number of barometric pressure samples was 22 items it is adequate for drawing a conclusion. In this group the fluctuation of methane content was between 38,34-60,66%. The highest value was at the 9th gas well, the lowest was at the 6th gas well. In the 3rd group the number of the samples was 22, the highest methane content, 61,41%, was measured at the 6th gas well the lowest, 25,73% was at the 2nd one.

Table 23. Methane content values of each gas well with regard to barometric pressure

Barometric pressure group	n [pcs]	**1. gas well** CH_4 [%]	**2. gas well** CH_4 [%]	**3. gas well** CH_4 [%]	**4. gas well** CH_4 [%]	**5. gas well** CH_4 [%]	**6. gas well** CH_4 [%]	**7. gas well** CH_4 [%]	**8. gas well** CH_4 [%]	**9. gas well** CH_4 [%]	**10. gas well** CH_4 [%]	**11. gas well** CH_4 [%]
1. group	3	56,40	24,27	54,73	54,77	63,03	62,30	56,73	53,83	53,37	52,03	47,97
2. group	22	51,57	40,46	46,47	53,01	53,28	60,66	52,60	58,29	38,34	52,34	47,91
3. group	22	41,37	25,73	38,89	52,82	48,51	61,41	51,83	60,40	54,00	56,25	42,02
Total	47	47,10	32,53	43,45	53,03	51,67	61,12	52,50	58,99	46,63	54,15	45,16

I carried out a homogeneity examination by the Levenne test and I determined whether the gas wells are homogeneous or heterogeneous (Table 24). For all of the gas wells I used the LSD test except for the 9th gas well as its sample was heterogeneous so I used the Tamhane test.

Table 24. Results of the statistical processes of each gas wells

	Results of homogenity examination	**Significant differences between group pairs in *P<5% level**	**Significant differences between group pairs in **P<1% level**	**Methane content differences CH_4 [%]**	
				***P<5%**	****P<1%**
1. gas well	homogeneous (LSD)	3.-2.	-	10,19%	-
2. gas well	homogeneous (LSD)	3.-2	-	14,73%	-
3. gas well	homogeneous (LSD)	3.-2.	3.-1.	7,58%	15,84%
4. gas well	homogeneous (LSD))	ns	ns	-	-
5. gas well	homogeneous (LSD)	3.-1.	-	14,52%	-
6. gas well	homogeneous (LSD)	ns	ns	-	-
7. gas well	homogeneous (LSD)	ns	ns	-	-
8. gas well	homogeneous (LSD)	ns	ns	-	-
9. gas well	heterogeneous (Tamhane)	3.-1 2.-1.	-	15,65% 15,02%	-
10. gas well	homogeneous (LSD)	ns	ns	-	-
11. gas well	homogeneous (LSD))	ns	s	-	-

ns = not significant, * = P<5%, ** = P< 1%

During the statistical process I found relationships between the barometric pressure groups that characterize each gas well. The results can be seen in Table 24. At the 1st, 2nd and 3rd gas wells I found significant difference, P<5%, between group pairs 3.-2. Between 3.-1. groups at the 5th and 9th gas well P<5% and between 3.-1. significant difference of group pairs is P<1%. At 4th, 6th, 7th, 8th, 10th and 11th gas wells analysis of variance between group pairs did not show significant difference. Due to these facts we can conclude that at these gas wells there is no connection between barometric pressure and methane content of the landfill gas.

In case of all the 11 gas wells I carried out a linear regressive examination taking both methane content changes and average barometric pressure values into account and the results can be seen in Table 25. The relationship between the methane content changes of a particular gas well and the barometric pressure can be calculated by the following equation.

From the processed data we can notice that barometric pressure only shows moderate relationship in the cases of the 1st, 3rd and 5th gas wells and their values are the following: 1st gas well r=0,4, 3rd gas well r=0,49, 5th gas well r=0,44. The results of the linear regression examination at the gas wells show negative correlation. The increase of the barometric pressure results in the decrease of methane content values. From the results of number 2,4,8,9,10 and 11 gas wells we can say that the closeness of relationships shows a loose correlation link between barometric pressure and methane content but it does not influence the methane content of landfill gas.

Table 25. Coefficient of correlation changes by gas wells with regard to methane content and barometric pressure

	Linear equation	**R^2**	**r**
1. gas well	y = -0,7708x + 833,47	0,1637	0,4045
2. gas well	y = -0,5037x + 546,44	0,0403	0,2007
3. gas well	y = -0,6815x + 738,75	0,2477	0,4976
4. gas well	y = -0,1881x + 244,93	0,0135	0,1161
5. gas well	y = -0,5939x + 657,59	0,197	0,4438
6. gas well	y = -0,003x + 64,164	2E-05	0,0001
7. gas well	y = -0,0848x + 139,02	0,0049	0,0701
8. gas well	y = 0,2166x - 161,96	0,0688	0,2622
9. gas well	y = 0,3701x - 330,93	0,0249	0,1577
10. gas well	y = 0,1483x - 97,161	0,012	0,1095
11. gas well	y = -0,3626x + 415,09	0,0261	0,1615

3.3.4. Changes of methane content of landfill gas with regard to different wind speed interval

During my examination I tried to find relationships between the different wind speed intervals and the methane content values of the landfill gas recovered from the refuse dump. During the construction of a landfill site the heights of the retaining walls can be as high as 15-30 meters. At this height we can assume that the wind conditions might have the effect that despite extraction methane can dissipate from the top layers of the dump. This mostly happens during the loading of the dump when the height of the 3m wide and 2m high ramparts on the outside edge of the retaining walls gets higher than the height of the waste in the refuse dump. As a result the methane content of the recovered landfill gas can significantly decrease and have higher oxygen content.
The results are in Table 26 where methane content changed between 1-68%. The most favorable value, 51,78% methane content was measured in the 2nd group in 0,6m/s>v_{sz}≤1m/s interval, with n=99 sample size. The least favorable value, 47,30%, was found in the 1st group – contrary to what I assumed – in the v_{sz}≤0,6 wind speed interval and in the 6th group, 49,53% in the v_{sz}>2,4m/s wind speed interval. From the results it can be seen that in groups 3,4,5 and 6 changes of wind speed shows small difference in methane content so it is necessary to examine the connection between the volume of gas recovery and prevailing wind speed. Variation of coefficient is CV%=22,81% in the wind speed interval of the 2nd group (0,6>v_{sz}≤1). I measured the most favorable methane content value in this case and the minimum and maximum values were between 14-66% methane content.

Table 26. Results of the relationships between wind speed intervals and methane content

Wind speed group	Wind speed interval [m/s]	n [pcs]	CH_4 mean [%]	Coefficient of variation CV% [%]	Std. deviation [%]	95% Confidence interval for mean		Minimum [%]	Maximum [%]
						Lower bound	Upper bound		
1. group	v_{sz} ≤ 0,6	88	47,30	31,22	14,771	44,17	50,43	7	66
2. group	0,6 > v_{sz} ≤ 1	99	51,87	22,81	11,832	49,51	54,23	14	66
3. group	1 > v_{sz} ≤ 1,3	99	49,81	30,45	15,169	46,79	52,84	1	66
4. group	1,3 > v_{sz} ≤ 1,8	99	48,65	30,58	14,880	45,68	51,62	1	66
5. group	1,8 > v_{sz} ≤ 2,4	66	50,95	29,26	14,908	47,29	54,62	5	68
6. group	v_{sz} >2,4	66	49,53	28,79	14,260	46,03	53,04	6	66
	Total	517	49,67	28,82	14,319	48,43	50,90	1	68

During the homogeneity tests of the group pairs the samples showed homogeneous results so at the statistical process I used the LSD test, results can be seen in Table 27. I found the largest difference between 2.-1. Group pairs with 4,57% methane content. Between group pairs the analysis of variance showed significant difference only between group pairs 2.-1. P<5% .

Table 27. Results of wind speed group pairs and methane content differences

Wind speed group	Wind speed interva [m/s]	**1. group** v_{sz}≤0,6	**2. group** 0,6>v_{sz}≤1	**3. group** 1>v_{sz}≤1,3	**4. group** 1,3>v_{sz}≤1,8	**5. group** 1,8>v_{sz}≤2,4	**6. group** v_{sz}>2,4
1. group	v_{sz} ≤ 0,6	-	*	ns	ns	ns	ns
2. group	0,6 > v_{sz} ≤ 1	4,571	-	ns	ns	ns	ns
3. group	1 > v_{sz} ≤ 1,3	2,512	2,059	-	ns	ns	ns
4. group	1,3 > v_{sz} ≤ 1,8	1,351	3,219	1,161	-	ns	ns
5. group	1,8 > v_{sz} ≤ 2,4	3,650	0,920	1,138	2,299	-	ns
6. group	v_{sz} >2,4	2,232	2,338	0,279	0,881	1,418	-

ns = not significant, * = P<5%, ** = P< 1%

For all the gas wells I carried out a linear regressive examination taking both methane content changes and wind speed intervals into account (Diagram 16). The relationship between the methane content changes of a particular gas well and the wind speed intervals can be calculated by the following equation: y=-5,28369x+56,452, R^2=0,1699. The coefficient of correlation is r=0,48 so the closeness of relationships shows moderate correlation between the change of the methane content in all gas wells and the changes of wind speed intervals at the refuse dump. On the basis of the linear regressive examination we can conclude that the changes of wind speed interval might decrease the methane content of the landfill gas.

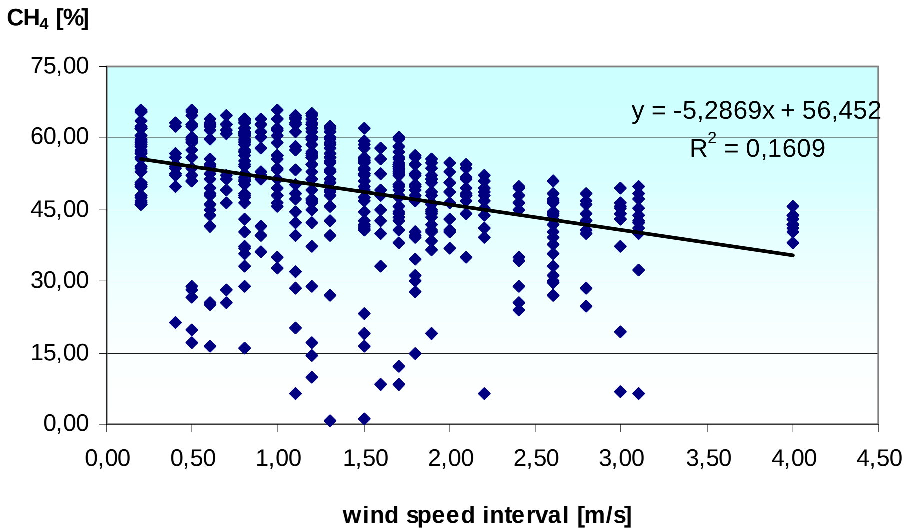

Diagram 16. Changes of the methane content of landfill gas in different wind speed intervals

Changes of methane content values of wind speed intervals by each gas well

During my examination I was looking for relationships between the characteristic methane content values of each gas well and the characteristic wind speed intervals at the refuse dump. So I combined all the 11 gas wells' methane content values and their belonging wind speed values. The results can be found in Table 28. From the results it can be seen that the least favorable value was found at the 5th gas well between 1.-6. wind speed interval group, 23,63-37,57%, the value of average methane content was 32,53%. The most favorable methane content value was found at the 6th gas well between geoups 1.-6. (58,06-63,85%), the average methane content was 61,12%.

Table 28. Methane content values of each gas well with regard to wind speed groups

Wind speed interval group	n [pcs]	**1. gas well** CH_4 [%]	**2. gas well** CH_4 [%]	**3. gas well** CH_4 [%]	**4. gas well** CH_4 [%]	**5. gas well** CH_4 [%]	**6. gas well** CH_4 [%]	**7. gas well** CH_4 [%]	**8. gas well** CH_4 [%]	**9. gas well** CH_4 [%]	**10. gas well** CH_4 [%]	**11. gas well** CH_4 [%]
1. group	8	39,28	34,06	37,68	55,11	49,59	58,06	49,99	60,34	46,08	48,81	41,33
2. group	9	49,00	37,57	48,04	57,63	53,06	59,32	55,01	60,61	44,79	54,59	50,97
3. group	9	48,74	33,39	41,90	54,07	48,07	63,10	52,52	57,62	42,01	55,92	50,60
4. group	9	52,94	23,63	45,71	48,18	54,54	61,37	54,31	55,24	44,10	53,78	41,37
5. group	6	38,95	33,87	41,27	57,82	53,13	63,85	52,20	61,38	56,38	59,00	42,62
6. group	6	51,63	33,67	45,35	44,32	52,00	61,80	49,67	60,05	51,10	53,68	41,60
Total	47	47,10	32,53	43,45	53,03	51,67	61,12	52,50	58,99	46,63	54,15	45,16

During the statistical evaluation I found a relationship between the methane content values which characterize each gas well and the wind speed interval groups. The results can be seen in Table 29. The homogeneity test was carried out by the Levene test and I used the LSD test in all the cases as the samples were homogeneous.

I found significant differences, P<5%, between 3.-1. group pairs at the 1st gas well, between group pairs 2.-1. at the 3rd gas well, between 6.-2. and 6.-5. group pairs at the 4th gas well and between 3.-1. and 5.-1. group pairs at the 6th gas well. At number 2,5,7,8,9,10 and 11 gas wells the analysis of variance did not show significant differences.

Table 29. Results of the statistical processes of each gas well

	Results of homogenity examination	**Significant differences between group pairs in *P<5% level**		**Significant differences between group pairs in **P<1% level**	**Methane content differences CH_4 [%]** *P<5%		**Methane content differences CH_4 [%]** **P<1%
1. gas well	homogeneous (LSD)	3.-1.		-	13,66%		-
2. gas well	homogeneous (LSD)	ns		ns	-		-
3. gas well	homogeneous (LSD)	2.-1.		-	10,36%		-
4. gas well	homogeneous (LSD))	6.-2.	6.-5.	-	13,31%	13,49%	
5. gas well	homogeneous (LSD)	ns		ns	-		-
6. gas well	homogeneous (LSD)	3.-1.	5.-1.	-	5,03%	5,78%	-
7. gas well	homogeneous (LSD)	ns		ns	-		-
8. gas well	homogeneous (LSD)	ns		ns	-		-
9. gas well	homogeneous (LSD))	ns		ns	-		-
10. gas well	homogeneous (LSD)	ns		ns	-		-
11. gas well	homogeneous (LSD))	ns		ns	-		-

ns = not significant, * = P<5%, ** = P< 1%

For all the gas wells I carried out a linear regressive examination taking both methane content values and wind speed values belonging to wind speed intervals into account. The relationship between the methane content changes of a particular gas well and the wind speed intervals can be calculated by the following equation (Table 30). From the processed data we can see that the effect of the wind speed interval changes on methane content in the cases of gas wells 4,5,7 and 10 correlation coefficient changed between r=0,57-0,66, the closeness of relationship shows moderate correlation. In the cases of gas wells 1,2,3,9 and 11 there are loose correlation relationships and correlation coefficient is between r=0,12-0,33. In the cases of gas wells 6 and 8 there is tight correlation and correlation coefficient is r= 0,74-0,76. On the whole we can say that the changes of wind speed intervals in a particular area influences the methane content of the produced landfill gas since the airflow on the side of the landfill causes vacuum on the top of the dump and pulls the valuable methane out of the waste dump so methane content can decrease.

Table 30. Coefficient of correlation changes by gas wells with regard to methane content and wind speed intervals

	Linear equation	**R^2**	**r**
1. gas well	y = -1,5841x + 48,555	0,0152	0,1232
2. gas well	y = -5,3454x + 43,672	0,0643	0,2535
3. gas well	y = -3,3061x + 50,314	0,1117	0,3342
4. gas well	y = -7,9509x + 63,502	0,4232	0,6505
5. gas well	y = -4,642x + 57,368	0,3338	0,5777
6. gas well	y = -6,1143x + 64,857	0,5621	0,7497
7. gas well	y = -5,7277x + 60,316	0,4445	0,6667
8. gas well	y = -6,8312x + 64,912	0,5902	0,7682
9. gas well	y = -5,3243x + 53,627	0,0956	0,3091
10. gas well	y = -5,6265x + 60,562	0,3346	0,5784
11. gas well	y = -5,7035x + 53,283	0,0995	0,3154

3.3.5. The quality parameter changes of landfill gas produced at the refuse dump regarding precipitation intensity

During my examination I tried to find relationships between the daily precipitation intensity provided by the meteorological station and the methane content values of the landfill gas recovered from the refuse dump (Table 31). As there can be significant differences whether landfill gas is produced in wet or dry waste and there can be differences in methane content as well so the examination of this field is very important. Minimum and maximum values ranged between 1-68% methane content. The most favourable value was measured at the 3rd and 4th groups, with 1-5 mm/day precipitation methane content was 54,65-50,14%. 48,91% methane content was found in the 1st group, with the most elements in it, with 0 mm/day precipitation. The least favourable value, 48,44% methane content was found in the 5th group with over 5mm/day precipitation.
The coefficient of variation was CV%=22,33%, standard deviation was s=12,207, the number of elements was n=55 elements in the 3rd group 3-5 mm/day quantity range. I measured the highest methane content values (CH_4=54,65%), and minimum and maximum values were between 17-66%.

Table 31. Results of the ralationships between precipitation intensity and methane content

Precipitation group	Precipitation [mm/day]	n [pcs]	CH_4 mean [%]	Coefficient of variation CV% [%]	Std. deviation [%]	95% Confidence interval for mean		Minimum [%]	Maximum [%]
						Lower bound	Upper bound		
1. group	0	286	48,91	29,91	14,633	47,21	50,61	1	68
2. group	0,1 - 1	77	49,78	27,43	13,657	46,68	52,88	17	66
3. group	1 - 3	55	54,65	22,33	12,207	51,35	57,95	20	67
4. group	3-5	33	50,14	30,21	15,152	44,77	55,51	1	64
5. group	>5	66	48,44	29,83	14,450	44,89	51,99	6	68
	Total	517	49,67	28,79	14,319	48,43	50,90	1	68

In the cases of 3rd and 4th groups we can see the connection between precipitation intensity and methane content of landfill gas, the results can be seen in Diagram 17. In the cases of the 1st and 2nd groups where precipitation intensity is 0-1 mm/day the average methane content values significantly decreased (48,91-49,78%), as the value of the necessary moisture content for anaerobic degradation decreased. On the other hand in the 5th group I observed that if precipitation was at or exceeded 5 mm/day then biological conditions got worse and the surroundings of the gas wells became watery so their productivity and methane content significantly decreased. During the homogeneity tests of the group pairs the samples showed homogeneous results so at the statistical process I used the LSD test.

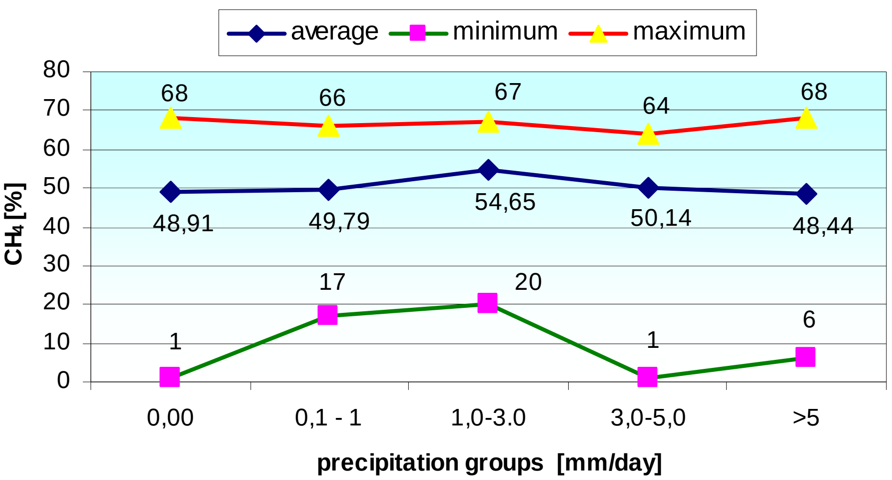

Diagram 17. Results of the relationship between precipitation intensity and methane content

After the statistical evaluation the results were the following: between group pairs 3.-1. and 5.-3. I found 5,735% and 6,208% methane content difference. Significant differences were also found in these groups. Between group pairs 3.-1. (sig=0,007) P<5% and between group pairs 5.-3. (sig=0,018) P<5% significant difference was found. In the other cases there was no significant difference.

I combined the amount of precipitation data provided by the meteorological station and the amount of methane content (Table 16). During the data processing I concluded that with regard to the quantity and quality of methane content the best period of the year is May and June as the average temperature and precipitation values have a good influence on the biological processes in the waste dump. Because of this I carried out a linear regression test regarding the changes of methane content of all the gas wells and precipitation data (Diagram 18). The relationship between the methane content changes and the precipitation intensity can be calculated by the following equation: $y=0,0442x+47,263$, $R^2=0,1964$. The closeness of the relationship shows moderate correlation as the coefficient of correlation is $r=0,44$. In case of positive correlation the increase of precipitation influences the methane content of landfill gas.

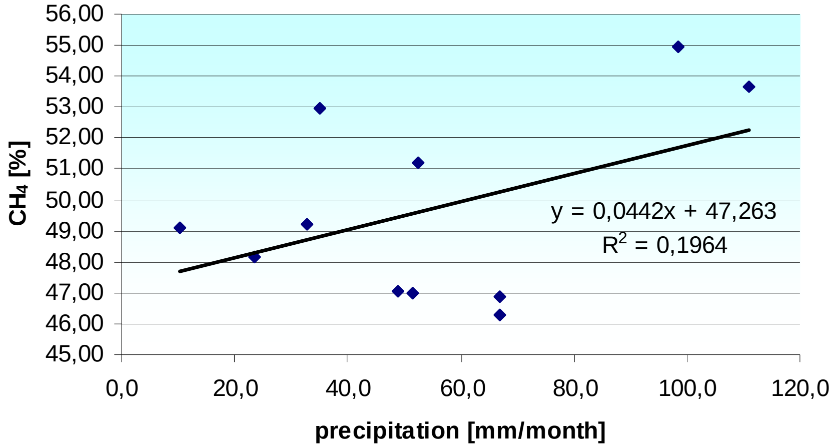

Diagram 18. Change of methane content with regard to precipitation intensity

I carried out further linear regression examination where I tried to find a relationship between the changes of monthly amount of landfill gas [m^3/month] and precipitation intensity [mm/month]. My results can be found in Diagram 19. The relationship between the change of the amount of landfill gas and precipitation intensity can be calculated by the following equation: $y=58,304x+20117$, $R^2=0,5026$. The coefficient of correlation is $r=0,71$ and the increase in precipitation leads to the increase of the amount of landfill gas.

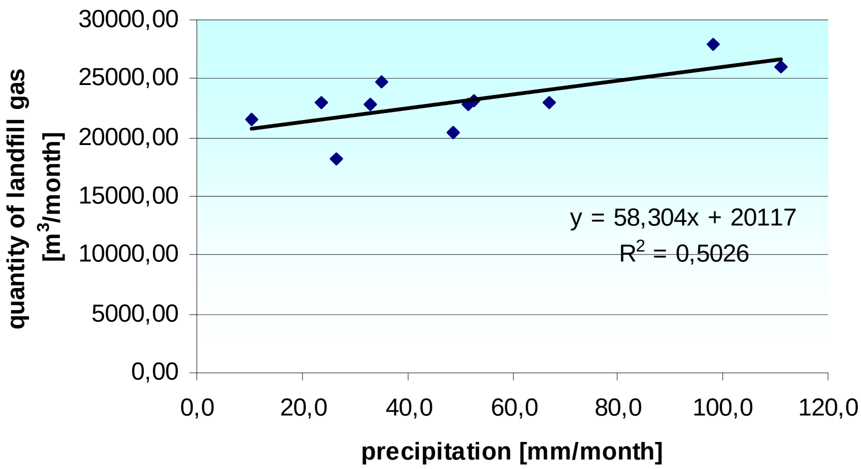

Diagram 19. Change precipitation with regard to the amount of landfill gas

3.4. Evaluation of results

Before my examination I defined the sample size for the statistical analysis. I also defined the standard deviation and average methane content values for a particular strand and estimation of errors and probability level where I carried out my tests had to be provided as well. The levels of probability during my tests were $P<3\%$ and $P<5\%$. In the light of my results the required sample size is $n=363$ in case of $h=3\%$ estimation of errors and in case of $h=5\%$ the sample size is $n=131$ in the case of the examination of all the gas wells and the different subfields. Due to that my $n=517$ sample size from all the gas wells is sufficient to carry out the examinations, statistical analysis and to draw the conclusions. The method of forming group pairs can be seen in Table 5.

Statistical process was carried out by analysis of variance by using SPSS for Windows 11.0 program where the relationships between the formed group pairs showed significant differences. Homogeneity tests were made by the Levene test, the comparison of the group pairs was made by the Tamhane and LSD tests. I also found it important to calculate the value of the coefficient of variation in case of all gas wells. By analyzing the coefficient of variation I tried to present the standard deviation within each group pair. This indicator can give an opportunity to compare homogeneity tests between group pairs.

4.4.1 Changes of the quantity parameters of landfill gas with regard to the vacuum used

I found that the operating parameters of the landfill gas extracting system used at the refuse dump has an effect on the changes of the methane content of the landfill gas. I determined the collection value according to the barometric pressure taking environmental pressure conditions into account. When the vacuum is higher than -0.9 mbar per gas well the methane content values significantly decrease. The relationship between vacuum values and the methane content of landfill gas shows $r=0{,}52$ coefficient of correlation which indicates moderate closeness of relationships. I examined and analyzed the differences at all the gas wells. I concluded that there are significant differences between gas wells as there are big differences between the organic matter content around the gas wells and their orientation. The results by gas wells can be seen in Table 10 where I found loose and moderate correlation relationships between the quantity parameters of collecting and landfill gas.

4.4.2 The quality and quantity parameter changes of landfill gas produced at the refuse dump with reagard to the average temperature intervals

According to the average characteristic of weather parameters at the refuse dump I found out how the changes of average temperature intervals influence the methane content of the recovered landfill gas. From the processed data I found that the changes of average temperature do not influence the methane content of landfill gas as the coefficient of correlation is $r=0{,}1029$. On the other hand the increase of average temperature might increase the methane content. As the refuse dump can be considered as a large bio-reactor, changes of external temperature only influences the upper layer of the waste and it does not influence the internal temperature of the waste. During the statistical analysis I found significant differences between gas wells which can be seen in table 15. As the orientation and the organic matter composition of the gas wells are different at each gas well there is a relationship between the changes of average temperature at some gas wells. I also found that at the refuse dump in a particular examination range the changes of average temperature intervals has an effect on the quantity of the produced landfill gas and coefficient of correlation is $r=0{,}42$.

4.4.3 Changes of the methane content of landfill gas with regard to relative air humidity

After data processing I found that at the refuse dump the changes of the methane content, recovered from the gas wells, are not influenced by relative air humidity as coefficient of correlation is r=0,02. Relative air humidity change in case of methane content by gas wells causes significant differences but the volume of this effect on the methane content of the total yield of landfill gas is not notable.

4.4.4 Changes of the methane content of landfill gas with regard to barometric pressure

After data processing I came to the conclusion that barometric pressure in the given region does not influence microbiological processes that occur within the waste and as a result does not influence the methane content of the recoverable landfill gas as coefficient of correlation is r=0,11. In the cases of the gas wells I became aware of significant differences between barometric pressure groups and their belonging methane content. From the linear regression tests (Table 25) it can be concluded that at certain gas wells there is a relationship between barometric pressure changes and the methane content of landfill gas because of the orientation of the gas wells.

4.4.5 Changes of methane content of landfill gas at the refuse dump with regard to wind speed intervals

I diagnosed how the different wind speed intervals at the refuse dump influence the methane content of landfill gas where coefficient of correlation is r=0,48. Between the variables there is negative correlation which means that when wind speed values increase methane content values decrease. This process can increase during the raising of the landfill site when the height of the 3m wide and 2m high ramparts on the outside edge of the prisms gets higher than the height of the waste in the refuse dump. By that the methane content of the recovered landfill gas can decrease and have higher oxygen content. After linear regression examination (Table 30) I found a moderate negative correlation in the cases of 4, 5, 6, 7 and 8 gas wells. In the cases of the other gas wells I found loose negative correlations. All things considered we can state that the wind speed intervals at the refuse dump influence the methane content of landfill gas.

4.4.6 The quality and quantity parameter changes of landfill gas produced at the refuse dump with regard to precipitation

I found that quality and quantity parameters are influenced by precipitation intensity. If the precipitation is high the methane content of landfill gas increases and coefficient of correlation is r=0,4429. The closeness of the relationships is moderate, correlation is positive so the rise of precipitation causes the rise of methane content of landfill gas.
Furthermore, I found that the rise of precipitation influenced the quantity of the produced and recovered landfill gas at the refuse dump and coefficient of correlation is r=0,71. The explanation for that is that moisture content for anaerobic fermentation is indispensable. The closeness of the relationships is strict, and the correlation is positive and the rise of precipitation causes the rise in the amount of landfill gas.

4. NEW SCIENTIFIC RESULT

In my PhD research the new scientific results can be summarized as mentioned below

1. I found that during the operation of the gas recovery system at the refuse dump the operating pressure values and the methane content of the landfill gas are related. I found that the gas recovery values of the extraction used in the operating system under operating conditions influence the methane content of the landfill gas *(correlation coefficient r=0.52)* and thus the exploitable quantities which can be described by the following equation: y=3,5607x+51,72, R^2=0,2644 and coefficient of correlation is r=0,52. By increasing the volume of extraction the quantity of the recovered landfill gas significantly decreases

2. By using statistical analysis I determined that within the characteristic weather parameters of a region the changes of the average temperature intervals do not influence the methane content of landfill gas at the refuse dump. The relationship between average temperature intervals and methane content of landfill gas can be described by the following equation: y=0,1948x+47,177, R^2=0,0106 and coefficient of correlation is r=0,1029. But certain tendencies can be seen between the rise of average temperature and methane content of landfill gas, in these cases the orientation of the gas well is significant. According to the examinations carried out under operating conditions I found out that the changes of the average temperature intervals influences the quantity of produced landfill gas. Relationships have been established between the average temperature changes and the quantity of landfill gas produced. The relationship between average temperature changes and the quantity of methane can be described with the equation: y=129,91x+21407, R^2=0,1628 and coefficient of correlation is r=0,42. In this case there is a positive correlation which shows that if the average temperature rises the quantity of landfill gas rises as well annually.

3. When processing the results of the experiments it was found that the changes in the relative humidity neither affect the microbiological processes taking place in the landfill, nor the methane content of the landfill gas. The relationship between the relative air humidity and methane content changes of the landfill gas can be described with the equation: y=-0,023x+51,478, R^2=0,0004 and correlation coefficient is r=0,02. During data processing I found out that from the environmental parameters at a particular refuse dump the characteristic atmospheric pressure changes will not affect the methane content of the landfill gas. Relationship between atmospheric pressure changes and methane content changes of the recovered landfill gas can be described by the following equation: y=-0,223x+277,22, R^2=0,0126 and coefficient of correlation is r=0,11. But there can be seen some relationships in the cases of some gas wells between the increasing atmospheric pressure and the landfill gas methane content but these changes do not show significant differences in the quality of the annual landfill gas.

4. Based on the statistical processes with regard to wind speed interval tests I concluded that the wind speed changes specific for the landfill site affect the methane content of the landfill gas. Relationships between wind speed changes and methane content can be described by the equation: y=-5,2869x+56,452, R^2=0,1699 and coefficient of correlation is r=0,48. Between the variables there is negative correlation, if wind speed increases the methane content values decrease. Closeness of relationships between wind speed changes and methane content are moderate.

5. I found that the rainfall intensity rates influence the processes taking place in a landfill, so the amount of landfill gas and its methane content. After data processing I came to the conclusion that rainfall intensity changes greatly influence the quantity of landfill gas and between variables there is a tight relationship. The relationship between the increase of rainfall intensity and the quantity of landfill gas can be described with the equation: $y=58{,}304x+20117$, $R^2=0{,}5026$ and coefficient of correlation is $r=0{,}71$. Correlation is positive between the relationships, if the intensity of rainfall increases the amount of landfill gas also increases. I also found that the increase of rainfall intensity influences the methane content of landfill gas between the variables I found a statistically moderate relationship. By the increase of precipitation intensity the methane content also increases which can be described by the equation: $y=0{,}0442x+47{,}263$, $R^2=0{,}1964$ and coefficient of correlation is $r=0.4429$.

5. CONCLUSIONS AND SUGGESTION

The purpose of my research is to examine the quantity and methane content of landfill gas originating from the characteristic organic matter potential, weather parameters and exploitation technology used in the region and by that, determine useful relationships. Results are defined in working dimensions where the quality and quantity of landfill gas is defined by the efficiency of the extraction system, environmental conditions, the composition of waste and the technology of unloading.

The results of my research draws the attention to the fact that the volume of extraction used at the refuse dump influences the methane content of the recovered landfill gas. In the cases of gas wells I suggest a transition to a telemetry system with continuous control instead of a periodical regulation of valves. It means that all the parameters about the quality of landfill gas, which are provided by the gas measuring points at the gas wells are stored on a computer. On the basis of the incoming information the opening angles of the valves can be calculated by the planned computer program. The operating of the valves can be solved by an electric engine so the opening values, determined by the computer, can operate from the central operating office. The telemetry system would monitor the data sent by the meteorological station and the volume of extraction at the gas wells could be determined on the basis of that. With the usage of it the most favourable quality and quantity parameters can be guaranteed.

The conclusions drawn during my PhD research strand about the quality and quantity changes of landfill gas with regard to average temperature intervals are the following. In case of unfavourable weather conditions or low average temperature it is advisable to return leachate that occurs at the refuse dump into the waste in order to create favourable microbiological conditions. The volume of extraction should be decreased in the unfavourable average temperature domains so gas wells, which recover only small quantities or low methane content landfill gas because of the unfavourable external temperature, can recover gas at an optimal extraction value.
Relative air humidity and barometric pressure changes do not immediately influence the processes inside the waste as they occur with a delay. But I could observe a relationship between barometric pressure changes and methane content and my suggestions are the following in this field: by processing weather parameters, forecasting and the values of the volume of extraction we can provide the most optimal gas recovery and methane content. The methane content of the landfill gas is influenced by the characteristic of wind speed intervals and the changes of wind direction. My proposals are the following: at the surrounding areas at gas wells leachate must be returned in the waste and moisture content level must remain the same and within the range of gas wells covering and closing must be done in order not to let landfill gas into the air. With the increase of wind speed the elements of the extraction system have to be coordinated in a way that the volume of the vacuum has to be increased until it levels off with the volume of the vacuum on top of the waste. Precipitation intensity has an effect on the methane content of landfill gas and its quantity values. My proposals are: when there is not much rainfall by the help of watering systems leachate should be taken out from containers onto the top of the waste so moisture can be maintained and flue-dust concentration can be decreased. When precipitation is high leachate should be vaporized by gas engines' waste heat so acidification, gas production and methane content decrease can be avoided.

Operators should take into account the volume of extraction and environmental parameters such as average temperature, precipitation intensity and wind speed in order to be able to plan the most favourable recovery of landfill gas and methane content.

6. SUMMARY

In our country and world-wide the amount of waste is growing rapidly due to economic development. It is true that the amount of selectively collected waste is also increasing and also the quantities of secondary materials as recycled materials quantities - so they can get back into the manufacturing process – however it is an important task to dispose of the waste at an up-to-date and environmentally friendly location. The theoretical and practical phenomenon confirms that processing the generated waste by modern European Union-compliant technology systems can be used as alternative energy instead of fossil energy sources to produce electricity and heat. The other aspect is to protect the environment, and therefore use measures and technologies, which provide possibility for minimizing the potential environmental problems during the placement and disposal of waste. The issue of landfill gases from the anaerobic decomposition of municipal waste has been dealt with since it was demonstrated that natural and anthropogenic methane, carbon dioxide emissions contribute to the development of the greenhouse effect phenomenon. The objective of my research is to examine and assess the factors influencing the development of landfill gas production at a waste disposal site that is characteristic of a given region. The landfill gas extraction was examined under operating conditions and it was found out which changes in the parameters caused the change of quantity and quality characteristics of the energetically utilized landfill gas.

In the results section I presented in detail the new scientific findings specific to each location, which were the following. I found that the gas recovery values of the extraction used in the operating system under operating conditions influence the methane content of the landfill gas *(correlation coefficient r=0,52)* and thus the exploitable quantities. I determined the average weather temperature changes within the parameters characteristic of a particular region do not affect the methane content of the landfill gas formed at the landfill site *(correlation coefficient r=0,10).* Relationships have been established between the average temperature changes and the quantity of landfill gas produced *(correlation coefficient r=0,42).*When processing the results of the experiments it was found that the changes of relative humidity neither affect the microbiological processes taking place in the landfill, nor the methane content of the landfill gas that can be energetically utilized *(correlation coefficient r=0,02).* I found that the atmospheric pressure changes will not affect the methane content in the landfill gas *(correlation coefficient r=0,11).* The wind speed changes specific for the landfill site affect the methane content of the landfill gas *(correlation coefficient r=0,48).* I found that the rainfall intensity rates influence the processes taking place in a landfill, so the amount of landfill gas and its methane content. The relationship between methane content and rainfall intensity can be described with the equation $y=0,0442x+47,263$ where $R^2=0,1964$ *and the correlation coefficient is* $r=0,44$. The relationship between rainfall intensity and the quantity of landfill gas can be described with the equation $y=58,304x+20117$ where $R^2=0,5026$ *and the correlation coefficient is* $r=0,71$.

Overall, in a particular landfill, the meteorological parameters are always changing; the organic matter input parameters are characteristic of the region therefore the extraction efficiency can only be changed by the control of the exhaust capacity. Therefore, research has great importance in this area of research to show which landfill gas parameters are generated with the climatic parameters and organic matter intake. Both the existing and proposed landfill sites might use the results of my doctoral research for the best available landfill gas extraction and methane content.

7. MOST IMPORTANT PUBLICATIONS RELATED TO THE THESIS

Referred articles in foreign languages

1. Molnár T. (2007): Quantitative and qualitive analysis of the biogas production from the municipal solid waste, Hungarian Agricultural Engineering N^0 20/2007, pp. 20-22, HU ISSN 0864-7410.
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