A BETTER MODELING OF LANDFILL GAS PRODUCTION FOR BETTER USAGE AS ENERGY SOURCE

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ABSTRACT: Landfill gas production modelling is made in these days using first order decay models which can be simple phase or multi-phase models. Among the most utilized software for landfill gas modelling there is also LandGEM v3.02. The LanGEM software model is offered by United States Environment Protection Agency and is a first order decay simple-phase model. However this software has his drawbacks and in the case of a landfill which not utilize the leachate recirculation the results are overestimated. Using an improved LandGEM model for landfill gas production modelling we can estimate correctly the quantity and the energy potential of landfill gas and we can implement appropriate solutions for electric energy production and for thermic energy recuperation. The case study for the research from this article I made it at Oradea's ecological landfill for non-hazardous wasteswhere the leachate recirculation is forbidden and the recovered landfill gas is utilized for electric energy production. In this case the landfill gas cannot be utilized directly for leachate evaporation. In consequence a solution will be utilized which will recuperate the residual thermic energy from the engines and exhaust pipes of these for leachate evaporation at lower pressure and lower temperatures.

KEY WORDS: landfill gas modelling, renewable energy, leachate evaporation

1. INTRODUCTION

Anaerobic decomposition of biodegradable wastes within the landfill frame lead to landfill gas formation, a gas which has in composition 50-60% methane and 35-50% carbon dioxide. Because of his great global warming potential European legislation impose the recovery and utilization of landfill gas for energy production if it is possible or if is not possible it must be flared.

For a proper use of landfill gas is necessary a correct estimate of landfill gas generation by software modelling.

2. LANDFILL GAS GENERATOIN MODELLING

LandGEM software model version 3.02 is developed by United States Environment Agency and uses a first order decay equation for prediction of landfill gas production in time.

$$Q_{CH_4} = \sum_{i=1}^{n}\sum_{j=0.1}^{1} k * L_0 * \frac{M_i}{10} * e^{-k*t_{ij}} \quad (1)$$

where:

- $Q_{CH4}$is quantity of generated methane,
- k is first order decay constant rate,
- $L_0$is methane potential generation capacity,
- $M_i$is mass of wastes landfilled in year i,
- t_{ij} is the age of section j of waste with mass M_i landfilled in year i.

For k and L_0parameters we can use the default values or we can use the landfill's measured specific values for wich we make the modelling.[1,2]

3. RESEARCH METHODOLOGY

For the case study I utilized the waste's data from Oradea's ecological landfill for nonhazardous wastes.

In the article "A method to estimate the methane generation rate constant (k) and the potential methane generation capacity (L_0) of municipal landfills of western Romania" I determined these parametersby successive modelling with LandGEM v3.02 starting from Europe's specific parameters of influencing factors and of waste particularities.[3] For Oradea's ecological landfill I determined in this way the values for first order decay constant rate $k\in[0.02,0.03]$ and for methane potential generation capacity $L_0\in[50,70]$ m^3/ton.

The values of parameter L_0estimated in this way are very close to Europe's values. The values of parameter k from [0.02,0.03] interval are rather specific for semi-arid areas and for wastes with low content of biodegradable substances. LandGEMsoftware's model equation uses as default value for parameter k the 0.04 value and is optimized for landfills that utilizes recirculation of leachate which have a production of landfill gas up to 35 % greater than the landfills that not utilizes recirculation of leachate.

In order not to underestimate the landfill gas generated in the landfills that utilizes the leachate recirculation, the LandGEM model that uses the equation (1) as calculation formula divides the amount of waste deposited in a year to 10 and uses time increments of 1 year / 10 for which calculates the amount of landfill gas generated .[4]For landfills that do not allow leachate recirculation the LandGEM model over-estimate the quantity of landfill gas generated due to small time intervals utilized.

In the case of recirculation of leachate , to form a certain amount of landfill gas is required a shorter time compared to the case where recirculation of leachate is not used to generate the same amount of landfill gas.(see figure 1)

In the case of LandGEM formula for subdivisions of time longer than a year / 10 approximation of the amount of gas generated may be similar to the case of not using leachate recirculation.(see figure 2)

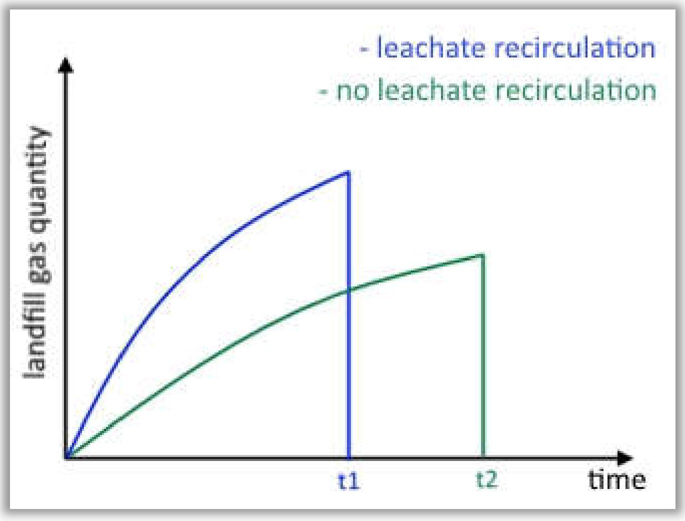

Figure 1 The time needed to form the same amount of landfill gas in case of leachate recirculation respectively in the case of not using leachate recirculation

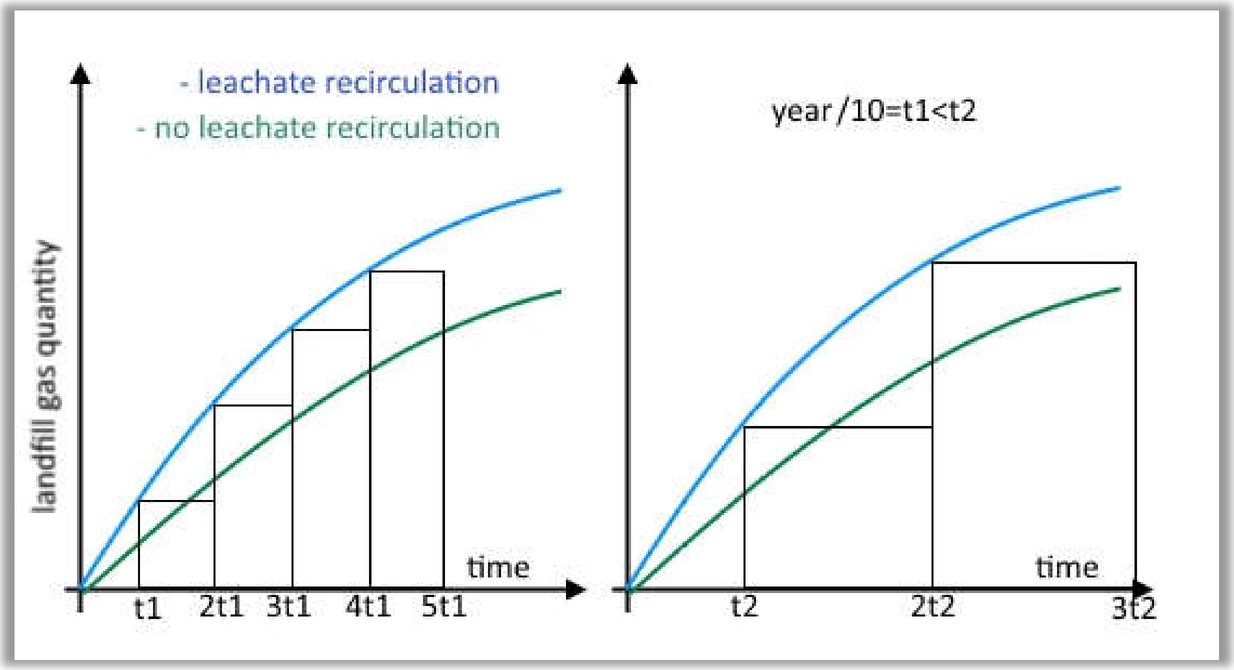

Figure 2 Approximation of the amount of landfill gas generated by LandGEM formula using time divisions higher than 1 year / 10

To test the LandGEM formula for time sections greater than 1 year / 10, I wrote the LFGMOD software version 1 in C# programming language, that uses LandGEM formula and allows the use of time division of a year of 1/10 , 1 / 8 , 1/6 , 1/5 , 1/4 or any value desired by the user.

In the graph from figure 3 are shown the results values for LFGMOD software modelling with time sections of year / 10, year / 8 , year / 6, year / 5 and year / 4 and the parameter k = 0.03 and L_0 = 65m^3 / ton.

For the second set of modellings (see figure 4) I renounced at time divisions of year / 10 and year / 4 (because the results were too big or too small compared with the measured data in the field) and I used value 0.04 for parameter k and value 50m^3/ton for parameter L_0.

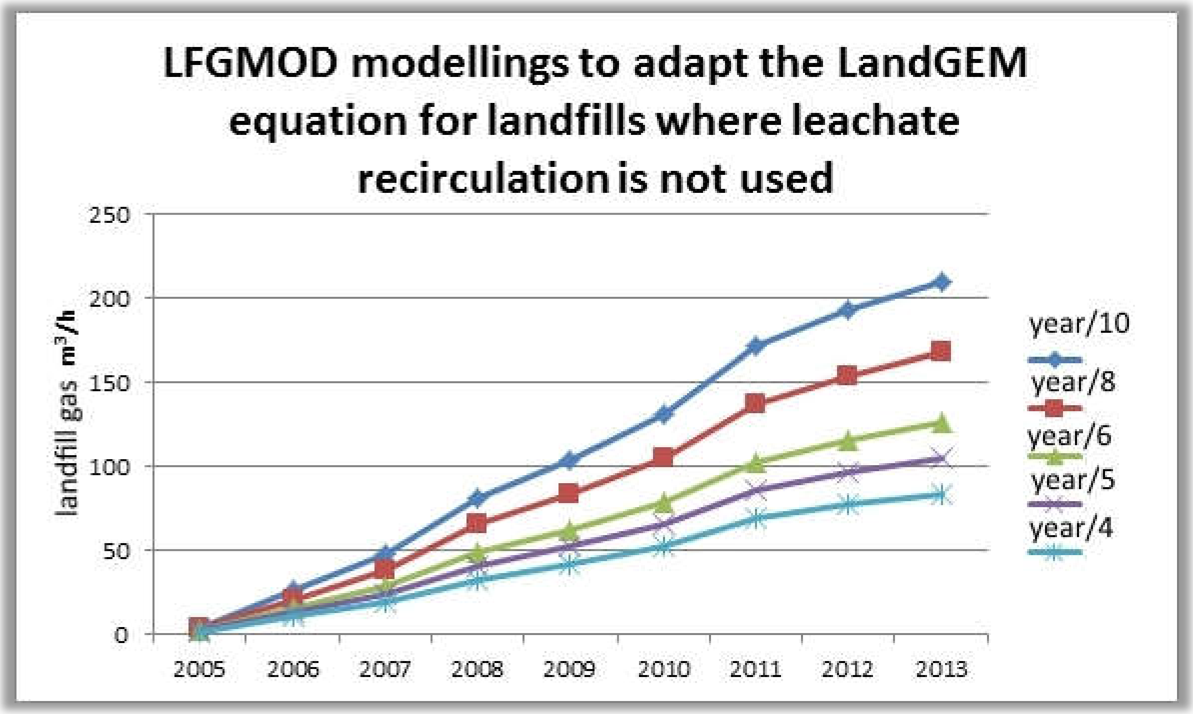

Figure 3 Modellins with LFGMOD software (k=0.03,L_0=65m^3/t)

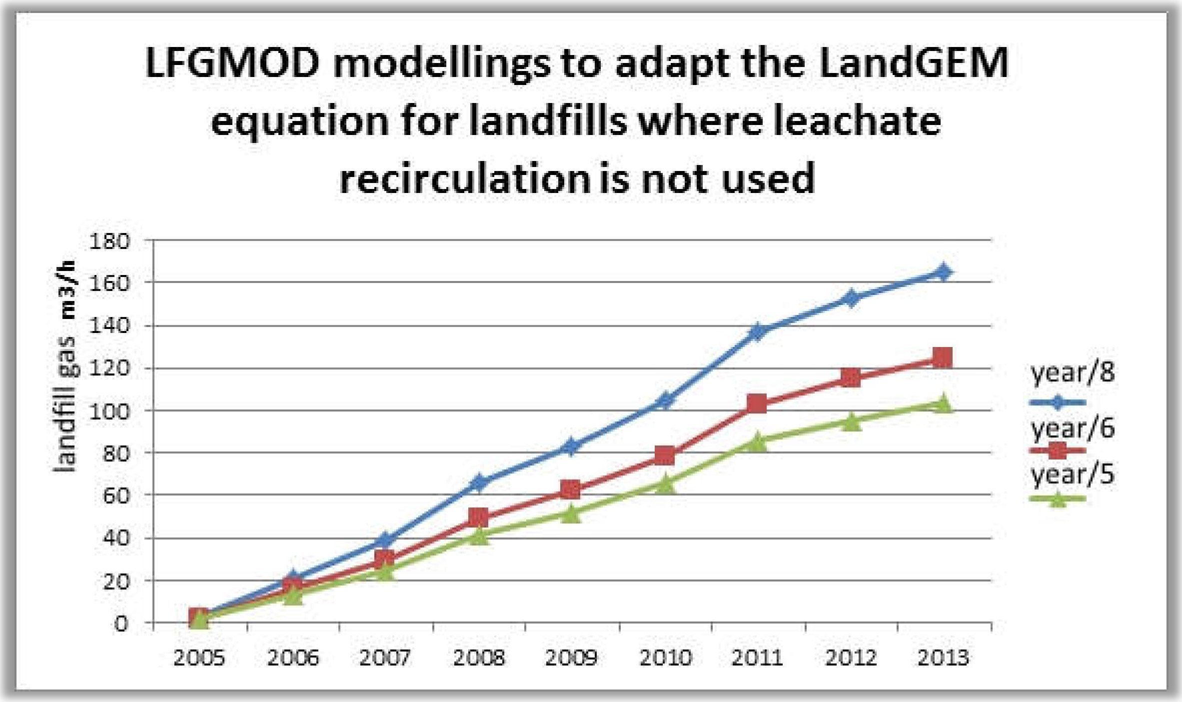

Figure 4 Modellins with LFGMOD software (k=0.04,L_0=50m^3/t)

For time section 1 year/6 used in LFGMOD software for modeling landfill gas generated from Oradea's ecological landfill(where leachate recirculation is not used) the results were closest to the values measured in the fields. Thus for Oradea's ecological landfill biodegradation rate constant is in the range [0.03,0.04] and methane generation potential in the range [50, 65] m3/t.

These values for k and L_0parameters can be used for initial modelling of landfill gas generated from Romania's landfills, because the wastes colected shows similar compositions (usually a landfill is serving a county with a county city,4-7 towns and villages with a population share of 50% representing city population and 50% representing the population from villages).

The calculation formula of LandGEM model optimized for landfills where leachate recirculation is not used and the composition of waste is not known implemented and tested with LFGMOD software version 1 will have the following equation:

$$Q_{CH_4} = \sum_{i=1}^{n} \sum_{j=0.166}^{1} k * L_0 * \frac{M_i}{10} * e^{-k*t_{ij}} \quad \textbf{(2)}$$

The advantages of LFGMOD software version 1 using parameters of biodegradation constant rate $k\in[0.03,0.04]$ and methane generation potential capacity $L_0\in[50,65]$ m^3/ton used for landfills from Romania where recirculation of leachate is not used and if the waste's composition is not known just the amounts of wastes landfilled or to be landfilled, are the following:

- Ease and speed of use,
- It is not necessary to know the composition of the waste,
- Very acurate results(not overestimated) in case of Romania's landfills(where leachate recirculation is not used).

In case of landfills where the composition of wastes is known, the equation of LANDGEM model uses the same value for biodegradation constant rate and for the methane generation potential capacity for the entire amount of wastes regardless of its composition.

For Oradea's ecological landfill, after the waste composition analysis,I divided the waste into four categories for which I calculated methane generation potential capacity, taking into account the share of category (see Table 1) .

Table 1L_0 values for different categories of waste and their share Oradea's ecological landfill

No.	Category of waste	Share of subcategory	Share of category	$L_0(m^3/t)$
1	Construction and demolition waste, Sewage sludge, Industrial waste.	9% 3% 1%	13%	27,5
2	MSW, Waste from gardens	70% 1%	71%	88
3	Food waste	2%	2%	73
4	Inert waste	15%	15%	0

For the four broad categories of waste in table 1 I used the following values for the rate of biodegradation : fast , moderate and slow and the share of a category of waste that decomposes quickly, moderately and slowly accorind to IPCC 2006 standard(see Table 2).

Table 2 Values for the rate of biodegradation by category and their share for Oradea ecological landfill

Biodegradation rate	K	Share of biodegradation rate I.P.C.C.
1 fast	0.06	10%
2 moderated	0.035	55%
3 slow	0.02	35%

On this classification of waste, methane generating potential capacity and biodegradation constant rate we can optimize the LandGEM formula in this way:

$$Q_{CH_4} = \sum_{i=1}^{n}\sum_{j=0.1}^{1}\sum_{p=1}^{3}\sum_{q=1}^{3} k_q * L_{0p} * \frac{M_i * P_p * P_q}{10} * e^{-k_q * t_{ij}} \quad \textbf{(3)}$$

where:

- $L_{0p}$is methane generation potential capacity of wastes from p category,
- $P_p * P_q$is the share of waste from category p with biodegradation constant ratek_q,
- $M_i$is teh amount of waste landfilled in year i,
- t_{ij} is the age of section j of waste with mass M_i landfilled in year i.

I implemented this formula in LFGMOD software version 2.This allows changing the biodegradation constant rate of the categories, the share of any waste category,theshare of biodegradation rates and calculates the methane generation potential capacity for the four categories. Using the data fromTable 1 and Table 2 and LFGMOD software version 2 which implements equation 3 I modeled the amount of landfill gas generated by the Oradea ecological landfill.For verification I multiplied the results by the efficiency of recovery system of landfill gas and compared the results with values measured on the field.

For equation 3 which is a modified version of LandGEM model formula the results were also very accurate compared to the values measured on the field.

Advantages of LFGMOD software version 2 overLandGEM software are:

- Use four categories of waste and if the waste composition changes over time , the program allows the use of specific values to the waste landfilled in every year ,
- Use a inert category of waste that does not generate landfill gas,
- Very acurate results(not overestimated) in case of Romania's landfills(where leachate recirculation is not used).

A comparison of the results obtained with LandGEM software with those obtained with improved LandGEM formula in the LFGMODsoftware version

1 and 2 are illustrated in the graph from Figure 5.It is noted that LandGEM formula overestimates the results by about 60% in the case of landfills where leachate recirculation is not used and the improved LandGEM formula in LFGMOD software version 1 and 2 has estimation errors under 5%.

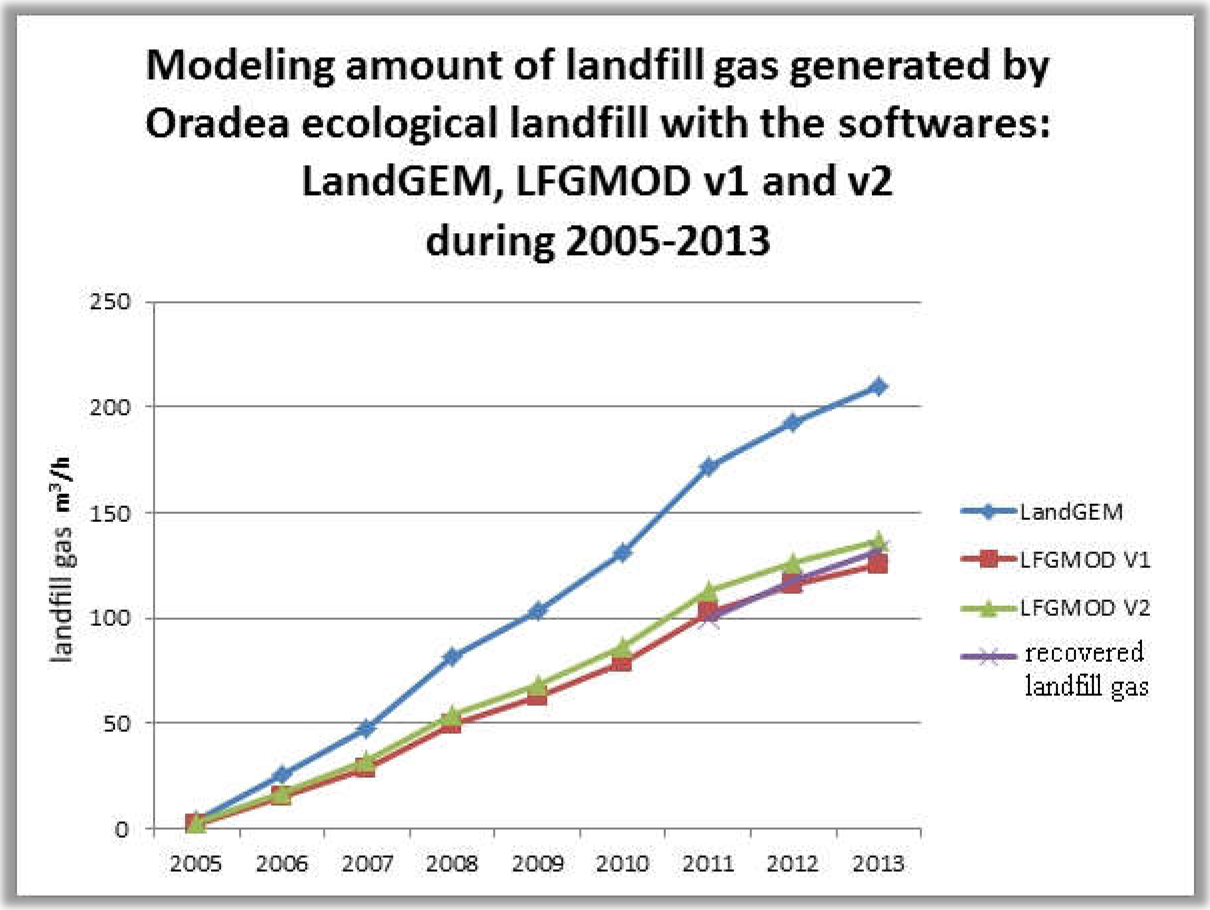

Figure 5 Modelling amount of landfill gas generated by Oradea ecological landfill with the software:LandGEM, LFGMOD v1 and v2 during 2005-2013

4. ENERGETIC VALORISATION OF LANDFILL GAS

At the Oradea's ecological landfill were installed two electricity generating units NRG250 - GV8DTI with the following features:

- 8 cylinder V engine,
- 14.6 liters capacity,
- 4 valves per cylinder,
- 1500 rotations / minute,
- gas supply quantity 105,2Nm^3 / h ,
- 6,2kW / Nm^3 = > 652kW input energy content,
- mechanical Power 260kW,
- electrical power 250kW,
- electrical Efficiency 38%
- thermic power296kW ,
- thermic efficiency 45.4 %,
- total Efficiency 83.68 %. [5]

According to the estimation of landfill gas production by 2025 generation unit should be supplemented according to the graph from Figure 6 .

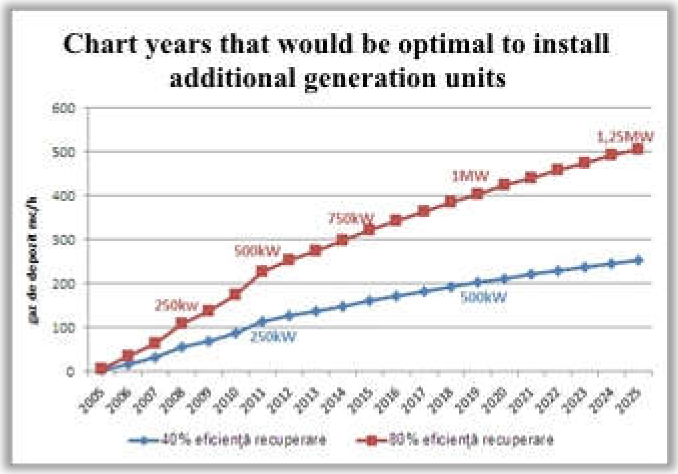

Figure 6 Chart years that would be optimal to install additional generation units at Oradea ecological landfill[6]

Waste heat can be recovered from the engine block dead and from the exhaust pipe and would be sufficient to treat the leachate in a evaporation system at low pressure and low temperature.

The system of the two-stage vacuum evaporation from Figure 7 uses two low pressure boilers. In the first boiler the concentrate is heated and the vapors are condensed resulting therefrom a first distillate which is heated in the second boiler and its vapors are condensed and thesecond distilled resultedis final.

At system boot, boiler 1 (blue in Figure 7) is filled with tap water and boiler 2 (brown in Figure 7) is filled with concentrate. Boiler 1 is heated by hot water from engine cooling system of the cogeneration system. The vapors from boiler 1 at pressure of 211mbar reach the condenser RBWT 02001 at 59°C.These heat up the concentrate in the boiler 2 to the temperature of 52°C . The vapors of concentarte from the boiler 2 at 106mbar pressure reach out the condenser RBWT 02101 with a temperature of 45°C. Here B031 distillate is formed and has 39°C. Sulfuric acid is added to this distillate and is introduced into the boiler 1 as the process of evaporation progresses and condenser RBWT 02001out the distillate B030 which is final at 56°C.

The vacuum system consists of two centrifugal pumps with ejector B030 and B031 using distillates as motor fluid using the Venturi principle.In boiler 2 the temperature and pressure is lower than in boiler 1, to trigger evaporation of the concentrate. (59°Ccompared to 45°Cand 211mbar compared to 105mbar). Both boilers are provided with a vacuumneutralization valve.

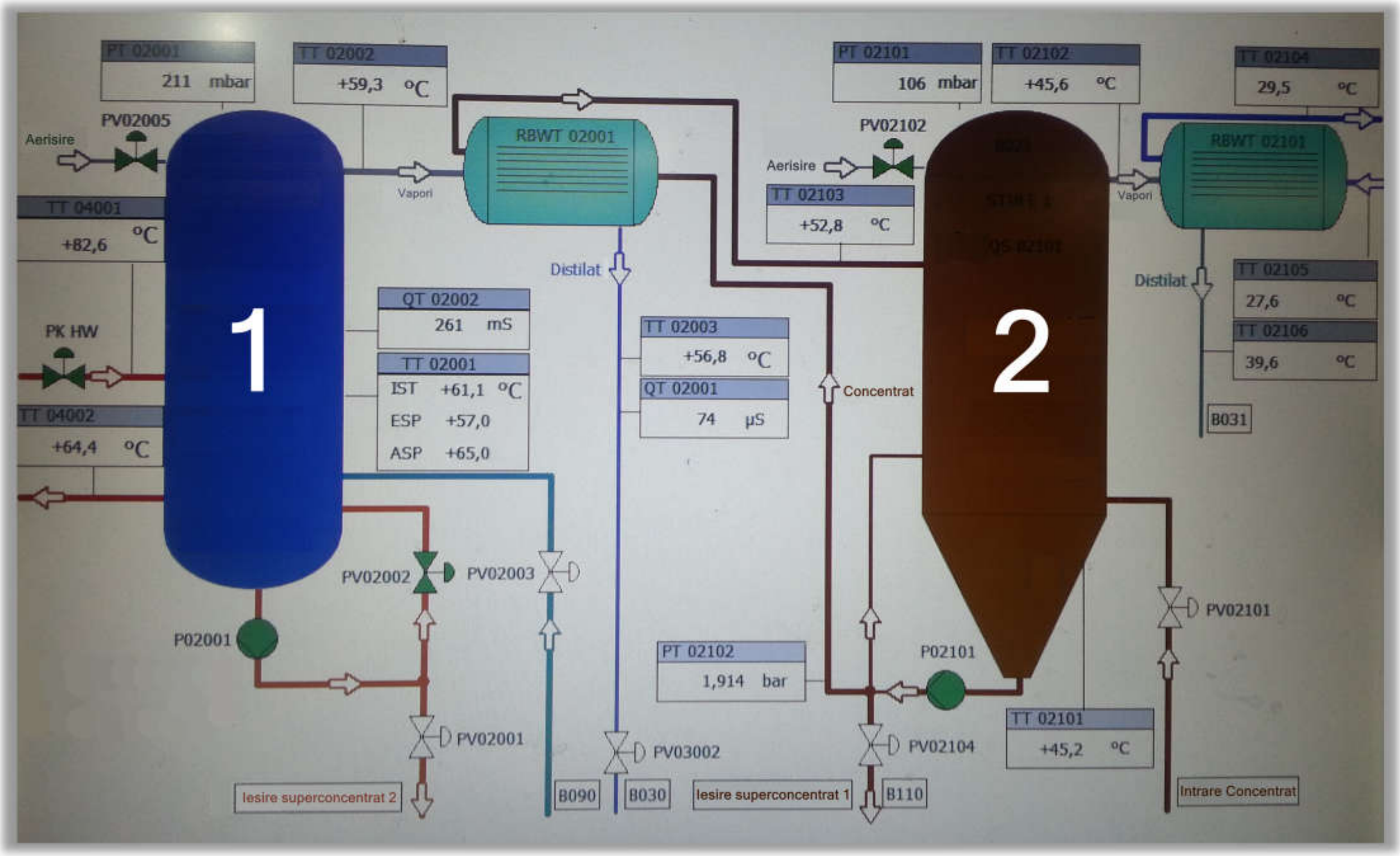

Figure 7 Twostages concentrate evaporator at low pressure

The amount of the resulting viscous concentrate or liquid is reduced by at least 70 % depending on the characteristics of the liquid being processed. To test this system concentrate samples were sent from Oradea ecological landfill to the laboratory for analysis and were processed identical to the presented system.The characteristics of the resulting distillate are shown in Table 3 and are in the limits imposed by the Technical standards of waters protection NTPA 002/2002 on conditions for wastewater discharge into the sewage systems or directly to treatment plants.

The two-stage evaporation system can treat up to 21m^3 per day of concentrate and from this point of view can cover volume generated by the PALL leachate treatment plant by reverse osmosis which is 19$m^3$of oncentrate. The necessary heat for the two-stage evaporation system can be supplied by engine cooling system water of cogeneration system installed at Oradea ecological landfill and by the thermic energy that can be recovered from their exhaust pipes.

The super - concentrate has a volume reduced by about 85 % compared to the initial treated concentrate volume.

Table 3 The characteristics of the distillate resulted from concentrate treatment with the two-stage low pressure evaporator

characteristic	Unit measure	NTPA 002	Value in distillatate
PH	-	6,5-8,5	8
Density	g/ml		
Color	-		Transparent
Conductivity	µS/cm		77
COD	mg/l	500	100
Chlorides	mg/l		<11
Fluorides	mg/l		
Ammonium nitrate	mg/l	30	15
Ammonium	mg/l		147,1
Pb	mg/l	0,5	<0,1
Cu	mg/l	0,2	<0,07
Organic solvent extractables	mg/l	30	<9
Anionic surfactants	mg/l		0,27
Sulphates	mg/l	600	278
Cr	mg/l	1,5	0,76
BOD5	mg/l	300	151,7
Ni	mg/l	1	0,49
Zi	mg/l	1	0,43
Mn	mg/l	2	1,04

5. CONCLUSIONS

The LandGEMmodel if it's used for a landfill where leachate recirculation is not used tends to overestimate the landfill gas production by 60%. By LFGMOD model version 1 and 2 introducedI improved LandGEMmodel equation in case of landfills that not recirculate the leachate, and the results have errors under 5%. The two version of the LFGMOD software can be used for landfills where the composition of waste is known or for landfills where the waste composition is not knownand leachate recirculation is not used with good results for prediction of landfill gas yelds.

Traditional models of evaporators use the landfill gas directly into a system which flares the leachate at high temperatures of hundreds of degrees. If the landfill gas is used to produce electricity, leachate evaporation can be done through a system of low pressure evaporation by recovering heat energy from the cooling system and the exhaust CHP engines.

At the ecological landfill in Oradea after the research will be installed such a system by evaporation at low pressure which will reduce the amount resulting concentrate by reverse osmosis treatment of leachate from 19m^3/day to 3-4m^3/day (about 85% reduction of the volume).

6. ACKNOWLEDGEMENTS

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