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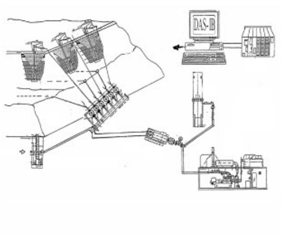

Optimisation of gas collection systems

Landfills, hazardous waste and abandoned waste disposal sites

 # 309

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Summary

Optimisation of gas collection systems appears useful in the event that the amount and quality of landfill gas decreases continuously and/or larger methane emissions over the landfill surface are ascertained. This applies in particular to landfills where a CHP plant is operated for the power generation and the feeding-in. To prevent reduced operation in the first instance or subsequent dismantling, as effective a utilisation as possible of the available landfill gas potential should be ensured. To achieve this, the operators have different possibilities. In the following text, in particular the optimisation of a gas collection system and the systematic approach will be presented. The possible higher expenditure means a further positive step to emission reduction, also with regards to the aftercare phase.

Index words

Landfill gas, optimisation, gas collection system, hazardous waste, abandoned waste disposal sites, landfill, optimisation, extraction system, gas wells

Introduction:

By terminating the placement of non-treated biological waste on landfills in 2005, a general decrease in the landfill gas quantities could be forecasted. The missing degradable organic material no longer allows a future biological-chemical landfill gas production. The composition of the landfill gas changes significantly, and the methane proportion and the gas quantity decrease or recede. The carbon dioxide, nitrogen and oxygen proportions increase. In addition, the ageing of the landfills leads to a deceleration of the conversion of organic material into methane which is still in process, until conversion is finally disrupted. Moreover, there are further boundary conditions, such as the sealing of landfills, which are counterproductive for continuous landfill gas production at a high level in terms of quantities. Sooner or later, every landfill, hazardous waste or abandoned waste disposal site with active gas collection and utilisation will reach this crossroads and, with a view to the decreasing landfill gas yields, will need to implement technical adaptations (alteration of existing CHP technology, flares etc. → poor gas treatment). But before reaching this moment, the operator should try to exploit the available landfill gas potential to the largest possible extent and to increase profitability or to keep it constant, and finally also to be well prepared for the period afterwards. The basis for this is an optimally operated gas collection system. In addition, optimisation measures can help to meet the requirements of the measurement and control programme of the "new" regulation for waste disposal sites to achieve emission reductions in the sense of environmental protection.

Contents

1 Optimisation:

1.1 Initial situation

In the first step of optimisation, it is useful to determine and evaluate the actual condition of the landfill gas collection system and of the related energetic utilisation (CHP). During this stage, the already available and compiled findings about the landfill and the measures undertaken are analysed. This also includes the evaluation of the available data, such as:

- Measurement reports of the individual gas wells (CH_4, CO_2, O_2, H_2S, pressure, flow rate, temperature, depth)
- Measurement reports of the gas collection stations (CH_4, CO_2, O_2, H_2S, pressure, flow rate, temperature; of the individual gas well connections and manifolds)
- Measurement reports of so-called "FID inspections" (sum of the emissions of hydrocarbons over the landfill surface)
- Measurement reports of any available stationary analyses (CH_4, CO_2, O_2, H_2S, pressure, flow rate)
- Annual quantities and the course (load curve) of landfill gas for energetic utilisation
- Basic conditions of the landfill (structure gas collection, any available landfill surface covering, technical equipment etc.)
- Water balance of the landfill (water build-up etc.)
- Any available measurement reports about the leachate / water build-up
- Condition of the gas collection system
- Any undertaken remedial actions or retrofitting measures (e.g. in the gas well)
- Currently implemented optimisation or adaptation measures (measurement intervals etc.)
- Experiences of the operator or of his employees
- Any implemented camera inspections of gas wells and pipes
- Evaluation and, if required, new development of gas prognosis models

- Measurement / sampling of gas control levels around the landfill

Primarily, it is important to show whether and how a possibly still available and unexploited landfill gas potential can be determined. This can be ascertained in particular using a landfill gas prognosis and by means of the edge surface and surface emissions. A landfill gas prognosis can, of course, only be a rough estimation of the landfill gas quantities which can still be expected. In this respect, a comparative check of the prognosis with the actually collected landfill gas quantities is inevitable, and possibly a new evaluation on this basis will be required. In the event that the actual quantities strongly deviate from the already conservative estimations regarding the gas quantities to be expected (from approximately 20 % onwards), a further-reaching analysis of the aforementioned data should take place. This analysis aims to determine exact measures for the planned optimisation. In the first place, those gas wells and landfill areas where, after the study of the above data, a larger landfill gas quantity or a better landfill gas quality can theoretically be expected should be examined more closely. Moreover, it is important to find out possible "adjusting screws" by means of which a landfill gas system can be optimised. These can be lines, dampers, sliding elements, compressors etc.

1.2 Implementation and evaluation

The following implementation and evaluation is based on a gas collection system as shown in Illustration 1.

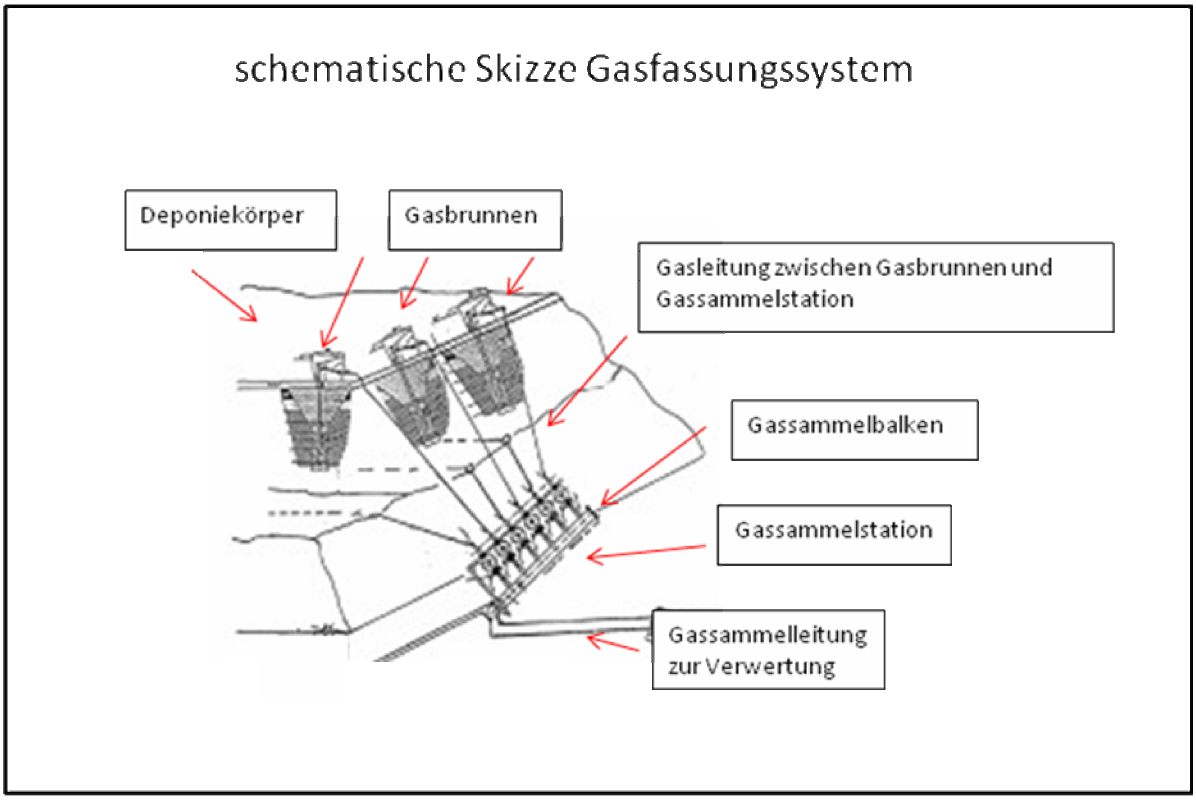


Illustration 1: Schematic drawing gas collection system, DAS – IB GmbH 2010: Landfill body / Gas well / Gas line between gas well and gas collection station / Gas manifold / Gas collection station / Gas collecting main for utilisation

As a basic principle, the following measuring devices should be used for the optimisation works:

- Landfill gas analysis device for the detection of CH_4, CO_2, O_2 in a measuring range between 0 and 100 vol.-%, and H_2S in the measuring range between 0 and 5000 ppm
- Pressure measuring device in the range between 0 and 150 $mbar_{g/u}$
- Anemometer in the measuring range between 0.6 and 40 m/s
- Light plummet with temperature indication [50m, -15 – 80° C]
- Temperature measuring device [-25 – 90°C]
- Meteorological station [air pressure in mbar, wind speed in m/s and temperature in °C]

All devices must be fully functional and calibrated correspondingly, so that measuring errors can be excluded. As a basic principle, measurements should be carried out over a sufficiently long period of time (depending on the measuring point and measuring device), and the results checked with regard to plausibility.

Optimisation measures typically start with a measurement campaign in the gas wells or gas collection stations selected for this purpose. This implies optical checks of the construction work and the necessary practical measurements of the following parameters in the gas wells:

- Pressure p in mbar
- CH_4-concentration in vol.-%
- CO_2-concentration in vol.-%
- O_2-concentration in vol.-%
- The flow rate (if possible) in m^3/h (or m/s)
- H_2S-concentration in ppm (or vol.-%)
- Depth of the well or water build-up/shearing-off (light-plummet measurement)
- Landfill gas temperature T in C°
- If required, damper position at the gas well
- Meteorological basic conditions

The ascertained data and values should be noted down in a suitable measurement report. In addition, the condition of the gas wells' outside should be examined, in particular with regard to the soundness and tightness of the gas well heads and connections. Besides the optical check, and according to experience, the "sloshing" of liquids (water build-up or "water pockets") can be perceived acoustically.

Subsequent to the termination of the measurement campaign "in the field", a "validation measurement" should take place within the shortest possible period of time (comparable conditions) at the respective gas collection station or substation in the corresponding individual lines. The parameters to be measured are almost analogue to the measurement in the wells themselves:

- Pressure p in mbar
- CH_4-concentration in vol.-%
- CO_2-concentration in vol.-%

- O_2-concentration in vol.-%
- The flow rate (if possible) in m³/h (or m/s)
- H_2S-concentration in ppm (or vol.-%)
- Landfill gas temperature T in C°
- Damper position at the individual line of the respective gas well
- Meteorological basic conditions

In addition, the outgoing gas-collecting main should be examined for the following parameters:

- Pressure p in mbar
- CH_4-concentration in vol.-%
- CO_2-concentration in vol.-%
- O_2-concentration in vol.-%
- Flow rate in m³/h (or m/s)
- H_2S-concentration in ppm (or vol.-%)
- Landfill gas temperature T in C°
- Damper position at the gas-collecting main
- Meteorological basic conditions

This procedure needs to be carried out for all gas wells and gas collection stations and thus represents a fault analysis for the system of the gas wells and gas collection stations, and also shows possible optimisation options.

1.3 Evaluation analytical optimisation

The above measurements serve as a source of information. Each parameter needs to be examined separately, individually and within the holistic context. In the following, the aforementioned parameters are examined according to this approach.

1.3.1 Landfill gas composition (CH_4, CO_2, O_2, H_2S)

The standard landfill gas composition depending on the phases according to Farquar is presented in Illustration 2, meaning that during the stable methane phase (phase IV, in which most of the landfills should be right now) a CH_4 concentration of approximately 50 to 70 vol.-% and a CO_2 concentration of approximately 40 to 50 vol.-% is estimated. The optimum CH_4/CO_2 ratio lies in the range between 1.3 and 1.5.

Phases according to Farquar:

I: Aerobic phase

II: Acid fermentation

III: Transient methane fermentation

IV: Stable methane phase (anaerobic)

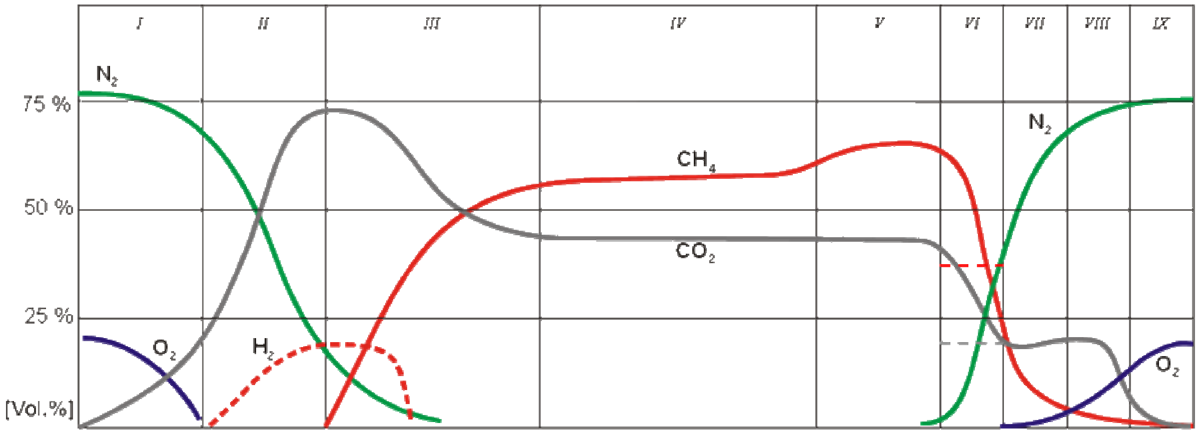
V: Long-term phase

VI: Air penetration phase

VII: Methane oxidation phase

VIII: Carbon dioxide phase

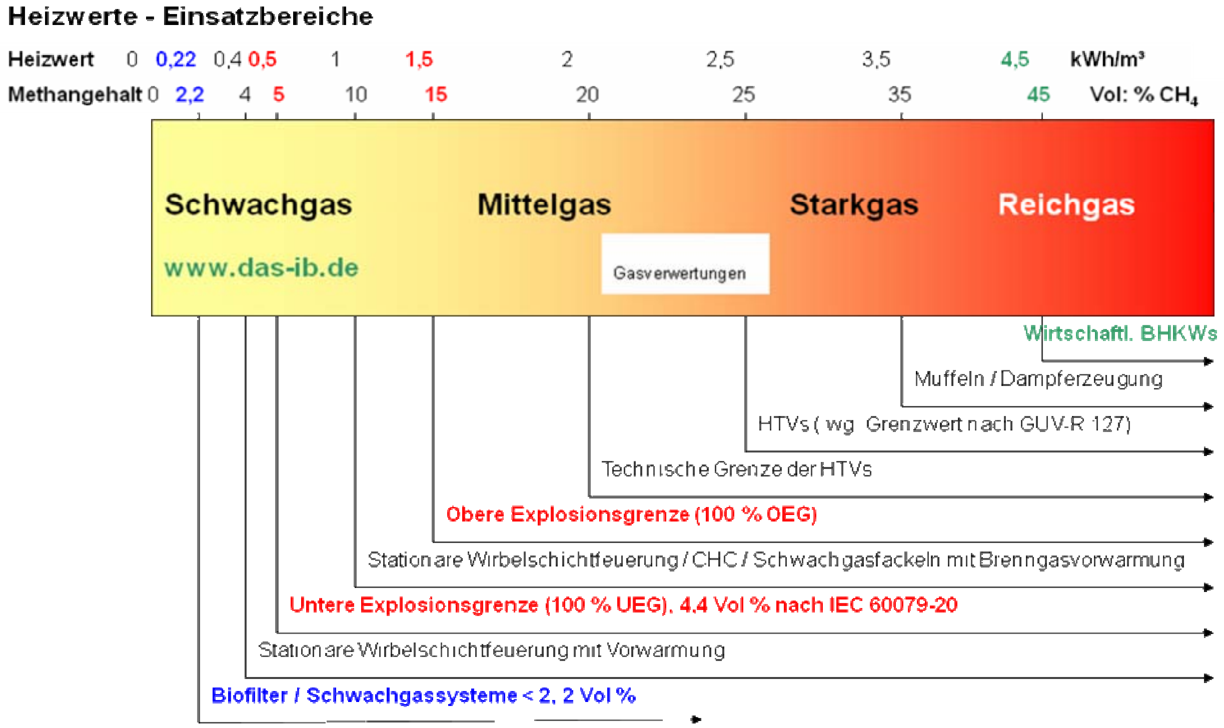
IX: Air phase



Ill. 2: Course of the landfill gas composition depending on the time with long-term model Franzius 1981 and Rettenberger & Mezger 1992.

During the long-term phase, the temporary increase of the CH_4 concentration can be expected. During the subsequent phases, however, a decay of the landfill gas production is to be anticipated and, with it, the decrease of the CH_4 and CO_2 concentrations with a simultaneous increase of N_2 and, later, also of O_2. The landfill gas quality described above, however, does not allow conclusions regarding the quantity. In the landfill gas prognosis, the quantity was estimated. For the optimum operation of a CHP (power generation), depending on the motor, a calorific value of at least 4.5 kWh is required. This corresponds to approximately 45 vol.-% CH_4. Therefore, it is the aim to always achieve a CH_4 concentration of > 45 vol.-% in the landfill gas. This means that those landfill areas (or gas wells) which show a CH_4 concentration of >

45 vol.-% should be subject to stronger extraction. In this respect, it must be observed that stronger extraction does not necessarily lead to better results. The CH_4 concentration can of course decrease after a certain time, even with stronger extraction by suction. This implies that the suction was too strong. Hence, the extraction system must be carefully adjusted and observed and, above all, over a longer period of time. The adjustment is effected via dampers or sliders. In addition, the suction pressure needs to be considered during the adjustment.



*Ill.3: Calorific values - fields of application, DAS – IB GmbH, Biogas- und Deponiega**shandbuch 8th edition** 2009*

In the event that different CH_4 concentrations are ascertained in the gas well and in the gas collection station, this is due to segregation processes or dilution effects only to a limited extent. If extraction does not take place in gas wells or in individual lines in the gas collection stations, higher CH_4 or lower CO_2 concentrations can be ascertained as a result of segregation processes. It is important to make sure during the measurement in gas collection stations that, depending on the degasification system, landfill gas is not sucked-off from the gas manifold in a "backward" manner.

In the event that oxygen is measured in the gas well, the reasons could be the following:

- Oversuction of the landfill section
- Leak at the opening well/landfill surface (sealing/collar) "Short circuit"
- Leak in the gas well itself
- Landfill is in a certain phase $\geq$ VII (methane oxidation phase)

In the event that oxygen is measured in the respective gas line in the gas collection station, the reasons could be the one or more of the following:

- Leak in the gas line from the gas well to the gas collection station

This can also be the reason when no oxygen is measured in the gas well but is measured in the respective gas line in the gas collection station.

The presence of oxygen should be avoided for safety- and dilution-related reasons. By checking the aforementioned causes and through fault elimination/readjustment of the gas collection where required, oxygen penetration can be prevented.

Like oxygen, hydrogen sulphide (H_2S) is an undesired landfill gas component. The quantity and also the concentration depend mainly on the deposited waste. In particular protein-containing and calcareous waste causes high H_2S concentrations in the landfill gas during degradation. In connection with humidity, H_2S forms an aggressive substance (sulphurous and sulphuric acid) which damages all metallic components and also the motor itself. In view of this, gas purification methods are often applied today upstream of the CHP to remove H_2S. If increased H_2S concentrations (> 20 ppm) are measured in the landfill gas, make sure there is no damage in the upstream system. If strongly increased H_2S concentrations are measured in the gas well, ensure that these concentrations are diluted to uncritical values in the gas-collecting main. If, however, strongly increased H_2S concentrations are already ascertained in the gas-collecting mains, the "originator" must be found out, in this case the gas well which supplies these critical concentrations in the landfill gas. After a benefit/danger analysis, this well should either be carefully operated in the future or entirely closed.

Note: High H_2S concentrations and moisture contents can cause faulty measurements in measuring devices (cross sensitivities).

1.3.2 Flow rate (landfill gas quantity)

Besides the composition of the landfill gas, the landfill gas quantity is also decisive for optimisation measures. As a general rule, this quantity is measured directly before utilising the gas. This allows statements regarding the total landfill gas quantity but not regarding the exact origin (landfill sections/gas wells). To be able to recognise which gas wells (landfill gas sections) are quantitatively profitable, these must be measured individually with the corresponding measuring devices (e.g. rotating-cup anemometer). Taking into consideration the pipe cross section, the exact quantity can then be determined. In the event that a well with a good CH_4 concentration shows only a low flow rate, this flow rate should be enhanced by adjusting the dampers. In this respect, it must be checked whether or not and which negative pressure exists. Further observance of the adjusted well is required analogously to 2.3.1, modification of the damper position. If only a low volume flow is measured or no volume at all and which cannot be enhanced readily, the following reasons are possible:

- Pipe plugging (e.g. as a result of deposits)
- Condensate build-up ("water pocket")
- Pipe sheared
- Filter section in the gas well reduced (e.g. as a result of deposits)
- Negative pressure too low (low dissipation of the compressor)

By checking the aforementioned reasons and by fault elimination, where required, it is possible to enhance the total volume flow.

1.3.3 Temperature

The temperature is another indicator for biological activity. Typically, the temperature of the landfill gas can cover a range of 20 to 60°C. For mesophilic methane bacteria, the ideal milieu conditions lie between approximately 30 and 40°C; the landfill gas temperature is then expected to be similarly high. If lower (< 30°C) or higher (> 45°C) temperatures are measured in the landfill gas, this indicates limited or impaired conversion processes in the landfill body. Temperature measurement should be carried out as close as possible to the "place of formation" of the landfill gas because the further away the measuring point is from the source, the more significant the measuring error or the lower the measured temperature is. In the event that the temperature is required as a necessary parameter for the determination of the standard volume flow, the selection of the measuring point in the landfill gas is of secondary importance.

1.3.4 Pressure

The measured (negative) pressure in the gas wells themselves and at the gas collection stations provides information on the suction degree. In particular, it can be ascertained by comparing the measurements whether or not suction is limited and, if so, where and as a result of what.

If the pressure in the well related to the respective line in the gas collection station is too high, the following causes may be responsible analogously to the low flow rate:

- Pipe obstruction (e.g. through incrustration)
- Condensate build-up ("water pocket")
- Pipe sheared
- Filter section in the gas well reduced (e.g. as a result of deposits)

If the pressure conditions of the respective pipe section are reversed, meaning the negative pressure in the gas collection station is very high compared to the gas well, an obstruction in the gas system between both must be assumed. The reasons for that can be the following:

- Pipe obstruction (e.g. through incrustration)
- Condensate build-up ("water pocket")
- Pipe sheared
- Condensate build-up in the gas manifold

By adjusting the pressure conditions in the gas collection station, the volume flow is directly set. By increasing the negative pressure, the volume flow increases. For this purpose, the respective dampers can be used or the performance of the compressor itself is adjusted. The compressor performance is adjustable depending on the compressor, controlling range and technical arrangement. Varying pressure measurements are an indicator for "water pockets" or sloshing liquid in the ductwork.

1.3.5 Damper position / technical regulations

The dampers are the most important set screws which normally exist on every landfill. In the ideal case, these should be available in the gas wells, in the individual lines in the gas collection station and also in the gas collecting main. Fine tuning is more or less feasible, depending on the type of dampers or the characteristics.

1.3.6 Gas well depth / water build-up

With the light plummet measurement in the gas well, a water build-up and its size can be ascertained. After reconciliation with the available documents regarding the gas wells (as-built drawings) can provide information about the filter section, and to what extent it is affected by a build-up. With this the effective filter section is known.

1.3.7 Meteorological basic conditions

The recording of the meteorological data serves to assess the conditions existing at the moment of measurement. With this, the meteorological influences on the acquired measuring data are taken into consideration. In particular the air pressure conditions, wind conditions and rain events need to be taken into account.

2 Optimisation measures

As a matter of principle, it is the aim to reduce emissions via the surface and to achieve an increase in the utilisable landfill gas quantity (CH_4 > 45 vol.-%) subsequent to the examinations described above mainly by undertaking the following measures:

- Adjustment/regulation of the available dampers to increase the utilisable landfill gas quantity or to increase extraction in those landfill areas in which a high landfill gas potential is still to be expected. This can also mean that gas wells in which the gas quality is no longer sufficient must be closed. However, it must be ensured that no enhanced emissions via the surface result from this. Finally, it should be the aim to leave these gas wells in the system by throttling them in such a manner that the "bad" proportion is evened out in the total landfill gas quantity and a value of > 45 vol.-% CH_4 is constantly maintained.

- Those gas wells in which the gas can no longer pass, probably as a result of water build-up, incrustation or shearing, need to be re-activated. In the first instance, this can be implemented by examining the problem (camera inspection). Depending on these results, flushing or, in the event of a water build-up, pumping out measures should be undertaken. Pumping out can be effected temporarily and also via so-called combined wells. In the case of sheared lines, it should be calculated whether or not these should be repaired.

- In the event that an insufficient gas passage is ascertained in landfill gas lines between the gas well and the corresponding gas collection station, these should be re-activated analogously to the gas wells. Water pockets etc. need to be permanently eliminated. If this cannot be implemented without complex measures (e.g. for lines below ground level), other measures could be undertaken, such as:
    - Install new ("unsupported", temporary) lines between the gas well and the gas collection station.
    - Bypassing/connection of the gas well with a fully functional gas well in the vicinity.
- Development and realisation of an exact measurement schedule (operational management) to be able to react within a very short period of time to changes and to obtain a kind of efficiency control.
- If leaks are detected, these need to be eliminated as a basic principle.

However, it is decisive during optimisations or modifications in the gas collection system (position of the dampers etc.) that these are continuously supported and observed, meaning that in the event that a damper position is modified (opening to enhance extraction) in the gas collection station, regular checks regarding the gas composition need to be effected to avoid possible oversuction, as the quality and quantity of the landfill gas will not predictably change. The quality and quantity depend mainly on the "catchment area" of the gas well and therefore on many factors (deposited waste, compaction, settlements, gas permeability, water balance, suction power, surface sealing, closeness to a talus etc.) which cannot be mastered in their entirety.

3 Practical example

An optimisation measure of the type described above was carried out on a landfill. In the first instance, the measurement campaign provided the results presented in Table 1 for a gas collection station and the related gas wells.

In this case, the essential adjustments were the further opening of the dampers of blind drains 6.14 and 6.06, and of the gas well 6.10. Through this measure, the landfill gas quantity could be increased from 249,3 Bm³/h to 309,7 Bm³/h and the landfill gas quality from a CH_4 content of 39.9 to 49.2 vol.-%. Over the year, at a constant and even extraction, this would amount to a landfill gas quantity of 450,000 m³ with a CH_4 content of approximately 50 vol.-%. This assumes that the available CHP was only operated under partial load (approx. 300 KW under possible full-load operation).

Tab. 1: Presentation results measurement campaign

Anhang
Tabelle **GSS 6**

Wetter	regnerisch	Wind	28 km/h	Uhrzeit	ca. 10 - 18 Uhr
Luftdruck	1020 hPa	Messgerät	GA 94	Probennehmer	Hiemstra
Temperatur	11°C	Datum	28.05.2009	Ort	

DN 50 (di 52mm)

Messstelle **GSS 6**	CH_4	CO_2	O_2	N_2	Verhältnis	H_2S	v	m	p	T	Klappenstellung	Reglerstellung	**Bemerkungen**
	Vol %	Vol %	Vol %	Vol %	CH_4 / CO_2	ppm	m / s	m^3/h	mbar	C°	° während der Messung immer 90°	0= AUF 13= ZU während der Messung immer 90°	
Rigole 6.14	50,3	38,8	0,0	10,9	1,3	120	1,32	10,1	-2,60	14,6	90	8	
Rigole 6.16	59,7	29,9	2,5	7,9	2,0	140	0,00	0,0	-4,1	14,1	90	8	Messwerte nach 10 minuten noch nicht stabil CH_4↑, CO_2↑, O_2↓
Rigole 6.15	39,5	25,6	0,0	34,9	1,5	140	0,00	0,0	-5,1	15	90	8	Brunnen mit Pumpe
GB 6.01	51,0	23,8	2,3	22,9	2,1	205	0,00	0,0	-6,2	14,8	90	7	Achtung H_2S, Brunnen mit Pumpe
GB 6.02	18,7	22,7	19,7	38,9	0,8	100	5,98	45,7	19,3	14,7	90	4	Sauerstoff!, Brunnen mit Pumpe
GB 6.03	39,4	30,6	0,0	30,0	1,3	120	2,34	17,9	-4,0	14,8	90	5	Brunnen mit Pumpe
GB 6.04	0,3	0,6	20,1	79,0	-	0	0,00	0,0	-3,9	13,9	0	7	Brunnen mit Pumpe
GB 6.05	55,0	34,1	6,3	4,6	1,6	600	7,34	56,1	-16,6	15,1	90	5	Achtung Sauerstoff und H_2S, Brunnen mit Pumpe
Rigole 6.06	63,2	36,7	0,0	0,1	1,7	140	10,95	83,7	-30,7	14,6	90	6	
GB 6.07	55,6	33,3	0,0	11,1	1,7	500	1,65	12,6	-6,4	14,8	90	5	Achtung H2S, Brunnen mit Pumpe
GB 6.08	47,4	29,7	0,0	22,9	1,6	200	0,93	7,1	-5,0	14,3	90	6	Achtung H_2S
SB210/GB 6.09	72,4	29,6	0,0	-2,0	2,4	>5000	0,00	0,0	-2,8	14,2	90	5	Achtung H_2S
GB 6.10	51,5	37,1	0,0	11,4	1,4	40	1,10	8,4	-2,6	14,3	90	8	Brunnen mit Pumpe
Gb 6.11	39,6	21,7	1,0	37,7	1,8	70	1,05	8,0	-10,5	14	90	7	
Sammelbalken DN 150	39,9	27,8	0,0	32,3	1,4	320	3,92	249,3	-37,5	15	90	90	

Wetter	regnerisch	Wind	24 km/h	Uhrzeit	ca. 9 - 17 Uhr
Luftdruck	1019 hPa	Messgerät	GA 94	Probennehmer	Hiemstra
Temperatur	13°C	Datum	02.06.2009	Ort	

Messstelle **GSS 6**	CH_4	CO_2	O_2	N_2	Verhältnis	H_2S	v	m	p	T	Klappenstellung	Reglerstellung	**Bemerkungen**
	Vol %	Vol %	Vol %	Vol %	CH_4 / CO_2	ppm	m / s	m^3/h	mbar	C°	° während der Messung immer 90°	0= AUF 13= ZU während der Messung immer 90°	
Rigole 6.14	49,8	39,1	0,0	11,1	1,3	90	5,32	40,7	-4,60	16,6	90	5	geöffnet am 28.5. von 8 auf 5
Rigole 6.06	58,6	36,7	0,0	4,7	1,6	140	12,95	99,0	-32,7	17,1	90	3	geöffnet am 28.5. von 6 auf 3
GB 6.10	51,0	42,3	0,0	6,7	1,2	45	3,20	24,5	-5,3	18	90	5	Brunnen mit Pumpe, geöffnet von 8 auf 5
Sammelbalken DN 150	49,2	33,4	0,0	17,4	1,5	290	4,87	309,7	-38,5	18	90	90	

auffällige Werte, beobachten
Achtung Sauerstoff oder niedriger CH4 Wert, Brunnen schließen
geschlossenen Klappen bzw. GB
ggf. Klappen weiter öffnen (evtl. nach Abpumpen bzw. Reinigen), beobachten

4 Summary

An optimisation of the existing gas collection system is always useful when the landfill gas quantity and quality decreases continuously and/or higher methane emissions via the landfill surface are ascertained. This applies in particular to landfills in which a CHP is operated for the conversion into electricity and feeding. Prior to reduced operation and possible subsequent dismantling, effective utilisation of the available landfill gas potential is essential. This is also a further step towards emission reduction in view of the aftercare phase.

The approach described above and the presentation is a possibility of utilising an existing landfill gas potential in a more efficient manner, but every landfill, hazardous waste or abandoned waste disposal site needs to be assessed individually. Making decisions on redevelopment measures is often a close call when the success of these is not guaranteed.

However, it is decisive that optimisation or modifications in the gas collection system are continuously supported and observed by skilled personnel, to be able to react to changes within the shortest period of time.

Finally, and for the sake of completeness, it should be mentioned that, through the aforementioned measures, a later concept development and the employment of poor-gas technologies cannot be prevented but only postponed. It is therefore advisable to acquire information about this special subject already at an early point in time (poor-gas treatment see DAS – IB concepts, e.g. Mainz – Budenheim and Buckenhof landfills).

5 Sources

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