# 33 years of experience in LFG extraction from theoretical gas prognoses to realistic gas extraction systems with LFG2E-Energy by CHP units and flares

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SUMMARY: more than 35 years ago, when the disposal of landfill gas (LFG) first started to become a public issue, only little experience had been gained in this field. Much has been achieved by now if we look at today's state-of-the-art in landfill gas engineering. Initial errors often made in the past included, for instance, the construction of oversized gas utilisation facilities due to a lack of fundamental data or major damage to gas collection systems, because uneven landfill settlement was not taken into account. From the point of view of plant engineers, even today, there are still difficulties that require special attention and sophisticated know-how. This abstract provides an overview on the developments in landfill gas engineering throughout the years. It also refers to the difficulties experienced today.

33 years of experience (including hits & flops) in LFG systems, design, construction and optimisation of different kinds of LFG collection systems is 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. In the following text/presentation, in particular the design, building and optimisation of the gas collection system and the systematic approach will be presented.

Index words

LFG, gas wells, Gas extraction systems, condensate shafts, manifold stations, booster, flare, analyser, gas wells, pipe work, dewatering, CHP, gas engines, Landfill gas, optimisation, gas collection system, MSW, disposal sites, landfill, optimisation, extraction system, methane emission, return of invest, LFG

## 1. DIMENSIONING OF LANDFILL GAS EXTRACTION FACILITIES

A gas prognosis, as accurate as possible, is indispensable for the correct dimensioning of an LFG extraction facility. Today, we use computer programs to establish the gas prognosis for a landfill site. These computer programs, however, are not based on mere mathematical logic; they also take plenty of empirical data into account. This way, the computer and our know-how provides us with values near to reality. Bear in mind that any gas prognosis can only be as good as the quality of the data used.

The specific programs we have developed at DAS-IB GmbH are constantly being optimised with the data gained from practical experience in plant construction and operation. It is recommended to test the expected gas quantities with a mobile flare and booster unit for at least 6 months if possible before finally implementing a stationary plant.

## 2. GAS COLLECTION SYSTEMS

In the past, most gas collection systems were of simple design, equipped with low-budget piping systems (e.g. quality of material, pipe diameter) and lacking any accessory facilities such as manifold stations with valves and sample points of measurement, or couples to control the quality and quantity of the gas extracted from the landfill. It was not possible to carry out measurements on single gas wells and optimise their performance. Low gas collection rates and high costs for the optimisation of the entire system called for a change of design. Today, every single gas well is connected to the closed circular pipeline of the gas collection system. The connection points – access provided at any time – are located in stationary buildings, the so-called “manifold-stations”, installed above ground or underground. From here, it is possible to monitor and optimise the performance of every single gas well by analysing and adjusting the parameters (gas flow rate, low pressure, quality, $CH_4/CO_2$ ratio and temperature of the gas). Regular controls and adjustments help to achieve the optimum gas collection rates.

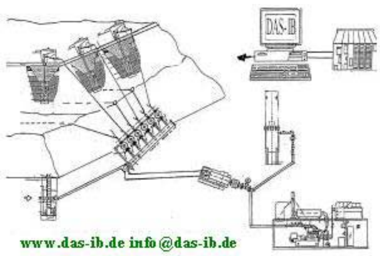


Figure 1 – Landfill gas extraction system (wellheads, manifold station, dewatering system, condensate wells, booster and flare system, gas utilisation facility, telecontrol system)

### 2.1 Gas wells

Extreme but natural settlements in the landfill body occur as a result of the biological conversion of solid waste components into landfill gas. Every cubic metre of landfill gas directly derives from the decomposition of about 1.2 kg of solid matter (plus leachate)! In order to take this fact into account and make control possible, the following aspects must be considered when installing gas wells on a landfill site:

1. Use telescopic gas pipes to compensate for the settling phenomenon
2. Fit a bellows expansion joint between the well head and the outgoing pipes

3. Outgoing pipe: 110 mm minimum diameter, with a gradient of 3-5% to prevent water seals
4. Provide a surrounding layer of clay and loam with sufficient thickness to prevent air entering the gas collection system from boundary areas
5. Mount sample points/couples and manual butterfly valves on the gas supply pipes and make sure they are put in the right places
6. Provide sufficient length of pipe upstream and downstream of the flowrate measuring device
7. Provide a facility to enter a remote-controlled camera for the video inspection of the gas network


Figure 2 – Landfill gas wells (head) / drilling / complete gas well

## 2.2 Gas manifold stations

Inside the manifold stations there are connections from the individual gas wells to the circular piping system going all around the site. For sampling and measuring purposes (gas analysis, temperature, pressure, flow), the connections should be fitted with ½" and ¾" grumbles as a minimum standard. Upstream and downstream the flow rate measuring device there must be a sufficiently long piece of pipe to provide an undisturbed intake and discharge of the gas. This will prevent faulty measurement as a result of turbulences in the gas flow. The length of test pipe is determined by multiplying the pipe diameter by a minimum of 10. Manual butterfly valves will be fitted to the downpipe, but their axis may not be vertical in order to prevent corrosion and problems caused by condensate and frost.

Every manifold station may be equipped with an automatic device for the pressure-controlled drainage of gas pipelines. In dependence on the capacity of the compressor used, small water seals will automatically be drained from the pipes. It is also recommended to provide a T-piece with a blind flange. This may be used later on to enter a remote-controlled camera for the video inspection of the gas pipelines.

Figure 3 – Gas manifold stations

**2.3 Condensate rejection**

Inside the landfill body, landfill gas is generated at a temperature of approximately 60-80°C and with a humidity of 100%. On its way from the gas wells to the flare stack and the gas utilisation facilities, the gas cools down and condenses. In order to avoid water seals, the gas extraction pipes have a gradient and are equipped with condensate traps. Simple solutions include siphons which recirculate the condensate to the landfill body. However, this is only recommended for sites with a landfill bottom liner. Alternatively, it is possible to install condensate wells which are equipped with different types of discharge facilities (deflectors, water separators, cyclone collectors or demisters). The condensate is pumped from the condensate well or removed by a collection lorry.

In order to prevent water from being sucked into the gas pipes, the minimum hydraulic gradient between the gas pipelines and the maximum water level should correspond to the maximum suction pressure of the compression units. Example: A blower with 150 mbar suction pressure (850 mbar g) requires a safe distance of 150 cm between the maximum water level and the gas extraction pipe. This distance is checked by level measuring to prevent damage to plant facilities (damage caused by water). In warmer countries, an extra device should monitor the minimum water level and switch off the booster system in the event that values fall below the minimum level (oxygen influx, explosion hazard).

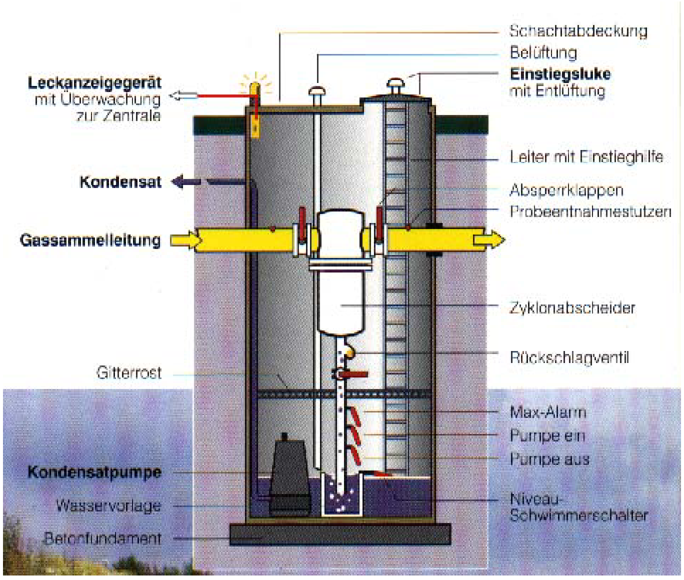

Figure 4– Condensate shaft

## 2. 4 Design concept for gas collection systems

As described hereinabove, the gas extraction system consists of branches to the gas wells and a circular pipeline that extends over the entire landfill. Apart from measurements and optimization work on the gas supply system and on the gas wells, the surface of the landfill body should be inspected at least once a year with a flame ionisation detector (FID). This is the only way to find out if in some areas gas escapes uncontrolled into the atmosphere. Additional gas wells may be installed in these places later on. In a budget calculation, the distance between the gas wells should not exceed 25 - 50m because as a matter of experience, the collecting area of a gas well is about 15-25 m.

However, laser systems and continuous measurement to control the emissions over the entire surface of a landfill are much better.


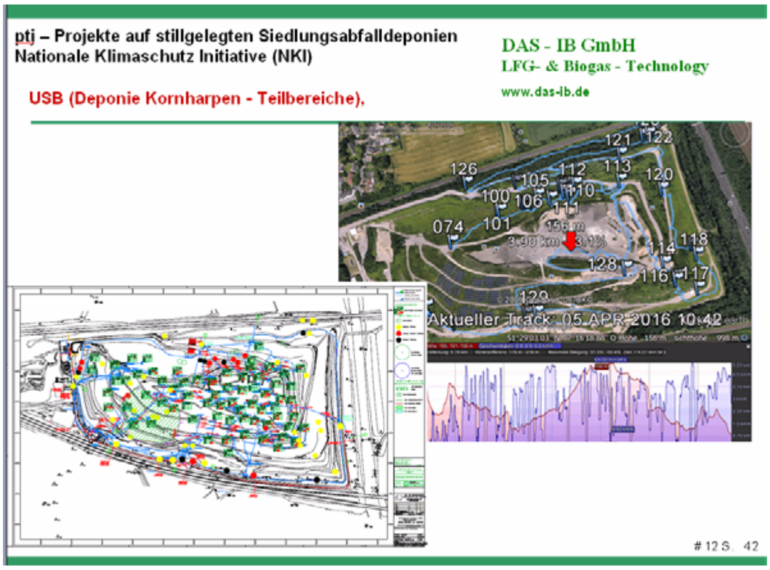


Figure 5 – Emissions measurement over the entire surface

In real terms, the landfill surface is not continuously sucked with an FID and no underpressure is applied / produced through wind by means of a suction bell / cup.
Through the forced underpressure which is applied through the FID, landfill gas is sucked by means of a small pump. For this moment of measurement, the methane is unable to react to $CO_2$ and $H_2O$ with the oxygen in the surface. The landfill surface, however, is actually a large biofilter through which, if the situation arises, landfill gas (methane) may slowly diffuse.
If a real surface emission should / must be determined, so-called FLUX boxes (instead of RMLD lasers) must be installed on the landfill body (surface), meaning virtually reversed base tubs that cling to the surface in a gastight manner, at whose outlet the real methane emission (pressureless) and the amount of gas must be measured.

## 3 MECHANICAL ENGINEERING

### 3.1. Gas compression unit / booster unit

Dependent of the location and weather, a landfill gas booster unit should be housed in a closed or open building that provides not only lighting and heating, but also ventilation and heating/cooling facilities and a $CH_4$ gas detector for explosion protection and / or as a signal for the gas engines (CHP units). The minimum standard equipment should be as follows:

1. Compression unit
2. Shut-off and control valves and other technical devices for flow regulation, i.e. bypasses and frequency converters to drive the booster motor
3. Measuring devices: total flux, suction pressure, delivery pressure, gas temperature

Flux may also be indirectly determined with the work's bench performance diagram (provided by the manufacturer of the system) and the equation p = f (F).

In Germany, a stationary gas analysis system is mandatory to protect installations from explosion hazards. This prescription and other regulations in force in Germany may differ from those to be observed in other countries. The same applies to the materials, fittings and structural components used, which – according to the national standards – require marks of conformity and certificates issued by the national authorities. In any case, plant operators should carefully check the material and perfect functioning of the components used. In no case should they accept material made with Al-Ni-Co metals.

Two important notes with regard to safety engineering:

1. If a facility for explosion protection is to be installed, the gas analysis system should indicate the concentration of $CH_4$ in the gas. Later, when the landfill gas serves as fuel for power generation, this signal can be used to control the gas engines.

The author of this abstract states that, according to the triangular explosion protection diagram shown in Figure 6, there is absolutely no possibility that explosive gas mixtures will continuously be delivered to the gas engine.

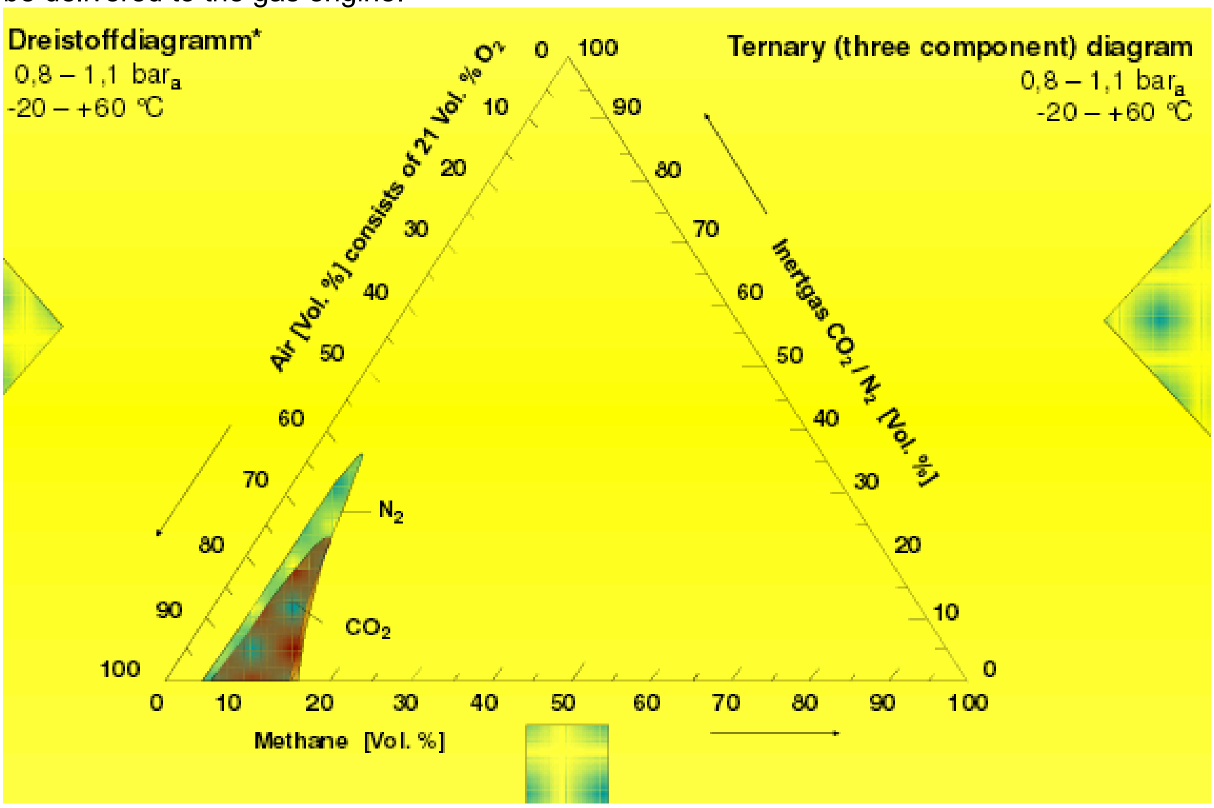


Figure 6 – Triangular explosion protection diagram,
Explosion limit of gas mixtures: Methane/Air/$CO_2$ and Methane/Air $N_2$;
concentrations are indicated in percent by volume in relation to the overall gas

mixture; 15/16 vol % by vol. $CH_4$ / explosion limit, i.e. 4.4/5 vol % $CO_4$ = 100% LEL

In general, it will not be necessary to install a gas analysis system inside the booster unit if other technical installations already provide an indirect analysis. Two examples:

1. Engines fuelled with landfill gas are designed for operation with methane concentrations of at least 35-40% $CH_4$ by volume. When running under full load conditions, they may even need a concentration of 50% $CH_4$ by volume. For technical reasons, these systems will automatically be cut off in the event that the methane concentration is too low.

2. Depending on the dimensioning of the burner system, flare units made by different manufacturers are designed to automatically cover methane concentrations of ± 5 to 10% by volume. In the event of a higher variation of $CH_4$, the UV sensor/burner control system (BCU) used for flame monitoring will automatically shut the system down.

Figure 7 – Booster and flares system (top) booster and CHP units (above)

### 3.2 Flare units / high temperature combustion

In the past, simple flare stacks with open combustion and large visible flames were used to burn the landfill gas (“candle” flares). As these installations did not meet any emission standards at all, they were gradually replaced by flares with closed combustion. Early flare types did not have any insulation, whereas today they are equipped with an insulated combustion chamber to make operation possible at a constant temperature for the entire turndown.

State-of-the-art high temperature flares burn the gas at temperatures of up to 1,200 °C. The combustion chamber of such flares has a 100 mm insulation of ceramic liners. Exhaust gas retention times can be clearly defined. In general, manufacturers also provide facilities for the continuous temperature regulation of the exhaust gas, i.e. thermocouples, controllers and fresh air regulation (louvers).

Throughout Europe and elsewhere, various regulations are currently in force for the combustion of landfill gas. According to German TA-Luft standards gas must be flared at 1,200°C. Exhaust gas values must not exceed 200 mg $NO_X$ and 100 mg $CO/Nm^3$. The “UK Guidance of Best Practise Flaring of Landfill Gas”, however, requests combustion at 1,000°C and exhaust gas values not exceeding 150 mg $NO_X$ and 50 mg $CO/Nm^3$. Both emission standards are based on a concentration of 3% of oxygen by volume in the exhaust gas. The latest discussions in Europe call for systems operating with temperatures of between 850°C and 1,100°C. In any case, these systems must all be able to reduce the parameter of all carbon compounds in the raw gas to a proportion of 100:1 of $C_{org}$ in the exhaust gas. Figure 7 shows the different types of flare stacks currently in use.

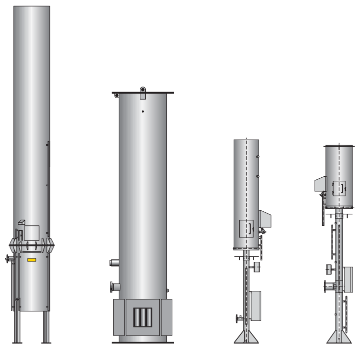

Figure 7 – Flare designs (from left: high temperate flare 1,200°C, 0.3s retention time to right: open “candle” flare without any emission standard)

For plant operators, it is important to know that flare manufacturers interpret the term "retention time" in different ways: Definitions include "from top of burner", "from within the flame", or "from above the maximum point of the flame" and this explains why the manufacturers' specification of the height of a flare stack may differ. The diameters also depend on the combustion temperatures. The slimmer and higher a high temperature flare is designed, the higher the combustion temperature will be for the entire range of control. Furthermore, there is a direct influence on the length of time the exhaust gas is retained from the point of the flame. The larger the diameter of the flare body, the lower the combustion temperature will be during operation with a partial load. In the low load range, at a firing performance of less than 70% the combustion temperature will be reduced to about 80%. A firing performance of 30%, however, will reduce the temperature to 50%.

Figure 8 – Ceramic lining inside the flare stack (insulation liner)

Furthermore, plant operators should pay special attention to the proper fitting of the ceramic insulation. The so-called “clips” are a relatively cheap solution, but due to scale loss they will soon fall off during fill load operation and need to be replaced, increasing the cost of plant operation and maintenance. Such a disadvantage is avoided with an insulation that is screwed to the flare body from the outside.

In any case, the flare should not be covered, as this would cause emissions to be deviated, increasing emissions in the site itself. The reflex of a cover or hat would also attract birds and insects and cause their death when they fall into the flare stack. Modern burner systems do not require a cover. They are not disturbed by rain or snowfall, and not even during ignition.

### 3.3 Landfill gas utilisation

In general, gas engines, steam engines and gas turbines may be used to generate power from landfill gas, but commercial and ecological criteria should be determined if power generation is profitable for the landfill management. It is important to keep in mind that gas utilisation cannot be considered as profitable anywhere in the world if the investment cost for gas extraction systems and power generation facilities is included in the cost estimate. If, however, the gas extraction system is excluded from calculations for ecological reasons ("global warming") it would be required anyhow, and if only the cost of a power generation facility is taken into account, then the operation of such a plant can be considered as profitable. Other important aspects are the quality of the landfill gas and the possibility to market not only the exhaust heat and the heat from the engines but also the power generated.

Most difficulties experienced with the quality of the gas are due to excessive concentrations of fluorine, chlorine and siloxane compounds in the raw gas. Gas purification by refrigeration or adsorption on activated carbon helps to solve such problems.

The best energy balance for an LFG power generation plant and the least line loss are produced when both the heat (from the exhaust and engine cooling water) and the electricity generated are used to supply not only the facilities on site but also consumers in the vicinity of the landfill site. The simplest solution from the economic point of view is to export the electric power to the local grid. These considerations should be taken into account when choosing the technical plant components: Possible options are gas turbines, gas engines, steam engines and steam turbines with a secondary muffle and exhaust heat recovery.

In some European countries, limiting values for exhaust emissions must be observed. This may have an influence on the design and efficiency of the engines used. The Jenbacher engine JES320, for instance, has an output of 826 $kW_{el}$ when operating in accordance with German TA-Luft standards. If exhaust emissions are disregarded, however, the same engine has an output of 1,006 $kW_{el}$.

Gas turbines are not often used because they operate with higher pressure (10-30 bar) and increase the cost of gas compression facilities. They also have a smaller electric efficiency ratio than gas engines. In general, gas engines are preferred to gas turbines, even for large plants with an output of 60-100 MW as there are some currently in operation in England, Australia and South Korea.

The combination of a steam piston engine with a steam turbine is sensible only in the event that LFG with an extremely high pollutant concentration needs to be disposed of in a high temperature flare because it is not suitable for utilisation in gas engines. In this case the only alternative is indirect steam generation with a waste heat boiler. The efficiency ratio, however, will be quite low.

Figure 8 Containerised booster system and gensets (CHP units) Clarke Energy Ltd. in Wales (top) and Vireo in Belarus (below)

### 3.4 Utilisation of low calorific value gas

Please refer to Figure 9 for a definition of low calorific value gas, which is the so-called "lean gas".

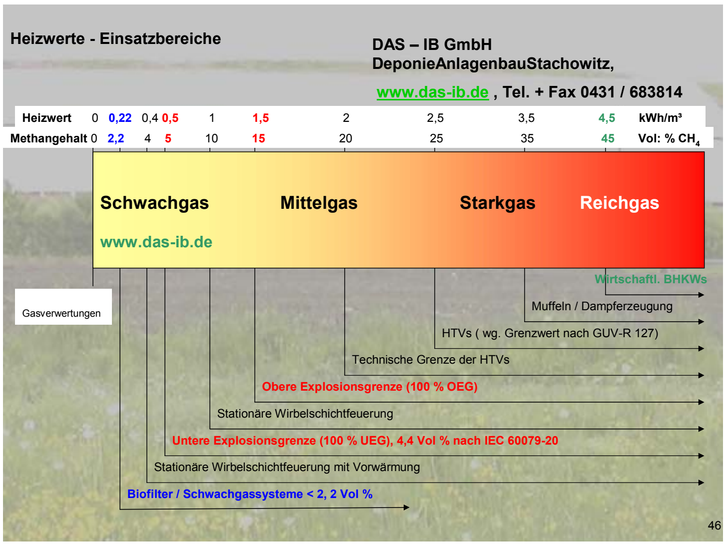

Figure 9 – Operation range of gas utilisation facilities

The gas production in an old landfill will continuously decrease. After about 20-30 years of time, the methane content and the gas flow rate will not be sufficient to flare the gas. Anyhow, the gas must be collected and disposed of. First, high temperature flares with auxiliary firing (e.g. natural gas) can be used. With ever decreasing gas quantities and low quality landfill gas, however, the operation of such facilities will be economically inefficient and can not be justified any longer. At the final stage, biofilters are commonly used to reduce odours, but they do not dispose of the methane and thus add to the greenhouse effect. Specially designed biofilters oxidise methane, but constitute a very costly investment and produce considerable operating expenses to keep the humidity and temperature at a sufficient level.

Practical alternatives are RTO and VocsiBox® facilities for the noncatalytic oxidation of landfill gas with low calorific value. The gas enters the RTO / VocsiBox® and passes over a noncatalytic reactor bed heated to a temperature of 1,000°C. The gas is fully oxidised by this process. The pollutants contained in the raw gas deliver the energy required for oxidation. With a concentration of ≥ 0.3% methane by volume in the raw gas, the process operation will be autothermal once the reactor is heated to its operating temperature.

Facilities for the treatment of low calorific value operate below the Lower Explosion Limit (LEL) of $O_2/CH_4$ gas mixtures, i.e. the gas mixture has a concentration of about 2-3% of methane by volume. But for safety reasons, air is added to the gas mixture, reducing the methane concentration to only 1% by volume.

Other solutions are: low calorific flares with heat exchanger in the exhaust gas to heat up the necessary fresh air and / or the landfill gas.


Figure 10 – CHC systems from LAMBDA GmbH; Germany

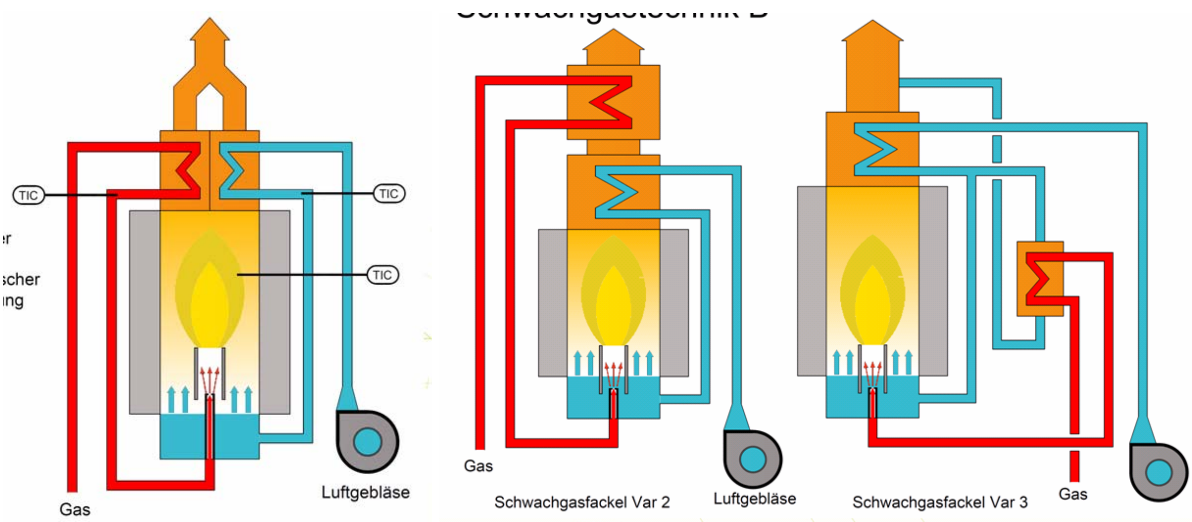


Figure 11 – Different heat exchanger systems for low calorific flares

Figure 12 – Low calorific flares right > 12 Vol % $CH_4$, middle > 5 Vol % $CH_4$, left < 5 Vol % $CH_4$

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