Why high temperature combustion of landfill gas?

Due to the accumulation of knowledge and the tightening of environmental law, the landfill technology has increasingly become concerned with the management of trace compounds in landfill gas.

With landfill gas, contamination is through sulphur, chlorine, fluorine, halogenated hydrocarbons and heavy metals. Other trace elements such as volatile organic compounds (VOC), impose environmental loading factors.

High temperature combustion is designed to safely and completely eliminate environmental risk.

The "clean" landfill gas

Under anaerobic conditions, methanogenic bacteria in household waste landfill sites produce gas that consists mainly of methane, carbon dioxide and water vapour.

Without a degassing plant, this gas forces its way to the surface and mixes with air or migrates through the soil to collect in cavities, hollows and shafts.

With a degassing plant, the landfill gas is recovered. The sub-ambient pressure allows air to penetrate the fill and the landfill will have a different composition.

Typical composition of landfill gas		**I** Vol. %	**II** Vol. %	**III** Vol. %
Methane	CH_4	65	50..45	25
Carbon dioxide	CO_2	35	45..35	20
Nitrogen	N_2	-	4...16	45
Oxygen	O_2	-	1...4	10
Vapour (humidity)	H_2O	100 %	100 %	100 %

I = natural escape of gas from the landfill

II = with an average gas extraction system and well sealed landfill surface

III = excess suction and insufficient landfill cover

The combustion of main components of landfill gas does not pose a problem as exhaust gas limit values are not exceeded even at normal combustion temperatures.

The real landfill gas

The modern landfill site contains a range of wastes, apart from the usual biodegradable wastes. Modern society contributes propellant gases, refrigerants, printed plastic packaging, metal tubes, batteries as well as everything else that belongs to today's "modern" household.

The composition of landfill gas under different management strategies varies and typical values of the trace compounds are reported in the table below. These values are based on comprehensive measurements.

Typical polluting compounds in lfg		**Average value** **I** mg/m^3	 **II** mg/m^3
Sulphur compounds * **e.g. mercaptan** **	$\sum$ **S**	200	150
Compounds of chlorine	$\sum$ **Cl**	100	50
Compounds of fluorine	$\sum$ **F**	20	10
Halogenated hydrocarbons	**CFC**	50	25
Halogenated aromatic hydrocarbons ***	**HAHC**	5...100	5...50
Heavy metals: **** **-** Cadmium - Mercury - Others	 **Cd** **Hg** $\sum$ **Met.**	 0..1 0..1 0..5	 0..0,5 0..0,5 0..3

I = natural escape of gas from the landfill

II = with an average gas extraction system and well sealed landfill surface

* When depositing gypsiferous waste, the concentration of sulphur can multiply

** Most important odour components in landfill gas

*** Proved aromatic hydrocarbons in landfill gas are benzene, toluene, xylene, etc.

**** The concentrations of heavy metals, cadmium, mercury, led, zinc, depend very much on the deposited waste.

The following table shows some organic polluting compounds (VOCs) usually found in landfill gas.

Components	Formula	Group	WPC mg/m^3	Typical concentr. mg/m^3	Peak concentr. mg/m^3
Chlorofluoromethane	**CH_2CHO**	A2		10	
Chlordifluormethane(R22)	**$CHClF_2$**		1’800	5	
Dichlorfluormethane(R21)	**$CHCl_2F$**		45	5	
Dichlordifluormethane(R12)	**$CHCl_2F_2$**		5’000	50	50
Trichlorfluormethane(R11)	**$CHCl_3F$**		5’600	10	
Trichlortrifluorethane(R113)	**$C_2Cl_3F_3$**		3’800	2	
Chlorethylene(VC)	**$C2H_3Cl$**	A1		10	200
Dichlormethane	**CH_2Cl_2**	B	360	20	1’000
1,1-Dichlorethylene	**$C_2H_2Cl_2$**	B	8		2
1,2-cis-Dichlorethylene	**$C_2H_2Cl_2$**		790	30	700
1,1,1-Trichlorethylene	**$C_2H_3Cl_3$**		1’080	2	400
Trichlorethylene(Tri)	**C_2HCl3**		270	10	190
Tetrachlorethylene(Per)	**C_2Cl_4**	B	345	10	180
Benzene	**C_6H_6**	A1		5	500
Toluene	**C_7H_8**		380	100	1’700
Xylene	**C_8H_{10}**		440	50	
Hydrocarbons	**CnH_{2n+2}**			300	
Ethanal	**CH_2CHO**	B	90	20	
Formaldehyde	**CH_2O**	B	0,6		
Hydrogen sulphide	**H_2S**		15	100	20’000
Sum of organic compounds	**-**	-	-	500	20’000
Mercaptane	**RSH**		1	2	200

Classification:

- Group A1: carcinogenic in humans
- Group A2: carcinogenic in experiments with animals
- Group B: justified suspicion of cancer causing potential

The combustion in flare stacks with open flames and temperatures of around 800 °C does not completely ensure the destruction of the VOCs. The exhaust gas will be poisonous.

Environmental specifications

In the industrialised Nations, the dangers of these processes are known. Binding limit values are laid down by the authorities and specialised institutes, for proper combustion:

TA-Luft Technical Directive for Air Pollution Abatement (Germany)

HMfUR Hessisches Ministry for Environmental Protection and Reactor Safety (Germany)

LRV Clean Air Act of Switzerland

Substances in exhaust gas	Indicated as	**Limit values** TA-Luft 1986	(1996) mg/m³	HMfUR 1989 mg/m³	LRV 1992 mg/m³
Dust	-	5	(10)	5	20
Carbon monoxide	CO	100	(100)	100	60
Nitrogen oxide ($NO + NO_2$)	NO_x	500	(200)	200	80
Sulphur dioxide	SO_2	500	(50)	500	50
Inorganic: **- Compounds of chlorine**	HCl	30	(10)	30	20
- Compounds of fluorine	HF	5	(1)	5	2
Unburnt carbon	C org.	20	(10)	20	20
Metals: **- Cadmium and its compounds**	Cd	--	(0,05)	--	0,1
- Mercury and its compounds	Hg	--	(0,05)	--	0,1
- Other metals	∑ Met.	--	(0,5)	--	1
Dioxin/Furane, TE	PAH's	--	ng/m³ (0,1) *	ng/m³ 0,1 *	ng/m³ --

The limit values are related to a residual oxygen content $0_{2\text{-residual}}$ of 3 Vol. % in dry exhaust gas, applicable for burner plants.

For utilisation in gas engines and -turbines, other higher values have to be taken into consideration.

*) The limit value for Dioxin/Furane in the combustion of landfill gas is based on the directive in respect of incineration plants for waste and similar combustible material 17.BImSchV (Germany). The limit value of the sum equivalence is 0,1 ng/m³ exhaust gas at 11 Vol. % $O_{2\text{-residual}}$ respective 0,18 ng/m³ at 3 Vol. % $O_{2\text{-residual}}$

Note $0{,}1\ ng/m^3 = 10^{-10}\ g/m^3 = 0{,}0000000001\ g/m^3$!

The table reflects the direction of development for setting the limit values: The latest directives (TA-Luft 1996 and LRV 92) are the most stringent and set a standard for practically all substances found in exhaust gas.

Therefore todays practised high temperature combustion is advantageously orientated to the stringent specifications. The limit values can definitely be observed.

The definition of high temperature process for landfill gas

High temperature combustion destroys the high molecular weight compounds - including the polycyclic aromatics and other complex HC compounds.

The actual temperature achieved, the temperature distribution and the residence time in this temperature zone are all vitally important in the achievement of environmentally safe combustion process.

High temperature combustion, related to landfill gas, can be defined as:

combustion at a minimum of 1000 °C

minimum 0,3 seconds retention time

no "cold" zones in combustion chamber

These specifications ensure that the limit values in the exhaust gases are never exceeded, even fallen short of.

Requirement for low emission flare and burner plants

In order to ensure that the limit values are maintained under all operational conditions, the physical requirement is defined as follows:

- generation and retainment of a constant combustion temperature > $T_{comb.}$-1000°C
- sufficient retention time $t_{ret.}$ at the defined retention time temperature, usually $t_{ret.}$ is > 0,3 s
- complete combustion

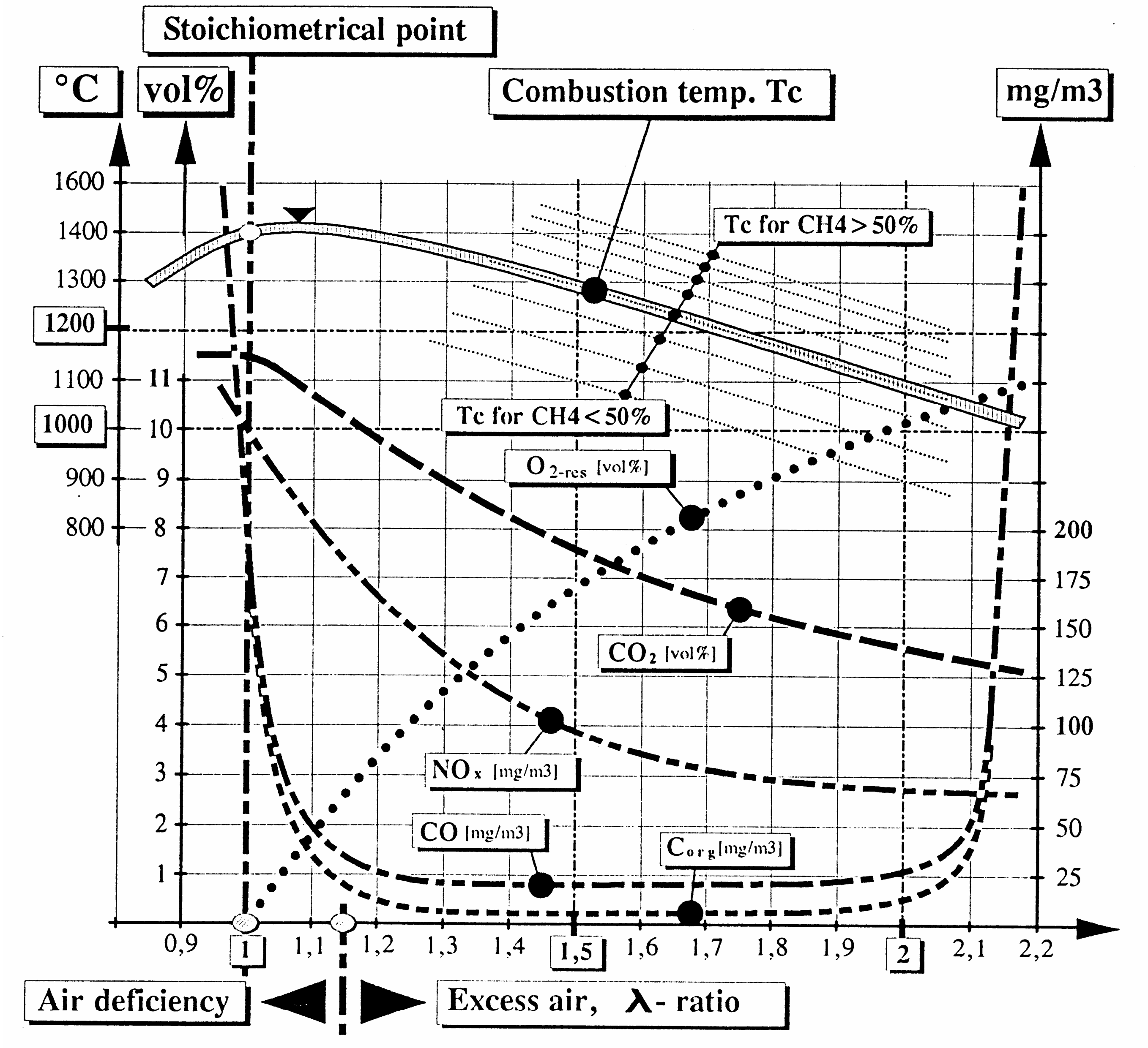
The following construction and thermodynamic requirements must be met in order to satisfy the above specifications:

- almost adiabatical combustion: for this purpose the combustion chamber is lined with generous internal insulation
- combustion in optimal range of excess air
- optimal mixing of landfill gas and combustion air
- homogeneous temperature distribution in the combustion chamber, prevention of cold zones in the combustion process, minimum drop in temperature towards the outside wall
- internal combustion: the end of the flame must lie under the upper edge of the combustion chamber at full load, so that a sufficient burn out zone remains
- quick acting automatic regulation of the optimal gas/air mixtures in order to keep a constant ratio at volume flow and heating value fluctuations.

Under these conditions, the following illustrated combustion characteristic can be achieved.

Combustion characteristic in relation to excess air and combustion temperature

The following diagramme depicts the relationship between excess air coefficient (Lambda), process temperature and combustion products when combusting landfill gas.



Lambda	=	Excess air coefficiency	NOx	=	Nitrogen (NO + NO_2) in exhaust gas
T_C	=	Combustion temperature	CO	=	Carbon monoxide in exhaust gas
$O_{2\text{-residual}}$	=	Residual oxygen content in exhaust gas	C_{org}	=	Unburnt carbons
CO_2	=	Carbon dioxide in exhaust gas			

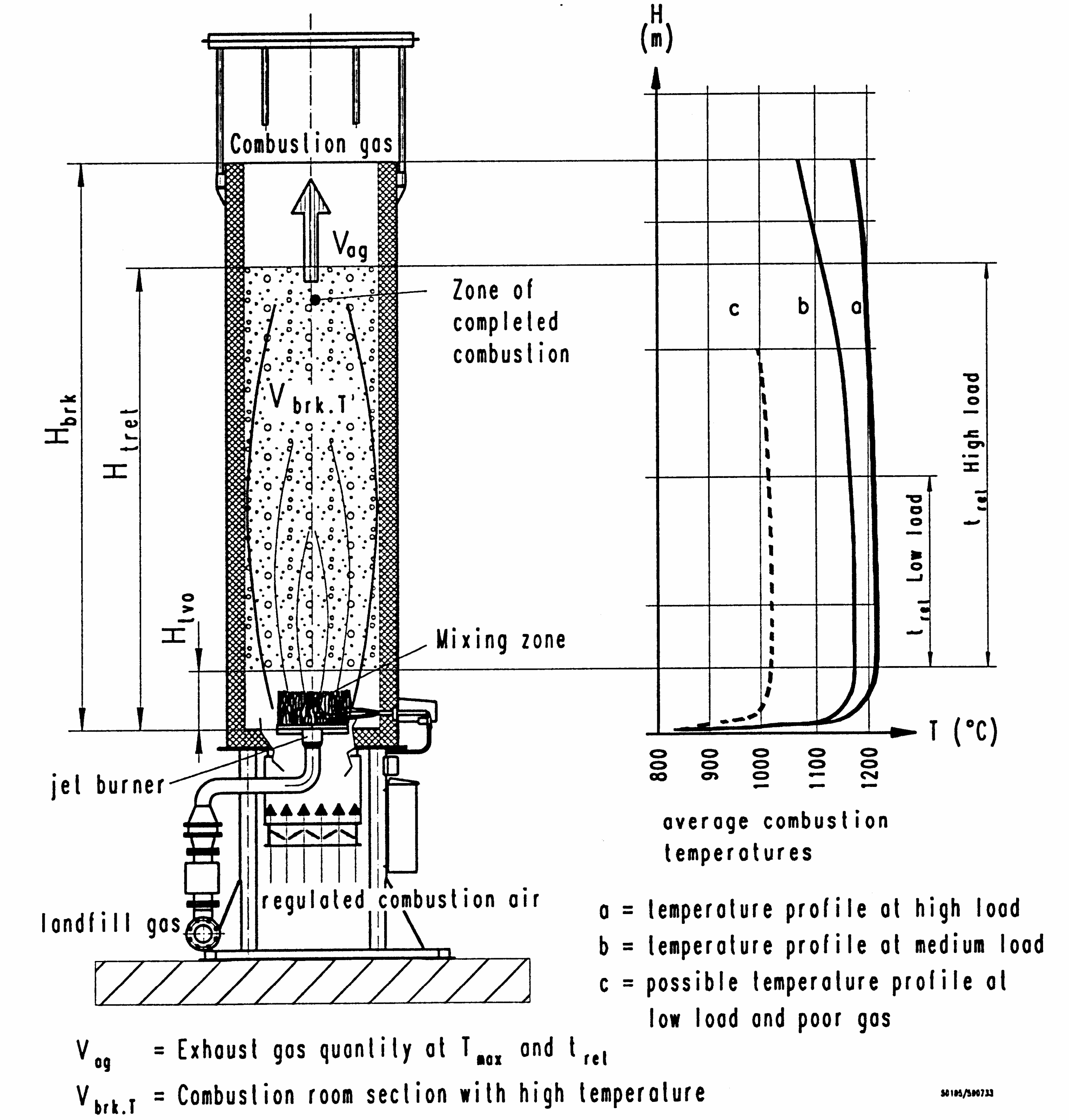
From this, it is clear that the minimum emission of contaminants is given in the combustion range of Lambda = 1,5...2.

Profile of the combustion chamber

The combustion chamber is lined with a generously dimensioned high temperature resistant insulation with an extremely low heat transition coefficiency.

Owing to the design of the burner, the flame is spaciously distributed. Accordingly, the temperature is evenly distributed over the profile section of the combustion chamber and very quickly achieved.

The following diagramme shows the temperature and retention time profile at peak and low load operation:



Emissions - exhaust gas measurements

Authorised Measuring Institutes in Switzerland (Ciba-Geigy), Germany (TüV-Rheinland), Austria and France carried out series of measurements.

The average value of the exhaust gas related to 3 Vol. % $O_{2\text{-residual}}$, is shown in the following table.

Substances in exhaust gas	Indicated as	Limit valve TA - Luft 1986 (1996) mg/m³		LRV Switzerland 1992 mg/m³	Measured values: Hofstetter HT Flare mg/m³	Measured values: Hofstetter horizontal HT chamber mg/m³
Dust		5	(10)	20	< 5	< 5
Carbon monixode	CO	100	(100)	60	5..20	5..15
Nitrogen oxide ($NO+NO_2$)	NO_x	500	(200)	80	40..80	20..50
Sulphur dioxide	SO_2	500	(50)	50	* 20..50	* 20..50
Inorg. chlorine compounds	HCl	30	(10)	20	* 5..10	* 5..10
Inorg. fluorine compounds	HF	5	(1)	2	* 0..1	* 0..1
Unburnt carbon	C_{org}	20	(10)	20	2..8	< 1
Dioxine/Furane	PAHs	ng/m³ --	ng/m³ 0,1	ng/m³ --	ng/m³ << 0,01	ng/m³ << 0,01

* The concentrations of sulphur dioxide and compounds of chlorine and fluorine as well as heavy metals in exhaust gas depend on the substances in the crude gas.

By analysing the crude gas, these can be determined in the planning phase. If they are known, a prognosis of the expected emission value is recommended. Hofstetter Umwelttechnik AG have the appropriate calculation programme in order to determine if pre-treatment of the crude gas is necessary.

These exhaust gas monitoring results show that high temperature combustion, as defined above, ensures the complete combustion of landfill gas and low exhaust gas emission levels. The stringent limit values imposed by the clean air specifications can be observed, in certain cases they are even considerably lower than the permitted level.

For more information, please apply to:

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