Biogas Flares

State of the Art and Market Review

Topic report of the IEA Bioenergy Agreement Task 24 - Biological conversion of municipal solid waste

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IEA Bioenergy

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Contents

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Introduction

The action of micro-organisms upon organic matter under anaerobic conditions produces biogas which is typically a mixture of methane and carbon dioxide as well as a many trace gases and vapours. This action is harnessed within a number of anaerobic bioprocesses such as Anaerobic Digestion (AD) and Landfill for the stabilisation of polluting organic matter contained with a range of solid wastes and wastewaters.

Within the anaerobic conversion of organic material over 90% of energy available in the organic pollutant is retained within the biogas as methane - very little is used to form sludge and this is a major benefit when compared with aerobic bioprocesses. A consequence of this is that the methane rich biogas has a high calorific value and can be used as a fuel. There are also serious safety and environmental considerations associated with biogas because methane is a potent greenhouse gas and forms explosive mixtures when mixed with air.

Therefore for reasons of safety and in order to realise the full environmental benefit from these anaerobic bioprocesses the biogas must be collected and burned with the energy recovered. Energy recovery schemes may be direct where the gas is used to provide heat to meet a local demand or indirect where the biogas is utilised within engines to raise power or drive machinery or vehicles.

Where there is more gas than can be used in the energy recovery system (through unusually high gas production rate or through breakdown/maintenance of the energy recovery system) then additional measures are necessary to eliminate the safety risks and protect the environment. There are three options

- storage
- additional energy recovery systems
- flare

Storage of biogas is possible for short periods without compression, but for periods of more than a few hours is generally impractical due to the large volume. Compression and high pressure storage is performed but is always linked to biogas upgrading due the problems of corrosion and high cost.

Additional energy recovery systems can be provided to give a level of redundancy to the boiler or gas engine. This may be a cost effective measure, but there have to be sufficient (and secure) outlet for the energy.

Biogas flares are used to safely burn biogas that is surplus to the demand of energy recovery plant or where recovery plant fails. They may also provide the only means of safely disposing of biogas produced by anaerobic bioprocesses where the economics of energy recovery have not proved viable.

This paper reviews the technology of flares as applied for the combustion of biogas and summarises the suppliers and costs of flare equipment.

Biogas Composition and Rates of Formation

Biogas composition and flow are basic considerations when approaching flare design as the gas is effectively the feedstock for the flare which may be viewed as a controlled combustion process. The composition of biogas is related to the nature of the organic material being digested; the higher the carbon content, the greater the concentration of methane within the gas. Practically most anaerobic bioprocesses stabilise organic wastes that are formed from mixtures of fats, proteins and simple carbohydrates and this typically gives rise to biogas composition illustrated below.

Biogas Composition

Typical Bulk Biogas Components	Trace Components
Methane 50-60%	Hydrogen
Carbon Dioxide 38-48%	Hydrogen Sulphide
Trace Components 2%	Non methane volatile organic carbons NMVOC
	Halo carbons

Biogas production rates are dependent on the type of anaerobic bioprocess. Within landfill, biogas flow and quality are subject to considerable spatial and temporal variations and this makes it difficult to predict biogas flows and to design and engineer biogas plant. The situation is simpler within AD plant where factors such as feedstock flow and reactor temperature can be controlled. Biogas yields from the three main types of anaerobic bioprocess are given below.

Biogas Yields from Anaerobic Bioprocesses

Anaerobic Bioprocess	Biogas yield
High Rate Wastewater AD	500 m^3 $tonne^{-1}$ COD removed
Municipal Solid Waste (MSW) AD	100 m^3 dry tonne of MSW applied
Landfill	5-10m^3 $tonne^{-1}$ $annum^{-1}$ for 5-15 years

Combustion basics

Understanding the combustion process provides an insight into the benefits of one flare type over another. It also provides a basis for emission standards and performance criteria used in the regulation of flares. The basic reaction that releases the majority of the energy within the biogas is the combustion of methane:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

Stoichiometrically we require 9.6 volumes of air per volume of methane to achieve complete oxidation. For the typical biogas composition given above this falls to 5.7:1. Similarly the energy release by pure methane is 36 MJ m^3 (gross calorific value) but this falls to 21 MJ m^3 for biogas.

Designs should aim to maximise the conversion of methane in order to minimise the release of unburned methane and any products of incomplete oxidation such as carbon monoxide. This is not the only unwanted bi-product of biogas combustion. Other species may be formed depending not only on the ratio of air: fuel but also the temperature and kinetics of the combustion reactions.

Undesirable Products of Biogas Combustion

Undesirable Product	Mechanism of Formation
• CO	Complete oxidation requires T >850 C and residence time of >0.3 seconds throughout the flame.
• Partially Oxidised HC • Dioxins and Furans • PAH	T >850C throughout the flame to prevent the formation of these species through unwanted molecular rearrangements.
• NO_x	Formed at >1200C by oxidation of $N_{2,}$, Also formed within the flame by the oxidation of nitrogenous NMVOC

Therefore in order to maximise the desirable reactions and minimise the undesirable ones we need to provide the following conditions within the flare:

- Temperature range 850-1200C;
- Residence time minimum of 0.3 seconds;

and it these two parameters, temperature and residence time, that form the performance specification for most advanced flares.

Flare Design

In designing a flare to meet the performance specification the following need to be considered:

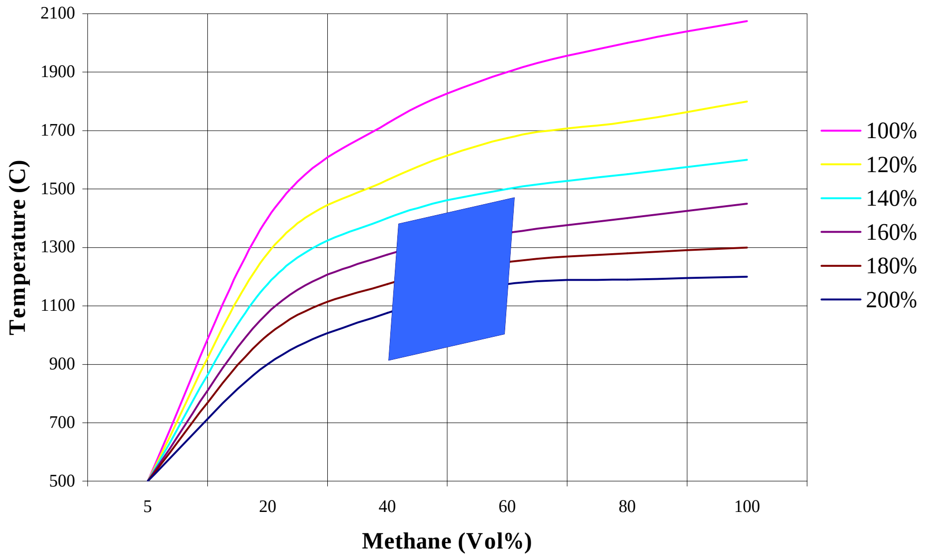
Flare Design Considerations

- Air Requirement
- Stack Exit Velocity
- Energy Release
- Exhaust Gas Flow Rate
- Residence Time

The temperature within the flame is governed by the amount of air added to the biogas. The theoretical relationship between excess added air and flame temperature based on the heat released from methane combustion is shown below.

Mapping the desired temperatures and typical biogas concentrations onto this plot and taking account of heat loss provides an operating range for flares, given by the blue envelope. Biogas

Flame Temperature (C) for CH_4/CO_2 Gas Mixture for a Range of Excess Added Air Concentrations



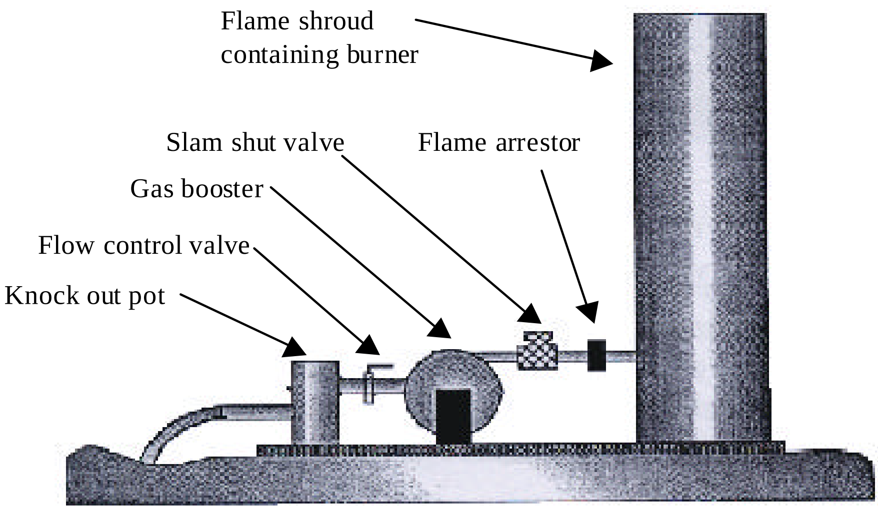
flares usually operate at the right hand side of the envelope at CH_4 >50% with the excess air to biogas ratio of the order of 10-15 volumes of air : biogas. Under these conditions the air is employed to both oxidise the biogas and cool the flame – it also propagates more turbulence and mixing. Mixing within the burn is crucial to ensure that all the biogas is burned uniformly and under ideal conditions.

Once the basic air requirement has been determined – the other parameters can be calculated. The principal combustion reaction is equimolar and therefore summing the fuel and air flow and adjusting for temperature gives the exhaust gas flow rate. Dividing this by the section of the enclosure gives the exit velocity. This needs to be sufficient to prevent the flame front travelling backwards down the burner but also not too great for the flare to blow itself out. The height of the flare at or above the design temperature is determined empirically and this can then be used to derive the retention time at the design temperature. Gas flow and calorific value of the major components determine the potential heat release.

OPERATIONAL REQUIREMENTS

Irrespective of the type of flare, safe, reliable operation of a flare requires a number of features in addition to the burner and enclosure. The more basic requirements are illustrated for an enclosed flare within the schematic below. The extent of gas cleaning or conditioning depends on the source and whether the gas is used in energy recovery plant where the tolerances are lower entrained particulates and for a number of the acidic gases formed during combustion. Essential safety features include a flame-arrestor, failsafe valve and ignition system incorporating a flame detector. A gas blower is also essential to raise the pressure of the gas to 3-15kPa at the burner.

Schematic Drawing of an Enclosed flare



More advanced flares may incorporate a number or other process control, emission monitoring and safety features. These may include:

Advanced biogas flare features

- Continuous Monitoring
- Telemetry
- Support fuel
- Control of air and fuel flow
- Flashback Detection
- Control of Recycle

It is important to note that the use of support fuel to supplement low calorific value (CV) biogas is not common practice and usually only applies to landfill biogas. The use of high-grade energy to support the disposal of biogas is expensive and will increase the overall burden of carbon dioxide to the environment. Ideally a more sustainable approach should be developed which optimises the quality of biogas recovered linked to timed control to so that biogas is only flared when the quality is adequate. Burners capable of flaring biogas with <10% CH_4 are available and may be deployed in these circumstances.

Recycle control is rare and is used to reduce NO_x formation but maybe employed where the biogas has a high component of nitrogenous compound or at sensitive locations where it is desirable to achieve very low standards of emissions.

Types of Flare

Flare types can be divided into two main types, open flares and enclosed flares.

Open Flares

An open flare is essentially a burner with a small windshield to protect the flame. Gas control is rudimentary - a coarse manual valve in many cases and the rich gas mixture, lack of insulation and poor mixing lead to an incomplete burn and a luminous flame which is often seen above the windshield. Radiant heat loss is considerable and this leads to cool areas at the edge of the flame and quenching of combustion reactions to yield many undesirable reaction products. The heat loss is so severe that open flares are sited 5-6 metres above the ground to protect workers and supply pipework hence the term elevated flare is often applied. However the simplicity of open flares makes it impossible to engineer them to meet emission standards that are now being applied in most developed countries. The absence of an enclosure and intense heat associated with open flares also make it very difficult to monitor emissions.

Historically, open flares have been popular because of their simplicity and low cost allied with the absence of emissions standards and controls. In the future the introduction of controls is likely to limit their use to mobile plant where simple skid mounted units can be deployed for safety and environmental control of biogas, particularly within landfill gas fields prior to the installation of permanent gas collection systems.

Enclosed Flares

Enclosed flares are usually ground based permanent plants which house a single burner or array of burners enclosed within a cylindrical enclosure lined with refractory material. Designed for purpose, the enclosure prevents quenching and as a result the burn is much more uniform and emissions are low. Monitoring of emissions is relatively straightforward and basic continuous monitoring of Temperature, hydrocarbons and carbon monoxide maybe incorporated as a means of process control.

The increased engineering and process control provide greater flexibility in terms of turn down - the ratio of minimum biogas flow to maximum biogas flow under which satisfactory operating conditions are maintained. Manufacturers typically quote turndown of 4-5:1 for biogas quality of 20-60% methane (by volume). Higher turndown is achievable of up to 10:1 but at the expense of the quality of burn as the heat release does not enable adequate temperatures to be achieved.

A further sub-classification of enclosed flares is based on the method of introducing the air to the biogas.

1. ***Diffusion aeration*** (where the air and landfill gas is mixed at the burner – likened to the use of a Bunsen burner with the port closed – the flame is slow to propagate and this leads to high enclosures to achieve burn-out)
2. ***Pre-aerated*** (usually achieved through a venturi – likened to the use of a Bunsen burner with the port open - the aeration being proportional to the feedstock flow)

Summary Features of Open and Enclosed Flares

Open Flares
- Cannot meet performance or emission criteria
- May be skid mounted and collapsed for transport
- Cost 20-75% of equivalent enclosed flare
- Suitable for temporary or test uses only

Enclosed Flares
- Meet performance and emission standards
- Permanent – 10-15m high
- Capable of operation over a wide range of combustion conditions
- Can be further engineered to meet specific site

Health, safety, environmental impact and regulation

The flare is a means of reducing the impact of biogas but it also introduces additional hazards or nuisances that that need to be considered holistically within a proper assessment before designing and siting a flare. The areas that should be covered in any assessment include

- Local and global air quality and the effect of undesirable reaction products
- Visual impact
- Noise impact
- Odour nuisance
- Explosion, fire and asphyxiation

Regulation of flares is piecemeal and this is an anomaly. A flare burning biogas containing 50% methane burning 1000 m^3 $hour^{-1}$ of biogas is releasing 5MWTh of heat and this is comparable with a reasonably sized plant or incineration process where there is well defined and detailed regulation and control. A number of countries have standards applying to flares and these usually take the form of operational standards or emission controls or both.

Regulation – operational standards

Standards range from simple planning conditions such as 'no visible flame' (directing the process operator towards an enclosed flare) to specifying a temperature and minimum residence time for combustion to minimise the formation of undesirable combustion products.

Combinations of Residence times and Temperature

UK (proposed)	0.3 seconds at 1000°C
USA	0.6-1.0 seconds at 850°C
Netherlands	0.3 seconds at 900°C
Germany	0.3 seconds at 1200°C

Regulation – emissions standards

Emissions monitoring, particularly of the more exotic emissions, is not straightforward and can be very expensive. Indeed, Dutch regulators acknowledge this – regulation is based on performance standard only. However, most countries that do regulate on emissions standards specify simple combustion parameters, setting emission limits for a range of outputs (such as SO_x, NO_x, CO, dust and HCl). For example, the proposed limits for the UK are given below.

UK Proposed Limits for Emission Concentrations

Carbon monoxide (CO)	50 mg/Nm^3
Oxides of nitrogen (NO_x)	150 mg/Nm^3
Unburned hydrocarbons	10 mg/Nm^3

Concentrations referred to Normal Temperature & Pressure (NTP = 0°C and 1013 mBar) and 3% oxygen.

Recommended Monitoring Regimes

Monitoring regimes should be specific to the individual flare and location, and be designed based on the results of the impact assessment. The table below provides a recommended monitoring regime applicable to enclosed flares.

Monitoring Level	Frequency	Type	Inlet Gas	Outputs
First	Weekly up to continuous	Routine inputs	CH_4, CO_2, O_2	
Second	Periodically or when a significant change in LFG composition	Routine inputs and outputs	CH_4, CO_2, O_2 plus gas flow rate	Bulk composition (O_2, CO_2, NO_x, CO, THC) Temperature and residence time
Third	Frequency subject to the findings of an environmental impact assessment (EIA)	Trace species	CH_4, CO_2, O_2 plus gas flow rate	As above plus HCl, HF, SO_2 and a range of oxygenated, aromatic, halogenated and sulphuretted

Suppliers and prices

Companies that design and build flares usually operate in wider markets such as combustion, landfill technology or environmental engineering. This is because the overall demand for flares is not sufficient to drive the formation of a dedicated biogas flares industry. However there are a number of companies which manufacture many units per annum and who operate internationally. There are also many smaller light engineering companies which produce more basic flares but who do not have the same grounding in combustion or environmental engineering. The major suppliers are

Established Suppliers of Biogas flares

Biogas (UK)
Haase Energie Technik (Germany)
Organics (UK)
Hofstetter (Switzerland)
John Zink (USA)

The ranges of prices (in US$) for open and enclosed flares (basic specification excluding civil engineering and monitoring etc.) are:

Open flare **$27,000 to $150,000**
(Temperature 850°C, 250-2000 Nm^3h^{-1})

Enclosed flare **$105,000 to $195,000**
(Temperature 1200°C, 0.3 seconds, 250-2000 Nm^3h^{-1})

The prices for flares vary widely depending on a number of factors, but as a general guide enclosed flares are about 1.5 to 2 times the price of an open flare with the equivalent duty.

About the IEA Bioenergy
The International Energy Agency (IEA) was founded in 1974 as an energy forum for 23 industrialised nations. The purpose of IEA Bioenergy is to increase the programme and project co-operation between participants. Bioenergy is defined as the production, conversion and use of material that is directly or indirectly produced by photosynthesis (including organic wastes) for the purpose of making fuels and substitutes for petrochemical and other energy-intensive products.

About Task 24 - "Energy from biological conversion of municipal solid waste"
Task 24 aims to provide reliable information on the cost-effectiveness of AD, markets for biogas and the other co-products, advanced technologies for biogas utilisation, environmental benefits, and institutional barriers. Five countries participate in the Activity: Denmark, Finland, Sweden, Switzerland, and the United Kingdom. The Activity's principal objectives are to accelerate exchange of information and practical experience, identify barriers to the deployment of AD technology, encourage the use of AD technology, and, where relevant, assist and encourage national Pilot and Demonstration programs. The goal of these objectives is to increase the deployment of AD technologies and to transfer the "lessons learned" from past experience.
The target audiences for the Activity's work products include municipal and regional waste-decision managers, AD industry suppliers, waste disposal developers and financiers, central agencies providing capital grants, and central agencies preparing environmental legislation.

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TASK 24 ENERGY FROM BIOLOGICAL CONVERSION OF ORGANIC WASTE

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