FLAREGAS CORPORATION
1[illegible]S Middletown Road
Nanuet, New York 10254
Phone 914-[illegible]23-[illegible]220

FLAREGAS
Flaregas Engineering Limited
West Drayton, Middlesex, UB7 7SJ, England

Towards quieter flaring

David Shore, C.Eng., M.I.Mech.E., A.M.Inst.F., M.I.Plant.E

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Noise pollution from Flares has for too long been an inconvenience accepted in petrochemical plants as an inevitable by-product of the flaring process, which process is, by its very nature, intended to reduce the hazards of unwanted pollution.

Recent authors have considered the subject in general terms and a sense of awareness is developing in planning for new plants whilst local and national legislation is beginning to impose more rigid controls on existing plant. This paper sets out to examine one approach to flaring and discuss how this approach assists noise reduction in flaring operations. The use of Ground Flares is also considered as an aid in noise reduction.

Smokeless Flaring It has been established by others[1,2] that [redacted] This is ~~especially~~ so [redacted] one [redacted] as the main means of smoke suppression. It is generally appreciated that [redacted] Firstly, there is that which results from ~~the combustion process~~ itself.

This noise is generated as a result of unsteadiness in the combustion process. In the turbulent combustion zone there is a non-uniform flow of reactive products due to random velocity perturbations[3] and re-entrainment of the products of combustion which creates unstable conditions in the flame zone. This instability is demonstrated visually as loose tongues of flame and is basically an inefficiency in the combustion process. Some of this inefficiency is demonstrated by an energy release in the form of noise rather than heat, the order of magnitude of these losses being 10^{-7}.

[redacted] at the tip [redacted] Consideration of the mechanical power of noise producing jets[4] suggests that the steam injection noise results from inefficiencies in the order of 10^{-3} and, indeed, it is this noise which is most commonly recognised as being objectionable in elevated flares and about which most is being and has been done.

There are a number of different methods of steam injection commercially available and each produces a different noise characteristic.

To appreciate why steam injection is used at all, a simple explanation of the principal mechanisms which take place in the hydrocarbon flare flame is useful. Raw gas flames rely on diffusion of the gases into the surrounding air producing a flammable mixture which can then burn if ignited. A flame envelope results and gases entering at the base of the flame are preheated by the burning zone. Depending on the size of flame and nature of the gas, the temperature of the unburnt gases can reach a point of which some cracking of these gases occurs. This produces free hydrogen and carbon before the burning zone is reached. When eventually the gases do reach the flame envelope, the available oxygen reacts more readily with the hydrogen than with the carbon. Some of this carbon which cannot react sufficiently quickly, cools and appears as smoke. [redacted]

Introduction of air also into the centre of the flame zone reduces smoke formation as more oxygen is made available at the time of dissociation of the hydrocarbon, permitting overall better combustion. This is the situation usually achieved in controlled burner installations such as boilers and furnaces.

Coanda Effect Injection Probably the most recent and advanced method of steam injection utilises the Coanda effect to introduce steam and air into the flaregases prior to combustion. The Coanda effect is that effect which allows a jet of fluid to adhere to a plane surface placed near to the line of the jet, even though that surface may be at an angle to the true line of the jet. Internal injectors, (Fig. 1) rather like venturies, are used. High pressure steam is fed to the narrow annulus and on leaving, the jet is deflected by the Coanda effect into the venturi-like section. As it flows into the throat it inspirates large volumes of air. By arranging these units in banks around the top of the flaretip, (Fig. 2) turbulent mixing of gas with steam and air is achieved before the gases enter the base of the flame. In consequence, whilst the steam itself is still effective, it is also the prime mover for the entrainment of air. These two features combine to permit smokeless flaring of even the heaviest and most difficult hydrocarbon gases.

Noise Tests This type of tip was originally developed with a view to reducing the noise levels encountered during flaring. The first model – built from mild steel and aluminium – was never fired on gas and was used only for noise testing. The figures obtained were extremely encouraging and so further tests were undertaken involving operational flare tips. It soon became obvious during the tests that not only were noise levels much lower than those usually experienced, but also there were savings in steam consumption. The entrainment of large volumes of air produced good combustion and, in some cases, gave indications of up to 30 per cent savings in steam usage to obtain a satisfactory smokeless condition.

From the initial flaring tests made on prototype tips, a dossier was compiled which permitted the formulation of some equations relating sound pressure level (SPL) to steam and gas rates. As time passed, more field applications of the Coanda tip began to be available for noise surveys and a pattern emerged between steam flow and SPL. The plot (Fig. 3) of these results enables prediction of flare noise based on a reasonably accurate estimation of the steam requirements for smokeless flaring. It has been found more realistic to relate noise to steam flow rather than to gas flow as different gases require different steam rates per pound of hydrocarbon, depending upon their composition. Further-more, each plant operator has a different opinion of what a smokeless flame should look like and how much more or less steam should be used. It is certainly not possible to generalise and assume a fixed norm for steam to hydrocarbon ratio.

Design Advantages Comparison of noise levels from the Coanda tip with those from other and more conventional types of steam injection reveals advantages on the basis of steam consumption. Many of these advantages are directly associated with the use of the Coanda injector. It is a well known principle amongst noise engineers, and has been demonstrated by investigators[1,2,5] that the noise characteristics of orifices can be adjusted by strategic positioning of multiple jet formations. In general, for any group of jets, as the ratio of total periphery to total flow area increases, the noise generated by a constant flow at constant pressure will probably decrease. The Coanda injector has as its steam orifice a narrow annulus with a relatively high periphery to area ratio. The difference in noise levels between this injector and a single circular orifice of equivalent area can be demonstrated by tests and the reductions obtained in using the Coanda injector may be as much as 10dB. (Fig. 4).

There are two basic reasons for this phenomenon. Firstly, as the jet noise is created by turbulent energy in the periphery of the jet stream as it shears through the otherwise still air, increasing the periphery reduces the concentration of this turbulent energy. Secondly, where jets are grouped such that the jet streams very quickly coalesce, then the noise is a function of the turbulent energy in the periphery of the "apparent" new jet stream. A further contributory factor to this reduction in noise levels stems from the fact that the multiple holes are, obviously, smaller than the single orifice. The noise produced at an orifice can be plotted as a frequency spectrum and it has been determined that high frequencies are generated close to the orifice and low frequencies far from the orifice.[6]

The peak power is usually generated in the higher frequencies and the smaller the jet, the further into the high frequencies goes the peak noise level. However, these high frequencies are those most affected by molecular absorption and are also highly directional, so whilst the sound power level (PWL) may not differ greatly between single and multiple jets, the recorded SPL and 'A' scale weighting could show a significant reduction.

The arrangement of Coanda injectors in the tip and the general efficiency curve of the injector, allows design steam pressures in the order of 50 psig. Other designs may be limited in respect of available orifices and often need to design up to 100 or 150 psig creating a further small increase in noise.

A further reason for the Coanda tip being quieter than its neighbours in terms of steam injection noise, stems from the advantages gained by entrainment of air into the gas stream. The better combustion achieved permits some steam saving to be made, again assisting in lowering noise levels.

This better combustion could, it might be argued, be detrimental as far as noise production is concerned. Combustion noise being generally related to the turbulent intensity of the flame, the pre-mixing of air with the gas could lead to more rapid combustion and increase the level of combustion intensity therefore being responsible for a higher level of combustion noise. It is known that complete mixing and straightening of the flow prior to combustion will lead to significant noise reduction[7]. Some attempt has been made in the Coanda tip to achieve this and in increasing combustion efficiency reduce the inefficiencies which produce the noise. Most of the turbulent mixing with steam and entrained air takes place within the tip as opposed to most other similar tips in which mixing does not occur until the gases have left the end of the tip.

Some of the turbulent energy noise is thus shielded by the tip itself. Visual observations of the flame from the Coanda tip do show an area of extremely good and stable combustion above the exit of the tip. Furthermore, due to the conical shape of the unit, the exit velocity of gases is approximately half of that through a straight tubular tip and this again will have an effect on the combustion noise created by turbulent energy and mixing with ambient air.

General Picture Having considered the individual design aspects of the Coanda tip, a comparison may be made between typical noise spectra using some different types of steam injection (Fig. 5). The simplest method of steam addition is to inject directly into the centre of the flare tip. This tends to increase the overall level of combustion noise but does not radically change its spectrum. This method of steam injection can be rather expensive on steam however, needing high steam to gas ratios which, if not properly controlled, can lead not only to suppression of thermal cracking but also to suppression of combustion.

The next, and possibly most common, method of steam injection is to use a ring of steam jets situated around the base of the flame. The high pressure jets of steam create turbulent mixing of steam and gas with some entrainment of air. It can also cause entrainment of the inert products of combustion thereby increasing local instabilities and the accompanying inefficiencies, with a consequent increase in noise levels. This type of tip is also susceptible to disruption of mixing in high wind conditions. The external jets are themselves extremely noisy and impose upon the spectrum some high frequency jet noise. It is noticed that other authors[8] have also found this to be a feature of the noise spectrum in that a high frequency peak is encountered which can only be removed by special treatment.

The Coanda tip does not demonstrate this feature of peaking in the high frequency ranges. Most of the noise is concentrated in the combustion frequencies which means that when presented as a dBA reading the Coanda noise levels are much more acceptable than those generated by other types of steam injection.

Noise, of course, attenuates with distance and attenuation is greater in the higher frequencies than in the lower due to air absorbtion and directivity effects. This means, for example, that at a distance of half a mile the noise which is actually heard is basically around the 500 cycle range which neither appreciably attenuates by air absorbtion nor is much weighted as an 'A' scale reading. The distance-attenuated plots (Fig. 6) of dBA show this comparison. Where high frequency is prominent in the generated spectrum, the distance-attenuated spectrum may still demonstrate high noise levels in these frequencies but nevertheless, combustion frequencies begin to play a more important part in audible noise. This causes a neighbourhood noise problem associated with the use of smokeless elevated flares, especially during the hours of darkness or out of normal working hours. This problem, coupled often with a desire for economy, has led to steam being turned off flares at night.

Ground Flares Noise is not the only neighbourhood problem after sunset, but also luminosity of an elevated flare flame can prove to be a source of annoyance to anyone trying to sleep. Perhaps this reason, rather than the noise problem, is causing more concentration on ground flare units. The ground flare is designed to dispose of some fraction of the plant flaring capacity inside a partly closed box thus hiding the flame for the major period of plant operations.

It has been suggested that grade level flares are likely to be some 10 dB[3] quieter than elevated flares buring at the same capacity. This noise reduction is probably due to the fact that the flame contained inside a box is protected from wind effects and sporadic cooling, and the stabilising effect of the heat re-radiated from the refractory walls reduces the random characteristics of combustion. The walls themselves will absorb some of the sound energy and help to cut down the SPL over the short distance.

More work is certainly necessary to determine operating noise levels from ground flares but available results suggest that the patterns will follow the same lines as furnace noise.

An empirical basis has been suggested by Davies[9] to allow 10 dB increase in furnace noise per tenfold increase in heat load. By calculating total PWL generated in operating ground flares and plotting these results against the furnace noise curve, it would appear that the line suggested by Davies is one of a family of lines. (Fig. 7). Each line representing a particular combustion density. Every ground flare would then have its own characteristic curve at an angle to the Davies line with the head of the curve set at the maximum design liberation and the combustion density required to achieve that design. Further work is planned with ground flares to examine this and other features. It is obvious, however, from present results that the noise follows a normal type combustion spectrum with no higher frequency peaks. (Fig. 8).

Also, in some cases where extremely difficult gases are involved and steam injection is again advantageous, a modification of the Coanda injector permits excellent results to be obtained without any obvious steam injection noise being involved and without significantly affecting the proposition of the combustion density curve.

It is hoped that this paper has been instructive to those not familiar with flaring and informative and interesting to those who may be involved in solving some of the problems discussed. The author has tried to show that it is no longer necessary to choose between the two evils 'smoke' and 'noise'. By correct design and selection of equipment it may be possible to reduce levels of both of these forms of pollution.

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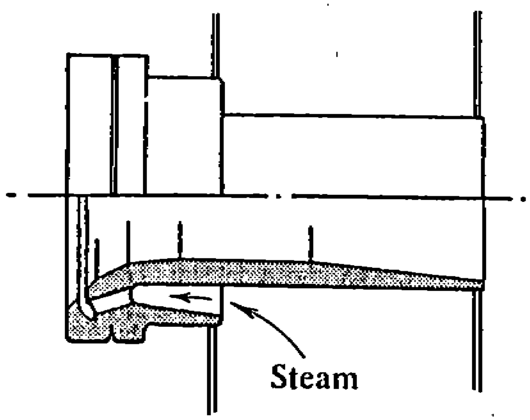
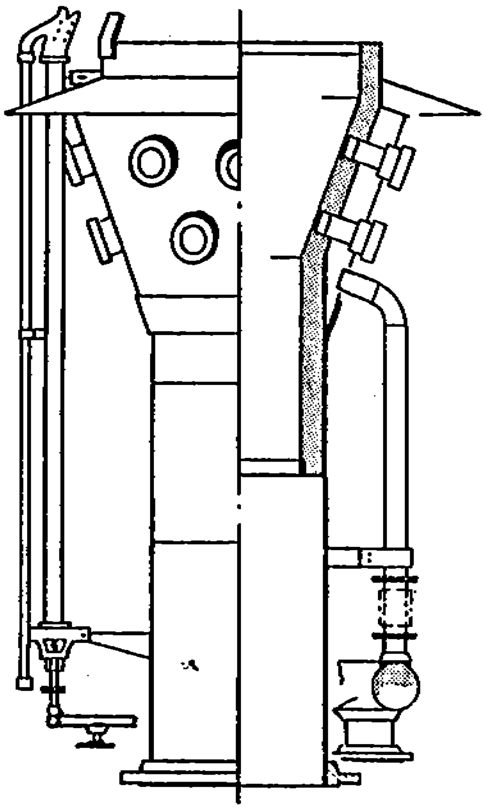
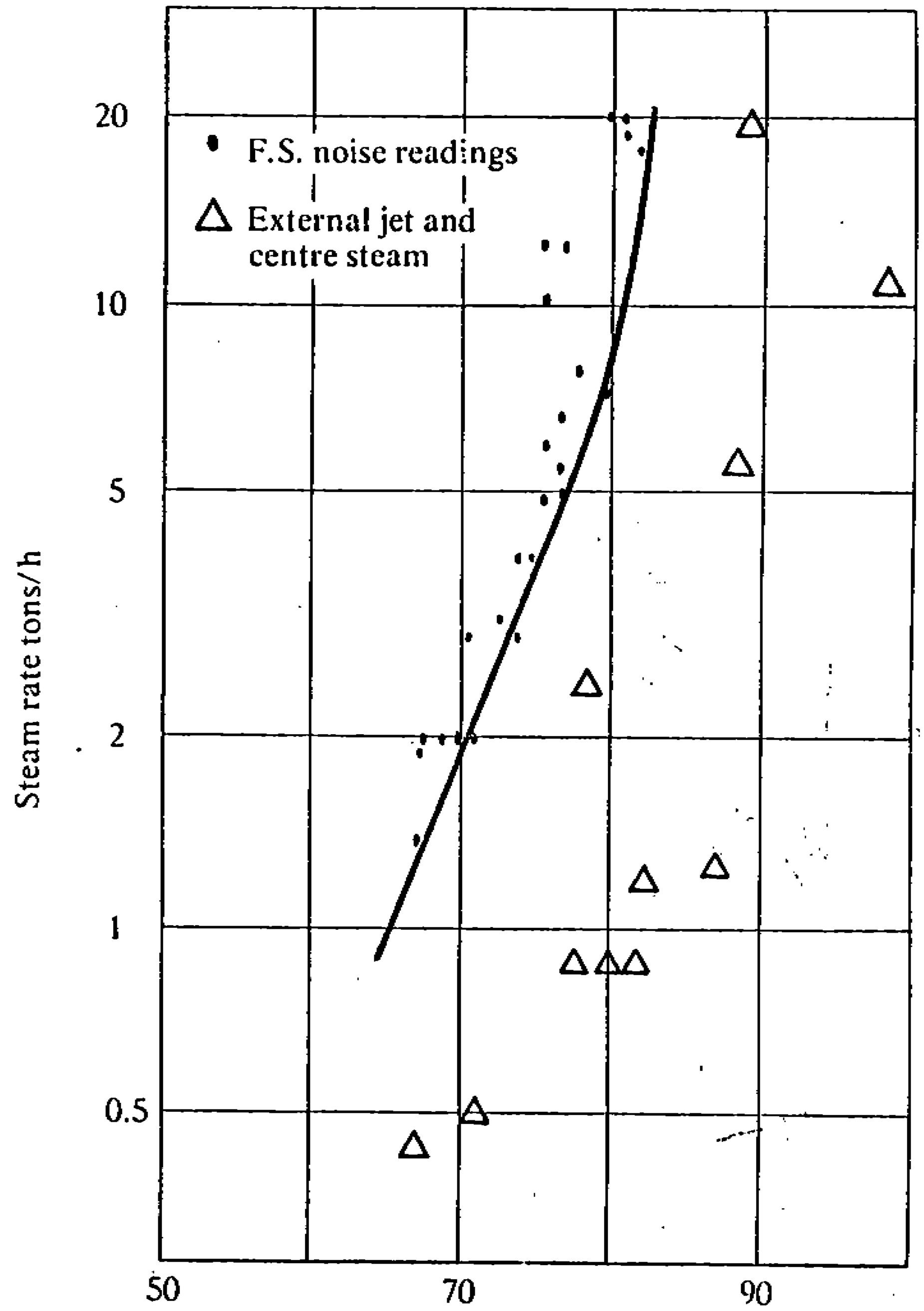


"Flarejector" ® Coanda injector Fig.1



Type F.S. anti pollutant flare tip Fig.2



dBA read (or corrected) at 150ft. from source Fig.3

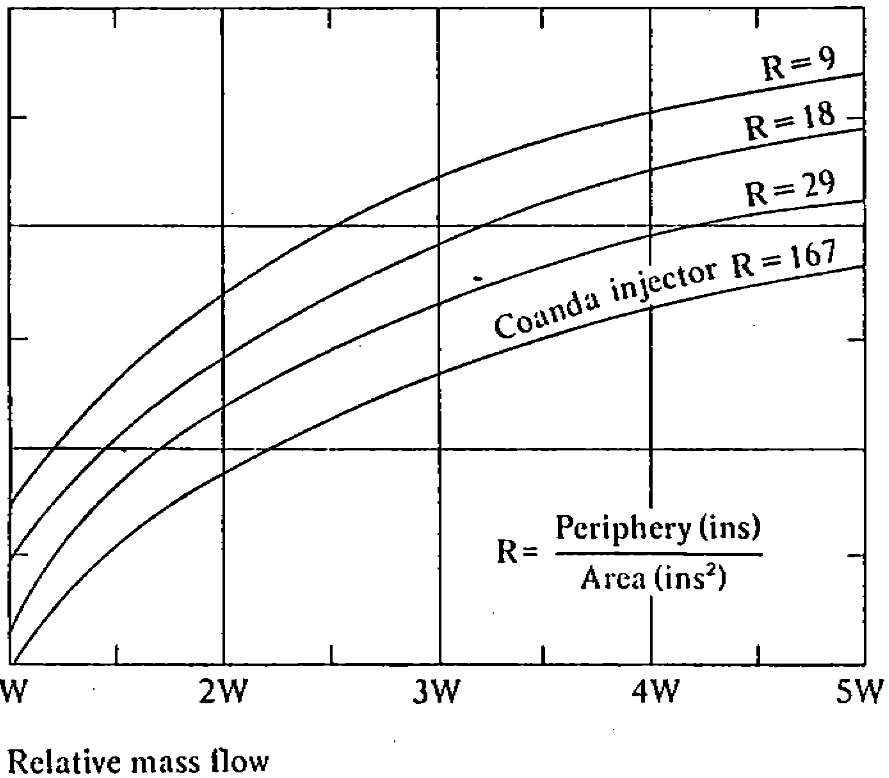
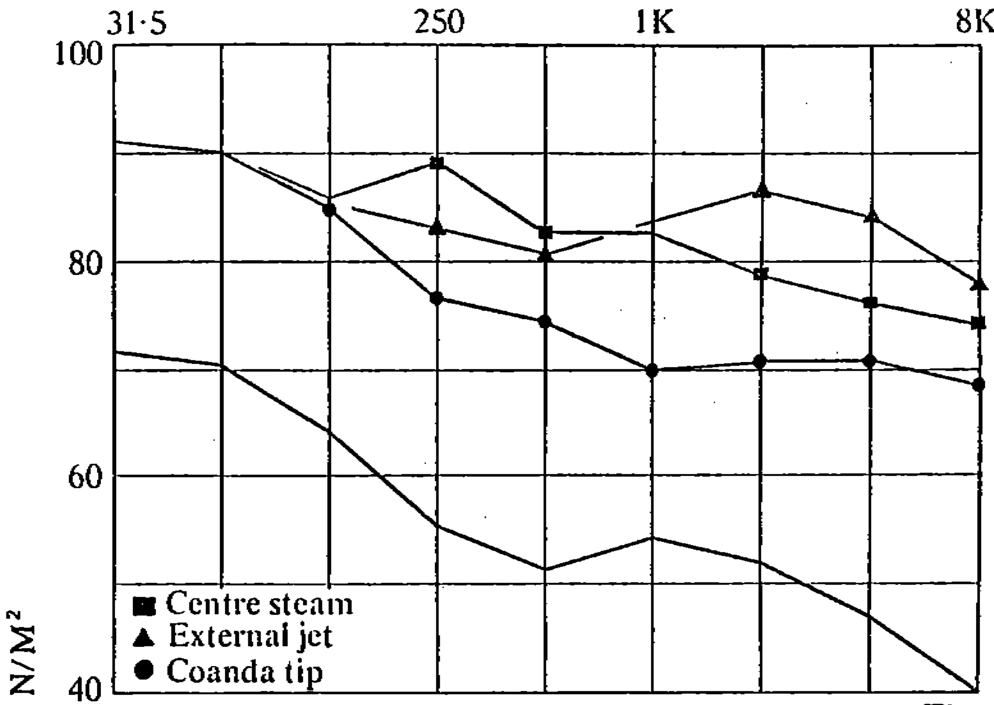


Fig.4



F.S. Spectrum 150ft. from source
20.4t/h C_3H_6 8t/h steam
Centre steam injection and external jet added for comparison of spectrum shape

Fig. 5

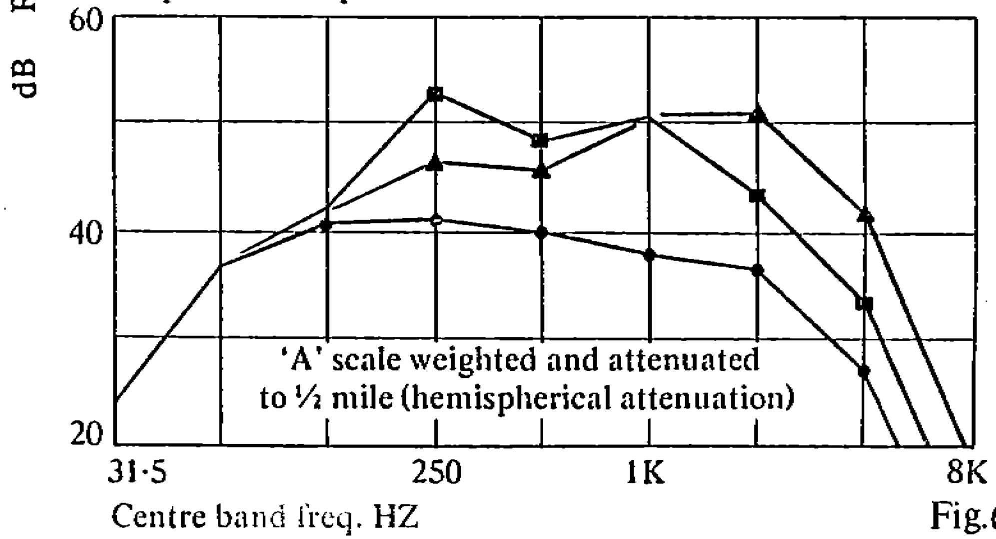


Fig.6

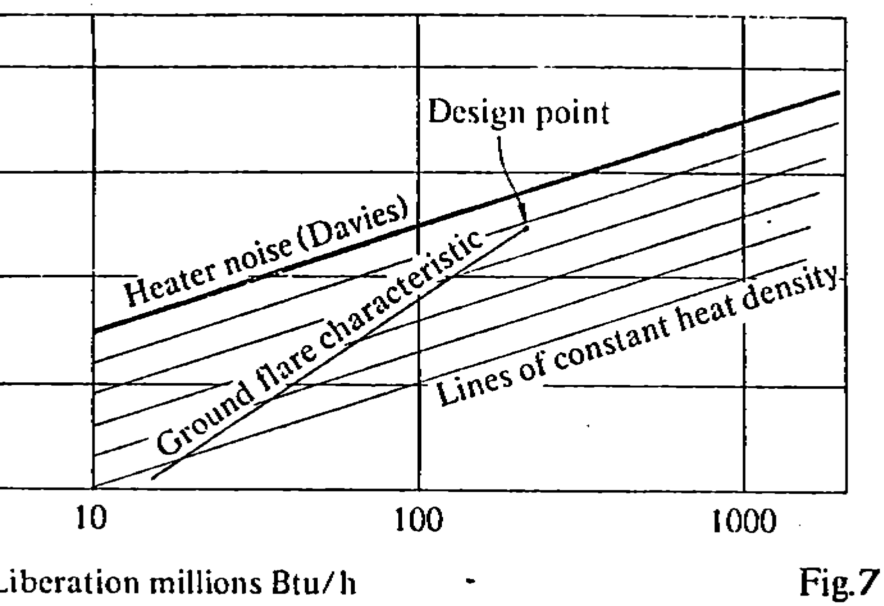

Design point
Heater noise (Davies)
Ground flare characteristic
Lines of constant heat density
10
100
1000
Liberation millions Btu/h

Fig.7

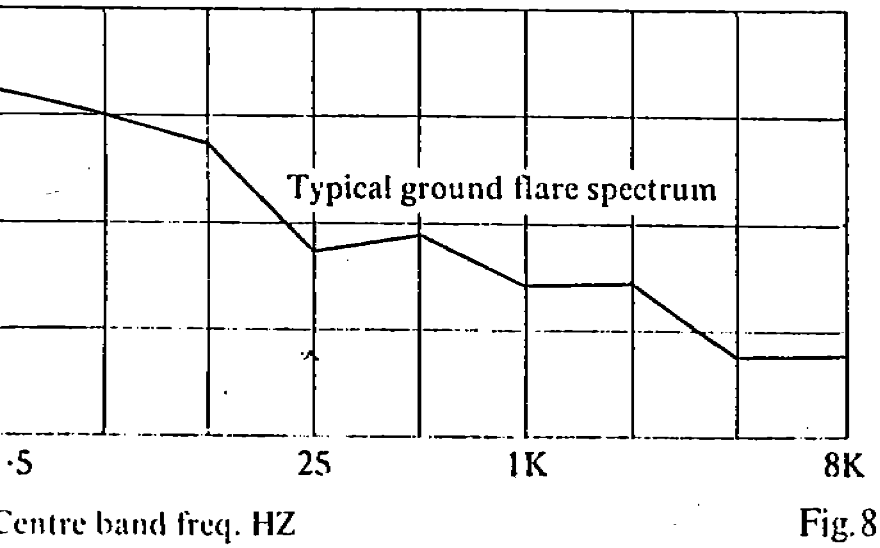

Typical ground flare spectrum
·5
25
1K
8K
Centre band freq. HZ

Fig. 8