

## A NOTE ON THE SPECTROGRAPHIC STUDIES OF MUNROE JETS

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### ABSTRACT

Spectra of Munroe Jets with different metals as liners were taken with a glass Constant Deviation Spectrograph and a quartz Intermediate Spectrograph. Preliminary studies indicate that the metal in the jet is partly in the vapour state and partly in the form of small fragments.

### Introduction

During the past ten years, the metal jets which are squirted from high explosive charges with metal-lined cavities have received considerable attention from both experimental and theoretical points of view. The hydrodynamic theories of jet formation and target penetration were presented by Birkhoff et al<sup>1</sup> and Pugh et al<sup>2</sup>. The exact physical state of the metal in a Munroe jet is still not thoroughly understood. Birkhoff et al<sup>1</sup> discussed two types of jets, 'particle or fragment' and 'continuous or fluid'. Koski et al<sup>3</sup> made time-resolved spectrographic observations of jets and concluded that the 'fast' jets were partly of a gaseous nature. Evans and Ubbelohde<sup>4</sup> suggested that metals like cadmium and zinc whose boiling points are low, might occur in the jet as a stream of dense vapour and metals like iron whose boiling points are high, might occur as a stream of fine fragments. One of us<sup>5</sup> (S. S.) took photographs of the travel of Munroe jets in air and observed notable differences for different metals.

In the fundamental studies of these jets it becomes necessary to determine experimentally such physical quantities as temperature, pressure and physical state of the metal in the jet. Because of the brief duration of the jet and the high temperature and pressure involved, the above mentioned quantities can be best determined in principle, by optical or spectrographic methods. The present note deals with some preliminary spectrographic studies of Munroe jets fired in air. Further work in this line is expected to throw light on the exact physical condition of the metal and the temperature in the jet.

### Experimental \*

Conical liners of 45° angle, outside base diameter of 1.5 inches and a thickness of 0.048 inch were machined from rods of different metals. These were then soldered to suitable lengths of gas pipes. High explosive, which was a mixture of TNT and Tetryl in the ratio of 70 : 30, was cast and 5.5 ozs. of it was used in each filling. A guncotton primer was used as a booster and was primed by an electric detonator. The equipment was fired vertically upwards in the air.

A Hilger Constant Deviation Wavelength Spectrometer with a camera attachment was used for photographing the spectra of the jets. This instrument has a dispersion of about 100Å/mm in the 5700Å region and about 22.5Å/mm in the 3850Å region. For protection, the instrument was kept inside an armour

plate shield at a distance of 30 meters from the place of firing. A glass lens of large aperture (10 cm) was fitted into the port hole of the shield for focussing the light on the slit of the spectrograph. The jets were fired vertically and the spectra of first eight feet of their travel were recorded on Ilford HP3 plates. A large slit width of 1.5 mm was used. The experiments were carried out during the nights in total darkness and it was thus possible to leave the shutter of the spectrograph open for photographing the phenomenon whose duration was extremely small.

With a view to studying the details of the spectrum and also observing it in the near ultraviolet region, the above experiments were repeated with a quartz instrument of higher dispersion, the Hilger Intermediate Quartz Spectrograph. This instrument has a dispersion of about 55Å/mm in the 4047Å region and about 15Å/mm in the 2536Å region. The glass lens in the port hole was replaced by a quartz lens of aperture 2.5 cm. The spectra were photographed from a distance of 7.5 meters. The slit width was 1.5 mm.

### Results and Discussion.

The different metals used as liners in the shaped charge were copper, zinc, tin, mild steel and aluminium. Figures 1 and 2 show the spectra of jets with these metals taken with the Constant Deviation instrument and the Intermediate Quartz instrument respectively. The spectra recorded by the quartz instrument were very weak due to the low speed of the instrument and the small aperture of the focussing quartz lens. Only two of the more intense spectra taken with this instrument are shown in Fig. 2. In Fig. 1 the spectra extend from 3,900Å to 5,900Å and in Fig. 2 they extend from 3,300Å to 7,000Å.

The spectra are not of uniform intensity in the vertical direction. This is due to the fact that the jet is not steady but one that is travelling in the vertical direction. Each spectrum is thus a time-resolved spectrum. But in the present experiments we have not attempted to study the time-resolved spectrum though such a study would yield interesting information about the various parts of the jet from its origin to its tip.

The spectra consist of emission lines and absorption bands superposed on a background of continuous emission. With a few exceptions, all the emission lines have been identified and found to belong to the vapours of the metal in the jet. It may be observed that in the first three plates in Fig. 1, a relatively strong line appears at about 5,880Å. It may be the sodium D line, but it is difficult to explain the presence of sodium in our experiments.

The continuous emission which is seen in all the spectra is possibly due to incandescent metallic particles in the jet. The strong absorption band in the region 5,100 to 5,000Å seems to occur in almost all the spectra. Using a higher dispersion spectrograph with greater speed it would perhaps be possible to trace the origin of the absorption bands to some of the familiar molecules and radicals present in the detonation products of the explosive filling.

The evaluation of the temperature of the jet by spectroscopic methods is rather an involved process, though a very reliable one. At the present stage of our experiments it has not been possible to follow up any one of these methods but it is hoped that our further work would include the accurate measurement of temperature. A rather rough estimate, however, from the relative intensities of Cu-lines gives a value around 4,500°C for the temperature in the jet. It

a  
b  
c  
d  
e

5872 A  
5700 A  
5218.2 A  
5153.2 A  
5105.5 A  
4651.1 A  
4587 A  
4378  
4275 A  
4062.7 A  
4022.7 A

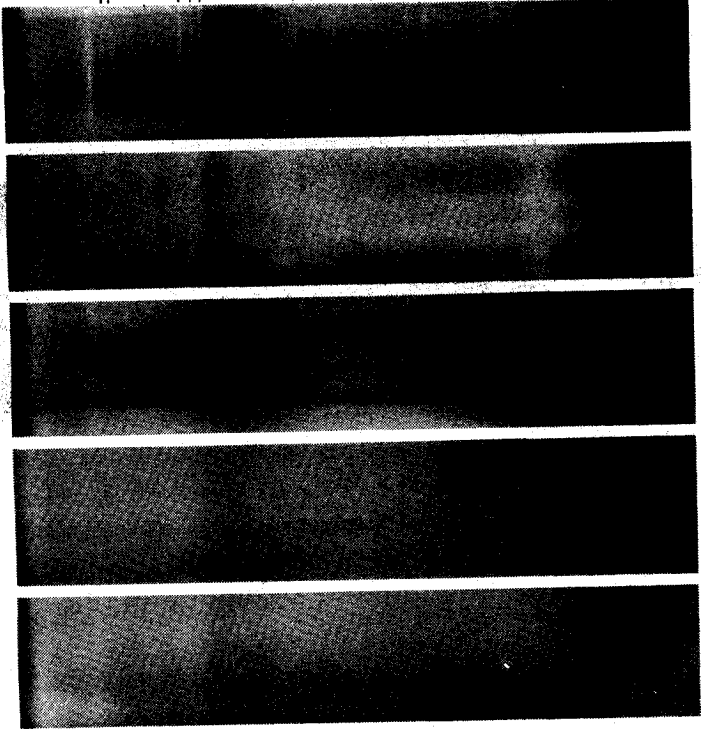
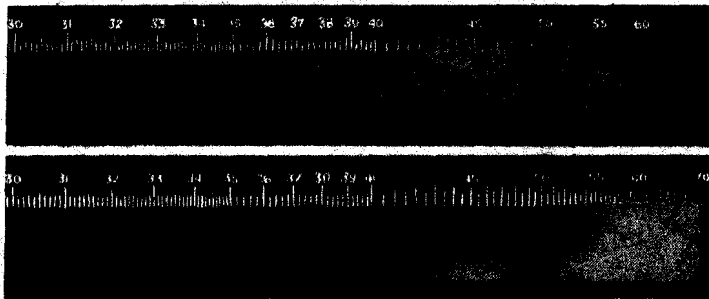


Fig. 1

Spectra of Munroe jets taken with a Constant Deviation Spectrograph, the conical liners being (a) Copper (b) Zinc (c) Tin (d) Mild-steel (e) Aluminium.

**Fig. 2**



Spectra of Munroe jets with an Intermediate  
Quartz Spectrograph, the conical liners being  
(a) Copper (b) Mild-steel

should be emphasized here that the concept of temperature is less definite when applied to streams of gases or jets which may not have attained an equilibrium state as regards the distribution of energy among the vibrational, rotational and translational states.

At the estimated temperature of about  $4,500^{\circ}\text{C}$  one would expect all the different metals used in these experiments to vaporise, fully or partly, in the jet and give out an atomic spectrum. This is in fact the case, as is evidenced by the appearance of atomic lines in the spectra. Only a single line is recorded in the spectrum of tin. This is so because tin has not many strong lines in this region of the spectrum. Similar is the case with aluminium. The two strong resonance lines of aluminium should have appeared at  $3,961.54\text{\AA}$  and  $3944.03\text{\AA}$ . But the interesting feature of the aluminium spectrum is that in the position of these two lines there occurs an absorption. It is possible that this absorption band is due to the re-absorption of these two lines by aluminium vapours.

The line spectrum of mild steel (Fig. 1d and Fig. 2b) is very weak. In fact except for a few very faint lines, only a continuum is recorded on these spectra. This indicates strongly that virtually the whole of the metal in the jet is in the form of particles or fragments and very little in the form of vapour. This view is further supported by the photographs<sup>5</sup> of the travel of the jet in air where several straight tracks emanating from the origin of the jet are seen. Eichelberger and Pugh<sup>6</sup> fired steel jets into cylinders of ice and found a collection of particles of size  $0.01$  to  $1.0$  mm in the ice.

The boiling point of iron is about  $3,000^{\circ}\text{C}$  at atmospheric pressure. It is known that the boiling point rises steeply with pressure, but no data is available when metals are subjected to such high pressures as that obtained in a jet. The occurrence of discrete incandescent particles of iron at an estimated temperature of  $4,500^{\circ}\text{C}$  in the jet may be explained by the rise of boiling point of iron due to the high pressure present in the jet.

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