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A High-Temperature Gas Heater

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Introduction

IN supersonic gasdynamic research, the need arises to preheat the gas, either to prevent condensation at high Mach number or for high-temperature investigation. Heating past the metallurgical limit necessitates costly and often complex equipment which puts such investigations beyond the reach of many researchers. Such standard heaters as the pebble-bed or arc have certain well-known disadvantages besides their high capital cost.

Allegre et al.[1] presented a graphite resistance heater which was fairly simple, offered continuous operation, and allowed ready control of pressure and temperature. The disadvantage was that the intricately machined resistance elements were vulnerable to the smallest oxidizing impurity in the gas. Replacement of the resistors was laborious and expensive.

A heater is presented in this Note which is both simpler and cheaper to construct and is more robust in service.

Description of the Heater

The heater, termed a "crucible heater," uses a bed of graphite chips as the heating element. Electric current passes through a graphite crucible into the chip bed and then through a graphite electrode which is partially submerged in the bed. Gas passes through the hot bed.

The heater is depicted in Fig. 1. A cylindrical crucible **a**, machined from electrode quality graphite contains a bed of graphite chips, **b**. A graphite electrode, **c**, intrudes, from above, centrally into the bed. The electrode is hollow and its bottom surface is formed by a perforated graphite plate, **d**. This plate has a set of slits and perforations, detailed in Fig. 2, which prevent obstruction of the perforations by the chips. Its purpose is to prevent the chips entering the electrode while allowing a free gas flow. The electrode fits into a tapered socket in the roof, **e**, of the pressure chamber.

The base of the crucible is screwed to a water-cooled stainless-steel member, **f**, which provides mechanical support and electrical supply. This member passes through the base of the pressure chamber. It is electrically insulated and pressure sealed by means of a nylon grommet, **g**. Copper strapping, **i**, supplies an electrical current which passes through the graphite bed and heats it. The body of the heater forms the other terminal.

Gas enters at **h** and traverses the stainless-steel heat-shielding passages before passing into the top surface of the bed, through the bed, and out via the hollow electrode. The electrode contains an internal graphite sleeve, **j**. The annulus between the inner and outer sleeve is packed with high-temperature insulating wool.

Operating Experience

Although only one heater is shown, three crucibles were run in parallel from a three-phase supply. The heater has been used extensively, primarily to heat nitrogen but also with other nonoxidizing gas mixtures. It has regularly been heated from cold to 1400°C in the space of 15 s and has run for prolonged periods without service.

Service has involved replacing the perforated plate in the graphite electrode and recharging the bed to replace oxidized material. Operation with deep beds and at high temperatures minimizes oxidation of the perforated plate because conversion of the oxidants to CO occurs within the bed.

The maximum operating temperature measured was 1620°C but this limitation was that of the thermocouple rather than the heater. It is anticipated that temperatures in excess of 2500°C could be maintained.

This arrangement allows high heat-transfer rates and a 400 cm^3 bed transferred 70 kW of heat on a continuous basis. The pressure drop across the bed is relatively small.

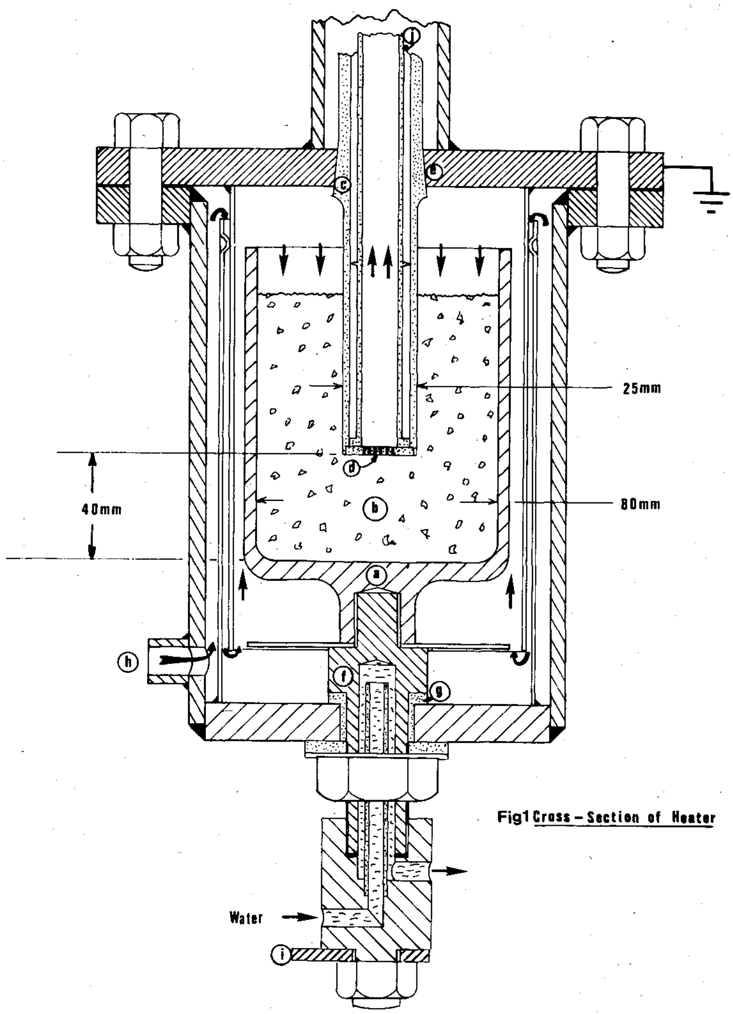

Fig. 1 Cross section of heater.

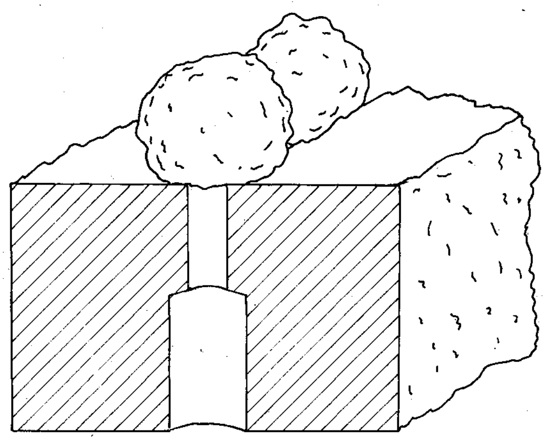

Fig. 2 Detail of perforated graphite plate (note that graphite chips cannot block the groove which communicates with holes drilled through the plate).

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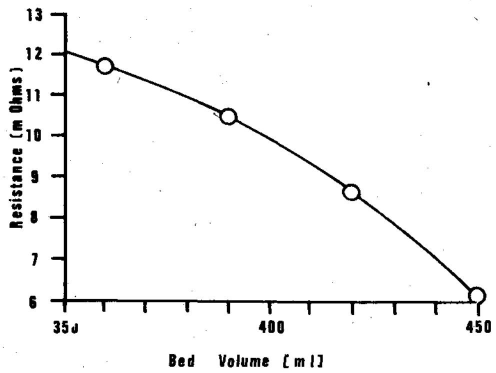

Fig. 3 Variation of resistance with bed volume.

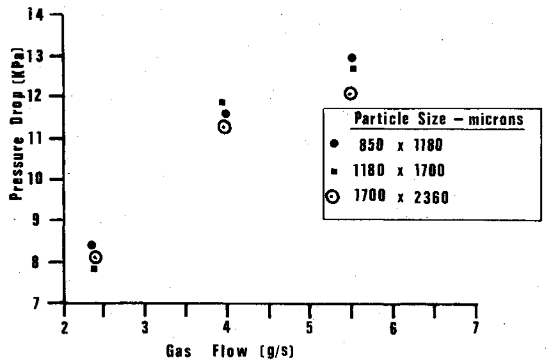

Fig. 4 Variation of pressure drop with flow.

Design Parameters

Characterizing the performance of such a bed is difficult because:

1) Electrical resistance depends upon the intergranular contact resistance which, in turn, depends upon temperature and intergranular force.

2) Electrical resistance under operating conditions is difficult to measure. Thyristor chopping of the electrical waveform was used as a current control device to control the heater. So, at another time, was a saturable reactor. In each case, simultaneous measurement of values for the distorted current and voltage waveforms was difficult. Moving iron instruments were used and it was recognized that, although the values obtained could be used for design purposes, the measurements would not be very accurate.

3) Electrical performance was found to depend strongly on the temperature history of the bed.

4) The bed performance was thought to depend upon the following parameters: bed geometry, chip size and shape, temperature variation in the bed, gas pressure, gas flow rate, and electrostatic forces near the bed surface resulting from the high currents. Consequently, because of the interdependence of these parameters, it is felt that any theory of bed behavior will require a multivariable regression on extensive data for its validation.

Such an extensive study has not been made, but some measurements are presented in order to permit design of further heaters.

Electrical Resistance

The effect of bed volume on electrical resistance for the geometry shown in Fig. 1 is illustrated in Fig. 3. Dependence upon gas flow, bed temperature, and bed particle size was not clear. However, for particles in the range of 850-2360 μm, temperatures of 500-1500°C, bed volumes of 360-450 ml, and nitrogen flows of 2-6 g/s, the electrical resistance remained within 0.005-0.015 Ω.

Pressure Drop

Figure 4 shows the variation of pressure drop with flow rate through the bed. Since the heated gas passed through a sonic throat of fixed diameter, the upstream pressure varied between 400 and 800 kPa to achieve the varying flow rates represented. Thus Fig. 4 should be recognized as merely suggesting the pressure drops which might be expected. The outlet temperature was held at 1000°C.

Conclusion

The heater reported shows a significant advance over previous heaters. It is simple and cheap to construct, allows continuous variation of pressure and temperature over a wide range (there is, in principle, no pressure limit), and can tolerate the oxidants found in commercially pure gases. It is robust in service and requires a minimum of attention. A fuller understanding of the heater's behavior will require a major investigative effort.

It is possible that the heater can be modified to handle oxidizing gases by the use of ferrochrome or silicon carbide chips instead of graphite chips. This will require sophisticated control of the power supply.

Acknowledgment

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Reference

[1] Allegre, J., Bisch, C., and Faulmann, D., "La soufflerie hypersonique SH3 du laboratoire d'Aerothermique du C.N.R.S." CNRS Pub. 272, 1966.

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Performance of Underwater Vehicles Employing Lift to Reduce Drag

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Introduction

UNDERWATER vehicles operate in a medium whose density is comparable to that of their own and therefore experience high skin friction relative to their weight. Performance of such vehicles, in terms of maximum speed or range, is therefore severely limited by the necessary volumes of power plants or energy sources. Most of the smaller vehicles are launched from tubes whose diameters are determined by external considerations so that required volumes are achieved by very slender configurations whose high ratio of surface area to volume renders them hydrodynamically inefficient.

Considerable effort has been expended on the development of vehicles whose boundary layers are maintained in the laminar state at high Reynolds by means of shapes which develop favorable pressure gradients over their forward regions, or by heating of surfaces to stabilize the flow and, thus, delay transition to the turbulent regime. Such vehicles are generally axisymmetric and must possess surface finish and profile tolerances of extremely high order. As an example, Lauchle et al.[1] built a 0.3 m maximum diameter

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