THE EFFECT OF A TRANSVERSE MAGNETIC FIELD ON THE FLOW OF A HIGH-TEMPERATURE ELECTRICALLY CONDUCTING GAS IN A CHANNEL WITH HIGH THERMAL INSULATION

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The experimental results of an investigation of the loss in pressure when a high-temperature electrically conducting gas ($T_0 \approx 3000$°K) flows in a cylindrical tube with a wall temperature $T \approx 1500$-2200°K in a transverse magnetic field of 10,000 G are presented. It is shown that the change in resistance when the magnetic field is present is due to the end effect and to an increase in the coefficient of friction.

It is well known that a magnetic field may affect the flow of an electrically conducting medium in two ways: because of the friction due to deformation of the velocity profile, and by a change in the gas-dynamic characteristics along the length of the channel, due to the action of electromagnetic forces on the flow. In the case of flow in a channel with cold walls these effects are difficult to separate due to the fact that the whole gas-dynamic picture is determined by intense heat exchange. If the channel is thermally insulated to a sufficient extent, it becomes possible to estimate the contribution of each of these effects. The purpose of this investigation was to set up a steady-state flow of high-temperature gas in a model with good thermal insulation, to measure the resistance of this channel, and to compare the results obtained with theory.

The experimental investigations were made on apparatus consisting of an electric arc heater and a cooled sectional model with a ceramic channel consisting of rings of magnesium oxide. The inner diameter of the output electrode of the heater and of the ceramic channel was 4 cm. The model consisted of six sections with an overall length of 90 cm. The part to be investigated was placed in the gap of a magnetic system. The magnetic field strength $B = 10^4$ G. To increase the electrical conductivity of the gas we added an easily ionized material, namely, K_2CO_3 powder and metallic potassium. This was added at the input to the first section of the model.

The main parameters of the flow in the various experiments lay within the following limits: flow rate of air $G = 55$-65 g/sec, average mass temperature of the flow $T_0 = 2900$-3300°K, rate of flow $u = 380$-500 m/sec, wall temperature $T = 1500$-2300°K, and conductivity $\sigma = 1$-1.6 mho/sec.

We measured the static pressure distribution along the length of the channel and the gas-dynamic parameter profiles at the exit from the model. The latter was found using a specially developed cooled enthalpy probe [1, 2].

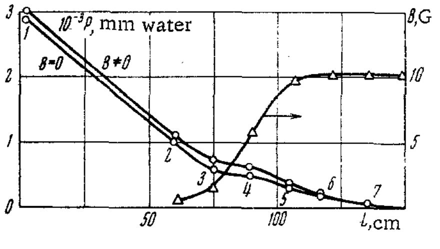

Fig. 1

Figure 1 shows the static pressure distribution along the length of the channel and the magnetic field distribution. For the same pressure at the exit from the model the change in the pressure for $B \neq 0$ was greater than for $B = 0$. The greatest difference between the curves is observed in the region where the magnetic field is increasing (the end region). It should be noted that in this model there is a change in the boundary condition with respect to the wall temperature (in the section 1-2, $T_0/T \approx 5$, while in the section 2-7, $T_0/T \approx 1.5$), so that in the initial section of the model there is a rearrangement of the temperature profile.

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TABLE 1

U,m/sec	T_0, °K	σ,mho/cm	Δp, mm water	Δp_1, mm water	Δp_2, mm water
434	3100	1.0	60	24	24
464	3290	1.3	90	34	28
500	3380	1.6	90	44	32
458	3295	1.3	70	33	32
448	3370	1.6	70	41	26
389	3050	1.0	40	22	20
400	3100	1.0	50	22	21

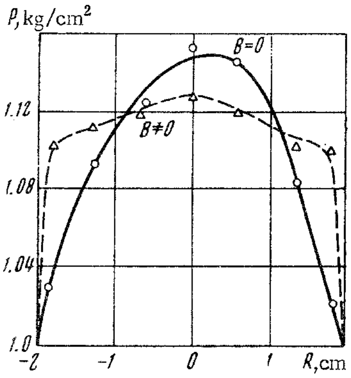

Fig. 2

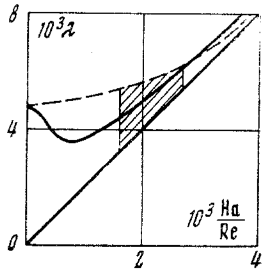

Fig. 3

According to additional estimates of the heat flows the thermal stabilization section occupies 8-12 gauges.

We will try to explain the increase in the pressure drop when B ≠ 0. As was stated above, the increase in loss may be due to a magnetohydrodynamic end effect and to an increase in friction due to deformation of the velocity profile.

The pressure losses due to the end effect can be calculated approximately from the relation [3]

$$\Delta p_1 = \frac{\sigma B^2 u d}{c^2} k$$

where Δp_1 is the loss in pressure, d is the diameter of the channel, c is the velocity of light, and k is a coefficient of proportionality which depends on the fullness of the velocity profile and the manner in which the magnetic field dies away in the end section.

As the fullness of the velocity profile increases the parameter k decreases, and it increases when the magnetic field falls very sharply. When the field falls very sharply (abruptly) and the velocity profile is uniform, k = 0.135, and if the velocity profile is close to a Poiseuille profile, k = 0.275. To determine the degree of fullness of the velocity profile we measured the profile of the total pressure in the output section of the channel (Fig. 2). The velocity profile in the experiments was less full (as compared with a uniform profile), and the magnetic field did not fall off very sharply. These effects partially compensate one another, so we therefore assumed that k = 0.1. The theoretical and experimental results are compared in the table.

We will now estimate the increase in λ (the coefficient of friction) when a transverse magnetic field is present under our experimental conditions. According to the various semiempirical theories [4] the coefficient of friction λ when there is a transverse magnetic field present should change considerably. Figure 3 shows the manner in which λ changes according to the various theories. The hatched region corresponds to the range of variation of the parameters in our experiment. As can be seen, we might expect an increase in λ from ten to fifty percent in our experiments. The fact that the magnetic field leads to a considerable filling of the velocity profile (and therefore to an increase in λ) was confirmed by the experimental determination of the profile of the total pressure at the exit from the channel.

The increase in Δp due to the end effect and the increase in λ when there is a magnetic field present agree, to a first approximation, with the measured results. The estimates made above show that the calculated increase in the pressure Δp due to the end effect ($\Delta p_1 \approx 35$ mm water) and due to the increase in λ ($\Delta p_2 \approx 25$ mm water) is extremely close to the value measured experimentally ($\Delta p \approx 70$ mm water).

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