assigned as editor of the periodical. As author, editor, corrector, and dispatcher he assumed an enormous load in the first year of development of the VDI.

In 1863 Redtenbacher died and Grashof's name was so esteemed that the technical university in Karlsruhe appointed him to be Redtenbacher's successor as superintendent of the engineering school. He also served as professor of applied mechanics and mechanical engineering and his lectures included strength of materials, hydraulics, and theory of heat in addition to part of the general engineering. Grashof gave up the editorship of the VDI periodical following his move to Karlsruhe; however, he remained as a director of the society, and in addition, he still carried on a very extensive writing activity. Grashof expected great things of the students, and clarity, certainty, and sharpness of expression distinguished his lectures. Grashof was known as a very earnest individual and even in troubled times he retained an atmosphere of genuine friendliness. He participated in charitable service activities and derived great personal satisfaction from these efforts. In spite of all his success, uninterrupted work and creativity he was known for his kind disposition and modest appearance.

Near the end of 1882 Grashof suffered a stroke, but recovered enough to resume his activity on a limited basis. In 1882 Grashof became a member of the standard calibration commission, and in 1887, a member of the governing body of the Physical-Technical Government Institute. In 1891 he suffered a second stroke and had to cease his activities. Two years later he died at the age of 67. The Society of German Engineers honored his memory by the erection of a Grashof monument in Karlsruhe and by the institution of the Grashof commemorative medal as the highest distinction that the society could bestow for merit in the engineering skills.

It is quite clear from this information that Franz Grashof had a major impact on the development of the engineering profession in Germany in the nineteenth century and merits the naming of the dimensionless group in his honor.

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EFFECTS OF TRANSPIRATION ON THE MHD FLOW NEAR AN OSCILLATING PLATE

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NOMENCLATURE

- B, external magnetic field flux density normal to the plate;
- $\bar{B}$, dimensionless magnetic field flux density, $B(2\sigma/\rho\omega)^{\frac{1}{2}}$;
- S, speed of mass transfer normal to the plate, leakage speed;
- $\bar{S}$, dimensionless mass transfer speed, $S/(2\nu\omega)^{\frac{1}{2}}$;
- t, time;
- u, fluid velocity parallel to the plate;
- $\bar{u}$, dimensionless fluid velocity, u/U_0;
- U_0, maximum velocity of the oscillating plate;
- y, the coordinate normal to the plate, distance from the plate;
- η, dimensionless distance, $y(\omega/2\nu)^{\frac{1}{2}}$;
- λ, dimensionless parameter, equation (3);
- ν, kinematic viscosity of the fluid;
- σ, electrical conductivity of the fluid;
- ρ, density of the fluid;

τ. dimensionless time. ωt;
τ_w. shearing stress at the wall;
ω. circular frequency of the oscillating plate.

THE RAYLEIGH problem in the presence of a magnetic field has been investigated by a number of authors [1–3]. They have assumed that the conducting incompressible fluid has constant properties throughout the flow field on an infinite flat plate and is subject to a uniform and constant magnetic field in the direction normal to the plate. They have also assumed that the induced magnetic field is negligible and no external electric field or pressure gradient is present. However, to the best knowledge of the author, this problem associated with mass leakage through the plate has not been studied. This note will discuss the effects of transpiration on the MHD flow near an oscillating flat plate. It is further assumed that the plate is uniformly permeable and the same fluid transfers at a uniform and constant rate through the dielectric wall which executes linear harmonic oscillations parallel to itself. Two cases will be considered: (1) space-fixed system (system fixed to the fluid at infinite distance from the plate) and (2) plate-fixed system (system fixed in the moving plate) [4].

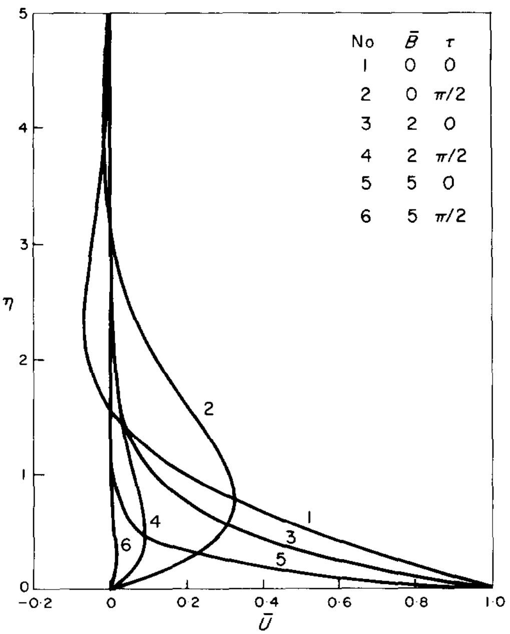

FIG. 1. Velocity profile for space-fixed system without transpiration.

SPACED-FIXED SYSTEM

The boundary layer approximation yields

$$\frac{\partial u}{\partial t} - S\frac{\partial u}{\partial y} = \nu\frac{\partial^2 u}{\partial y^2} - \frac{\sigma}{\rho}B^2 u. \tag{1}$$

where u is a function of y and t. The boundary conditions are: $u(0, t) = U_0 \cos \omega t$ and $u(\infty, t) = 0$. Equation (1) is a linear second-order partial differential equation and has a closed form solution

$$\bar{u}(\eta, \tau) = e^{-\lambda\eta}\cos\left(\tau - \frac{\eta}{\lambda - \bar{S}}\right) \tag{2}$$

where

$$\lambda = \bar{S} + [\![\tfrac{1}{2}\{\bar{S}^2 + \bar{B}^2 + [(\bar{S}^2 + \bar{B}^2)^2 + 4]^{\frac{1}{2}}\}]\!]^{\frac{1}{2}}. \tag{3}$$

Equation (2) represents the steady-state solution of the oscillation after the decay of the transient motion. It shows

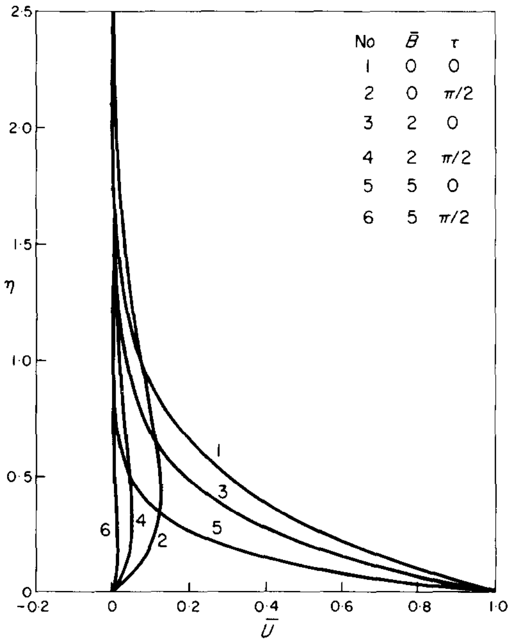

FIG. 2. Velocity profile for space-fixed system with suction. $\bar{S} = 1{\cdot}0$.

that the velocity profile has the form of a damped harmonic oscillation, the amount of damping depending on the strength of the imposed magnetic field, the rate and the direction of mass transfer. The motion of fluid apart from the plate always lags behind the motion of the plate by an amount of time $\eta/(\lambda - \bar{S})\omega$ which is also a function of the magnetic field strength and the mass transfer rate. When $\bar{S} = 0$ and $\bar{B} = 0$, equation (2) reduces to a velocity profile for the classic Rayleigh problem [5]. Figures 1–3 show the effect of transpiration and magnetic field at two instants of time. When $\bar{B} \geqslant 10$ and $\bar{S} \geqslant -5$ or $\bar{B} = 0$ and $\bar{S} \geqslant 5$, the effect of oscillation is confined to a small region ($\eta \ll 1$) in all cases.

The shearing stress at the wall is given by

$$\tau_w = \left(\frac{\nu\omega}{2}\right)^{\frac{1}{2}} \rho U_0 \sin(\tau - \phi) \qquad (4)$$

where

$$\tan\phi = \lambda(\lambda - \bar{S}).$$

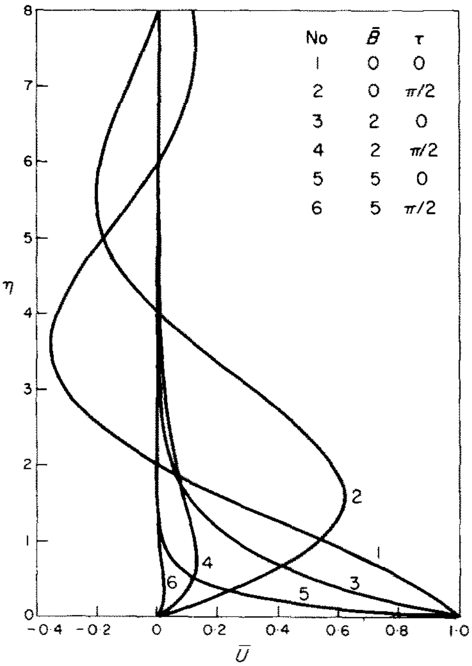

FIG. 3. Velocity profile for space-fixed system with injection. $\bar{S} = -1{\cdot}0$.

Thus the shearing stress at the wall lags behind the forced oscillation of the wall by an amount of time $(\phi + \pi/2)/\omega$.

PLATE-FIXED SYSTEM

The boundary layer approximation produces a linear second-order partial differential equation

$$\frac{\partial u}{\partial t} - S\frac{\partial u}{\partial y} = \nu\frac{\partial^2 u}{\partial y^2} - \frac{\sigma}{\rho}B^2(u - U_0\cos\omega t). \qquad (5)$$

By using the boundary conditions, $u(0, t) = U_0 \cos\omega t$ and

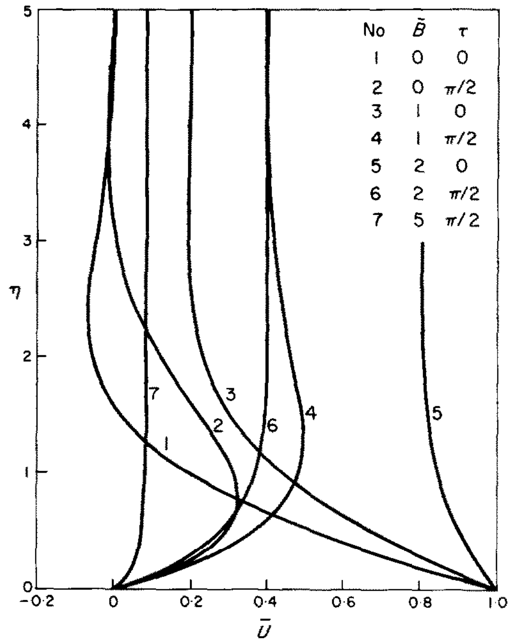

FIG. 4. Velocity profile for plate-fixed system without transpiration.

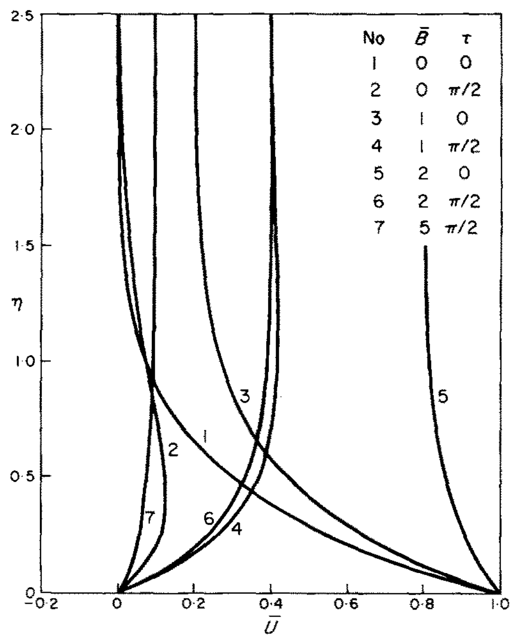

FIG. 5. Velocity profile for plate-fixed system with suction. $\bar{S} = 1{\cdot}0$.

$u(\infty, \tau)$ = finite, a closed form solution is obtained as follows:

$$\bar{u}(\eta, \tau) = \frac{\bar{B}^2}{\bar{B}^4 + 4}(\bar{B}^2 \cos\tau + 2\sin\tau) + \frac{2e^{-\lambda\eta}}{\bar{B}^4 + 4} \times \left[2\cos\left(\tau - \frac{\eta}{\lambda - \bar{S}}\right) - \bar{B}^2 \sin\left(\tau - \frac{\eta}{\lambda - \bar{S}}\right)\right]. \quad (6)$$

where λ is defined by equation (3). Equation (6) also represents the steady-state solution of the oscillation. The velocity profile mainly consists of two components, namely a constant-amplitude harmonic oscillation of the fluid at infinity accelerated by the magnetic field and a damped harmonic oscillation near the plate induced by the viscous effect of the fluid in contact with the plate. Figures 4–6 show the effect of transpiration and magnetic field at two instants of time. Curves 1 and 2 are only for comparison purposes. When $\bar{B} = 5$ and $\tau = 0$, the dimensionless fluid velocity decreases from unity to 0·994 within a short distance ($\eta \leqslant 0{\cdot}8$) in all three cases. Then the whole fluid oscillates with the plate at almost equal amplitude when $\bar{B} \geqslant 10$ and $\bar{S} \geqslant -5$.

The shearing stress at the wall is given by

$$\tau_w = \frac{(2\nu\omega)^{\frac{1}{2}} \rho U_0}{\bar{B}^4 + 4} \sin(\tau - \psi) \quad (7)$$

where

$$\tan\psi = \frac{2\lambda(\lambda - \bar{S}) - \bar{B}^2}{\lambda(\lambda - \bar{S})\bar{B}^2 + 2}.$$

Thus the shearing stress at the wall lags behind the forced oscillation of the plate by an amount of time $(\psi + \pi/2)/\omega$. The amplitude of the wall shearing stress in this case is $2/(\bar{B}^4 + 4)$ times that of the wall shearing stress considered previously.

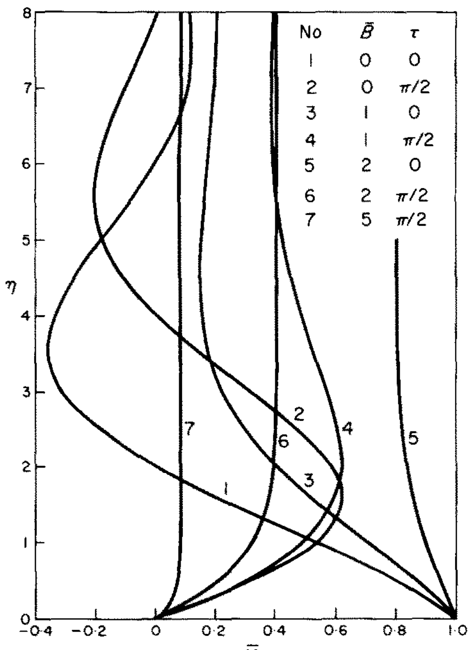

FIG. 6. Velocity profile for plate-fixed system with injection, $\bar{S} = -1{\cdot}0$.

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