

emissivity is markedly dependent on temperature. Thus  $\epsilon' = 0.92$  when  $T = 873^\circ\text{K}$  and with increase in temperature falls to  $0.82$  when  $T = 1173^\circ\text{K}$ . The quantity  $\epsilon_\lambda$  is  $0.75-0.90$  in the range  $\lambda = 1.2-2.2 \mu\text{m}$ , which corresponds to maximum absorption by the skin of humans.

#### NOTATION

$E$ , radiation density;  $K_C$ , calibration constant;  $e$ , electromotive force (emf);  $Q_R$ , radiative component of total heat emission;  $Q_T$ , total heat emission;  $\eta = (Q_R/Q_T) \cdot 100\%$ , radiant efficiency;  $I_\varphi$ , radiation intensity in a given direction, W/stere;  $I_\perp$ , radiation intensity in the normal direction;  $\varphi$ , angle measured from the perpendicular to the heat-emitting surface;  $h$ , height of heater installation;  $\sigma_0$ , Stefan-Boltzmann constant;  $T$ , temperature;  $F_e$ , effective area of heat-emitting surface of heater;  $q_0$ , specific heat load;  $P$ , gas pressure;  $\epsilon$ , emissivity ( $\epsilon_\varphi$ , in a given direction;  $\epsilon_\perp$ , in the normal direction;  $\epsilon_\lambda$ , spectral emissivity;  $\epsilon'$ , integral emissivity);  $\lambda$ , wavelength.

#### LITERATURE CITED

1. B. A. Khrustalev, *Inzh.-Fiz. Zh.*, 18, No. 4 (1970).
2. V. P. Dushchenko et al., *Inzh.-Fiz. Zh.*, 11, No. 3 (1966).
3. A. M. Levin et al., in: *Scientific Works of Gipronigaz: Use of Gas in the National Economy*, No. III [in Russian] (1965).
4. O. N. Bryukhanov, *Theory and Practice of Gas Combustion* [in Russian], Nedra (1963).
5. B. A. Khrustalev and A. M. Rakov, *Heat and Mass Transfer in One- and Two-Phase Media* [in Russian], Nauka, Moscow (1971).
6. W. Z. Black and R. J. Schoenhals, *J. Heat Transfer*, 90, 420 (1968).
7. B. S. Itsikson and Yu. L. Denisov, *Infrared Gas Heaters* [in Russian], Nauka, Moscow (1969).
8. O. A. Gerashchenko and V. G. Fedorov, *Technology of Heat-Engineering Experiments* [in Russian], Naukova Dumka, Kiev (1964).
9. M. Jakob, *Heat Transfer*, Wiley (1949).

#### MEASUREMENT OF THE WAVE PARAMETERS OF LIQUID FILM FLOW BY THE METHOD OF LOCAL ELECTRICAL CONDUCTIVITY

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A method of measuring the wave parameters of a liquid film is described which differs from those known earlier in that it permits the simultaneous determination of the phase velocity, length, and amplitude of the waves and provides a greater volume of information.

Knowledge of the hydrodynamic laws of liquid film flow (thickness of the film and phase velocity, length, and amplitude of the waves) is necessary for the calculation of technological processes in different fields of engineering [1, 2]. A number of methods exist for their measurement [3-7], each of which has its drawbacks, and not one of these methods permits the simultaneous measurement of all the hydrodynamic parameters.

These drawbacks can be avoided with the use of the method of local electrical conductivity, which consists in the direct recording of the instantaneous values of the strength of the current passing through the liquid film between two electrodes located in the immediate

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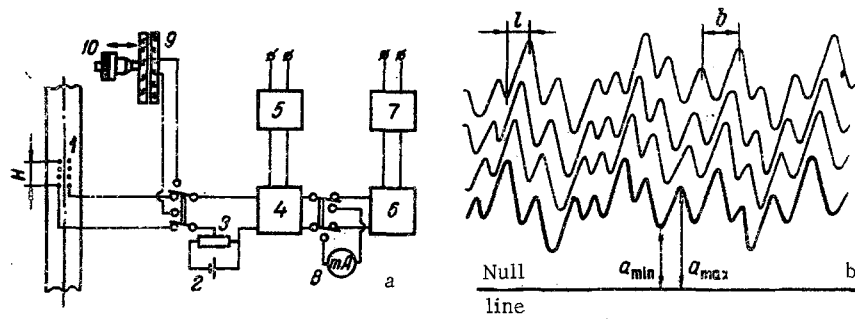


Fig. 1. Diagram of measurement of wave parameters of a liquid film. a: 1) Working electrodes; 2) power supply; 3) potentiometer; 4) amplifier; 5) UIP-1 stabilized power supply; 6) N-700 loop oscillograph; 7) rectifier; 8) reference milliammeter; 9) calibration cell; 10) micrometer screw; b: oscillogram.

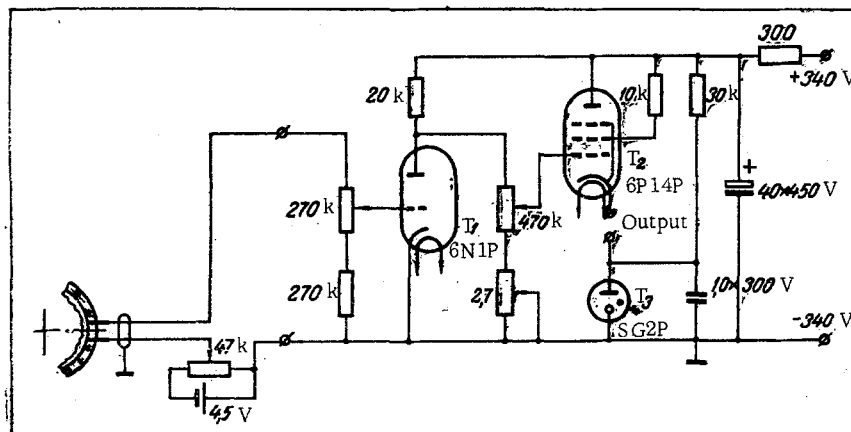


Fig. 2. Diagram of direct-current amplifier.

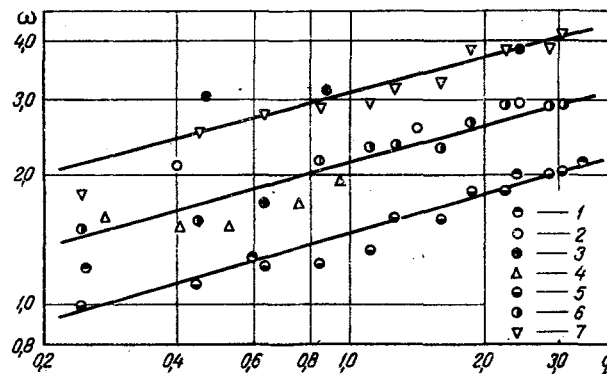


Fig. 3. Comparison of experimental data on the phase velocity of waves. Data of [6] with gas velocity  $W$ , m/sec: 1) 14; 2) 27; 3) 41; 4) data of [7] with  $W = 30$  m/sec; data of [11] with  $W$ , m/sec: 5) 19; 6) 30; 7) 42.  $q$ ,  $m^3/m \cdot h$ .

vicinity of one another and embedded flush with the wall. The shape of the electrodes and the material from which they are made can be varied [8-10]. Depending on the objectives of the experimental studies the diameter of the electrodes can vary from 0.1 to 3 mm and the distance between them from 2 to 12 mm. For example, an electrode diameter of 0.2-0.3 mm and a distance between them of 2-3 mm can be recommended for measuring the fine structure of the surface layer of a liquid film less than 0.3 mm thick, while pickups with an electrode diameter of

0.8–1.2 mm and a distance between them of 4–5 mm can be recommended for measuring the wave parameters of "thick" films more than 0.3 mm thick.

A schematic diagram of the measurement of the wave parameters of a liquid film is presented in Fig. 1a. The strength of the current between the electrodes depends on the thickness of the liquid layer above the electrodes. The galvanometer of a loop oscillograph included in the circuit records on photographic paper a periodic curve (Fig. 1b) for which the frequency of the peaks corresponds to the frequency of passage of the wave crests above the electrodes, while the deviation of the beam from the null line corresponds to the thickness of the liquid film at the given time.

To eliminate the effect of the process of electrolysis the voltage supplied to the electrodes must be less than the dissociation voltage. Since a liquid with a low conductivity is most often used in the studies, the current strength in the circuit is low and the signal must be amplified in order to record it on the loop oscillograph. One version of a direct-current amplification circuit which permits the amplification of both the constant and the variable components of the current is shown in Fig. 2.

The amplifier is two-stage with a galvanic connection between the stages. To compensate for excess bias on the grid of tube  $T_2$  of the cathode circuit the latter includes a stabilatron tube  $T_3$ . The gain is regulated by a potentiometer and the null setting is also accomplished with a potentiometer. The galvanometer of the N-700 loop oscillograph is connected to the cathode circuit of tube  $T_2$ , since the galvanometer insulation is designed for only 300 V.

For the measurement of the phase velocity of the waves one must use several pairs of electrodes arranged successively one after another along the length of the tube. The distance between these pairs is 3–5 mm. Because of the motion of the waves along the surface of the liquid film the oscillograms recorded by each pair of electrodes are shifted in phase relative to one another. From the size of this shift one can determine the phase velocity of the waves,

$$\omega = \frac{H}{\tau} = \frac{Hu}{l} \quad (1)$$

The length of the waves is determined from the equation

$$\lambda = \frac{\omega}{\tau_1} = \frac{\omega b}{u} \quad (2)$$

The amplitude of the waves is determined as

$$\alpha = \frac{a_{\max} - a_{\min}}{a_{\max} + a_{\min}} \quad (3)$$

The difficulty in the measurement of the instantaneous values of the thickness of a liquid film consists in the absence of an analytical connection between the current strength in the circuit and the film thickness [8]. In this connection the relationship between the deviation of the beam from the null line on the oscillogram (Fig. 1b) and the film thickness is established by calibration using a calibration cell which consists of two parallel plates between which the test liquid is pumped. One of the plates was moveable and was moved with a micrometer screw. Electrodes were set in the stationary plate, accurately reproducing the geometry of the working electrodes.

The method of local electrical conductivity was used to measure the wave parameters of a water film moving together with an air stream in a wide range of loads on the liquid and the gas [11–13]. The studies showed that the wave parameters of the liquid film have a statistical nature, with the distribution law for these quantities being close to a normal distribution. The results of measurements of the phase velocity of the waves were compared with the data of other authors [6, 7] (Fig. 3) obtained under similar conditions by the method of motion-picture photography. The comparison showed their good agreement.

The method of measuring the wave parameters of a liquid film which was discussed permits the determination of the phase velocity, length, and amplitude of the waves with free drainage of the liquid film and in two-phase flows.

## NOTATION

$\omega$ , phase velocity of wave;  $\tau$ , time of passage of a wave crest from one pickup to the other;  $\tau_1$ , time of passage of two successive waves over a pickup;  $H$ , distance between pairs of electrodes;  $u$ , rate of advance of photographic paper of oscillograph;  $l$ , displacement on oscillogram of wave profiles obtained from different pickups;  $b$ , distance between crests of two successive waves on one oscillogram obtained from one pickup;  $a_{\max}$ ,  $a_{\min}$ , film thickness at crests and troughs of waves, respectively.

## LITERATURE CITED

1. N. M. Zhavoronkov and V. A. Malyusov, *Teor. Osnovy Khim. Tekhnol.*, 1, No. 5 (1967).
2. S. S. Kutateladze, *Principles of Heat and Mass Exchange [in Russian]*, Nauka, Moscow (1972).
3. H. Breuer, *VDI-Forschungsheft*, 457 (1956).
4. A. E. Dukler and P. O. Bergelin, *Chem. Eng. Progr.*, 48, No. 11 (1952).
5. F. P. Stainthorp and J. M. Allen, *Trans. Inst. Chem. Engrs.*, 43, No. 3 (1965).
6. R. M. Nedderman and C. J. Shearer, *Chem. Eng. Sci.*, 18, No. 10 (1963).
7. N. H. Taylor, G. F. Hewitt, and P. M. C. Lacey, *Chem. Eng. Sci.*, 18, No. 8 (1963).
8. G. F. Hewitt, R. D. King, and P. C. Lovegrove, *AERE-R3921* (1962).
9. J. A. R. Bennett, J. G. Collier, H. R. C. Pratt, and J. D. Thornton, *Trans. Inst. Chem. Engrs.*, 39, No. 1, 113-126 (1961).
10. J. J. van Rossum, *Chem. Eng. Sci.*, 11, No. 1 (1959).
11. A. D. Sergeev and N. A. Nikolaev, *Tr. Kazansk. Khim.-Tekhnol. Inst. im. S. M. Kirova*, No. 48, 53 (1972).
12. L. P. Kholpanov, G. G. Fedorov, V. A. Malyusov, and N. M. Zhavoronkov, *Heat and Mass Transfer*, Vol. 4 [in Russian], Minsk (1972), p. 39.
13. N. A. Nikolaev, A. D. Sergeev, L. P. Kholpanov, V. T. Zabrudskii, V. A. Malyusov, and N. M. Zhavoronkov, *Teor. Osnovy Khim. Tekhnol.*, 9, No. 3 (1975).

## LOGARITHMIC EQUATIONS FOR THE RESISTANCE OF TURBULENT FRICTION FOR A VISCOUS LIQUID AND POLYMER SOLUTIONS

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It is shown that resistance equations of the Prandtl type for the flow of a viscous liquid and polymer solutions in the mode of minimal resistance in pipes and near a plate can be approximated with sufficient accuracy by simpler logarithmic equations.

### Flow of a Viscous Liquid in Smooth Pipes

It is well known [1] that in a steady developed turbulent stream near a wall there exists a region of flow with an average velocity distribution close to logarithmic, and in accordance with the asymptotics (as  $Re \rightarrow \infty$ ) there exists the logarithmic resistance law (the Prandtl equation)

$$1/\sqrt{\lambda} = a \lg(Re\sqrt{\lambda}) + b. \quad (1)$$

It turns out that the equation gives satisfactory accuracy in the entire range of Reynolds numbers  $4 \cdot 10^3 < Re < 10^7$  of practical interest if one sets

$$a \approx 2.0; \quad b \approx -0.8. \quad (2)$$

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