DIRECT HEATING OF FLUIDIZED PHASE BY ELECTRIC CURRENT

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Аннотация—На основании полученных результатов исследования составлено уравнение для расчета времени, иеобходимого для периодичекого нагрева ожиженной фазы, Получено также уравнение для величины максимальной температуры ожиженной фазы, которым можно пользоваться при заданных условиях проведеник иροцесса Исследовано влияние ряда иараметров на электрическую проводимость ожиженной фазы, состоящей из зерон криптоля и активированного угля. Разработаи также новый метод оиределения критической скорости ожижения.

NOMENCLATURE

ρ_k, specific resistance of fluidized phase at critical velocity of fluidization [Ω cm];

A_1, constant [Ω cm/(g/cm^2)];

P_s, static pressure [g/cm^2];

a_1, exponent;

H_f, electric conductance of the fluidized phase [$1/\Omega$ cm];

H_{20}, electric conductance of the fluidized phase at 20°C [$1/\Omega$ cm];

α, temperature coefficient [$1/degC$];

t_f, temperature of the fluidized phase [°C];

A_2, constant [$1/\Omega$ cm V];

a_2, exponent;

I, electric current intensity [A];

η_w, thermal efficiency;

t_1, temperature of incoming gas [°C];

t_2, temperature of outflowing gas [°C];

Q_d, thermal energy supplied to system [kcal];

Q_b, thermal energy supplied to the bed [kcal];

Q_g, thermal energy taken by gas [kcal];

Q_s, heat losses [kcal];

U, voltage [V];

τ, time of heating up [h];

G_s, weight of bed [kg];

c_s, specific heat capacity of bed [kcal/kg degC];

k_L, linear heat-transfer coefficient between system and surroundings [kcal/m h degC];

L_f, height of fluidized phase [m];

W, mass flow [kg/h];

c_p, specific heat capacity of gas [kcal/kg degC];

G_e, weight of electrodes [kg];

c_e, specific heat capacity of electrodes [kcal/kcal degC];

W_a, equivalent heat capacity of fluidizing column [kcal/degC];

ψ, coefficient accounting for heating of walls in fluidizing column;

$\check{Y}$, temperature modulus;

$\check{m}$, angle factor [$1/h$];

INTRODUCTION

AT PRESENT the following methods of fluidized phase heating are used: (a) direct heating by a hot fluidizing factor; (b) direct heating due to exothermic reactions proceeding in the systems being fluidized and (c) indirect heating.

These methods have been studied by Heerden

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[1], Adams [2], Ciborowski [3], Kettering [4], Frantz [5] and other investigators.

Direct heating of fluidized phase by electric current is a more complicated procedure by contrast to the methods which have been used up till now. To design the heaters of this type it is necessary to know not only the heat-transfer coefficients between solid grains and fluidizing gas, but also the influence of various parameters upon the electric conductance of the fluidized phase. The application of the fluidized phase as a resistive material makes the use of additional heaters unnecessary. Moreover it allows rapid control of the temperature when the whole bulk of fluidized phase is being heated.

To use fluidized phase as a resistor a number of experiments were necessary for the determination of various parameters which influence its electrical resistance.

DESCRIPTION OF EXPERIMENTAL INSTALLATION

With the help of the experimental installation (Fig. 1) one can estimate the velocity of fluidization, measure the specific resistance of the fluidized phase, study the temperature and voltage influence upon the electric resistance of the fluidized phase. It also allows investigation of periodical heating of the fluidized phase and also the process of heating of the fluidizing gas which depends on the fluidized phase, in which takes place direct transformation of electric energy into heat.

Three columns are used for the experiment. The first column is made of celluloid sheet 3 mm thick, with square cross-section and 37 mm side. Electrodes made of thin nickel sheet are affixed along the whole length of two adjacent walls of the column. The bottom of the column is made of sponge glass. In the apparatus the height of the fluidized phase is observed through the transparent walls of the column.

The second column is made of glass with an internal diameter of 46 mm and height of 500 mm. This column contains copper elec-

trodes 2.2 mm thick and 36 mm high with 33 mm space between them and carbon electrodes 6 mm thick and 60 mm high, their non-isolated portions being 45 mm and the distance between their axes 29 mm. The bottom of the column is made of porous heat resistant glass.

The third is a glass column with 56 mm internal diameter and carbon electrodes 6 mm thick. The electrodes are vertically adjusted in parallel with the column walls. The space between the electrode axes is 35 mm. The bottom and other parts of the column are similar to those of the second column.

To control the gas flow velocity a needle valve is used. To measure the velocity of the nitrogen or air flows a Rotameter and measuring orifices are used. The pressure drop on the porous bottom and the bed is measured by a manometer.

For temperature measurements over the range from $20°$ to $100°C$ thermocouples and mercury thermometers are used. Higher temperatures had to be measured with a set of mercury thermometers because of the presence of some very intensive spark discharges.

The resistance of the fluidized phase was measured with the Wheatstone bridge and an ohmmeter. The measurements of the intensity and voltage of both direct and alternating currents were performed by the universal meter UM-3. The overall electric energy consumption was measured by a.c. energy meter.

Alternating current was used from 220 V mains. To obtain direct current a selenium rectifier with maximum rated voltage of 11 V was applied. In the case of d.c., use was made of slide rheostats; for a.c., auto-transformers were employed.

The incoming fluidizing gas was heated by an electric heater. The height of the fluidized phase in the column was measured by a millimeter scale fixed to the column wall and by means of a probe inserted through the top of the column. The position of the end of the probe was adjusted by a screw, the result being read from the scale on one side.
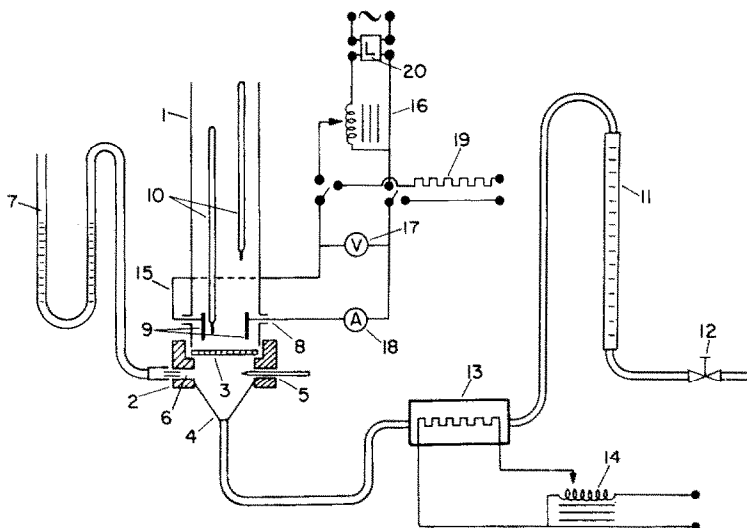
FIG. 1. Scheme of apparatus.

1.—fluidizing column, 2.—rubber connection, 3.—porous bottom of column, 4.—funnel, 5.—thermometer, 6.—channel in the rubber connection, 7.—manometer, 8.—glass holders for fastening electrodes, 9.—electrodes, 10.—thermometers, 11.—rotameter, 12.—needle valve, 13.—gas heater, 14.—auto-transformer, 15.—electrode terminals, 16.—auto-transformer, 17.—voltmeter, 18.—ammeter, 19.—sliding rheostat, 20.—one-phase electric energy meter.

To dry the air employed, a column filled with calcium chloride and silica gel was used.

PRELIMINARY EXPERIMENTAL RESEARCH

Preliminary experimental research was carried out in a cylindrical column with copper electrodes. Activated carbon and cryptol were examined, air being used as a fluidizing gas. Such fluidized phase is confirmed to be a conductor but its electric resistance is much higher than that of the fixed bed. It is found that the resistance of the fluidized phase is greatly affected by moisture in the investigated system. Therefore, to study the specific conductance of the fluidized phase, samples are used which have first been dried in a laboratory dryer. The air used for fluidization is also being dried in columns filled with calcium chloride and silica gel.

Further experiments were carried out on direct heating of the fluidized phase by electric current.

The following phenomena were observed during heating:

1. Spark discharges between solid grains. Maximum discharges are concentrated around the electrodes immersed into the fluidized phase.

2. Electrization of the coke and cryptol grains which deposited on the surfaces of the glass walls of the column and the thermometers. This phenomenon is similar to that on electrization of the fluidized phase observed during the experiments carried out by Ciborowski and Wlodarski [6].

3. It appeared that in spite of the preliminary drying of material of the bed, during electric heating of the fluidized phase in the columns the resistance of the tested samples increased. The higher was the temperature of the system being fluidized, the bigger was the increase of the electric resistance of the fluidized phase.

It was found that the increase in the resistance was greatest when the material was fresh. After ten or more hours' electric heating of the

fluidized phase only very slight increase in the resistance was observed, which remained almost the same for several hours. Preliminary stabilization of the bed material was performed directly by electric current.

DETERMINATION OF THE CRITICAL VELOCITY OF FLUIDIZATION

The critical velocity of fluidization of the studied activated carbon and cryptol fractions was determined by two methods: by measuring the pressure drop of air flowing through the bed in the fluidizing column and by the electrical method developed by the authors and based on measurements of the electric resistance of the bed in the column depending on the velocity of the flowing air.

Cryptol and activated carbon were studied. The material was ground and passed through sieves with orifices of 0·077 mm, 0·10 mm, 0·20 mm, 0·315 mm, 0·50 mm, 0·63 mm, 0·80 mm, 1·00 mm, 1·25 mm and 1·6 mm.

The measurements were carried out in a cylindrical column with an internal diameter of 46 mm. The column was provided with copper electrodes 2·2 mm thick placed inside in parallel with the axis of the apparatus. The space between the electrode axes was 33 mm, their heights 36 mm. The horizontal portion of the electrodes was insulated. Two electric meters, independent of each other, an ohmmeter and a Wheatstone bridge were used to measure the electric resistance.

The electric resistance of the tested fractions was measured when the electrodes were fully immersed in the bed. Each column was filled with 70 cm³ of the tested fractions. After levelling the bed in the column, electric resistance of the stationary material was measured with no air access. After the electric resistance of the fixed bed had been measured, compressed air was supplied under the porous bottom of the apparatus. Further measurements of the electric resistance of the bed were carried out for various constant velocities of air flowing through the fluidizing column.

For velocities higher than the critical, the reading of the electric resistance is difficult due to great oscillations of the pointer.

Measurements with a compensator are also impeded because of the short-term momentary variations of the resistance of the fluidized phase.

The study of the electric resistance of the fluidized phase was terminated at velocities at which the errors of measurement exceeded 12 per cent. All the measurements were taken at 18° to 20°C. From the data obtained for cryptol the curves were plotted in the co-ordinates: resistance of fluidized phase R versus velocity of the flowing air U (Fig. 2).

Similar curves were plotted for activated carbon (Fig. 3). The critical velocity of fluidization can be estimated from these curves (Figs. 2 and 3).

Critical velocities of fluidization have also been estimated for separate fractions of cryptol and activated carbon by measuring the pressure drops over the bed depending on the velocity of the air flowing through the column.

The results obtained by both methods are given in Table 1. The differences between them are small and within the range of the measurement errors.

THE INFLUENCE OF THE STATIC PRESSURE OF FLUIDIZED PHASE UPON ITS ELECTRIC RESISTANCE

Different quantities of tested fractions of cryptol and activated carbon were put in the cylindrical column with carbon electrodes. The experiments carried out at 20°C showed that with a small amount of the material the process of fluidization was disturbed and the critical velocity of fluidization could not be determined electrically. When the height of the bed is equal or greater then the distance between electrodes, then after the critical velocity of fluidization is passed over, the electric resistance of the fluidized phase reaches a constant value within the given range of gas velocities (Fig. 4).
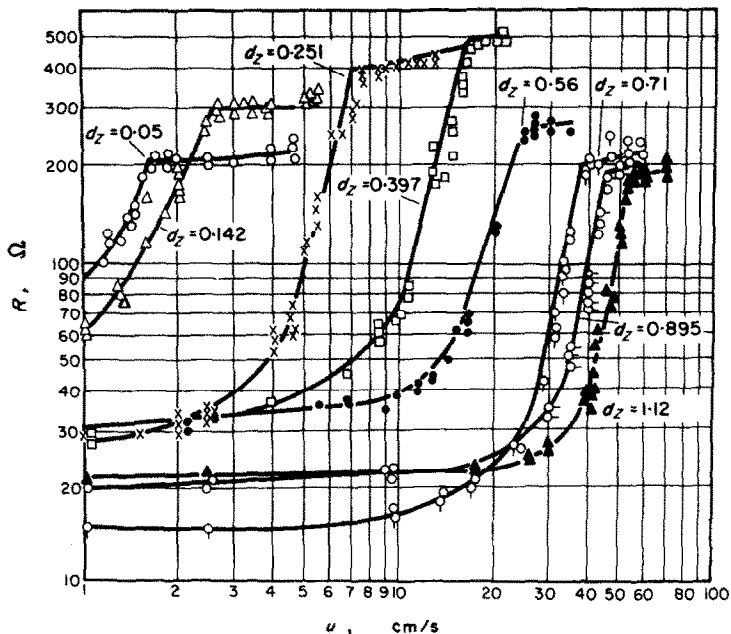
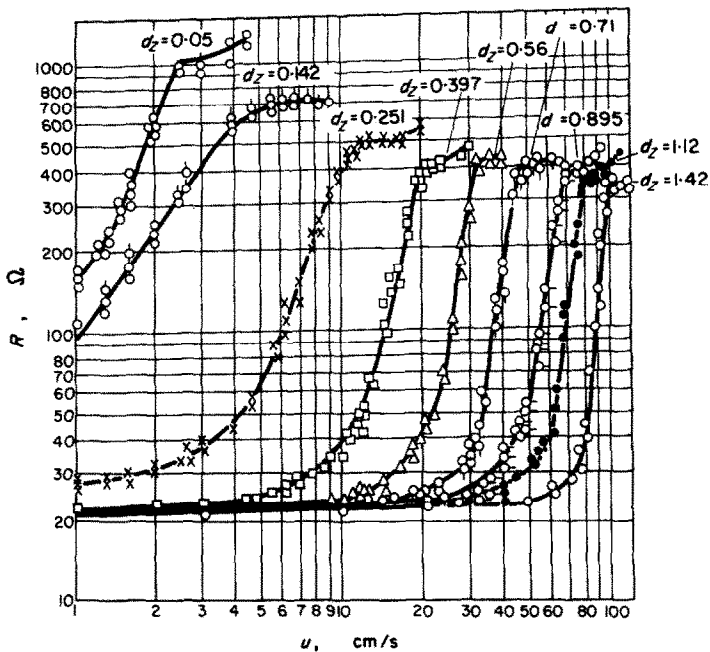FIG. 2. Influence of the cryptol grain diameter and air velocity upon electric resistance of bed.

FIG. 3. Influence of the activated carbon grain diameter and air velocity upon electric resistance of bed.

Table 1

Nos.	Equivalent diameter (mm)	Cryptol		Activated coal	
		$U_{k\Delta p}$ (cm/s)	U_{k_E} (cm/s)	$U_{k\Delta p}$ (cm/s)	U_{k_E} (cm/s)
1	0·05	1·70	1·62	2·50	2·46
2	0·142	3·05	2·68	5·62	5·52
3	0·251	7·48	7·17	13·6	12·90
4	0·397	17·30	16·10	22·50	21·70
5	0·560	20·70	24·10	31·20	31·20
6	0·710	37·40	37·45	46·20	46·20
7	0·895	45·40	45·10	69·40	67·90
8	1·120	53·8	54·20	79·50	80·10
9	1·420	72·0	71·85	102·00	98·90

The range of fluidizing gas velocities, for which the total resistance of the fluidized phase was almost constant, depended upon the mass of cryptol and activated carbon used in the experiment. Further increase of gas velocity generated vortices during fluidization. Formation of large gas bubbles was observed which led to further increase of the electric resistance of the system.

With normal fluidization the oscillations of the instantaneous resistance did not exceed 6 per cent of the mean value. Depending on the

amount of charge and diameters of grains supplied the alteration of the instantaneous resistance was on the average from 2 to 6 per cent.

With the increase of the charge and hence with the increase of the static pressure in the column of the fluidized phase, its electric resistance decreased. This occurred independently of the kind of material and the type of columns used for the experiments.

The results obtained for cryptol are represented in co-ordinates ρ_k, the specific resistance of the fluidized phase at the critical velocity of fluidization, versus P_s, the static pressure of the fluidized phase (Fig. 5).

FIG. 5. Influence of static pressure of the fluidized phase upon specific resistance of bed at critical velocity of fluidization for cryptol.

Similar graphs are plotted for the tested fractions of activated carbon (Fig. 6).

It is found from the results obtained that the dependence between the specific resistance and static pressure of the fluidized phase can be expressed by the equation

$$\rho_k = A_1 \cdot P_s^{-a_1}$$

The values of the constant A_1 and the exponents a_1 depended on the kind of the material and grain diameters.
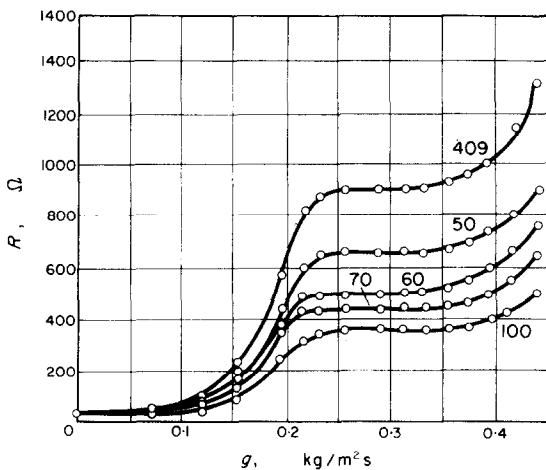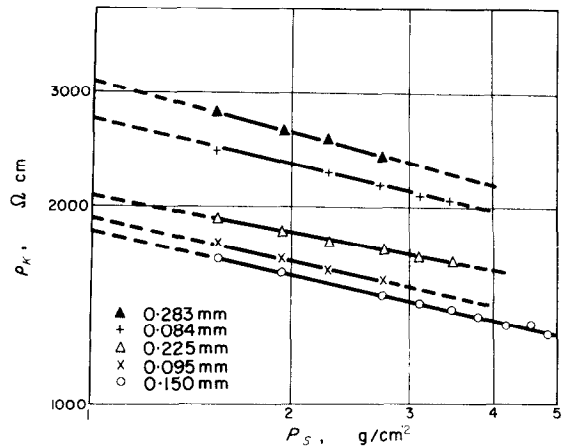

FIG. 4. Influence of the mass of activated carbon and velocity of the fluidizing gas (nitrogen) upon the overall resistance of samples under test. The results are obtained in a cylindrical column.
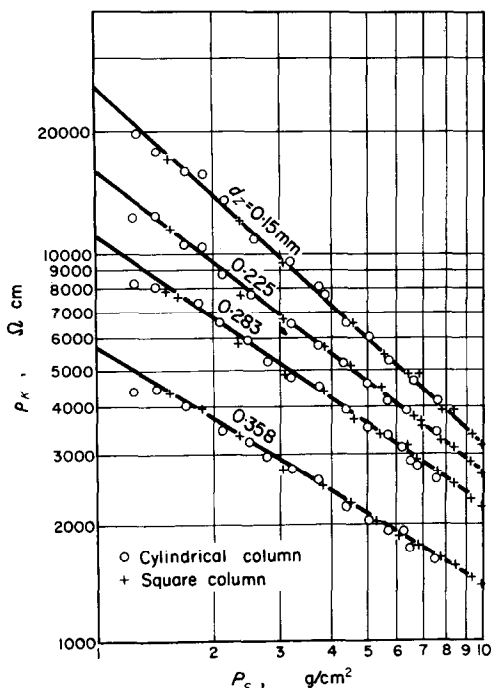
FIG. 6. Influence of static pressure of the fluidized phase upon specific resistance of the bed at critical velocity of fluidization for activated carbon.

The observed influence of the static pressure of the fluidized phase upon its electric resistance was probably due to the decrease of porosity of the bed with the increase of the charge.

THE INFLUENCE OF TEMPERATURE UPON THE ELECTRIC CONDUCTANCE OF FLUIDIZED PHASE

To carry out the experiments over the temperature range from 25° to 200°C glass columns were used. The tested fractions of the material were first heated electrically for more than ten hours to obtain a bed which would not change its electric properties during experiments. The series of experiments being over, the stability of the electric resistance of the studied fluidized phase was verified.

The measurements were performed with established voltage between the electrodes immersed into fluidized phase and with the given flow of nitrogen used as the fluidizing gas.

The fluidizing phase was heated beforehand by blowing warm nitrogen through it and by means of an electrical spiral wound round the column. After the temperature reached a constant value, electric current was supplied to the fluidized phase for some seconds and the current intensity was measured. At the same time it was checked whether the voltage between electrodes had changed. It was found from the experiments that the electric conductance of the fluidized system under test increased with temperature (Fig. 7).

The dependence between the temperature and electric conductance of the fluidized phase can be represented by the equation:

$$H_f = H_{20}[1 + \alpha(t_f - 20)].$$

The electric conductance of the fluidized phase also depended on the voltage applied. The effect of the voltage upon the value H_{20} is expressed by the equation

$$H_{20} = A_2 U^{a_2}.$$

THE INFLUENCE OF THE VOLTAGE UPON THE ELECTRIC CONDUCTANCE OF THE FLUIDIZED PHASE

During the experiments with constant fluidizing gas flow and constant temperature the applied voltage was increased and the current intensity was measured. It was found that the dependence between the current intensity and the voltage could not be represented by a straight line, and the deviation increased as the particle diameters of the samples used became larger (Figs. 8 and 9).

The dependence between the current intensity and voltage is established from the equation

$$I = A_2 . U^{1+a_2}.$$

Hence it follows that the electric conductance of the fluidized phase is also a function of the voltage
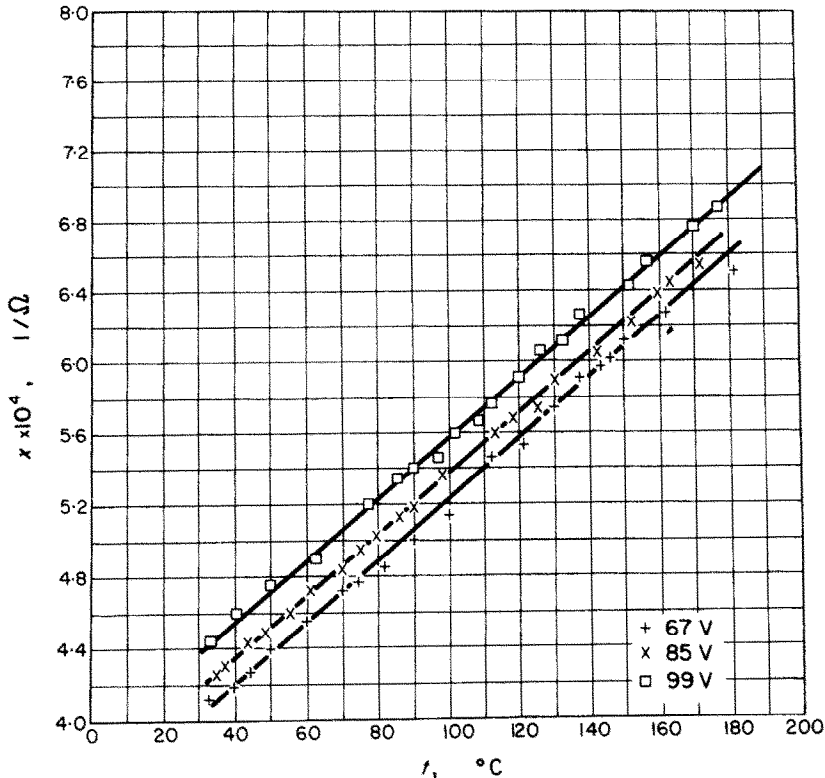
$$H_f = A_2 U^{a_2}.$$

FIG. 7. Temperature effect upon electric conductance of the fluidized phase at various voltages for cryptol grains with 0·15 mm equivalent diameter.

ELECTRIC ENERGY TRANSFORMATION INTO HEAT DIRECTLY IN THE FLUIDIZED PHASE

The experiment was carried out in a cylindrical column of 46 mm in internal diameter with carbon electrodes. Before the experiment started the fluidized phase was heated electrically till the reproducible results were obtained. The investigation was carried out with various flows of the fluidizing gas, the velocity of which was higher than the critical one. The voltage on the electrode terminals ranged from 90 to 220 V, and the maximum temperature of the fluidized phase was 225°C. The fluidizing gas (air) flowing through the column was simultaneously heated by heated grains of activated carbon and by spark discharges. The dependence between the temperature t_2 of the air being heated, temperature t_f of the fluidizing phase and the initial air temperature t_1 is expressed by the equation

$$\eta_w = 1 - \frac{t_f - t_2}{t_f - t_1}$$

η_w ranged from 0·9 to 0·99 for the studied air flows from 493 to 982 kg/m² h.

The following can be attributed to the merits of the heaters of this kind:

(1) Quick start.
(2) Large gain in temperature of fluidizing gas at a small height of the fluidized phase.
(3) Small volume of the apparatus.
(4) Simple control which can be fully automatic.

The defects of the system are as follows: great electric resistance of the fluidized phase
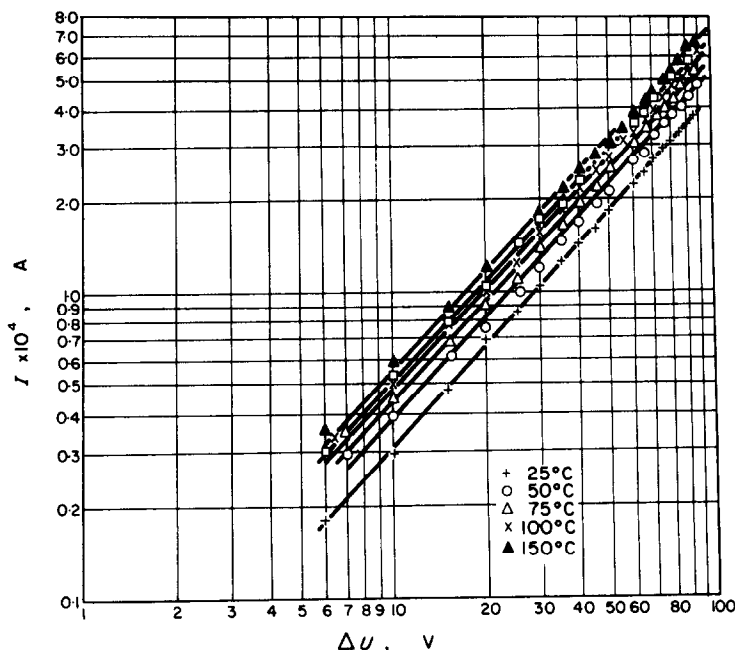
FIG. 8. Dependence between the intensity of current flowing through the
fluidized phase which consists of cryptol grains with 0·15 mm equivalent
diameter, and voltage at various temperatures.

relative to the resistance of the same material in the stationary bed and the necessity for an accurate control of the process, since should fluidization cease a steep increase in the electric current and temperature of the bed would follow.

PERIODICAL HEATING UP OF FLUIDIZED PHASE

The experimental investigation was carried out in a cylindrical column 56 mm in diameter. It was found during the previous experiments that the smallest oscillations in the instantaneous variations of the electric current occurred in the materials with the equivalent grain diameters of 0·095 and 0·15 mm. This is why cryptol fractions with 0·15 mm equivalent diameter were also used for the experiment. This was carried out with a constant nitrogen flow and constant voltage between the electrodes. During the experiment the temperature of the fluidized phase and the outflowing gas were increasing. At the same time the resistance of the fluidized phase decreased.

To correlate the obtained results an equation was derived describing the process of this kind. On the basis of the data obtained from the measurements and the above equation a method was developed for this calculation of periodical heating of the fluidized phase directly by electric current.

EQUATIONS FOR PERIODICAL HEATING OF THE FLUIDIZED PHASE DIRECTLY BY ELECTRIC CURRENT

The following conditions were accepted when deriving the equation. The quantity of the bed material, the mass flow of gas and voltage on the electrodes remain constant during the experiment. The heat capacity of the apparatus walls is considerably smaller than that of the fluidized phase and it is, therefore, neglected. The system being heated is in the surroundings
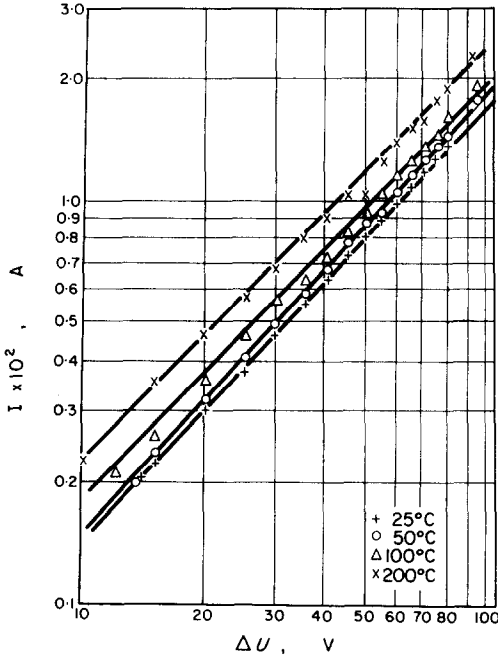
FIG. 9. Dependence between the intensity of current flowing through the fluidized phase which consists of cryptol grains with equivalent diameter of 0·95 mm, and voltage at various temperatures.

at constant temperature t_1 equal to the temperature of the gas entering the column. The temperature t_f of the fluidized phase is equal to the temperature t_{f_1} of the grains of solid. The initial temperature t_{f_1} of the fluidized phase is equal to the ambient temperature t_1.

From the equation

$$dQ_d = dQ_l + dQ_g + dQ_s \qquad (1)$$

where

$$dQ_d = 0.86U^2 H_{t_1}[1 + \alpha|t_f - t_1|]\,d\tau \qquad (2)$$

$$dQ_l = G_s c_s\,dt_f \qquad (3)$$

$$dQ_s = k_L L_f|t_f - t_1|\,d\tau \qquad (4)$$

$$dQ_g = Wc_p|t_2 - t_1|\,d\tau \qquad (5)$$

since

$$\eta_w = 1 - \frac{t_f - t_1}{t_f - t_2} \qquad (6)$$

it follows

$$dQ_g = Wc_p\eta_w|t_f - t_1|\,d\tau. \qquad (7)$$

After substituting the values from equations (2), (3), (4) and (7), rearranging

$$dt_f = \left\{\frac{0.86U^2 H_{t_1}}{G_s c_s} + \left[\frac{0.86U^2 H_{t_1}\cdot\alpha}{G_s c_s} - \frac{Wc_p}{G_s c_s}\eta_w\right.\right.$$
$$\left.\left. - \frac{k_L L_f}{G_s c_s}\right]|t_f - t_1|\right\}\,d\tau \qquad (8)$$

and by denoting in terms of

$$\frac{0.86U^2 H_{t_1}}{G_s c_s} = A \qquad \frac{k_L L_f}{G_s c_s} = C$$

$$\frac{0.86U^2 H_{t_1}\cdot\alpha}{G_s c_s} = P \qquad \frac{Wc_p}{G_s c_s} = B$$

one gets

$$d\tau = \frac{dt_f}{A - (B\eta_w + C - P)(t_f - t_1)}. \qquad (9)$$

On substituting

$$B\eta_w + C - P = \tilde{m}$$

one gets

$$d\tau = \frac{dt_f}{A - \tilde{m}(t_f - t_1)}. \qquad (10)$$

By integrating equation (10) one gets

$$\tau + c_1 = \frac{1}{\tilde{m}}\ln[A - \tilde{m}(t_f - t_1)]. \qquad (11)$$

The constant of integration obtained for initial conditions

$$\tau = 0 \qquad \text{and} \qquad t_f = t_1$$

is

$$c_1 = -\frac{1}{\tilde{m}} - \ln A. \qquad (12)$$

Then

$$-\tilde{m}\cdot\tau = \ln\left[1 - \frac{\tilde{m}}{A}(t_f - t_1)\right] \qquad (13)$$

or
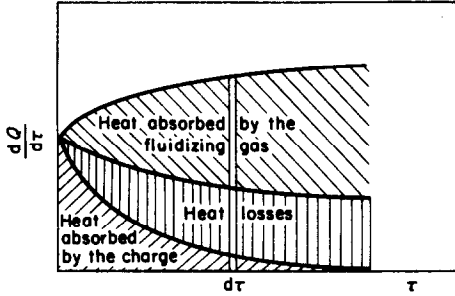
$$\exp[-\tilde{m}\tau] = 1 - \frac{\tilde{m}}{A}(t_f - t_1). \qquad (14)$$

FIG. 10. Dependence between the amount of heat supplied to the system for the time $d\tau$ and the time of process duration.

By substituting (15) into (13) one gets

$$\ln \frac{t_{f,\max} - t_1}{t_{f,\max} - t_f} = \check{m} \cdot \tau. \qquad (17)$$

Substituting

$$\ln \frac{t_{f,\max} - t_1}{t_{f,\max} - t_f} = \check{Y} \qquad (18)$$

one obtains

$$\check{Y} = \check{m} \cdot \tau \qquad (19)$$

where

$$\check{m} = \frac{1}{G_s c_s}(W \cdot c_p \cdot \eta_w + k_L \cdot L_f - 0.86 U^2 \cdot H_{t_1} \cdot \alpha) \qquad (20)$$

For conditions

$$\tau = \infty \quad \text{and} \quad t_f = t_{f,\max} \qquad (15)$$

$$t_{f,\max} - t_1 = \frac{A}{\check{m}}$$

or

$$t_{f,\max} = \frac{0.86 U^2 H_{t_1}}{W c_p \eta_w + k_L L_f - 0.86 U^2 H_{t_1} \cdot \alpha}. \qquad (16)$$

DISCUSSION OF THE EXPERIMENTAL RESULTS

From the results of the measurement and equation (18) the values of modulus $\check{Y}$ are

Table 2

	Min	Y (50 V)	Y (60 V)	Y (70 V)	Y (80 V)	Y (90 V)	Y (100 V)
1	0	0.000	0.000	0.000	0.000	0.000	0.000
2	1	0.239	0.190	0.185	0.187	0.182	0.207
3	2	0.441	0.391	0.411	0.382	0.351	0.398
4	3	0.692	0.595	0.640	0.598	0.456	0.534
5	4	0.844	0.798	0.818	0.766	0.700	0.693
6	5	1.025	0.980	0.940	0.940	0.880	0.822
7	6	1.250	1.200	1.080	1.110	1.050	0.988
8	7	1.540	1.390	1.240	1.225	1.210	1.155
9	8	1.720	1.610	1.450	1.385	1.380	1.300
10	9	1.945	—	1.675	1.635	1.560	1.475
11	10	2.250	1.920	1.900	1.840	1.730	1.610
12	11	—	—	2.130	2.010	1.910	1.764
13	12	3.360	2.300	2.280	2.210	2.040	1.805
14	13	—	—	2.470	2.322	2.280	1.995
15	14	—	2.990	—	2.460	2.450	2.230
16	15	3.380	2.990	—	2.800	2.600	2.380
17	16	—	—	2.980	3.020	2.760	2.458
18	17	—	—	3.380	3.020	2.890	2.640
19	18	—	—	3.380	3.310	2.890	2.740
20	19	—	3.680	—	—	3.330	3.000
21	20	—	—	3.380	3.710	3.580	3.140
22	21	—	—	4.080	—	—	3.330
23	22	—	—	4.080	—	3.990	3.330
24	23	—	—	—	—	—	3.550
25	24	—	—	—	—	5.390	3.840
26	25	—	—	—	3.710	5.390	3.840
27	30	—	—	—	4.420	5.350	4.720

calculated. The maximum temperature of the fluidized phase obtained during the experiment was denoted by $t_{f,\,\mathrm{max}}$.

The calculated values of $\breve{Y}$ are represented in Table 2, and on their basis the curves are plotted in co-ordinates $\breve{Y} - \tau$ in Fig. 11. Empirical equations are also constructed which describe the dependence between the modulus $\breve{Y}$ and time of periodic heating of the fluidized phase τ. These equations are in agreement with the above dependence (19)

$$Y = \tilde{m}.\tau.$$

It appeared that the value $\tilde{m}_t$ calculated from equation (20) exceeded the experimental value. This difference is determined by the fact that in the derivation of the equations the heating up of the bottom and walls of the column was neglected. By introducing into equation (19) the correction ψ accounting for the simultaneous heating of the apparatus walls and bottom one gets

$$\breve{Y} = \psi.\tilde{m}_t.\tau$$

where

$$\psi = \frac{\tilde{m}_p}{\tilde{m}_t}.$$

Experiments show that in the theoretical equation (19) describing the time of the periodical heating of the fluidized phase it is also necessary to take into account the equivalent heat capacity of the apparatus W_a or the factor ψ accounting for simultaneous heating up of the bottom and walls of the column. Heat capacity of the electrodes should also be taken into account too.

Hence

$$\breve{Y} = \psi \frac{Wc_p\eta_w + k_L L_f - 0.86 U^2 H_{t_1}.\alpha}{G_s c_s + G_e c_e}.\tau$$

or

$$\breve{Y} = \frac{Wc_p\eta_w + k_L L_f - 0.86 U^2 H_{t_1}.\alpha}{G_s c_s + G_e c_e + W_a}.\tau.$$
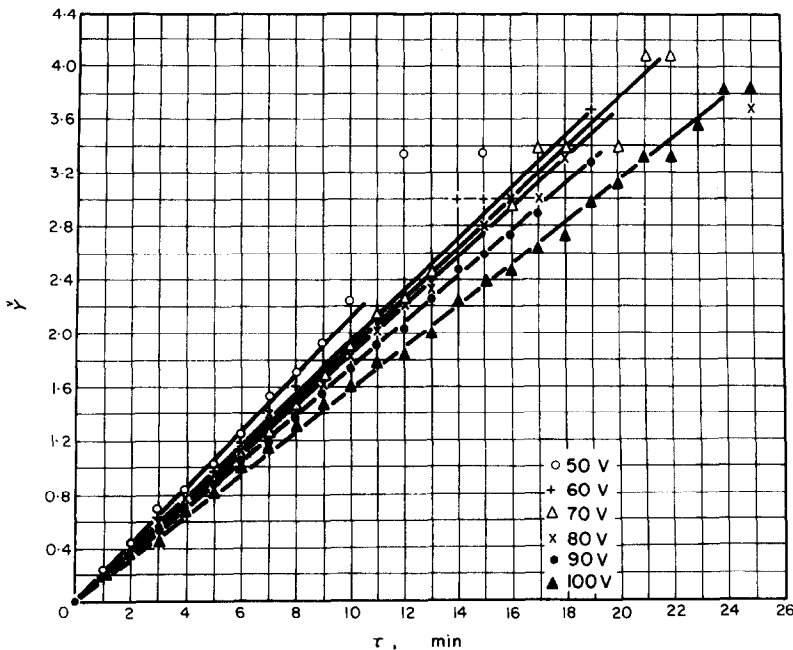
The maximum temperature can be found from equation (16).

Fig. 11. Dependence between the modulus $\breve{Y}$ and the time of periodical heating of fluidized phase τ for a given nitrogen flow of 2.56×10^{-4} kg/s at various voltages.

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Abstract—On the basis of the results obtained from the investigation an equation is proposed for the calculation of the time required for periodical heating of the fluidized phase. An equation describing the maximum temperature of the fluidized phase is also obtained, which can be used when the conditions under which the process occurs are known. The influence of a number of parameters upon the electric conductance of the fluidized phase consisting of cryptol and activated coal grains is studied. A new method is also developed for the estimation of the critical velocity of fluidization.

Résumé—Sur la base des résultats obtenus au cours de l'étude, on propose une équation pour calculer le temps nécessaire au chauffage périodique de la phase fluidisée. On obtient aussi une équation décrivant la température maximale de la phase fluidisée, qui peut être employée lorsque les conditions du processus sont connues. L'influence de quelques paramètres sur la conductibilité électrique de la phase fluidisée consistant de cryptol et de grains de charbon activé est étudiée. Une nouvelle méthode est également exposée pour estimer la vitesse critique de fluidisation.

Zusammenfassung—Auf Grund der erhaltenen Versuchsergebnisse wird eine Gleichung vorgeschlagen zur Berechnung der erforderlichen, periodischen Heizdauer für eine verflüssigte Phase. Daneben wurde auch eine Gleichung für die Maximaltemperatur der verflüssigten Phase erhalten. Sie kann bei bekannten Prozessbedingungen verwendet werden. Der Einfluss einer Reihe von Parametern auf die elektrische Leitfähigkeit einer verflüssigten Phase aus Kryptol und Aktivkohlengranulat wird untersucht. Ausserdem wurde eine neue Methode zur Abschätzung der kritischen Verflüssigungsgeschwindigkeit entwickelt.