# SPECIFIC HEAT OF RAJASTHAN DESERT SAND FROM 280°K TO 500°K

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**A steady-state method is used for the measurement of specific heat of Rajasthan desert sand as a function of temperature. The measured values of specific heat vary from 0·194 cal/gm/°C (at 280°K) to 0·239 cal/gm/°C (at 500°K). A curve of the form $C=A+BT$ is found to follow the experimental data. A nomogram is also drawn to estimate the effective specific heat of porous materials from the knowledge of specific heats of constituents and mass porosity.**

A knowledge of thermal conductivity, thermal diffusivity, and specific heat of soil and desert sand is of interest to agriculturists, meteorologists, engineers, and military planners. A wide experimental study has been done on thermal conductivity and thermal diffusivity[1-5] leaving aside the measurements of specific heats. These thermal properties are related by $\alpha = K/\rho C$ where $\alpha$ is the thermal diffusivity, $K$ is thermal conductivity, $C$ is specific heat and $\rho$ is density. The accurate experimental specific heat data may serve as a basis for a direct computation of thermal conductivity from the knowledge of thermal diffusivity, or vice versa, from the given relation. Recently the authors[6] have discussed the experimental measurements of effective specific heat of porous materials using a continuous flow electrical method. In the present paper, employing the similar technique, specific heat of desert sand has been measured as a function of temperature and from the experimental results, an empirical expression has been suggested.

The advantage of the continuous flow electrical method is that it is free from calorimetric errors inherent in other methods: (i) The heat loss while in transfer from the source to object can be eliminated, (ii) No correction need be applied for thermal capacity of the calorimeter, and (iii) The value of specific heat can be measured over a narrow range of temperature. There are also some disadvantages: (i) Relatively large quantities of the sand sample are required, and (ii) The measurement may take a fairly long time because steady conditions are attained slowly.

## MATERIALS AND METHODS

### *Apparatus*

The experimental arrangement is illustrated in Fig. 1. It consists of a three walled glass tube having a nichrome heater wire, in the form of a spiral, stretched in the innermost tube of internal diameter 1.4 cm and 40 cm length. This is surrounded by a vacuum jacket silvered on both sides and is further jacketed for oil circulation at constant temperature. A container, made of copper, is mounted above the tube from which desert sand at a constant temperature falls continuously into the tube and finally comes out through a regulated nozzle. The container is maintained at a constant temperature by oil circulation through the jacket provided with it. The outer portion of this jacket is wrapped with an insulating material. A steady current, from

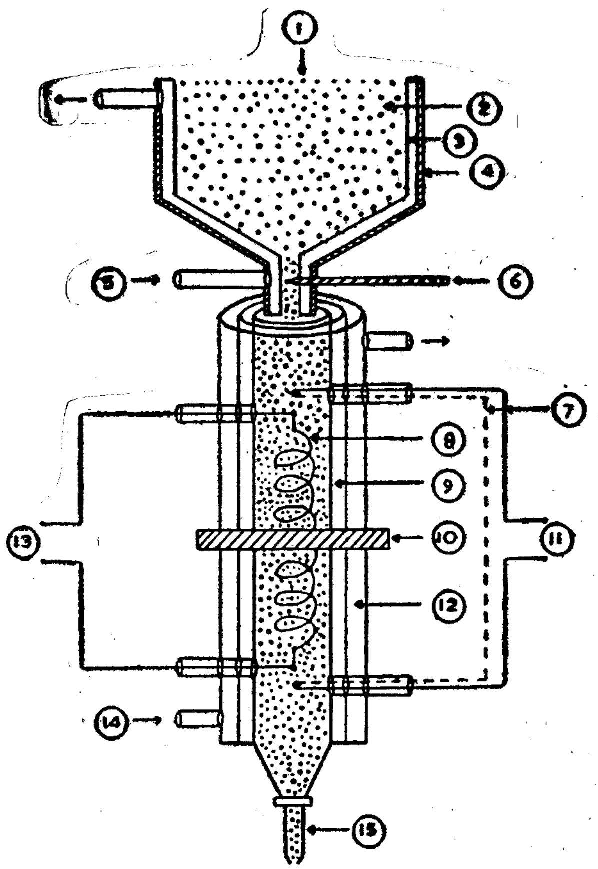


Fig. 1—Schematic diagram of continuous fall method for the measurement of specific heat of desert sand.

(1) Container, (2) Desert sand, (3) Jacket surrounding container for oil circulation, (4) Asbestos wrapper, (5) Oil from thermostat, (6) Mercury thermometer, (7) Copper-constantan thermocouple, (8) Heater wire, (9) Evacuated and silvered double walled glass tube, (10) Glass tube coupled to a vibrator, (11) emf measurement device, (12) Jacket surrounding glass tube for oil circulation (13) Current supply circuit (14) Oil from thermostat, and (15) Nozzle.

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a set of acid accumulators is passed through the heating coil and the corresponding resistance of coil is simultaneously measured. To measure the temperature difference down the desert sand column in the tube, a copper-constantan thermocouple is installed as shown in Fig. 1. A mercury thermometer is employed to note the temperature of falling desert sand. A vibrator is coupled to the three walled glass tube to ensure the constant rate of fall of the sand material which is coming out through the nozzle and it also prevents sticking of the sand particles in contact with the glass wall.

A thermostat (fitted with distributed heater; efficient stirrers and an electromagnetic relay) is used to provide oil at constant temperature (fluctuation $\pm 0.2°C$) which is circulated through the jackets by a motor. In the container jacket, the oil is circulated with a view to raise the temperature of the desert sand to a value at which the specific heat is required while in the glass tube jacket, the oil is circulated to maintain the temperature of the desert sand falling from the container.

*Theory*

In addition to Joule heating, the heat may also be contributed by friction among the desert sand grains. For the estimation of energy contribution due to friction, the desert sand was allowed to fall through the tube when there was no current in the heater wire and temperature rise of desert sand column was found to be less than 2 $\mu v$ (0.05°C) while in the measurements of specific heat the order of the temperature rise was 400 $\mu v$ (10°C). As such the energy contribution due to friction is negligibly small compared to Joule heating. Thus we can write,

$$I^2 R \times 10^7 = JMC \triangle T + H \quad (1)$$

where

$I$, is current (ampere), $R$, resistance (ohm); $J$, mechanical equivalent of heat (ergs/cal); $M$, rate of fall of desert sand (gm/sec); $C$, specific heat of desert sand (cal/gm/°C); $\triangle T$, temperature rise (°C) and $H$, heat loss due to radiation, convection and conduction.

For the elimination of heat loss factor $H$, the experiment was repeated at different rate of fall with an adjustment of current for the same rise of temperature $\triangle T$. Thus we have,

$$C = \frac{(I_1^2 - I_2^2) \ R \times 10^7}{J(M_1 - M_2)\triangle T} \quad (2)$$

where $M_1$ and $M_2$ are two different rates of fall corresponding to current values $I_1$ and $I_2$ respectively for the same rise of temperature $\triangle T$.

In equation (2) it is practically possible to adjust $I_1$ and $I_2$ but somewhat difficult to adjust $M_1$ and $M_2$ precisely so as to obtain exactly the same $\triangle T$ in both cases. In these measurements, $\triangle T$ was found to be of the order of 400 $\mu v$ (10°C) and as such $H$ can be regarded as almost to be same in the experiments whenever $\triangle T$ differed by less than 10 $\mu v$ (0.25°C). Thus the specific heat values can be calculated from

$$C = \frac{(I_1^2 - I_2^2) \ R \times 10^7}{J(M_1 \Delta T_1 - M_2 \Delta T_2)} \quad (3)$$

## EXPERIMENTAL PROCEDURE AND RESULTS

The desert sand samples used in the measurements were thoroughly washed in the water and carefully dried. Then a sample to be tested was filled in the container and allowed to fall through the innermost tube. Oil at constant temperature was circulated through surrounding jackets of both container and glass tube. The apparatus was left for a sufficient time (average four hours) till the desert sand attained a constant temperature.

A steady current, from a set of acid accumulators, was passed through the heating coil and the temperature differences down the desert sand column were recorded by the thermocouple. It took usually two hours to obtain steady state conditions. At this stage, the readings for temperature rise, quantity of electrical energy supplied to heating coil and rate of fall of desert sand were simultaneously taken. The values of specific heat were calculated from equation (3). The measurements were made on five desert sand samples collected from different places of Rajasthan *viz.*, Jaisalmer, Jaipur, Jalore, Bikaner and Jodhpur. Their physical properties were :

Colour : brown; Bulk density : 1.50—1.60 gm/cc; Predominant grain size : 0.10—0.20 mm; Specific gravity : 2.57—2.70 gm/cc; Absorption of water by desert sand at 20°C: 0·028 kg/kg.

At the room temperature the specific heat of these samples was found to be :

Jaisalmer = 0.201 cal/gm/°C
Jalore = 0.199 cal/gm/°C
Jodhpur = 0.202 cal/gm/°C
Jaipur = 0.198 cal/gm/°C
Bikaner = 0.201 cal/gm/°C

These values are averages of several determinations and reproducibility is within eight per cent.

Since the specific heat values were found to be similar for five desert sand samples tested, it appears to be reasonable to assume the same value of specific heat for desert sands of all other places. Finally measurements were carried out on Jaipur desert sand sample over temperature range from 280°K to 500°K. These values are reported in Table 1. Further, these data are plotted in Fig. 2 to get a correlation between specific heat and temperature. It is apparent that experimental data can be approximated by a straight line as shown in Fig. 2. The equation for such a straight line is of the form

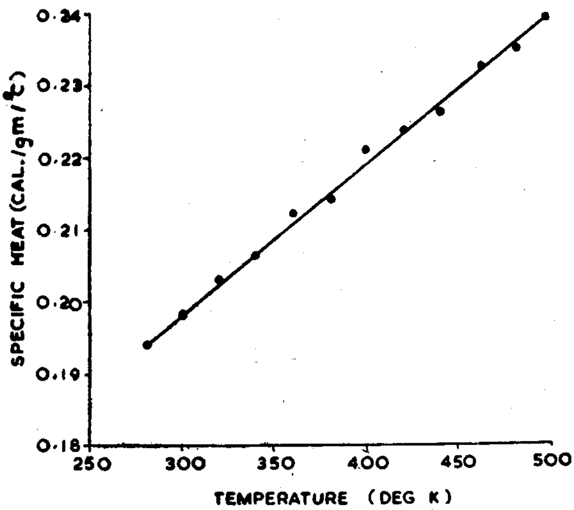


Fig. 2—Specific heat of Rajasthan desert sand as a function of temperature.

$$C = A + B\,T$$

where $C$ is specific heat of desert sand, $T$ is temperature in degree Kelvin and $A$ and $B$ are constants.

From Fig. 2, the constants $A$ and $B$ were calculated and the empirical formula relating the specific heat of desert sand with temperature is given by

$$C = 0.137 + 2{\cdot}045 \times 10^{-4}\,T$$

## CONCLUSIONS

The specific heat of Rajasthan desert sand of different places is found to be almost same. The specific heat varies by 22 per cent in the temperature range 280-500°K and its value at any temperature can be predicted from the expression $C = 0.137 + 2.045 \times 10^{-4}\,T$.

TABLE 1

SPECIFIC HEATS OF RAJASTHAN DESERT SAND AT DIFFERENT TEMPERATURE

| Specific heat (cal/gm/°C) | Temperature (°K) | Specific heat (cal/gm/°C) | Temperature (°K) |
|---|---|---|---|
| 0·194±0·008 | 280 | 0·222±0·009 | 400 |
| 0·198±0·008 | 300 | 0·224±0·009 | 420 |
| 0·203±0·008 | 320 | 0·226±0·010 | 440 |
| 0·206±0·008 | 340 | 0.233±0·012 | 460 |
| 0·212±0·008 | 360 | 0·235±0·013 | 480 |
| 0·214±0·009 | 380 | 0·239±0·015 | 500 |

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## REFERENCES

1. CHAUDHARY, D.R., AGRAWAL, M.P. & BHANDARI, R.C., *Indian J. pure appl. Phys.*, 4 (1969), 252.
2. KERSTEN, M.S., Thermal properties of solids" University of Minnesota, Bulletin No. 28 June, 1, 1949.
3. BANSAL, T.D., *Scient ind. Res.*, 8 (1962), 285.
4. AGRAWAL, M.P. & BHANDARI, R.C., *Appl. Sci. Res.* 23 (1970), 113.
5. INGERSOLL, L.R. & KOEPP, O.A., *Phys Rev.*, 24 (1924), 92.
6. CHAURASIA, P.B. LAL, CHAUDHARY, D.R. & BHANDARI, R.C., PRAMANA, 3 (1974), 383.
7. CHAURASIA, P.B. LAL, CHAUDHARY, D.R. & BHANDARI, R.C., *J. appl chem & Biotechnol.*, 24 (1974), 437.

*Appendix*

**"Estimation of effective specific Heat of porous materials by a nomogram"**

Recently authors[6] have confirmed the Ulrich expression[7], after an experimental investigation, for the prediction of effective specific heat of porous materials consisting of solid-liquid phase system. The expression is

$$C_E = \phi\, C_l + (1-\phi)\, C_s$$

where

$C_E$ is effective specific heat of porous materials; $\phi$, Mass porosity (defined as the fractional mass of liquid present in the total mass of system); $C_l$, Specific heat of liquid and $C_s$, Specific heat of solid phase.

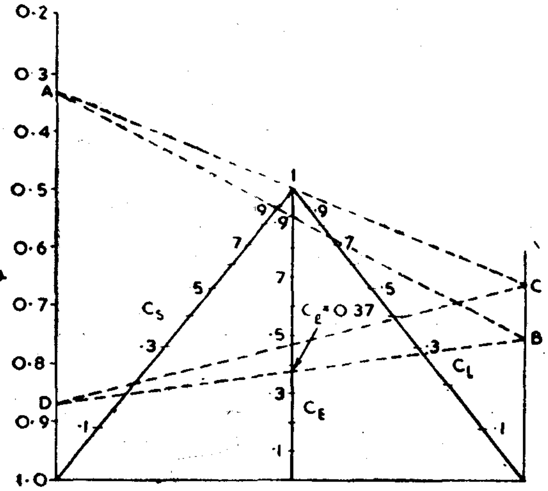


Fig. 3—Nomogram for the prediction of effective specific heat of two-phase porous materials.

Chaurasia *et al*[7] have provided nomograms for the estimation of effective thermal conductivity of porous materials along with graphical determination of porosity from the given values of densities of phases present in the system. The above expression is used in the construction of the present nomogram (Fig. 3) which enables the effective specific heat of the system to be predicted from the knowledge of the specific heats of the constituents and mass porosity. The nomogram is to be used as follows:

(*i*) Mark a point (A) for the given value of mass porosity on $\phi$ scale,

(*ii*) Join this point (A) with the given value of specific heat of liquid on the $C_l$ scale using a ruler and extend it up to the intersection point (B) on the right line. Also draw a straight line from (A) passing through the junction point of the nomogram (Marked by 1) up to right line for a point (C),

(*iii*) Again join the point (C) to the $\phi$ scale giving a point (D) passing through the given value of specific heat of solid phase on the $C_s$ scale,

(*iv*) Now connect these points (B) and (D), the intersection point on the $C_E$ scale gives the required value of effective specific heat of porous material.

*Example*: Sand-stones[6] in isobutyl alcohol ($C_s$ = 0.200 cal/gm/°C, $C_l$ = 0.716 cal/gm/°C and $\phi$ = 34.0%).
The value of $C_E$ computed from the nomogram is 0.37 cal/gm/°C,
(This example is drawn by dotted line on Fig. 3)
Experimental[6] value of $C_E$ is 0.36 cal/gm/°C.

The effective specific heats for certain porous materials estimated by present nomogram are reported in Table 2 and experimental values are also given for the comparison.

Table 2

Comparison of a few experimental and present nomogram values for $C_E$

| Samples Solid phase/Liquid phase | Specific heat of constituents (cal/gm/°C) | Mass porosity (gm/gm in %) | $C_E$ by present nomogram (cal/gm/°C) | $C_E$ by experimental value (cal/gm/°C) | References |
|---|---|---|---|---|---|
| Sand-stones/Water | 0·20/1·00 | 34·0 | 0·47 | 0·46 | 6 |
| Sand-stones/Turpentine oil | 0·20/0·41 | 20·1 | 0·24 | 0·24 | 6 |
| Calcareous earth/Water | 0·20/1·00 | 43·0 | 0·54 | 0·53 | 5 |
| Sugar/n-octane | 0·27/0·57 | 25·1 | 0·35 | 0·34 | 6 |
| Charcoal/Kerosene oil | 0·16/0·52 | 43·4 | 0·31 | 0·29 | 6 |