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Optimization of Rock Size in Beds Used for Cooling of Buildings

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The results of a study on the optimization of rock size for beds used in cooling of buildings are presented. To effect economy in the system it is important that the power consumption is low. Use is, therefore, made of the relationship between the rock size, velocity of air and the power consumption to determine the optimum size of rocks. The results obtained show that rocks having equivalent diameter of 10 mm should be used for economical running of such systems. The velocity of cool air passing through the bed has been restricted to 400 m/hr.

Cooling of buildings utilizing thermal storage beds has been shown to be a promising approach in India[1] and elsewhere[2]. It has been shown to be economical also[3]. However, the design of a randomly packed particulate bed for this purpose is a complex problem. Considerable work has been done on various design aspects of these thermal storage beds[4,5], but a standard procedure is still not available. An attempt was made by the author[4] in this direction, wherein design curves were developed covering most of the variables.

In this paper the results of a study on the optimization of rock size based on economical running of the system are presented.

Design parameters

In the design of thermal storage beds, several parameters are to be considered, such as heat load (h_1), rock size (d_r), velocity of air passing through the bed (v), pile volume (V), air circulation rate (a_c), pressure drop (Δp), volumetric heat transfer coefficient (h_v), cooling time (C_t) and air and pile temperatures (t_a, t_s). It is also important not only to know the power consumption by the system for a given task but also to have an idea of the economics as a whole, since an alternative system can be adopted only if it is economical and promises distinct advantages over the existing systems of cooling the buildings. The design curves were developed involving all these parameters and were presented in an earlier paper[4].

Optimization of rock size

To obtain satisfactory results and to effect economy in the working of the system, it is important that power consumption is low. The major parameters that control power consumption are rock size, volume of the pile and the velocity of air.

The power consumption in circulating cool air through thermal storage beds can be expressed as:

$$\text{Power consumption} = \frac{a_c \times p_d}{\eta} \quad \text{... (1)}$$

where a_c is air circulation rate in $m^3 hr^{-1}$; p_d, the total pressure drop in the pile in mm of wg; and η, the efficiency of the fan.

But

$$a_c = v \cdot A_a \quad \text{... (2)}$$

where v is the velocity of cool air; and A_a, the equivalent area of air passing through the pile.

Further

$$p_d = \Delta p \cdot L \quad \text{... (3)}$$

where Δp is the pressure drop per unit length; and L, the height of the pile.

Therefore

$$\text{Power consumption} = \frac{v \cdot A_a \cdot \Delta p \cdot L}{\eta} \quad \text{... (4)}$$

We have

$$\text{Rock fraction } (\varepsilon) = \frac{\text{Vol. of the rocks}}{\text{Vol. of the pile } (V)}$$

$$= \frac{\text{Eq. area of rocks } (A_r)}{\text{Cross-section area of pile } (A_p)}$$

Therefore,

$$A_p \cdot \varepsilon = A_r$$

or $A_p - A_r = A_p (1-\varepsilon)$

$$A_a = A_p (1-\varepsilon) \quad \text{... (5)}$$

Substituting for A_a in expression (4), we get

$$\text{Power consumption} = \frac{v \cdot A_p (1-\varepsilon) \cdot \Delta p \cdot L}{\eta}$$

$$= \frac{v(1-\varepsilon) \cdot \Delta p \cdot V}{\eta} \quad \text{... (6)}$$

$$= \frac{\varphi(v) \cdot \psi(\varepsilon) \cdot V}{\eta} \quad \text{since } (A_p \cdot L = V)$$

This implies that the efficiency of the fan remaining constant ($\eta = 0.6$), at a given volume of the pile

$$\text{Power consumption} \propto v \quad \text{... (7)}$$

$$\propto \varepsilon \quad \text{... (8)}$$

The curves based on Eq. (6) are shown in Fig. 1. The power consumption factor may be defined as the ratio of power consumption in circulating the cool air and the volume of the pile. The value of equivalent diameter of the rocks ranges from 3 to 25 mm and the air velocity in the range 20-400 m hr^{-1}. A careful study of these curves reveals that the rock size could be optimized for a given velocity and power consumption. It is seen that the slope of the curves changes at 10 mm rock size. This is also evident from Table 1. This

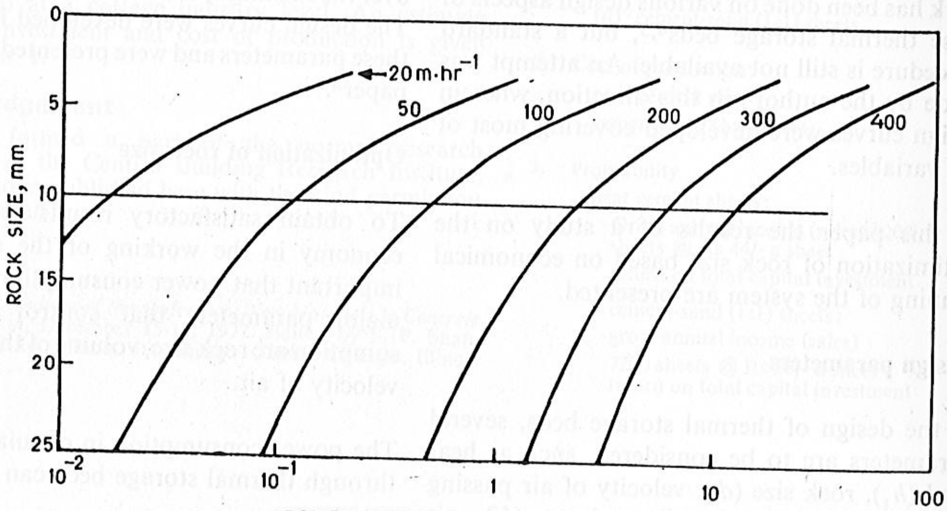

Fig. 1—Change in power consumption factor versus rock size at different air velocities

Table 1—Variation of Power Consumption Factor with Rock Size and Air Velocity

Sl No.	Rock size mm	Air velocity in pile × 10^2, m/hr					
		20	50	100	200	300	400
1	25.0	0.26	1.89	9.13	49.38	139.83	299.75
2	22.0	0.34	2.40	11.39	60.20	168.22	357.41
3	20.0	0.42	2.88	13.59	70.57	195.29	409.14
4	16.0	0.65	4.75	20.23	101.55	274.63	570.45
5	12.7	1.03	6.94	31.05	150.79	399.13	815.64
6	10.0	1.68	11.14	48.95	230.13	595.73	1171.60
7	6.3	4.37	28.35	120.30	538.16	1337.80	2606.70
8	3.0	19.14	122.00	502.70	2131.90	5067.44	9491.90

means that power consumption increases rapidly with small changes in rock size beyond this size of rocks. Hence, the optimum value of rock size may be taken as 10 mm equivalent diameter, which is approximately equal to 12.5 mm rock size in practice. In this study, only the rock sizes available in practice are considered.

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