is more during morning and evening and less during the other parts of the day. Fig. 16.3 shows a hydrograph of hourly demand for the maximum day. For a uniform 24 hour pumping, the pumping rate will be equal to the mean hourly demand, shown by the line *PQ*. The required storage is then obtained by planimetering or determining in some other manner the area (shown shaded) between curve *BEC* and the line *PQ*. This area can be easily converted into units of volume to yield the required storage in million litres.

From the above graph, it is clear that in absence of an equalizing reservoir, the maximum rate of pumping required would be 22000 lit/min. But by provision of an equalizing reservoir of 2.38 million litres capacity, the maximum rate of pumping required will be only 14938 lit/min. This is about 67.9% of that required with no storage.

(*b*) **Mass Curve Method.** A mass curve of demand is the cumulative demand curve, and is obtained by continuously adding

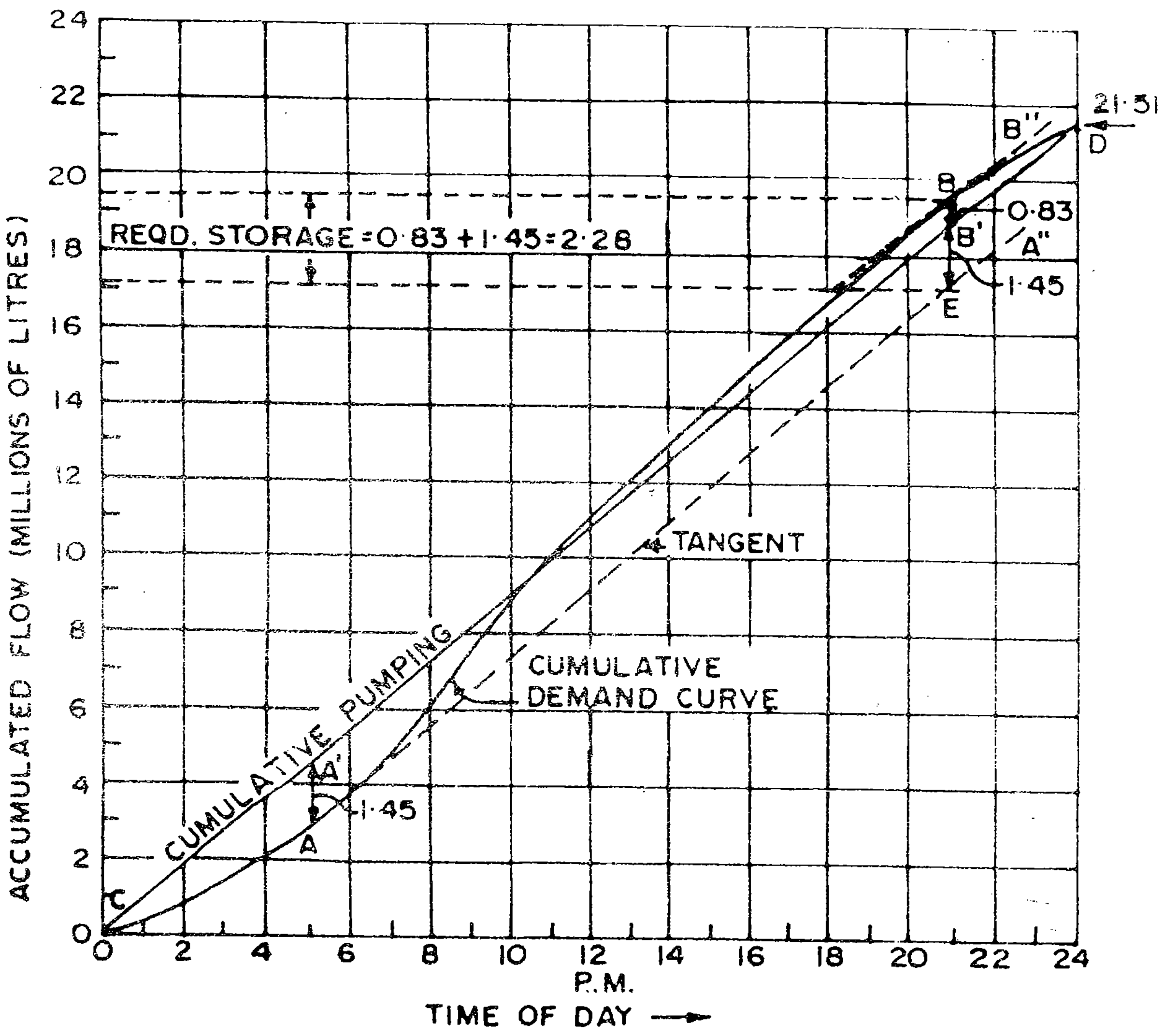


FIG. 16.4. MASS CURVE METHOD OF EQUALIZING STORAGE (SEE EXAMPLE 16.1)

the hourly demands and plotting these against time (hours) of the maximum day. Fig. 16.4 shows the mass demand curve *CAB* in thick line. A mass demand curve continuously rises. The steepness of the mass curve indicates a higher rate of demand, while flat portion shows the lower rate of demand. Line *CD* is the line indicating cumulative pumping at uniform rate. If pumping is to be done for all the 24 hours, the mass curve *CD* for pumping will be obtained by joining the two ends *C* and *D* of the mass curve of demand. In order to determine the required storage capacity, draw tangents, through lowest point *A* and highest point *B*, parallel to pumping rate line *CD*. The highest vertical distance *BE* between the two tangents will then give the required capacity of the equalizing reservoir. This is so because at *A* (6 A.M.), there is excess supply equal to *AA'* which should be stored, while at *B* (about 8.30 P.M.) there is deficit *B B'* which must be drawn from the storage that is replenished by mid-night. The required storage capacity will thus be the sum of morning excess *A A'* and evening deficiency *B B'*. In other words we have

$$S = E_p + E_d \qquad ...(16.3)$$

where $S$ = storage capacity required

$E_p$ = max. excess of supply through pumping

$E_d$ = max. excess of demand (or max. deficiency).

**Example 16.1.** *Table 16.1 shows the hourly demand for the maximum day. Assuming a 24 hour pumping at uniform rate, determine the storage capacity of equalizing reservoir. What will be the uniform pumping rate ?*

TABLE 16.1

| *Time* | *Average hourly demand rate (litres per min.)* | *Time* | *Average hourly demand rate (litre per min.)* |
|---|---|---|---|
| 12 | 0 | 12 | 18,000 |
| 1 P.M. | 8000 | 1 P.M. | 16,000 |
| 2 | 9000 | 2 | 15,000 |
| 3 | 10,500 | 3 | 15000 |
| 4 | 11,000 | 4 | 15,500 |
| 5 | 12,000 | 5 | 16000 |
| 6 | 15,000 | 6 | 16,500 |
| 7 | 17,500 | 7 | 17,000 |
| 8 | 20,500 | 8 | 17,000 |
| 9 | 22,000 | 9 | 15,000 |
| 10 | 21,500 | 10 | 12,000 |
| 11 | 20,000 | 11 | 10,000 |
| | | 12 | 9,000 |

TABLE 16.2.

| Time (1) | Average hourly demand rate l.p.m. (2) | Hourly demand (litres) (3) | Cumulative demand (litres) (4) | Average hourly demand minus hourly demand i.e. 896250 – col. (3) (5) – | + |
|---|---|---|---|---|---|
| 12 | 0 | 0 | 0 | — | |
| 1 A. M. | 8000 | 480000 | 480000 | | 416250 |
| 2 | 9000 | 540000 | 1020000 | | 356250 |
| 3 | 10500 | 630000 | 1650000 | | 266250 |
| 4 | 11000 | 660000 | 2310000 | | 236250 |
| 5 | 12000 | 720000 | 3030000 | | 176250 |
| 6 | 15000 | 900000 | 3930000 | 3750 | |
| 7 | 17000 | 1020000 | 4950000 | 123750 | |
| 8 | 20500 | 1230000 | 61800000 | 333750 | |
| 9 | 22000 | 1320000 | 7500000 | 423750 | |
| 10 | 21500 | 1290000 | 8790000 | 393750 | |
| 11 | 20000 | 1200000 | 9990000 | 303750 | |
| 12 | 18000 | 1080000 | 11070000 | 183750 | |
| 1 P. M. | 16000 | 960000 | 12030000 | 63750 | |
| 2 | 15000 | 900000 | 12930000 | 3750 | |
| 3 | 15000 | 900000 | 13830000 | 3750 | |
| 4 | 15500 | 930000 | 14760000 | 33750 | |
| 5 | 16000 | 960000 | 15720000 | 63750 | |
| 6 | 16500 | 990000 | 16710000 | 93750 | |
| 7 | 17000 | 1020000 | 17730000 | 123750 | |
| 8 | 17000 | 1020000 | 18750000 | 123750 | |
| 9 | 15000 | 900000 | 19650000 | 3750 | |
| 10 | 12000 | 720000 | 20370000 | | 176250 |
| 11 | 10000 | 600000 | 20970000 | | 296250 |
| 12 | 9000 | 540000 | 21510000 | | 356250 |
| | Total | 21510000 | | 2280000 | 2280000 |
| | Average | $\frac{21510000}{24}$ = 896250 litres/hour | | | |

**Solution :**

Knowing the average hourly demand rate (l.p.m.) the hourly demand, in litres, can be calculated by multiplying it by 60. Column 3 of Table 16.2 shows the hourly demand, while column 4 shows the cumulative hourly demand. The average demand is obtained by taking the sum of column 3 and dividing it by 24. It comes out to be 896250 litres/hour. Thus, the pumping rate will be 896250 litres/hour or 14938 litres/min. Fig. 14.3 shows the hydrograph of demand in which the line *PQ* represents the pumping rate of 14938 litres/min. Column 5 shows the average hourly demand minus hourly demand.

The mass curve is shown in Fig. 16.4. *CD* is the line for cumulative pumping for 24 hours at a constant rate of 0.896 million litres/hour. Tangents are drawn at the lowest point *A* and apex *B*, parallel to *CD*. The maximum vertical ordinate *BE* between the two tangents gives the required storage, which comes out to be 2.28 million litres. Alternatively, the storage capacity is equal to $(AA'+BB')= 1.45+0.83 = 2.28$. This evidently is equal to the sum of negative (or positive) entries of column 5 of Table 16.2. This is about 10.6% of day's consumption.

**Alternative analytical solution :**

From Table 16.2 (column 3), total demand in 24 hours = 21510000 litres.

$$\therefore \quad \text{Pumping rate} = \frac{21510000}{24} = 896250 \text{ litres/hour.}$$

Table 16.3 shows the alternative computations :

From Table 16.3. we find that :

Max. Excess demand, $E_d = 828750\ l$

Max. excess pumping, $E_p = 1451250\ l$

$$\therefore \quad S = E_d + E_p = 828750 + 1451250 = \mathbf{2280000} \text{ litres.}$$

**Example 16.2.** *Find the reservoir capacity for the data of Table 16.1 if the pumping occurs between 6 A.M. and 6 P.M. (i.e. for 12 hours) only.*

**Solution :**

The total volume of water required to be pumped is 21.51 million litres, and this is to be accomplished in 12 hours, between 6 A.M. to 6 P.M. Hence in the mass curve shown in Fig. 16.5, draw the cumulative pumping line *AB* so that total pumping of 21.51 million litres is accomplished between 6 A.M. to 6 P.M. Project point *A* vertically upward to intersect with the cumulative demand

**TABLE 16.3. (Example 14.1)**

| *Time* | *Hourly demand (l)* | *Cumulative demand (l)* | *Hourly pumping (l)* | *Cumulative pumping (l)* | *Excess demand* | *Excess pumping (l)* |
|---|---|---|---|---|---|---|
| *(1)* | *(2)* | *(3)* | *(4)* | *(5)* | *(6)=(3)−(5)* | *(7)=(5)−(3)* |
| 12 | 0 | 0 | – | – | – | – |
| 1 A.M. | 480000 | 480000 | 896250 | 896250 | – | 416250 |
| 2 | 540000 | 1020000 | 896250 | 1792500 | – | 772500 |
| 3 | 630000 | 1650000 | 896250 | 2688750 | – | 1038750 |
| 4 | 660000 | 2310000 | 896250 | 3585000 | – | 1275000 |
| 5 | 720000 | 3030000 | 896250 | 4481250 | – | 1451250 |
| 6 | 900000 | 3930000 | 896250 | 5377500 | – | 1447500 |
| 7 | 1020000 | 4950000 | 896250 | 6273750 | – | 1323750 |
| 8 | 1230000 | 6180000 | 896250 | 7170000 | – | 990000 |
| 9 | 1320000 | 7500000 | 896250 | 8066250 | – | 566250 |
| 10 | 1290000 | 8790000 | 896250 | 8962500 | – | 172500 |
| 11 | 1200000 | 9990000 | 896250 | 9858750 | 131250 | – |
| 12 | 1080000 | 11070000 | 896250 | 10755000 | 315000 | – |
| 1 P.M. | 960000 | 12030000 | 896250 | 11651250 | 378750 | – |
| 2 | 900000 | 12930000 | 896250 | 12547500 | 382500 | — |
| 3 | 900000 | 13830000 | 896250 | 13443750 | 386250 | – |
| 4 | 930000 | 14760000 | 896250 | 14340000 | 420000 | – |
| 5 | 960000 | 15720000 | 896250 | 15236250 | 483750 | – |
| 6 | 990000 | 16710000 | 896250 | 16132500 | 577500 | – |
| 7 | 1020000 | 17730000 | 896250 | 17028750 | 701250 | – |
| 8 | 1020000 | 18750000 | 896250 | 17925000 | 825000 | – |
| 9 | 900000 | 19650000 | 896250 | 18821250 | 828750 | – |
| 10 | 720000 | 20370000 | 896250 | 19717500 | 652500 | – |
| 11 | 800000 | 20970000 | 896250 | 20613750 | 356250 | – |
| 12 | 540000 | 21510000 | 896250 | 21510000 | – | – |

curve at $A_1$. Construct line $A_1 B_1$ parallel to $AB$, where point $B_1$ is the intersection of line $A_1 B_1$ with the vertical extended upward from 6 P.M. on the abscissa. The required storage will then be ordinate $B_1 E$. This is evidently equal to ordinate $A A_1$ + ordinate $BE$ = 3.93 + 4.80 = 8.73 million litres. This is about 40.6% of the day's consumption.

The analytical solution is given in Table 16.4. Since pumping is done only for 12 hours

$$\text{Pumping rate} = \frac{21510000}{12} = 1792500 \text{ l/hour.}$$

**TABLE 16.4 (Example 16.2)**

| *Time* (1) | *Hourly demand* (*l*) (2) | *Cumulative demand* (*l*) (3) | *Hourly pumping* (*l*) (4) | *Cumulative pumping* (*l*) (5) | *Excess demand* (6)=(3)−(5) | *Excess pumping* (*l*) (7)=(5)−(3) |
|---|---|---|---|---|---|---|
| 12 | 0 | 0 | – | – | – | – |
| 1 A.M. | 480000 | 480000 | – | – | 480000 | – |
| 2 | 540000 | 1020000 | – | – | 1020000 | – |
| 3 | 630000 | 1650000 | – | – | 1650000 | – |
| 4 | 660000 | 2310000 | – | – | 2310000 | – |
| 5 | 720000 | 3030000 | – | – | 3030000 | – |
| 6 | 900000 | 3930000 | – | – | 3930000 | – |
| 7 | 1020000 | 4950000 | 1792500 | 1792500 | 3157500 | – |
| 8 | 1230000 | 6180000 | 1792500 | 3585000 | 2595000 | – |
| 9 | 1320000 | 7500000 | 1792500 | 5377500 | 2122500 | – |
| 10 | 1290000 | 8790000 | 1792500 | 7170000 | 1620000 | – |
| 11 | 1200000 | 9990000 | 1792500 | 8962500 | 1027500 | – |
| 12 | 1080000 | 11070000 | 1792500 | 10755000 | 315000 | – |
| 1 P.M. | 960000 | 12030000 | 1792500 | 12547500 | – | 517500 |
| 2 | 900000 | 12930000 | 1792500 | 14340000 | – | 1410000 |
| 3 | 900000 | 13830000 | 1792500 | 16132500 | – | 2302500 |
| 4 | 930000 | 14760000 | 1792500 | 17925000 | – | 3165000 |
| 5 | 960000 | 15720000 | 1792500 | 19717500 | – | 3997500 |
| 6 | 990000 | 16710000 | 1792500 | 21510000 | – | 4800000 |
| 7 | 1020000 | 17730000 | | 21510000 | – | 3780000 |
| 8 | 1020000 | 18750000 | | 21510000 | – | 2760000 |
| 9 | 900000 | 19650000 | | 21510000 | – | 1860000 |
| 10 | 720000 | 20370000 | | 21510000 | – | 1140000 |
| 11 | 600000 | 20970000 | | 21510000 | – | 540000 |
| 12 | 540000 | 21510000 | | 21510000 | – | 0 |

From Table 16.4, we find that

Max. excess demand $E_d = 3930000$ litres

Max. excess pumping, $E_p = 4800000$ litres

$$\therefore \quad S = E_d + E_p = 3930000 + 4800000 = 8730000 \text{ litres}$$

= 8.73 million litres