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MME345 Foundry Engineering

Lecture B10: Case Study in Design of Feeding a System

1. Calculation of Feeder Size

Many techniques are available for feeder size calculation. Here the modulus method will be followed. The modulus, M, of a casting is defined as

$$M = V/A \qquad (1)$$

where V is volume and A is cooling area of casting.

According to Chworinov, solidification time increases as the volume to area ratio, and hence M, increase. Thus

$$t \propto (V/A)^2 \qquad (2)$$

or, $$t = CM^2 \qquad (3)$$

where, t is solidification time, and C is constant.

Moduli of different simple shapes are given in **Fig. 1**.

In practical situations, complex shapes are involved. For complicated shapes, the casting is subdivided into smaller basic shapes and modulus is calculated for each section. Only cooling surfaces are considered and imaginary contact surfaces are omitted during modulus calculations. Feeding requirement for each section is then calculated for each section as required. Complex shapes and junctions are approximated by simulation bodies as outlined in **Fig. 2**.

As a general rule, the feeder must solidify no sooner than the casting has solidified (freezing time or heat transfer criterion). Also, the feeder must contain sufficient liquid to meet the volume contraction requirement (feed volume criterion). Thus a feeder of optimum size must satisfy both of these requirements.

Heat transfer criteria

According to Wlodawer's technique, the modulus of the feeder should be greater than that of the casting. Thus, using a 20% factor of safety,

$$M_F \geq 1.2\, M_C \qquad (4)$$

where M_F and M_C are modulus of feeder and casting, respectively.

To avoid shrinkage cavities near the feeder neck the following ratio should be maintained:

$$M_C : M_N : M_F = 1 : 1.1 : 1.2 \qquad (5)$$

where M_N is modulus of neck of feeder at the junction of casting.

Feed volume criterion

The feeder should not only solidify later than the casting, it should also have enough volume to compensate the shrinkage. Feed volume requirement is given by the relation:

$$\varepsilon V_F = \alpha (V_F + V_C)$$

or, $$V_F = \alpha V_C / (\varepsilon - \alpha) \qquad (6)$$

where ε = efficiency of the feeder ($\cong$14% for cylindrical feeder with H=1.5 D), α = solidification shrinkage, V_F = volume of the feeder, and V_C = volume of the casting.

The feeder volume given by the feed volume requirement does not depend on the casting shape but that given by the mass transfer or modulus criterion does.

The higher of the two values of feeder volume given by equations (4) and (6) is taken as the actual volume of the feeder.

2. Determination of Feeder Shape

According to equation (3), solidification time depends upon the square of modulus of the casting. Sphere, having the smallest modulus per unit volume, is therefore the ideal shape for a feeder. But a spherical feeder practically too difficult to mould and consequently cylindrical feeders are mostly used.

3. Feeding Distance

In normal conditions, there is a limit to how far a feeder can feed along a flow path. Up to this distance from feeder, the casting will be sound. Beyond this distance the casting will exhibit porosity. For feeding distance rule, see **Fig. 3**.

4. Increasing Feeing Efficiency

There are number of ways by which the efficiency of a feeder can be increased. Some of the most common ways are:

1. By using feeder head with a higher feeding efficiency
2. Feeder insulation
3. Use of exothermic materials

Details of these processes are given in **Fig. 4**.

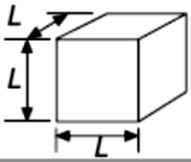
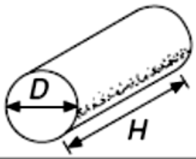
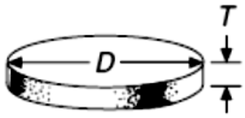
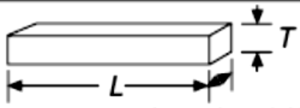
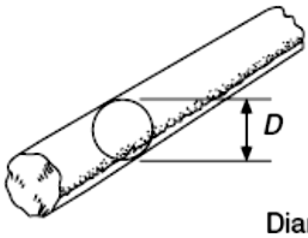
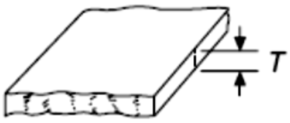
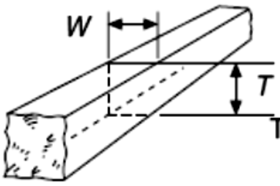
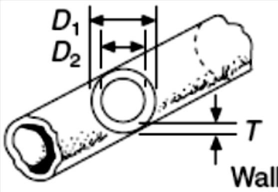
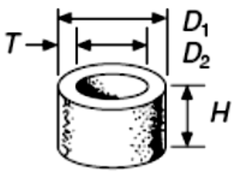
Shape	Dimensions	Modulus
(a) Cube	 Side = L	$\frac{L}{6}$
(b) Cylinder	 Diameter = D Height = H	$\frac{DH}{2D+4H}$ *Note*: If $H = D$ the modulus is $\frac{D}{6}$
(c) Disc	 Diameter = D Thickness = T	$\frac{DT}{2D+4T}$
(d) Bar or plate	 Length = L Width = W Thickness = T	$\frac{TWL}{2(TW+WL+LT)}$
(e) Endless cylinder (ends terminated by another part of casting)	 Diameter = D	$\frac{D}{4}$ *Note:* Because radial heat flow is faster than that from a flat surface, calculated moduli for endless cylinders may be reduced by multiplying by 0.85
(f) Endless plate (terminated on all sides by another part of casting)	 Thickness = T	$\frac{T}{2}$
(g) Endless bar (ends terminated by another part of casting)	 Thickness = T Width = W	$\frac{TW}{2(W+T)}$
(h) Endless hollow cylinder	 $OD = D_1$ Dia. core = D_2 Wall thickness = T	$\frac{D_1 - D_2}{4} = \frac{T}{2}$
(i) Annulus	 $OD = D_1$ Dia. core = D_2	$\frac{(D_1 - D_2)}{2(D_1 - D_2) + H}$ $= \frac{TH}{2(T+H)}$

Fig.1: Moduli of some common shapes.

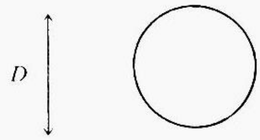
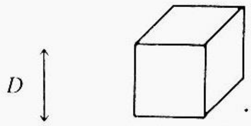
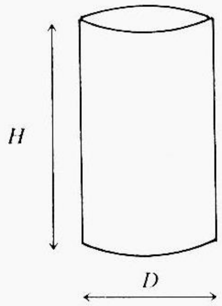
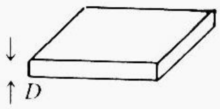
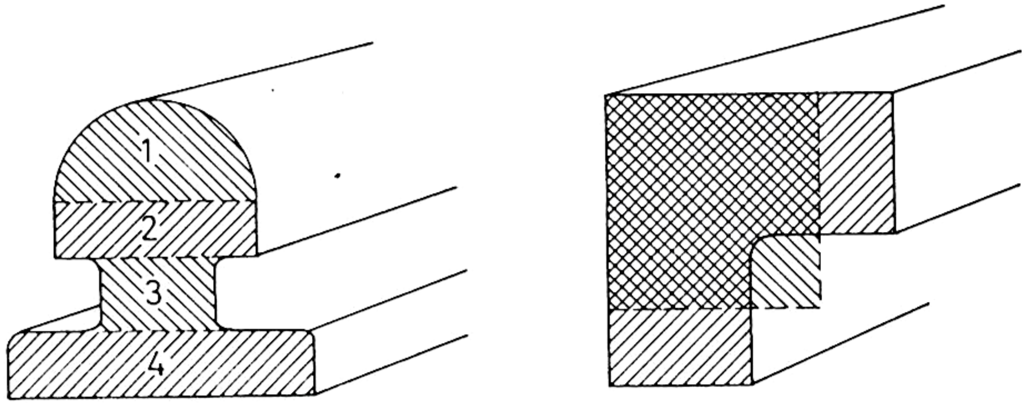
Shape			*Modulus*			
			100% Cooled area		*Base uncooled*	
Sphere			$\frac{D}{6}$	$0.167D$	—	—
Cube			$\frac{D}{6}$	$0.167D$	$\frac{D}{5}$	$0.200D$
Cylinder		*H/D*				
		1.0	$\frac{D}{6}$	$0.167D$	$\frac{D}{5}$	$0.200D$
		1.5	$\frac{3D}{16}$	$0.188D$	$\frac{3D}{14}$	$0.214D$
		2.0	$\frac{D}{5}$	$0.200D$	$\frac{2D}{9}$	$0.222D$
Infinite cylinder		∞	$\frac{D}{4}$	$0.250D$	–	–
Infinite plate			$\frac{D}{2}$	$0.500D$	–	–

Fig.1: Moduli of some common shapes (contd..)



(i) (ii)

Fig. 2: Method of determining modulus of irregular shapes. The cross-section is determined either (i) by subdivision into simple shapes and (ii) by approximated by substitute shapes.

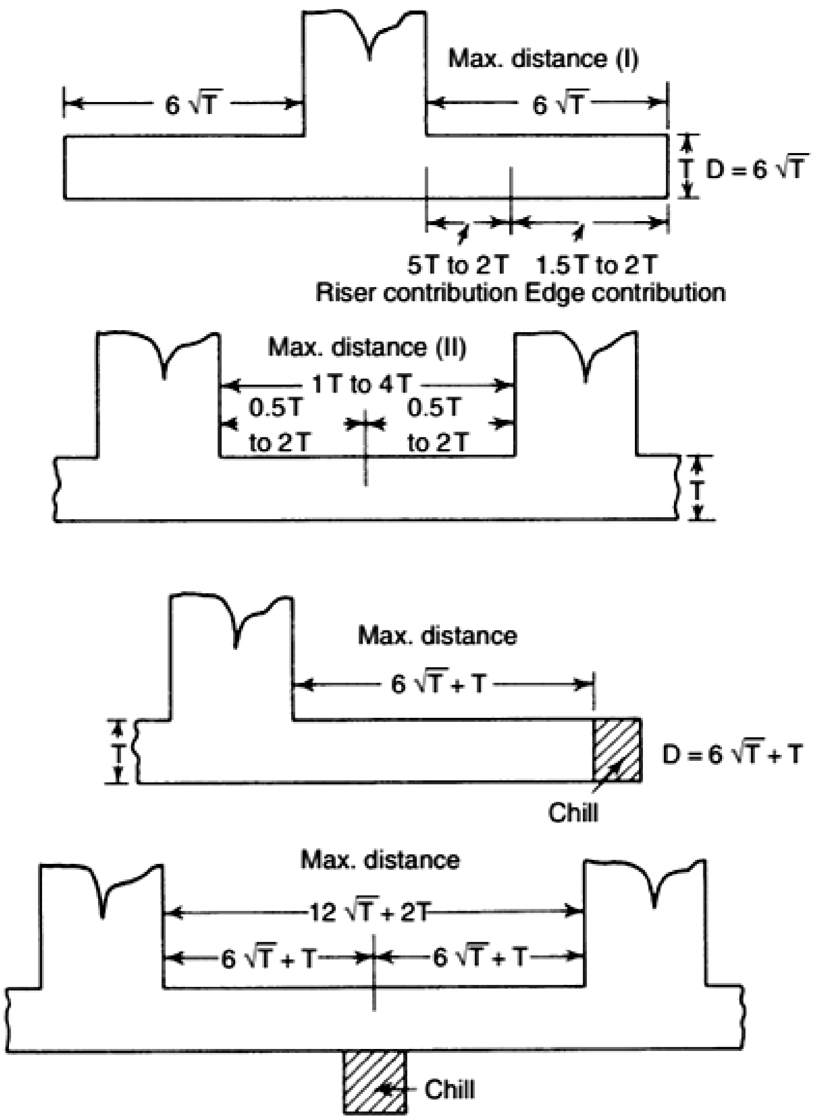


Fig. 3a: Feeding distances for steel bars cast in greensand.

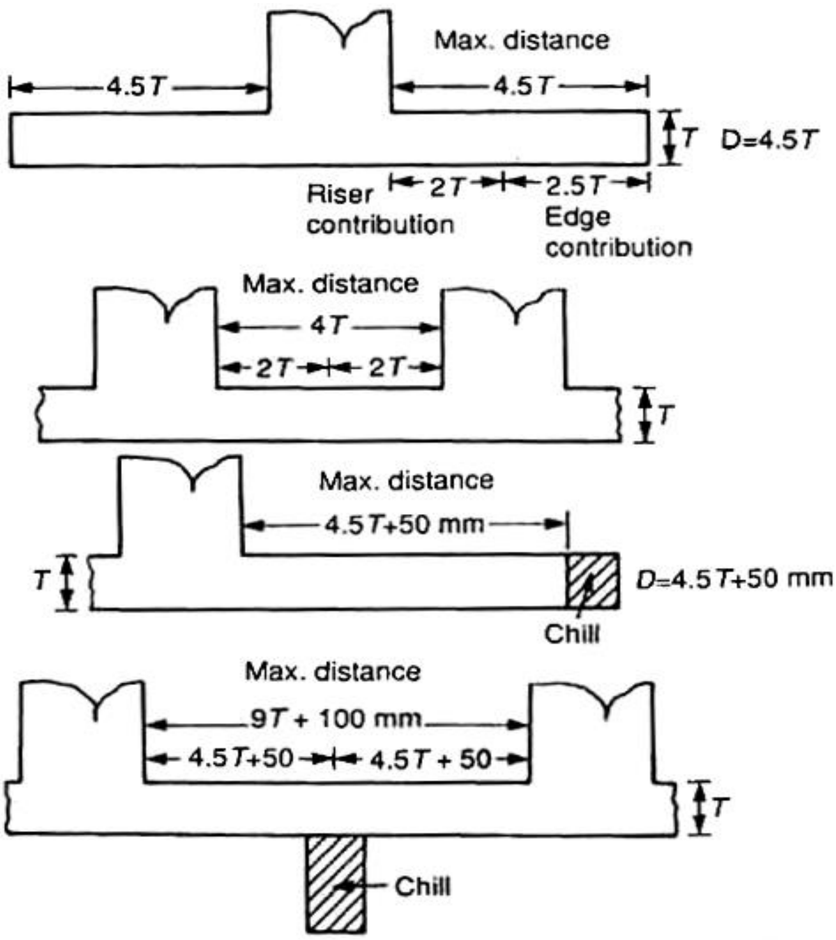


Fig. 3a: Feeding distances for steel plates cast in greensand.

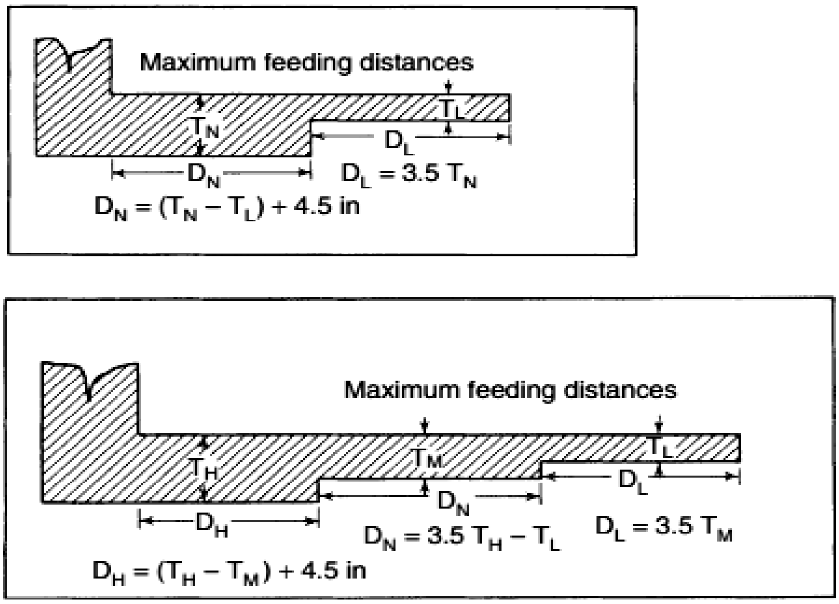


Fig. 3c: Feeding distances for dual and multiple gates.

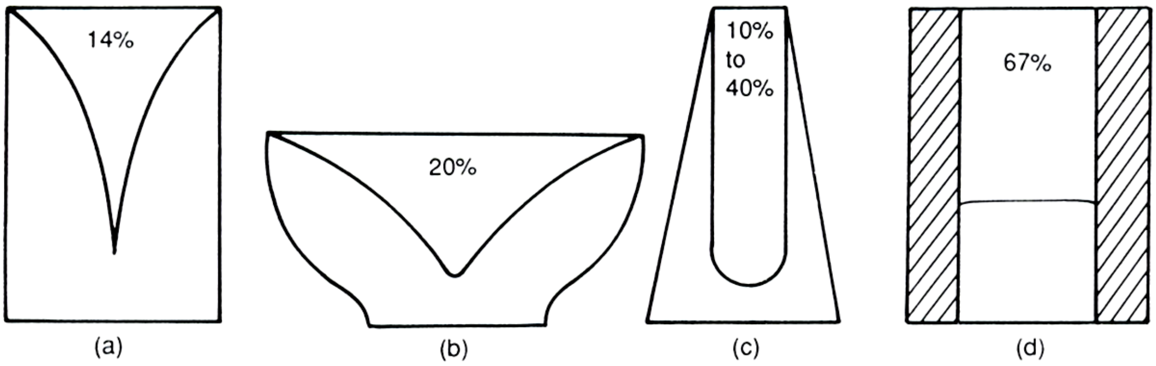
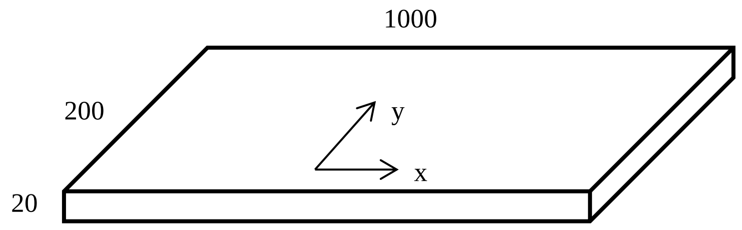


Fig. 4: Metal utilisation of feeders of various forms moulded in sand. The (a) cylindrical and (b) hemispherical heads have been treated with normal feeding compounds; (c) the efficiency of the reverse tapered heads depends on detailed geometry; (d) shows an exothermic sleeve.

Case Study

Design a suitable feeding system for the following plate casting (dimensions are in mm).



Aluminium casting
Density = 2.7 g/cc

Moulding system: Greensand
Pouring temperature = 700 °C

Solution:

Volume of casting, V_C = 100 x 20 x 2 = 4000 cc

Let us assume that a cylindrical feeder (H = 1.5 D) will be placed on top of the casting.

Thus, a T-junction will be created between the casting and the feeder.

Now let us first consider the **Junction Criterion** (or, freezing time criterion) requirement of the feeding design.

Considering the casting as an infinite plate, its modulus

$$M_C = t/2 = 20/2 \text{ mm} = 10 \text{ mm} = 1.0 \text{ cm}$$

Then, according to the T-junction criterion, the modulus of the feeder

$$M_F = 2\,M_C = 2\,(1.0 \text{ cm}) = 2.0 \text{ cm}$$

For the given cylindrical feeder (H = 1.5 D) with base-uncooled (i.e., not in direct contact with the liquid metal), its modulus

$$M_F = 3D/14 = 2 \text{ cm}$$

$$D = 9.33 \text{ cm}$$

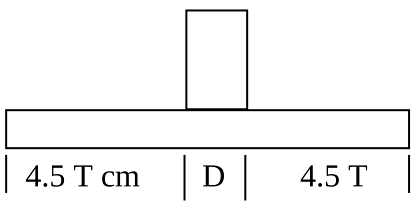
$$H = 1.5\,(9.33 \text{ cm}) = 14.0 \text{ cm}$$

Then the volume of a single feeder of D = 9.33 cm and H = 14.0 cm is

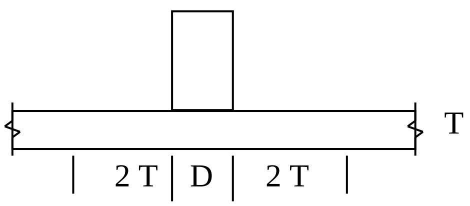
$$V_F = (\pi/4)\,D^2 H \text{ cc} = (\pi/4)\,(9.33)^2\,(14) = 957 \text{ cc}$$

Now we have to determine the number of feeder of this size and shape to be required by the given casting. To determine this, we need to calculate the **feeding distance** of this feeder.

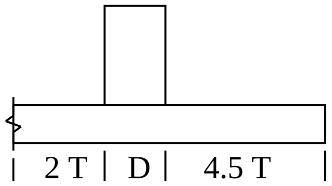
Consider the following 4 situations of using the feeder on top of the casting:



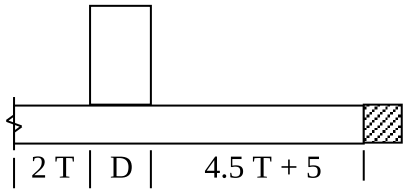
Type 1 (both end effect)



Type 2 (no end effect)



Type 3 (one end effect)



Type 4 (one end effect + chill)

Then, the total feeding distance for each situation

For type 1, F_d = D + 9 T = 9.33 + 9 (2.0) cm = 27.33 cm

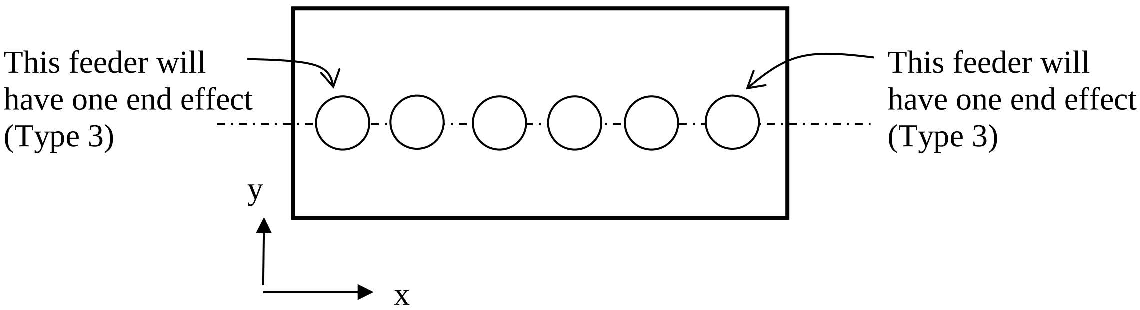
For type 2, F_d = D + 4 T = 9.33 + 4 (2.0) cm = 17.33 cm

For type 3, F_d = D + 6.5 T = 9.33 + 6.5 (2.0) cm = 22.33 cm

For type 4, F_d = D + 6.5 T + 5 = 9.33 + 6.5 (2.0) + 5 cm = 27.33 cm

Thus, as the casting width (along y-direction) is 20 cm, if a feeder is placed at the centre (Type 1), it will feed the whole casting along the y direction.

Along the x direction, however, multiple feeders are required.



The two extreme end feeders (Type 3) will cover a distance of 2 (22.33) = 44.66 cm.

Distance remaining to feed along x-direction = 100 – 44.66 cm = 55.34 cm.

Within this distance, the feeders to be placed will have no end effect (Type 2).

Thus, number of type 2 feeder required within this distance of 55.34 cm = 55.34 cm / 17.33 cm = 3.19 ≈ 4 nos.

Thus, total number of feeder required = 2 + 2 = 6 nos.

Total volume of all feeders = 6 (957 cc) = 5742 cc.

If two end chills are used, then

2 x Type 4, F_d = 2 (27.33 cm) = 54.66 cm

No. of Type 2 = (100 – 54.66) / 17.33 = 2.62 ≈ 3 nos.

So, total no. of feeder required = 2 + 3 = 5 nos.

Total feeder volume requirement = 5 (957 cc) = 4785 cc.

Let us now consider the second criterion i.e., the **Volume Criterion** requirement of the feeding design.

According to this rule

$$V_F = \alpha V_C / (\varepsilon - \alpha)$$

For aluminium casting, $\alpha = 7\ \% = 0.07$, and the efficiency of the given feeder, $\varepsilon = 0.14$.

Then the volume of feeder required is

$$V_F = (0.07)\ (4000\ cc) / (0.14 - 0.07) = 4000\ cc$$

If an insulating sleeve is used, then the efficiency of feeder is 67%. Then

$$V_F = (0.07)\ (4000\ cc) / (0.67 - 0.07) = 467\ cc$$

Comparing the junction and volume criteria, the volume calculated by junction criterion is greater than that calculated by volume criterion. Thus the former will apply.

Hence, if no chill is used, 6 feeders of dimension D = 9.33 cm and H = 14.0 cm will be used and the total volume of the feeders will be 5742 cc. Alternately, if two end chills are used, only 5 feeders of the same dimensions will be needed and the total volume of the feeders will be 4785 cc.