THE THEORY OF TUBE-MILLING*

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As experience has greatly increased our knowledge of the most economical methods of using the tube-mill, it has, at the same time, opened up fresh problems which still await both theoretical and practical solution.

The whole subject may conveniently be considered under the two heads of design and operation. These may be further sub-divided as follows:

Design.—(a) Shape; (b) Dimensions; (c) Linings; (d) Discharge; (e) Feed; (f) Prime mover; (g) Measuring apparatus.

Operation.—(a) Speed of revolution; (b) Load of pebbles; (c) Working level of load; (d) Size of pebbles; (e) Coarseness of feed; (f) Amount of feed; (g) Moisture in feed; (h) Fluctuations in power and speed.

Shape.—From the fact that the operation of a tube-mill depends almost entirely upon centrifugal force arises the theoretical deduction that a long cylinder is the most suitable shape. The length of this cylinder will be determined (if trunnion bearings are used) by strength of material which it is economical to use for its walls, and generally by the amount of feed which it is possible to pass through the tube. The maximum length must obviously not exceed that at which the discharged product is as fine as the final pulp required, and in order that capacity may be fully utilized it is probably best that the pulp discharged should not contain much more than half its weight reduced to the desired fineness. Thus if the final product desired is of —90 material, the tube discharge should not have much more than 45 per cent. of this grade. This ensures a full supply of material to be crushed up to the very end of the mill, though the feed end will be working under the more favorable conditions. The practical limit will favor length (giving larger units), while the merely theoretical aspect would be in the other direction, which tends to remove from the circuit all material fine enough as soon as it is produced. The short tubes temporarily in favor in some parts of the world principally owe their adoption to some other feature of their design, whose effect is not fully appreciated, or to the fact that the tonnage of sand fed is too small for the most efficient work in longer tubes.

The only other shape suggested is a combination of the cylinder with a double cone, and this design is apparently based upon a misapprehension of what takes place in the tube of ordinary shape. This mill aims to provide special arrangements for graduating the power to the work required, but having a varying diameter must be driven at a speed which, however carefully chosen, must be incorrect for a great portion of the load. The varying crushing power, in a direction parallel with the axis, so expensively attained in the Hardinge Mill, is inevitably present in the ordinary mill, in a direction at right angles to the axis, and the well known tendency of the smaller pebbles to travel toward the discharge end of the standard tube mill, gives the advantage of reducing the power consumed at the point where the feed has naturally become finer. It is obvious that the unit of capacity is more cheaply obtained in a cylinder than in a double cone, and no defence of any sort has been put up for the cone at the inlet end.

It might be suggested that a slightly tapered cylinder (say 2 in. wider at inlet than outlet) would be useful, as the lining, if 2 in. thicker at inlet than discharge, as is common with silex liners, would have a cylindrical surface when new, and while giving a uniform "life" along the tube, would improve the tendency to keep the larger pebbles near the feed end and provide a longer average drop at this point where the feed is coarsest.

This construction would not interfere with giving correct speed more than the wear of liners does at present, but it is doubtful if the increased capital required could not be better utilized in a different type of liner, especially as the extra diameter at inlet would have an unfavorable effect upon the adjustment of the "working level" subsequently referred to.

Dimensions.—Having concluded that the shape most suitable is a long cylinder, the relative and absolute dimensions of length and diameter require further consideration.

The diameter of a tube mill will depend upon the size of the largest pieces in the feed and the largest pebbles which can conveniently be used. The weight of the pebble and the diameter of the tube are to some considerable extent mutually compensating factors whose product will determine the largest pieces permissible in the feed.

The longest drop any pebble in a tube will get will be in the layer corresponding with an "angle of departure" of 45 deg., if the speed of revolution is sufficient to give any layer that angle; if not, the outer layer will have the longest drop. The drop cannot therefore exceed 0.8 x diameter of "circle of reference." (The "circle of reference" is the locus of centres of pebbles touching the lining of the tube, and the "angle of departure" is the angular distance from horizontal diameter of tube at which a pebble begins its curve of flight.)

The ft. lb. of energy required to smash any piece of average ore will vary as the square of its diameter, and may be from 2 to 6 ft. lb. for a 1 in. diameter piece, in accordance with shape, etc.

Assuming a maximum of 6 ft. lb. for 1 in. feed, pebbles approximately spherical with Sp. Gr. 2.75, and tube linings of 4 in. thickness, if the largest pieces of ore to be fed were of 1 in. diameter the following would be diameter of tubes required:

For a 4-in. pebble a tube diameter of 39 in.; for a 3-in. pebble a tube diameter of 76 in.; for a 2-in. pebble a tube diameter of 226 in. In a similar manner it may be calculated that a standard tube of 5 ft. 6 in. x 22 ft. will not take a feed coarser than ½ in. unless a sufficient proportion of pebbles larger than 2 in. are present.

Similarly, if it were required to design a tube to take ore direct from the rock-breakers with a maximum size of 3 in., the diameters corresponding with various pebble sizes, putting the blow required at 36 ft. lb., and allowing for a lining 4 in. thick would be:

For 6 in. pebbles a tube of 5 ft. 2 in. dia.; for 5-in. pebbles a tube of 8 ft. dia.; for 4-in. pebbles a tube of 14 ft. 6 in. dia.

As, however, the blow is mitigated by resistance of semi-fluid pulp so that in practice it is found that feed larger than ½ in. is somewhat unsatisfactory with the 5 ft. 6 in. tube, though the pebbles present therein will average about 0.65 lb. (2¼ in.) with lumps of rock fed in at an average of about 2 lb., it is probable that a suitable tube for taking ore direct from the rock-

*Extracts from a paper presented at a meeting of the Chemical, Metallurgical and Mining Society of South Africa.