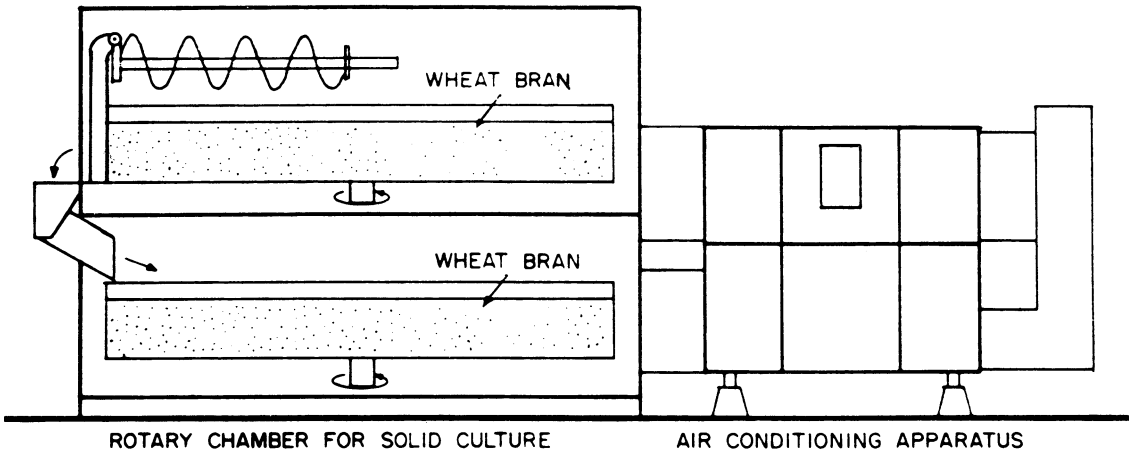

Figure 9.17. Rotary, automatic koji-making apparatus. The apparatus has a two-storied chamber. Each chamber has a large rotary tray on which wheat bran is heaped evenly. After inoculated fungus has grown sufficiently, solid culture is transferred by a screw conveyor to the lower rotary-tray hopper. (With permission, from N. Toyama, *Biotechnol. Bioeng. Symp.*, Vol. 6, pp. 207–219, 1976, John Wiley & Sons, Inc., New York.)

volume, low-product-value processes (e.g., waste treatment and fuel-grade ethanol production). Multistage continuous systems improve the potential usefulness of continuous processes for the production of secondary metabolites and for the use of genetically unstable cells. The fed-batch system is widely used in commercial plants and combines the features of continuous culture and batch that allow the manufacturer to maintain flexibility and ease of intervention. The perfusion system is another option that is particularly attractive for animal cells.

Immobilized cell systems offer a number of potential processing advantages, and the commercialization of such systems is proceeding rapidly where cell culture is expensive and difficult (e.g., animal cell tissue culture). Physical entrapment or encapsulation is used in most cases, although adsorption onto surfaces or covalent binding of cells to surfaces is possible.

In some cases, self-immobilization on surfaces is possible and a biofilm is formed. Biofilm reactors can apply to tissue culture, mold, and bacterial systems. Biofilm-based reactors are very important in waste-treatment applications and in natural ecosystems. The analysis of immobilized cell reactors is analogous to that for immobilized enzyme reactors except for the feature of biocatalyst replication.

Solid-state fermentations share some characteristics with immobilized cell systems, but differ in that no discernible liquid is present. SSFs have found important uses in the production of some traditional fermented foods and may have use in upgrading agricultural or forest materials and in the production of mold products requiring full mold differentiation.