Trickling biological filters consist of a packed bed of inert support particles (sand or plastics) covered with a mixed culture of microorganisms in the form of a film or slime layer and cell aggregates. The column is loosely filled with packing material to yield a void fraction of 0.4 to 0.5. The filter bed is usually arranged in the form of a rather shallow bed with a high diameter-to-height ratio ($D/H \approx 3$) to avoid possible clogging problems and axial variations. Waste-liquid is fed to the top of the bed using rotary liquid distributors. The waste-liquid flow rate should be low enough to avoid creating shear forces that would remove biofilms from the surfaces of support particles. Air enters the bed from the bottom and moves upward by natural convection. The driving force for air circulation is the temperature difference created by heat released by biological oxidations. The reaction medium is highly heterogeneous, having temperature, pH, dissolved oxygen, and nutrient profiles throughout the column. The thickness of the biofilm and the composition of the organisms in the biofilm may vary with the length of the column. Dissolved-oxygen limitations are likely because of the high density of cells, unfavorable hydrodynamic conditions, and diffusion barriers within the film. Preaeration of the feed waste-water stream (to saturate with oxygen) and high liquid circulation rates may partly alleviate oxygen transfer problems.

As the liquid flows downward in the column on the surface of microbial films, organic compounds (substrates) diffuse through the microbial film and are utilized by organisms simultaneously. The liquid film over the biomass film should be thin enough to allow adequate aeration. A typical liquid film thickness is on the order of 0.01 mm, and biofilm thickness is 0.25 mm. Typical hydraulic residence times in trickling biological filters (TBF) are 0.5 to 4 h for high-rate filters using recirculation of effluent. Trickling filters are more stable against shock loads than are activated-sludge units. Trickling filters also entail lower operating costs and often give better effluent clarity compared to activated-sludge units. However, capital cost and space requirements for trickling filters are higher than for activated-sludge units, and trickling filters remove a smaller fraction of the soluble organics. Also, the maximum concentration of BOD in the influent is more constrained in trickling filters than in activated-sludge systems. A major problem with the operation of trickling filter units is poor control of conditions (T, pH, DO) due to the heterogeneous nature of the system. A comparison of trickle biological filters (TBF) with activated-sludge units (ASU) is presented in Table 16.3.

The liquid effluent of TBFs is usually recycled to obtain more complete removal of BOD from waste-water streams. Figure 16.8 is a schematic of a trickling biological filter.

The substrate balance on a differential height of a trickling biological filter yields

$$-F\,dS_0 = N_s aA\,dz \qquad (16.41)$$

where F is liquid flow rate (l/h), N_s is the substrate flux or rate of substrate utilization per unit surface area of biofilm (mg S/cm^2 film h), a is biofilm surface area per unit volume of the bed (cm^2 film/cm^3), and A (cm^2) and z (cm) are the cross-sectional area and the height of the bed, respectively.

The substrate flux or rate of substrate consumption is

$$N_s = -D_e \left.\frac{dS}{dy}\right|_{y=L} = \eta \frac{r_m S_0}{K_s + S_0} L \qquad (16.42)$$