same heterogeneity in environment that exists at the larger scale. In many cases, scale-up will require using existing production facilities, so it is important to mimic those production facilities at a smaller scale. At the smaller scale, many parameters can be tested more quickly and inexpensively than at the production scale. Also, such a small-scale system can be used to evaluate proposed process changes for an existing operating process.

Figure 10.8 is a sketch of a smaller-scale apparatus to approximate the types of variations in substrate and dissolved-oxygen concentrations that might be expected from a mixing-time analysis (or from estimates from time constants) or from actual data on residence-time distributions from a large reactor. The difference between this scale-down apparatus and a traditional smaller-scale fermenter in a pilot plant is that the type of apparatus described in Fig. 10.8 is constructed specifically to mimic a known piece of equipment. It should be noted that the apparatus in Fig. 10.8 would not mimic temperature heterogeneity as it might exist in the larger system. Modifications to control temperature separately in each subvessel could be made.

Such a scale-down apparatus could be used to estimate the system's response (e.g., growth rate, product formation, and formation of contaminating by-products) to changes in medium composition (e.g., a new supplier of raw materials), introduction of modified production strains, use of different inoculum preparations, new antifoam agents, and for testing for O_2 and CO_2 tolerance. Corrective protocols can be suggested also for use in the large-scale system by simulating the response to pH or oxygen-probe failure or compressor failure during different phases of the fermentation.

Construction of scale-down apparatus can be a powerful complement to mathematical models, scale-up rules, and traditional pilot-plant operation.

Examples 10.2, 10.3 and 10.4 illustrate scale-up issues.

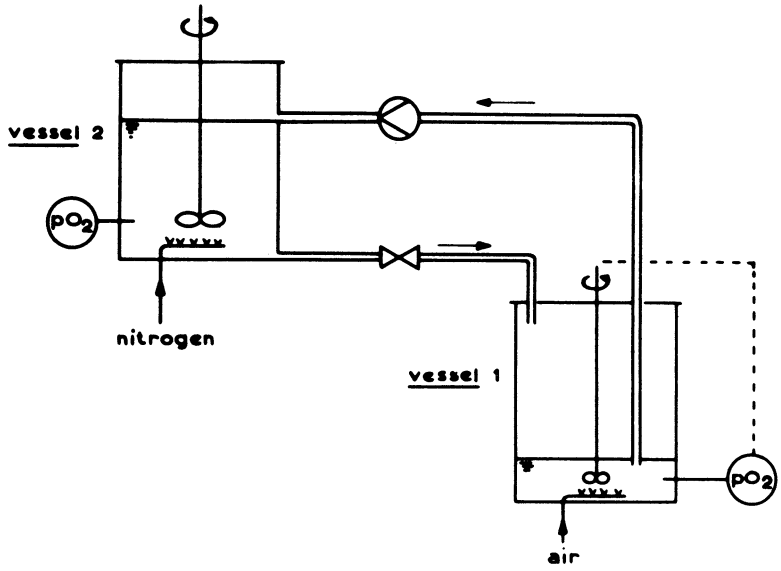

Figure 10.8. Experimental setup for scale-down experiments. (With permission, from N. W. F. Kossen, in T. K. Ghose, ed., *Biotechnology and Bioprocess Engineering*, United India Press, New Delhi, 1985, pp. 365–380.)