8. Aspects of scale-up of BFBR

The BFBR must be scaled-up for practical application in industrial and municipal sewage treatment. Actual scale-up is not within the scope of the thesis. This chapter briefly discusses the scale-up and engineering issues that need to be confronted in the further development of the BFBR.

The potential applications of the BFBR are in treatment of effluents from

- Papermills using wastepaper
- Dairy
- Food processing
- Sewage treatment
- Slaughterhouses
- Edible oil

8.1. Process design specifications

The BFBR process design parameters recommendations is culled from the experimental data (Chapter 6) and given below:

a. Organic loading rate
   COD loading rate: 6 to 8 kg COD/m$^3$/d.
b. Filter specifications:
   - Filter media size: 1 to 1.5 mm
   - Filter depth: 10 to 15 cm
   - Filtration velocity: 1 to 2 m/h
   - Filter pressure drop: < 20 cm w.c.
   - Filter backwash velocity: 130 m/h
   - Bed expansion: 30%
   - Filter backwash interval: 15 to 30 minutes
   - Filter backwash volume: ~ 100% of filter volume

The BFBR mathematical model (Chapter 7) can be used to improve the COD loading rate specification if the wastewater can be characterized in detail.
8.2. Reactor vessel shape and L/D ratio.

The BFBR shape can be either circular or rectangular in cross-section. The cylindrical shape is cost-effective for tall reactors. The trend in advanced high-rate anaerobic reactors is taller reactors (large L/D), reducing the footprint. The L/D ratio for BFBR is limited only by the need to provide sufficient cross-sectional area for arrangement of the filter within the reactor. The filter area required is determined by filter load. Filter hydraulic loading rates are determined by backwash requirement in the treatment of high-strength effluent, whereas, in the treatment of low strength effluent, the hydraulic load generated by effluent as well as backwash are both equally significant.

8.3. Mixing system

BFBR reactors will generate scum at least during load increases. Scum breaking needs special designed agitators. Reactor design with small liquid-gas interface confines scum accumulation in a small area and makes it easier to design scum disintegrating equipment. Usually mechanical agitators are required for disintegrating scum. It is difficult to provide top entry mechanical mixers in a BFBR because of the filter arranged inside the reactor. It is easier to provide a gas mixer in the BFBR, the mixer having the double function of driving backwash at regular intervals even in the absence of gas generation in the reactor. Gas mixers are not very effective in disintegrating scum. Hence, in the treatment of scum forming complex wastewater (such as dairy effluent), simple gas spargers should be replaced by large bubble mixers (eg. the Infilco-Degremont Cannon mixer\textsuperscript{56}). Alternately, the reactor hydrodynamics can be tailored with draft tube and flow deflectors so as to create high velocity suction of scum into the liquor.

8.4. Backwash

If the strength of the waste is at least 4 g-COD/l, gas production will be sufficient for driving the backwash. Nevertheless, a gas recirculation system is need for backwash during start-up.

The head required for backwash is less than 50 cm. The head requirement need not be confused with liquid head above the filter top. The driving head is
the pressure of gas in the gas accumulation tank. The depth of filtered treated effluent above the filter bed need not be equal to the head required for filter backwash. But the volume of filtered treated effluent should be sufficient for backwash.

8.5. Filter arrangement

The filter area required is large. The simplest design is inside the reactor vessel. A GLS separator similar to UASB positioned below the filter prevents gas entry into the filter bed and reduces the sludge load on the filter. The filter is retained with mesh on top and the bottom of the filter chamber can be open. The filter has to be partitioned to ensure uniform fluidization and reconstitution of the filter bed. The scale-up of the filter assembly is simple parallel arrangement of several small-size filter chambers.

8.6. Filter media manufacture

EPS resin is used in the manufacture of moulded polystyrene foam articles. The first step in the manufacture of moulded polystyrene foam articles is expansion of resin into beads by steaming. Hence, it is possible to source the filter material by specifying the resin and time of expansion. The sorting of expanded beads by size and density requires to be carried out specially as these operations are not used in any of the current applications of EPS.

8.7. Design of automatic filter backwash control system

The backwash control system can be electric or hydraulic.

The electric system requires level or pressure sensors and control valves to trigger the backwash. The outflow of gas from the gas pressure chamber (gas accumulator) has to be completed in less than 10 seconds during which the filter bed expands. Hence large gas exit pipe has to be provided. The valves have open fully and close in this interval. Ordinary full port large size valves cannot open and shut at high speed and special actuators are needed. The level sensor / pressure sensor has to work in a environment where foam and scum are present. It has to be mounted so as to be serviceable without shut-down of the reactor.
The hydraulic gas siphon does not have mechanical and electrical issues, but scale-up is difficult. To recapitulate, the hydraulic gas siphon comprises a downcomer, a riser and a slug catcher. As gas accumulates, the gas-liquid interface in the downcomer is depressed, till gas can exit via the riser. Gas exit should form a slug (Taylor bubble) that pushes out the liquid in the riser to a slug catcher. Thereby the liquid seal is broken and gas collected in the accumulator escapes till liquid enters via the downcomer and the liquid seal reforms. When scaling up to large diameter risers, it is critical to ensure that gas should form a slug and not trickle out through the riser liquid pool. The designer needs to understand the hydrodynamic conditions for slug formation in vertical pipe flow in order to design an automatic hydraulic backwash system.

### 8.8. Start-up and shut down issues

BFBR start-up is very similar to UASB reactors. Availability of high activity seed sludge will help start-up the reactor quickly. Even poor quality seed sludge can be used for start-up since washout is less than in other reactors. BFBR reactor with protozoa rich sludge would take time to reach optimal operating efficiency. Further during shutdown, the protozoa population is likely to be wiped out and will take 2 to 3 weeks to re-establish.

### 8.9. Remarks on costs

BFBR costs are comparable with that UASB reactors of similar reactor vessel sizes. The BFBR reactor vessels has to fit in gas accumulators and filtered liquid pool. The volumes of filter, gas accumulator and filtered liquid pool are less than 10% of the volume of reactor. In order to have gas pressure of 0.5 to 1m w.c. in the gas accumulator, gas collection GSS baffles must be at least 1 m below the lowest liquid level. The volume above the GSS baffles is considered inactive. In all, as a preliminary estimate, the reactor vessels are about 25% larger than the active volume required for specified loading and conversion efficiency.