Tubular Photobioreactors: A Comparison of Glass and Polymer Tubes from the Viewpoint of a Glass Manufacturer

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Tubular Photobioreactor Systems
Glass and polymer systems share a few common features

Pros:
I. Closed systems (low risk of contamination, culture crashes)  
II. Huge surface to volume ratio – good light dilution/utilization.

Cons:
I. Oxygen accumulation in loop lengths > 500m (then degassing tank)  
II. Overheating (but spray-water cooling)

Algatechnologies, Israel (glass tubes)  
BGG, China (glass tubes)  
AlgaePARC, Wageningen, NL (polymer tubes)
Tubular materials in direct comparison

Glass (Borosilicate) vs. PMMA and PVC

**Glass**
- Ø=65mm, d= 2.2 mm
- SCHOTT Duran® standard PBR glass tubes

**PMMA**
- Ø=63mm, d= 4.69 mm
- Sample received from outdoor-PBR operator

**UV-PVC**
- Ø=90mm, d=4.05 mm
- Advertised by manufacturer for use in outdoor PBRs with solar illumination
Transmission of Glass and Polymer tubes

**UV-PVC:**  
T~0 in \( \lambda < 400 \text{nm} \) and low T in VIS

**Glass, PMMA:**  
High transmission > 90%
Solar Degradation of Glass and Polymer tubes

- **Glass**: ≤0.1, 1 sun exposure, ~1y 420-720nm
- **PMMA**: 0.7 ± 0.3
- **UV-PVC**: 80.4

- **Duran**: 0 and 383 days 1x Sun
- **PMMA**: 0 and 385 days 1x Sun
- **UV-PVC**: 0 and 385 days 1x Sun

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Thermal Expansion

Glass (Borosilicate) vs. PMMA, PVC

The thermal expansion of polymers is 10-20 fold higher than glass
Tube Sag and Racking
Glass (Borosilicate) vs. PMMA, PVC

- Sag of polymer tubes is 10x larger than glass tubes
- Glass temperature where materials get soft:
  PVC 79°C  PMMA: 105°C  Duran: 525°C

Glass tubes are stiffer → less supports / poles

Source: SCHOTT AG Simulation
Blue (⌀=65mm, d= 2.2 mm) → Glass: SCHOTT DURAN®
Grey (⌀=63mm, d= 4.69 mm): PMMA,
Black (⌀=65mm d=4.05 mm): UV-PVC
Mechanical Cleaning of Glass Tubular PBRs

In situ with a pig…

…or with chemistry
(HCl, H2O2, citric acid, NaOH, Ozone…)

…or with pellets

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Glass is harder for higher scratch resistance

Glass (Borosilicate) vs. UV-stabilized Polyvinylchloride (PVC) and PMMA

\[ H_{IT} = \frac{F}{\pi \cdot (2R_i h_{pmax} - h_{pmax}^2)} \]

- \( h_{max} \) (polymer) \(~ 20-25 \mu m\)
- \( h_{max} \) (glass) \(~ 3 \mu m\)

Smother Glass Surfaces for less Biofilm Formation
Glass (Borosilicate) vs. UV-stabilized Polyvinylchloride (PVC)

Borosilicate Glass (DURAN®)

Source: Scanning electron microscopy (SEM) pictures, atomic-force microscopy (AFM) pictures and $R_{RMS}$ measurement by SCHOTT AG

Polymer (UV-stabilized PVC)

Advanced Study
How exactly does surface roughness influence bio-film build-up and cleaning of PBRs?

Source: Scanning electron microscopy (SEM) pictures, atomic-force microscopy (AFM) pictures and $R_{RMS}$ measurement by SCHOTT AG

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Typical Outdoor Lifetimes of Algae Culture Containments

- Plastic bags: 2-4 years
- UV-PVC: 3-5 years
- PMMA tubes: 8-12 years
- Glass tube PBR: >50 years

Information mostly obtained in private communications with PBR operators.
1. Comparison of Glass and Polymer Tubes for Tubular Photobioreactors

2. Trends and New Technologies
Trends and new Technologies

1. Market on the rise: Waste water cleaning (Clearas)

2. Vertical glass tube PBR (ecoduna, AT)

3. Artificial LED Illumination for PBRs
Growing Market: Waste Water Cleaning

Example: Clearaswater’s Advanced Water Recovery Process

Algae bloom after discharge of waste water with phosphorous from commercial agricultural runoff, sewage, and industry → Algae release toxins: risk for aquatic life and human health (when swimming or drinking the water)

With algae, by the same principle, waste water can be cleaned from phosphorus and nitrates.
Ecoduna (AT) – vertical tubes with air-lift
The vertical PBR of Ecoduna, AT

All advantages of a closed, glass-tubular system:
→ Durability, cleanability, low risk of contamination...

Large surface to volume ratio – good light dilution, i.e., less photoinhibiton effects → high areal growth efficiencies.

Airlift drives culture
→ No pumps necessary
→ Uniform distribution of nutrients
→ No O₂-intoxication
→ Continuous harvest

In plan: Production with 600 m³/ha PBR → 100 t/(ha·y)
Artificial LED Illumination of Photobioreactors

Advantages of artificial LED illumination (indoor application):
• Production 24 hour per day
• Optimum choice of illumination spectrum (white, red…)
• Independence of weather (indoor production)
Summary

1. Glass tubular PBRs allow for stable and efficient algae production for many years.

2. New, major applications of glass tubular PBRs:
   (i) Algae waste water cleaning
   (ii) Vertical PBRs
   (iii) PBRs with LED illumination
Thank you for your attention

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