## Response to oral examination report

The changes highlighted in the oral examination supersede those in the individual examiners' reports, with the exception of the minor corrections at the end of Prof. Leslie's report. We will start with those.

1. P5: Some details for reference [39] are missing (volume and page numbers).

The bibtex entry for this article has been updated.

@article{krujatz2015,

title = {Light-Field-Characterization in a Continuous Hydrogen-Producing Photobioreactor by Optical Simulation and Computational Fluid Dynamics},

volume = {112},

issn = {00063592},

number = {12},

journal = {Biotechnology and Bioengineering},

doi = {10.1002/bit.25667},

author = {Krujatz, Felix and Illing, Rico and Krautwer, Tobias and Liao, Jing and Heibig, Karsten and Goy, Katharina and Opitz, J{\"o}rg and Cuniberti, Gianaurelio and Bley, Thomas and Weber, Jost},

year = {2015},

keywords = {},

pages = {2439-2449}

}

1. P5: The reference by Minkewich (2004) cites data collected at 860 nm. This contradicts the statement on the lack of specific and relevant wavelength data for cultivation of Rb capsulatus. Candidate should clarify if this data is relevant or not for the current study.

This reference shows that there is a higher photosynthetic efficiency for each photon entering the system. This shows that the efficiency changes for different wavelengths, but doesn’t quantify the resulting growth rate or limiting parameters on wavelength or intensity.

The most interesting study done in that respect was with the series of three papers by Zhou et al. (2014, 2015, 2015a). There they look at photoperiod, light intensity, and wavelength however clarifications sought from the corresponding author showed these studies could not be used with confidence in our own work. They used a photometric basis, not a radiometric basis for all wavelengths and intensities, and when asked, could not explain which particular wavelengths were used (just red, blue, green, yellow, white, etc). By knowing the exact band of wavelengths, we could back-calculate to find a radiometric basis in the experiments.

1. Page 7 Equation 1. Sc is not defined in list of symbols. Nomenclature and symbols for all equations should be checked before final submission

The second term on the left side of Eq.\ \ref{eq:eulerian\_pde} represents convection of the particles with the velocity of the fluid phase(s), coupling the flow and concentration fields. This coupling is one-way since the solids concentration does not influence the flow field. The first term on the right hand side of the equation represents diffusion processes, and is normally included for numerical stability with the diffusion coefficient $\Gamma$ set arbitrarily low. The second term on the right hand side of the equation (S\textsubscript{C}) represents all sources and sinks of the scalar quantity C.

1. Page 8 Equation 2. Subscripts a, D and p not defined in list of symbols

**Added:**  
For Eulerian-Lagrangian references, a particle (P) is tracked through the fluid field, and is subjected to drag force ($\mathbf{F}\_D$), gravity, and lift and external forces ($\mathbr{F}\_a$). Eq.~\ref{eq:lagrangian\_ode} describes this behaviour.

1. Page 8. The use of Reference [57] does not support the statement as this work does not compare Eulerian and Lagrangian approaches for particle transport in enclosed air spaces. Please revise

I pointed my reference manager to the wrong (Zhang 2007). I have now pointed the claim to this following reference.

Z. Zhang and Q. Chen, “Comparison of the Eulerian and Lagrangian methods for predicting

particle transport in enclosed spaces,” Atmospheric Environment, vol. 41, no. 25, pp. 5236–5248,

2007. ISBN: 1352-2310.

1. Page 8 There is a section of text (paragraph) that is missing between page 8 and 9. Logic of the two paragraphs does not flow.

**I have added the following into that section, and removed the mentions of the various CFD packages as they don’t add much to the analysis.**

To summarise, the most common and important physical phenomena to consider when modelling photobioreactors are:

\begin{itemize}

\item hydrodynamics, mixing and mass transfer

\item radiative transfer

\item physiology and biokinetics

\item biofilms

\item methods for coupling all physical phenomena

\end{itemize}

Microbial physiology and growth kinetics can be simulated well in lumped parameter systems, where spatial variations are considered negligible, however when coupling occurs with the remaining physical phenomena, spatial variations should be taken into account. Computational fluid dynamics is a discipline allowing users to account for these changes in space, however these simulations should be accompanied by proper error and convergence analysis.

1. Reference [75] is missing the year of publication. (should be 2013). Also, as the results from reference [75] conclude that Type 2 models best approach for out door but type 3 may be better for indoor systems. Features of these models are reiterated in the introduction to section 1.3 which is confusing.

The year of publication was there. I used IEEE referencing style for this thesis which puts the publication year at the end of the reference. Reference 75 (Bechet et al.) is now reference 76 due to adding in Zhang 2007 above.

**Reformulate this section?**

1. Page 10. There is some confusion on the use of symbols. In Equation 1 B listed in text as extinction coefficient – It is assumed that this is comparable to the attenuation coefficient as described in the symbols list. Please use consistent nomenclature.

I wrote a spiel on the Beer Lambert law (eq 1.4) where I explained what beta was. I have also clarified that beta is the sum of kappa and sigma and what their units are. I have also changed the extinction coefficient beta to epsilon to be in line with eq 1.5 and for the mass extinction (attenuation) coefficients which are denoted by E.

I have changed all instances of “extinction” to “attenuation” in the document. They have the same meaning, but it is true that flip-flopping from one to the other reduces the clarity of the document.

This approach lumps the absorption (κλ) and out-scattering (σλ) coefficients into one extinction coefficient (epsilon λ) by addition. The spectral absorption, out-scattering and extinction coefficients all of the units of $m^-1$.

1. Page 12. Difficult to follow the logic of paragraphs 2,3 and 4. The sudden introduction of “solution scheduling “ is confusing. This could be improved by beginning paragraph 4 with the sentence. Examples of where spectral simulations were carried out using the FVDOM or DOM....”

The first few sentences did appear to be out of place. I have moved them to the end of that paragraph as they conclude rather than introduce anything.

1. Page 16 Equation 1.6 has no units. Please provide units for all equations.

For each term in the equation, I have included the units and the description of what each variable does physically.

1. Objective 1: please explain, more clearly, the selection of the anaerobic model and the Monod kinetics;
2. Chapter 3: please plot velocity distributions predicted for both configurations, and add a paragraph to discuss about the effects of configurations/geometries on the results; acknowledge any shortcomings of the work in this regard;
3. In Equation 3.12, D should be taken out of the Laplacian operator; Diffusion plays an important role in biofilm modelling, the effect of the biofilm matrix (e.g. EPS) and cell mobility on the D value should be discussed;

I have taken the diffusion coefficient outside of the laplacian.

1. In Chapter 3, Newtonian flow was assumed, which is reasonable for this work. However, the assumption should be stated more clearly, and conditions for such an assumption to be valid/invalid should be discussed;
2. Slide 23, Figure 3-4: explain how the plot was generated; explain why the frequencies are different; explain the physical reason(s) for the differences; also, the take-home messages for readers should be made clearer;
3. Chapter 3: add “mesh independence test”;
4. Fig 4-18: Please comment on the oscillations on the curves, explain the reason(s) – is it a numerical issue? Discuss what could happen after 10 days.
5. Fix up any other spelling mistakes throughout the thesis.

References

Q. Zhou, P. Zhang, and G. Zhang, “Biomass and carotenoid production in photosynthetic

bacteria wastewater treatment: Effects of light intensity,” Bioresource Technology, vol. 161,

pp. 451–454, 2014. bibtex\*[pmid=24731915].

Q. Zhou, P. Zhang, G. Zhang, and M. Peng, “Biomass and pigments production in photosynthetic

bacteria wastewater treatment: Effects of photoperiod.,” Bioresource Technology, vol. 179,

pp. 505–509, 2015. Publisher: Elsevier Ltd.