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CENTRE FOR RENEWABLE ENERGY AND SUSTAINABLE ENERGY STUDIES

9th RENEWABLE ENERGY POSTGRADUATE SYMPOSIUM, REPS

The treatment of waste-waters in a Thermosiphon Photobioreactor (TPBR) using *Rhodopseudomonas palustris*

Presented by:

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Under Supervision of Dr. Robbie Pott

13 September, 2018

WATER RESEARCH COMMISSION

THE MANDELA RHODES FOUNDATION

INTRODUCTION

- **Closed PBR**
  - Technical systems for bioconversion by photosynthetic microorganism
  - Biohydrogen for example is one desired product from the bioconversion
  - But uncompetitive with the current hydrogen production method
    - High energy consumption associated for aeration/or agitation
    - Mechanical stress and cell death from pneumatic and mechanical pumps
    - Increased material, operational and production cost, up to *circa* 80% of total cost

- **Thermosiphon PBR**
  - Natural fluid circulation is achieved by thermosiphon effect

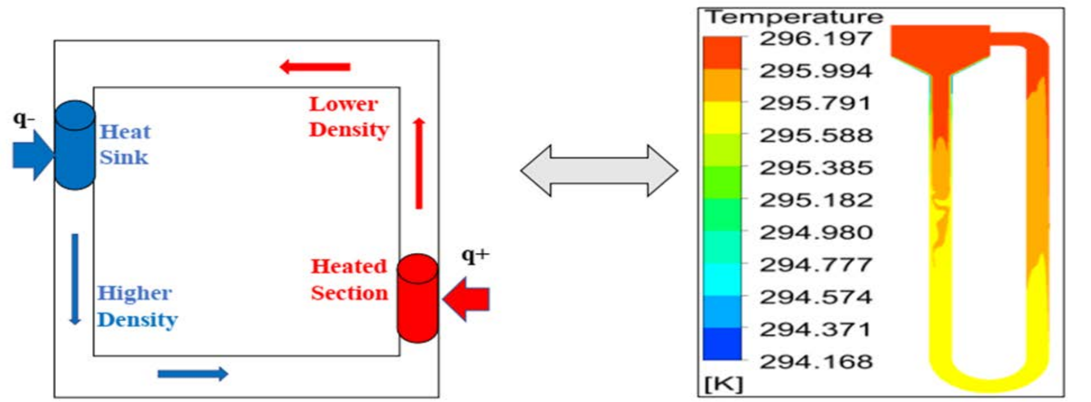


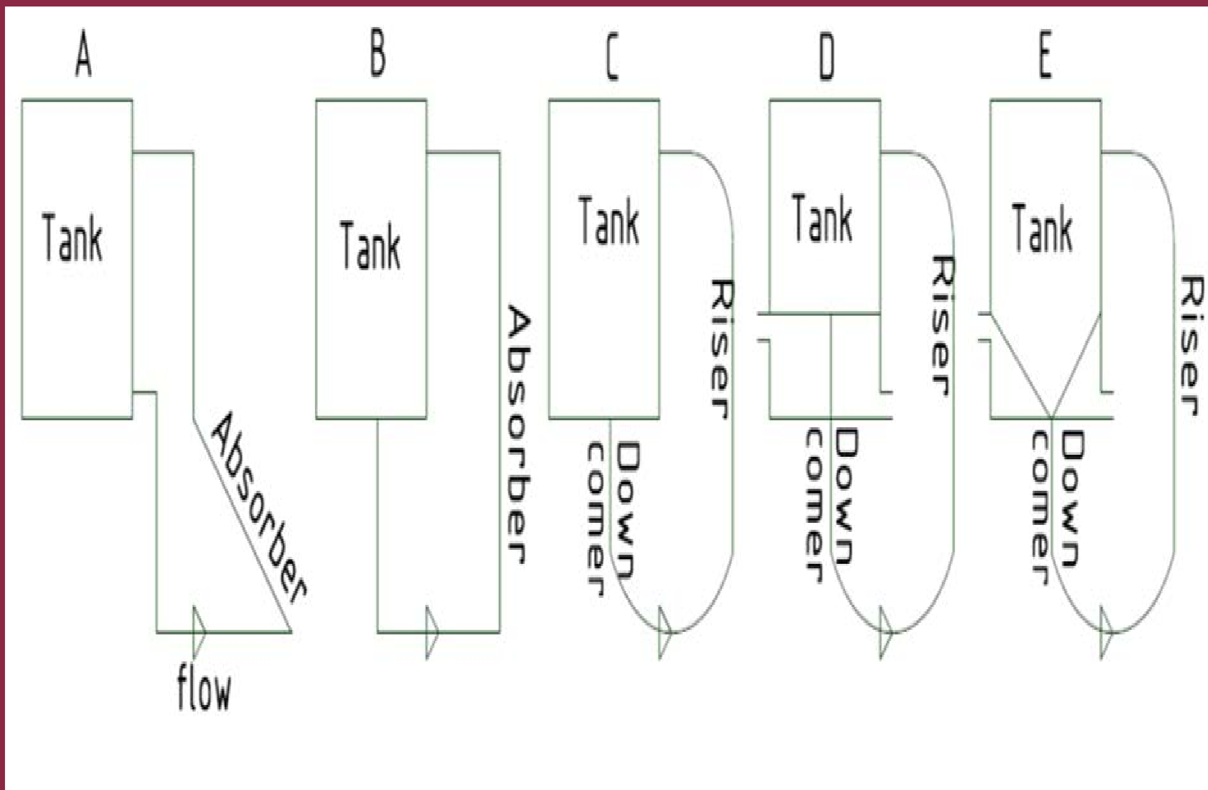
Fig 1. Thermosiphon principle in closed loops

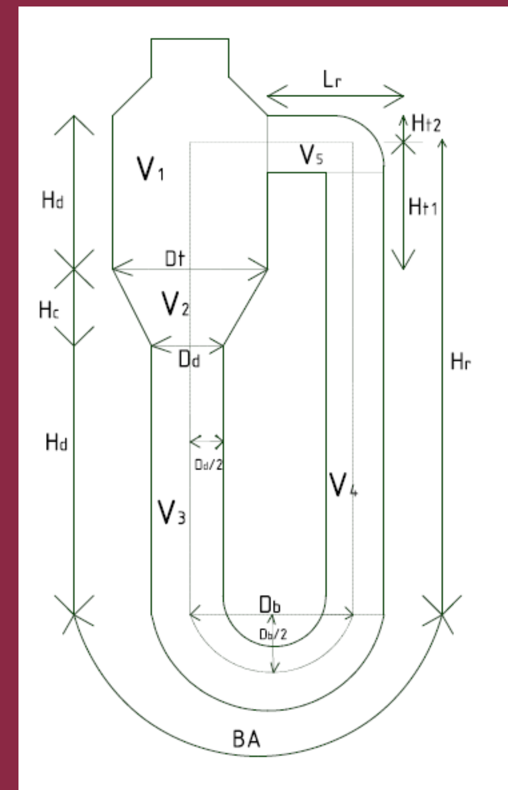
Fig 2. CFD model of thermosiphon Photobioreactor (TPBR)

AIMS

- To use CFD modeling and experiments in developing a PBR technology based on the thermosiphon effect.
  - To develop a TPBR geometry and construct it for fluid testing.
  - To numerically evaluate passive fluid within the TPBR.
  - To validate the TPBR with experiments

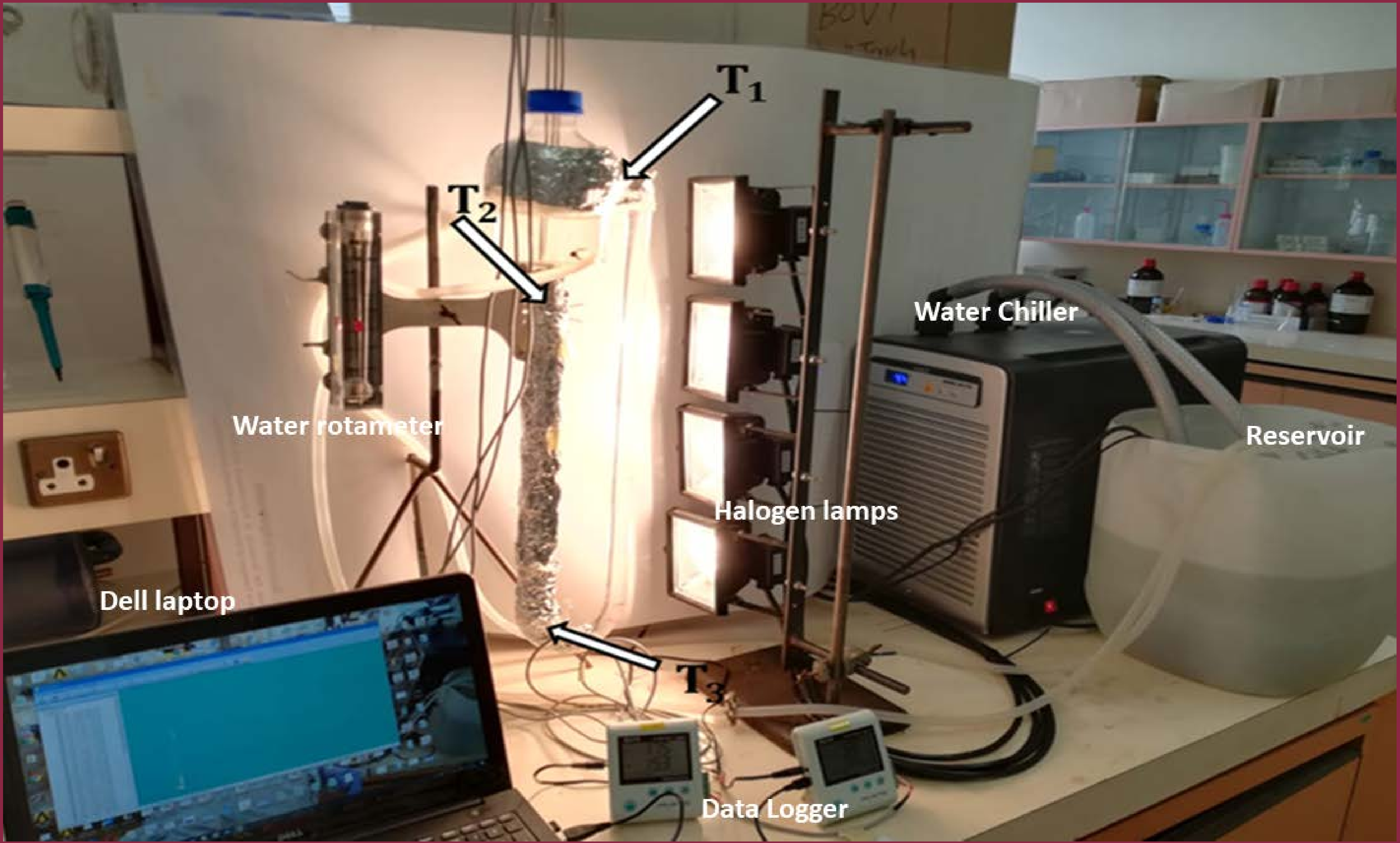
TPBR GEOMETRY DEVELOPMENT





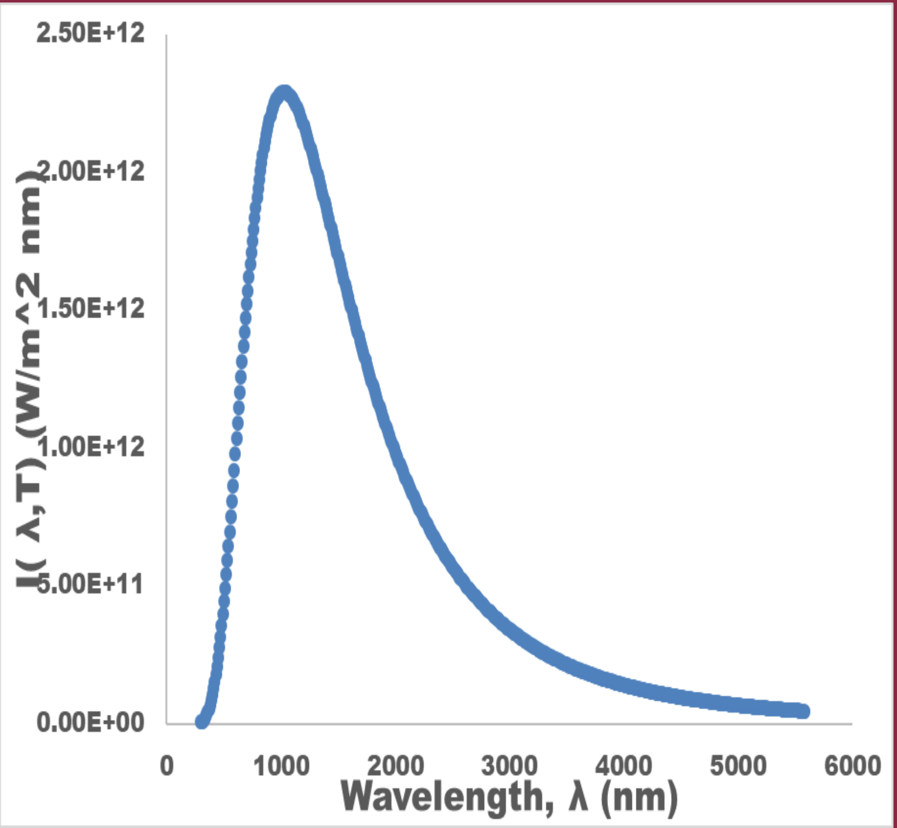
$$\underbrace{\pi(D_t/2)^2 H_t}_{V_1} + \underbrace{\frac{\pi H_c}{3}\left[(D_t/2)^2+(D_d/2)^2+D_t * D_d\right]}_{V_2} + \underbrace{\pi(D_d/2)^2\left[H_d + BA + H_r + L_r\right]}_{V_3+V_4+V_5} = \underbrace{1,000,000}_{V_T} \quad (1)$$

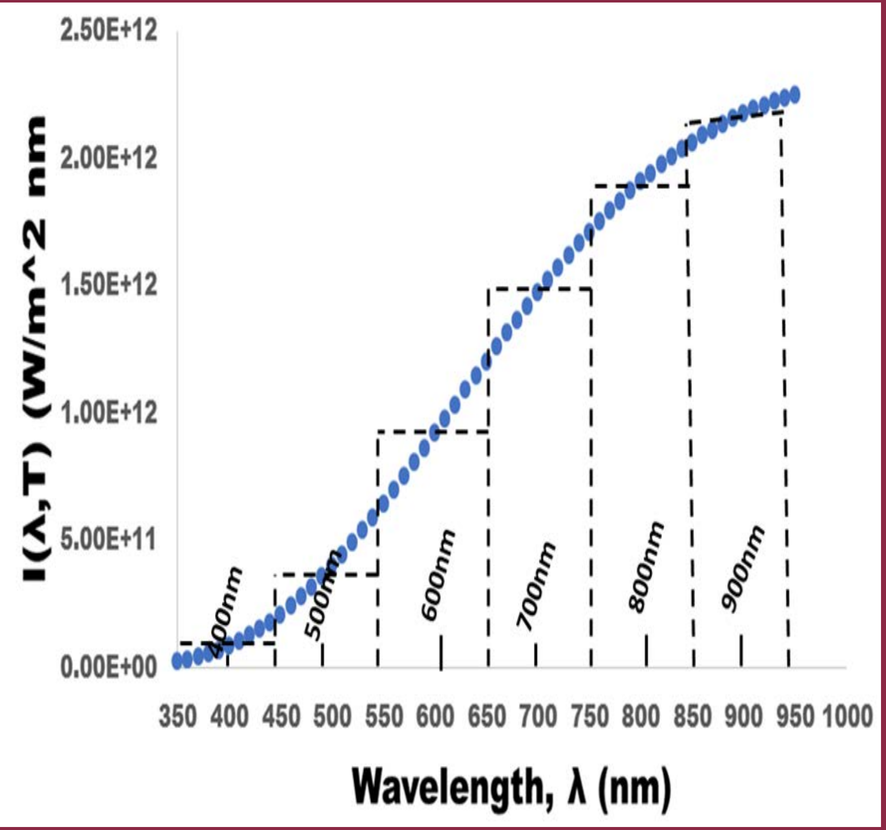
EXPERIMENTAL SETUP



LIGHT ABSORPTIVE MODEL

- LIGHT GENERATION



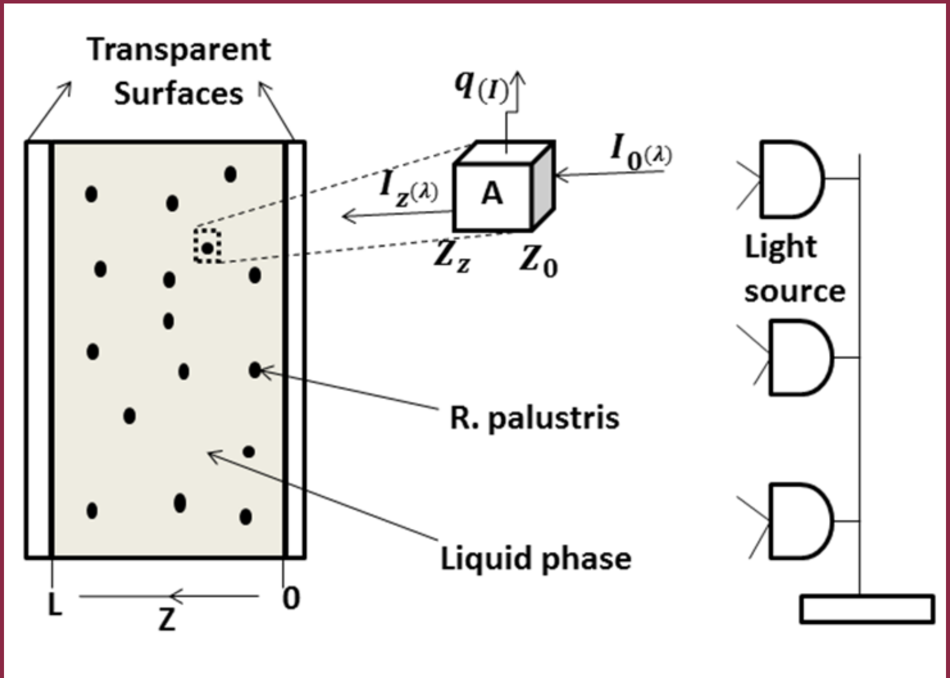


$$I(\lambda, T) = \frac{2\pi hc^2}{\lambda^5} \frac{1}{e^{-hc/\lambda KT} - 1} \quad (2)$$

$$I(T) = \int_{350}^{950} I(\lambda, T)\, d\lambda \quad (3)$$

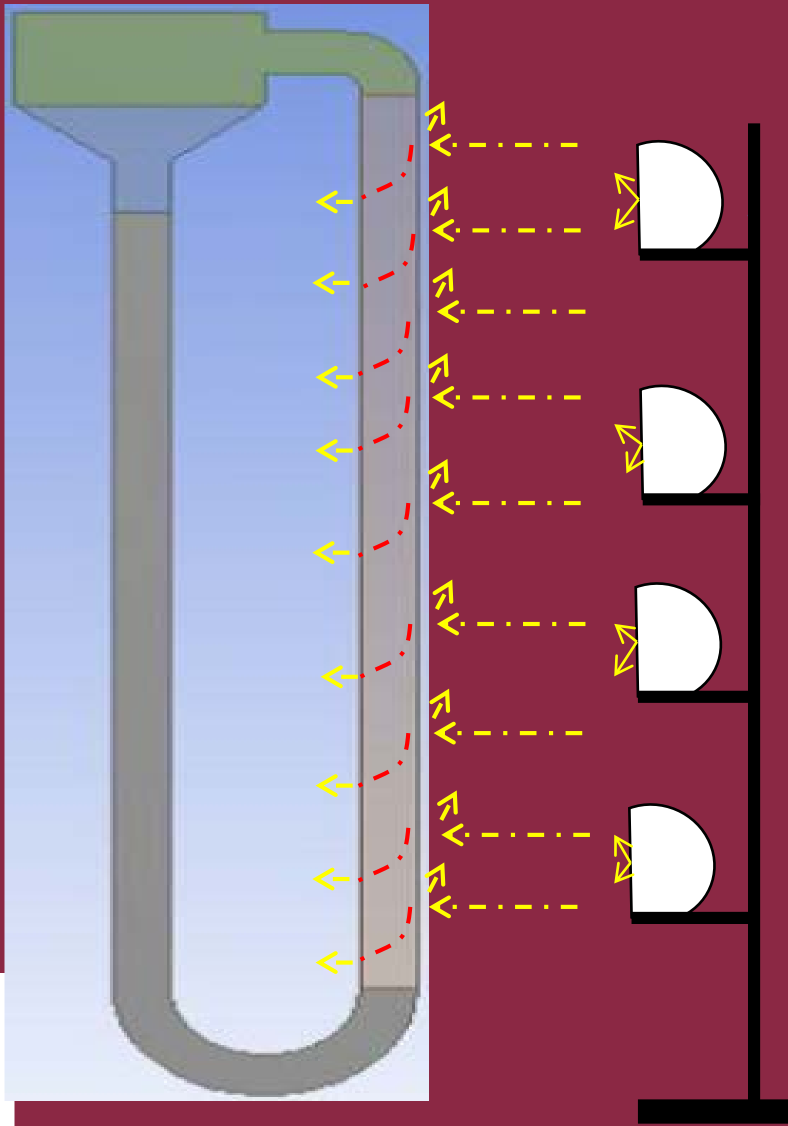
LIGHT ABSORPTIVE MODEL

- LIGHT PENERATION



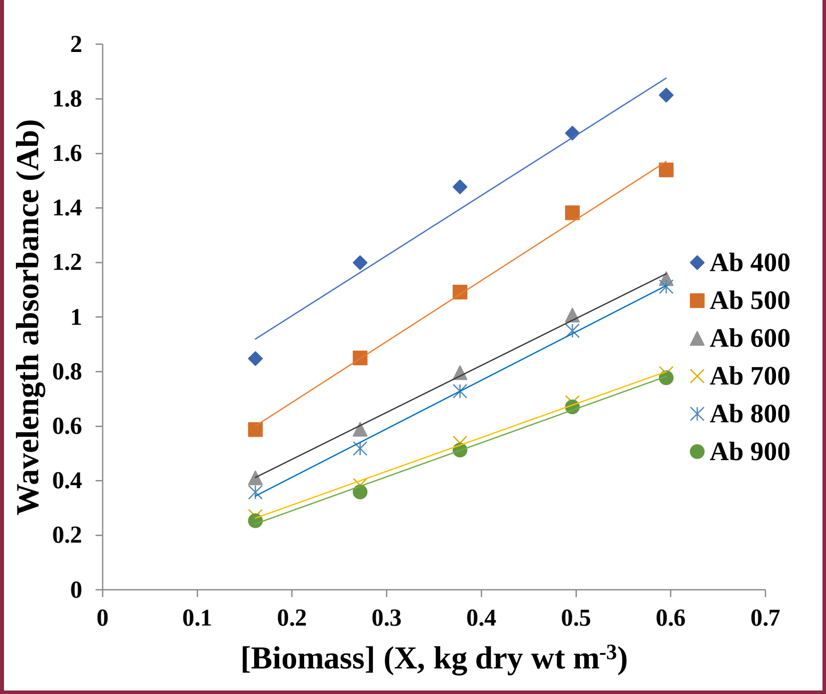
$$q_{(I)}(W/m^3) = \frac{dI_{(\lambda)}}{dZ} \equiv -K_0 I_{0(\lambda)} e^{-K_0 Z} \qquad (4)$$

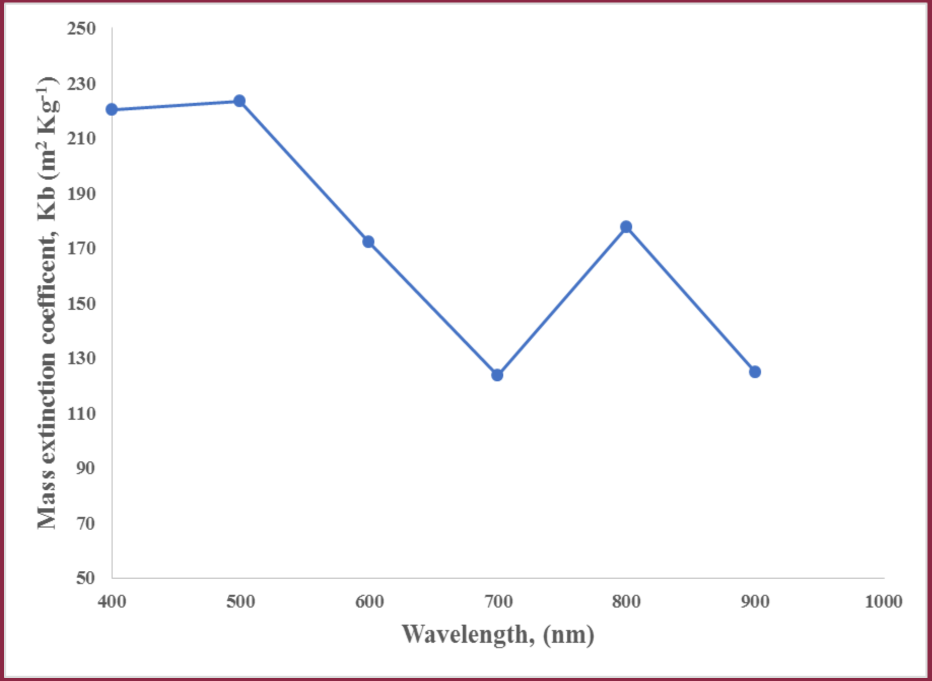
$$q_{(I)}(W/m^3) = \int_{350}^{950} \frac{dI_{(\lambda)}}{dZ} d\lambda = \int_{350}^{950} -K_0 I_{0(\lambda)} e^{-K_0 Z} d\lambda \qquad (5)$$



LIGHT ABSORPTIVE MODEL

- SPECTRAL EXTINCTION COEFFICIENT OF *R. PALUSTRIS*

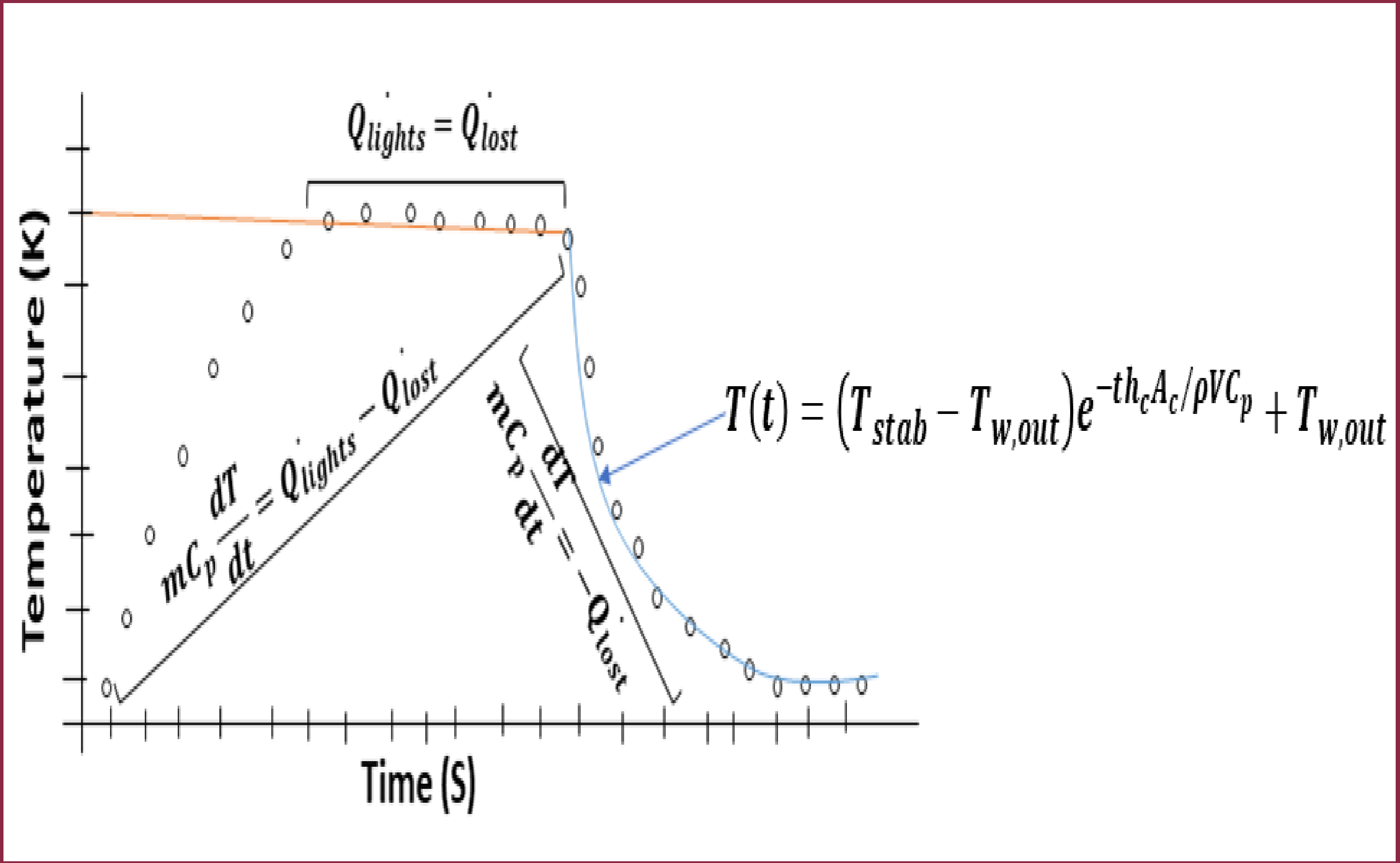




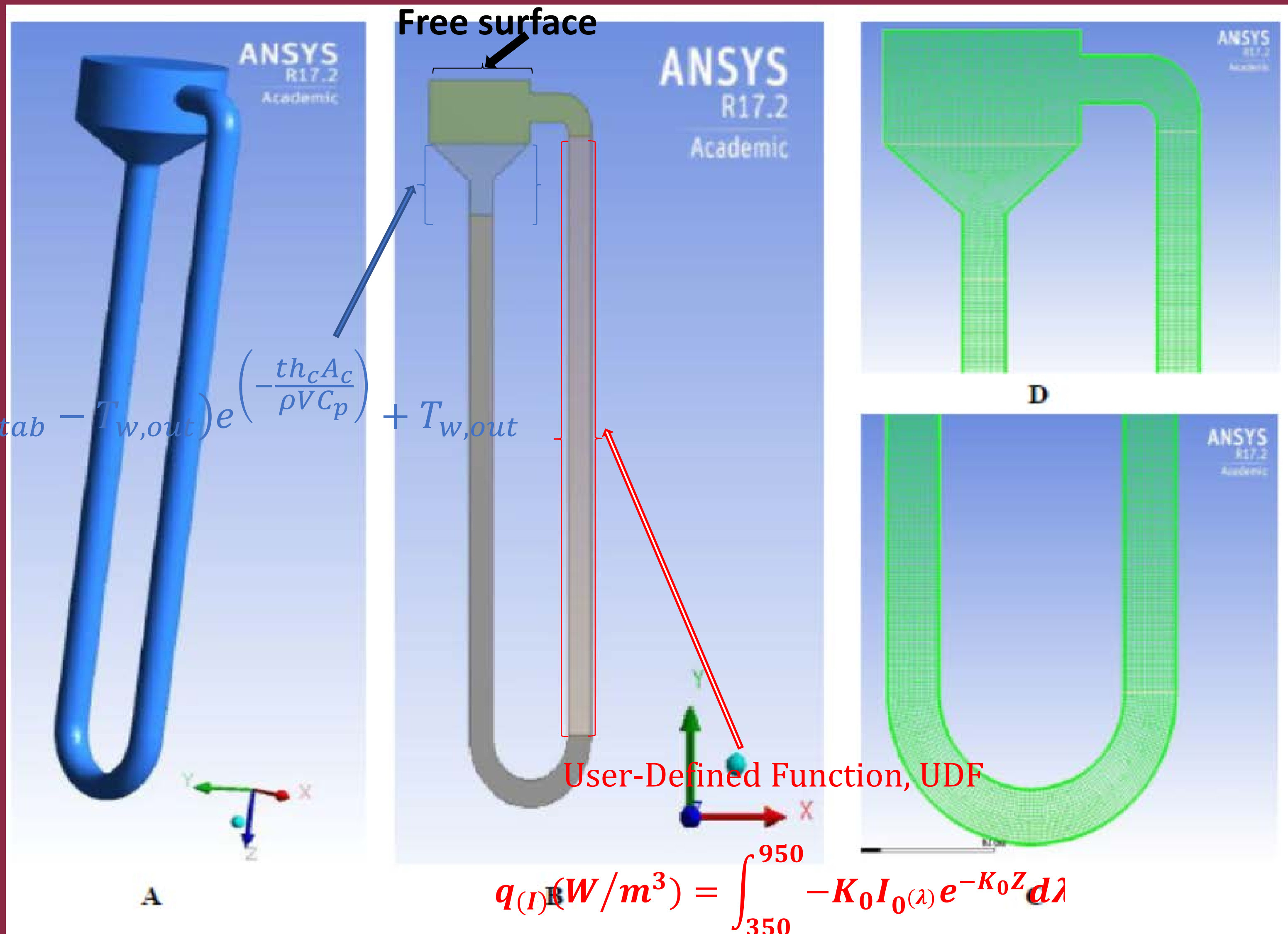
$$K_b = \left[\frac{slope\ of\ Ab\ vs\ [Biomass]}{Z_{cuvette}(m)}\right]_{400}^{900} \qquad (6)$$

LIGHT ABSORPTIVE MODEL

- SENSIBLE HEATING FROM LIGHT ABSORPTION



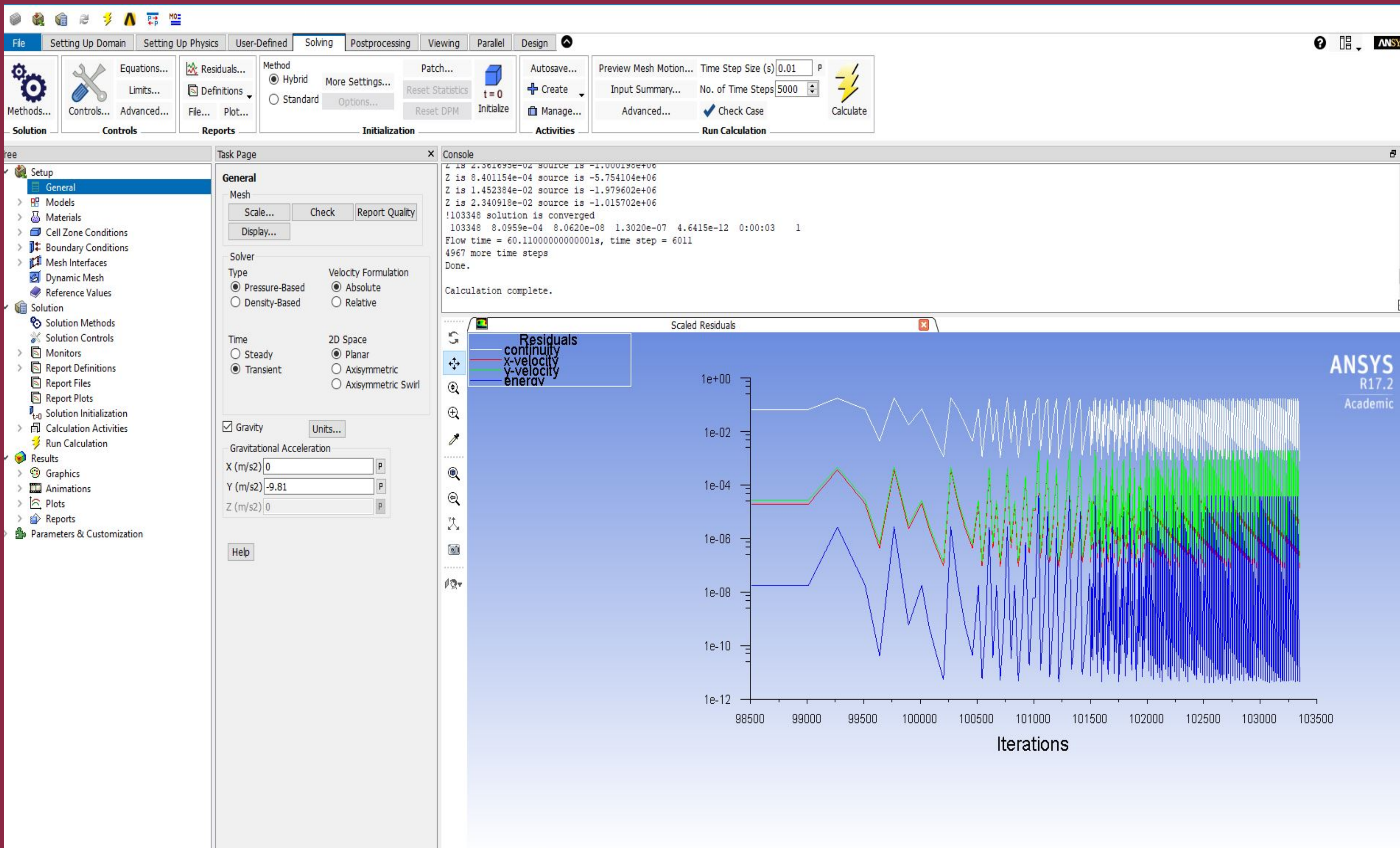
CFD MODELING



$$T(t) = (T_{stab} - T_{w,out})e^{\left(-\frac{th_c A_c}{\rho V C_p}\right)} + T_{w,out}$$

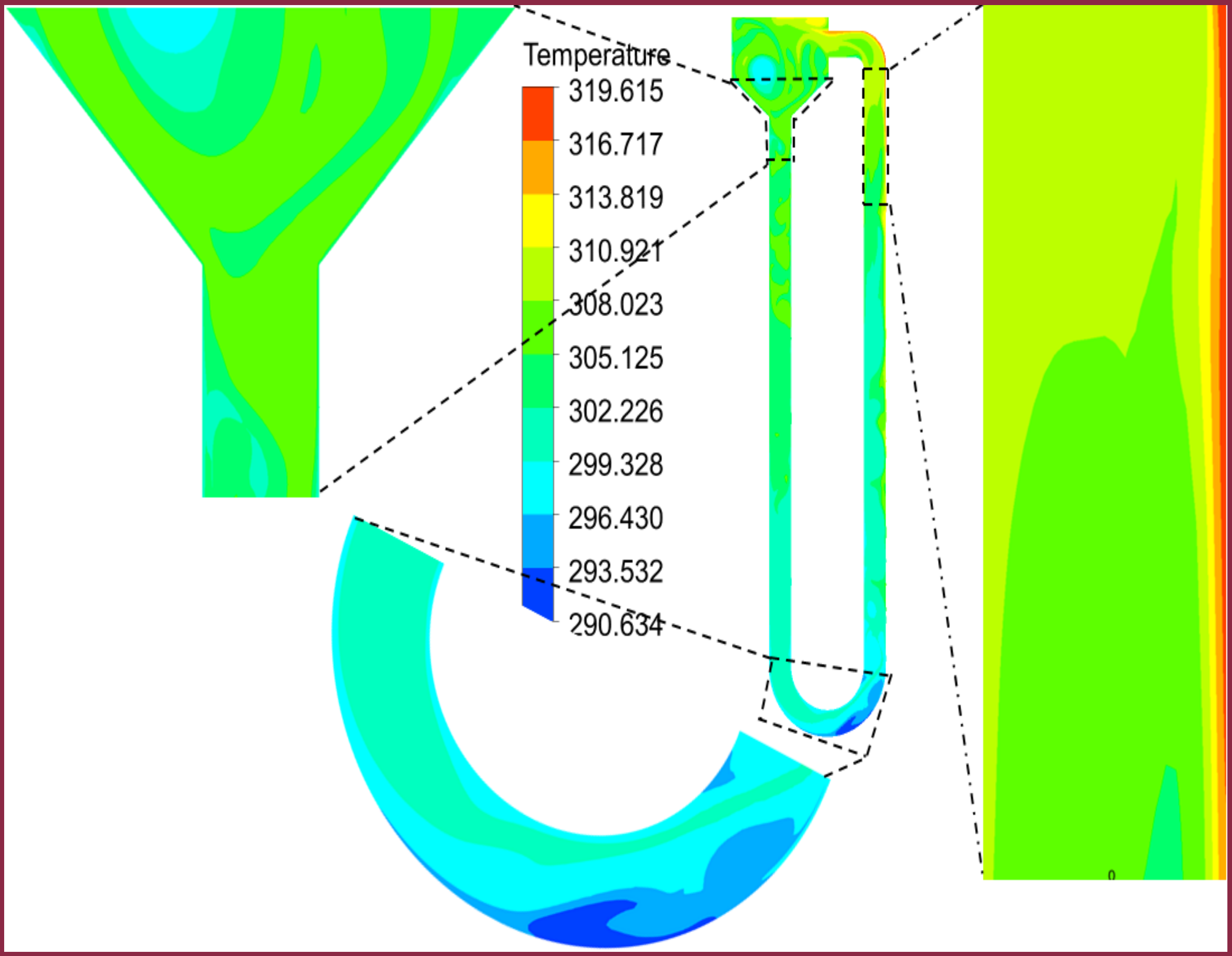
$$q_{(I)}(W/m^3) = \int_{350}^{950} -K_0 I_{0(\lambda)} e^{-K_0 Z} d\lambda$$

SOLUTION CONVERGENCE CRITERIA



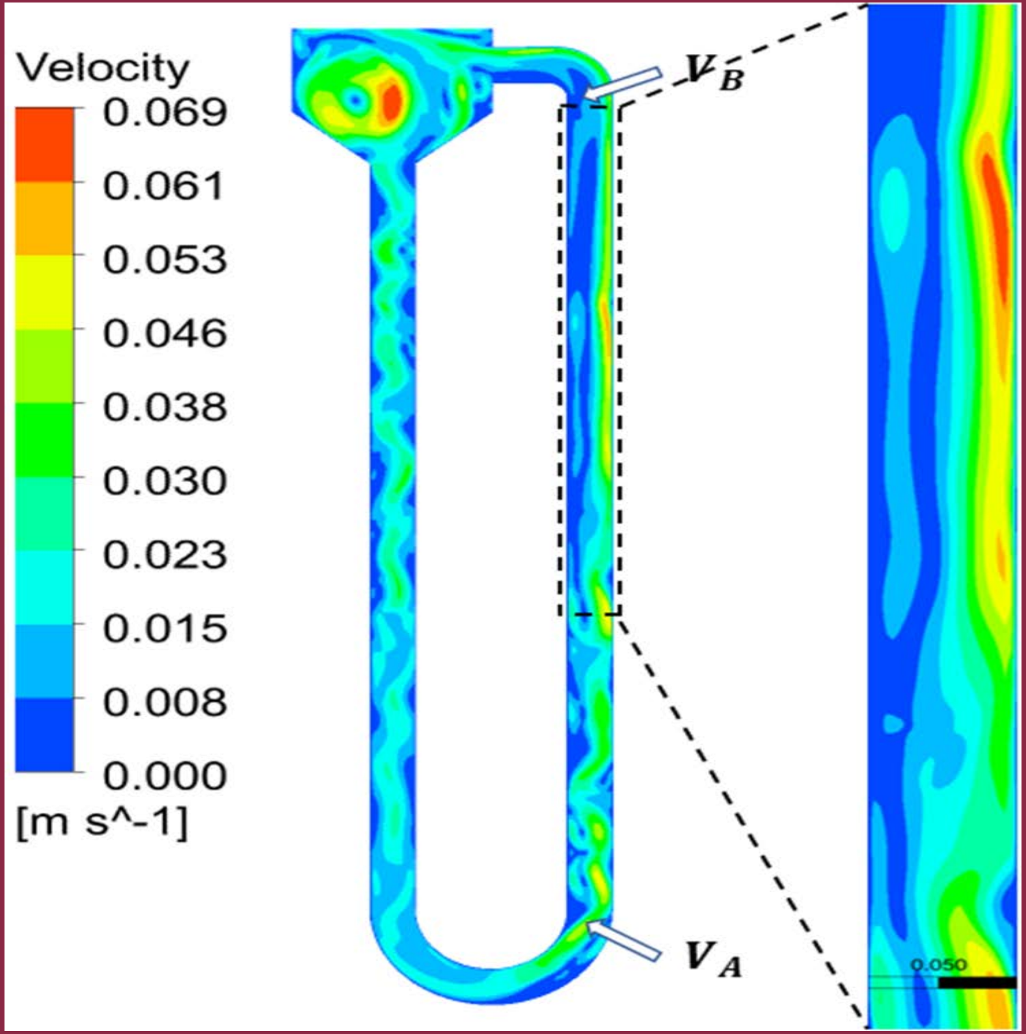
NUMERICAL SIMULATION RESULTS

- TEMPERATURE PROFILE



NUMERICAL SIMULATION RESULTS

- VELOCITY PROFILE



EXPERIMENTAL FLUID DYNAMICS RESULTS

- FLOW VISUALIZATION

0s 15s 30s 45s 60s

VALIDATION EXPERIMENTS

- TEMPERATURE

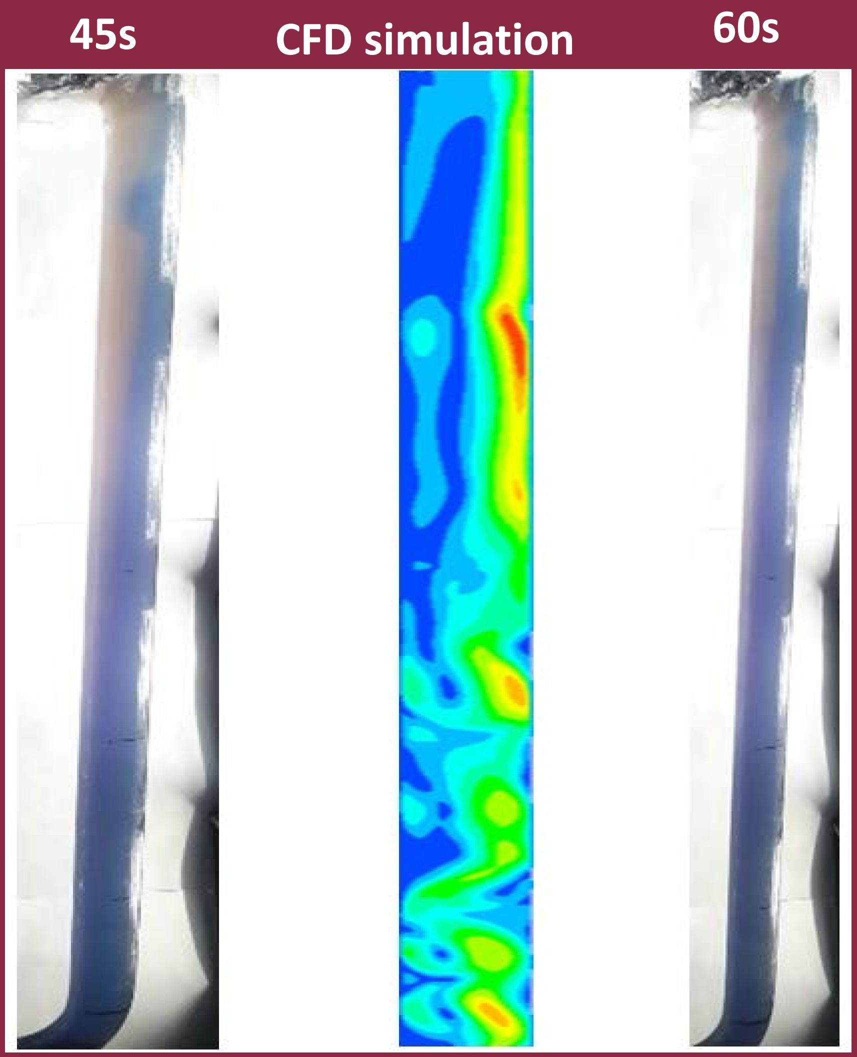
Measuring point	Experiment (K)	CFD simulation (K)	Deviation (%)
T_1	$317.7 \pm \mathbf{0.5}$	307.9	3.1
T_2	$313.8 \pm \mathbf{0.6}$	305.5	2.7
T_3	$312.6 \pm \mathbf{2}$	299.5	4.2

- VELOCITY

Measuring point	V_1	V_2	Local velocity $\lvert V_2 - V_1 \rvert$
Experiment (m/s)	Unmeasured	$0.011 \pm .\mathbf{0010}$	$0.009 \pm .\mathbf{0.0004}$
CFD simulation (m/s)	0.0161	0.00763	0.0085
Overall deviation (%)			9.2

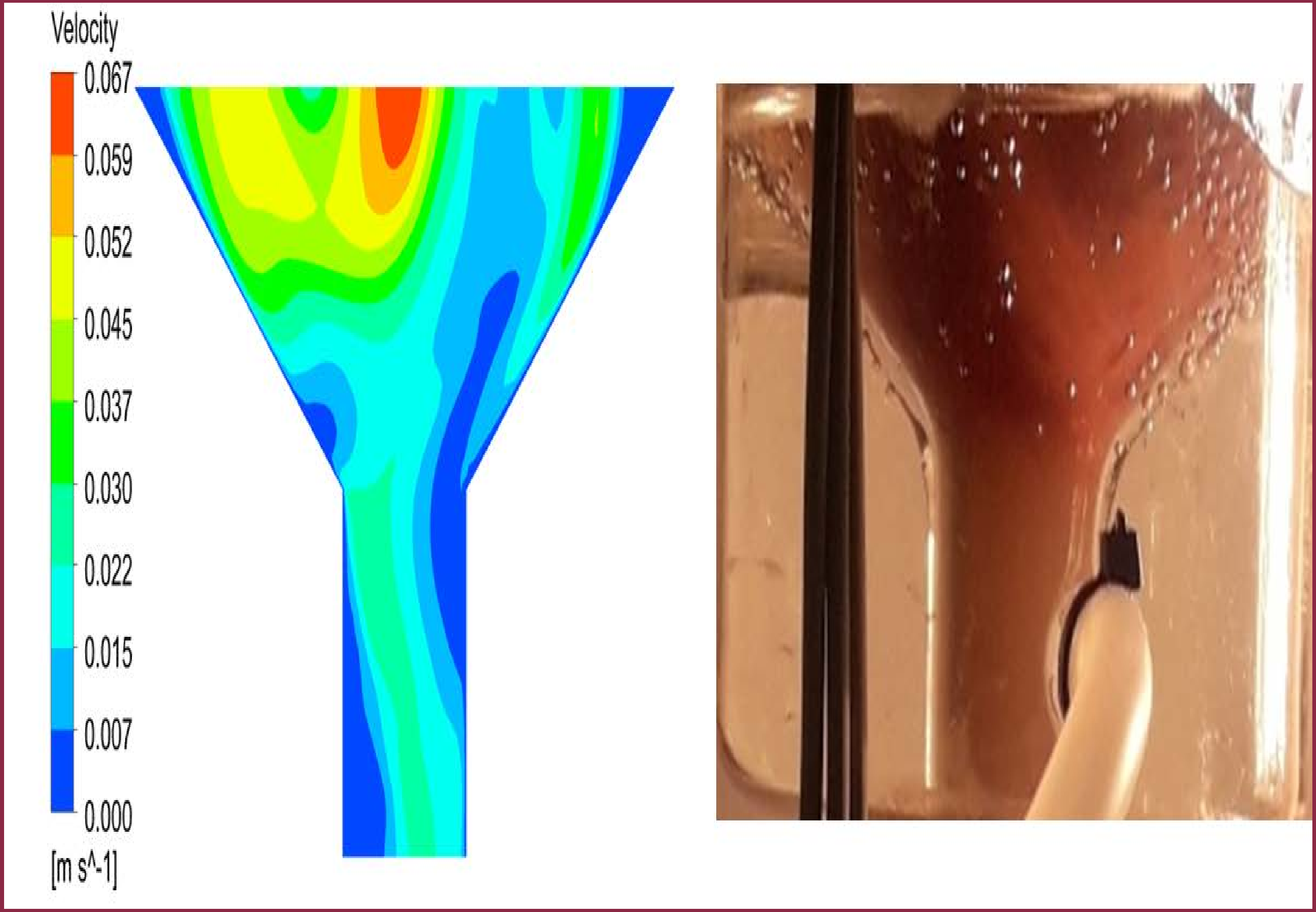
VALIDATION EXPERIMENTS

- RISER'S FLOW PROFILE

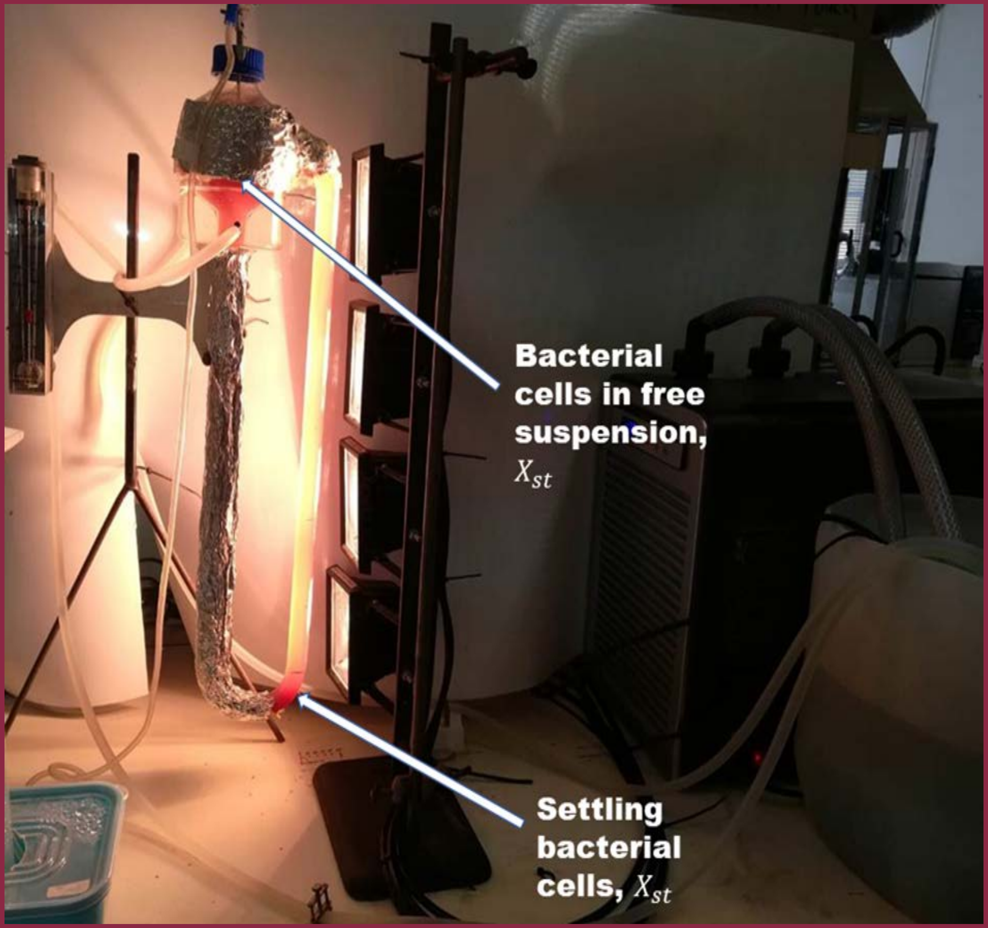


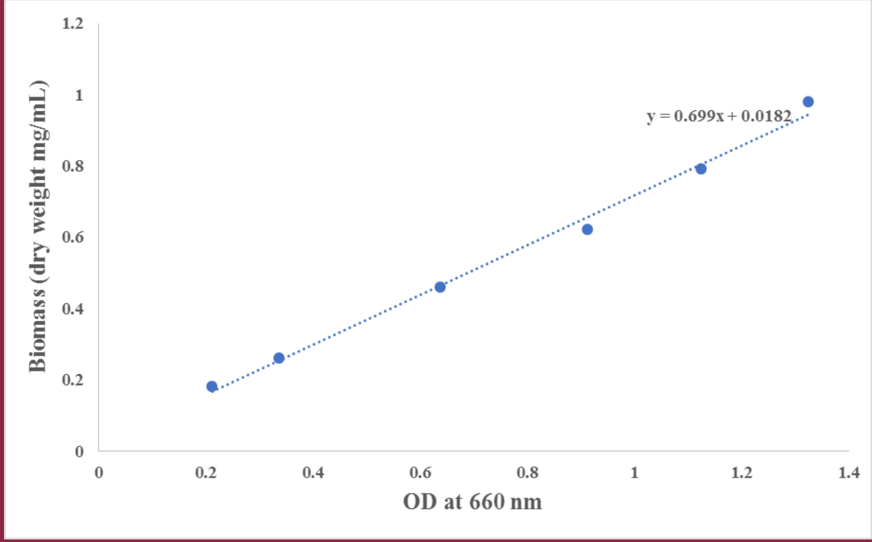
VALIDATION EXPERIMENTS

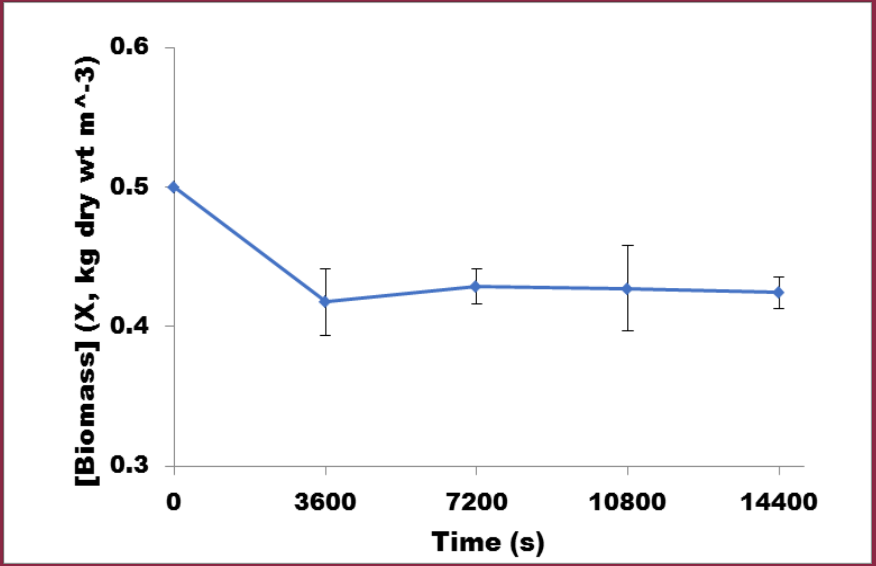
- STORAGE TANK'S FLOW PROFILE



RATE OF CELL CIRCULATION







$$Xs_t = X_0 - X_t \quad (7)$$

CONCLUSION

- A Thermosiphon Photobioreactor (TPBR) has been successfully designed, fabricated and demonstrated.
- Passive fluid flow and heat transfer within the TPBR has been examined numerically and experimental.
- The TPBR agrees well with theoretical predictions to less than 5% and 10% for temperature and local velocity measurement.
- Flow visualization revealed light absorption to significantly affect fluid circulation and mixing.
- The TPBR provided satisfactory fluid circulation, maintaining 88% bacterial cells in free suspension

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