Thermal characterization of biofouling around a dynamic submarine electrical cable

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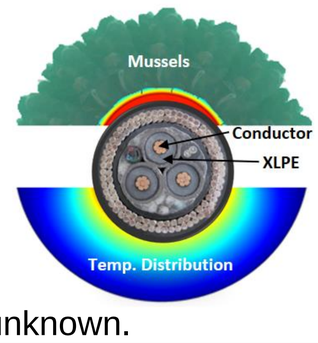
Context

Introduction and problematic



– High voltage dynamic cable is a key component in the power transmission system of floating offshore wind turbine
– High voltage dynamic cables are dimensioned to remain below 90°C into the conductor and XLPE in normal operating conditions.
– Growth of biofouling, particularly mussels can modify the heat transfer around the cable.
– If the temperature of the conductor increases above 90°C, then the XLPE (cross-linked polyethylene) insulation system is damaged and the electrical conductor conductivity will decrease.
– Modelling the thermal effect of mussels on the high voltage dynamic cable is important however the thermal characteristics of mussels are unknown.

Objective

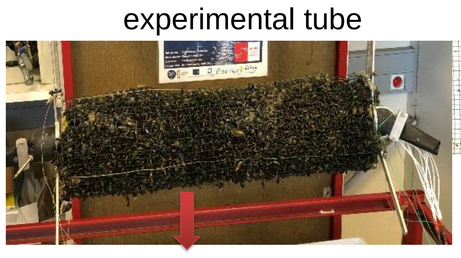
– Thermal characterization of different types of mussels (Juvenile, mix (Juvenile & Adult) and Adult) by estimating the effective thermal conductivity of mussels k_{biof} and the heat transfer coefficient of the water around the mussels h_w.

METHODOLOGY

Stationary method (Analytical)

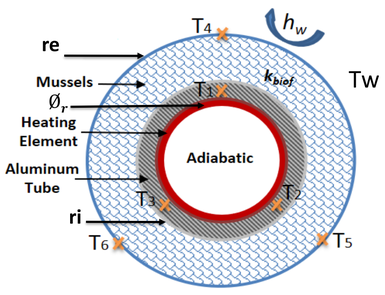
Uniform colonization of mussels around the experimental tube

Mussel's fixation on the experimental tube



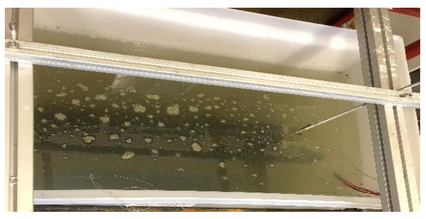
Mussels

Steel net (1cm mesh)



Middle cross-section of the experimental tube covered with uniform colonization of mussels.

Measurement in a water tank filled with sea water



Thermal conductivity of biofouling (Fourier's law):

$$\lambda_{biof(W/m.K)} = \frac{\ln\left(\frac{re}{ri}\right) * Ø_r}{2\pi * L * (Tav1 - Tav2)}$$

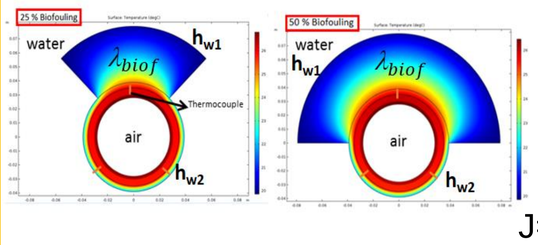
Heat transfer coefficient of water around the mussels (Newton's law):

$$h_{water(W/m^2.K)} = \frac{Ø_r}{2\pi * re * L * (Tav2 - Tw)}$$

*** Tav1: average of (T1,T2 and T3)**
Tav2: average of (T4,T5 and T6)

Stationary method (Finite elements)

Non-uniform colonization of mussels around the experimental tube



Estimation of λ_{biof} and *hw* by simplex minimization method:

$$J = \sum_{i=1}^{n} \left(T_{numerical}(\lambda_{biof}, h_{w1}, h_{w2}) - T_{measured}\right)^2$$

n : number of thermocouples
λ_{biof} : Thermal conductivity of biofouling
h_w : heat transfer coefficient of the water around the mussels.

Results

Uniform colonisation of mussels

1 Juvenile mussels 2 Mix(Adult&Juvenile)mussels 3 Adult mussels

Effective thermal conductivity and heat transfer coefficient of water around the mussels

Mussel's Type	Φ (%)	λ_{biof} (W/m.K)	Absolute Uncertainty of λ_{biof} (W/m.K)	Relative Uncertainty of λ_{biof}	hwater (W/m^2.K)	Absolute Uncertainty of h (W/m^2.K)	Relative Uncertainty of h
Juvenil Mussels (Aluminum tube only)	14	4.40	± 0.4	9%	3395	± 1123	33%
Mix (Adult & Juvenile) Mussels (Aluminum tube only)	19	8	± 0.52	6.5%	873	± 164	19%
Adult Mussels (Aluminum tube only)	30	12.80	± 0.97	7.6%	2682	± 1003	37%

Φ*: Water porosity

$$\lambda_{Juvenile} < \lambda_{Mix} < \lambda_{Adult}$$

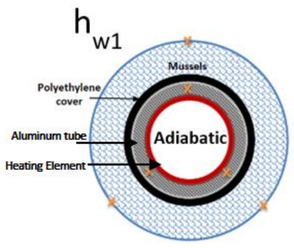
$$\Phi_{Juvenile} < \Phi_{Mix} < \Phi_{Adult}$$

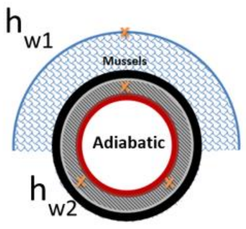
Conclusion

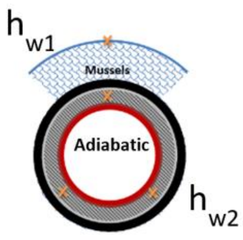
- Effective thermal conductivity of mussels depends on the age mussels (Juvenile, mix or adult) which has different percentage of water porosity.
- Effective thermal conductivity of mussels is higher than the water thermal conductivity due to internal convection in the water porous media of mussels.
- Juvenile mussels have the smallest effective thermal conductivity compared to the mix (juvenile and adult) and adult mussels.
- Convective resistance is smaller than the conductive resistance.

Non-uniform colonisation of mussels

100% coverage 50% coverage 25% coverage







Effective thermal conductivity and heat transfer coefficient of water around the mussels for non-uniform distribution

Colonization	λ_{biof}	Sensitivity	h_{w1}	Sensitivity	h_{w2}	Sensitivity
%	$W.m^{-1}.K^{-1}$	°C	$W.m^{-2}.K^{-1}$	°C	$W.m^{-2}.K^{-1}$	°C
25	1.4	1	1510	0.1	1960	0.9
50	1.9	1	310	0.1	3910	0.88
100	1.6	5	910	0.1	-	-

Future work

- Experimental tubes will be inserted in the Mediterranean sea and the Atlantic ocean to have a natural growth of biofouling around the tubes.
- Modelling the thermal and mechanical effect of the growth of biofouling around the dynamic cable.
- Tracking the growth of biofouling with the estimation of h_{biof} of biofouling using non stationary method.

LOGO

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