COST EMF - MED (Action BM1309):
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STSM Report:

Validation thermophysical fluid EMF model for phased array hyperthermia treatment planning

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Abstract:

At the Academisch Medisch Centrum (AMC), we have been developing a fluid simulation module as an extension to our hyperthermia treatment planning system. This development focused on simulation of treatments in the pelvic area, and in particular of the urinary bladder. One step that was still incomplete was extensive validation of the fluid model. This validation was performed as part of the STSM by benchmarking against experimental values and comparison with validated software developed at Chalmers.

At Chalmers Tekniska Högskola, a hyperthermia microwave applicator for the brain is being developed (the Chalmers Hyperthermia Helmet). Treatment simulation to further optimize the design of the applicator is hampered by the lack of appropriate modelling of Cerebrospinal Fluid (CSF) in the hyperthermia treatment planning system. We adjusted the fluid module developed at the AMC for modelling CSF, improving simulation results for the Chalmers Hyperthermia Helmet.

A. Purpose of the STSM

The purpose of this STSM was two-fold. First, we aimed to validate our in-house developed hyperthermia treatment planning software, Plan2Heat, using the know-how present at Chalmers; secondly, we wanted to investigate the theoretical heating capabilities of the hyperthermia helmet being developed at Chalmers. As a consequence of this collaboration, we also expected the ties between our two institutes to strengthen.

The principle aim of the researcher is to optimize the temperature distribution during locoregional bladder hyperthermia treatment by using three dimensional (3D) steering of the temperature rise, guided by high resolution hyperthermia treatment planning system and 3D temperature data. To this end, we developed a fluid modelling extension to our treatment planning system. Part of the validation of this software extension consisted of comparison with existing computational fluid dynamics software, *i.c.* COMSOL. As our institute lacks access to and experience with COMSOL, we have chosen to collaborate on this issue with Chalmers.

The group at Chalmers saw this collaboration as an opportunity to make use of our institute's experience with hyperthermia treatment planning for the development of their hyperthermia helmet and predicting its heating capabilities. More in particular we used Plan2Heat with the fluid model extension to investigate hypothetical brain hyperthermia treatments.

B. Work Description

The validation of the fluid extension to Plan2Heat consisted of two parts. First, a volumetric comparison of the temperature and velocity distribution between the newly developed / implemented fluid model and the existing computational fluid dynamics module of multi-physics software package COMSOL. Second, an experimental study that compared temperature simulations by both packages with measurements at a (necessarily limited) number of measurement points. The experimental measurements yield information over the temperature accuracy of both models, which is the quantity of interest; whereas the numerical comparison yields information on a greater number of variables, and allows for comparison throughout the entire simulated volume. The development of the fluid extension to Plan2Heat took place before the STSM, whereas the validation was done during my time at Chalmers.

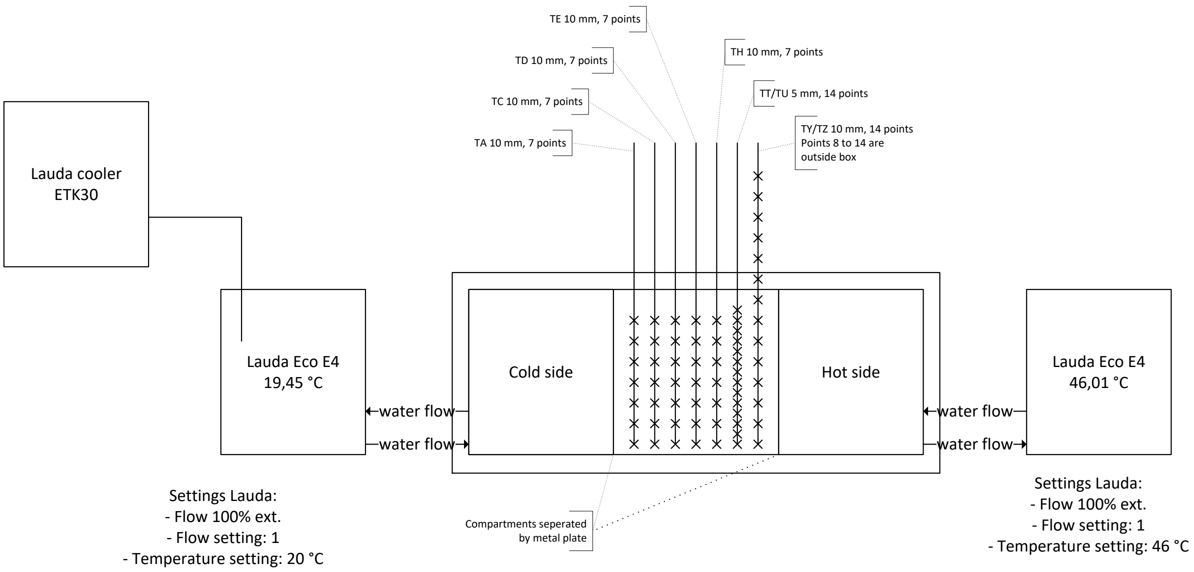


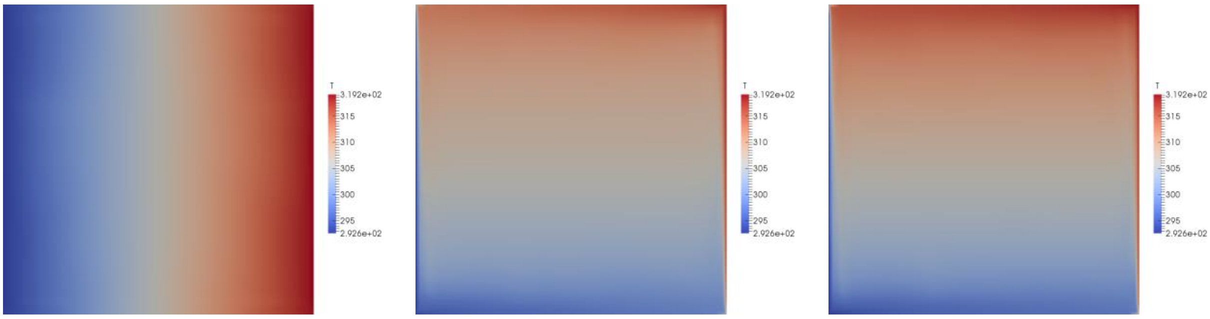
Figure 1.
Schematic experiment setup. The compartments and the Laudas are filled with distilled water. The thermocouple probes are inserted in the middle compartment via catheters. Settings of the Laudas are indicated in the figure. The temperatures of the water baths are checked with an Isotech TTI-10 thermometer with a probe (Isotech 935-14-61), accuracy better than 0.05 °C.

Next, we worked on applying the fluid model to brain hyperthermia treatment planning. The cerebrospinal fluid (CSF) in the brain is expected to have a noticeable influence on the temperature distribution in the brain. Because of the very different distribution of the fluid in the brain, compared to the urinary bladder, and because of the much higher resolution required for brain treatments, some adaptations had to made to the software we developed (in particular to the preparatory parts creating and preparing the computational mesh).

Additionally, I presented my past and current work and that of the AMC hyperthermia group to the Chalmers Signals & Systems hyperthermia group, and attended a number of their group meetings and seminars in order to exchange knowledge.

C. Results

We are still working on finalising the analyses, so the results mentioned here are still preliminary. However, it seems safe to conclude that our fluid model is sufficiently accurate for its intended purposes.



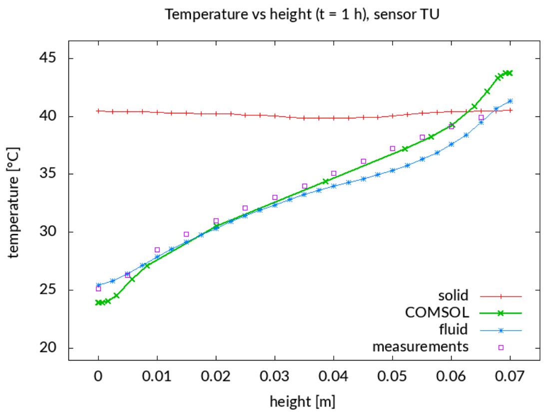


Figure 2.
Temperature measurements and simulations at time t = 1 h. There are vast differences between the solid and fluid models, and much more subtle ones between the Plan2Heat and COMSOL fluid modules. Temperature differences during the experiment are considerately larger than those during hyperthermia treatment.
Top: *cross section along the central plane, showing the solid model (left) the fluid model (centre) and the COMSOL model (right).*
Bottom: *simulated and measured temperature at time t = 1 h along sensor TT/TU (marked in figure 1).*

Although overall, the temperature differences with and without the fluid module are smaller than expected, locally, incorporating the fluid model for the brain hyperthermia treatment planning is yielding results that are noticeably different from those obtained with a solid-only model. As we have so far examined only one example, it is still too early to determine in which cases the Chalmers Hyperthermia Helmet can obtain clinically relevant temperatures, without creating potentially dangerous hot spots.

	conventional		convective		difference		
	CSF	tumour	CSF	tumour	CSF	tumour	
T_{min} [°C]	10.86	33.66	11.75	32.63	−4.34	−1.36	
T_{90} [°C]	32.29	37.46	32.32	37.48	−0.94	−0.02	
T_{50} [°C]	37.45	37.98	37.56	38.04	0.04	0.04	
T_{10} [°C]	40.53	38.77	40.54	39.12	1.21	0.37	
T_{max} [°C]	45.00	43.34	45.35	43.67	8.91	4.88	
T_{ave} [°C]	37.09	38.04	37.19	38.17	0.10	0.13	
SD [°C]	3.06	0.75	2.97	0.82	1.13	0.30	
volume [ml]	340.826	92.031	340.826	92.031	60.1	0.3	< −0.5 °C
					73.6	6.9	> 0.5 °C

Table 1.
Main statistics for CSF and tumour temperature for a brain hyperthermia treatment planning example using the conventional software and the convective model. Overall, temperatures are only slightly higher in the convective model, but the extremes can be quite pronounced. T_n is the temperature exceeded by n % of the considered volume. The volumes in the difference *column are the volumes with clinically relevant temperature differences of more than 0.5 °C in absolute value.*
Antenna settings have been optimized using the conventional software, and the same settings have been applied for the convective model. Larger differences are to be expected when the settings will be reoptimized using the treatment planning software with the fluid module.

D. Future collaboration with host institution

Collaboration between home and host institutions is continuing, especially where the development of the Chalmers Hyperthermia Helmet is considered.

E. Expected Publications

A manuscript on the implications of improved CSF modelling for the Chalmers Hyperthermia Helmet is currently in preparation. Whether the validation of the AMC fluid module for Plan2Heat merits a publication on its own, or will be part of a publication with a wider scope, is under discussion.

F. Other Comments

We do not have any additional comments.

Confirmation by the host institution of the successful execution of the STSM:

We confirm that Gerben Schooneveldt has performed the research work as described above.

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