Thermal simulation of MARTA

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Introduction

This study is made in support of the MARTA (Muon Auger RPC for the Tank Array) proposal (note GAP-2013-020). It is foreseen that gaseous particle detectors, Resistive Plate Chambers (RPCs), may be placed underneath the SD tanks within a concrete support structure. As RPCs are gaseous detectors, sensitive to temperature, it is important to ascertain the expectable temperature excursions on the detector.

The study was made using the commercial finite-elements solver COMSOL Multiphysics, modelling the air flow, the detectors and the ground under realistic temperature and wind data.

Geometry and data

A general view of the simulation geometry is shown in Fig. 1, based on the current preliminary MARTA design. Some relevant sections can be seen in Fig. 2, along with the respective thermal conductivities.

Fig. 1 – Representation of the SD detector, the concrete support, the RPC and the ground surface. By symmetry, only one half of the volume is simulated.

The simulation is based on one year of temperature and wind speed data from the LASER station at the AUGER site. The soil characteristics were taken from http://apollo.lsc.vsc.edu/classes/met455/notes/section6/2.html.

Additionally the tank walls (13 mm of high-density polyethylene\(^1\)) and a 5 cm thick plug of expanded polyethylene on the openings of the pre-cast were mathematically


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modelled as a surface property (volume collapsed into a surface with the same thermal resistance).

Fig. 2 - Thermal conductivity of the different materials used in the study (log scale of units W/(m·ºK)). The thermal conductivity of the stagnant fluids was decupled to account roughly for free convection without detailed fluid modelling (treating the fluid as static). Vertical and horizontal scales in meter.

Model

The modelling proceeds in two steps. First the air velocity field is calculated for the average wind speed, taking special attention to the correct modelling of the boundary layers. A representation of this solution can be seen in Fig. 3.

To avoid modelling the free convection of the stagnant fluids, the thermal conductivity of these fluids was decupled, trying to account roughly for convection while treating the fluid as static.

The time-dependent thermal solution of the whole volume, including forced convection from the wind field, is calculated with the incoming wind temperature as given by the atmospheric data and the wind speed scaled in accordance with the same data. The initial temperature is uniform and equal to the average yearly air temperature, causing an unphysical initial transient.

The atmospheric data was smoothed and values taken every 4 hours. The stored solution has the same granularity but interpolated values may be used internally to assure an accuracy of 1/1000 in the temperature (~0.3 ºK). An example of the resulting temperature field can be seen in Fig. 4.

Insolation was not modelled. This impacts mostly the daily modulation of the temperature, but it will be seen that the daily variation is very effectively attenuated by the thermal inertia of the system.
Fig. 3 - The air velocity field calculated for the average wind speed.

Fig. 4 - Example temperature map (in °C), taken 1 m from the center of the tank on a particularly cold night. It is also shown the 0°C isothermal. Note the downwind plume of hotter air.
Results

In Fig. 5 are shown the temperatures of the test points; incoming air flow (input variable); centre of the SD tank; ground at 0.2 and 0.6 m depths; the two opposite corners of the RPC lower gap (innermost and outermost).

It can be seen that the daily variations are very effectively quenched by the thermal inertia of the system. All above-ground structures seem to follow closely the seasonal average air temperature, so none of the test points ever descends below freezing temperature. The most exposed corner of the RPC sees a temperature range approximately from 2°C to 20°C.

The underground temperatures show a variation smaller and delayed with respect to the air temperature, expressing the large thermal inertia of the soil. This range is also smaller than the measurements taken on the Lamar test site and provided by Jeff Brack (Fig. 6). A more detailed comparison, with the correct input data, would be very useful in validating the model.

Fig. 5 – Air (input) temperature and the solution for some relevant points of the system. Note that for the first moments there is an unphysical response dictated by the unrealistic initial conditions (uniform temperature) and then there is a convergence to the average air temperature.
An important point is the temperature variation across the RPC, which cannot be compensated by voltage adjustments but must be accommodated within the RPC counting plateau. It can be seen in Fig. 7 that, discounting the unphysical initial transient, this difference is at maximum about 3.5°C.
Conclusion

Although a detailed comparison with measured data is still missing, the model response seems physically plausible.

Within the present formulation, all above-ground structures follow closely the seasonal average air temperature but the daily variations are effectively quenched by the thermal inertia of the system, so none of the test points ever descends below freezing. The most exposed corner of the RPC sees a temperature range approximately from 2ºC to 20ºC and variations across the RPC never exceed 3.5ºC.

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