

The APP as a Tool, A First Principles Approach

Roger W. Pryor, Ph. D.

Pryor Knowledge Systems, Inc., Bloomfield Hills, MI, USA

Introduction

The APP discussed in this paper is based on a COMSOL Multiphysics® 1D heat transfer model that analyses the heat flow through a double pane window, with a gas chamber between the two panes, as would normally be mounted in the wall of a building, a container or a refrigerated chamber. The double pane window has air on both the inner and outer sides, and a gas of choice between the two panes. The app discussed herein allows for the modification of the inner and the outer temperatures, the pane material parameters, the pane spacing and the selection of the gas between the two panes. This 1D model and APP provide computational results for the evaluation of this and similar heat transfer problems much more rapidly than will an equivalent 2D or 3D model.

This APP models the calculation of heat loss (gain) under stationary (steady-state) conditions, for a wide range of applied conditions. New physical parameters for the variation of the pane materials (heat capacity, density, thermal conductivity) may be entered along with the surface heat flux to allow a broad range of single layer, multi-layer and composite material calculations.

This APP is suitable for the modeling of the estimated heat loss (gain) in rooms, greenhouses, ovens, refrigeration units, experimental chambers, battery-pack assembly separation, etc. Also, the structural concept of the underlying model (gas chamber isolation) has specifically been employed [1] to significantly reduce the prospect of cascade thermal runaway, due to heat transfer, in experimental high-density Li-ion battery pack assemblies.

Underlying Theory

The APP presented here calculates the temperature gradient (differential) that arises along the heat flow path in this 1D Multiphysics model, as heat flows from the left-most environment, into/out-of the Double Pane Gas Chamber Model. Depending upon the temperature entered in the edit windows, heat flows into/out-of the left-most surface of the Double Pane Gas Chamber Model Geometry, through the

intervening interface materials and then into or out-of the right-most surface and into/out-of the surrounding environment.

In the case of this model, the heat flow is governed by the conductive heat flow equation for solids [2]:

$$\rho C_p \frac{\partial T}{\partial t} + \nabla \cdot q = 0 \quad (1)$$

$$\text{where } q = -k\nabla T$$

where also:

ρ is the density of the material (kg/m³)

C_p is the heat capacity at constant pressure (J/kg*K)

T is the absolute temperature (K)

k is the thermal conductivity (W/m*K)

q is the conductive heat flux (W/m²)

1D Multiphysics Model

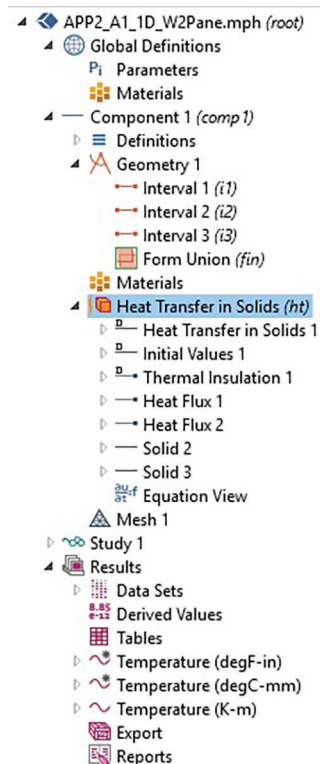


Figure 1 Double Pane Gas Chamber Model

Figure 1 shows the 1D Multiphysics Model tree configuration as seen in the Model Builder Window.

The Geometry comprises three intervals. Interval 1 and Interval 3 are the Panes. Interval 2 comprises the gas chamber. Figure 2 shows a 3D rendition of the 1D model [3]. Mounting materials for the panes and sealing the gas chamber are not shown for clarity.

Figure 3 shows the Interval boundaries of intervals 1, 2, and 3. They are designated by round dots located at each interval end and between the interval segments. Since this model is a 1D model, only the segmented centerline geometry, shown in Figure 3, is necessary to calculate each heat transfer solution and obtain the calculated results computed within this model and the APP.

All solutions of this model are computed using the Heat Transfer in Solids Module and a Stationary Solver. The results of those solutions are presented in the form of three 1D graphical presentations, using the units of, degF-in, degC-mm, and K-m. In the resulting 1D plots, the temperature is shown as a function of the distance (location of the measurement point) into the geometry of the Double Pane Gas Chamber Model from the left-most extent (start) of the linear geometry to the right-most extent (end). In the event that the inner temperature is lower than outer temperature, the same directionality applies and the slope of the solution lines will be reversed.

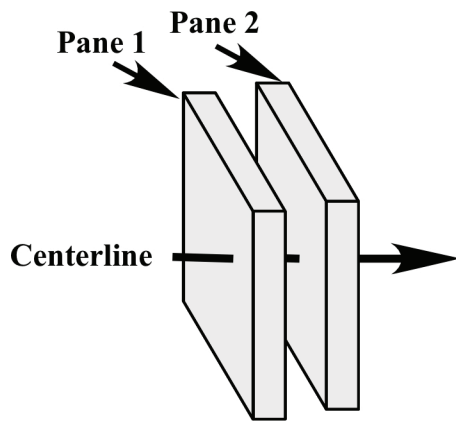


Figure 2 Two Panes Plus Gas Gap



Figure 3 Intervals 1, 2 and 3

Application Builder

Figure 4 shows the Double Pane Gas Chamber APP user panel. The user panel comprises the primary and

secondary edit windows, the Compute button and the calculated Results display. Figure 5 shows the Double Pane Gas Chamber APP Builder Tree, as viewed in Application Builder. The Application Builder Tree shows the forms that comprise the Double Pane Gas Chamber APP and also the Menu bar controls.

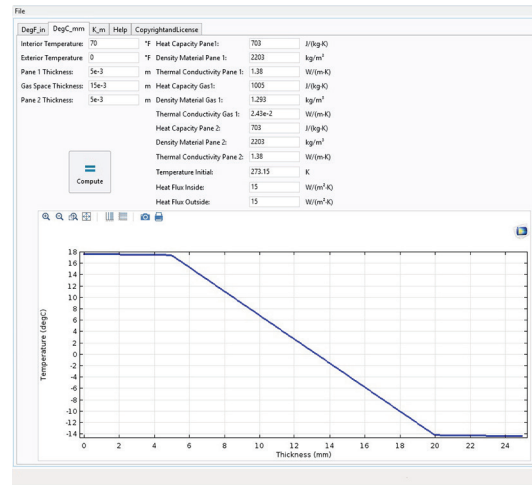


Figure 4 Double Pane Gas Chamber APP

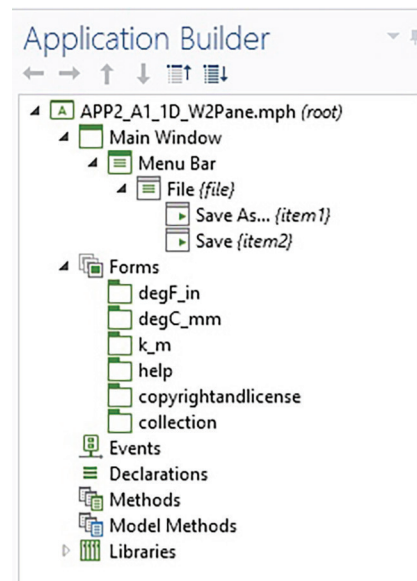


Figure 5 Double Pane Gas Chamber APP

The Primary APP Parameter edit windows are shown in Figure 6. These include the Interior Temperature (degF), Exterior Temperature (degF), Pane 1 Thickness (m), Gas Space Thickness (m) and Pane 2 Thickness (m). Temperature can alternately be entered as degrees C or K, if followed by [degC] or [K] respectively. Thickness can be entered as inches,

centimeters, or millimeters, if followed by [in], [cm], or [mm], respectively.

Interior Temperature: °F

Exterior Temperature: °F

Pane 1 Thickness: m

Gas Space Thickness: m

Pane 2 Thickness: m

Figure 6 Primary APP Parameters

Heat Capacity Pane1: J/(kg·K)

Density Material Pane 1: kg/m³

Thermal Conductivity Pane 1: W/(m·K)

Heat Capacity Gas1: J/(kg·K)

Density Material Gas 1: kg/m³

Thermal Conductivity Gas 1: W/(m·K)

Heat Capacity Pane 2: J/(kg·K)

Density Material Pane 2: kg/m³

Thermal Conductivity Pane 2: W/(m·K)

Temperature Initial: K

Heat Flux Inside: W/(m²·K)

Heat Flux Outside: W/(m²·K)

Figure 7 Secondary APP Parameters

The Secondary APP Parameter edit windows are shown in Figure 7.

The user of the Double Pane Gas Chamber APP can first insert the Primary Parameters in the edit windows shown in Figure 6. Next, the user of the Double Pane Gas Chamber APP can insert the Secondary Parameters in the edit windows shown in Figure 7. In the event that no new parameters are entered, the default parameters displayed will be used to find a solution.

Once any new parameters have been entered, then the Compute button, shown in Figure 4 is clicked. The results are then displayed in three different tabs: degF-in, degC-mm and K-m, as shown in Figures 8, Figure 9 and Figure 10.

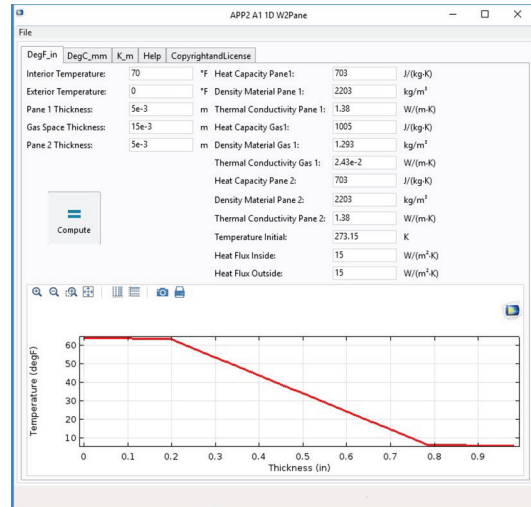


Figure 8 Double Pane Gas Chamber (degF-in)

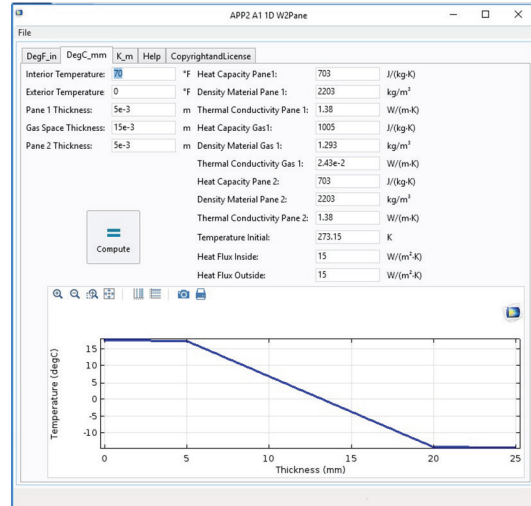


Figure 9 Double Pane Gas Chamber (degC-mm)

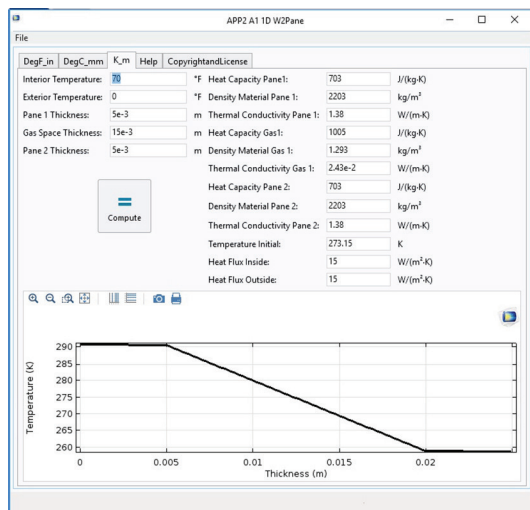


Figure 10 Double Pane Gas Chamber (K-m)

The user can vary the primary and secondary parameters of the Double Pane Gas Chamber APP to explore and analyze most desired pane and gas material combinations.

Conclusions

The primary conclusion that can be drawn from this paper is that this 1D APP facilitates accurate First Principles analysis to show preliminary evaluation results. This APP allows the modeler to determine the proper direction to pursue when undertaking further more difficult, complex problem calculations that potentially require additional 2D or 3D analysis.

Building an application (APP) from an exploratory model and running it with COMSOL Server allows non-modeling scientists, engineers and staff to explore combinations of design and material changes that they could not easily explore otherwise. This allows all members of the company structure to more easily reach accommodation on the design of a new or revised product.

References

1. R.E.White, Personal Communication, 2017
2. COMSOL, HeatTransferModuleUsersGuide, V. 5.3, p. 143
3. R.W. Pryor, Multiphysics Modeling Using COMSOL 5 and MATLAB, p. 37