Optimum Insulation Thickness Distribution for Heat Loss Uniformity from Heated Corrugated Pipes

R. I. Bourisli
Department of Mechanical Engineering, Kuwait University, Kuwait

INTRODUCTION: Insulation of pipe is everywhere. For many non-circular pipes, insulation is not optimum. Heat leaks from sections not sufficiently insulated while other sections are "over-insulated." The plan is to optimize the layout of the insulation material is optimized in a way that eliminates heat leaking spots—*i.e.*, make heat loss *uniform*.

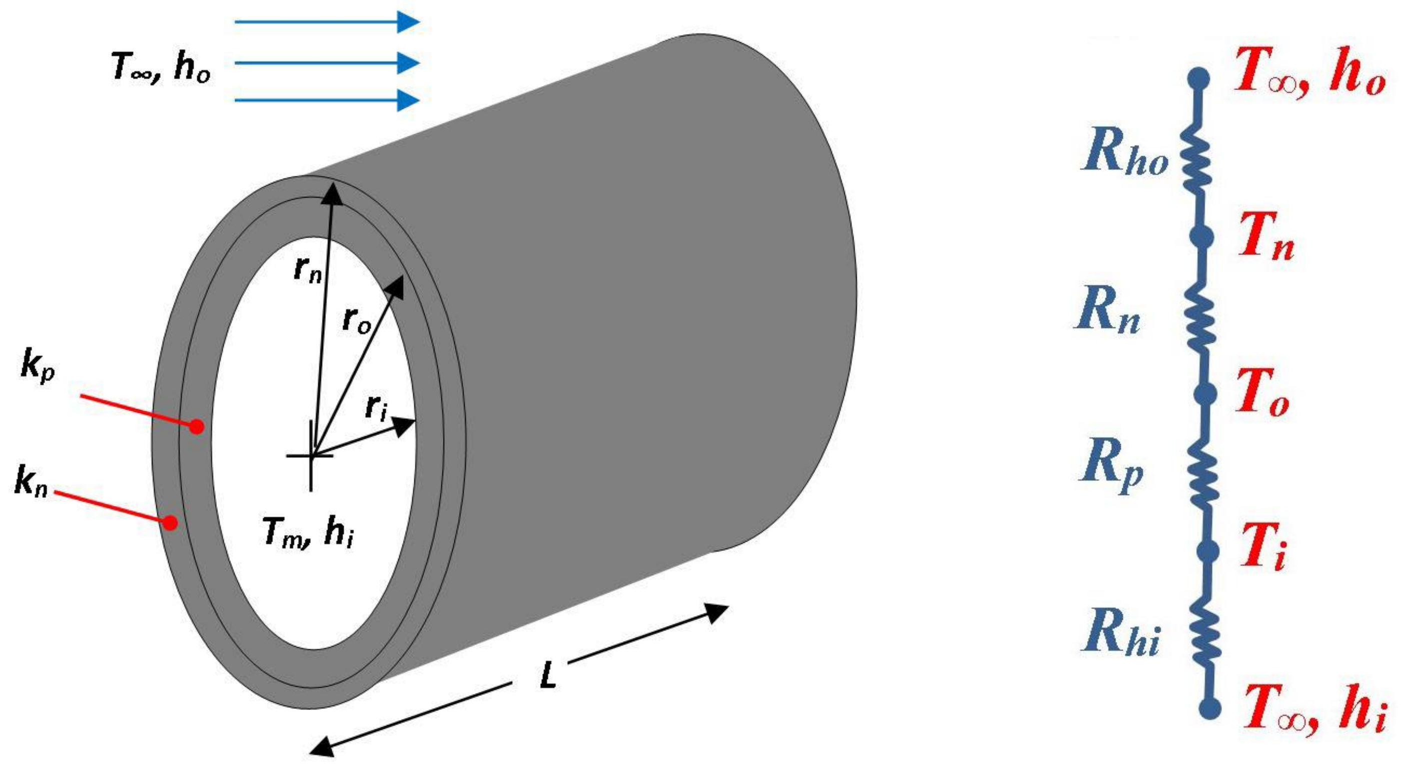


Figure 1. Schematic and thermal circuit representation of the problem.

Axial functions of the pipe and insulation surfaces are written in terms of axial location along the pipe axis. A sinusoidal function is assumed for the geometry.

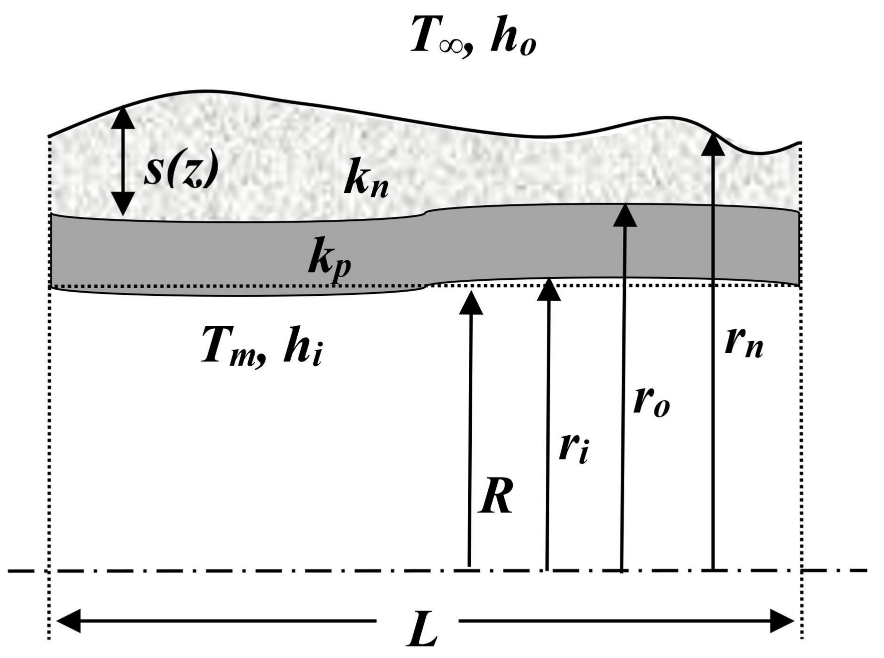


Figure 2. Axial pipe geometry.

METHODS AND RESULTS: The problem is solved using two approaches: 1) the total heat loss in a section is written as a function of *z* (the pipe axial dimension) and the thermal resistance representation is differentiated and set to zero to find the insulation thickness that makes the heat loss uniform.

$$R_{tot} = \frac{1}{2\pi L h_i r_i} + \frac{\ln\left(\frac{r_o}{r_i}\right)}{2\pi L k_p} + \frac{\ln\left(\frac{r_o+s(z)}{r_o}\right)}{2\pi L k_n} + \frac{1}{2\pi L h_o (r_o+s(z))}$$

This results in a first-order, nonlinear, ODE,

$$\frac{dR_{tot}}{dz} = \left[\frac{-F(z)}{H_i P^2(z)}\right] + \left[\frac{-F(z)}{K_p P(z) Q(z)}\right] + \left[\frac{1}{K_n[Q(z)+s(z)]}\frac{ds(z)}{dz} - \frac{F(z)s(z)}{K_n Q(z)[Q(z)+s(z)]}\right] + \left[\frac{-F(z)}{H_o[Q(z)+s(z)]^2} - \frac{1}{H_o[Q(z)+s(z)]^2}\frac{ds(z)}{dz}\right]$$

which is solved by the 4th-order Runge-Kutta method,

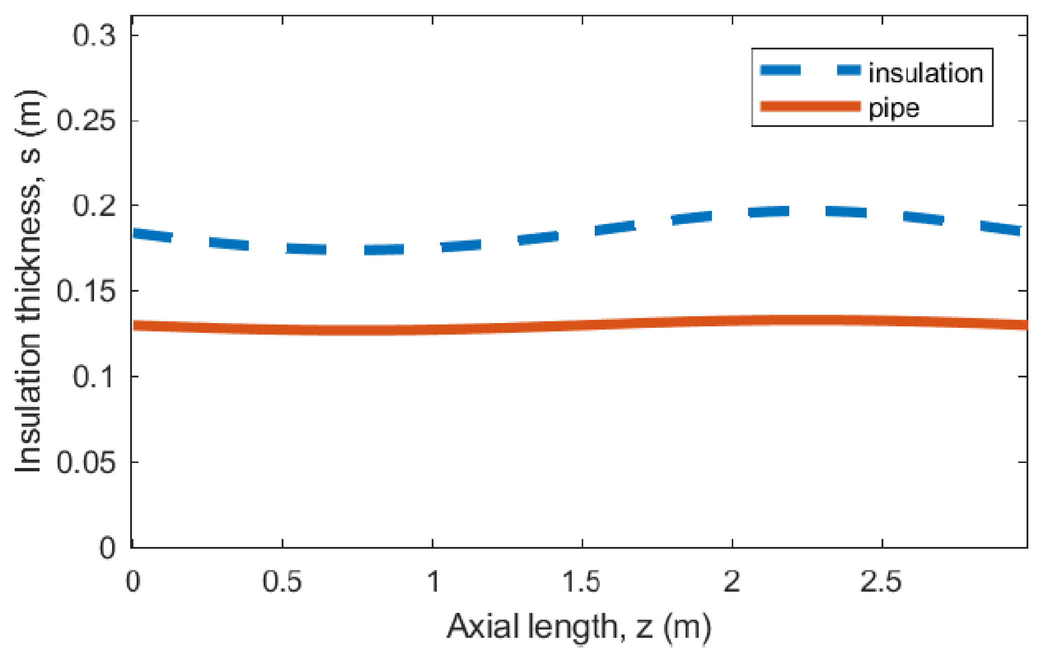


Figure 3. RK4 results for the optimum insulation prole over the sinusoidal pipe.

In the second approach, **COMSOL Multiphysics® Optimization Module** is used to optimize:

a) points along the axis for the radial position defining the outer surface of the insulation;

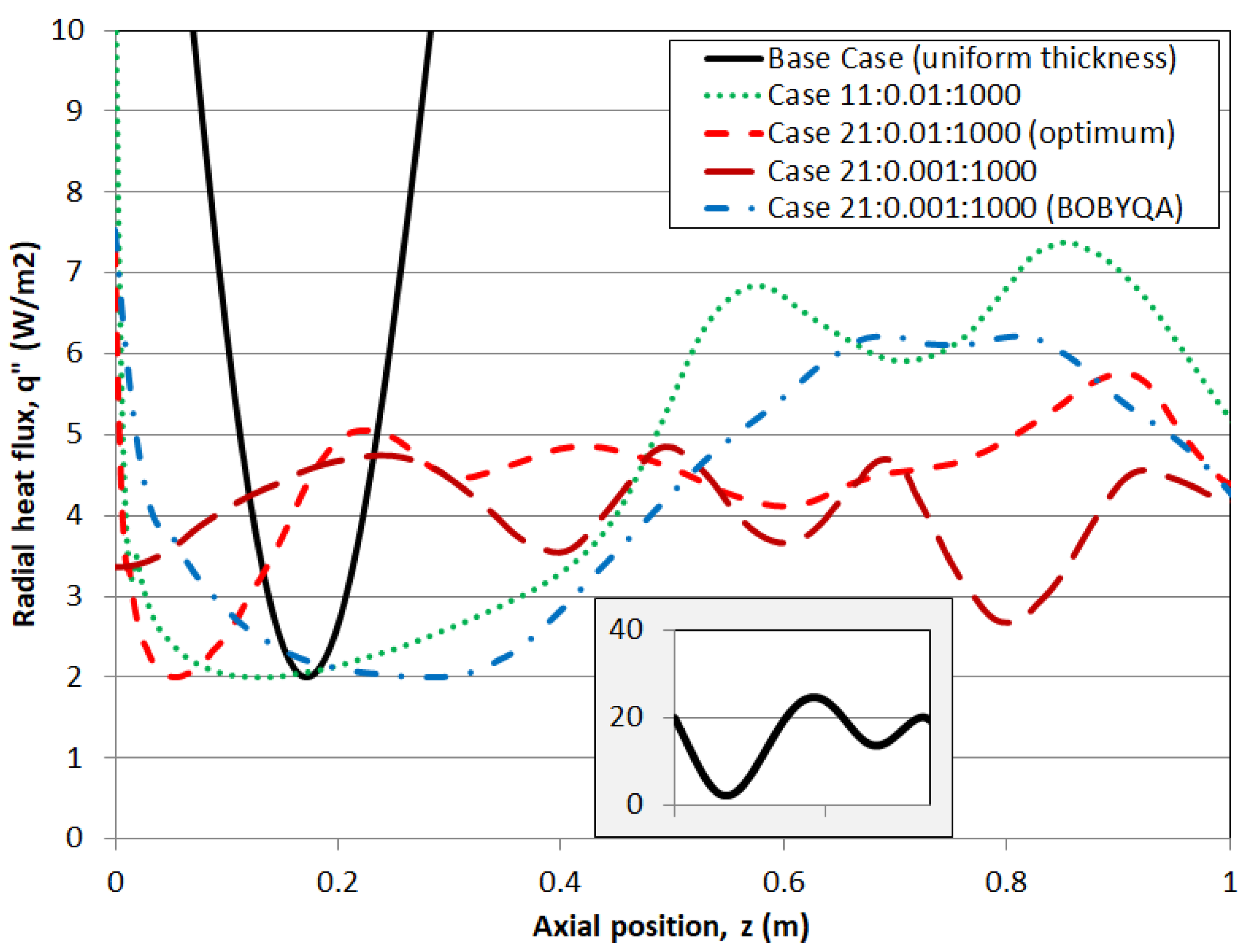


Figure 4. Radial heat flux as a function of the axial position for a number of optimization settings. Insert is for uniform thickness case.

b) and a parameter (and then two) used to define a closed-form function draw the outer surface of the insulation.

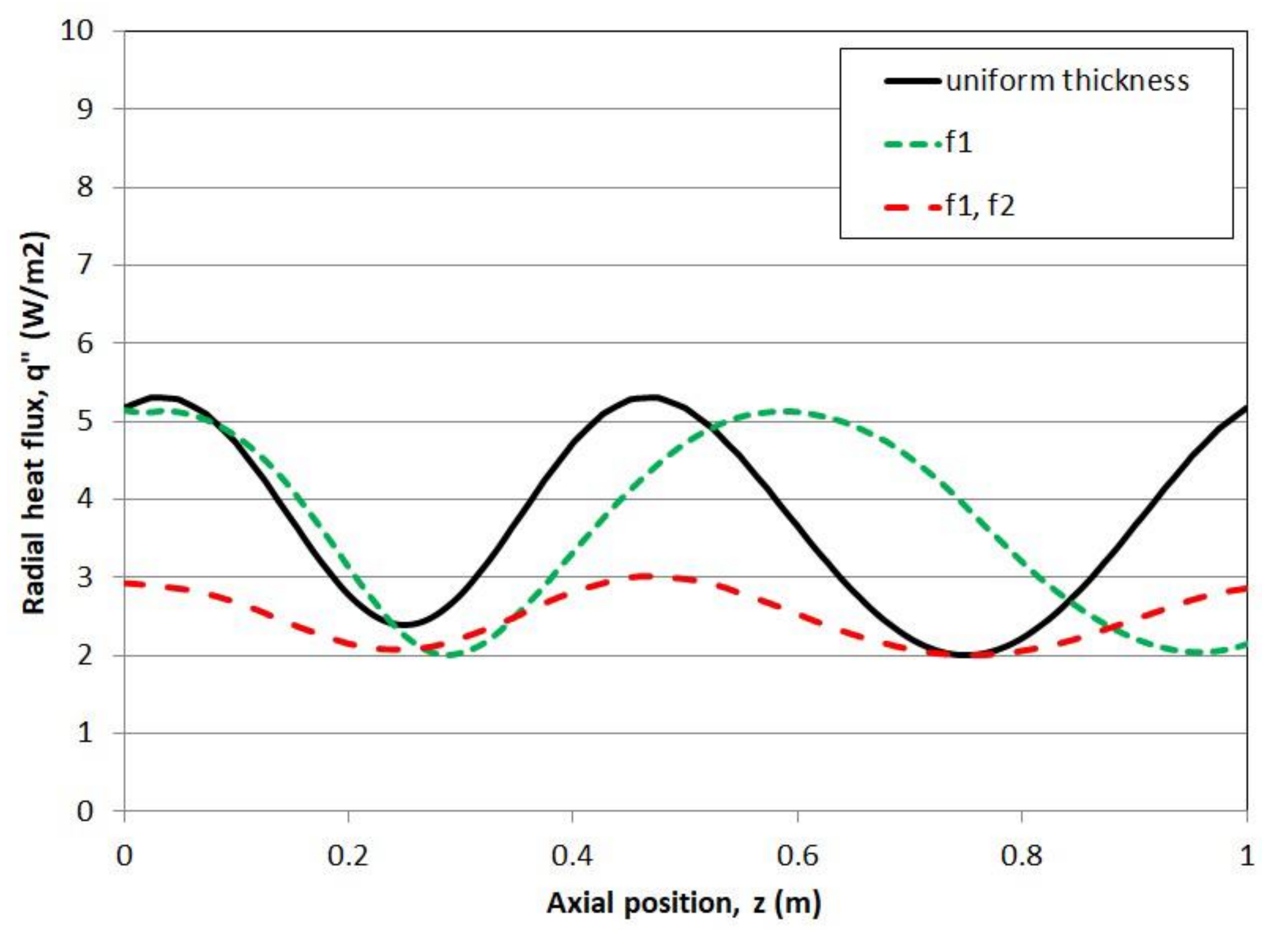
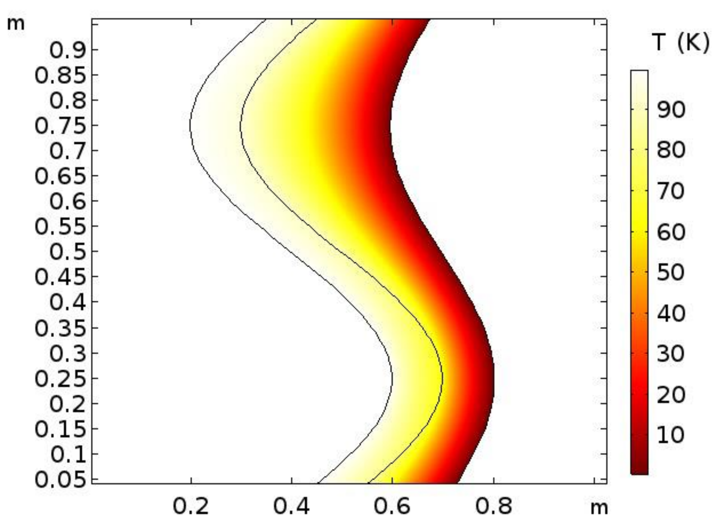


Figure 5. Radial heat flux as a function of the *z*.

CONCLUSIONS: The methodology can be applied to almost any problem in heat transfer, provided the correct definition of the objective function is used. Optimum points layout and functions cut the waste in insulation material significantly, as shown.



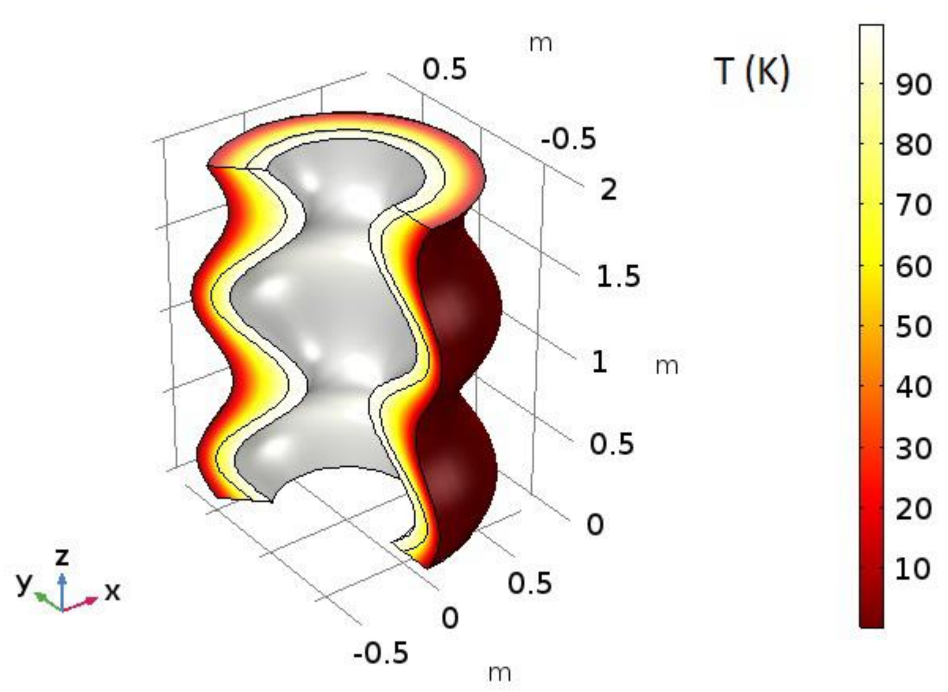


Figure 6. 2D and 3D temperature contours