Fuel Tank Design Optimization in Extrusion Blow Moulding

Thibault, Francis

Fuel Tank Design Optimization in Extrusion Blow Moulding

F. Thibault
Industrial Materials Institute
National Research Council of Canada

The aim of this paper is to present the development of design optimization software environment for the manufacturing of blow moulded multilayer fuel tanks. Based on gradient optimization methodology, the optimization software (BlowDesign) loops over the finite element simulation technology (BlowView) developed at the National Research Council (NRC) of Canada to improve the design of the final part.

A new design optimization scheme is proposed to improve the part design using two main consecutive optimization steps: the die geometry and the processing conditions optimization. The die geometry optimization consists of manipulating the geometry of the bushing-mandrel shape in order to distribute the material uniformly around the inflated part using static flexible deformable ring (SFDR) die technology. The process optimization consists in the manipulation of design variables such as the extrusion flow rate, extrusion time, pre-blow pressure, the vertical wall distribution system (VWDS), the partial wall distribution system (PWDS) or the die slide motion (DSM) to minimize the part thickness variance around the desired thickness distribution or to minimize the part weight subject to a minimum thickness constraint based on client performance criteria. During the former optimization, a barrier layer thickness optimization is performed simultaneously to minimize the hydrocarbon permeation through the tank wall to satisfy the daily emission imposed by government regulation.

The efficiency of the design optimization scheme has been investigated on several fuel tanks for automotive industry over the years. In this work, the proposed optimization approach will be investigated on a specific fuel tank. The optimization has proven to be an excellent tool to improve the design by decreasing the objective function and satisfying the process constraints over optimization iterations.

CASE STUDY: PROCESSING PARAMETERS AND BARRIER LAYER OPTIMIZATION

Since the permeation model has been validated adequately [1], this model has been implemented into the BlowDesign optimization software of the NRC. The software manipulates the design variables or processing parameters subject to process constraints such as extrusion time, parison length and finally the permeation rate per day. At each optimization iteration, BlowDesign modifies the design variables to minimize the objective function, which is defined as the PFT thickness standard deviation subject to a target thickness value. In the plastic fuel tank industry, it is well accepted that the PFT minimum target thickness value should be around 3.0 mm.

So at each time the processing parameters are updated, the thickness distribution on the PFT will be modified accordingly. For a specified thickness distribution, a gradient-based algorithm is used to update the % thickness barrier layer to satisfy a given permeation constraint such as 10 mg/day. This procedure assumes that the % thickness barrier layer will be modified slightly and will not affect the overall thickness distribution predicted by the CNRC software technology.

To illustrate the optimization procedure, a PFT tank of Kautex Company will be used. The initial design of the PFT is composed of 6 layers of polymeric materials as illustrated in Table I. The initial barrier layer percentage has been decreased intentionally in order to let the optimization software adjusting it over the optimization iteration. At each iteration, the layer barrier percentage is modified to satisfy the permeation constraint of 10 mg of permeant per day. Figure 1 shows typical finite element meshes used to model the parison extrusion, the parison inflation and finally the deflashing of the part.

Table 1. Percentage, diffusion and permeability coefficients of each polymeric material used in PFT.

PFT Layers of Initial design	Layer Percentage [%]	Diffusion Coefficient [m^2/s]	Solubility Coefficient [g/g]
Outer HDPE	24.7	5.5e-12	6.8e-2
Outer LLDPE adhesive	2.5	8.2e-12	1.49e-1
EVOH Barrier	0.3	5.0e-13	5.0e-4
Inner LLDPE adhesive	2.5	8.2e-12	1.49e-1
Inner HDPE	50.0	5.5e-12	6.8e-2
Outer HDPE	20.0	5.5e-12	6.8e-2

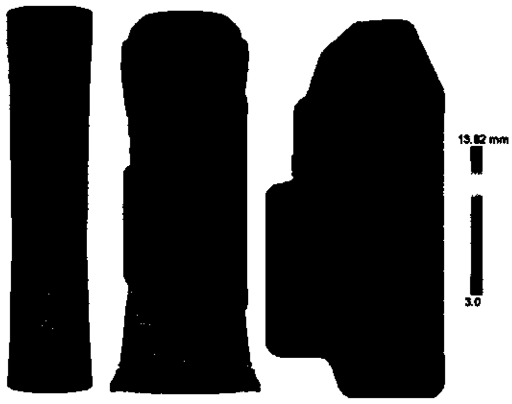

Figure 1. Typical finite element meshes used for the simulation of the extrusion blow molding.

Figure 2 illustrates the thickness distribution and the hydrocarbon emission flux per unit area [mg/day/m^2] variations for the initial design. Knowing the total surface area of the tank shell and the pinch-off zone, the total permeation can be evaluated. One can notice that the initial design does not satisfy the permeation constraint since a total of 90.8 mg per day of hydrocarbon is emitted when 0.3% of EVOH is used. It can also be observed that where the PFT thickness is small, the permeation is high and vice-versa, which is consistent in physical terms.

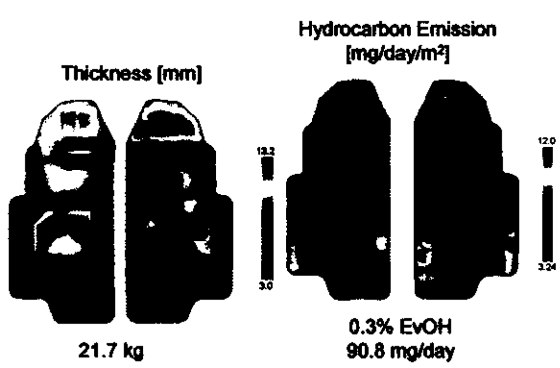

Figure 2. Thickness and hydrocarbon emission flux distributions for the initial design.

During the optimization process, the %EVOH is manipulated in order to satisfy the daily permeation constraint. In Figure 3, the gradient-based algorithm has found after 6 optimization iterations, that 3.81% of EVOH should be used to satisfy the daily permeation constraint of 10 mg/day for the given thickness distribution. The part weight has been decreased from 21.7 kg down to 17.6 kg and satisfies the thickness constraint of 3 mm. In the industry, a 3 to 5% of EVOH is used to satisfy the PZEV (Partial Zero Emission Vehicle) regulation, which is close to the predicted value (3.81 %EVOH).

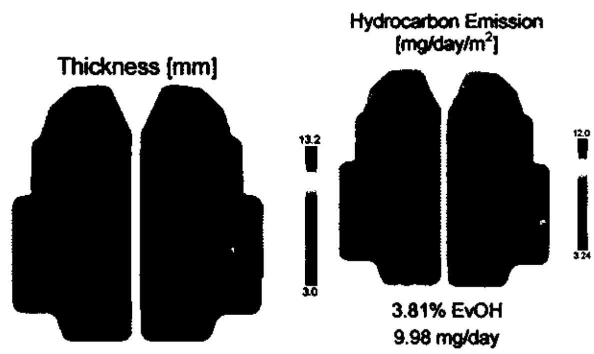

Figure 3. Thickness and hydrocarbon emission flux distributions for the optimal design.

References

1. Z. Benrabah, Thibault F. and R. Diraddo, 2006. Finite Element Modeling of Fuel Emission for Thermoplastic Multilayer Fuel Tanks with Optimization of Barrier Properties, SAE Transactions Journal of Fuels and Lubricants, 2006-01-0625.

2. Laroche, D., Kabanemi, K., Pecora, L., and DiRaddo, R., Polymer Engineering and Science, vol. 39 (7), pp.1223-1233, 1999.

3. Laroche, R., DiRaddo, R., and Pecora, L., Proceeding of the 5th International Conference on Numerical Methods in Industrial Forming Processes, 1995.

4. Milliste M., Lear Automotive Company, Concord, Ontario, Private Communication, 2001.

5. VanderPlaats, G.N., 1999. Numerical Optimization Techniques for Engineering Design, VanderPlaats Research & Development, Inc., Colorado Springs, CO, USA.