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Recycling of rigid foam from end-of-life refrigerators

The objective of the work was to develop a polyol from the chemical recycling of rigid refrigerator foam waste, which could be incorporated into a newly formulated polyol, to be used in the production of new refrigerators. Using a polyol generated by glycolysis of rigid foam recovered from end-of-life refrigerators a polyol formulation containing 40 % of recycled material was shown to give equivalent performance to new polyol blend raw materials. The global refrigerator manufacturer, Electrolux, collaborated on this project. Details of the project include formulation and physical property information.

Introduction

Purcom has worked with chemical recycling technology since 2006. The project described presented the company with an opportunity to validate the technology via collaboration with an internationally recognized manufacturing company.

Electrolux Brasil was selected as a partner for the research project. Since Electrolux works with global raw material suppliers, the project was considered a research investment rather than a commercial opportunity. Electrolux generated 40 tonnes of waste rigid PU foam monthly.

Experimental

The project started with Electrolux providing enough rigid foam scrap so that different possibilities for chemical recycling could be evaluated.

Several polymer degradation processes were evaluated using "aminolysis", "glycolysis", and "acidolysis." The polyurethane depolymerization process proved to be more effective using the "glycolysis" process.

For the glycolysis, scrap rigid foam was mixed with the same amount of glycol. To accelerate the reaction, an organo metallic salt catalyst was added.

Process temperatures varied in a range from 150 to 300 °C. After starting the reaction, it took two hours to add all the scrap and it took four hours to complete the process. The use of finely powdered scrap foam gave a faster rate of glycolysis.

Figure 1:
Rigid foam from end-of-life refrigerators

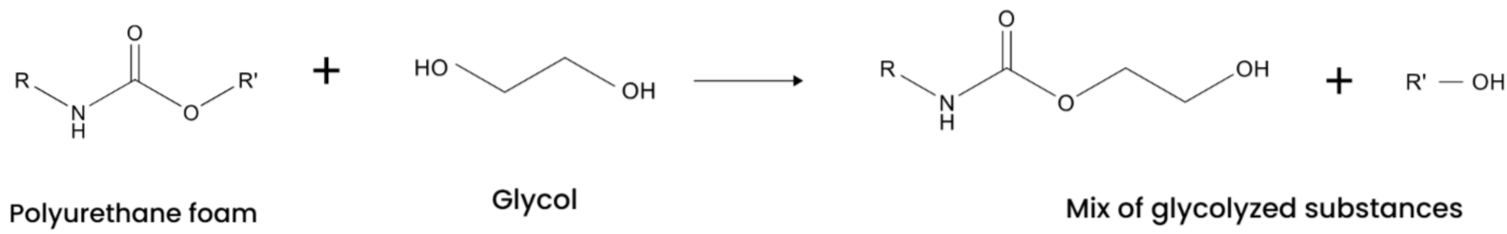

Figure 2:
Glycolisis reaction

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Two glass reaction vessels with 20 l capacity were used to prepare four batches (80 kg) of recycled polyol. This material was blended with the additional components to produce 200 kg of blended polyol, which was used for refrigerator insulation at the Electrolux plant in Curitiba. The characteristics of the initial polyol from the glycolysis process were as follows:

Property	Units	Value
Initial experiment		
Hydroxyl value	mg KOH/g	669
Viscosity at 25 °C	mPa.s	2,200
Acid value	mg KOH/g	0.41

Table 1:
Recycled-based formulated polyol formulation

Further laboratory experimentation resulted in the development of a polyol based on recycled rigid foam that gave optimum performance. This material had the characteristics shown in **Table 2**.

Property	Units	Value
Final polyol		
Hydroxyl value	mg KOH/g	402
Viscosity at 25 °C	mPa.s	17,000
Specific gravity	g/cm^3	1.18
Acid value final blend	mg KOH/g	0.93

Table 2:
Characteristics of final recycled polyol

Recycling of rigid foam from end-of-life refrigerators

With this recycled polyol obtained by recycling described above, a refrigerator formulation that would meet the process used by Electrolux was developed.

The refrigerator insulation process used by Electrolux involved the following process:

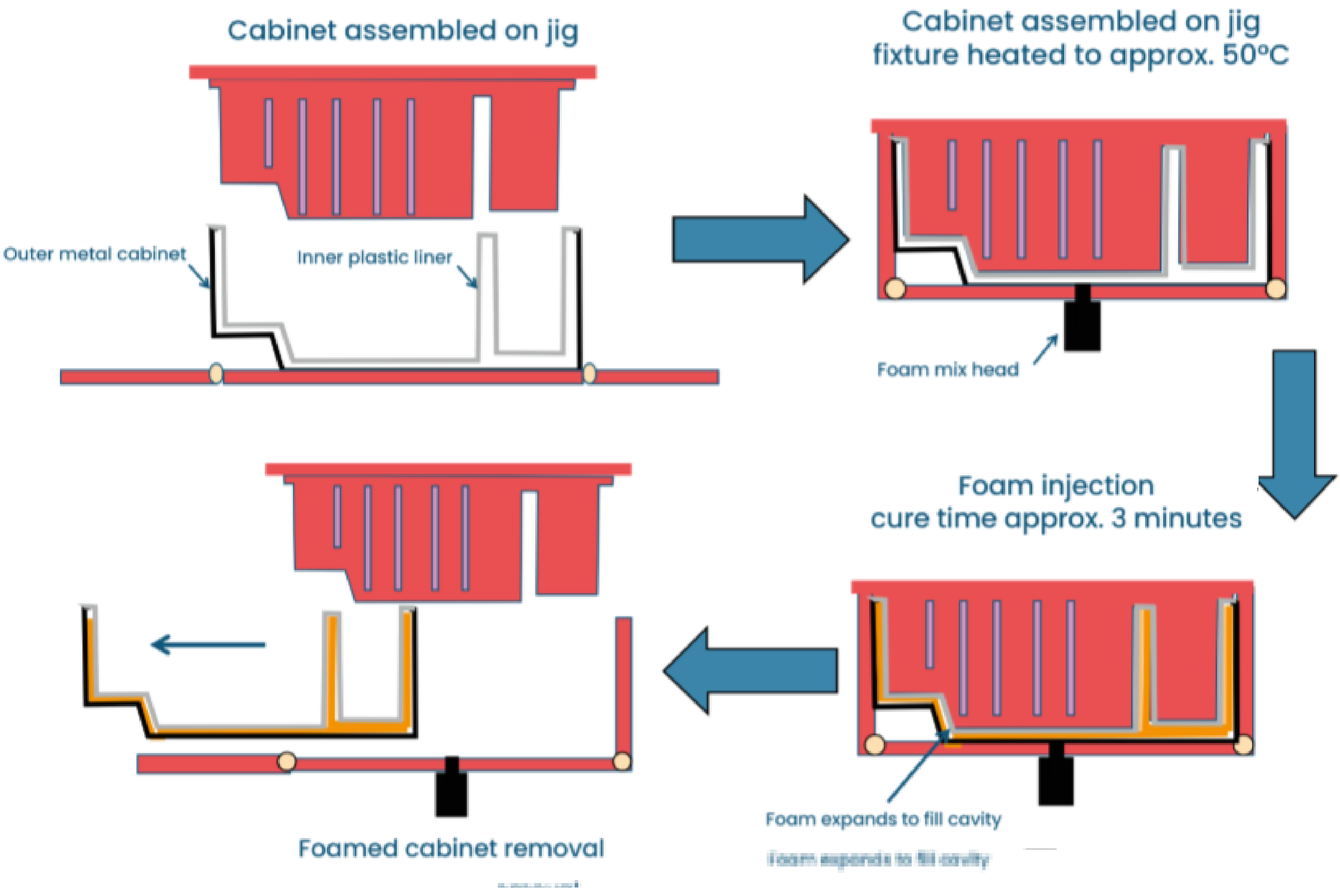

Figure 4:
Refrigerator foaming jigs

Electrolux refrigerator insulation recipe	
Formulated polyol blend	100 pbw
Cyclopentane	13 pbw
pMDI	140 pbw
Reactivity at 25 °C lab cup test	
Cream time	9 s
Gel time	41 s
Tack free time	57 s
Free rise density	21.3 kg/m³ (1.33 lbs/ft³)

Table 3:
Electrolux standard recipe for refrigerator insulation

The following formulation was developed:

Figure 5:
Laboratory production of foam test blocks

Ingredient	Percentage	Characteristic
Recycled polyol	40.00	OHv = 402
Amine based polyol	10.00	OHv = 640
Glycerine based polyol	20.00	OHv = 372
Vegetal polyol	8.00	OHv = 240
Polypropylene glycol	5.00	OHv = 110
Sucrose base polyol	11.62	OHv = 360
Surfactant	1.90	
Catalyst A	0.60	
Catalyst B	0.30	
Catalyst C	0.30	
Water	2.27	
Total	100.00	

Table 4:
Foam formulation containing recycled polyol

Physical properties of the formulated polyol	
Specific gravity	1.09 g/cm³
Viscosity at 25 °C	1,680 mPa.s

Table 5:
Physical properties of formulated polyol blend

Results and discussion

On the day of the test at the Electrolux Curitiba production facility, the polyol blend with recycled content was loaded into the foam dispensing unit tank. The calibration and other process parameters were not changed. Refrigerator cabinets were foamed using the same demolding time as used for standard production.

After demolding, foam-to-substrate adhesion was checked and found to be identical to the foam system currently used. Refrigerators were insulated until the polyol tank reached the refill level. At that moment, the tank was reloaded with a 50/50 blend of current Electrolux polyol/recycled polyol.

Refrigerators were injected without any process changes, and everything continued to perform in accordance with standard production requirements. Electrolux carried out all physical and performance tests on the injected refrigerators and the results were equivalent to standard production without any change in physical and thermal properties.

Rigorous testing was carried out to verify that the recycled polyol blend produced foam was dimensionally stable. Using a freezer door panel, the maximum distortion recorded was 0.2 mm.

Sample reference	Recycled polyol blend 100 %	Recycled polyol / BHL* blend 50/50%
Sample with lowest density	30.90	30.50
Sample with highest density	31.51	30.60
Mean	31.21	30.55
Installed foam compressive strength kg/cm²		
	1.79	2.00

(* blend from third party supplier)

Table 6:
Foam installed density (kg/m³) and compressive strength

Sample	Door type	Distortion of upper part	Distortion of lower part	Total distortion
Before thermal cycling				
1	Freezer	2.30	-0.30	0.24
2	Freezer	1.10	-0.40	0.10
3	Freezer	0.90	-0.50	0.35
4	Freezer	1.30	-0.30	0.67
After thermal cycling				
1	Freezer	1.60	-0.20	0.20
2	Freezer	1.70	-0.30	0.20
3	Freezer	1.40	-0.20	0.55
4	Freezer	1.50	-0.40	0.64
Difference				
1	Freezer	-0.70	-0.10	-0.04
2	Freezer	-0.60	-0.10	0.10
3	Freezer	-0.50	-0.30	0.20
4	Freezer	-0.20	0.10	-0.03

***Table 7*:**
Dimensional stability testing of foam from freezer cabinet door

Conclusion

- All chemicals and molded foam physical properties remained within those specified by the manufacturer. Some properties were improved, such as tear strength improved by 10 % and sound attenuation improved by 13 %.
- The biobased product showed processability very similar to the petroleum-based product.
- The final piece has a visual appearance that is in accordance with what is required by the refrigerator manufacturer.
- It was possible to develop a product with 56 % biocarbon content based on polyol (The % biocarbon results were done by Beta Analytics following the ASTM D6866-22 Method B (AMS) TOC standard).

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