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INFLUENCE OF SAMPLE QUANTITY ON GEL CONTENT DETERMINATION OF SOLAR EPE ENCAPSULANTS: A STATISTICAL EVALUATION USING THE SOXHLET EXTRACTION METHOD

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ABSTRACT

Gel content is a critical quality parameter for crosslinked solar encapsulants such as EVA and EPE (Enhanced Polyolefin Elastomer). It directly reflects the degree of crosslinking achieved during lamination and influences mechanical integrity, adhesion, thermal stability, and long-term module reliability. The present study investigates the influence of sample quantity on gel content determination using the Soxhlet extraction method.

Three different EPE sample quantities (0.5 g, 1.0 g, and 2.0 g) were evaluated under identical extraction conditions. Results indicate a consistent increase in measured gel content with increasing sample weight. Average gel content values increased from 92.98% for 0.5 g samples to 95.17% for 1.0 g samples and 95.93% for 2.0 g samples. The findings suggest that sample mass significantly impacts measured gel content and should be carefully controlled during laboratory testing to ensure reproducibility and inter-laboratory consistency.

KEYWORDS: Solar encapsulant, EPE, Gel Content, Crosslinking, Soxhlet Extraction, Sample Weight, Photovoltaic Modules.

INTRODUCTION

Gel content Solar module encapsulants require adequate crosslinking to provide long-term durability and environmental protection. Gel content testing is widely used to assess the extent of polymer network formation after curing.

The Soxhlet extraction method quantifies the insoluble fraction of the polymer by removing uncross linked materials using an organic solvent. The remaining insoluble fraction is expressed as gel content percentage:

$$Gel\ Content(\%) = \frac{Final\ Sample\ Weight}{Initial\ Sample\ Weight} \times 100$$

Although industry standards specify extraction procedures, limited information is available regarding the influence of sample quantity on measured gel content. This study aims to analyze the effect of sample mass on gel content determination for EPE solar encapsulants.

Experimental Setup Material.

Encapsulant Type: EPE

Extraction Method: Soxhlet Extraction

Test Replicates: Two per sample weight

2.2 Sample Quantities Evaluated

Sample Quantity	Replicates
0.5 g	2
1.0 g	2
2.0 g	2

2.3 Gel Content Calculation

$$Gel\ Content(\%) = \frac{W_f}{W_i} \times 100$$

Where:

- W_i = Initial Sample Weight
- W_f = Final Sample Weight after extraction

3. Experimental Data

3.1 Raw Results

Sample Weight	Initial Weight (g)	Final Sample Weight (g)	Gel Content (%)
0.5 g	0.6202	0.5730	92.39
0.5 g	0.6985	0.6536	93.57
1.0 g	1.2443	1.1804	94.86
1.0 g	1.1490	1.0971	95.48
2.0 g	2.5778	2.4602	95.44
2.0 g	2.5322	2.4416	96.42

4. RESULTS AND DISCUSSION

4.1 Effect of Sample Quantity

The measured gel content increased with increasing sample quantity.

Sample Quantity	Average Gel Content (%)
0.5 g	92.98
1.0 g	95.17
2.0 g	95.93

- Improvement Observed
- From 0.5 g to 1.0 g:
- 95.17−92.98=2.19%95.17 - 92.98 = 2.19\%95.17−92.98=2.19%
- From 1.0 g to 2.0 g:
- 95.93−95.17=0.76%95.93 - 95.17 = 0.76\%95.93−95.17=0.76%
- Overall increase:
- 95.93−92.98=2.95%95.93 - 92.98 = 2.95\%95.93−92.98=2.95%
- The increase becomes less pronounced above 1 g, indicating stabilization of measured gel content.

4.2 Possible Reasons

1.Lower Weighing Error

Small samples are more sensitive to balance variations.

For example:

Error of ±0.005 g on a 0.5 g sample = ±1.0%

Error of ±0.005 g on a 2.0 g sample = ±0.25%

Therefore, larger sample quantities reduce relative weighing uncertainty.

2. Sample Heterogeneity

Solar encapsulants may exhibit localized variations in curing.

A small 0.5 g specimen may not adequately represent the overall laminate structure. Larger samples capture a broader area and provide a more representative measurement.

3. Handling Losses

Very small extracted residues are more susceptible to:

Mechanical losses

Mesh transfer losses

Particle detachment during drying

These losses artificially reduce final weight and lower the calculated gel content.

4. Improved Statistical Representation

Larger samples reduce the effect of local material variability and therefore improve repeatability.

4.3 Repeatability Analysis

Standard Deviation

• Sample Quantity	• Standard Deviation (%)
• 0.5 g	• 0.84
• 1.0 g	• 0.44
• 2.0 g	• 0.69

- The 1.0 g samples demonstrated the best repeatability.

Coefficient of Variation

• Sample Quantity	• CV (%)
• 0.5 g	• 0.90
• 1.0 g	• 0.46
• 2.0 g	• 0.72

The lowest variation was observed for the 1 g sample quantity, suggesting this may provide the optimum balance between accuracy and test practicality.

5. Industrial Implications

The observed increase in gel content with sample mass demonstrates that test conditions significantly influence reported values.

If different laboratories use different sample quantities:

Gel content results may differ by approximately 3%.

Material acceptance decisions may be affected.

Cross-laboratory comparison becomes difficult.

For solar encapsulant quality control, a fixed sample quantity should be standardized.

Based on the present study:

0.5 g tends to underestimate gel content.

1.0 g provides excellent repeatability.

2.0 g provides the highest measured gel content but may increase extraction time and solvent usage.

6. CONCLUSION

This study evaluated the influence of sample quantity on Soxhlet gel content determination of EPE solar encapsulants.

- Key findings include:
- Gel content increased with sample quantity.
- Average gel content values were:
- 92.98% for 0.5 g samples
- 95.17% for 1.0 g samples
- 95.93% for 2.0 g samples
- The total increase from 0.5 g to 2.0 g was approximately 2.95%.
- Larger sample quantities reduce weighing uncertainty and improve representation of the material.
- The 1.0 g sample quantity exhibited the best repeatability.
- Standardization of sample quantity is essential for reliable gel content measurement in solar encapsulant quality control.

Recommendations for Future Work

- Investigate EVA, POE, and EPE encapsulants separately.
- Study sample quantities ranging from 0.25 g to 5 g.
- Evaluate the effect of extraction time on gel content.
- Compare Soxhlet extraction with xylene immersion methods.
- Establish an optimized laboratory standard for Renewsys encapsulant testing

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