



Universiteit
Leiden
The Netherlands

Foam Rheology Near the Jamming Transition

Woldhuis, E.L.

Citation

Woldhuis, E. L. (2013, December 11). *Foam Rheology Near the Jamming Transition*. *Casimir PhD Series*. Retrieved from <https://hdl.handle.net/1887/22836>

Version: Not Applicable (or Unknown)

License: [Leiden University Non-exclusive license](#)

Downloaded from: <https://hdl.handle.net/1887/22836>

Note: To cite this publication please use the final published version (if applicable).

Cover Page



Universiteit Leiden



The handle <http://hdl.handle.net/1887/22836> holds various files of this Leiden University dissertation.

Author: Woldhuis, Erik

Title: Foam rheology near the jamming transition

Issue Date: 2013-12-11

Foam Rheology near the jamming transition

Proefschrift

ter verkrijging van
de graad van Doctor aan de Universiteit Leiden,
op gezag van Rector Magnificus prof. mr. C. J. J. M. Stolker,
volgens besluit van het College voor Promoties
te verdedigen op woensdag 11 december 2013
klokke 8:45 uur

door

Erik Woldhuis
geboren te Alkmaar
in 1984

Promotiecommissie:

Promotor: Prof. dr. M. L. van Hecke (Leiden)

Copromotor: Dr. B. P. Tighe (Technische Universiteit Delft)

Leden: Dr. P. Schall (UvA)

Prof dr. E.R. Eliel (Leiden)

Dr. V. Vitelli (Leiden)

Prof dr. H. Schiessel (Leiden)

Prof dr .T. Schmidt (Leiden)

Casimir PhD series, Delft-Leiden 2013-3

ISBN: 9789085931737

Dit werk maakt deel uit van het onderzoeksprogramma van de Stichting voor Fundamenteel Onderzoek der Materie (FOM), die financieel wordt gesteund door de Nederlandse Organisatie voor Wetenschappelijk Onderzoek (NWO)

Contents

1	Introduction	7
1.1	Jamming	8
1.2	Rheology of Complex Fluids	10
1.3	Jamming & Rheology	14
1.4	Our Approach	15
2	Bubble Model and Simulations	17
2.1	Microscopic Model	17
2.1.1	Intermezzo: Roads not Traveled	19
2.2	Simulations	20
2.2.1	Nuts and Bolts	21
2.3	Phenomenology	23
2.3.1	Elastic and Viscous stress	23
2.3.2	Rheological Curves	24
2.3.3	Correlation Length	25
2.3.4	Δv -distributions	27
3	Scaling Model	29
3.1	Ingredients	29
3.1.1	Power Balance	29
3.1.2	Effective Strain	30
3.1.3	Elasticity Relation	30
3.2	Regimes	31
3.2.1	Crossovers	34
3.3	Rescaling Flow Curves	35
3.3.1	Collapse Plots	36
3.3.2	Results	38
3.3.3	Conclusion	42
4	Scaling Model under Scrutiny	43
4.1	Ingredients in Full Form	43
4.2	Testing Power Balance	45
4.3	Extracting Coefficients	47

4.4	Regimes and Crossovers revisited	51
4.4.1	Regimes	51
4.4.2	Synthetic data	53
4.4.3	Conclusion	56
4.5	Testing the Other Model Ingredients	56
4.5.1	Testing Elasticity Relations	57
4.5.2	Testing the Two Strains	58
4.6	Conclusion	59
5	Normal Stress	61
5.1	Scaling Model	61
5.1.1	Testing the Elasticity Relation	62
5.2	Regimes	64
5.2.1	Crossovers	67
5.3	Plotting and Results	67
5.3.1	Collapse Plots	67
5.3.2	Prefactors	68
5.3.3	Regimes and Collapse	69
5.4	Conclusion	71
6	Microscopic Behavior	73
6.1	Dissipation and Relative Velocity Distribution	73
6.1.1	Second Moment	73
6.1.2	Fourth Moment	76
6.1.3	Sixth and Higher Moments	81
6.1.4	Conclusion	81
6.2	Forces and Stresses	82
6.2.1	Conclusion	90
7	Non-linear Scaling Model	91
7.1	Microscopic Model	91
7.2	Scaling Model	92
7.2.1	Energy Balance	92
7.2.2	Effective Strain	92
7.2.3	Elasticity Relation	93
7.3	Regimes	94
7.3.1	Shear Stress	95
7.3.2	Normal Stress	97
7.4	Plotting	98
7.4.1	Shear Stress	98
7.4.2	Normal Stress	99
7.5	Experimental Implementations	100
7.5.1	Katgert Foam Data	100
7.5.2	Nordstrom Colloid Data	102
7.5.3	Conclusion	104

8	Testing the Non-linear Scaling Model	107
8.1	Massless Particle Code	107
8.1.1	Conclusion	110
8.2	Massive Particle Code	110
8.2.1	Implementation	110
8.2.2	Testing the Effect of Mass	111
8.2.3	Different α_v	116
8.3	Conclusion	118
9	Appendices	119
9.1	Z	119
9.2	Appendix: First Moment	121
9.3	Appendix: Correlation Strain	122

