

MORPHOLOGICAL COARSENING IN THIN LIQUID FILMS

by

NARENDRA KUMAR AGNIHOTRA

DEPARTMENT OF CHEMICAL ENGINEERING

Submitted

in fulfillment of the requirements of the degree of

Doctor of Philosophy

to the

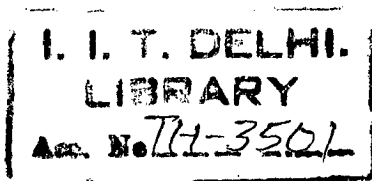


INDIAN INSTITUTE OF TECHNOLOGY, DELHI
INDIA

APRIL 2007



TH
532.62
AGN-M



Certificate

This is to certify that the thesis titled "**MORPHOLOGICAL COARSENING IN THIN LIQUID FILMS**" being submitted by Narendra Kumar Agnihotri in the Department of Chemical Engineering, Indian Institute of Technology, Delhi, for the award of the degree of Doctor of Philosophy, is a record of bona-fide research work carried out by him under my guidance and supervision. In my opinion, the thesis has reached the standards fulfilling the requirements of the regulations relating to the degree.

The results contained in this thesis have not been submitted to any other university or institute for the award of any degree or diploma.



Dr. Rajesh Khanna

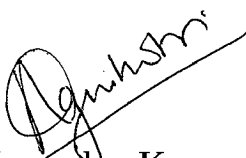
Associate Professor

Chemical Engineering Department
Indian Institute of Technology Delhi

Acknowledgments

I am truly indebted to my supervisor, Dr. Rajesh Khanna for great amount of encouragement, motivation and support I have received from him. I feel very fortunate that I got an opportunity to work under him. In all the difficult situations that I faced in my personal, academic, and professional life, I got invaluable support from him. I feel very grateful to my institute, I.I.T. Delhi for giving me a wonderful learning experience during the this period. I am grateful to my parents for giving me their immense love, support and great gift of a life. The only possible way to express my gratitude in real sense to all those people who helped me so generously is to try to be equally generous and helpful to the fellow living beings who might approach me in future. I hope to try to do so sincerely.

New Delhi



Narendra Kumar Agnihotri

Abstract

The coarsening dynamics of thermal noise at the free surface of a thin liquid film sandwiched between a solid and a bounding fluid is investigated based on the numerical solution of the 2-D thin film equation under the influence of various disjoining pressures. These fluctuations spontaneously amplify and coarsen to morphologically phase separate into a high curvature drop phase surrounded by a low curvature flat film phase whenever the disjoining pressure is made up of an attractive long range and repulsive short range component. The onset of this Morphological phase separation (**MPS**) is taken to be the appearance of the flat film. The completion of **MPS** is characterized by appearance of flat film at all possible locations in the film. It is seen that coarsening, as denoted by the number of hills and valleys (N) in the pattern, occurs via two distinct stages *viz.*, (1) **Pre-MPS** and (2) **Post-MPS**. An obscure intermediate stage, **MPS** stage, spanning the duration of time between the onset and completion of **MPS** is also identified. While, the exponent in power law dynamics of the type $N \propto t^\alpha$, t is time, remains constant ($-1/4$ for $2D$ and $-1/3$ for $3D$) for **pre-MPS** and ($-1/3$ for $2D$ and $-1/2$ for $3D$) for **post-MPS** stage and varies slightly between $-1/10$ to $-1/20$ for later part of the **pre-MPS** stage, it changes from a very high value (~ -2) to a very low value ($\rightarrow 0$) for the **MPS** stage. The **MPS** stage, depending on its exponent, can merge with either of the other two stages and apparently disappear. The rate of coarsening in all three stages depend on the average space available to each hill *viz.*, total domain size divided by total number of hills.

Contents

1	INTRODUCTION	1
1.1	Applications of supported thin liquid films	2
1.2	Morphological coarsening in thin liquid films	3
1.3	Limitations	10
1.4	Organization	11
2	THEORY	13
2.1	General system of study and governing equations	13
2.1.1	Excess intermolecular forces	15
3	METHODOLOGY	23
3.1	Linear analysis	24
3.2	Initial and boundary conditions	27
3.3	Nondimensionalization	27
3.4	Numerical Scheme	28
3.5	Choice of force fields	29
4	HOW TO TRACK COARSENING?	31
5	PRE-MPS STAGE OF COARSENING	45
5.1	Unusual behavior in the early stages of evolution	46
5.1.1	Predewetting Stage in LW Films	48

5.1.2	Pre-MPS Stage in LWC Films	54
5.1.3	Pre-MPS Stage in LWAB Films	57
6	POST-MPS STAGE OF COARSENING	63
6.1	Post-MPS stage in LWC films	63
6.2	Post-MPS stage in LWAB films	69
7	MPS STAGE OF COARSENING	77
8	COARSENING IN 3-D	95
8.1	Governing Equation	95
8.2	Numerical Method	96
8.3	Results	97
9	CONCLUSIONS	103
10	Bibliography	107