Preface

Mixture concepts are nowadays used in a great number of subjects of the biological, chemical, engineering, natural and physical sciences (to name these alphabetically) and the theory of mixtures has attained in all these disciplines a high level of expertise and specialisation. The digression in their development has on occasion led to differences in the denotation of special formulations as ‘multi-phase systems’ or ‘non-classical mixtures’, ‘structured mixtures’, etc., and their representatives or defenders often emphasise the differences of these rather than their common properties.

This monograph is an attempt to view theoretical formulations of processes which take place as interactions among various substances that are spatially intermixed and can be viewed to continuously fill the space which they occupy as mixtures. Moreover, we shall assume that the processes can be regarded to be characterised by variables which obey a certain degree of continuity in their evolution, so that the relevant processes can be described mathematically by balance laws, in global or local form, eventually leading to differential and/or integral equations, to which the usual techniques of theoretical and numerical analysis can be applied.

Mixtures are generally called non-classical, if, apart from the physical laws (e. g. balances of mass, momenta, energy and entropy), also further laws are postulated, which are less fundamental, but may describe some features of the micro-structure on the macroscopic level. In a mixture of fluids and solids – these are sometimes called particle laden systems – the fraction of the volume that is occupied by each constituent is a significant characterisation of the micro-structure that exerts some influence on the macro-level at which the equations governing the processes are formulated. For solid-fluid mixtures at high solids fraction where particle contact is essential, friction between the particles gives rise to internal stresses, which turn out to be best described by an internal symmetric tensor valued variable. Obviously each special application may give rise to its own such internal variable. The mixture is non-classical as a result that each such variable is described by its own dynamical equation.

Our own interest in mixtures has been their use in the description of the flow of debris, mud and slurry in various forms in the geophysical environment: avalanches of snow, gravel, soil, the catastrophic motion of debris as a solid-fluid compound, the motion of lahars in pyroclastic flows from volcanoes, sub-aquatic turbidity currents, catastrophic sediment transport in fluvial hydraulics, and the destabilisation of soil slopes and dams due to heavy rain fall, etc. Because of this background, this monograph is in many respects focussing on these applications, and certainly the geological, geophysical and geotechnical bias is apparent. Nevertheless, we believe that scientists from other fields might equally profit: process and chemical engineers interested in the transportation of products, mechanical engineers and chemists interested in fluidised and spouted beds, bubbly flows, sprays and combustion in flames, physical limnologists and oceanographers, atmospheric scientists etc. in subaquatic sediment transport and aerosol dispersion, etc.

The text uses methods of rational thermodynamics, which is an extensively developed field. We draw the readers' attention to TRUESDELLs writings [119], [121], to MÜLLER [97] and LIU [78], [80] for basic knowledge in continuum mechanics and thermodynamics. As for mathematics, we use the level of University calculus and analysis covering vector and Cartesian tensor calculus and some aspects of differential equations. Knowledge of the elements of exterior calculus may also be helpful, but is not absolutely necessary.

The work for this monograph commenced in early 2005 when LS was preparing his Diploma (M. Sc.) thesis 'A non-classical debris flow model, based on a concise thermodynamic analysis' under the supervision of KH. This thesis has been the basis for this monograph, but is founded on earlier work by SVENDSEN & HUTTER (1995) [115] and SVENDSEN, HUTTER and LALOUI (1999) [116]. These papers concentrated on the thermodynamic formulation of structured visco-elastic mixtures, on the one hand, and on constitutive modelling of dry granular materials when quasi-static frictional (plastic) behaviour is included, on the other hand. In early 2005 a thorough thermomechanical formulation of solid-fluid mixtures, in which the solid constituents would exhibit both dynamic viscous and quasi-static frictional effects, was still missing. However, there was some hope that the above works [115], [116] would provide a supporting guideline for the derivation of a structured thermodynamic mixture theory with frictional properties.

For several reasons, there is a necessity of such a fundamental analysis. Geotechnical engineers and engineering geologists are in need of mathematical models, which are capable of describing the motion of debris in unstable soil slopes, landslides, mud flows, etc., from initiation through their catastrophic advance down to their settlement in the run-out region. This embraces a huge range of mechanical behaviour, from quasi-static soil plasticity prior to rapid flow initiation through criticality, when shear banding initiates the ensuing catastrophic motion, which is basically viscous, to the strongly decelerating and likely compacting motion into the deposition area. This motion is often complicated by the presence of an additional fluid and possibly gas (air) and may be additionally affected by e. g. fluidization, reverse grading according to particle size, de-mixing and complete or partial saturation.

Geotechnical engineers encounter this complexity e. g. in dam break problems, artificial slope stability analyses and questions of safety of soil construction sites. In engineering geology, analogous problems arise in hurricane or typhoon generated mud flows and sturzstroms, in earthquake induced debris flows, sub-aquatic turbidity currents, lahars and related pyroclastic flows and dense as well as particle-laden snow avalanches (flow and powder snow avalanches).

To cover the entire flow regime from the quasi-static deformation of the water saturated soil prior to the formation of a strong shear zone and the associated transition to the dynamic behaviour of the relevant mixture, and finally into the deposition area, the dominant constitutive regimes change from elasto-visco-plastic, through primarily viscous to again consolidating elasto-visco-plastic behaviour. In a multi-constituent mixture, this may be coupled with segregation mechanisms due to particle size (Brazil nut effect) or a layering in essentially separated flows of a dense granular material, underlying a slurry, or in the deposit by a separation into a wet upper layer of solids underlain by a saturated mixture.

The development of a thermodynamically based set of field equations for a structured mixture is, however, desperately needed, even when only purely mechanical processes are in focus, since rather controversial opinions exist among scientists of different groups; these groups represent the *mixture* and *multi-phase* theorists. The controversy between these two groups centers around the question of 'which forms the solid and fluid stress tensors, and in turn, interaction force should be'. Claims are made about the structure of the flux terms in the momentum equations prior to any postulation of a constitutive model, a claim that is premature and pretty empty anyhow if stated prior to a complete exploitation of the Second Law of Thermodynamics with all its inferences.

It is the thesis of this small book that differences in these quantities are vacuous prior to a complete thermodynamic analysis, and indeed, it will be shown that exploitation of the Second Law of Thermodynamics will be the vehicle by which any such possible disagreement can be resolved. This is even so, when purely mechanical formulations are in focus, since the Second Law of Thermodynamics determines for a given constitutive class the equilibrium, among other things, values of the constituent stress tensors and interaction forces (and other field quantities). Differences of two distinct thermodynamic mixture formulations can then be clearly identified as differences in the constitutive postulates – and perhaps in differences of the exploitation of the Second Law of Thermodynamics and its underlain peculiarities.

This book, written during the last three years by both authors, is the product of a joint effort, with the analysis performed more by LS, and the conceptual activity and the physical motivation of the approach and the interpretation of the results primarily done by KH. He is also chiefly responsible for all errors which may still remain. In the process of development of the theory, we have been mostly working alone. Nevertheless, Dr. Ioana Luca, from Academia Sinica, Taiwan has closely followed the developments and used the results in her own work on avalanching solid-fluid avalanche flows. Her questions and critique has helped us in smoothing arguments here and there. Moreover, we thank Prof. Bob Svendsen, Institute of Mechanics, Department of Mechanical Engineering, Dortmund University of Technology, Germany and Prof. Leslie W. Morland, Department of Mathematics, University of East Anglia, UK for their reviews of an earlier draft. The criticism of these three people has led to improvements, which are now incorporated in the text.

Finally, we thank Springer Verlag and its personnel for the supportive help and advise in the production of the book.

November 2008

Academia Sinica, Nangang/Taipei (Taiwan), *K. Hutter*
Technische Universität Darmstadt (Germany), *L. Schneider*

http://www.springer.com/978-3-642-02967-7

Solid-Fluid Mixtures of Frictional Materials in Geophysical and Geotechnical Context
Based on a Concise Thermodynamic Analysis
Schneider, L.; Hutter, K.
2009, XXIV, 247 p. 63 illus., Hardcover
ISBN: 978-3-642-02967-7