PhD Thesis by Brage Rugstad Knudsen
"On Shut-In Based Production Optimization of Shale-Gas Systems"

Preliminary Report of External Examiner

The thesis is concerned with the development of shale-gas well and network models and efficient optimization schemes for scheduling of well shut-ins in large scale shale-gas systems. Major challenges for developing suitable models and scheduling/optimization techniques include:

- The need for mathematical models that sufficiently describe the time-varying behaviour od shale wells, the reservoir and pipeline network - which are adequate for optimization and scheduling strategies
- The need to address shut-in strategies in scheduling models of shale-gas multi-well, multi-pad networks
- The need to develop suitable algorithms for the solution of large-scale mixed-integer non-linear & linear optimization problems, which provide the typical representation for the shut-in scheduling of such complex networks

The thesis, of 187 pages involving 6 chapters and an appendix represents important contributions towards addressing these major challenges, advances the state-of-the-art and sets a sound and firm basis for further important developments in the field.

Chapter 1 provides a comprehensive introduction of the shale-gas production system, a literature review of the subject, with emphasis on the shale-gas well network modelling issues, mixed integer programing and related Lagrangian relaxation/decomposition techniques – along with a detailed account of the thesis objectives, contributions and publications originated from the thesis. The four main subsequent chapters are then presented, essentially from submitted/accepted papers. Chapters 2 and 3 constitute the backbone of the thesis and its major developments. Chapter 2 presents the foundations of an approximate model for the representation of shale-gas well operation, followed by an analysis of how the essential parameters of the model can systematically be determined and updated [if necessary]. For multiple wells operation, this leads to a mixed integer mathematical formulation that was addressed in a number of ways based

on generalized disjunctive programming principles; reformulation in MINP and MILP problems are presented and the benefit of accounting for shut-ins is clearly demonstrated. Chapter 3 then build on the developments of chapter 2 presenting a decomposition strategy for the efficient and practically attainable solution of shut-in scheduling problems for large scale multi-well, multi-pad shale-gas networks. Chapter 4 further extends the concepts within the supply chain of natural gas based power systems, exploring the idea how shale-gas operational features can bring economic benefits acting as on-demand storage under varying demands. Again, computational strategies are presented to tame the solution complexity of the underlying large-scale mixed integer optimization problems, representing the overall scheduling operation. Finally, chapter 5 presents a heuristic approach to determine 'good' feasible solutions for convex MINLP problems – with concluding remarks and further recommendations briefly outlined in chapter 6. The presentation of the material presented in the various chapters would have benefitted by including, for each case developed, a sufficiently small motivating example where all the steps of the developed sophisticated algorithms are detailed and explained. This will help the readability and reproducibility of the developed and proposed techniques. It will also help elucidating the advantages and disadvantages in terms of theoretical rigour, computational efficiency, etc. The relevant well established research area of scheduling techniques in process systems engineering [and its wealth of literature available] - and concepts and tools from it – could have been perhaps explored and elaborated further.

The thesis certainly contains enough material of publishable quality to top journals in the field of process systems engineering and mathematical programming. It is recommended that the PhD degree be awarded to the candidate, subject to a satisfactory performance in the oral examination in clarifying a number of issues as highlighted above.

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