

# Simulation and Control of Large Natural Gas Storage Caverns

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## Abstract for the Poster session

A sophisticated computer program for the dynamic simulation of large natural gas storage, called VECTORS (VERTical Cavern Thermo-physical OpeRations Simulator) is presented in this poster. VECTORS is developed as a joint effort by the Norwegian oil and gas company Statoil and the system company Computer Aided Research Development Instrumentation And Control (CARDIAC). The simulator has a general applicability to any high-pressure storage, and is commercialized by CARDIAC. VECTORS are developed with a graphical user interface, running on Windows 95 and Windows NT. The numerical routines are developed in FORTRAN and C++. The graphical user interface is built in the modern flow sheet programming environment, G (LabVIEW<sup>®</sup>), from National Instruments.

Deep caverns are used as temporary storage for natural gas to meet fluctuations in gas demand, sometimes even price fluctuations. This poster describes the simulated operation and control of such storage facilities in a large distribution system for natural gas on the European continent. The storage provides a filter for the demand fluctuations, facilitating a better pressure control on the demand side. In a deregulated gas market a storage facility may also take advantage of fluctuating gas prices. Hence, it is important to model both the operating conditions of the storage, as well as the main characteristics of the fluctuating demand and eventually the fluctuating prices.

The pressure requirements on the demand side do not allow the cavern pressure, neither to drop below a lower safety limit above the net pressure, nor to rise above an upper safety limit. Furthermore, the caverns are always wet, and the natural gas may form hydrates in contact with water below a so-called "hydrate curve" in a p-T diagram. This limits the rate of withdrawal of gas from the cavern, so that hydrates are not formed due to the drop in temperature by gas expansion. Hydrates may block the valves and disturb the operation of the caverns significantly.

It is highly desired to perform a model predictive control of the charging and discharging of the caverns to meet the demand fluctuations, and eventually the price fluctuations, in an optimal way, still within the constraints imposed by the pressure and hydrate conditions of the cavern. However, this requires a fairly sophisticated model of the large cavern, to incorporate all thermodynamic properties, as well as hydrate kinetics in a large volume with varying temperature throughout and varying pressure from top to bottom. Furthermore, the heat and mass transfer (basically water vapor) between the gas and the cavern walls must be accounted for in the model.

The poster demonstrates such a sophisticated model, both in the poster text and pictures and by a live simulation on a PC. The simulations demonstrates how the cavern conditions will develop under varying rates of charge and discharge of the gas storage, conditions that are essential for the application of the model for optimization and control.

VECTORS is a really complex computer program, that can be used to simulate withdrawal and injection of a large-scale system of several salt caverns. All the numeric and the description of the cavern characteristics can be set up by an easy to use graphical interface. The simulation model and its program are commercially available and applicable to any other pressure storage systems by a replacement of the physical and thermodynamic property packages. VECTORS are State-of-art technology for gas withdrawal and injection. The present version of VECTORS utilizes the STEPÓ package of PVT data from the Danish company CALSEP.

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