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Kameleon FireEx in Safety Applications

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Abstract

Kameleon FireEx is a user friendly three dimensional transient simulator for fire and gas dispersion analyses. The simulator is based on some of the latest advancements in computational fluid dynamics. Sub models included are the k-ε turbulence model, the Eddy Dissipation Concept of turbulent combustion, the Eddy Dissipation Soot Model, the Discrete Transfer model of radiative transfer, and a two phase spray model for handling of water systems for fire suppression. Additional submodels include a Reynolds stress model and options for detailed chemistry treatment of the combustion process. The code also includes multiblock technique. An important feature is a link to the finite element code USFOS for complete analysis of the dynamic structural response of structures exposed to fires, making Kameleon FireEx a complete integrated tool for fire analysis. The efficient user interface makes the code easy to operate, and an interactive control part gives the user the opportunity to change operational parameters of the CFD code during run time, to specify what data to look at in a graphical instructive display etc.

Kameleon FireEx has shown to be an efficient tool for a wide range of safety problems in the oil and gas industry, and the paper presents a number of safety applications performed with the code :

- riser rupture and subsequent fire development
- fire development in an offshore module
- dynamic structural respons of a platform exposed to fire
- fire extinguishment by water deluge systems

The code including the submodels has been extensively tested and validated.

Kameleon FireEx is developed at NTNU/Sintef Energy Research, Division of Applied Thermodynamics and Fluid Dynamics, by the financial support from Statoil, Ruhrgas, Gaz de France, Elf and the ENI-group. Associated partner has been Sandia National Laboratories, USA. A new company, Computational Industry Technologies AS (ComputIT), has been established for commercialization of the code.

Introduction

The oil and gas industry deals with highly dangerous substances, which under unfavourable conditions can cause severe and extensive damage to personnel, structures, process equipment and environment. Unfortunately we have seen several examples of this, emphazising the need for reliable prediction tools both to minimize the accidental risk through optimum design, and to minimize the concequences if leakages and fires occur. An important aspect in this respect is that use of detailed simulations and analyses to improve safety also can contribute to the most cost effective design.

The consequences of oil and gas fires can be tremendous and it is essential that analyses of fires and consequences of such in all project phases are based on the ultimate exisiting knowledge to ensure as good design basis as possible. Fires are dynamicly developing phenomena that can be supressed by active and passive protection systems, and this paper shows examples of fire mitigation by detailed modelling and simulation of water systems.

Water systems are used to supress or extinguish fires. In general extinction may result from different imposed conditions on the combustion process as for instance cooling effects, chemical effects, turbulence effects, and additives to the flame. Practical design of such systems are dependent on detailed physical knowledge of the combustion process and in Kameleon FireEx the detailed modeling of extincion processes is closely linked to the Eddy Dissipation Consept for turbulent combustion.

Kameleon FireEx has been used for years in a large number of gas dispersion and fire analyses in the oil and gas industry, and has shown to be a very user friendly and efficient tool in safety applications.

The present paper shows a few examples of use of Kameleon FireEx in safety applications.

Kameleon FireEx

Kameleon FireEx (KFX) is a field model gas dispersion and fire simulator, developed at the Norwegian University of Science and Technology (NTNU) and SINTEF Applied Thermodynamics and Fluid Dynamics in Trondheim, Norway.
Kameleon FireEx is capable of calculating heavy and light gas dispersion as well as hydrocarbon liquid pool fires and gas jet fires, in enclosures and in open air. In addition fire suppression using deluge systems can be included in fire scenario simulation and interact with the flow and energy field in the gas phase. Simulation of dynamic structural respons to fire loads is also a feature through the inteface to the finite element code USFOS.

User friendliness and operational flexibility have been in focus during the development of Kameleon FireEx, and the graphical user interface called Lizard has been developed in close co-operation with the users of the simulator. Lizard handles geometry definition and inspection, setting up boundary conditions and various running parameters. In addition Lizard offers very efficient possibilities for computational steering. This means that the user has graphical output of results and a graphical user interface where it is possible to change parameters for the calculation as the calculation is running. This enables early detection of unrealistic conditions or conditions different from the desired, and can save a lot of misused computation time. The user has interactive control over both 2-D and 3-D graphical output that can also be sampled for creation of animations of transient development.

Advanced 3-D rendering of the gas, soot, and temperature fields based on ray tracing is used to create realistic pictures and animations of fire developments. This rendering technique gives a unique opportunity to interpret the results of the transient calculations and to increase the understanding of the complicated flame physics that is very important in fire safety design.

The simulator uses a Cartesian finite volume technique to solve the averaged basic transport equations from fluid dynamics. Sub models included are the k-ε turbulence model, the Eddy Dissipation Concept of turbulent combustion, the Eddy Dissipation Soot Model, the Discrete Transfer model of radiative transfer, and a Lagrangian two phase spray model for handling of water systems for fire suppression. The release of water sprays may be positioned freely in the computational domain and trigged by simulated temperature sensors. Additional submodels include an optional Reynolds stress model and options for detailed chemistry treatment of the combustion process. The code includes a multiblock technique for simultaneous solution in blocks of structured grids, and a compressible version of Kameleon FireEx has also been developed.

Kameleon FireEx has been extensively tested and validated against experimental data ranging from small scale laboratory flames to large scale jet and pool fires. This includes work performed by Sintef as well as independent testing by the users of the code: Ruhrgas, Gaz de France, ENI group division Agip, Elf and Statoil. Comparison with large scale pool fire experiments at the Sandia National Laboratories in USA have also been done, and most results show very good agreement with simulations results.

A very important feature is the interface with the finite element code USFOS for complete analysis of the dynamic structural response of structures exposed to fires, making Kameleon FireEx a complete integrated tool for fire analysis.

Large scale experiments at the Norwegian Fire Research Laboratory at SINTEF on a structure exposed both to extensive fire loads as well as to mechanical loads, has been used for verification of the integrated KFX-USFOS simulation system. Measured fire data, steel temperature and stress development, deformation and collaps of the structure are very close to the simulation results.

Kameleon FireEx in safety applications

Kameleon FireEx has been used for safety purposes in a large number of gas dispersion and fire analyses in the oil and gas industry for several years. In the following some examples are given.

Riser rupture and subsequent fire development

Figure 1 below shows a sequence of pictures describing a raiser rupture scenario. The sequence shows the different phases in the calculated development. In the first phase the rupture hole gives raise to a free jet directed towards the incoming wind. The gas from the jet mixes with the air and forms a premixed cloud which moves with the wind under and around the platform. In the second phase the cloud arrives an ignition source and the cloud ignites and a flame propagate through the gas mixture towards the rupture hole. The flame needs some time to penetrate upwind into the large volume of gas mixture near the leakage, but it finally find a way under the platform. In the third phase the flame consumes the large volume of premixed gas and a large fireball raises into the air above the platform. Finally in the last phase, the gas burns as stable jet fire as long as gas continues to leak out of the hole. Animation of the results is generated and has in general shown to be an efficient help for visual understanding of most kind of gas dispersion and fire phenomena.

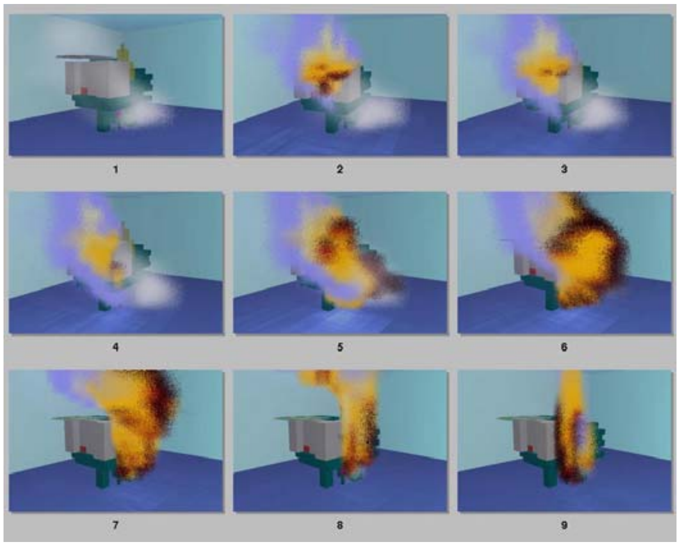

Figure 1

Use of deluge system for a fire in cellar deck of an offshore platform

Limitations in the fire water supply system on an existing installation required analysis of fire spreading and heat load distribution throughout the platform during a pool fire

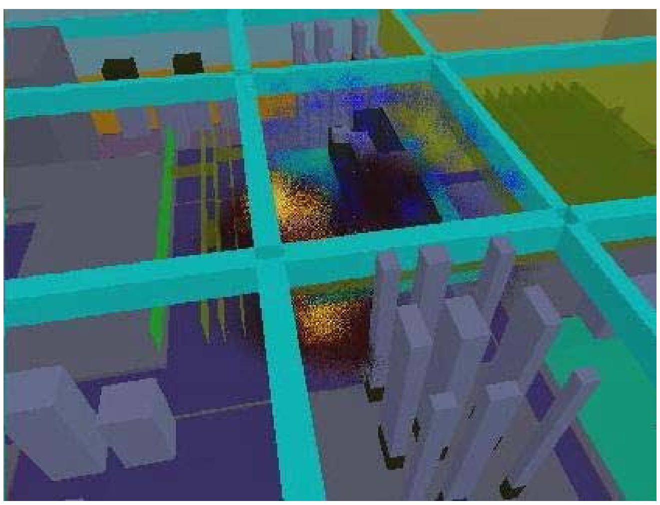

Figure 2

accident. The cellar deck shown in Figure 2 consists of several modules with rather open connection to each other and they are fairly filled with process equipment. A pool fire is simulated in one of the two centre modules. Virtual activation sensors are placed in all the modules and the deluge system is automatically activated as the fire develops. First the deluge system is activated in the module with the fire and when the hot gases enter neighbouring modules the deluge systems in these are also activated. The main purpose of this study was to find out if and how fast the deluge systems in the different modules would be activated.

Deluge water test rig

Figure 3 shows calculation of a flame affected by deluge water in a test rig at the Norwegian Fire Research Laboratory at SINTEF. The test rig consists of a steel cylinder, 3 meters in diameter and 8 meter high. A large gas burner is placed in the lower part of the cylinder. The air intake is through a slit around the cylinder close to the bottom under the burner. The maximum heat release is 10 MW. Deluge water can be supplied through different nozzles at different heights in the centre of the cylinder. Temperatures and heat-load are monitored in the centre and at the walls. The reduction of heat release due to water effects is measured in the outlet at the top. Simulations with different droplet size distribution have been performed as a parameter analysis, and verification work on comparison of the simulation results with measurements is ongoing.

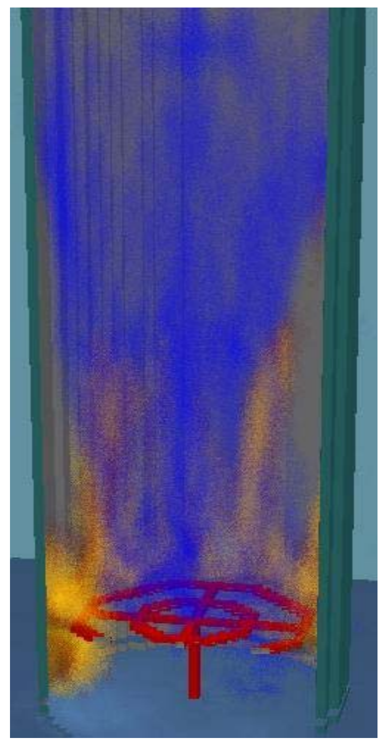

Figure 3

Dynamic structural respons of a platform exposed to fire

The integrated fire analysis tool has been used for several studies regarding for instance the need for fire insulation of offshore structures. Figure 4 shows the temperature development and structural behaviour of an existing offshore module exposed to a pool fire (gas fires analysed as well). The module is exposed to heavy mechanical loads on the roof and the loads from the fires chosen in the study therefore exposed the ceiling structure most. Serious deformation was observed in parts of the structure and the analysis lead to the conclusion that it was sufficient to insulate the roof support with passive fire protection. About 20% of the total surface was proposed to be insulated and the structure has shown to withstand both calculated pool and jet fires for one hour. In general the integrated KFX–USFOS tool has shown to be a cost efficient method with respect to optimization of fire insulation.

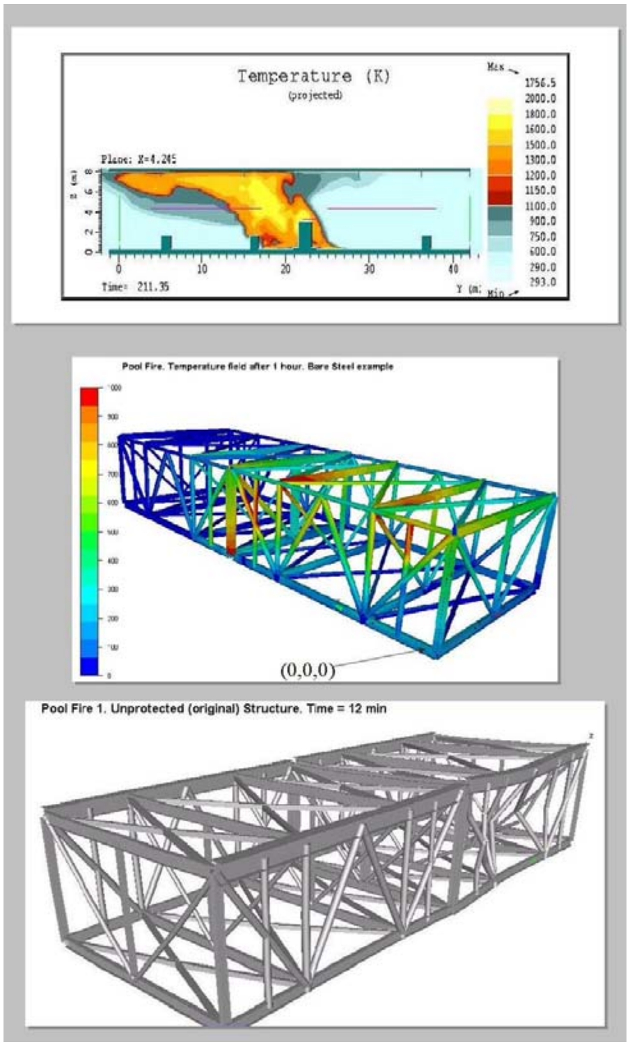

Figure 4

Conclusions

The simulator Kameleon FireEx has been developed by Sintef by the financial support of Statoil, Ruhrgas, Gaz de France, Elf and the ENI group. The aim has been to develop an efficient tool for practical gas dipersion and fire analysis for safety promotion in the oil and gas industry.

The interphase with the finite element code USFOS makes Kamleon FireEx a complete integrated tool for gas dispersion and fire analysis including the dynamic structural response of structures exposed to fires

The fire water spray model implemented in Kameleon FireEx is very efficent for analysis of water deluge systems.

Kameleon FireEx has shown to be an efficient tool for a wide range of safety problems in the oil and gas industry and has been used for a large number of industrial analyses. The paper presents a number of safety applications performed with the code.

Acknowledgements

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References

1 Vembe BE, Lilleheie NI, Holen J, Magnussen BF, Velde B, Linke G, Genillon P, :"Kameleon FireEx – A simulator for gas dispersion and fires". Presented at the International Gas Research Conference 98 (IGRC98), San Diego, California
2 Magnussen, B.F., "Modelling of NO_x and Soot formation by The Eddy Concept". Presented at the International Flame Research Foundation 1st Topic Oriented Meeting, Amsterdam, Holland (1989)
3 Shah, N.G. "The Computation of Radiation Heat Transfer", Ph.D. Thesis, University of London, Faculty of Engineering, 1979
4 Holen, J, Brostrøm, M and Magnussen, B. F: "Finite Difference Calculation of Pool Fires" 23. International Symposium on Combustion 1990.
5 Kee, R., Miller, J. A and Jefferson, T. H., "CHEMKIN A General Purpose, Problem Independent, Transportable, Fortran Chemical Kinetic Code Package", SAND80-8003, 1980.
6 Holen, J., Lakså, B., Fagertun, J. A. and Magnussen, B. F., "Fully Three-Dimensional Calculation of Large Scale Diffusion Flames". Proceedings Thirteenth Task Leaders Meeting of the IEA Working Party on Conservation in Combustion, USA, 1991
7 Van Doormal, J.P., Raithby, G.D, "Enhancement of the SIMPLE Method for predicting Incompressible Fluid Flows". Numerical Heat Transfer, Vol. 7, 1984.
8 Launder, B. E., and Spalding, D. E. "The Numerical Computations of Turbulent Flows". Computer Meth. In Appl. Mech. And Eng. 3, 1974.
9 Tesner, P. A., Snegiriova, T. D and Knorre, V. G. Combustion and Flame. 17, 253, 1971
10 Magnussen, B. F., Private notes 1997.
11 Holen, J. K. and Vembe, B. E., "Benchmarks Calculated with Kameleon FireEx", SINTEF Energy Reserach Report TR F4709, 1998.
12 Launder, B. E. "On the Computation of Convective Heat Transfer in Complex Turbulent Flows", Journal of Heat

Transfer, 110, 1998.