Science@ifpen

Issue 14 - September 2013

Two of the main investigation fields being studied within the Applied Mechanics Division are understanding the physical phenomena governing industrial processes and accurately determining the lifespan of technological products in their environment. In these fields, the quality of our research — both academic and in terms of industrial transfer — is recognized worldwide.

IFPEN is thus one of the top five organizations in the world in terms of scientific publications in the research areas of dispersed-phase flow simulation or the mechanical behavior of polymer materials. Concerning the renewable marine energies, IFPEN is among the top three patent filers concerning aerodynamic efficiency and floating platforms suitable for offshore wind turbines. This issue illustrates six significant topics that can be addressed using the Division's expertise in fluid and solid mechanics, ranging from theoretical aspects to the design of complex technological equipment.

We hope that you will enjoy this issue.

Éric Heintzé,
Head of the Applied Mechanics Division

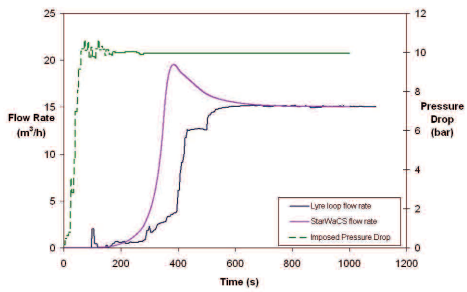
Waxy crude oils: may the flow be with you!

Waxy crude oils demonstrate complex behavior, which can lead to problems transporting them in pipelines. Below a certain temperature, a network of crystallized paraffins develops and forms a heterogeneous and weakly compressible gel, demonstrating visco-plastic, thixotropic rheological behavior. In particular, this phenomenon occurs during production shutdowns and the main problem for oil operators is then to determine the pressure required to start the oil flowing again.

Hence IFPEN has developed the StarWaCS numerical model, capable of simulating the restart of a waxy crude oil flow. However, to predict this process, it is essential to know the structure of the gelified paraffinic crude, which depends greatly on its thermal and mechanical history.

The Cold Start methodology has been developed and patented to achieve this. Its objective is to determine the state of the gel (viscosity, mechanical resistance, compressibility, etc.) following the cooling process. Using rheometric tests and thermal calculations, the structure of the gelified paraffinic crude is thus assessed and provided as an initial input into the StarWaCS flow simulator. The simulator is then used to determine the restart pressure. The Cold Start methodology and StarWaCS tool have been validated using data derived from tests performed in a 140 m experimental Lyre loop.

The next developments will focus on modeling the gel formation process and the impact of pressure on its structure. ■



Evolution over time of the volumetric flow rate measured in the Lyre loop and calculated with StarWaCS during restart.

A. Wachs, G. Vinay, *I. Frigaard,* A 1.5D numerical model for the start-up of weakly compressible flow of a viscoplastic and thixotropic fluid in pipelines, *JNNFM, 2009, 159.*
DOI: 10.1016/j.jnnfm.2009.02.002

G. Vinay, I. Hénaut, C. Cassar, Restart of waxy crude oils: a new approach to determine the initial gel structure, *4th Conference on Viscoplastic Fluids, Brazil, 2011.*

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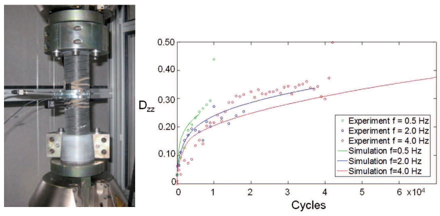
Seabeds have composite fibre

In offshore oil production, drilling or production risers link wells to the floating platform. In deep and ultra-deep water, the weight of the riser becomes very substantial and lightening it becomes a crucial challenge. One of the options being considered by IFPEN, working closely with companies operating in the sector, is to use composite materials in the manufacture of these pipes.

To introduce this technology in a marine environment, it will be necessary to overcome a number of obstacles, including prediction of the evolution over time of the materials' mechanical properties, their resistance to fatigue and, more generally, calculation of the lifespan of the composite structures. Today, due to a lack of simple dimensioning tools, composite structures are often produced with high safety coefficients in order to preserve their integrity throughout their lifetime, making this technology economically unviable at present.

IFPEN has redoubled its efforts to try to gain a clearer understanding of this problem. It has thus developed a model for damage to composite tubular structures. Based on similarities in behavior between the damage accumulation and visco-elasticity of composite materials, the model is used to predict the evolution of damage and hence the lifespan of a structure subjected to fatigue or creep stresses.

The research makes an important contribution in terms of the use of composite structures subjected to repeated mechanical stresses. It does not consider stresses related to the marine environment, however, the influence of which can be crucial. That is the next development stage that needs to be tackled to



Test-simulation comparison of fatigue damage to a composite tube.

address the challenge of ultra-deep water and propose optimized composite structures.

Y. Poirette *et al.*, Field Testing of Hybrid Choke and Kill Lines, *OTC Proceedings, 2009, Houston, Texas. DOI: 10.4043/20077-MS*

P. Treasurer et al., Characterisation and analysis of carbon fibre/epoxy composite tubes, *ICCM proceedings, 2009, Edinburgh, UK.*

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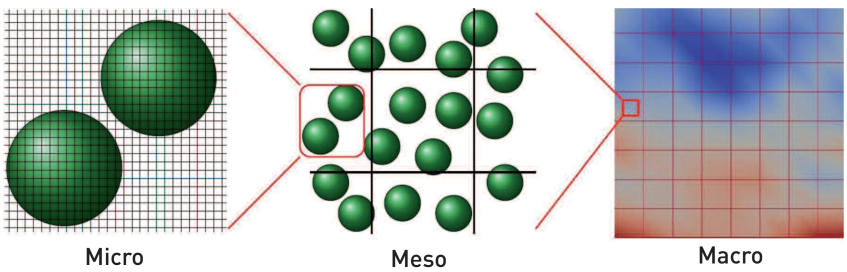
Particle: Quo vadis?

What happens to a solid particle in a fluid flow? Which intuitive ideas prove to be correct: if it is small, it is transported at the speed of the flow; if it is alone, it causes little perturbation to the flow; if its internal temperature is the same as the flow, it does not exchange heat with the latter... But what about large, numerous particles, with a different temperature from the fluid? The answer is more complicated.



Multi-scale vision of particle flows.

In this case, the particles and the fluid exchange momentum and heat. These exchanges govern the particle flow dynamics and, in particular, the trajectory of the particles. At present, these particulate flows are only partially understood, despite the fact that they are found in numerous industrial processes (catalytic reactors) and natural phenomena of interest to the oil sector (sedimentary transport, for example). It is for this reason that IFPEN is involved in the numerical modeling of these flows and has developed its own computational tool PeliGRIFF (Parallel Efficient LIbrary for GRains In Fluid Flow). This code integrates physical models on different scales of description: micro, meso and macro, always remembering that the smaller the scale, the more computing resources are required (up to several billion unknowns and several thousand processes). The most recent code evolutions comprise a fluid/particle model on a meso scale, a chemical kinetics model on a micro scale (for the reactive aspects) and second-order accurate numerical schemes (enhanced precision).

The next developments will focus primarily on the ability to treat particles with a non-convex shape and the coupling with nanometric-scale chemical reaction simulation tools (molecular dynamics, DFT, Ab Initio).

A. Wachs, Rising of 3D catalyst particles in a natural convection dominated flow by a parallel DNS method, *Computers & Chemical Engineering, 2011, 35(11), 2169-2185. DOI: 10.1016/j.compchemeng.2011.02.013*

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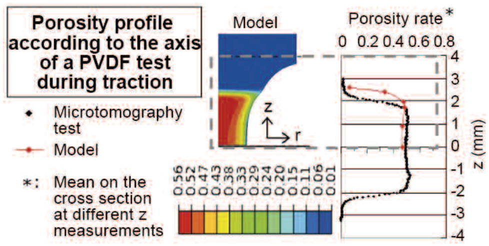
Not so fanciful plastics

Semi-crystalline polymers are seeing their use extended to increasingly severe industrial applications. Consequently, these materials need to withstand severe stresses (pressure, temperature) in an often aggressive environment (fluid, gas). In particular, the cavitation process — which can be observed in certain mechanical stress configurations — is a source of major concern for the oil industry.

In order to determine the relevance of technological concepts including semi-crystalline polymers and predict their lifetime, IFPEN is developing specific mechanical behavior laws to perform mechanical analyses of structures using the Finite Element Method.

The challenge is to provide the industry with access to an integrated process (virtual design) for predicting the mechanical behavior of technological products using these materials. At IFPEN, an original modeling method has been proposed for this type of material: the VIScoPOL model. The model can be used to examine the effects of pressure, viscosity and three-dimensional mechanical load, as well as the damage mechanisms that may result. Confidence in the behavior models used is essential for virtual design. It is for this reason that investigation and validation work has been carried out regarding the cavitation process, on the basis of in situ microtomographic analyses to measure porosity.

Beyond the purely mechanical aspects inherent to these viscoplastic materials, interaction effects between mass transfers (additive loss, absorption and desorption of gas) and mechanical behavior may be a source of damage phenomena. Study and modeling of these interactions now represent some of the work conducted at IFPEN.



N. Brusselle-Dupend, L. Cangémi, *Mechanics of Materials, 2008, 40, 743–760. DOI: 10.1016/j.mechmat.2008.03.011*

N. Brusselle-Dupend, E. Rosenberg, *J. Adrien, Materials Science and Engineering A, 2011, 530, 36–50. DOI: 10.1016/j.msea.2011.09.009*

C. Baudet, *J.-C. Grandidier,* ***L. Cangémi,*** *Journal of the Mechanics and Physics of Solids, 2011, 59, 1909–1926. DOI: 10.1016/j.jmps.2011.04.010*

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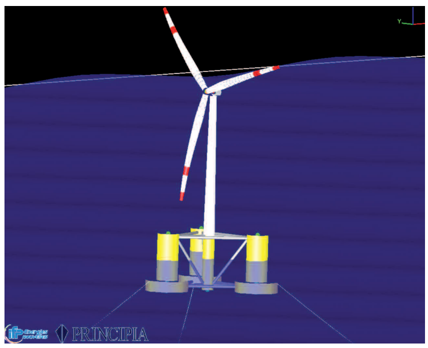
When wind turbines sail away!

Offshore wind is an emerging field where current fixed-bottom technology has seen limited when water depths exceeds 50 m. So new solutions are currently being explored, with, in particular, the development of floating supports. To this end, IFPEN is designing a new floating platform dedicated to multi-megawatt wind turbines to be installed along the French coast.

The challenge here is to propose a device with a competitive coast of energy. First, it is necessary to design a floating support and a mooring system that enables the turbine to operate in optimal conditions whatever sea, wind and current loads. Secondly, the whole system needs to be able to withstand extreme 50-year return period sea-states. The main design difficulties are related to the fact that numerous physical phenomena interact between each other. Strong interactions emerge, for instance, between the turbine, its control system, the floating support and the mooring system, combining aerodynamics, hydrodynamics and mechanics. To address these challenges, IFPEN has worked in collaboration with Principia to develop a numerical design tool taking into account all the physical phenomena involved. This tool has been used to study a variety of floating support configurations,

The project led to the emergence of an innovative support concept — now patented — that is currently being examined in greater details for various operating conditions in order to optimize its performance.



Example of a platform being studied for floating offshore wind power.

T. Perdrizet, J.-C. Gilloteaux *et al.,* Fully coupled floating wind turbine simulator based on nonlinear finite element method - part II: validation results, *Proc. OMAE 2013.*

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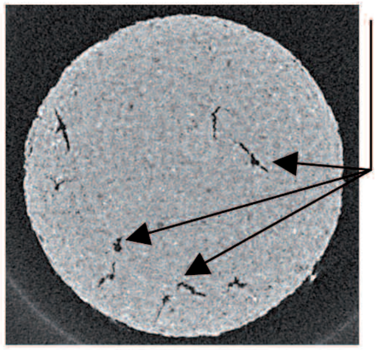
Catalyst supports under pressure

The need for refined fuels with a very low sulfur and heavy metal content is driving constant improvements in the performance of hydrotreatment catalysts. The latter are composed of an active phase dispersed on a porous gamma-alumina support. Optimization of the support's porosity is one of the keys to its performance.

However, this optimization is achieved to the detriment of its mechanical resistance. Yet, catalysts, in the form of extruded granules measuring just a few millimeters, are subjected to high levels of mechanical stress during their transportation and use within reactors that are several meters high. A mechanical resistance that is too low may cause damage to the granules and the formation of fragments and fine particles, detrimental to the operation of the industrial unit.

The approach adopted by IFPEN, in collaboration with the MATEIS laboratory (INSA de Lyon, CNRS), consists in determining the damage modes for different types of stresses on supports with a very variable porosity, and identifying the microstructure defects triggering these ruptures. The method implemented is based on a combination of mechanical tests, coupled with systematic observation of the rupture surfaces under a scanning electron microscope and testing for critical defects by X-ray microtomography.



Reconstruction by X tomography of the cross section of a catalyst support.

The study under way revealed the influence of micrometric extrusion defects for mechanical resistance to crushing, particularly for the most porous extruded materials. Two options are being considered to improve the mechanical resistance of supports: improving their crack propagation resistance or minimizing manufacturing defects.

***D. Staub**, S. Meille, J. Chevalier, **V. Le Corre**, Proceedings of the 13th European Inter-Regional Conference on Ceramics (CIEC 13), 2012, Barcelona.*

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Nominations

• **Olivier Appert,** *Chairman and CEO of IFPEN, has been appointed to the Board of Directors of EDF as a State representative, replacing Yannick d'Escatha (June 2013). This appointment bears testimony to IFPEN's influence in the energy sector and is recognition of the expertise of its personnel in this field.*

• **Pascal Barthélemy,** *Executive Vice-President of IFPEN, has been appointed President of the Innovation Committee of the strategic commission for the Chemicals-Materials sector (June 2013). This appointment will allow IFPEN to contribute to the debates and work of the committee, bringing its vision of the challenges facing the sector, as well as its expertise in the field of research and innovation.*

• **Olga Vizika-Kavvadias,** *Geosciences Director at IFPEN, has been appointed to the Board of Directors of the* École nationale supérieure d'Électricité et de Mécanique *(ENSEM) in Nancy (June 2013).*

Upcoming scientific events

• *IFP Energies nouvelles "Rencontres scientifiques" event* ***– Viscoplastic Fluids: From Theory to Application –*** *18-21 November 2013, IFPEN Rueil-Malmaison.*

• *IFP Energies nouvelles "Rencontres scientifiques" event* ***– Creating the next generation laboratory to develop innovative materials and additives for energy (NEXTLAB 2014) –*** *2-4 April 2014, IFPEN Rueil-Malmaison.*

• *IFP Energies nouvelles "Rencontres scientifiques" event* ***– Photocatalysis for Energy –*** *15-17 October 2014, IFPEN Lyon.*

Publications

• *Fabrice Bertoncini, Marion Courtiade-Tholance, Didier Thiébaut –* ***"Gas Chromatography and 2D-Gas Chromatography for Petroleum Industry – The Race for Selectivity"*** *– Éditions Technip. ISBN: 9782710809920*

• *Hervé Toulhoat, Pascal Raybaud –* ***"Catalysis by Transition Metal Sulfides – From Molecular Theory to Industrial Application"*** *– Éditions Technip. ISBN: 9782710809913*

• *François Badin –* ***"Hybrid vehicles – From components to system"*** *– Éditions Technip. ISBN: 9782710809944*

Managing Editor: Marco De Michelis
Editor-in-chief: Sophie Jullian
Editorial commitee: Xavier Montagne, Xavier Longaygue, Laurent Forti
Graphic Design: Esquif
ISSN No. 1957-3537

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Document printed on 100% FSC-certified paper, partially recycled in a printing plant with the Imprim'Vert green printing label