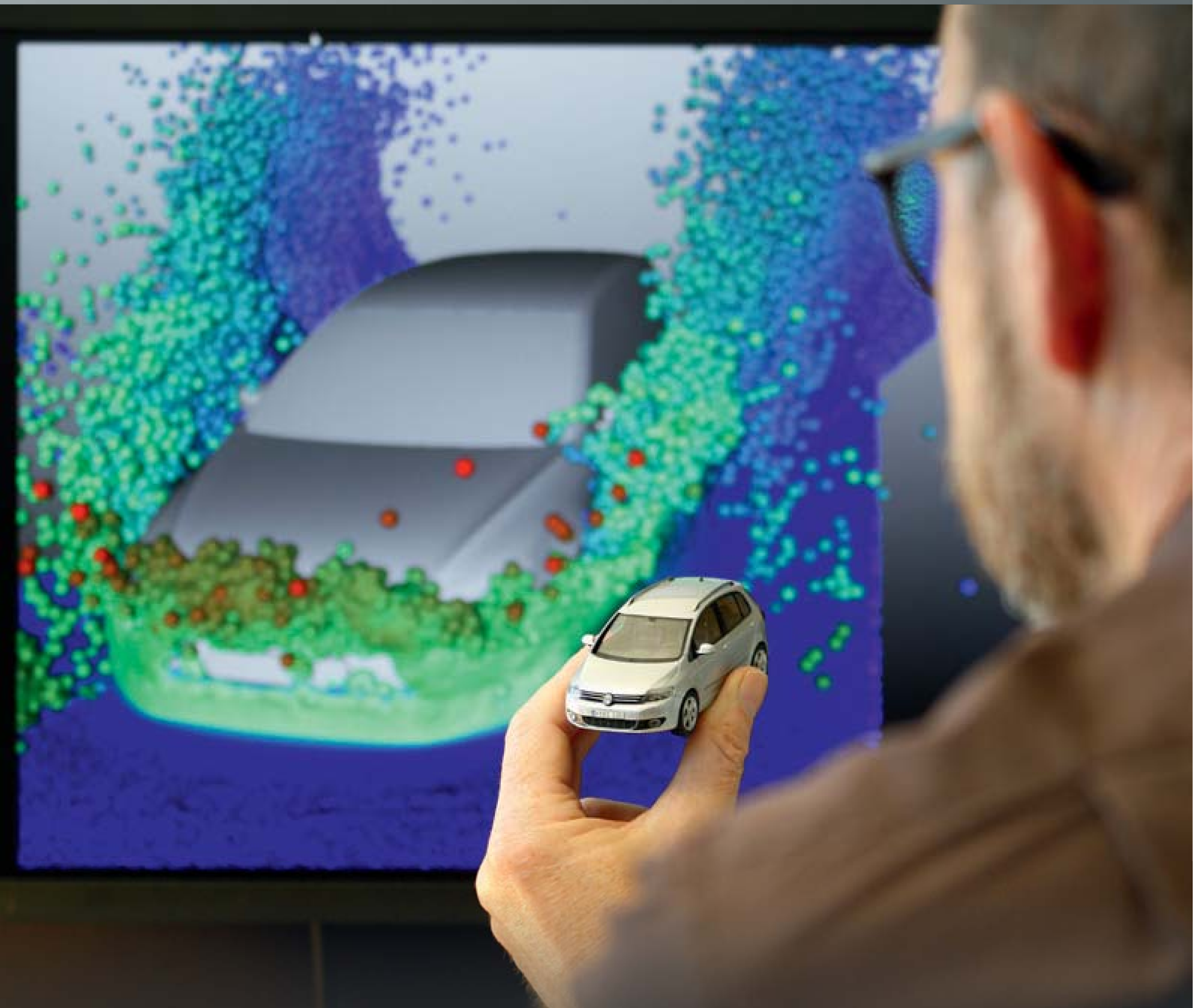
TRANSPORT PROCESSES



Many industrial processes can be simulated using numerical methods, especially, in the area of fluid mechanics. One particularly efficient meshfree solver is the Finite Pointset Method, which was developed by the department and is constantly being expanded. The selected application was prepared with our main cooperation partners and shows a simulation of vehicle passing through water.

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The core competence of the department is the mathematical modeling of complex industrial problems and the development of efficient algorithms for their numerical simulations. The specific problems mainly occur in the context of the technical-natural sciences (fluid dynamics, radiative transport, optics, structural mechanics, etc.) and, after modeling, result in differential equations that can be generally characterized as transport algorithms. The biggest issues, in the eyes of our industry customers, typically concern product optimization or the design of production processes. The portfolio of the department includes collaborative research and development projects with our industrial partners, studies that include design and optimization recommendations as well as software programming of modules or complete tools. The year 2016 was a very successful one for the department, both scientifically and economically. The introduction of a double-head in the department significantly strengthened and focused the group organization. The following pages provide a review of the methodical developments in the four working groups that play a role in various applications. The range of industries we support includes: technical textiles, automobile manufacturing and automotive suppliers, mechanical and plant engineering, process engineering as well as the medical technology and energy sectors. The problems tackled may fall under the areas of fluid dynamics, fluid-structure interaction, fiber dynamics, thermodynamics, and energy distribution.

MAIN TOPICS

- Flexible structures
- Meshfree methods
- Fluid dynamics in process design
- Energy grids and model reduction

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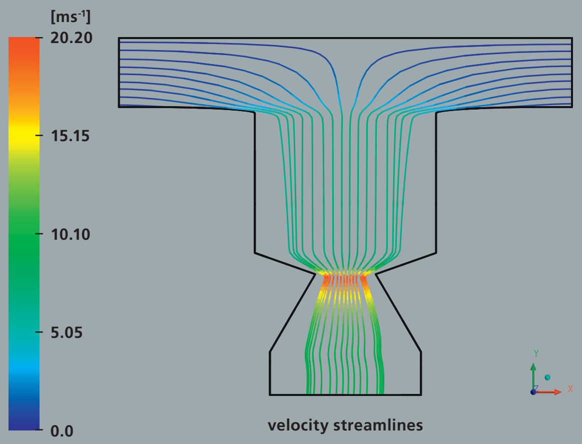

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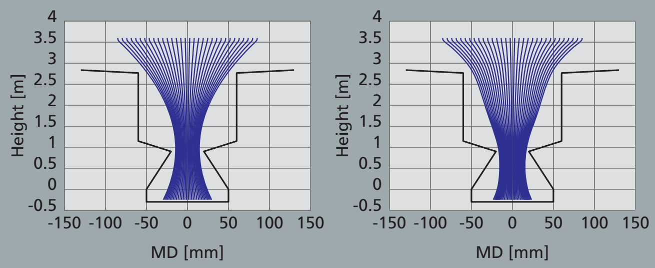


2

MODELING AND SIMULATION: VISCOELASTIC MELT SPINNING PROCESSES

1 *Aerodynamic acceleration area in a spinning process; with color-coded streamlines of the velocity magnitude*

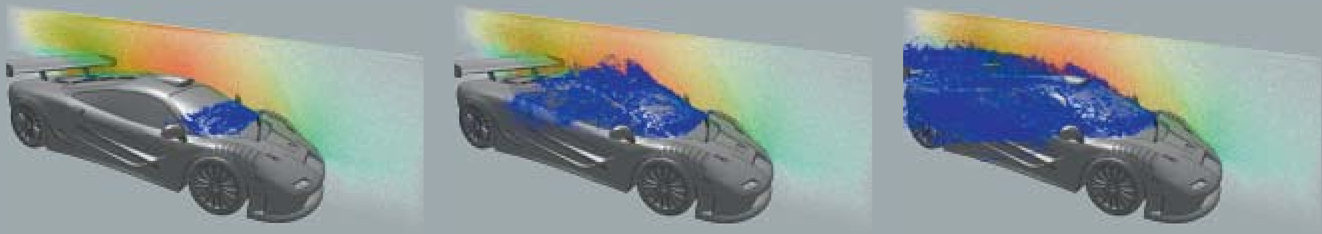
2 *Fiber dynamics model with viscous (left) and viscoelastic (right) materials*

In spinning processes a hot liquid jet is extruded from a nozzle and mechanically or aerodynamically stretched. By cooling down it solidifies and forms an elastic inextensible thin fiber. Process simulation and design require an appropriate material modeling that covers the full range from the viscous jet behavior at the nozzle to the elastic behavior of the final fiber.

Over the past years, Fraunhofer ITWM has developed a new viscoelastic material law for Cosserat rod models and achieved a major advance in the realistic simulation of the spinning process. The Cosserat rod models are based on an one-dimensional balance of mass, linear and angular momentum, and energy along the fiber curve. Conventional simulations using a viscous material model provide an incorrect dynamic for the cooled fibers as they do not account for bending characteristics. The new viscoelastic model, however, overcomes this limitation and provides realistic results throughout the entire process. As desired, the model shows viscous material behavior at the higher temperature boundaries and flexible elastic behavior for the lower temperatures.

The importance of viscoelastic material modeling can be seen from a simple, two-dimensional example: A fiber bundle leaves the spinning pack so the fibers can be cooled and drawn by the air coming from both sides. The machine geometry has a constriction where the velocity of the air flow increases and the fiber jets are pulled through. The fiber simulation results are shown for viscous and viscoelastic material laws, respectively. After just a short running time in the case of viscous material behavior, the fiber curvature is no longer flexible and cannot change because of the cooling. In contrast, the viscoelastic model captures the bending of the cooled fibers and allows the actual overall dynamics to be simulated.

Fraunhofer ITWM successfully implements the new model in combination with a library of flow-interaction models to support the design of modern fiber production plants and further optimize existing processes.



1

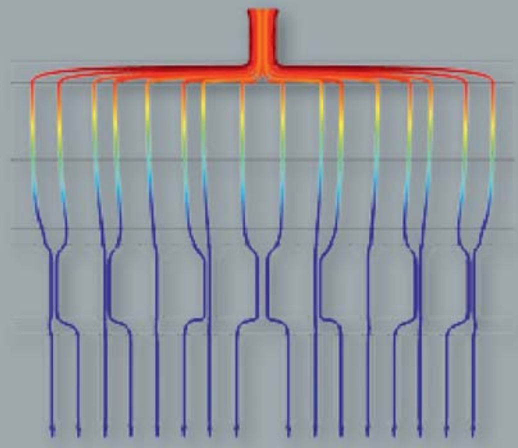
MESHFREE SIMULATION OF FLUID DYNAMICS AND CONTINUUM MECHANICS

Meshfree numerical methods are increasingly used to simulate various industrial processes and operations, in particular, for problems in fluid dynamics or continuum mechanics. The Transport Process department has been developing the Finite Pointset Method (FPM) as its own meshfree simulation tool since the year 2000. FPM is based on a non-meshed cloud of numerical points that represent the continuum and move at the material velocity (Lagrangian method). In effect, FPM is able to very simply and naturally model processes with free surfaces, phase boundaries, and moving geometry parts.

Since 2002, the main focus has been on developing an implicit FPM variant, which enables numerical simulations of incompressible or slightly compressible processes (low Mach numbers). In 2014, the Fraunhofer-internal cooperation project MESHFREE was started together with Fraunhofer SCAI, with the aim of coupling the algebraic multigrid method (SAMG) with FPM. For this purpose, SAMG is being adapted specifically to the meshfree characteristics of FPM. The large sparse systems of equations resulting from implicit formulations can be solved more robustly and much faster using the FPM-SAMG variant. In fact, the simulations for some industrial applications have only become possible as a result of this cooperation.

Industrial projects have already been successfully completed using the coupled approach in 2016. In addition to the FPM-SAMG coupling, the illustrated application couples two independently running FPM simulations. One of the simulations calculates the air flow around a vehicle, while the other simulation models the flow of rain or spray water. Information is exchanged between both simulations: the spray water simulation requires data from the air phase, mainly speed and pressure, while the air flow simulation requires input about the current location, size, and number of spray water droplets. Each simulation uses the integrated SAMG method. Such processes are difficult to reproduce using traditional mesh based simulation methods. The MESHFREE simulation tool opens a whole new range of possibilities for the design of vehicles and components.

1 *Interaction of air and spray flows around a vehicle at various simulation times*



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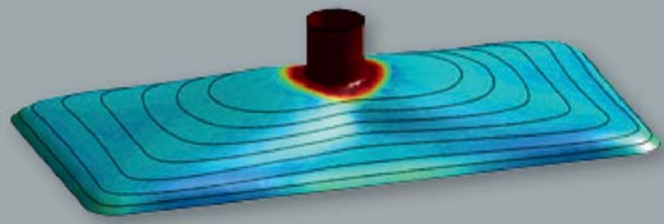


2

1 *Paths of the polymer particles through a typical spin pack*

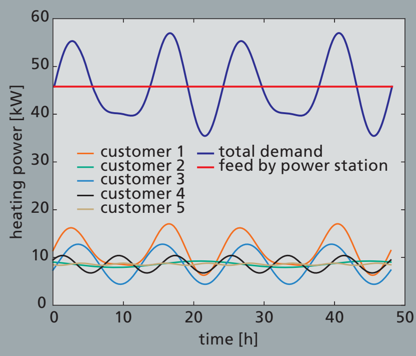
2 *Optimized distributor cavity between input pipe and filter*

ANALYSIS AND OPTIMIZATION OF POLYMER SPIN PACKS

Spin packs are used in the production of synthetic fibers. Typically, melted polymer is disbursed in the spin pack under pressure, passing through multiple filter layers, before it is then pressed through fine capillaries in the spinning plate to be spun into fibers. Depending on the process parameters, the polymer being used, and the specifications of the finished product, different problems can be encountered: Excessive residence times under temperature or high shear rates can degrade the polymers and high pressure drops can hinder the process and reduce the potential output.

ITWM uses flow simulations in combination with in-house developed analysis tools to identify weak points in the design of spin packs. ANSYS Fluent is the standard tool used for the flow simulations. Models for the shear and temperature-dependent viscosity describe the non-Newtonian polymer rheology. But the key aspect is the interpretation of simulation results. Therefore, a representative number of movement paths of the polymer particles are tracked through the entire pack. Relevant variables like residence time, pressure, temperature, or shear rate are evaluated along these paths. This is performed for the pack a whole as well as for the individual components so, in the end, a causative component is identified for each problem. For example, excessive residence times leading to a degradation of the polymers may often occur in the distributor cavity located at the transition between the inlet tube and the filters. Using the geometry optimization methods developed at ITWM, such cavities can be given a flow optimized design, free of harmful dead zones. In contrast, high pressure drops can occur in the fine feed channels required for bi-component spin packs. The simulation-supported analysis permits targeted design improvements, which eliminate the need for costly trial-and-error attempts.

ITWM has accumulated broad experience and competence in this area. They include the analysis and optimization of existing designs as well as design support for new packs. In addition to single component and bi-component packs, other polymer extrusion systems can be studied, for example, polymer filters. These evaluations include detecting the typical sources of error as well as targeted searches for application-specific problems. Generic optimization tools can be extended to customized solutions.



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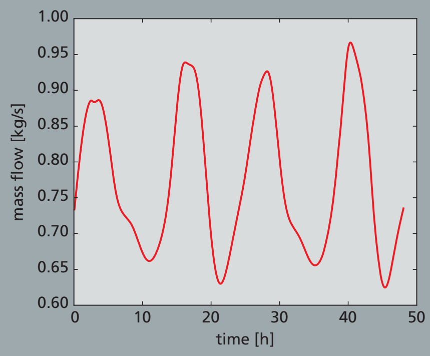

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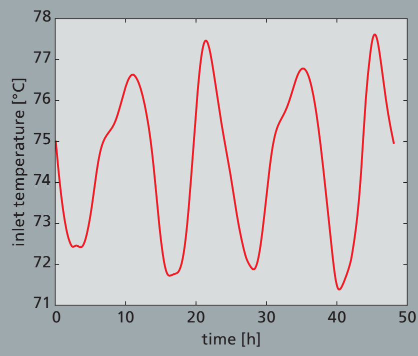

3

DYNAMIC NETWORK SIMULATION FOR INCREASING EFFICIENCY IN DISTRICT HEATING POWER SYSTEMS

District heating power stations (DHP) are mainly used to supply heat and warm water. However, suppliers also generate a good part of their revenues from selling electricity from cogeneration of heat and power. When district heating networks are integrated and dynamically controlled as energy storage units, turbine operations can be made more efficient and firing additional boilers may be avoided. The optimization of operational processes at the power station requires all components to be mathematically represented as accurately as possible. In terms of the district heating network, this means not just the static states, but also the full dynamics must be considered over time. Current software products to support DHP operations are either focused on the optimal use of local resources (where the district heating network is treated as an unstructured sink) or on supplying safely all customers (where consideration is given to detailed, locally resolved hydrothermal models of the power grid). These packages do not include an overall optimization with variable operating conditions. Sponsored by the Federal Ministry for Economic Affairs and Energy (BMWi), this ITWM project is implemented in cooperation with GEF (a German engineering company) and TWL (Technische Werke Ludwigshafen) with the aim of achieving the integration of a dynamic network model into the optimization of power station operations. A dynamic simulation of the district heating power grid is itself of measurable benefit to the operator. For example, the inlet temperatures at the power station and mass flow fed into the network can be controlled as a function of the variable customer demand for heat over time in such a way that the output supplied by the plant remains constant and reliable – even at times of peak usage. The integration of costly gas turbines for the additional heat generation can be minimized or even completely avoided.

The district heating model now in use still has too many degrees of freedom for a comprehensive optimization of operations. To forecast pressures and temperatures, it must be substantially compressed without any significant loss in accuracy. Here, we rely on the use of mathematical methods of parametric model reduction. The optimization challenges are characterized by the limiting conditions of the forecasts for stochastic fluctuations in usage and prices. To improve the forecasting model, we perform simulations for historical time series. A software wizard is being developed to perform potential analyses for the TWL power stations and to present the added value of this new approach to the entire sector.

Coverage of periodically variable demand with constant power feed through by combined regulation of mass flow and input temperature:

1 *Variable customer demand and constant power feed*

2 *Control of mass flow*

3 *Control of inlet temperature*