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Virtual Experiments: Numerical Computations as a Powerful Tool for Engineers

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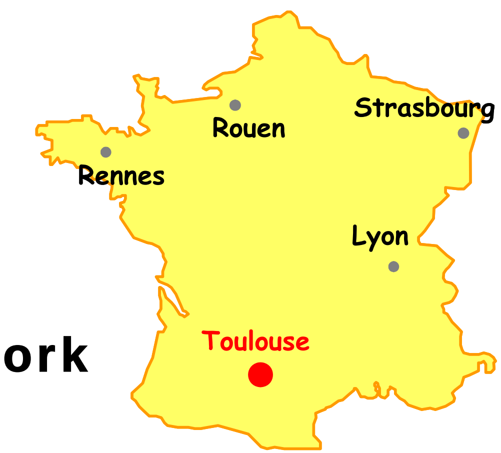
INSA: National Institute of Applied Sciences

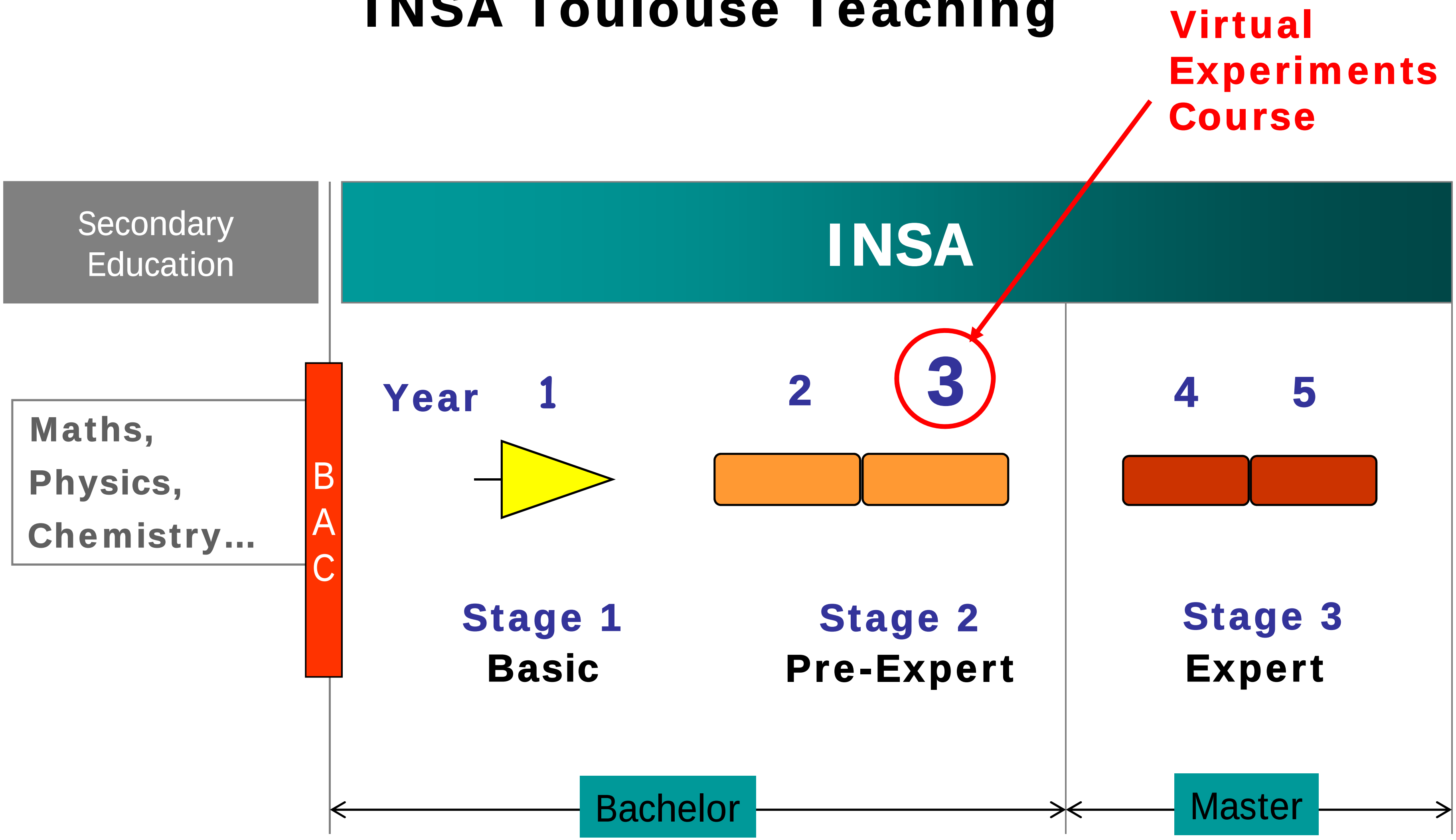
In Toulouse

- **2100 Students**
- **500 Graduates each year**
- **More than 500 Foreign Students**
- **223 Permanent Academic Staff**
- **10 Engineering Specialities**
- **9 Research Laboratories**

INSA Network



INSA Toulouse Teaching



INSA Toulouse Teaching: Course details

Virtual Experiments Course

1st Year	2nd year Pre-orientation	3rd year Pre-orientation	4th year Specialization	5th year Engineer
Scientific Basis	ICBE Chemic, Bio, Environ	Chemical	Chemical & Env.	
		Biochem.	Biochem.	
Humanities	IC Construction Engineering	Civil Eng.	Civil Eng.	
		Mechanic Eng	Mechanical Eng.	
			Systems Eng.	
	IMACS Material, Compon., Syst.	Control, Elec	Control, Electrical	
		Physics	Physics	
Personal Options	MIC Modeling, Information Communication.	Computers	Computer Sciences	
		Math, models	Math, models	
		Network, Telec.	Network, Telec.	

TRAINING

TRAINING

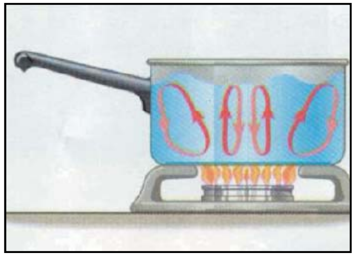
TRAINING

TRAINING

Virtual Experiments Course

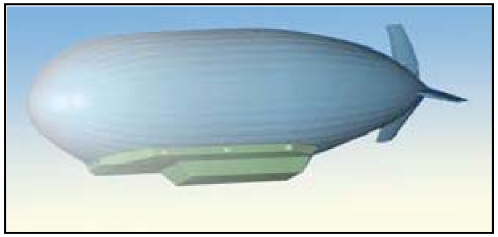
Objective: To initiate student to multiphysics numerical simulation by approaching concrete cases

Outline:
- Quick description of **Finite Element Method**
- **4 projects** performed by students (about 10h each)

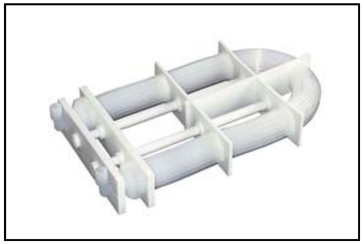


1. Natural convection in a pan (www.nanoscience.info)

2. Application of buoyancy to airship (Aerospace Adour Technologie)

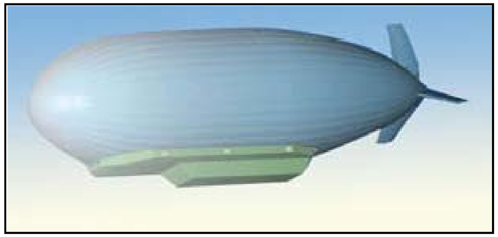


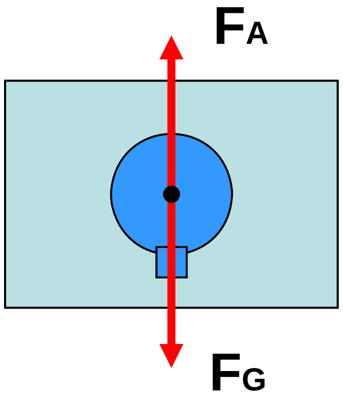
3. Hollow fiber cartridge to filter tap water (Dom source)



4. Heat exchanger (www.directindustry.fr)

2. Application of buoyancy to airship



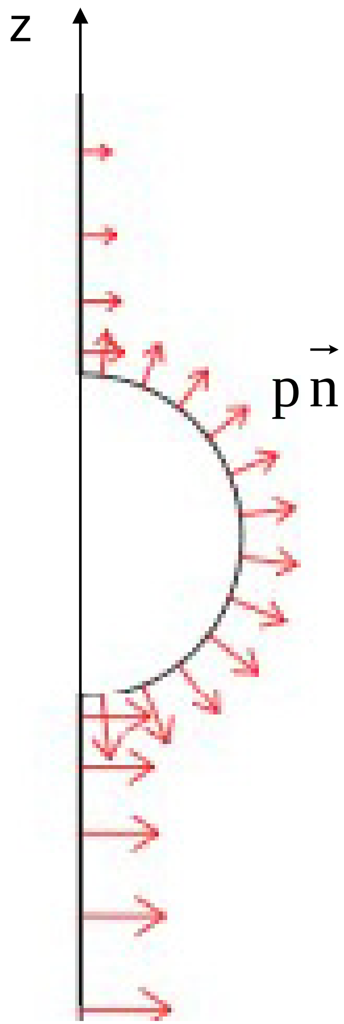


- **Buoyancy force**
- **Gravity force due to natural convection**

⇒ **Static of fluid**
outside

⇒ **Combined incompressible NS equation and convection diffusion heat transfer equation**
inside

Application of buoyancy to airship

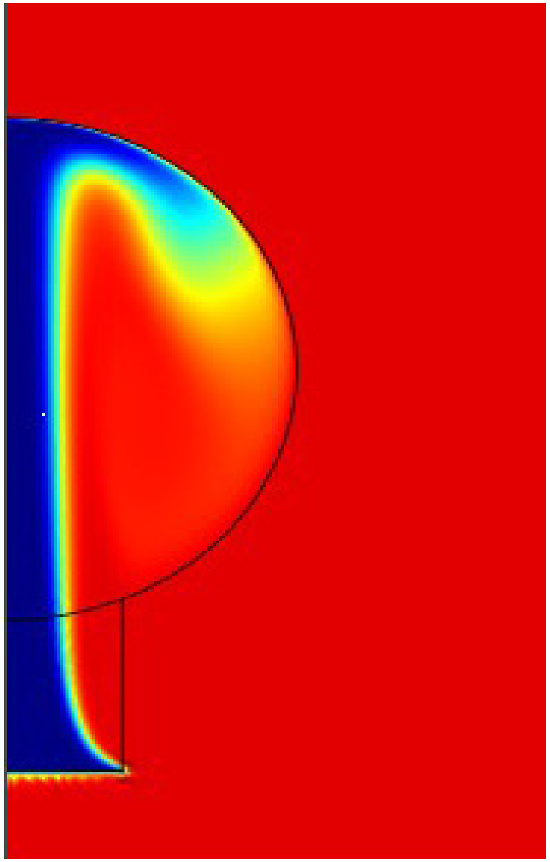


1st step : buoyancy analysis
Pressure around a sphere

- Quiescent fluid with gravitational force
- Pressure map in the fluid obtained with N-S equations
- Integrate the pressure to obtain the buoyancy force
- Recover the Archimede law by varying properties

$$F_A = \iint \left(-p\,\vec{n}\right).\vec{e_z}\, dS$$

Application of buoyancy to airship



2nd step : thermal coupling
Flow induced by thermal convection

- Coupling N-S and heat transfer with the Boussinesq approximation
- Buoyancy force calculated by surface pressure integration
- Weight calculated by volume integration

Discussion on the available force of the airship

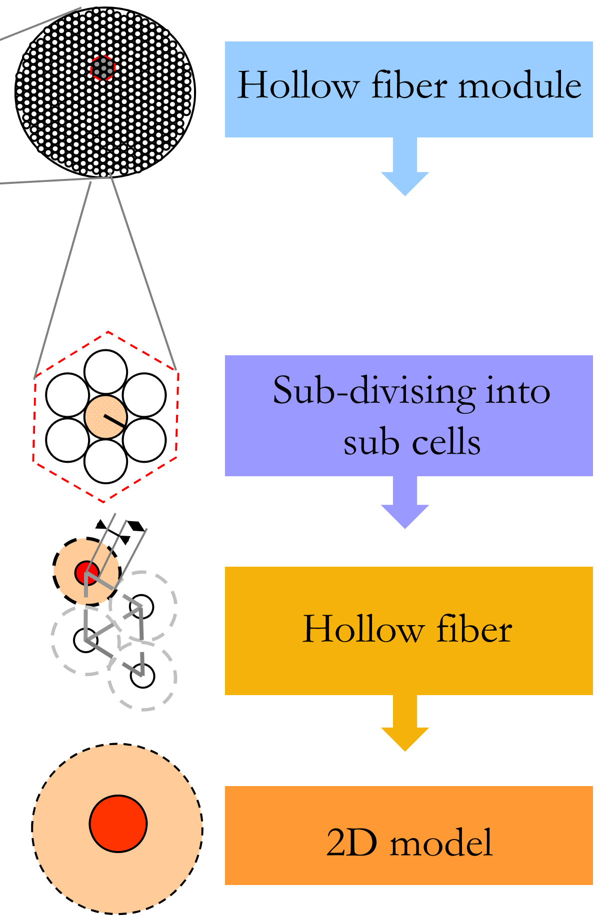
$$F_G = \iiint \rho(T)\, g\, dV$$

3. Hollow fiber cartridge to filter tap water

Real Filter → **Simplified Model**

Cartridge

Hollow fibers



- **Regular arrangement of cylinders**
- **The fluid flow is calculated on a unit cell of this arrangement**

Happel's free surface model *:

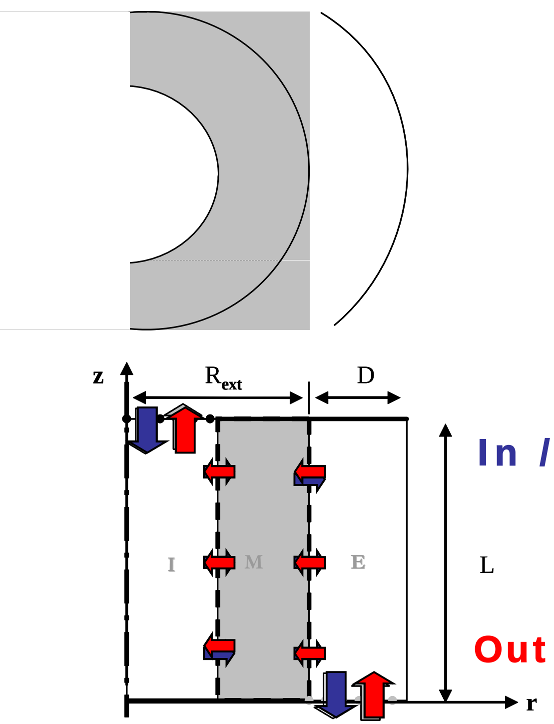
- **The inner cylinder consists of one single hollow fiber**
- **The outer cylinder is a fluid envelope with a free surface used to account for packing effect**

* Happel, Viscous flow relatives to array of cylinders, AIChe, 1959

Hollow fiber cartridge to filter tap water

1st step : Fluid flow without particles

•Coupling Navier Stokes and Darcy Brinkman model

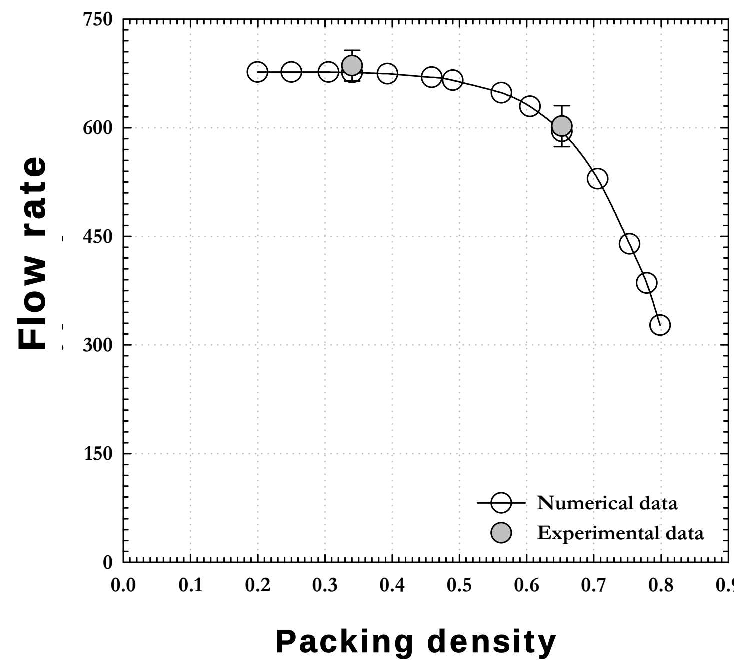


In / Out filtration

Out / In filtration

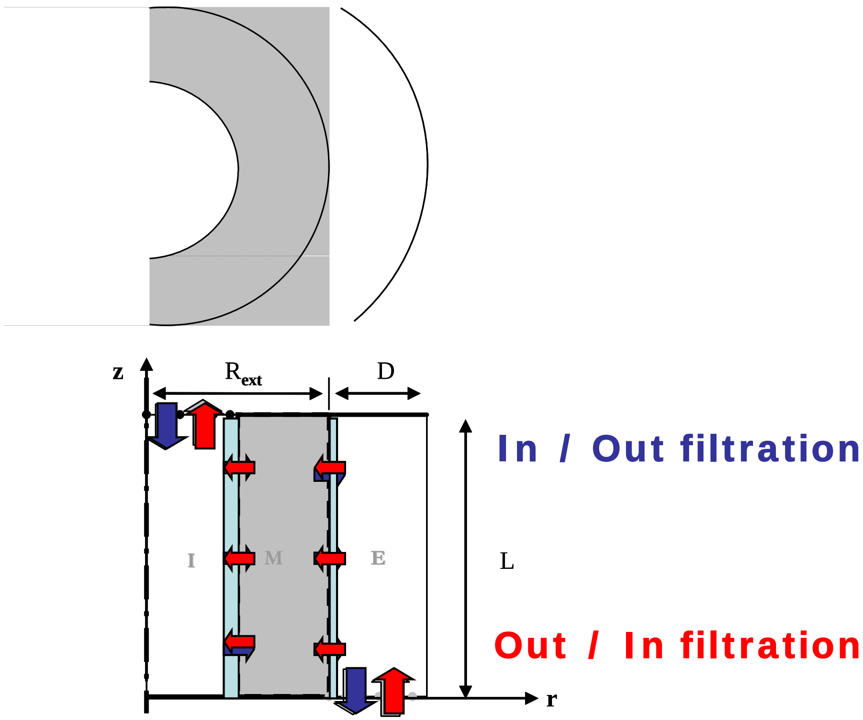
•Good agreement with experimental results

•Discussion on flow rate values



Hollow fiber cartridge to filter tap water

2nd step : Fluid flow with particles

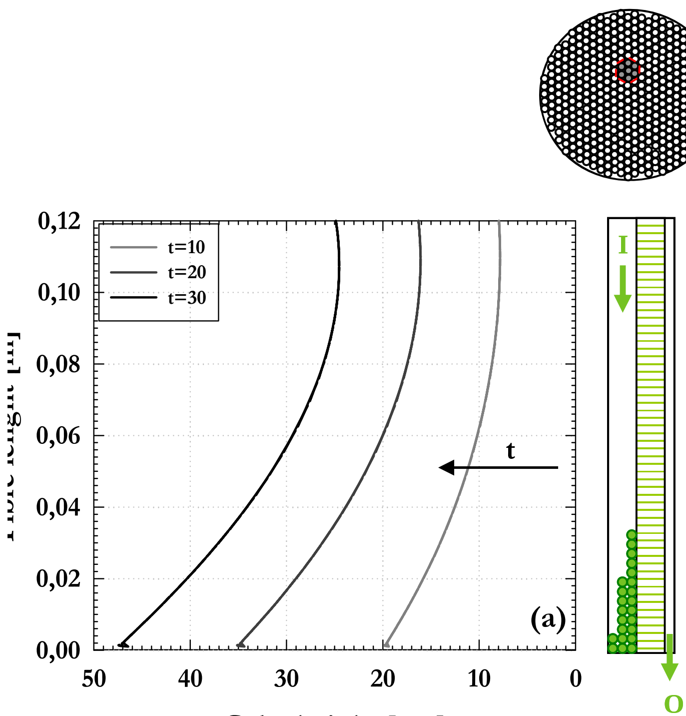


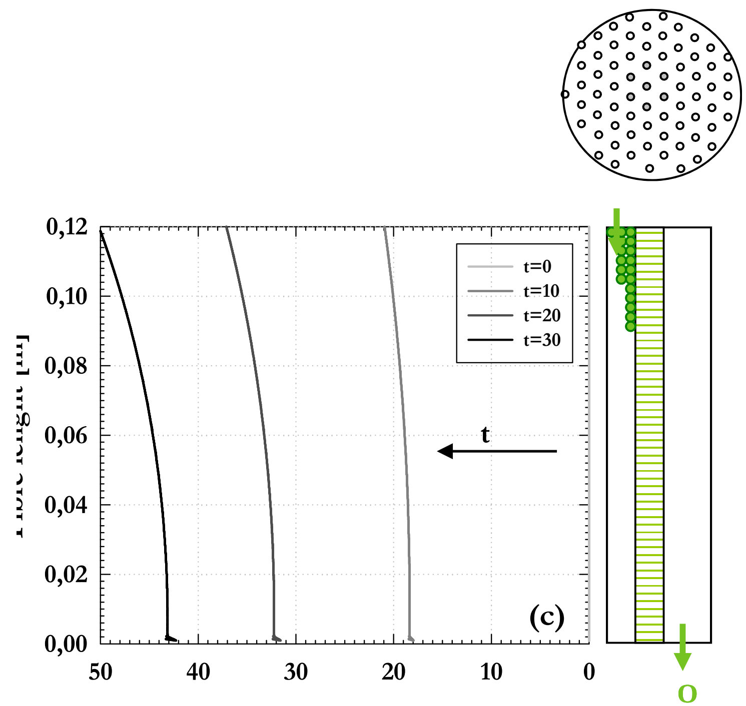
- Coupling Navier Stokes and Darcy Brinkman model
- Particles follow the streamlines
- Using moving mesh ALE to model cake formation

Hollow fiber cartridge to filter tap water

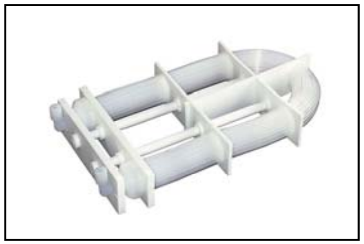
2nd step : Fluid flow with particles

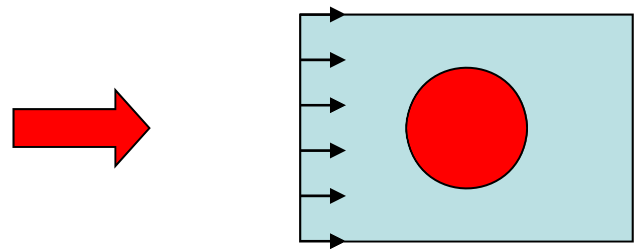
At what time should we replace the filter cartridge?





4. Heat Exchanger





- heated cylinder cooled by a laminar fluid flow
- external flow normal to the axis of the circular cylinder

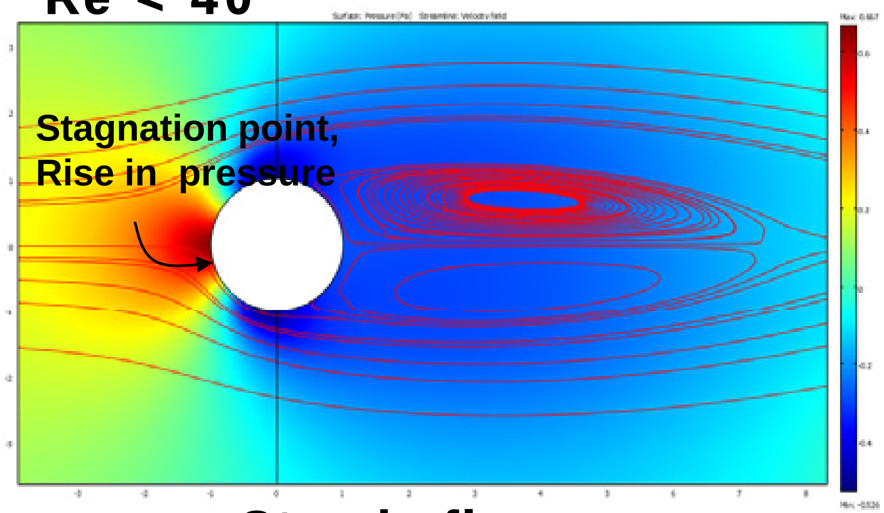
- fluid-thermal coupling :

  combined incompressible NS equation
  and convection diffusion heat transfer equation

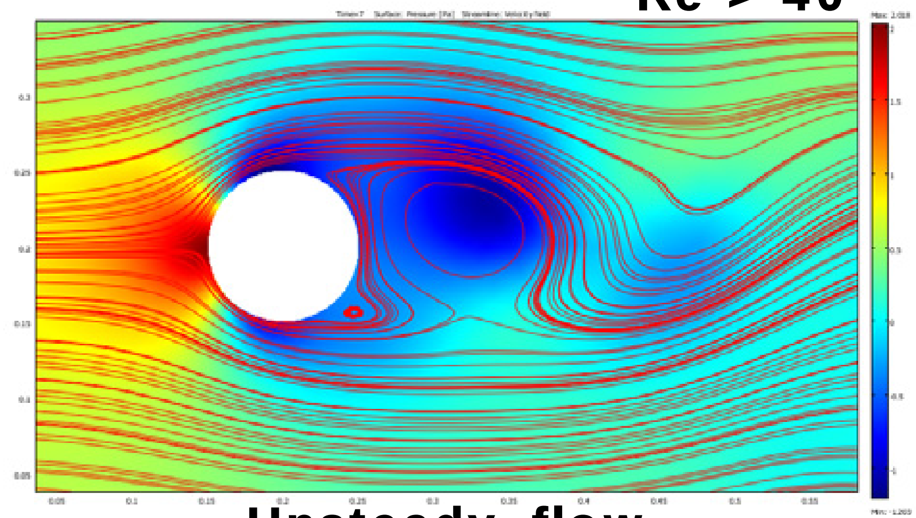
Heat Exchanger

1st step : circular cylinder in a cross flow, isothermal condition

Re < 40



Re > 40



Steady flow

- Two symmetric vortex

Unsteady flow

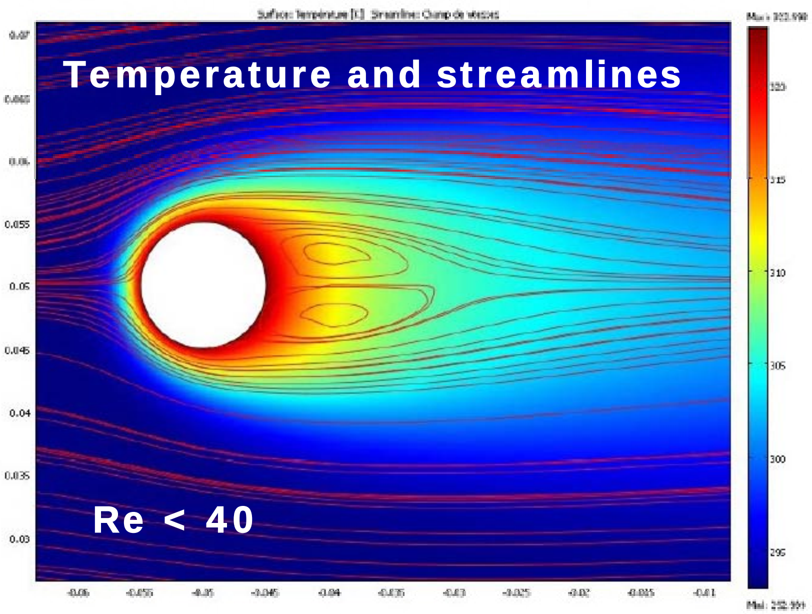
- Karman vortex street observed with a repeating pattern of swirling vortices.
- Period of the vortex shedding

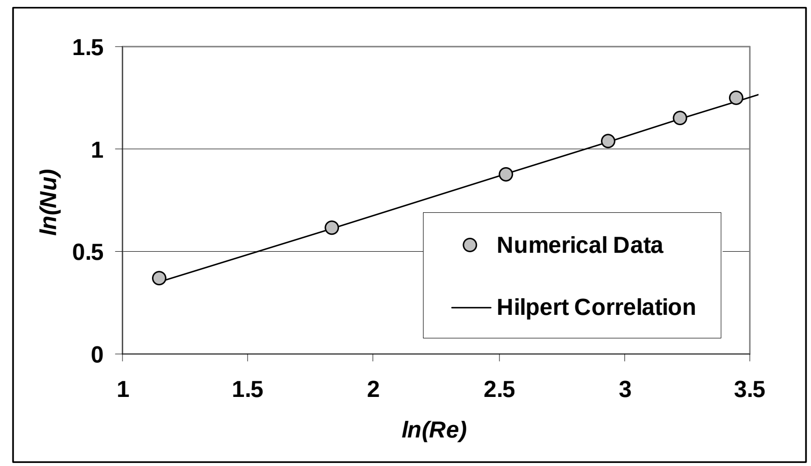
Comparison with literature results

M. Schäfer & S. Turek, 'Benchmark computations of laminar flow around cylinder', E.H. Hirschel (editor), *Flow Simulation with High-Performance Computers II*, 547–566, 1996.

Heat Exchanger

2nd step : introduction of thermal coupling flow around a heated cylinder





- Maximum of the local heat flux at the stagnation point
- Total heat flux calculated by integration of the normal local heat flux on the whole cylinder ⇒ Nusselt number

- **Several fluids studied**

  ⇒ Correlations of the overall average Nusselt number obtained
- **Very good agreement between numerical results and Hilpert Correlation**

Conclusions

COMSOL Multiphysics: a useful tool for teachers

-To illustrate physical phenomena

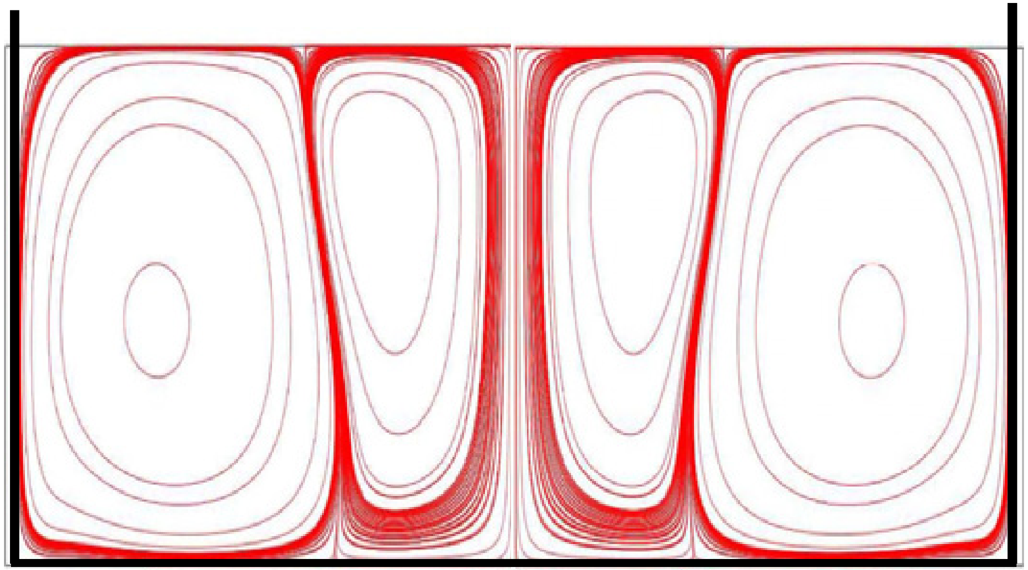
ex: buoyancy
fluid flow / porous media flow
convection heat transfer

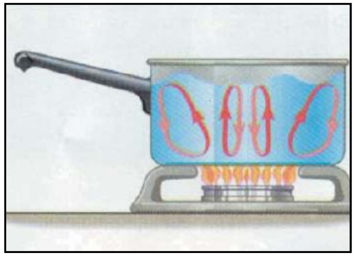
-To approach techniques of numerical simulation

geometry,
mesh,
boundary conditions,
solver,
postprocessing

→ **In order to initiate future engineers to multiphysics numerical simulation**

Thank you





Natural Convection in a pan