Flow Assurance

In the oil industry, the term flow assurance refers to the set of practices that aim to ensure the integrity of elevation and transport systems, allowing the free flow of the transported fluids. These practices encompass prediction, prevention, and mitigation of problems that can occur from the wells up to the processing units, such as the formation of wax and hydrate deposits, equipment impairment in the presence of undesirable multiphase patterns such as slug flow, pipeline corrosion due to detaching of the liquid film in annular two-phase flow, among others.

Examples of preventive measures are the use of thermal insulation to avoid deposition of organic material in the lines, and use of internal coating. The use of PIGs for deposit removal, on the other hand, is an important mitigation tool when avoiding the problem in the first place is not possible.

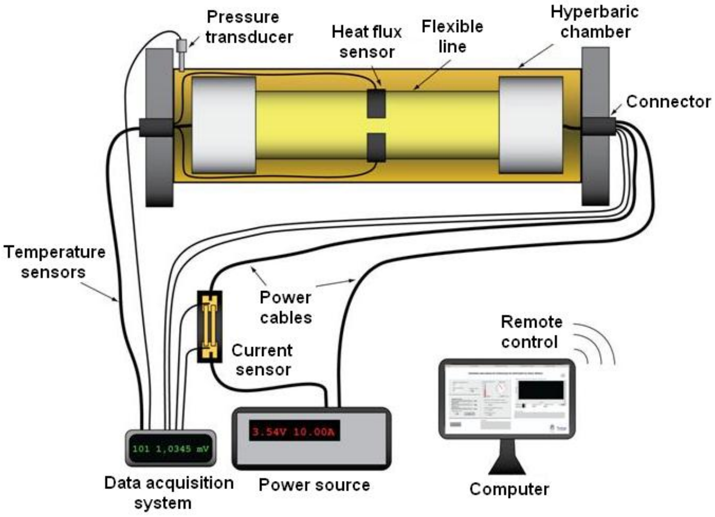
Since 2005, flow assurance has been an important topic of study at the Laboratory of Fluids Engineering, supporting the oil and gas sector and also generating academically interesting challenges. The main topics approached in the laboratory are heat transfer and thermal insulation in pipelines, wax deposition, and the flow of heavy oils with temperature-dependant viscosity. The dynamics of mulitiphase flows, whose comprehension is also important in the field of flow assurance, constitutes by itself a broad research line at LEF.

Dutos inutilizados por deposição severa de parafina (Petrobrás)

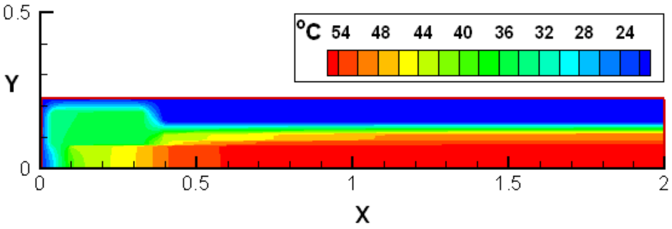
• Heat Transfer and Thermal Insulation of Subsea Flow Lines

Depending on temperature and pressure conditions, as well as fluid composition in subsea lines, deposition of mineral compounds, wax and hydrates in the wall may occur. Such deposits, which are usually formed when the temperature difference between the oil and the exterior of the line is large, can drastically increase pressure losses. Hence, an experiment was designed for evaluating heat transfer and optimizing thermal insulation in flow lines, with the goal of avoiding these problems.

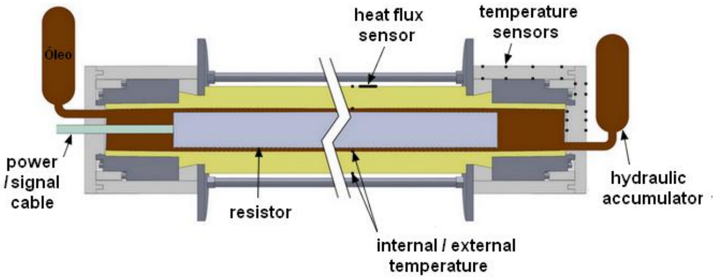
For these tests, a sample of a real line is instrumented, in order to determine the heat exchange coefficient – characterized by the set of materials composing the line – for different levels of hydrostatic pressure, with an uncertainty level of around 5%. Additionally, LEF can count on a partnership with CTDUT for extra infrastructure, such as a hyperbaric chamber and other facilities .

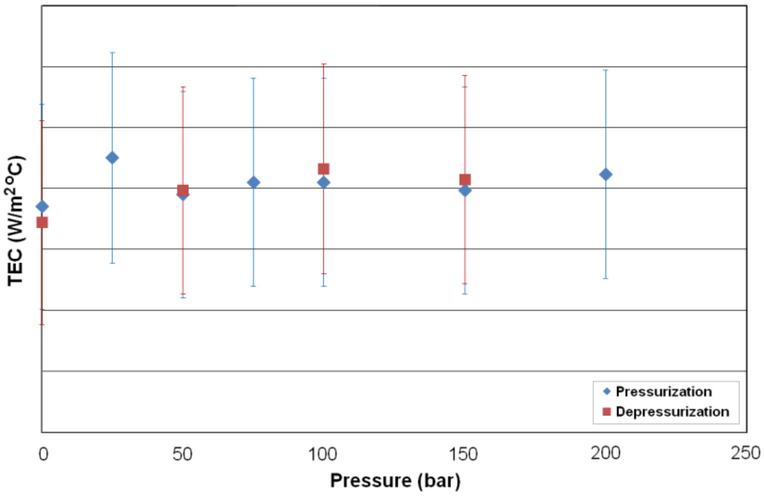


Right: results for thermal exchange coefficient (values cannot be disclosed). Below: Temperature distribution on the sample, obtained through numerical simulations conducted by a collaborating research group.



Temperature and heat flux sensor calibration is performed at the laboratory in the same conditions as the final tests. Left: basic experimental setup. Below: instrumentation details on the internal part.





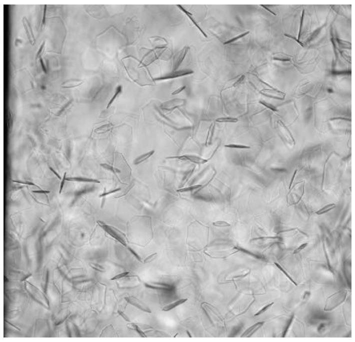
Flow Assurance

Some of the equipment / facilities used in these studies are:

- ***Heat flux sensor (TNO/TPD), with sensitivity from 20 to 25 W/m^2/mV, uncertainty of 3%, 100^{o}C maximum temperature, 110 bar maximum pressure and 0.25 W/mK thermal conductivity;***
- ***Agilent 34972A data acquisition system;***
- ***HP 6031A power source;***
- ***Hyperbaric chamber and other facilities at CTDUT.***

• Wax Deposition

Although there are ways to avoid the formation of wax (paraffin) deposits in oil transport lines, such as thermal isolation, for example, they can elevate production costs, leading to the infeasibility of some flow lines. Thus, it becomes important to better understand the deposition process once it has been initiated, seeking to prevent the negative effects and find new solutions.



Formation of paraffin crystals

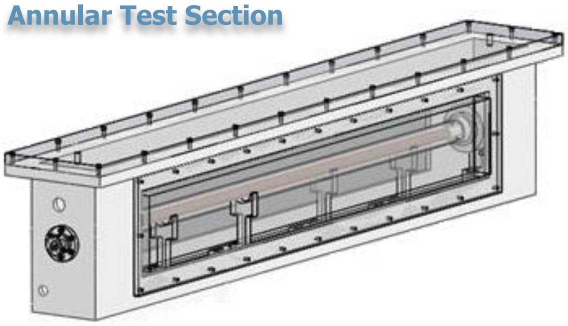
The oil is a complex mixture, containing from hundreds to thousands of components. The fractions which comprise n-alkanes, iso-alkanes and naphthenes with carbon number greater than 18 are called paraffins. Most paraffins with high molecular weight are soluble in oil at reservoir temperature. However, once below the WAT (Wax Appearence Temperature), some components of the mixture go through phase transformation, and paraffin crystals form and interconnect, creating a gel-like structure. This structure can then block production lines, wells, processing equipment and so on.

While much effort has been made, the wax deposition process is not fully understood yet. Its modeling is complicated, and involves from the thermodynamic disequilibrium that generates solid crystals to the shear stress capable of removing the gel deposit at the surface. The mechanisms suggested in the literature as responsible for deposition go from molecular diffusion to particle transport mechanisms. Thus, this is a field of multidisciplinary knowledge, involving heat transfer, fluid mechanics, thermodynamics, phase transformation, among others.

The strategy is to conduct experiments that can reproduce situations found in oil production and transport, but with simple geometries, model fluids, and known boundary conditions. Tests are performed with controlled internal and ambient temperatures , in two kinds of test section geometries.

Experimental results from LEF have been contributing, for over a decade, to some progress in the physical understanding of the mechanisms involved in the formation of solid wax deposits in ducts. Moreover, a relevant experimental database is created and made available for comparisons with theoretical and numerical models, helping improve them. Numerical simulations are performed by a collaborating research group.

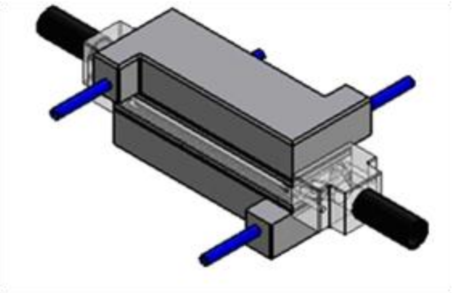
Annular Test Section



Some of the results from the wax deposition experiments are:

- ***Thickness and growth rate of deposits (spatial and temporal profiles), evaluated from analysis of digital images acquired for diffrent temperature and velocity conditions***
- ***Flow temperature distribution***
- ***Velocity profiles***
- ***Thermal properties of the deposits (k, c_p), measured after removal by the end of the process***
- ***Deposit composition***
- ***Pressure drop in lines with presence of deposits***

Rectangular Test Section



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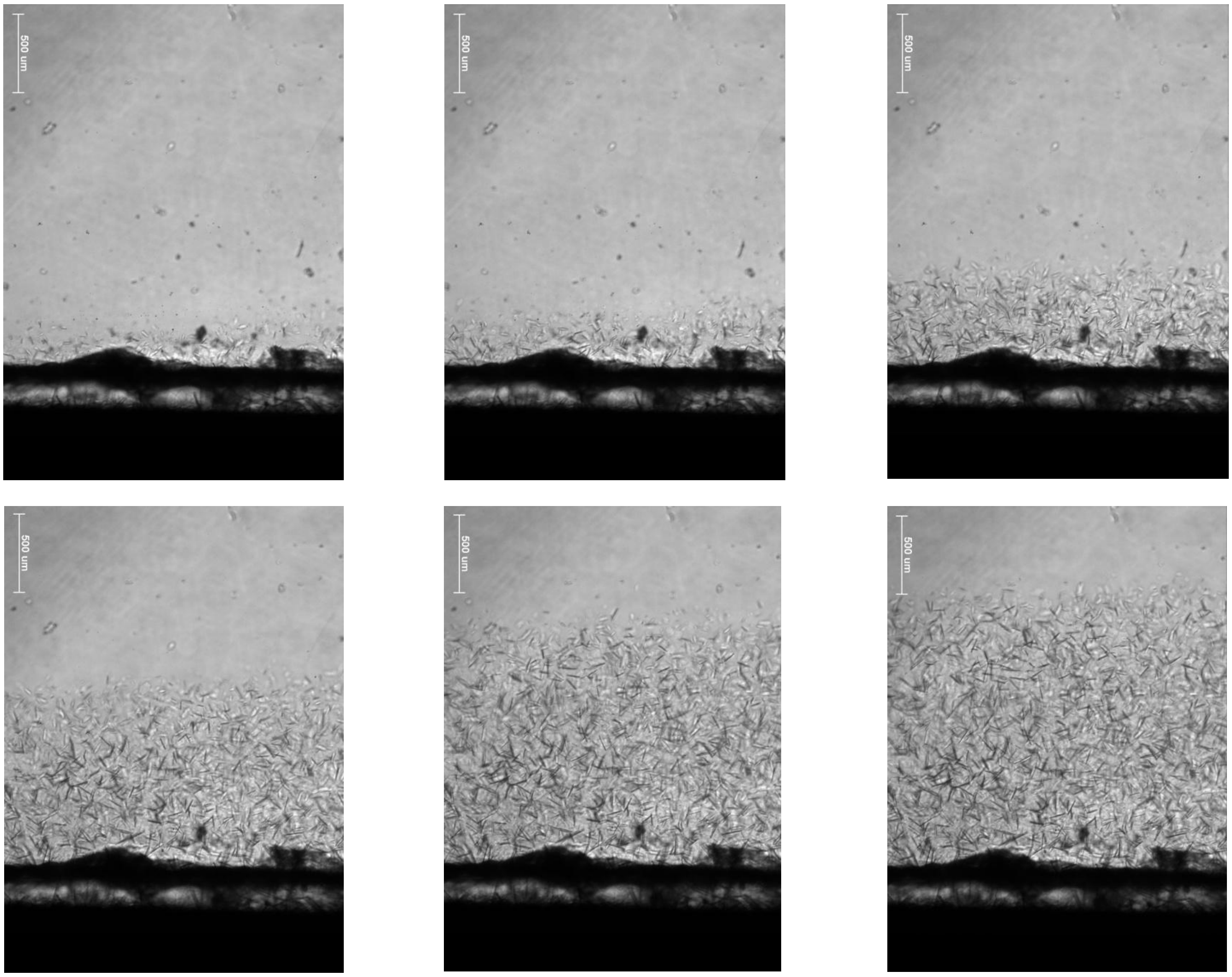
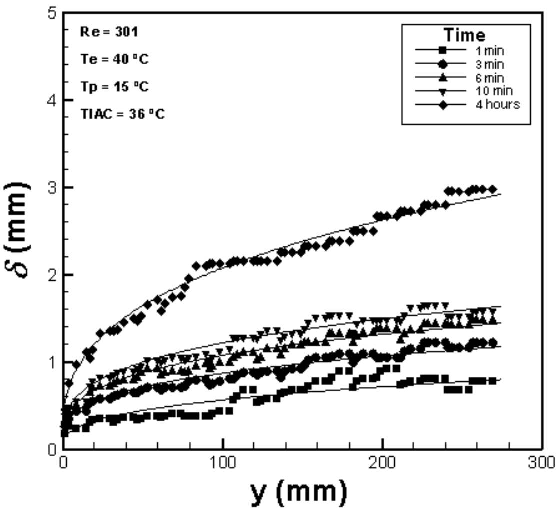


Above: series of instantaneous images depicting the deposition process triggered by cooling of the wall in a flow with suspended crystals in rectangular test section.



Above: temporal evolution of deposition profiles.

Laboratory infrastructure for this research field includes:

- ***40mm (outside diameter) annular test section, with 10mm annular space and 1m length, for visualization and measurement of deposition dynamics and generation of experimental database***
- ***40mm x 10mm rectangular test section, with 150mm length, for characterization of deposit properties***
- ***Optical microscope***
- ***Volumetric pumps***
- ***Tanks***
- ***Thermostatic chillers***
- ***Cameras***
- ***Power supplies and controllers***
- ***Heating tapes***
- ***Heat flux and temperature sensors***
- ***Data acquisition systems***

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- **Heavy Oil Flows**

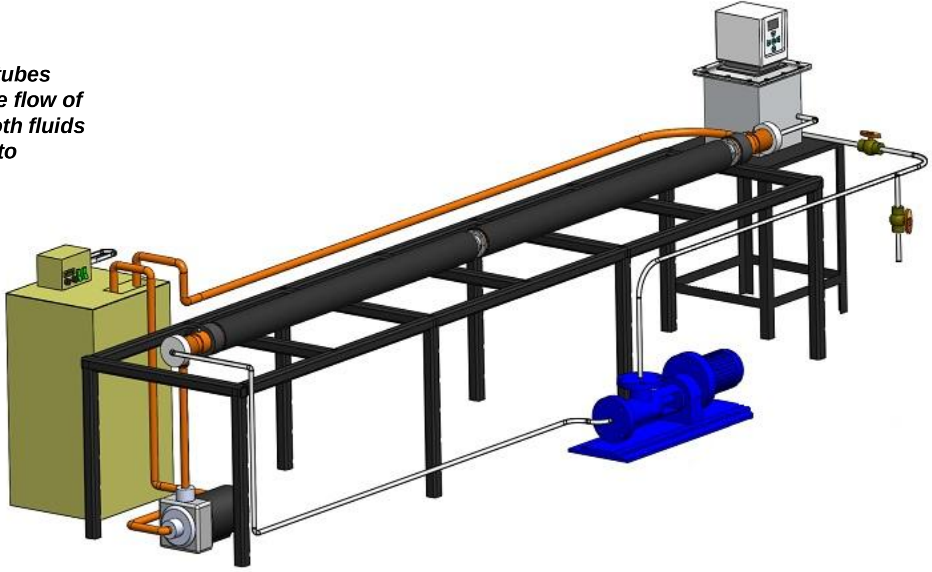
Due to the low temperature levels in deep sea oil fields, heat transfer from the oil inside flow lines to the marine environment can lead to its cooling and consequently to an increase in viscosity, which in turn implies higher power consumption for pumping. Hence, it is common to thermally isolate the ducts, with the goal of reducing heat losses.

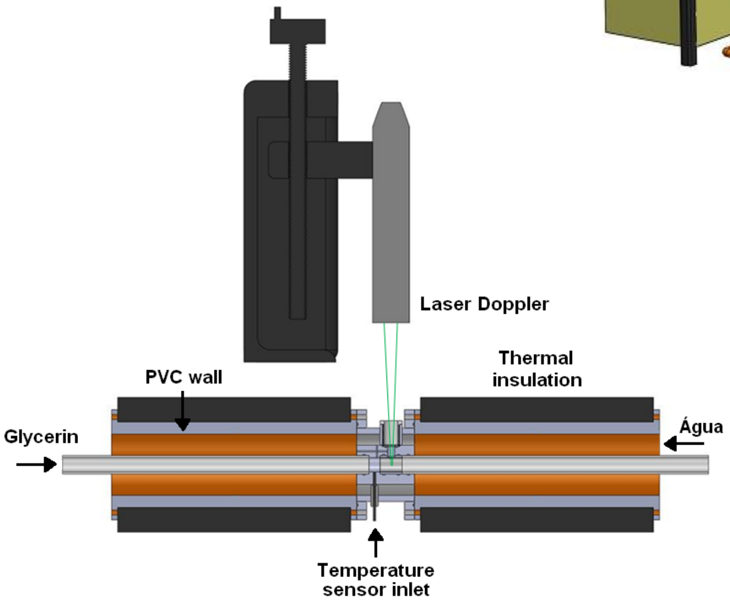
Because of these losses along the duct, the oil temperature varies continuously along its length, and radial temperature gradients also appear. The relationship between flow rate and pressure drop in the line deviates from the linear behavior expected for fluids with temperature-independent properties. The presence of natural convection streams can also change flow characteristics, significantly shifting velocity profiles away from the parabolic profiles expected for hydrodynamically developed laminar flows of Newtonian fluids, and imposing additional effects in the flow pressure drop.

The ability to predict the behavior of heavy oil flows in subsea pipelines is fundamental to the design of pumping installations and to the analysis of hydrodynamic behavior of the ducts. It is thus necessary to understand the mechanisms controlling this type of flow, evaluating the relative importance of each one, such that simple and reliable numerical models can be developed and used safely for system design.

In order to contribute to the analysis of these questions, LEF performs experiments in a small-scale duct, within a range of non-dimensional parameters corresponding to actual operating situations. A model fluid is used, with properties similar to petroleum, notably the function describing the relation between temperature and viscosity.

In order to reproduce field conditions, two concentric tubes are used, one for the working fluid and the other for the flow of refrigerant fluid. Thermostatic bath circulators keep both fluids at the desired temperatures. Thermocouples are used to register temperature in key locations.





Besides pressure drop and centerline temperature measurements, radial temperature and velocity profiles are measured in different streamwise locations. Velocity profiles are obtained with Laser Doppler Velocimetry.

A visualization window was designed to allow optical access for the laser beams to the interior of the duct for the velocity measurements, minimizing the effects of the presence of media with different refraction indices (air, water-ethylen glycol and glycerin solution), which would otherwise cause undesired distortions.

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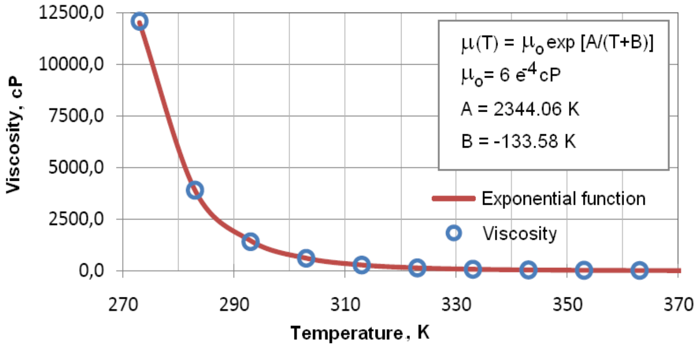
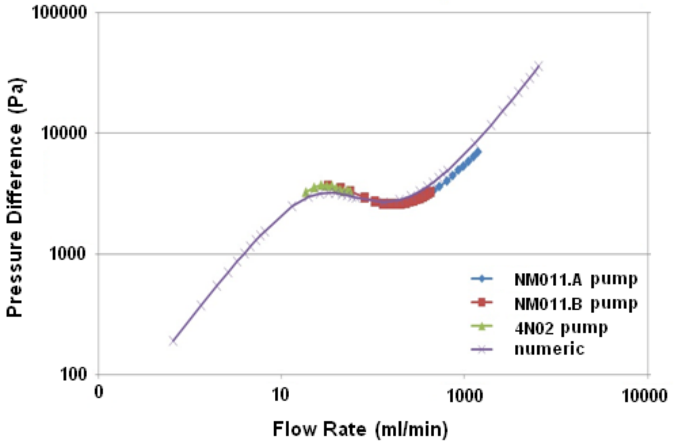
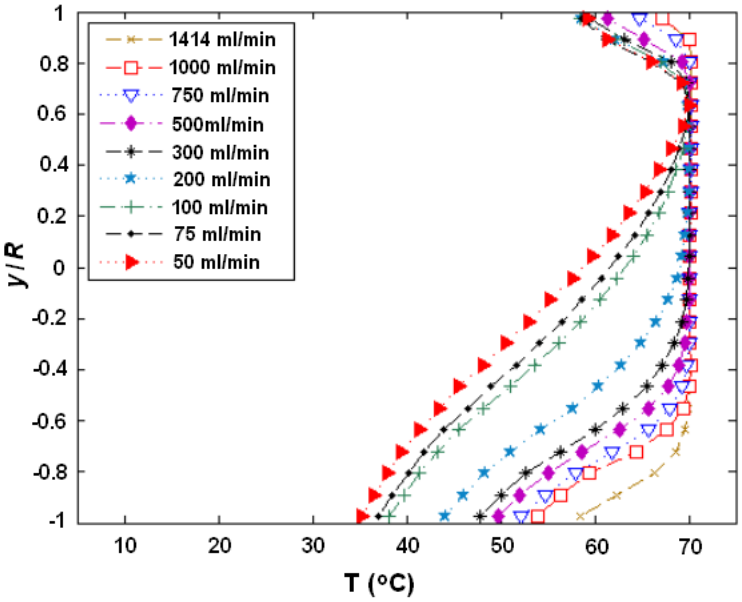
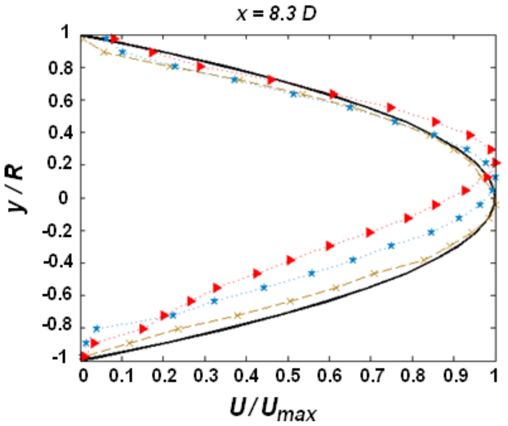




Above: dependancy of viscosity with temperature, measured experimentally and modeled with an exponential function.

Right: pressure differential measured experimentally for different flow rate ranges (through the use of different pumps), and comparison with numerical results.





Above: radial profiles of streamwise velocity. Due to natural convection, profiles deviate from the parabolic analytical profile (full black line).

Left: radial temperature profiles for different flow rates.

Some of the equipment available for these experiments are:

- *Thermoscientific SC100 thermostatic bath circulator, for high temperatures*
- *Thermoscientific Merlin NESLAB M75 thermostatic bath circulator , for low temperatures*
- *NETZSCH NM011 progressive cavity pump*
- *NEMO 4N02 progressive cavity pump*
- *Dancor CP centrifugal pump*
- *Zurich manometer*
- *Agilent 34970A data acquisition system*
- *TSI Innova 70 Laser Doppler*

Partnerships

REPSOL CAPES anp Agência Nacional do Petróleo, Gás Natural e Biocombustíveis Technip take it further. PETROBRAS CENPES CTDUT CNPq

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