CFD APPLIED TO PETROBRAS REFINING PROCESS
DEVELOPMENT AND OPTIMIZATION – PRESENT,
FUTURE AND CHALLENGES –

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- Fabio Santos
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- Waldir P. Martignoni
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Summary:

:: Introduction
:: PETROBRAS R&D Overview
:: Refining Challenges and Applied Technologies
:: CFD Applied to Refining Technologies Development
:: CFD_NET on Refining: REDE CFD
:: Conclusions
Computational Fluidodynamics has been used as a very powerful tool for science and academic development and also in industrial scales for some specific tasks, even so, there are many aspects of CFD that still now need further development in order to be ready for an overall full Industrial scale application.

Petroleum Refining deals with very complex flows, like multiphase, non-Newtonian, turbulent, high temperature and high pressure, reactive flows, besides large and complex equipment.

Fully application of CFD to such processes is still not possible due to lack of trustful models, solvers and hardware, however carefully analyzed situations allow us to take advantage of this technique for solving refining development and optimization problems.
PETROBRAS started developing its own softwares in the eighties, for several applications, but in the nineties, in order to take advantage of large developing teams, switched to commercial codes.

Nowadays PETROBRAS is investing a large amount of human power and resources in CFD application to large Industrial equipment simulation, like, Cyclones, Risers, Regenerators, Prilling Towers, Reactors, multiphase flows in general, etc.

PETROBRAS is certainly one of the largest commercial CFD code users.
In order to speed up this kind of development, a CFD net has been created, involving several Brazilian Universities and Research Centers, furnishing them with experimental laboratories and suitable Instruments, computational hardware and resources to hire high trained Experts.

Environmental issues have been the Oil Refining Industry development driving force for last decades and will continue even more intensive in the future, but economical issues due to the increase in oil consumption vs shortage will play an important role in this new scenario.

New scientific developments in physical models and model solving, cheaper high performance computers are mandatory for achieving trustful simulation.
2- PETROBRAS – OVERVIEW

PETROBRAS MAIN ACTING AREAS

- Production
- Distribution
- Transport
- Exploitation
- Gás
- Environmental Management
- Refining and Petrochemistry
- Products
- Energy
2- PETROBRAS – OVERVIEW
TECHNOLOGICAL DEVELOPMENT PROGRAMS

PROFEX
Exploration

PROCAP
Deep Water

INOVA
Innovation on Fuel

PROTER
Refining

PROAMBR
Environmental

PROPES
Heavy Oils

PRODUT
Ducts and Pipelines

PROPRAP
Advanced Recuperation

PROREC
Optimization and Reliability

PROGAS
Gás

PROGER
Renewable Energies
Time evolution of Refining Technologies - Hardware and Products
Starting of Barril Bottom Program

Heavy Oil UFCC’s

Starting FCC Catalyst Production-FCCSA

Starting of PROTER Strategic Refining Technological Program

1ª application of BR HDT Technology Qav: REDUC

1ª application of BR RFCC Technology: RECAP

2ª application of BR RFCC Technology to de Instáveis: REPLAN

2ª application of BR HDT Technology to de Instáveis: RPBC

1ª application of BR Coke Technology: REGAP

2ª Application of BR Coke Technology: REGAP

3ª Application of BR Coke Technology: REPLAN

4ª Application of BR Coke Technology: REPLAN

5ª COQUE

8º HDT

1ª application of BR Coke Technology: RPBC

Startign of Optimization Programa at AB

Startign of The Technological Program: PROREC

Startign of The Main Industrial Automation Plan: PDAI

Starting of The Main Industrial Automation Plan: PDAI

Starting of PROTER Strategic Refining Technological Program

Implementation of SIX Technological Park.

1ª application of BR Coke Technology: RPBC

New Diesel HDT’s REGAP, REDUC, REPLAN & REPAR

New series of Catalysts of high accessibility for Catalytic Cracking.

Introduction of BR Renewable Technology: HBIO

Modernization:

3º RFCC

5º COQUE

8º HDT

REFAPs

Startign of Optimization Programa at AB

Startign of The Main Industrial Automation Plan: PDAI

Starting of The Technological Program: PROREC

Startign of the Center Of Excelenc on Studies and Dynamic Analysis of AB : CEAD

1ª application of BR Real Time Optimization Technology: REVAP

Beginning of New Materials For Heavy Oil Processing

1ª Application of BR Coke Technology: RPBC

Startign of SDCDs REDUC e REVAP

3º Application of BR Coke Technology : REPLAN

2º Plan of Metalurgic Suitability.

87 89 90 94 95 98 99 00 01 03 04 05 06
Refining Challenges and Applied Technologies – AB-RE

“Starting of Barril Bottom Program”

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RFCC Technology: RECAP

1ª application of BR HDT Technology Naftenic Oil: LUBNOR

2ª application of BR HDT Technology to de Instáveis: REPLAN

Instáveis: RPBC

2ª application of BR RFCC Technology to RLAM

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Starting BLENDDING of Gasolina-REVAP and Diesel-REPLAN

2ª Application of BR Coke Technology: REGAP

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Heavy Oil UFCC’s

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Refining Challenges and Applied Technologies – AB-RE

Introduction of Extra Quality
BR QAV

Starting Of Quality Strategic Management
(SGQ): Diesel & Gasoline

Starting Of Quality Strategic Management
(SGQ): QAV

Metropolitan Diesel Production

Lead Free Gasoline

Production of F1 Gasoline

Production of PODIUM Gasoline

Anticipation of Diesel 500 ppm Production
de Diesel 500 ppm (RJ, MG e SP)

Starting Diesel PODIUM

Implementation of Engine Lab at The South

Production of PREMIUM Gasoline

Starting of the Product Technological Program (INOVA)

Starting of Technological Programs: Lubs (PROLUB), Diesel (PRODIESEL), Gasoline (PROGASOLINA) and High Value Products (PROPAG)
Applied Refining Technologies in Order to Achieve 2002-2006 Goals.
Refining Applied Technologies in order to Achieve the Goals: 2002 – 2006:

Main Goal: Increasing in National Oil Processing Capacity:
Refining Applied Technologies in order to Achieve the Goals: 2002 – 2006:

:: Petrobras RFCC Technology and High Accessibility Catalysts;

:: Increasing of Hardware Reliability;

:: High Metalurgic Standard Able to Process Marlin Heavy Oil;

:: Petrobras Technology of Vacuum and Atmospheric Residuum Coking.

:: PETROBRAS Hydrotreatment Technologies to REPLAN, REGAP, REPAR, REDU, REFAP;
The PE 2015: New Technologies for New Challenges

- **Strategic Plan - 2015**

- **Reliability Technologies & Hardware (Assets) Optimization**
- **New Technologies for Conventional Processes and Products**
- **Emission Reduction Technologies and Use of Natural Resource**
- **Technologies of New Training Standards** (Simulation)
- **Renewable Sources Technologies** (Bio-Technologies, ...)
- **Ultra Low Sulfur Contend Fuel Technologies**
- **Technologies for Using Natural Gas as Feedstock** (Gasification ...)
- **Inovation and Advanced Technologies** (Mecatronics, Nanotechnology, Slurry-beds ...)
- **Futuristic View** (Cars, Refineries ...)
- **Investment Portfolio**
CFD applied to Refining Technologies Development in Order to Achieve 2002-2021 GOALS.
:: Development and Application of Reliable Fluidodynamics Models and Solving Techniques for:

- Operating Problems Diagnosis;
- Existing Processes Optimization
- New Processes Equipment and Components Conception, Design.

Contribution to Operational Refining Costs Optimization and Reduction of Failure Probability due to Improvements in Operating Problems Diagnosis.
For a Single Phase Incompressible Flow the Generalized Navier Stokes Equation contains all Information but Boundary and Initial Conditions (Frisch, 1995).

\[
\partial_t u + u \cdot \nabla u = -\nabla p + \nu \nabla^2 u
\]

\[
\nabla \cdot u = 0
\]

This includes Turbulence- DNS.

Initial and BC may not be the Problem.

The Main Problem, that remains for Centuries is Solving the Equation
For a Multiphase Phase Incompressible Flow the Generalized Navier Stokes Equation needs, besides, Boundary and Initial Conditions for all Phases, Body Forces $b_k$ and Phase Interaction $\beta_{ik}$ constitutive Equations.

\[
\partial_t \varepsilon_k u_k + \nabla \cdot (\varepsilon_k u_k u_k) = -\nabla p + \nabla (\varepsilon_k \nu_k \nabla u) + b_k + \beta_{ik}
\]

\[
\nabla \cdot (\varepsilon_k u_k) = 0
\]

\[
\sum_{k=1,N} \varepsilon_k = 1
\]

The SECOND Phase (Particle, Droplet, Bubble or Other Continuous Phase) Initial and Boundary Conditions may not be so clear, even for well design Experiments.
:: For Large Industrial Equipments, lots of Information, regarding BC and Initial Conditions are difficult to define;

:: Numerical Methods may not be Suitable, due to the Equipment Size;

:: In Real Operating Conditions We need to Consider Heat and Mass Transfer, Phase Change, Reaction and Turbulence, all at once;

:: Normally a very Complex Geometry
\( \frac{\partial}{\partial t} u + u \cdot \nabla u = -\nabla p + \nu \nabla^2 u \)

\( \nabla \cdot u = 0 \)

CFD Applied to Refining Technologies Development

**CFD – UNDER DEVELOPMENT**

MODEL

SOLVER

PROBLEM

HARDWARE
• Cyclone Inlet Conditions (PSRI data)

Blind Tee Disperses Solids Entering Cyclone (More Turbulence)

Elbow Causes Solids to Form a Coherent Strand Before Entering the Cyclone (Less Turbulence)

---

Material: FCC Eq. Catalyst
Cyclone Size: 19.75-in (50-cm)
Entry: Tangential
L: 2 lb/ft³ (32 kg/m³)
Riser Termination:

<table>
<thead>
<tr>
<th>Inlet Gas Velocity, ft/s</th>
<th>Overall 1st Stage Cyclone Efficiency, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>99.5</td>
</tr>
<tr>
<td>30</td>
<td>99.9</td>
</tr>
<tr>
<td>40</td>
<td>99.99</td>
</tr>
<tr>
<td>50</td>
<td>99.99</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Inlet Gas Velocity, m/s</th>
<th>Overall 1st Stage Cyclone Efficiency, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>99.5</td>
</tr>
<tr>
<td>0.2</td>
<td>99.9</td>
</tr>
<tr>
<td>0.4</td>
<td>99.99</td>
</tr>
<tr>
<td>0.6</td>
<td>99.99</td>
</tr>
</tbody>
</table>

---

Material: FCC Eq. Catalyst
Cyclone Size: 21-in (53-cm)
Entry: Tangential

L: 1.9 lb/ft³ (30 kg/m³)
Riser Termination:

<table>
<thead>
<tr>
<th>Overall 1st Stage Cyclone Efficiency, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blinder-Tee</td>
</tr>
<tr>
<td>Elbow</td>
</tr>
</tbody>
</table>

---

Material: FCC Eq. Catalyst
Cyclone Size: 21-in (53-cm)
Entry: Tangential

L: 60 ft/s (18.2 m/s)
Riser Termination:

<table>
<thead>
<tr>
<th>Overall 1st Stage Cyclone Efficiency, %</th>
</tr>
</thead>
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<td>Elbow</td>
</tr>
</tbody>
</table>

---

Inlet Gas Velocity, ft/s

Inlet Gas Velocity, m/s

Inlet Gas Velocity, ft/s

Inlet Gas Velocity, m/s
• Cyclones – Usual Boundary Conditions
• Cyclones – Troubleshooting
• Cyclones – Troubleshooting
• Cyclones – Troubleshooting
:: For Large Industrial Equipments, lots of Information, regarding BC and Initial Conditions are difficult to define;

:: Numerical Methods may not be Suitable, due to the Equipment Size;

:: In Real Operating Conditions We need to Consider Heat and Mass Transfer, Phase Change, Heterogeneous Reaction and Turbulence, all at once;

:: Normally it varies from Dense (Moving Bed) to very Dilute Flow (10^{-6})

:: Up to now We considered only Cold Flows

:: Probably one of the largest World effort in Solving Industrial Problems.
:: Radial and Axial Gas Solid Mixing – LES Model

K – ε Model  LES Model  LES Model
PETROBRAS Research Center
CFD Applied to Refining Technologies Development

Divisions

- Distillation
- Desalting
- FCC and Gasoline
- CS and PFCC
- Delayed Coking
- Deasphalting
• **Baffles design studies**
  
  – Optimize the first baffle height, above vapor inlet
  
  – Uniformity of vapor flow after the last baffle

• **Case studies**
  
  – Coker fractionators
• **Inlet device studies**
  - Establish criteria for new designs
  - Understand the vapor distribution
  - Evaluate baffles spacing

• **Case studies**
  - FCC main fractionator
• **Empty spray section design**
  - Inlet characteristics studies
    - Axial velocity profiles
  - Heat and Mass transfer

• **Case studies**
  - Vacuum towers
  - Coker fractionators

**spray section**

**vapor inlet**
**Inlet Feed Device**

- Reduce the liquid drag and velocity peak
- Improve the vapor distribution
- Modifying the feed nozzles

**Case studies**
• **Liquid Distributors**
  - The effect of the previous section in liquid distribution

• **Advantages:** Evaluate geometric arrangement in distributors previous section

• **Case studies**
  - Atmospheric towers
CFD_NET APPLIED TO REFINING: REDE CFD

- **Objectives:** The Computational Fluidodynamics NET on Refining Processes, Applied to Oil, Gas and Renewable Energy Sources has as main objectives to Implement Actions in order to Elaborate Studies, Develop R&D Projects, Define and Create Infra Structure, and Develop Human Resources on Fluid Dynamics Through the Associated Institutions.

- **INFRASTRUCTURE and P&D PROJECTS**

::

**Members – Infrastructure Projects:**

- UNICAMP, UFSC, UFRJ (EQ), UFU (MEC), UFMG, PUC-RIO - OK

- USP (CHEM, MEC, MAT APL), UnB, UNESP, ITA, IME, CTA UFRJ(COPPE ), UFU (MEC), – ON THE WAY
CFD_NET APPLIED TO REFINING: REDE CFD

CFD APPLIED TO REFINING

Multiphase Flow (I)  Combustion and Fuels (II)

ÁREA

SUB-AREA  G-S-L (i)  G-S (ii)

INDUSTRIAL COM. (i)  COMB in ENGINES (ii)

GROUP

EXP (1)  NUM (2)  EXP (1)  NUM (2)  EXP (1)  NUM (2)

:::

SUB-GROUP  APL (a)  FUND (b)  APL (a)  FUND (b)  APL (a)  FUND (b)

GAS-LIQUID-SOLID and GAS-LIQUID FLOWS, HEAT AND MASS TRANSFER, CHEMICAL REACTION, COALESC. AND BREAKUP, POPULATION BALANCE, DRAG AND DEFORMATION, HDT/HCC BUBBLE COLUMNS, SLURRY BEDS FLUIDIZATION, DISTIL. TOWERS

GAS-SOLID FLOWS: MODELS, DRAG, EXTRA FORCES, TURBULENCE, HEAT AND MASS TRANSPORT, CHEMICAL REACTION, MULTIPHASES, EROSION, MODEL SCALEUP, MEASURING TECHNIQUES, RISERS, CYCLONES, REGEN., STRIPPERS STAND-PIPES, BENDS, VALVES

COMBUSTION MECHANISMS AND KINETIC PARAM. DETERM., REDUCED MODELS, MEASURING TECHNIQUES, TURBULENCE, EVAPORATION, MULTIPHASE COMBUST., BURNERS, FLAMES, DATA BASE ALTERNAT. FUELS, GASEF. AND OXICOMBUST.

COMBUSTION MECHANISMS AND KINETIC PARAM. DETERM., REDUCED MODELS, MEASURING TECHNIQUES, TURBULENCE, EVAPORATION, MULTIPHASE COMBUST., IGNITION/EXTINCTION, DETONATION MODERN FUELS – BIO/GTL. ENGINE DYNAMICS.
<table>
<thead>
<tr>
<th>PROJECT</th>
<th>UNIVERSITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>CFD Evaluation of coke formation inside tubes - Delayed Coking Process</td>
<td>UNICAMP 10</td>
</tr>
<tr>
<td>Fischer Tropsch and Hydrocracking Bubbling Bed Fluidodynamics Evaluation</td>
<td>FURB/UNICAMP</td>
</tr>
<tr>
<td>Development of Turb. Comb. Models Based on Eulerian/Lagrangian Tech.on the Immersed</td>
<td>PUC/UFU</td>
</tr>
<tr>
<td>Development of Numerial and Experimental Gas-Liquid Multiphase Flows</td>
<td>UFSC/FURB</td>
</tr>
<tr>
<td>Development of Numerial and Experimental Gas-Solid Multiphase Flows</td>
<td>UNICAMP/FURB</td>
</tr>
<tr>
<td>Improvement and Application of CFD Techniques for Adaptative Characterization of Petroleum Fractions</td>
<td>COPPE_1</td>
</tr>
<tr>
<td>Development of Methods for the Solution of Multivariate CFD-PEB Models</td>
<td>COPPE_3</td>
</tr>
<tr>
<td>Simulation of The Combustion of Petroleum Coke in a Fast Fluidized Bed</td>
<td>UNICAMP</td>
</tr>
<tr>
<td>Numerical Simulation of Multiphase Liquid Sheet Formation</td>
<td>UFU</td>
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<tr>
<td>Numerical Simulation of Multiphase Flow in Pipes</td>
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<tr>
<td>Numerical Analysis of Multiphase Pipe and Cyclone Erosion</td>
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<tr>
<td>Application of LES to Gas-Solid Flows</td>
<td>UNICAMP</td>
</tr>
<tr>
<td>Residual (Bunker) Oil Combustion Studies</td>
<td>PUC</td>
</tr>
<tr>
<td>HydroCyclones for Water Oil-Separation</td>
<td>UFRJ-EQ</td>
</tr>
<tr>
<td>DNS Solution of Turbulent Complex Flows in Refining Processes</td>
<td>UFRJ-EQ/UFU</td>
</tr>
<tr>
<td>Optimization of Oxi-Gasification Process</td>
<td>UFRJ-EQ</td>
</tr>
<tr>
<td>Analysis of Coalescence in Dessalting Units</td>
<td>UFRJ-EQ</td>
</tr>
<tr>
<td>Development of a Methodology based on CFD for Industrial Burners Optimization</td>
<td>PUC</td>
</tr>
<tr>
<td>Optimization of Mixing Time in Tanks</td>
<td>UNICAMP</td>
</tr>
<tr>
<td>Development of a Measuring Divice based on Optic Fibers Probe for Gas-Solid Systems</td>
<td>UNICAMP</td>
</tr>
</tbody>
</table>
• SUPPORTING LABORATORIES AND PILOT PLANTS – CLUSTERS (800)
Conclusions

- Basic Engineering introduces innovation, generated by Design and R&D people interaction, in new and existing units;

- CS and PFCC division from CENPES/PETROBRAS rely on CFD tools to increase equipment life-time, safety, efficiency and mechanical integrity in order to minimize problems and increase reliability!

- So, it is possible to take advantage of CFD tools to Develop, Design and Optimize Processes in the Refining Industry;

- However we need more reliable Models, Solvers and more powerful Computers in order to solve Real Large Problems,

- Therefore, PETROBRAS is doing its part on the Game, Investing.

- We should hurry up with our Simulations before Crude Oil finishes.
THANK YOU
Perspectives for the future Refining Industry

FUTURISTIC VIEW (Cars, Refineries …)
Objectives:
- New Emissions Standards
- CO2 Balance—“well to wheel analysis”
- Fuel Economy

Means:
- Spark Ignition Direct Injection - GDI
- Compression Ignition D.I.
- Hybrid Vehicles
- Electric Vehicles
- Fuel Cells

Demands:
- OBD- Automatic Driving
- Field Performance Viability
- Long Lasting
- After-Treatment
Hydrogen Production

- Steam Reforming Hydrogen Production Cost Reduction;

- Alternative Hydrogen Production Processes: Reform With CO$_2$, gasification Catalytic Gasification of Residues, Direct Methane Decomposition,

- Ceramic Membranes Applied to Synthesis Gas Production
Fossil Resources:

- Ultra Low Sulfur fuels
- Synthetic fuels - GTL

Alternatives:

- Natural Gas
- Bio- oxygenated: Ethanol, Biodiesel
- Emulsions
- Di Methil Ether
- Di Methoxi Methane
- Hydrogen

Means:

- Fuel Design
- Engine CFD Simulation and Optimization
Petrobras Downstream Challenges

- Compliance to increasing environmental requirements
- Increase of domestic oil processing (heavy)
- Product quality enhancement
- Increase of diesel and gasoline production to support demand
Petrobras Investment Plan
(2007 – 2011)

US$ 87.1 billion

Note: Includes International
US$ 23.1 billion in the Downstream segment ... 

... of which US$ 14.2 billion in Refining

Refining 61%
Pipelines 14%
Sea Transport 12%
Petrochemical 13%

Fuel Quality 31%
CapEx 19%
Maintenance/HSE 14%
Conversion 26%
Others 10%
Bio-fuels Production

Agribusiness

Farming

Seeds

Crushing

Processed Oil

Transesterification

Ethanol

or

Methanol

Glycerin + Others

Biodiesel

Distributors

B₂ or B₅

Diesel

Stations

Diesel

Refinery

Hydrogen

Diesel fractions

H-BIO

or

Or
HBIO is a process of:

- Oil refining that utilizes vegetable oils as raw material in order to obtain diesel oil

- Hydrogenation of a blend of diesel and vegetable oils