Some Fluid Flow challenges in the oil industry

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PETROBRAS - Research Center

Artificial Lift and Flow Assurance Group

EBECEM 2008

Topics

- **Overview:**
  - PETROBRAS and its Research Center
  - The Artificial Lift & Flow Assurance Group
- **Two cases:**
  - The Single Phase Case
  - The “MOBO” Case

PETROBRAS

CENPES

Research and Development Center

PETROBRAS IN NUMBERS - 2007

- Market Value: **US$ 242,7 billion**
-Net Operating Revenues : **US$ 87,7 billion**
- Net Income : **US$ 13,1 billion**
- Investments : **US$ 21,0 billion**
- Shareholders: **272.952**
-Employees: **68.931**
- Reserves (SPE):**15.000 billion** barrels of oil and gas equivalent (boe)
- Production Platforms: **109 (77 fixed; 32 floating)**

-Productive Wells: **12.935 (738 offshore)**

-Daily Production:

1.918.000 barrels per day (bpd) of oil and LPG

62 MM m³ (**382.000 boe) per day of natural gas**

-Refineries: **15**

-Yield From Refineries: **1.965 million barrels a day**

-Tanker Fleet: **153** (**54** belonging to Petrobras)

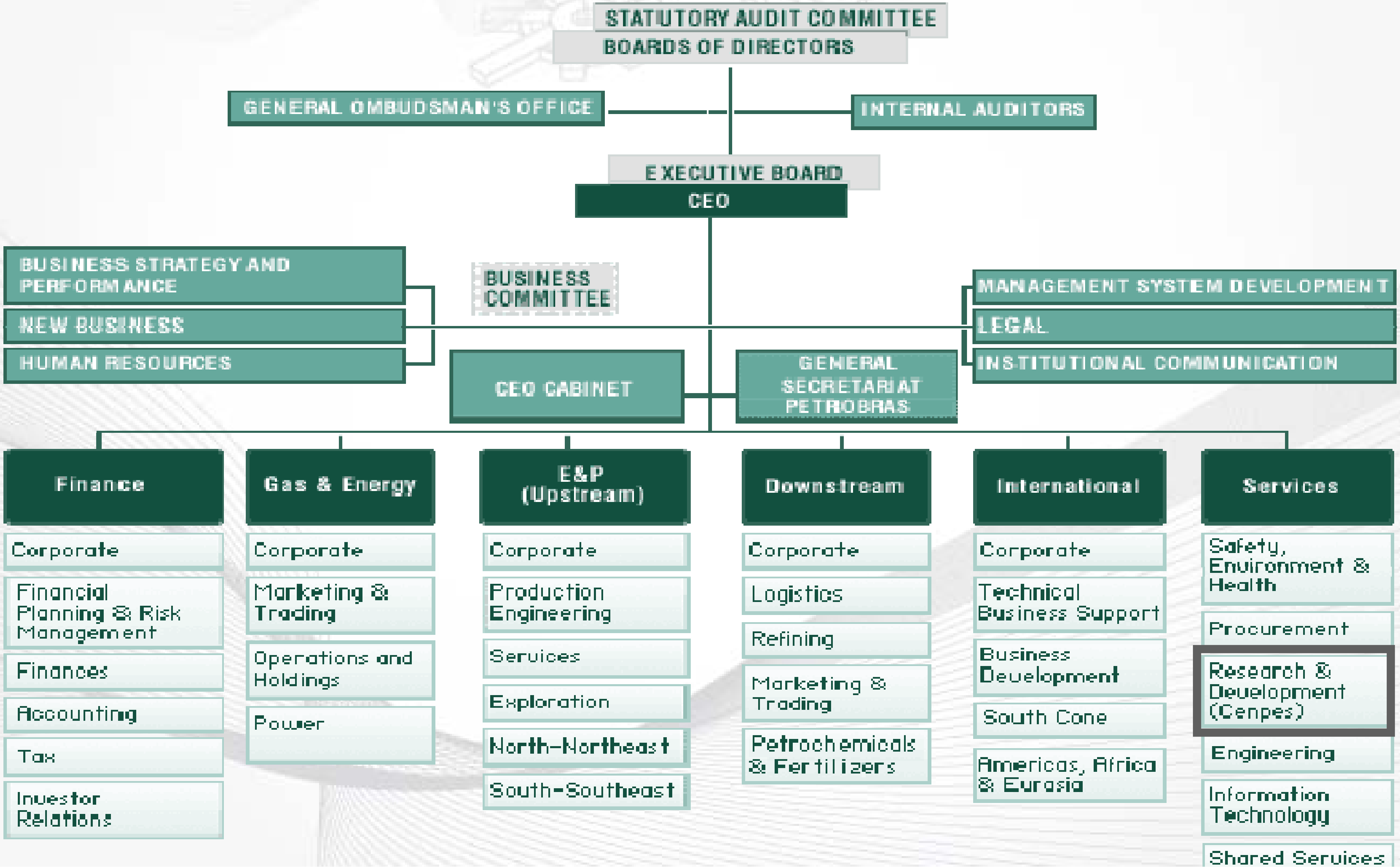
-Gas Stations: **5.973**

- Fertilizers: **3** Plants: 235,000 tons of ammonium,

700,000 tons of urea

- Pipelines: **23.142** Km

PETROBRAS ORGANIZATIONAL CHART



2008

Original Site:

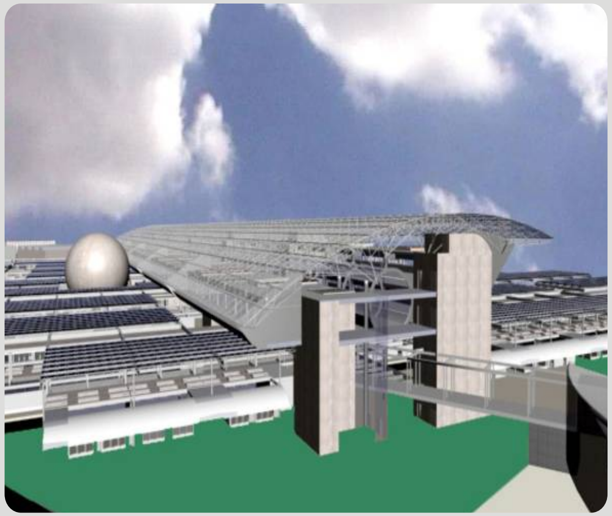
Total Area:**114.000 m²**

Building:**75.000 m²**

137 Laboratories

30 Pilot plants

2010



CENPES Expansion and

Data processing integrated Center:

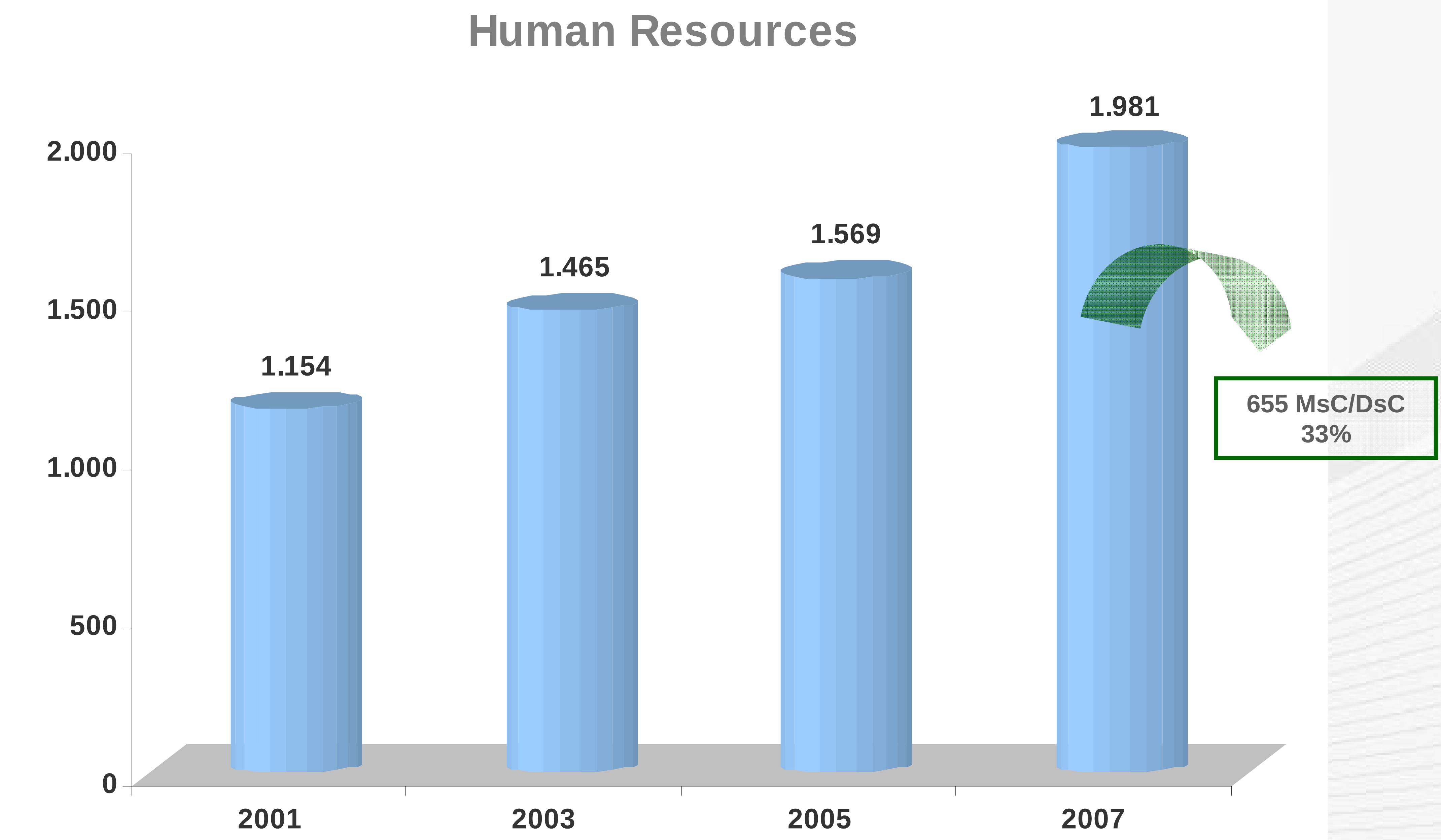
Total Area: **190.000 m²**

Building: **114.000 m²**

PETROBRAS CENPES Research and Development Center

PETROBRAS R&D Center

Expansion (Jan/2008)


Human Resources
2.000
1.500
1.000
500
0
1.154
1.465
1.569
1.981
2001
2003
2005
2007
655 MsC/DsC
33%

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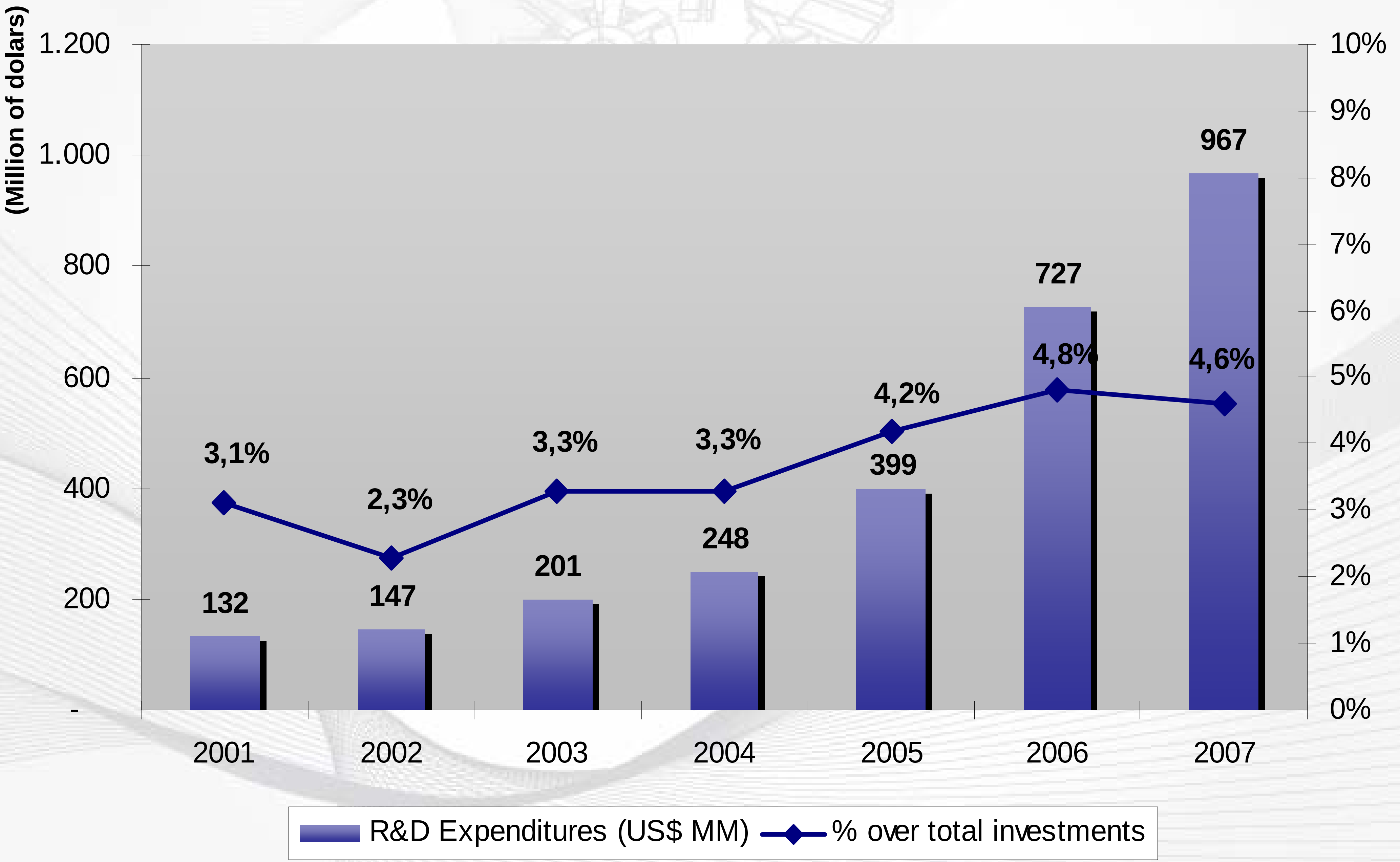
R&D EXPENDITURES



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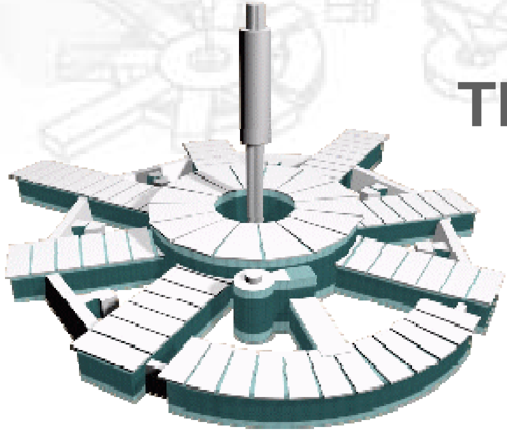
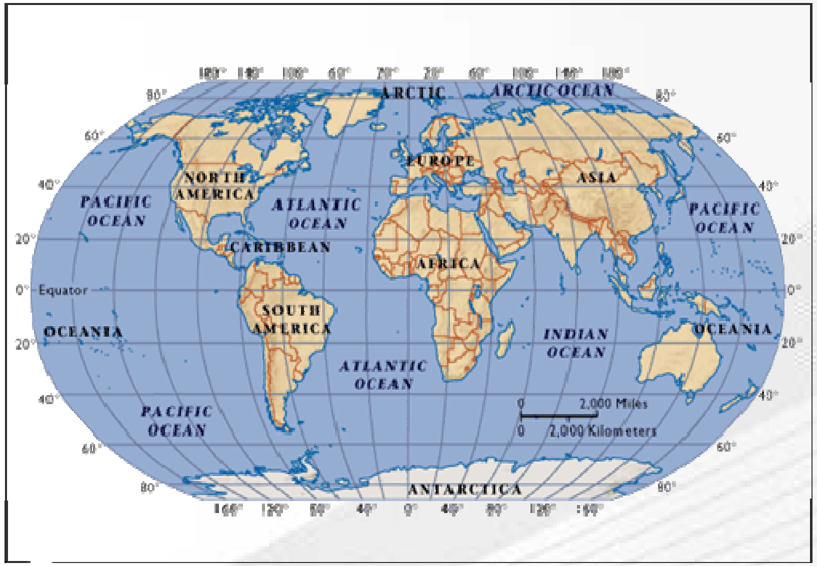
TECHNOLOGICAL INTEGRATION



R&D
CENTER



Types:

- ✓ Contracts and agreements with Universities and Research Centers with internal financial support
- ✓ Contracts with external financial support
- ✓ Networks of excellence

Over 120 Brazilian Institutions

Types:

- ✓ Joint Industry Projects
- ✓ Cooperating Research
- ✓ Strategic Alliances
- ✓ Technology Interchange

Over 70 International Institutions

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Research and
Development Center

TECHNOLOGICAL INTEGRATION PROGRAM WITH BRAZILIAN R&D INSTITUTIONS

Funding for R&D projects is na obligatory part of the brazilian concession agreements

- **38 networks spread across different oil & gas themes**
- **7 local competence groups**
- **71 Institutions spread across 19 units of the brazilian federation**

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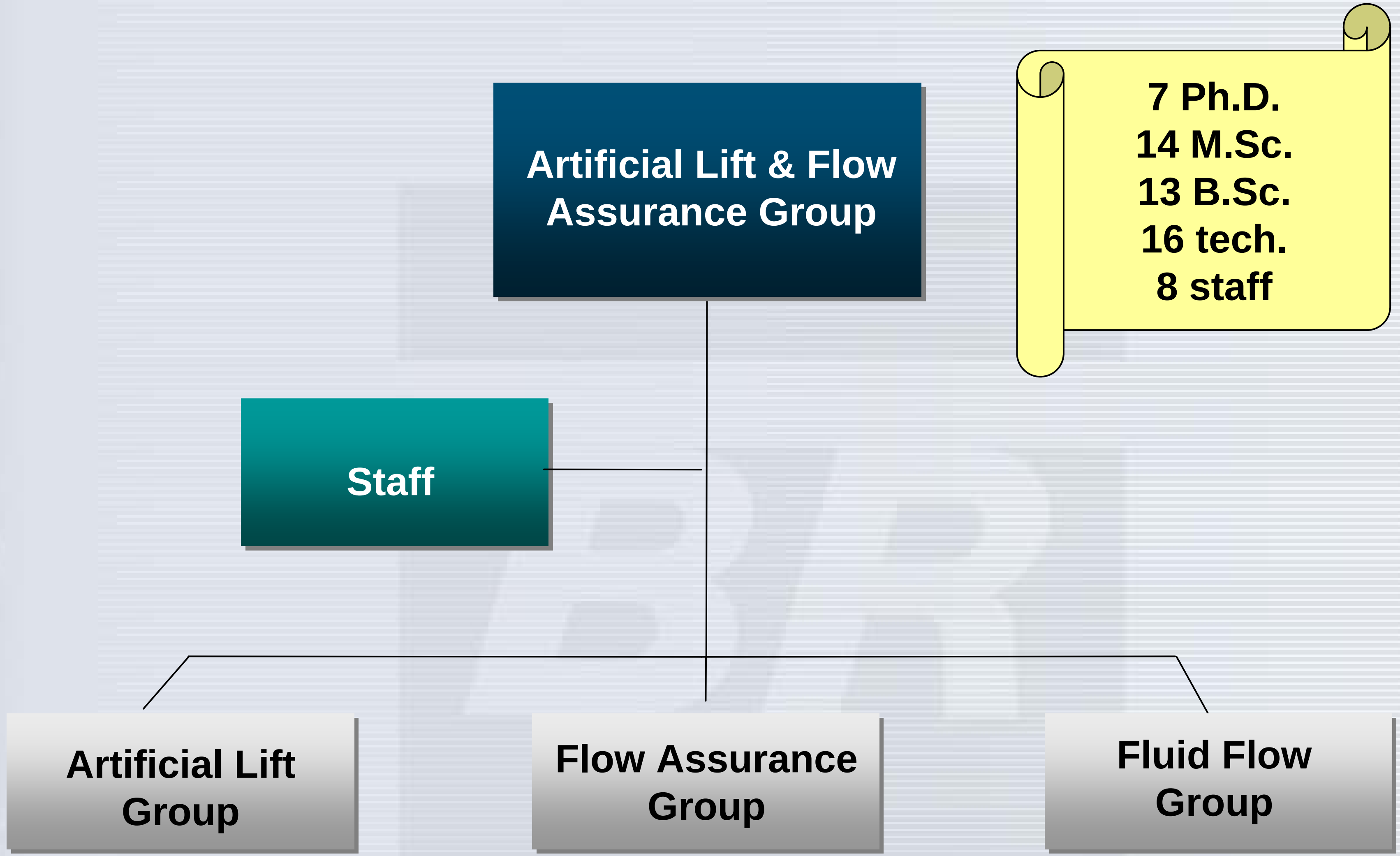
The Artificial Lift and Fluid Flow Group


Artificial Lift & Flow Assurance Group
7 Ph.D.
14 M.Sc.
13 B.Sc.
16 tech.
8 staff
Staff
Artificial Lift Group
Flow Assurance Group
Fluid Flow Group

Artificial Lift Group

3 Ph.D.
5 M.Sc.
4 B.Sc.

Real Time Control Lab.

Main Challenges:

Gas Lift in Subsea wells
High power, Long Life ESP in Subsea wells
Subsea Multiphase Pumping System
Real Time Production Optimization
Heavy Oil Artificial Lift

Flow Assurance Group

3 Ph.D.
4 M.Sc.
3 B.Sc.
11 Tech.

4 Chem. Labs.

Main Challenges:

Hydrates formation & mitigation techniques
Organic Deposition (Wax & Asfaltenes)
Inorganic Deposition (Scale)

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Fluid Flow Group

5 M.Sc.
6 B.Sc.
5 Tech.

Fluid Mechanics Lab.

Main Challenges:

Multiphase Flow Experimentation & Modeling
Multiphase S.-State & Transient Simulation
Leak-Detection Systems
Emulsion & High Viscosity Fluid Flow

Focus:

Heavy Oil Scenario:

Emulsion viscosity forecast

Subsea Scenario:

Slug structure forecast

Two-phase Offshore Gas Pipelines:

Leak detection system

The "Multi-phase Flow in Pipes" Network

The Network:

PETROBRAS

UNICAMP
UFRJ
PUC-Rio
UFSC
UTFPR
UFU
USP-SP
USP-SC

Purpose:

Develop R&D Activities with focus on Multiphase Flow in Pipelines

Subjects:

- Slug Flow Structure
- 3-phase flow
- Wave propagation in 2-phase flow
- Multiphase Flow in Large Diameter Pipelines
- Friction factor in flexible lines
- Nanotechnology to reduce friction factor (?)

First 3 Years => ~ R$ 25 MM (US$ 14 MM)

- Buildings
- Labs & Equipments
- Class rooms & Offices
- R&D Projects

Two interesting problems:

The Single Phase case

The “MOBO” case

The Single Phase Case

Background:

Single phase (oil) flow

Steady state

Laminar Flow (Re @ pipe inlet < 800)

Flow rate: 16.000 m^3/day

Pipe length: ~ 20 kms

Pipe diameter: 12 inches

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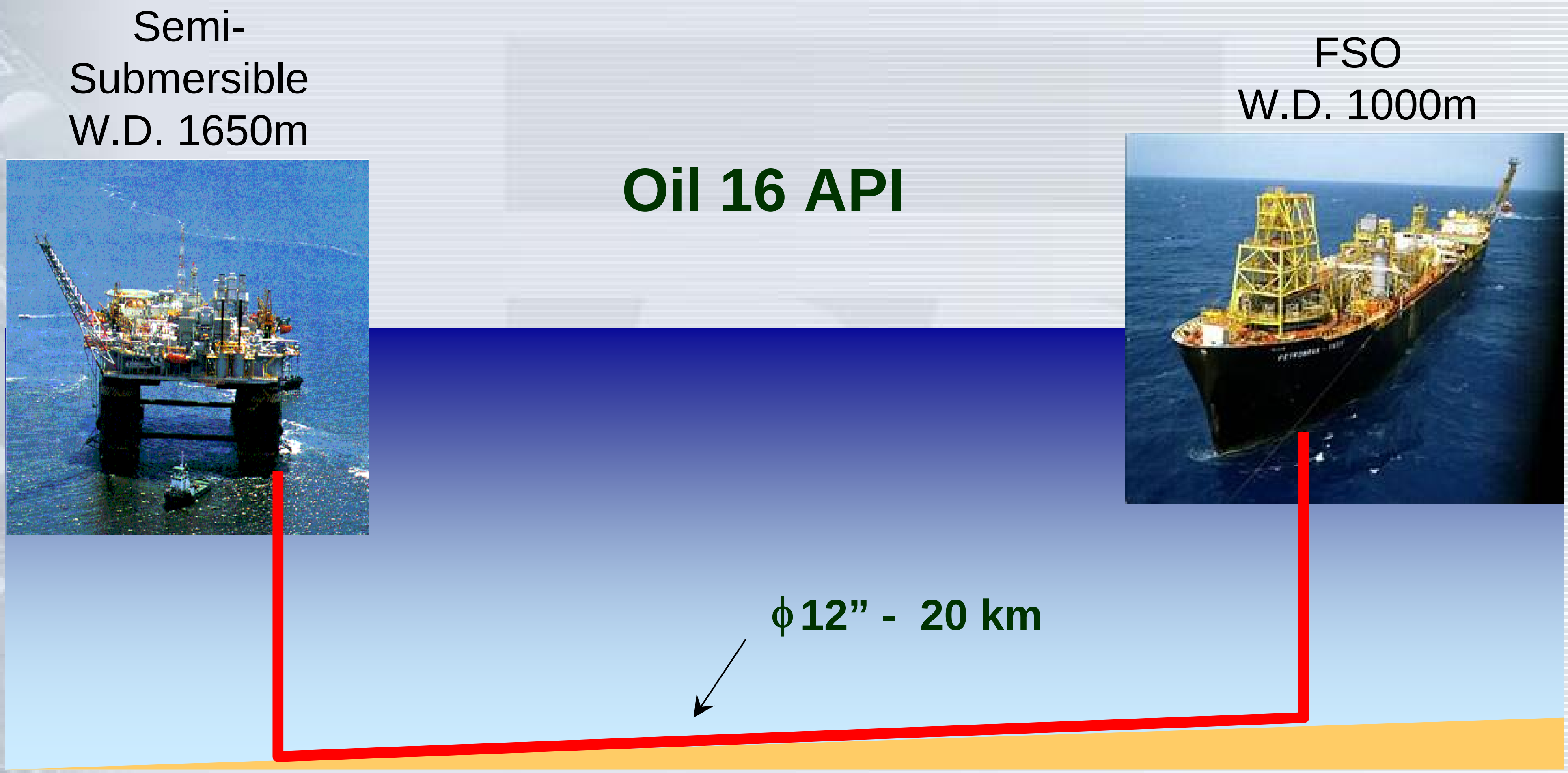
The Single Phase Case



Is there any problem?

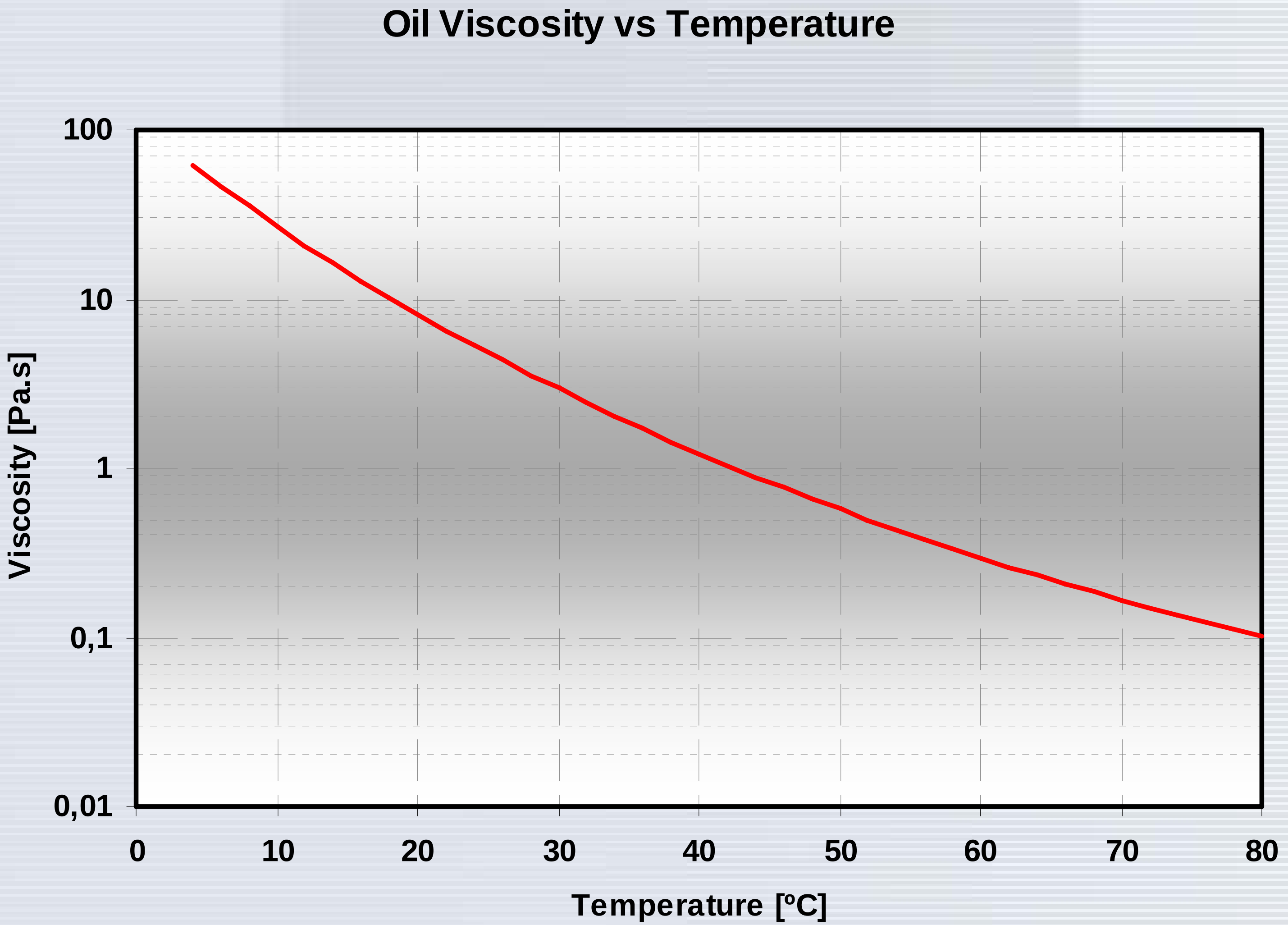
<u>Hint:</u>

Heavy Oil (16 ºAPI → 960 kg/m^3)

Flow temperature @ pipe inlet: 60 ºC

Subsea temperature: 4ºC

Is there any problem?



The Single Phase Case

The Problem...

Heavy oil viscosity varies strongly with temperature.

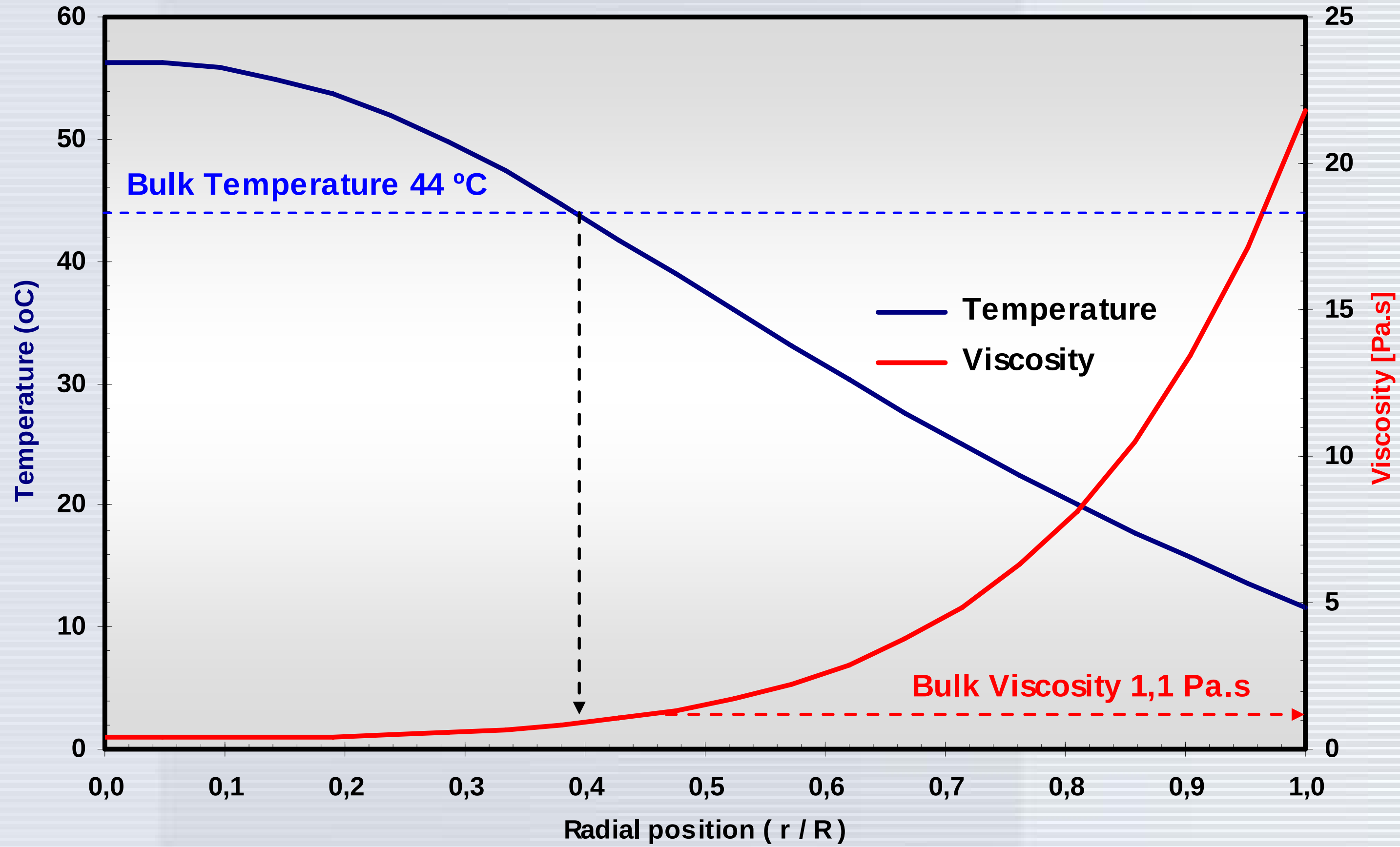
1D models assume:

- Poiseuilli velocity profile at laminar regime
- Constant viscosity along pipe section

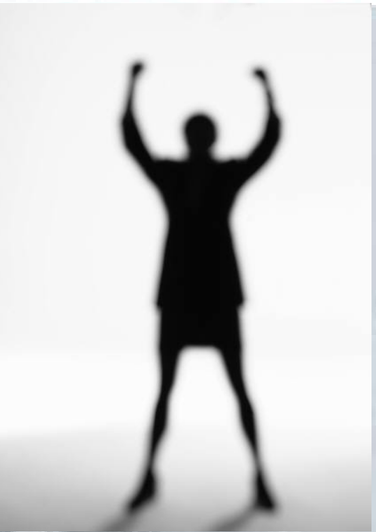
Depending on pipe insulation, the Radial Temperature Gradient may not be neglected.

The Problem...

Temperature & Viscosity Profile
10 kms from entrance



Does this temperature/viscosity radial gradient impacts pressure drop forecast?



The solution...

$$u_r \frac{\partial u_r}{\partial r} + u_z \frac{\partial u_r}{\partial z} = -\frac{1}{\rho}\frac{\partial p}{\partial r} + \frac{1}{\rho}\left[\frac{2}{r}\frac{\partial \mu r \frac{\partial u_r}{\partial r}}{\partial r} + \frac{\partial \mu\left(\frac{\partial u_r}{\partial z} + \frac{\partial u_z}{\partial r}\right)}{\partial z} - \frac{2\mu}{r^2} u_r\right]$$

$$u_r \frac{\partial u_z}{\partial r} + u_z \frac{\partial u_z}{\partial z} = -\frac{1}{\rho}\frac{\partial p}{\partial z} + \frac{1}{\rho}\left[\frac{1}{r}\frac{\partial \mu r\left(\frac{\partial u_r}{\partial z} + \frac{\partial u_z}{\partial r}\right)}{\partial r} + 2\frac{\partial \mu \frac{\partial u_z}{\partial z}}{\cdots}\right]$$

$$\frac{1}{\alpha} u_z \frac{\partial T}{\partial z} = \frac{1}{r}\frac{\partial r \frac{\partial T}{\partial r}}{\partial r} + \frac{\mu}{2}\left(\frac{\partial u_z}{\partial r}\right)^2$$

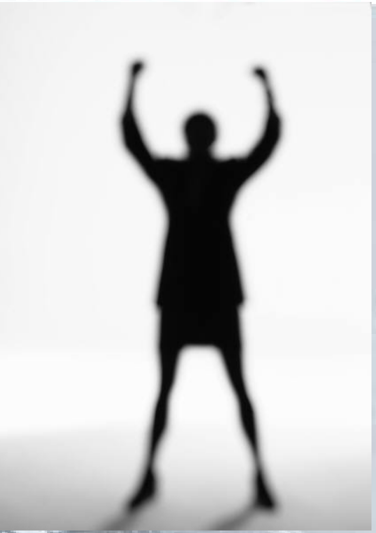
$$\frac{dp}{dz} = \frac{Q}{\pi}\frac{1}{\int_0^{r_w} r\left[\int_{r_w}^{r} \frac{r}{\mu(T)} dr\right] dr}$$

$$\frac{Q}{2\pi\alpha}\frac{\int_{r_w}^{r} \frac{r}{\mu(T)} dr}{\int_0^{r_w} r\left[\int_{r_w}^{r} \frac{r}{\mu(T)} dr\right] dr}\frac{\partial T}{\partial z} = \frac{1}{r}\frac{\partial r \frac{\partial T}{\partial r}}{\partial r} + \frac{1}{2\mu(T)}\left(\frac{rQ}{2\pi\int_0^{r_w} r\left[\int_{r_w}^{r} \frac{r}{\mu(T)} dr\right] dr}\right)^2$$

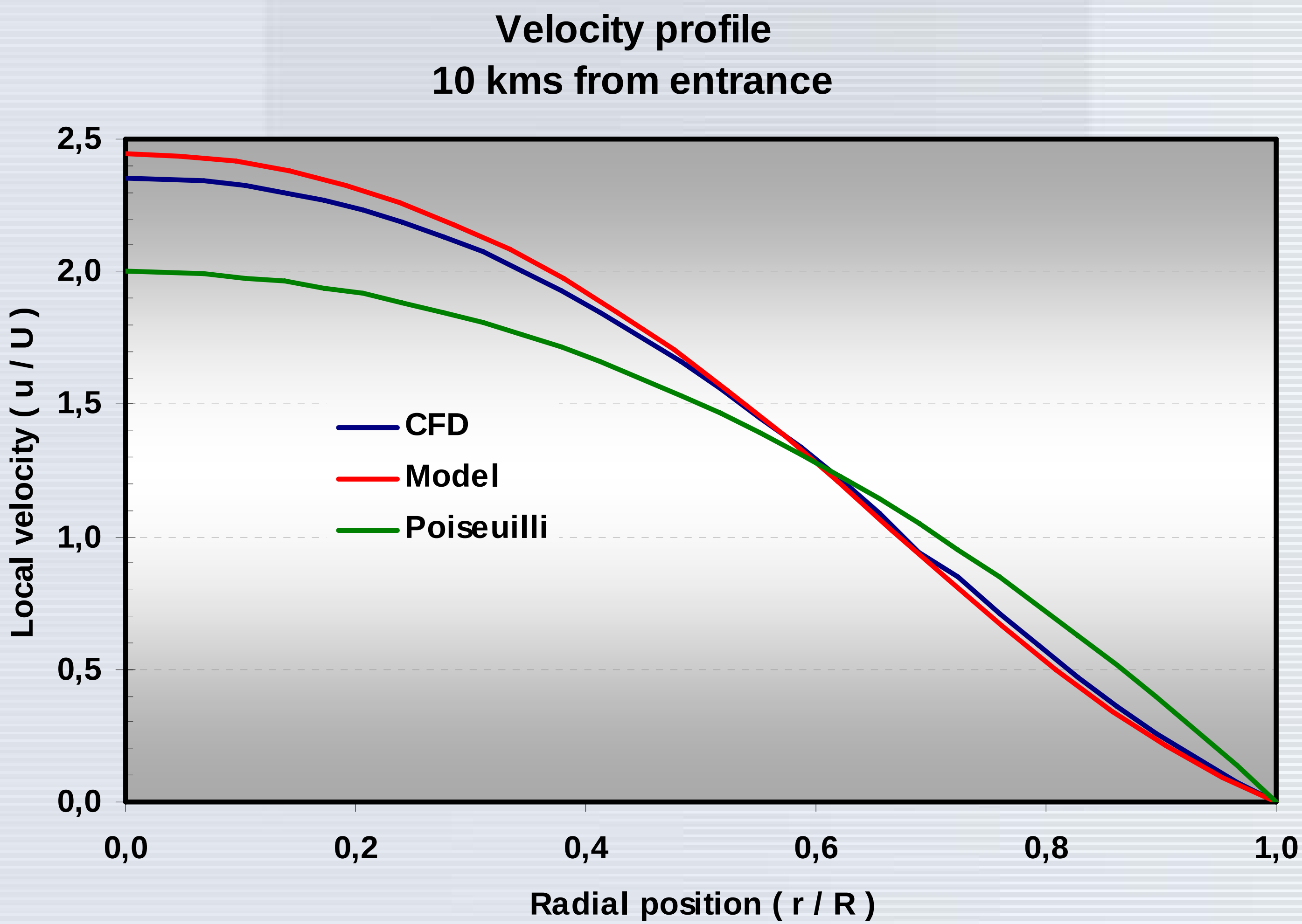
... a simplified 2D model based on Navier Stokes equations

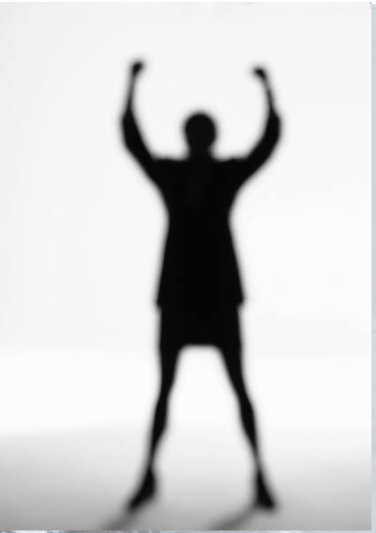
Model: Poiseuilli solution with *viscosity = f(radius)*

The Single Phase Case



Comparing results with CFD and 1D commercial code





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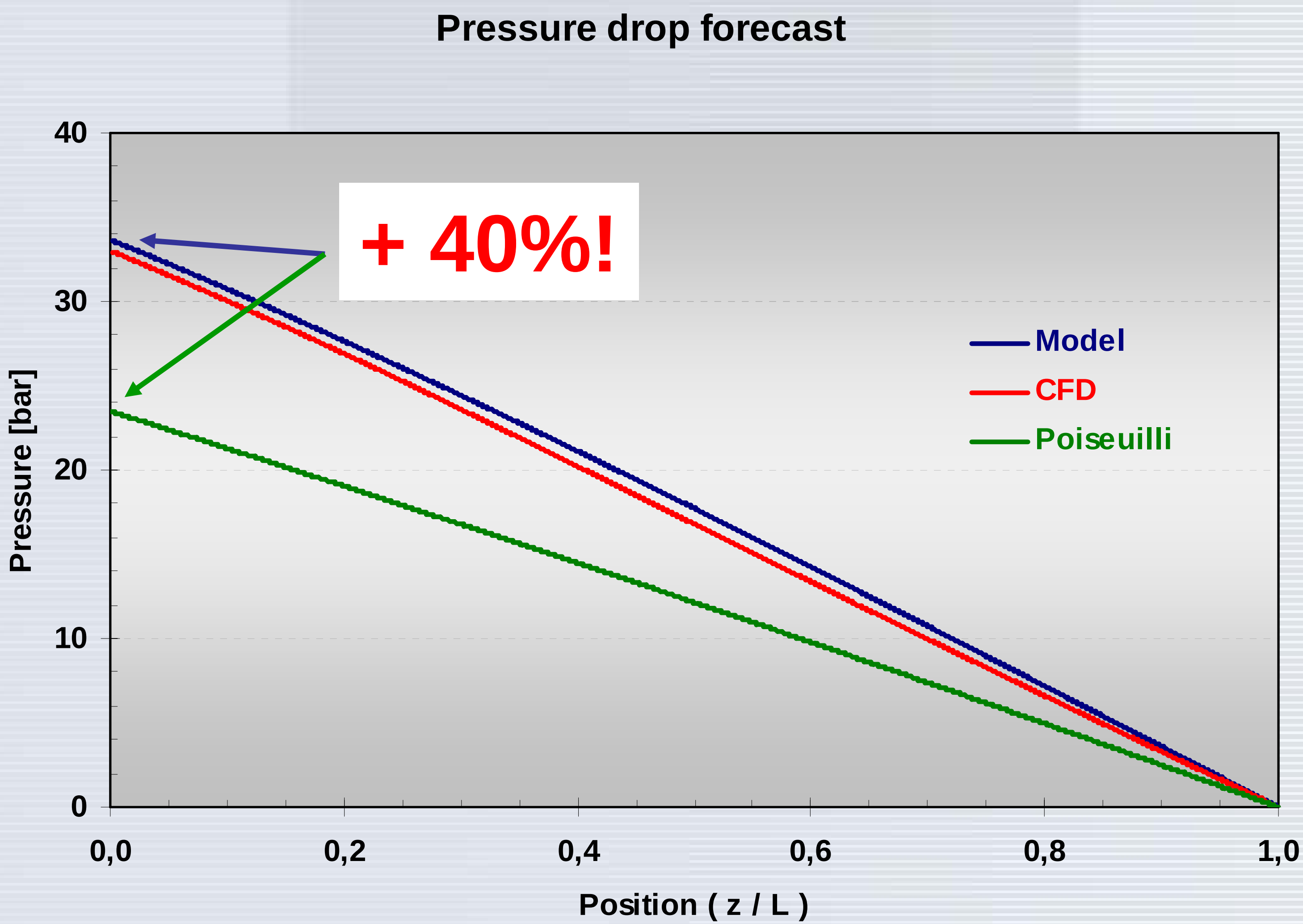


The Single Phase Case

Status today:

Final user requests model validation using actual measured data

A R&D activity was approved to validate the proposed model, in cooperation with a Brazilian University

A friendly software based on the model shall be built and made available for the final user.

The “MOBO” Case

Background:

- **Electrical Submersible Pumps have being used in Oil Industry ~ 100 years (onshore application)**
- **PETROBRAS was the first to use this technology downhole in offshore wells ~ 10 years ago**

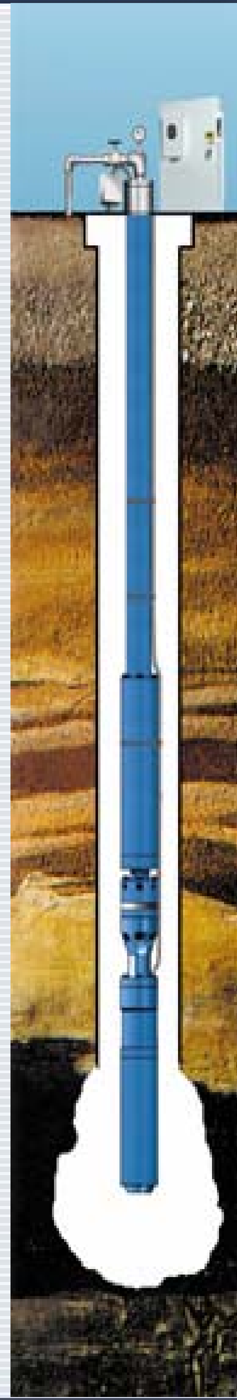
The MOBO Case

Background:

ESP Characteristics:

- Geometry designed for downhole installation (typically 40 meters long, OD < 20 cm)
- The produced fluid cools the electrical motor
- May handle up to 40% of Gas

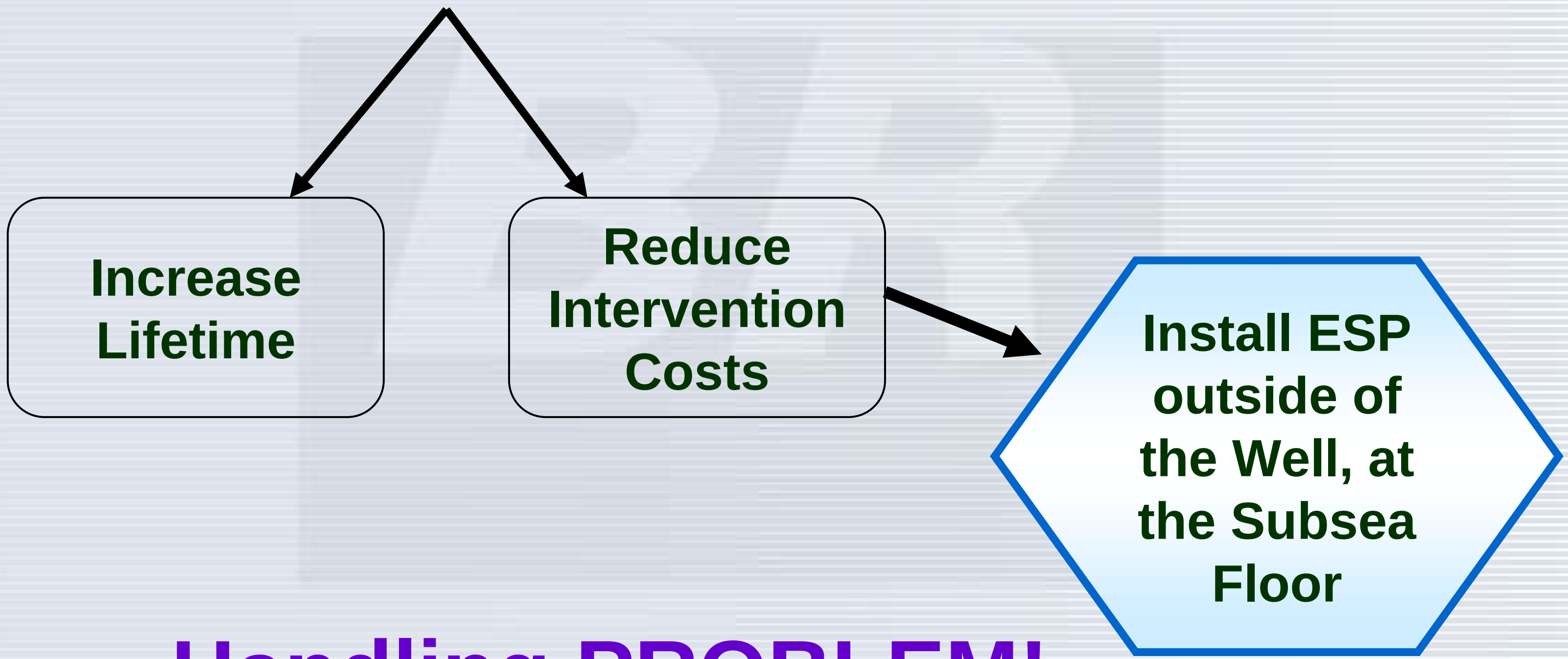
- Increase production (may double oil flow rate)
- Mean Time Between Failure ~ 3 years



From Baker website

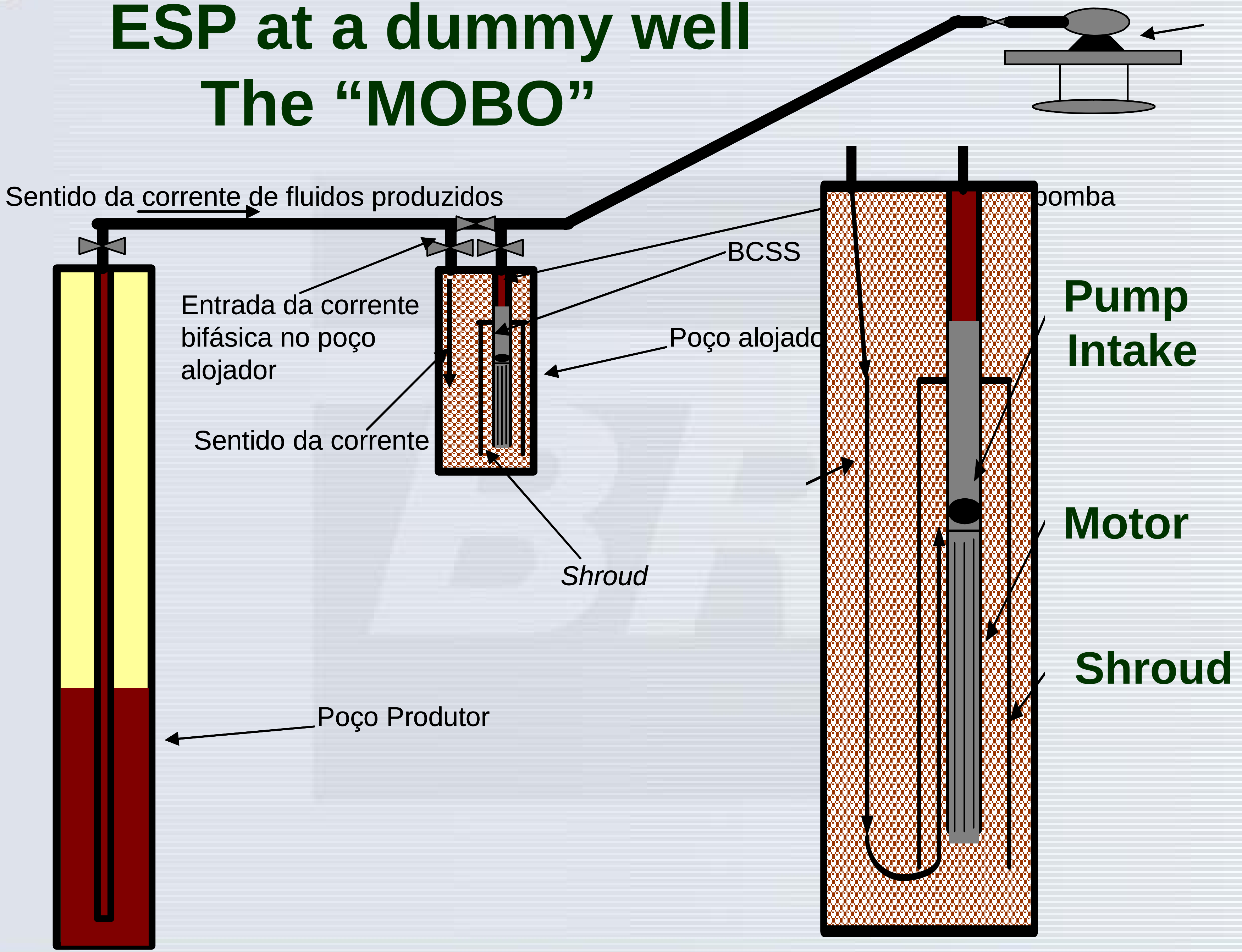
Background:

- High intervention costs at Deep Water Installation
- ESP presents Low $$ attractiveness



Handling PROBLEM!

ESP at a dummy well
The "MOBO"



The MOBO Case

Is there any problem?

<u>Hint:</u>

The system would be tested producing from a well 200 m distant

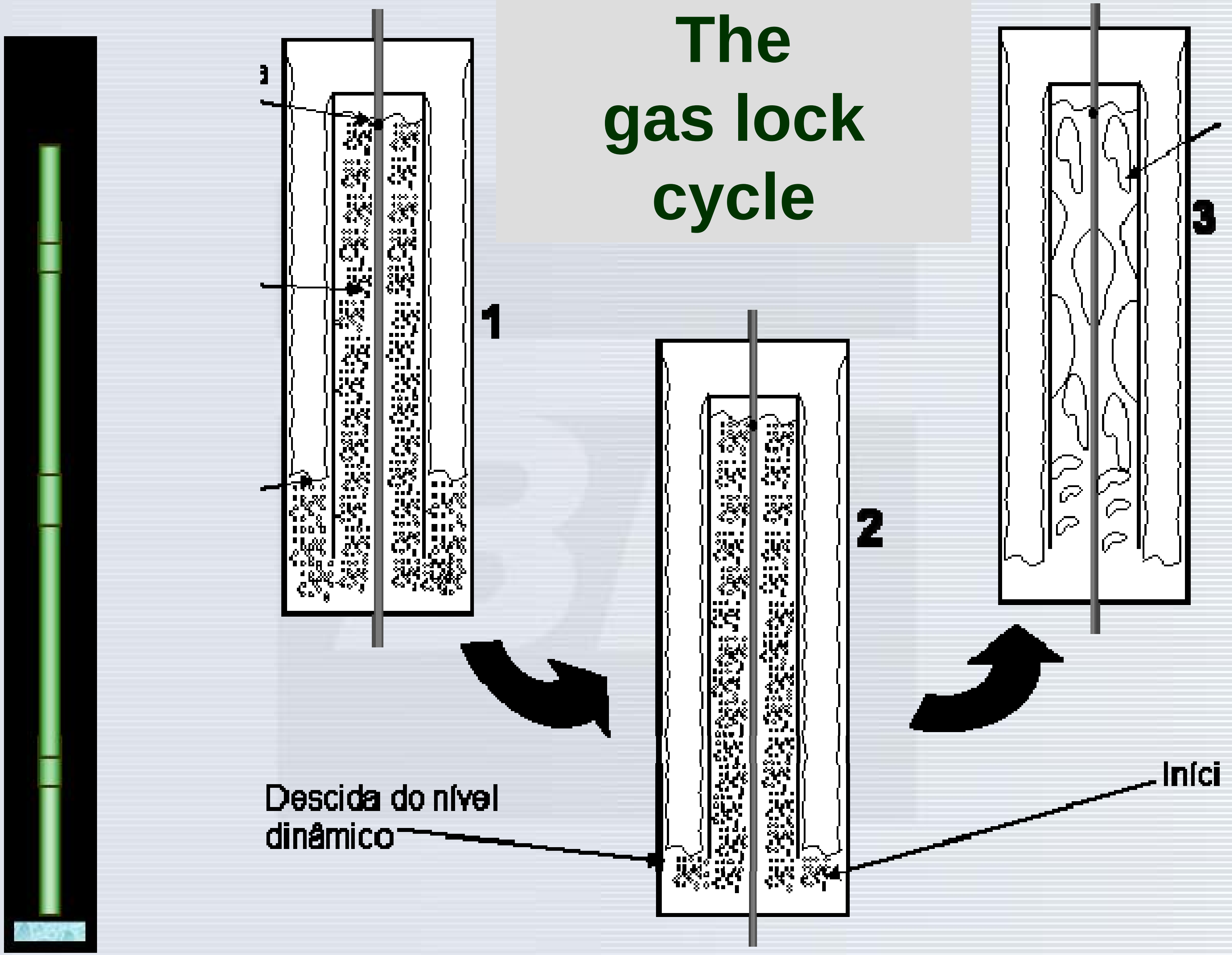
This well should produce with ~ 20% GVF

The Problem...

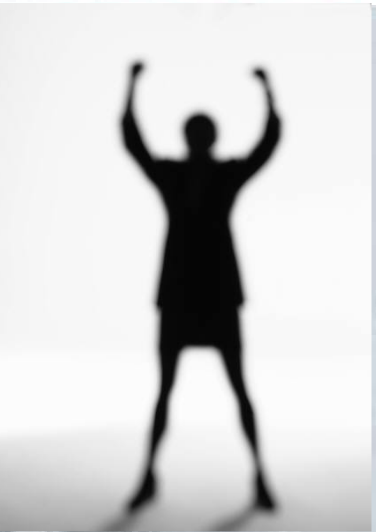
- The pump may handle 40% Gas.
- Slug flow occurs between the well and the MOBO
- The flow entering the MOBO faces expansion
- Gas-Liquid Separation may occur, creating a Gas-Liquid interface

The MOBO Case

The gas lock cycle



The MOBO Case



The solution...

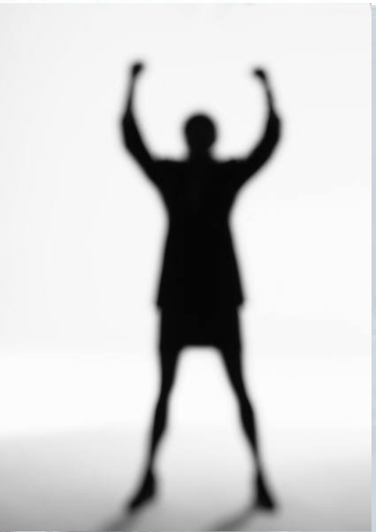
A similarity study was done and a physical model was built (scale 1:7) to observe the problem

- → The problem occurs!

A simple solution was required:

- → The system was under manufacture
- → The solution should be tested previously
- → Lack of time!

The MOBO Case

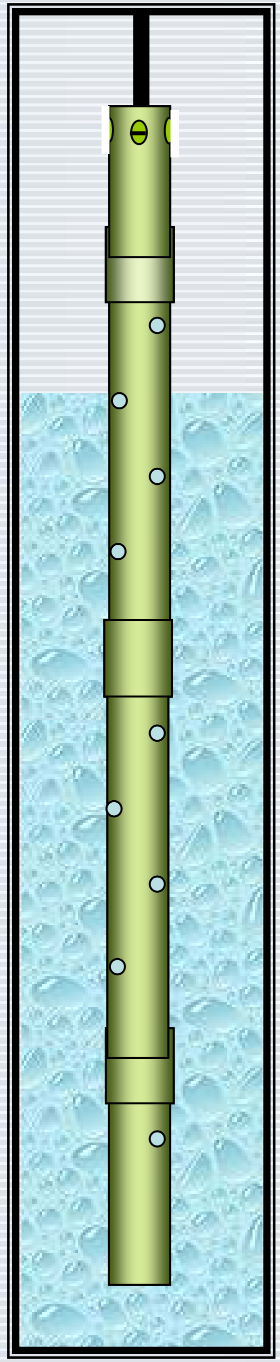


The solution...

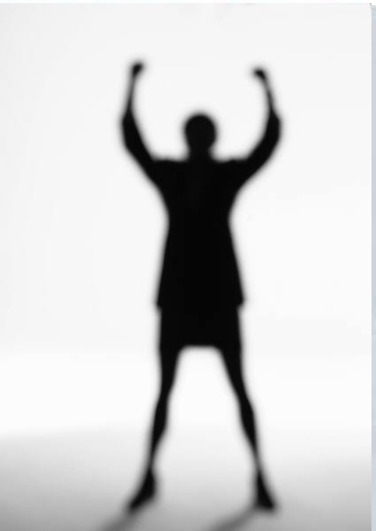
To drill small holes along the Shroud...

small enough to avoid the liquid shortcut when 100% liquid

large enough to allow all the gas shortcut when 40% gas



The MOBO Case

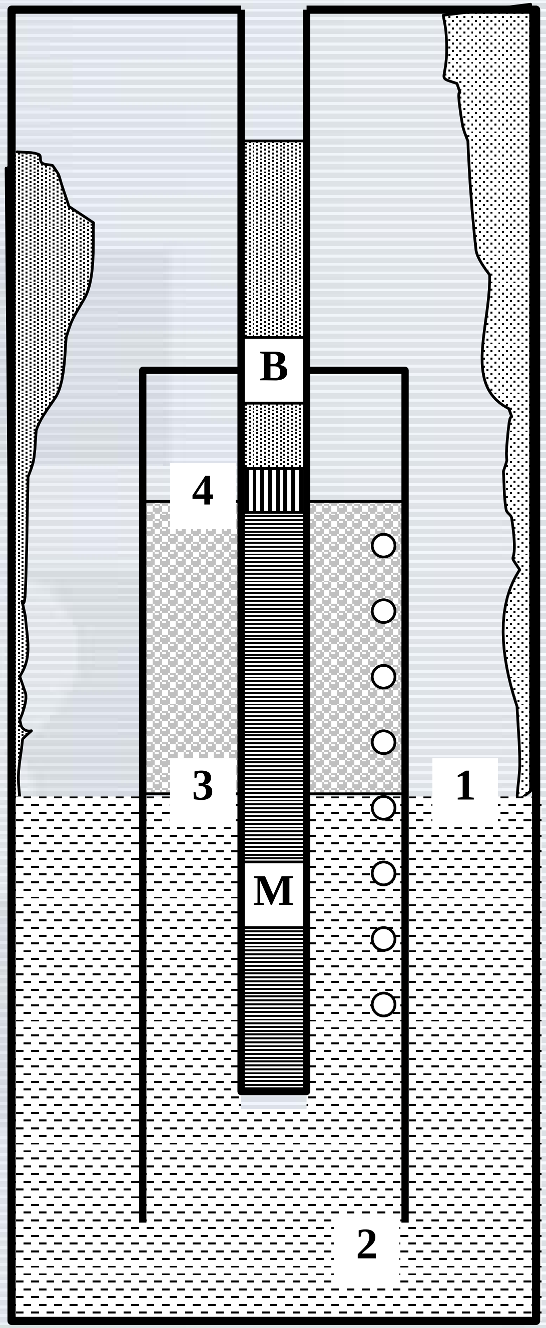


The solution...

The solution was tested in the scaled loop with success

The change order was acceptable for the field prototypes

Four systems were installed in Golfinho Field, at Espírito Santo Basin.



The MOBO Case

Status today:

2 MOBO's started operation in December 2007

2 others not in operation yet

# 1:	**Liquid flow rate: 36.000 bpd**
	Water Cut: 60%
	Gas Volume Fraction: 5% @ pump inlet
	Running OK
# 2:	**Liquid flow rate: 10.000 bpd**
	Water Cut: 4%
	Gas Volume Fraction: 40% @ pump inlet
	Running with instabilities – Pump GVF limit!

Thank You