Gas-Lift Optimization in Satellite Wells

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Motivation

Problem Formulation

Santos Multi-Reservoir Production System

Summary

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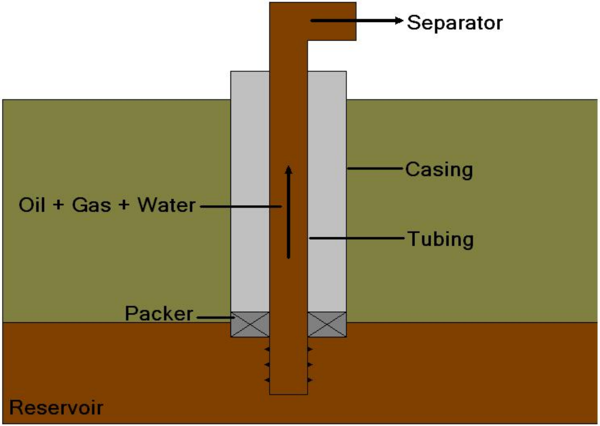
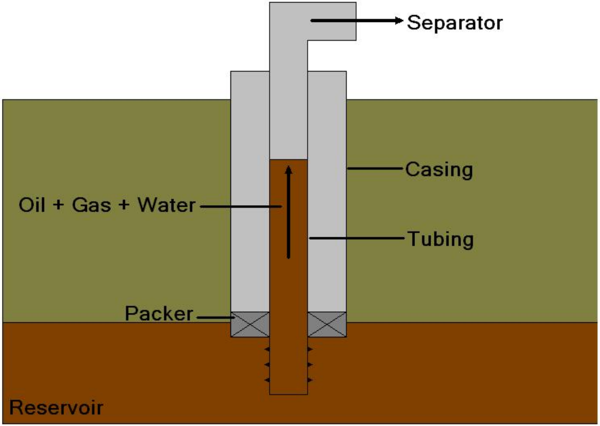
Motivation: production from mature fields

Young oil field



Motivation: production from mature fields

Mature oil field (without artificial lifting)



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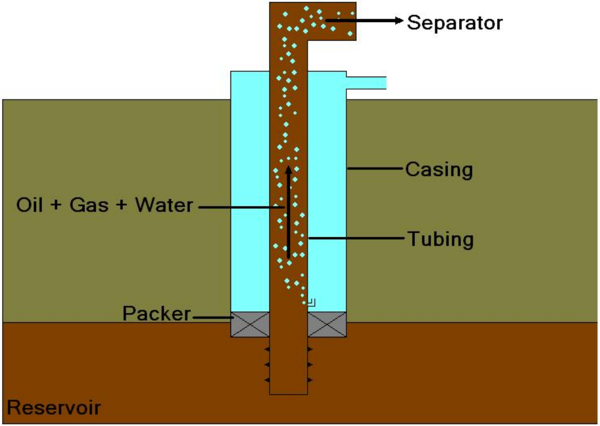
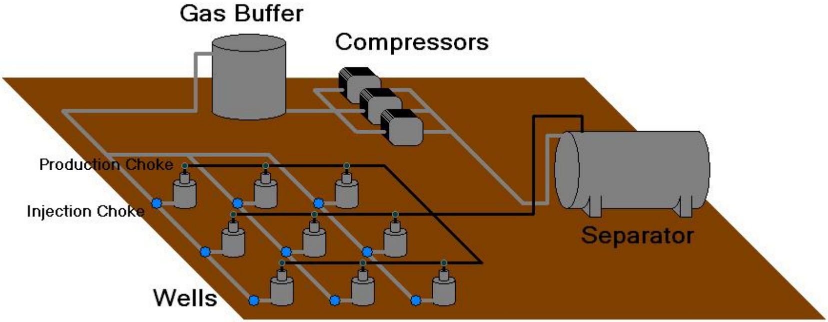


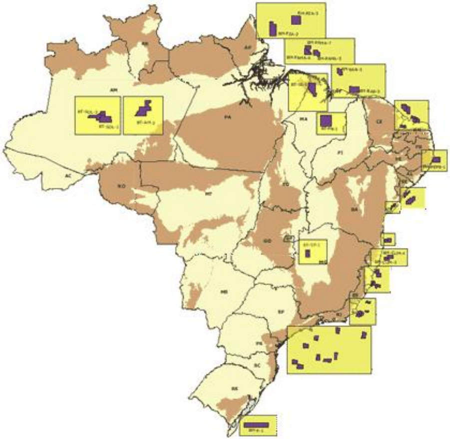
Motivation: production from mature fields

Gas-lift system



Motivation: production from mature fields

60% of Brazilian oil fields are gas-lifted



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Practical Application

Petrobras bundled:

- An in-house well simulator (Marlim)
- Algebraic Modeling Languages (GAMS and AMPL)
- Optimization solvers (CPLEX, Gurobi, and CBC)

in a software package denominated BR-SIOP. It is available in Infogrid platform to run on a computer cluster.

Remarks:

- The baseline version of BR-SIOP optimizes daily production of platforms that operate with gas-lifted satellite wells.
- It is the most common configuration in Campos Basin.

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BR-SIOP GLC

- Mathematical model for gas-lift optimization of satellite wells in offshore operations.
- Model implemented in BR-SIOP, Petrobras.

FPSO Cidade de Santos

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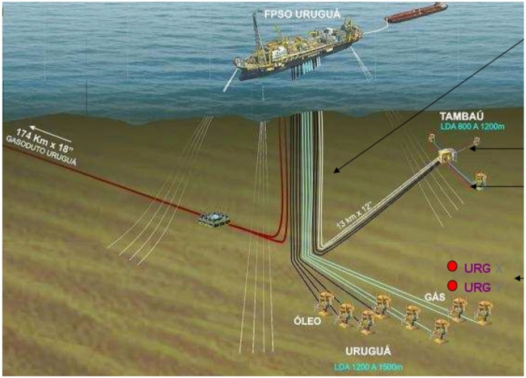
FPSO Santos produces from two reservoirs, Tambau and Urugua.



Sets

- $\mathcal{N}$: set of production wells.
- $\mathcal{P}_{\mathrm{wh}}^{i}$: breakpoints for well-head pressure of well i.
- $\mathcal{Q}_{\mathrm{gl}}^{i}$: breakpoints for gas-lift injection rate of well well i.
- $\mathcal{R}^{i}$: breakpoint pairs considering well-head pressure and lift-gas rate for well i, $\mathcal{P}_{\mathrm{wh}}^{i} \times \mathcal{Q}_{\mathrm{gl}}^{i}$, including naturally flowing conditions.
- $\mathcal{R}_{+}^{i}$: breakpoint pairs not considering naturally flowing conditions, $\mathcal{P}_{\mathrm{wh}}^{i} \times \{Q_{\mathrm{gl}}^{i} \setminus \{0\}\}$.
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Parameters

- $\widehat{q}_{\mathrm{o}}^{i}(whp^{i}, q_{\mathrm{gl}}^{i})$: oil rate from well i, at well-head pressure whp^{i} and lift-gas injection q_{gl}^{i}.
- gor^{i}: gas-oil ration for well i.
- $wcut^{i}$: water cut.
- $q_{\mathrm{gl,min}}^{i}$: minimum lift-gas injection rate.
- $q_{\mathrm{gl,max}}^{i}$: maximum lift-gas injection rate.
- whp_{min}^{i}: minimum pressure.
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- $q_{\mathrm{l,max}}$: Liquid handling capacity of the platform.
- $q_{\mathrm{w,max}}$: Water handling capacity of the platform.

- $q_{\mathrm{flare,max}}$: Limit for gas flaring.
- $q_{\mathrm{flare,min}}$: Minimum rate for gas flaring.

- $qgtc$: Gas compression capacity.
- q_{turbine}: Gas demand for electric turbine.
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Parameters

- $(t^i_{\text{lb}}$ and $t^i_{\text{ub}})$ are two parameters that impose conditions on well operations:
  - $(0, 0)$ forces well i to be closed during the optimization process.
  - $(0, 1)$ allows the optimization algorithm to decide whether to operate well i or not.
  - $(1, 1)$ forces well i to be producing.
  - $(1, 0)$ not a viable setting.
- enable^i allows well i to operate without gas-lift injection, naturally flowing production.

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Variables

Platform Variables:

- $q_{\mathrm{gas-prod}}$: total gas produced.
- $q_{\mathrm{gas-lift}}$: total gas allocated for injection.
- q_{exp}: total gas exported.
- q_{flare}: total gas flared.

Well i's Variables:

- q_{o}^{i}: oil production rate from well i.
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- whp^i: well i's head pressure.
- t^i: well activation, 1 if well is active, 0 otherwise.
- t^i_{gl}: glc operation, 1 if gas is injected, 0 otherwise.
- t^i_{surg}: assumes value 1 if well is naturally flowing, 0 if operated with lift-gas injection.
- κ^i_q: auxiliary SOS2 variable.
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- $\mu^i_{p,q}$: weighting variable for piecewise-linear approximation.

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Cascading objectives:

1. $f_1 = \max \sum_{i \in \mathcal{N}} q_{\mathrm{o}}^{i}$: oil production maximization.
2. $f_2 = \min q_{\mathrm{flare}}$: gas flare minimization.
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Platform Constraints

Platform constraints:

- $q_{\text{gas-prod}} = \sum_{i \in \mathcal{N}} q_{\text{g}}^{i}$
- $q_{\text{gas-lift}} = \sum_{i \in \mathcal{N}} q_{\text{gl}}^{i}$
- $q_{\text{exp}} = q_{\text{gas-prod}} - q_{\text{flare}} - q_{\text{turbine}}$
- $q_{\text{gas-prod}} + q_{\text{gas-lift}} - q_{\text{flare}} \leq qgtc$

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Platform constraints:

- $q_{\text{exp}} \leq q_{\text{exp}}^{\text{max}}$
- $q_{\text{flare,min}} \leq q_{\text{flare}} \leq q_{\text{flare,max}}$
- $\sum_{i \in \mathcal{N}} \left(q_{\text{o}}^{i} + q_{\text{w}}^{i} \right) \leq q_{\text{l,max}}$
- $\sum_{i \in \mathcal{N}} q_{\text{w}}^{i} \leq q_{\text{w,max}}$

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Well Constraints

Constraints on each well $i \in \mathcal{N}$:

$$q_{\mathrm{o}}^{i} = \sum_{(p,q)\in\mathcal{R}_{+}^{i}} \mu_{p,q}^{i} \cdot \widehat{q}_{\mathrm{o}}^{i}(p,q) + \sum_{(p,q)\in\mathcal{R}_{0}^{i}} \mu_{p,q}^{i} \cdot \widehat{q}_{\mathrm{o}}^{i}(p,q)$$

$$q_{g}^{i} = rgo^{i} \cdot q_{o}^{i}$$

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$$t^i_{\mathrm{gl}} \cdot q^i_{\mathrm{gl,min}} \leq q^i_{gl} \leq q^i_{\mathrm{gl,max}} \cdot t^i_{\mathrm{gl}}$$

$$t^i \cdot whp^i_{\mathrm{min}} \leq whp^i \leq whp^i_{\mathrm{max}} \cdot t^i$$

$$\sum_{(p,q)\in\mathcal{R}^i_+} \mu^i_{p,q} = t^i_{\mathrm{gl}}$$

$$\sum_{(p,q)\in\mathcal{R}^i_0} \mu^i_{p,q} = t^i_{\mathrm{surg}}$$

$$t^i = t^i_{\mathrm{gl}} + t^i_{\mathrm{surg}}$$

$$t^i_{\mathrm{lb}} \leq t^i \leq t^i_{\mathrm{ub}}$$

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SOS2 Constraints

To impose the piecewise-linear approximation of the production functions, for each well $i \in \mathcal{N}$:

$$\kappa_p^i = \sum_{q \in \mathcal{Q}_{\mathrm{gl}}^i \setminus \{0\}} \mu_{p,q}^i, \ \forall p \in \mathcal{P}_{\mathrm{wh}}^i$$

$$\kappa_q^i = \sum_{p \in \mathcal{P}_{\mathrm{wh}}^i} \mu_{p,q}^i, \ \forall q \in \mathcal{Q}_{\mathrm{gl}}^i \setminus \{0\}$$

and

$(\mu_{p,q}^i)_{(p,q) \in R_0^i}$, $(\kappa_p^i)_{p \in \mathcal{P}_{\mathrm{wh}}^i}$ and $(\kappa_q^i)_{q \in \mathcal{Q}_{\mathrm{gl}}^i \setminus \{0\}}$ are SOS2

and

$$\mathrm{enable}^i \leq t_{\mathrm{surg}}^i$$

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To impose the piecewise-linear approximation of the production functions, for each well $i \in \mathcal{N}$:

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and

$$(\mu_{p,q}^i)_{(p,q) \in R_0^i}, \ (\kappa_p^i)_{p \in \mathcal{P}_{\mathrm{wh}}^i} \text{ and } (\kappa_q^i)_{q \in \mathcal{Q}_{\mathrm{gl}}^i \setminus \{0\}} \text{ are SOS2}$$

and

$$\mathrm{enable}^i \leq t_{\mathrm{surg}}^i$$

SOS2 Constraints

To impose the piecewise-linear approximation of the production functions, for each well $i \in \mathcal{N}$:

$$\kappa^i_p = \sum_{q \in \mathcal{Q}^i_{\mathrm{gl}} \setminus \{0\}} \mu^i_{p,q}, \ \forall p \in \mathcal{P}^i_{\mathrm{wh}}$$

$$\kappa^i_q = \sum_{p \in \mathcal{P}^i_{\mathrm{wh}}} \mu^i_{p,q}, \ \forall q \in \mathcal{Q}^i_{\mathrm{gl}} \setminus \{0\}$$

and

$$(\mu^i_{p,q})_{(p,q) \in R^i_0}, \ (\kappa^i_p)_{p \in \mathcal{P}^i_{\mathrm{wh}}} \text{ and } (\kappa^i_q)_{q \in \mathcal{Q}^i_{\mathrm{gl}} \setminus \{0\}} \text{ are SOS2}$$

and

$$\mathrm{enable}^i \leq t^i_{\mathrm{surg}}$$

Summary

Motivation

Problem Formulation

Santos Multi-Reservoir Production System

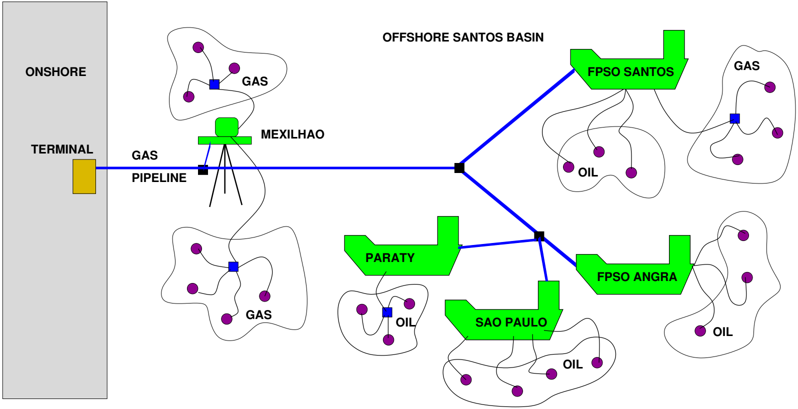
Santos Basin

Santos Basin is a very large, multi-reservoir oil field.

Features:

- 300 Km off the coast.
- Several reservoirs: Gas, Post-Salt, and Pre-Salt.
- 5 operational FPSOs, 27 to be commissioned.
- Shared drainage and processing facilities.

Santos Basin: Production System



- Several production units sharing resources, facilities and goals.
- High content of CO_2 in gas produced from Pre-Salt reservoirs.

Santos Basin: Production System

Challenges:

- Several production units sharing resources, facilities and goals.
- Dynamically evolving production infrastructure.

$\Longrightarrow$

Needs for Production Optimization:

- General models for production units.
- Models of shared resources.
- Coordination of production and control.

Santos Basin: Production System

Challenges:

- Several production units sharing resources, facilities and goals.
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$\Longrightarrow$

Needs for Production Optimization:

- General models for production units.
- Models of shared resources.
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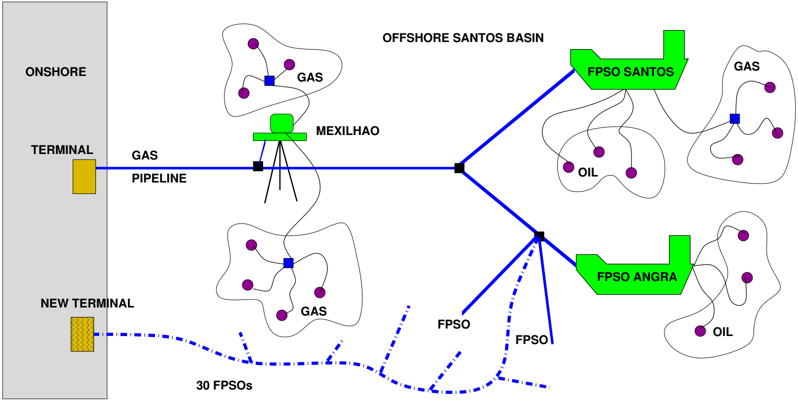
Santos Basin: Future Production System



- New subsea gas pipeline.
- 27 FPSOs to be commissioned.

Gas-Lift Optimization in Satellite Wells

- End!
- Thank you for your attention.