enhanced NOM Allocator

Digital Oilfield for Gas Nomination Allocation

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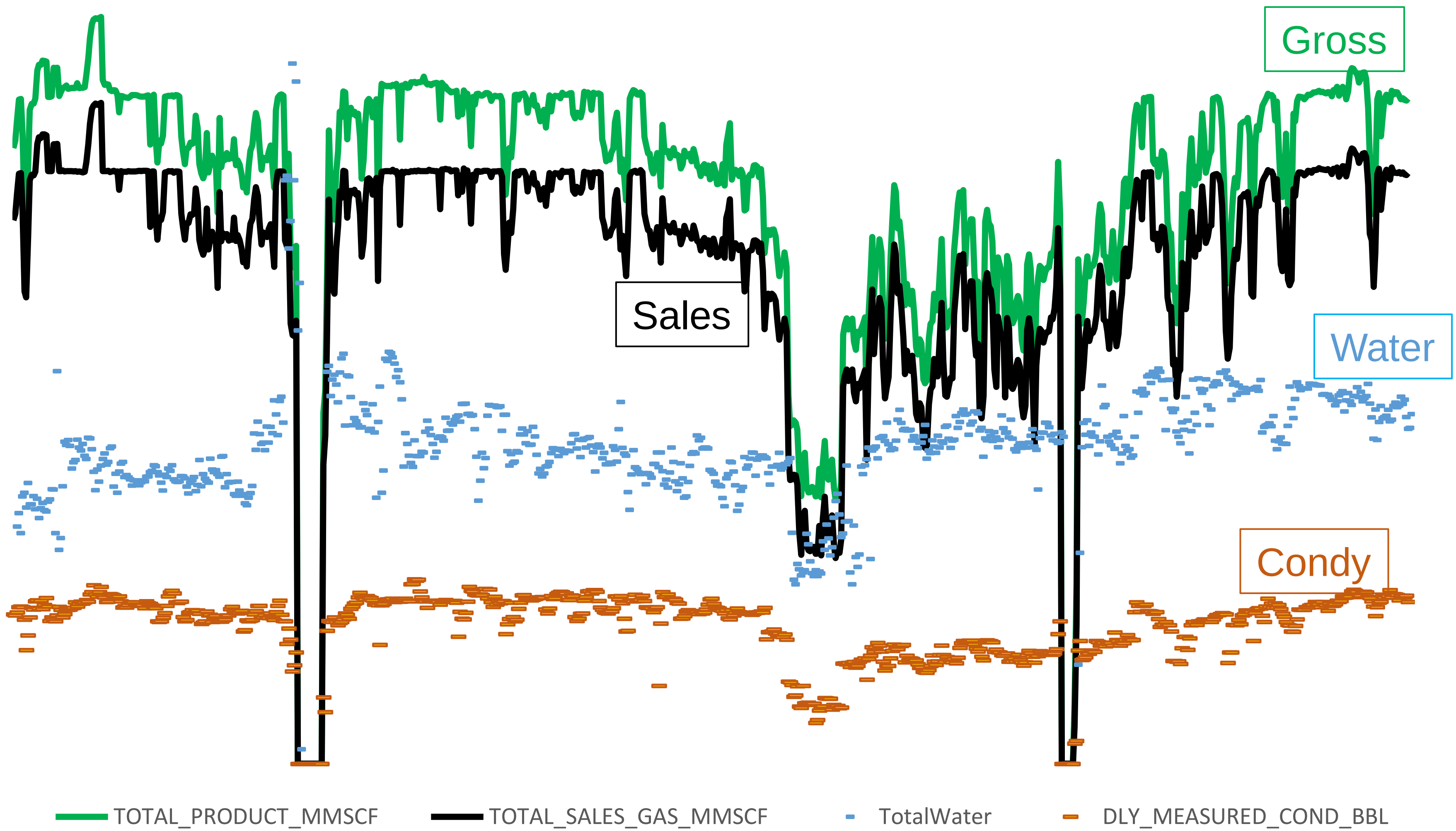
17 February 2022

- How to fulfill buyer's daily sales gas demand?



Overview

Unit partners want their wells produce according to an agreed ratio

Buyer nominate a daily sales gas rate with acceptable CO_2

How much gas rate for each well?

Facility have limited capacity on water and sand handling

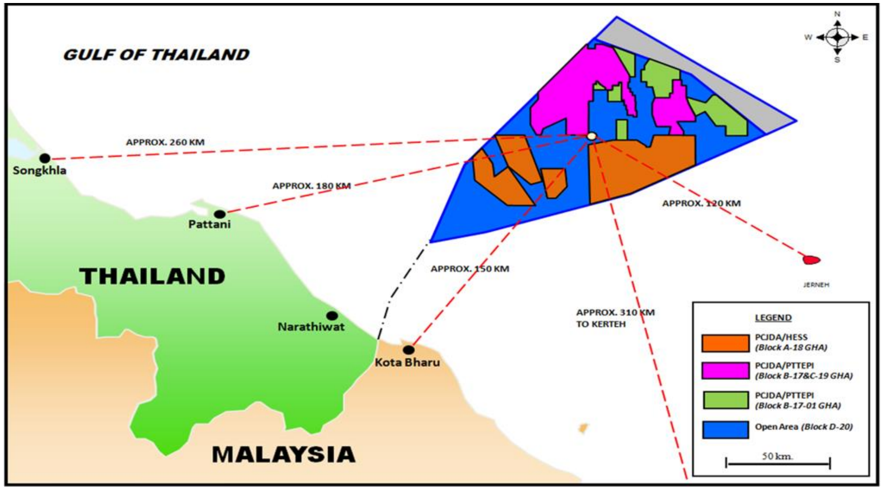
Some wells are sensitive (low rate, close to system pressure, etc)

Outline

- A brief overview of our operations
- The objectives of our operations
- Formulating the objectives as an optimization problem
- Deriving all equations
- Optimization setup
- Implementations
- Future improvement

A Brief Overview of Our Operations (1)

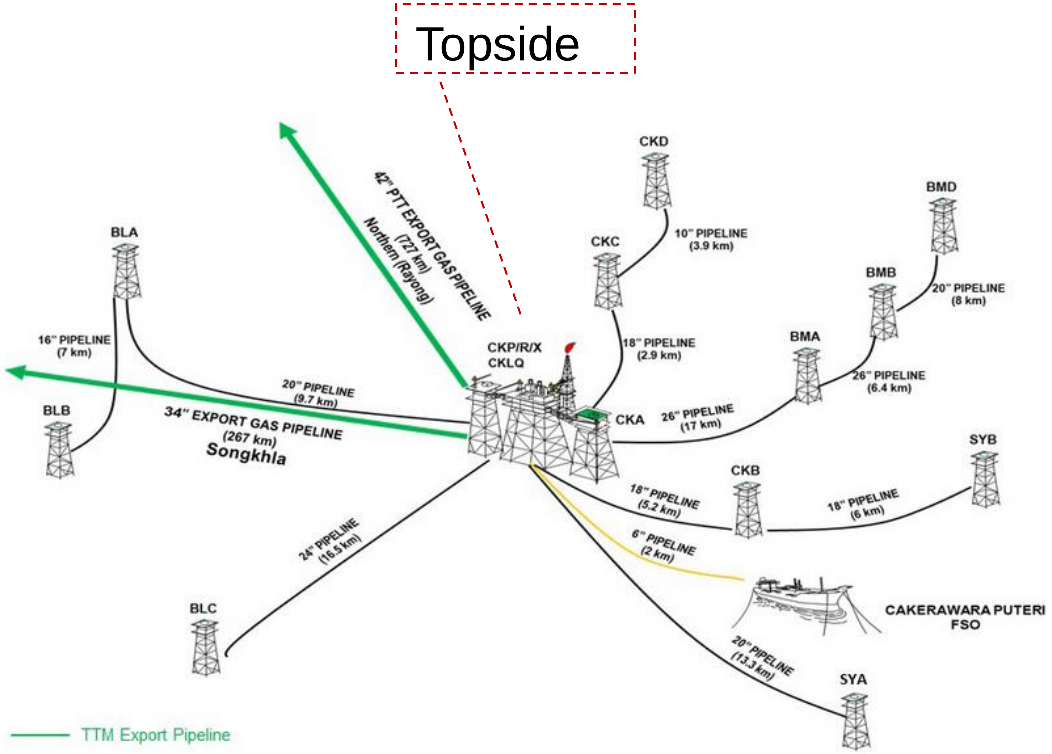
- Complex Geology:
  - Multiple stacked tidal to shallow marine sands
  - Facies ranging from:
    - Low quality bioturbated sand
    - Intermediate quality heterolithic sands
    - High quality massive channel sand



Source: mtja.org

A Brief Overview of Our Operations (2)

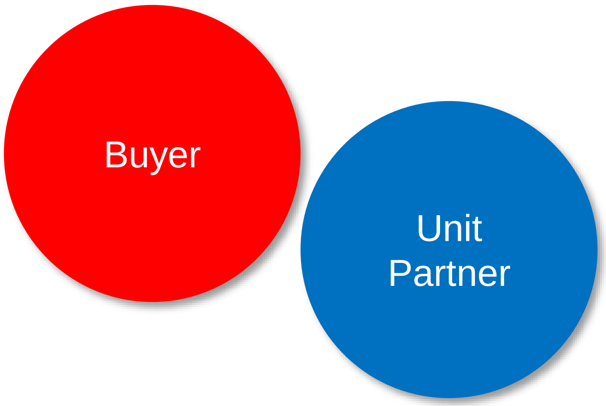
- 12 wellhead platforms
- Numerous development wells
- Single processing hub
- Limited metering

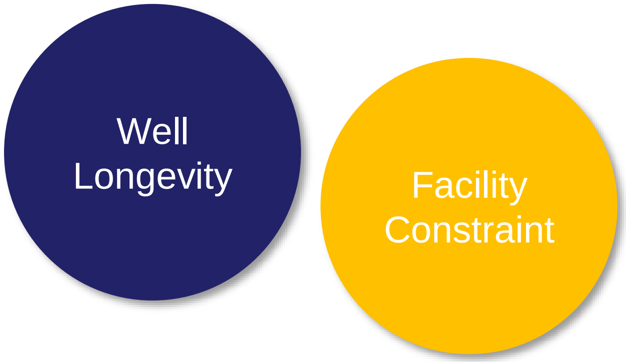


Source: mtja.org

The Objectives of Our Operations

- Objectives
  - – Meet buyer's demand (we have a dedicated buyer):
    - Daily sales gas nomination (fluctuating)
    - CO_2 specification
  - – Meet unit partners' demand:
    - Production meets agreed capital expenditure (CAPEX) ratio
  - – Ensure longevity of wells
    - Be conservative in changing choke size (especially for sensitive/cyclic wells)
  - – Meet facility constraint
    - Facility capacity in handling produced water
    - Facility capacity in handling produced sand





Formulating The Objectives As An Optimization Problem (1)

Buyer's requirement

Sales gas production (MMscfd)

CO_2 specification

Error = Demand - Base

$$\epsilon_S = \left| Q_{s,NOM}(t) - Q_s(t) \right| \leq \epsilon_T$$

$$x_f\ (t) = \frac{\sum_{i=1}^{N} Q_{g,i}(t) x_i(t)}{\sum_{i=1}^{N} Q_{g,i}(t)}$$

Weighted Average CO_2

$$x_f\ (t) \leq x_{T,\max}$$

Facility constraints

Sales = f(Gross Rate, Feed CO_2)

$$Q_{s,i}(t) = Q_{g,i}(t) \times \underbrace{\left(m\left(x_f(t)\right) x_i + b(x_f(t)\right)}_{\text{Shrinkage factor } (CO_2 \text{ removal})}$$

Shrinkage factor (CO_2 removal)

Flare + Membranes

http://dreamstime.com/royalty-free-stock-photo-flare-boom-nozzle-fire-offshore-oil-rig-image28254785

Formulating The Objectives As An Optimization Problem (2)

- Ensure profitability of unit partners share: $u_j < 100\%$
  (in terms of sales)

Recall: $\epsilon_S = \left| Q_{g,NOM}(t) - Q_g(t) \right| \leq \epsilon_T$

1st Unit Partner's requirement

$$\epsilon_1 = |u_1 Q_{g,NOM}(t) - Q_{s,j=1}|$$

2nd Unit Partner's requirement

$$\epsilon_2 = |u_2 Q_{g,NOM}(t) - Q_{s,j=2}|$$

Conflicting scenario:
The buyer wants low CO_2, but one of unit partner's well has high CO_2.

Formulating The Objectives As An Optimization Problem (3)

- Taking care of sensitive wells

Sensitive wells

$$\min\left(Q_{g,i}\right) = \max\left(Q_{g,i}\right) = Q_{g,i}(t-1) = Q_{g,i}(t)$$

Non-sensitive wells

$$\min\left(Q_{g,i}\right) \leq Q_{g,i}(t) \leq \max\left(Q_{g,i}\right)$$

Symbol	Description	Unit
i	well	
$Q_{g,i}$	Well gross gas rate	mmscfd
$Q_{s,i}$	Well sales gas rate	mmscfd
x_i	Well CO_2 concentration	
x_f	Feed blend CO_2 concentration	
x_s	Sales CO_2 concentration	
Q_g	Total gross gas rate	mmscfd
Q_s	Total sales gas rate	mmscfd
N	Number of wells	
m	Shrinkage slope	
b	Shrinkage coefficient	

$$Q_g = \sum_{i}^{N} Q_{g,i}$$

Total Gross Rate

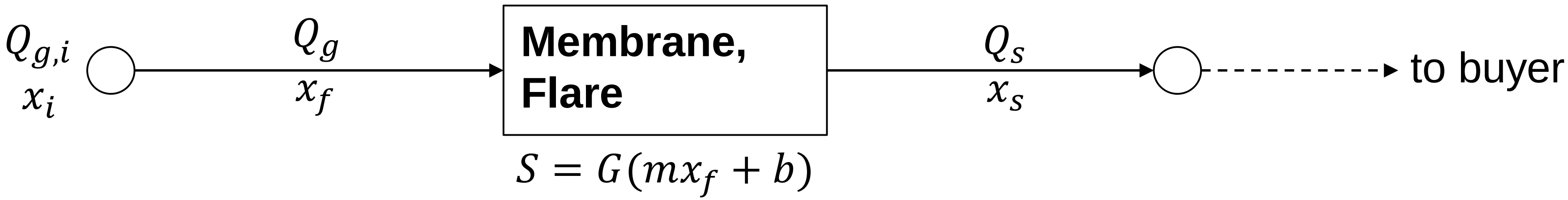
$$Q_s = \sum_{i}^{N} Q_{s,i}$$

Total Sales Rate

$$Q_s = Q_g(mx_f + b)$$

Shrinkage

- To meet buyer's sales gas rate demand, we need to sufficiently remove the CO_2 content.



$$Q_g = \sum_{i}^{N} Q_{g,i}$$

Total Gross Rate

$$Q_s = \sum_{i}^{N} Q_{s,i}$$

Total Sales Rate

$$Q_s = Q_g(mx_f + b)$$

Shrinkage

Is well-level shrinkage equivalent to total-level shrinkage?

- We can rephrase this question as:

$$\sum_i^N Q_{s,i} = Q_{s,1} + \cdots + Q_{s,N} = Q_{g,1}(mx_1 + b) + \cdots + Q_{g,N}(mx_N + b) = Q_g(mx_f + b) \quad ?$$

Proof:

$$Q_{g,1}(mx_1 + b) + \cdots + Q_{g,N}(mx_N + b)$$

$$= m(Q_{g,1}\, x_1 + \cdots + Q_{g,N}\, x_N) + b(Q_{g,1} + \cdots + Q_{g,N})$$

$$= m\sum_{i=1}^{N} Q_{g,i}\, x_i + b\sum_{i=1}^{N} Q_{g,i} = m\sum_{i=1}^{N} Q_{g,i}\, x_i + bQ_g$$

$$= Q_g\left(m\frac{\sum_{i=1}^{N} Q_{g,i}\, x_i}{Q_g} + b\right) = Q_g\left(mx_f + b\right) \quad \blacksquare$$

Weighted average CO_2: $$x_f = \frac{\sum_{i=1}^{N} Q_{g,i}\, x_i}{\sum_{i=1}^{N} Q_{g,i}}$$

Representing CO_2 with Gross Heating Value (GHV)

Variable	Definition	Unit
Q_s	Sales gas rate	MMscfd
Q_g	Gross gas rate	MMscfd
$\hat{H}$	Calorific value*	MMbtu/MMscf
x_f	Blend gross/feed CO_2	
H_g	Calculated GHV (gross)	MMbtu
H_s	Allocated GHV (sales)	MMbtu
H_T	Total topside GHV	MMbtu
x_s	Target sales CO_2	

Variable	Definition
w	Well index
p	Platform index

Variable	Definition
$m(x_s)$	Shrinkage slope
$b(x_s)$	Shrinkage intercept

Currently, we have

$$H_{g,p} = \sum_{i\in p} (Q_{g,i}\hat{H}_i) = \sum_{i\in p} \hat{H}_{g,i}$$

$$H_{s,p} = \frac{H_{g,p}}{\sum_p H_{g,p}} H_T = \frac{H_{g,p}}{\sum_i H_{g,i}} H_T$$

$$H_{s,i} = \frac{H_{g,i}}{H_{g,p}} H_{s,p}$$

$$Q_{s,i} = \frac{H_{s,i}}{\sum_i H_{s,i}} \left((mx_f + b) \sum_i Q_{g,i} \right)$$

We can write,

$$H_{s,i} = H_{g,i} \frac{H_{s,p}}{H_{g,p}} = H_{g,i} \frac{\frac{\cancel{H_{g,p}}}{\sum_i H_{g,i}} H_T}{\cancel{H_{g,p}}} = \frac{H_{g,i}}{\sum_i H_{g,i}} H_T$$

$$\sum_i H_{s,i} = \sum_i \left(\frac{H_{g,i}}{\sum_i H_{g,i}} H_T \right) = \frac{H_T}{\sum_i H_{g,i}} \sum_i H_{g,i} = H_T$$

Hence,

$$Q_{s,i} = \frac{H_{s,i}}{\sum_i H_{s,i}} \left((mx_f + b) \sum_i Q_{g,i} \right) = \frac{\frac{H_{g,i}}{\sum_i H_{g,i}} \cancel{H_T}}{\cancel{H_T}} \left((mx_f + b) \sum_i Q_{g,i} \right) = \frac{H_{g,i}}{\sum_i H_{g,i}} \left((mx_f + b) \sum_i Q_{g,i} \right)$$

$$= \frac{Q_{g,i}\hat{H}_i}{\sum_i (Q_{g,i}\hat{H}_i)} \left((mx_f + b) \sum_i Q_{g,i} \right)$$

$$\boxed{Q_{s,i} = \frac{Q_{g,i}\hat{H}_i}{\sum_i (Q_{g,i}\hat{H}_i)} \left((mx_f + b) \sum_i Q_{g,i} \right)}$$

GHV-based Gross to Sales Conversion (Final Result)

$$Q_{s,i} = \frac{Q_{g,i}\widehat{H}_i}{\sum_i \left(Q_{g,i}\widehat{H}_i\right)}\left((mx_f + b)\sum_i Q_{g,i}\right)$$

Variable	Definition	Unit
$Q_{s,i}$	Sales gas rate	MMscfd
$Q_{g,i}$	Gross gas rate	MMscfd
$\widehat{H}_i$	Calorific value*	MMbtu/MMscf
Q_{NOM}	TTM's nominated sales gas	MMscfd

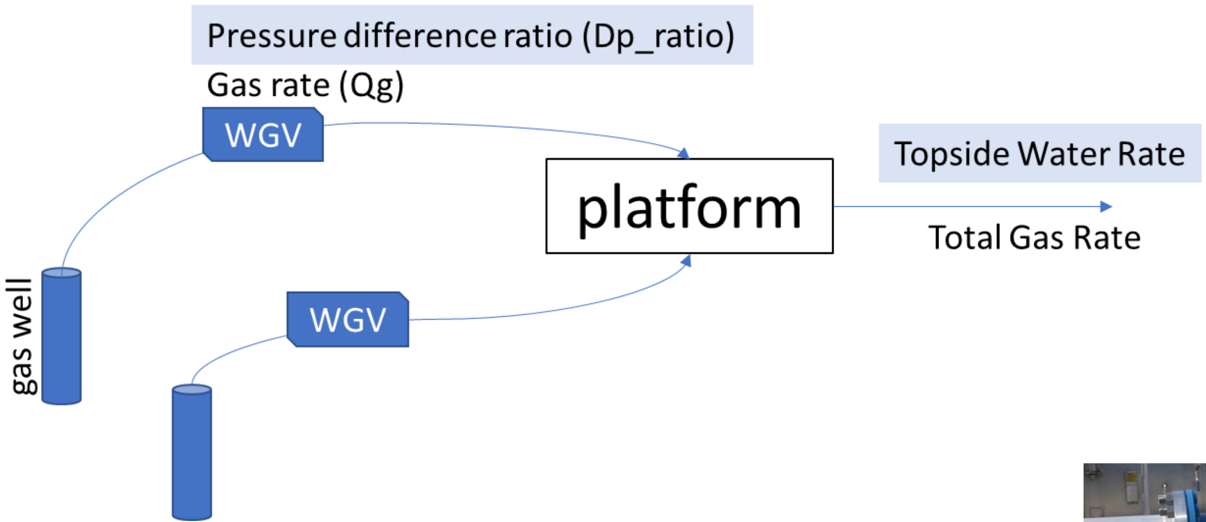
Note: Calorific value can be found from WMI with unit of btu/scf

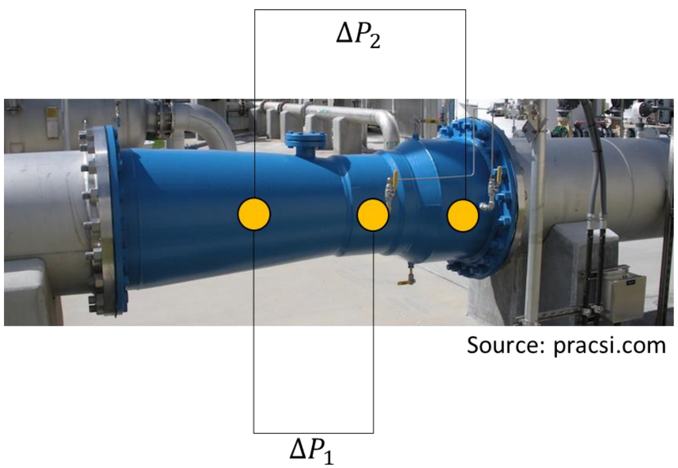
GHV vs CO_2

- As GHV increase, CO_2 decreases.
- To check whether your numerical optimization module is correct, check the GHV value against metering.
- In our experience, the optimization module yield lower value compare to observed.

Correction to well rates with single DP (delta P) meters

- For flowlines with WGV, we use the DP ratio to compute the well gross gas rate.





Source: pracsi.com

WGV: wet gas venturi meter

$$DP\ Ratio = \frac{\Delta P_2}{\Delta P_1}$$

Correction to well rates with single DP (delta P) meters

- But some of our old wells don't have WGV attached to their flowlines.
- Hence, the derived gross gas rate need to be corrected.
- Let W be the set of all wells, and W_1 be the set of all wells with WGV. Hence, $W_2 = W - W_1$ is the set of all non-WGV wells.
- We call $i \in W_1$ as dual-DP wells, and $i \in W_2$ as single-DP wells.

Correction factors

$$Q_{g,i}^c = Q_{g,i} k_1 + k_2$$

Corrected well gross gas rate

Computed well gross gas rate

Thus,

$$\boxed{Q_g^c = \sum_{i \in W_1} Q_{g,i} + \sum_{i \in W_2} \left(Q_{g,i} k_1 + k_2\right)}$$

Unit Partners Requirement

- In our fields, there are unit partners. Share agreement was made based on CAPEX ratio, in percentage, i.e. $u_1 + u_2 + w_0 = 100\%$.
- This agreement dictates how we operate our wells.
- Let W be the set of all wells. Let U_1 and U_2 be the set of all wells belonging to the first and second unit partners respectively.
- Thus, the set $W - U_1 - U_2 = W_0$ be the set of all non-unit wells.
- Therefore, the following constraints can be set:

1st Unit Partner's requirement

$$|u_1 Q_{g,NOM}(t) - Q_{s,j=1}| = |u_1 Q_{g,NOM}(t) - \sum_{i \in U_1} Q_{s,i}| \leq \delta$$

2nd Unit Partner's requirement

$$|u_2 Q_{g,NOM}(t) - Q_{s,j=2}| = |u_2 Q_{g,NOM}(t) - \sum_{i \in U_2} Q_{s,i}| \leq \delta$$

Non-unit

$$\sum_{i \in W_0} Q_{s,i} = Q_s - \sum_{i \in U_1} Q_{s,i} - \sum_{i \in U_2} Q_{s,i}$$

Sensitive wells

$$\min(Q_{g,i}) = \max(Q_{g,i}) = Q_{g,i}(t-1) = Q_{g,i}(t)$$

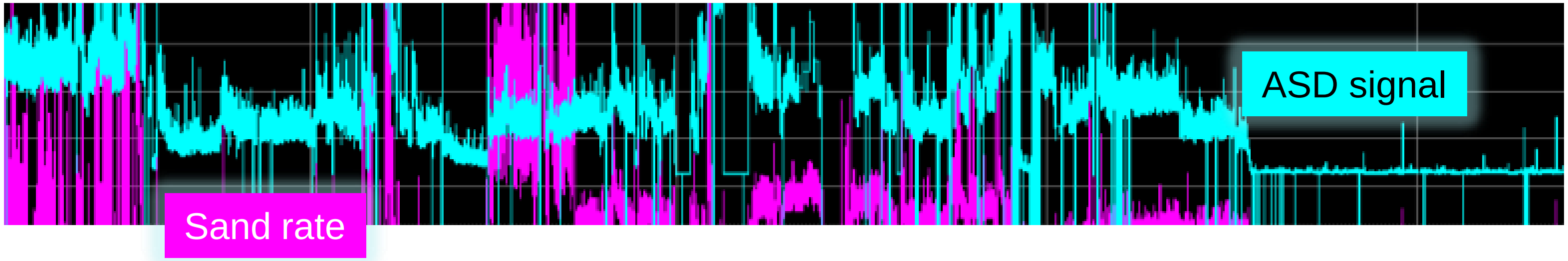
Non-sensitive wells

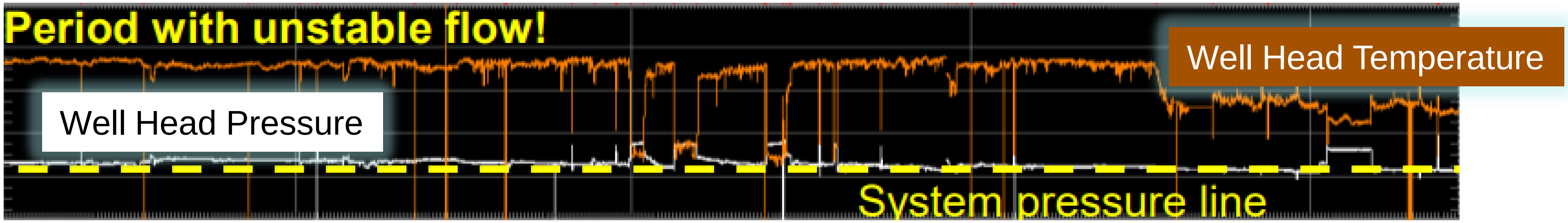
$$\min(Q_{g,i}) \le Q_{g,i}(t) \le \max(Q_{g,i})$$

Subjective:
5 mmscfd

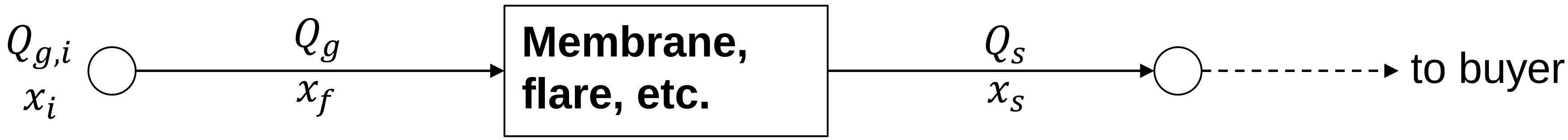
MSFR
Max Sand Free Rate

Noisy reading from Acoustic Sand Device (ASD)





- Objective is to minimize the error related to the following:
  - Buyer's sales gas nomination
  - Buyer's CO_2 requirement
  - Unit partners' CAPEX ratio (i.e. share)
- by adjusting $Q_{g,i}$ (including single-DP correction factors)



$$Q_s = Q_g(mx_f + b)$$

Sensitive wells

$$\min(Q_{g,i}) = \max(Q_{g,i}) = Q_{g,i}(t-1) = Q_{g,i}(t)$$

Non-sensitive wells

$$\min(Q_{g,i}) \leq Q_{g,i}(t) \leq \max(Q_{g,i})$$

Getting the list of sensitive wells

- From WMI (Well Management Information) database

```
'record WELL_PRIORITY
sqlStr2 = "SELECT WELL_PRIORITY FROM            vIPDS_Latest_MSFR_CO2 WHERE Well='" & wnam(i) & "';"
Set rs2 = oConn2.Execute(sqlStr2)
wdat.Cells(1 + i, 3).CopyFromRecordset rs2
```

```
=IF(C2="2","N","Y")
```

This influence how well max and min rates are calculated.

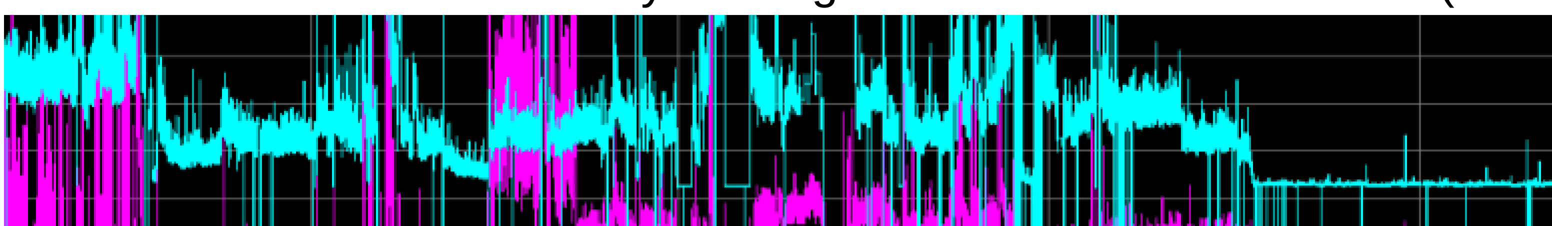
Obtaining well maximum rates, CO_2

- These values were also obtained from a database view.

```
'record MSFR
sqlStr2 = "SELECT MSFR FROM                vIPDS_Latest_MSFR_CO2 WHERE Well='" & wnam(i) & "';"
Set rs2 = oConn2.Execute(sqlStr2)
wc.Cells(21 + i, 6).CopyFromRecordset rs2

'record CO2
sqlStr2 = "SELECT CO2 FROM                vIPDS_Latest_MSFR_CO2 WHERE Well='" & wnam(i) & "';"
Set rs2 = oConn2.Execute(sqlStr2)
wc.Cells(21 + i, 3).CopyFromRecordset rs2
wc.Cells(21 + i, 3) = wc.Cells(21 + i, 3) / 100

'record GHV (or CV, i.e. calorific value)
sqlStr2 = "SELECT GHV FROM                vIPDS_Latest_MSFR_CO2 WHERE Well='" & wnam(i) & "';"
Set rs2 = oConn2.Execute(sqlStr2)
wc.Cells(21 + i, 5).CopyFromRecordset rs2
```

MSFR: Maximum sand free rate.
This value is determined by production engineers – typically based on acoustic sand device.

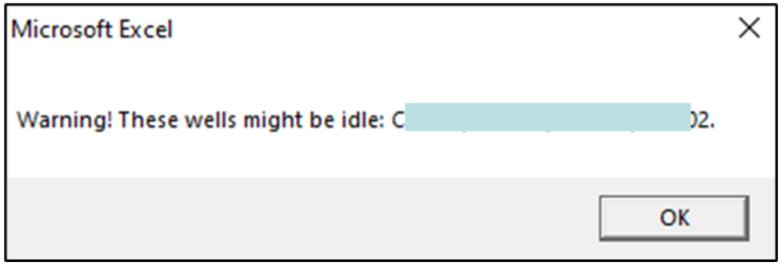
Noisy reading from Acoustic Sand Device (ASD)



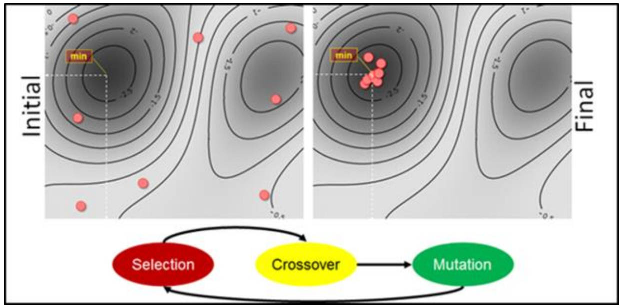
Obtaining temperature

- Get snapshot temperature to determine the status of each well (online or offline).
- T < 40 Celsius may indicate that the well is idle, or broken sensor.

```vb
'//------checking for possibility of a wells being idle; temperature < threshold (40 C) -----
'note: rate reading might gave the wrong reading
Dim wIdle As String

wIdle = ""
For i = 1 To nrow1

    'search for possibly idle wells
    If wc.Cells(i + 21, 4) > 0.0000001 And wc.Cells(i + 21, 7) < wc.Cells(9, 7) Then
        wIdle = wIdle & wc.Cells(i + 21, 2) & ", "
    End If

Next i



If wIdle <> "" Then

    'replace last character with a dot
    wIdle = Left(wIdle, Len(wIdle) - 2)
    wIdle = wIdle & "."

    MsgBox "Warning! These wells might be idle: " & wIdle
End If
```



Optimize using
Evolutionary Algorithm
~ 3 mins



Setting objectives:

```
' //---------------------OPTIMIZATION STARTS HERE---------------------------

'find solution gross rates

    'initialize optimized gross vectors (see column "S")
    'For i = 34 To 161
        'Worksheets("ProdAlloc").Range("I" & i) = Worksheets("ProdAlloc").Range("G" & i)
    'Next i

    'remove previous added constraints
    SolverReset

    'configure optimizer
    'SolverOptions Precision:=0.001, MaxTime:=300, Convergence:=0.0001, MutationRate:=0.1, PopulationSize:=150, RandomSeed:=0, MaxTimeNoImp:=50
    SolverOptions MaxTime:=300, MaxTimeNoImp:=80

    'set objective function and control parameters (i.e. every platform's gross rate)
    'note: MaxMinVal=2 means minimize
    SolverOK SetCell:="$H$7", MaxMinVal:=2, ByChange:="$I$34:$I$161", Engine:=3
```

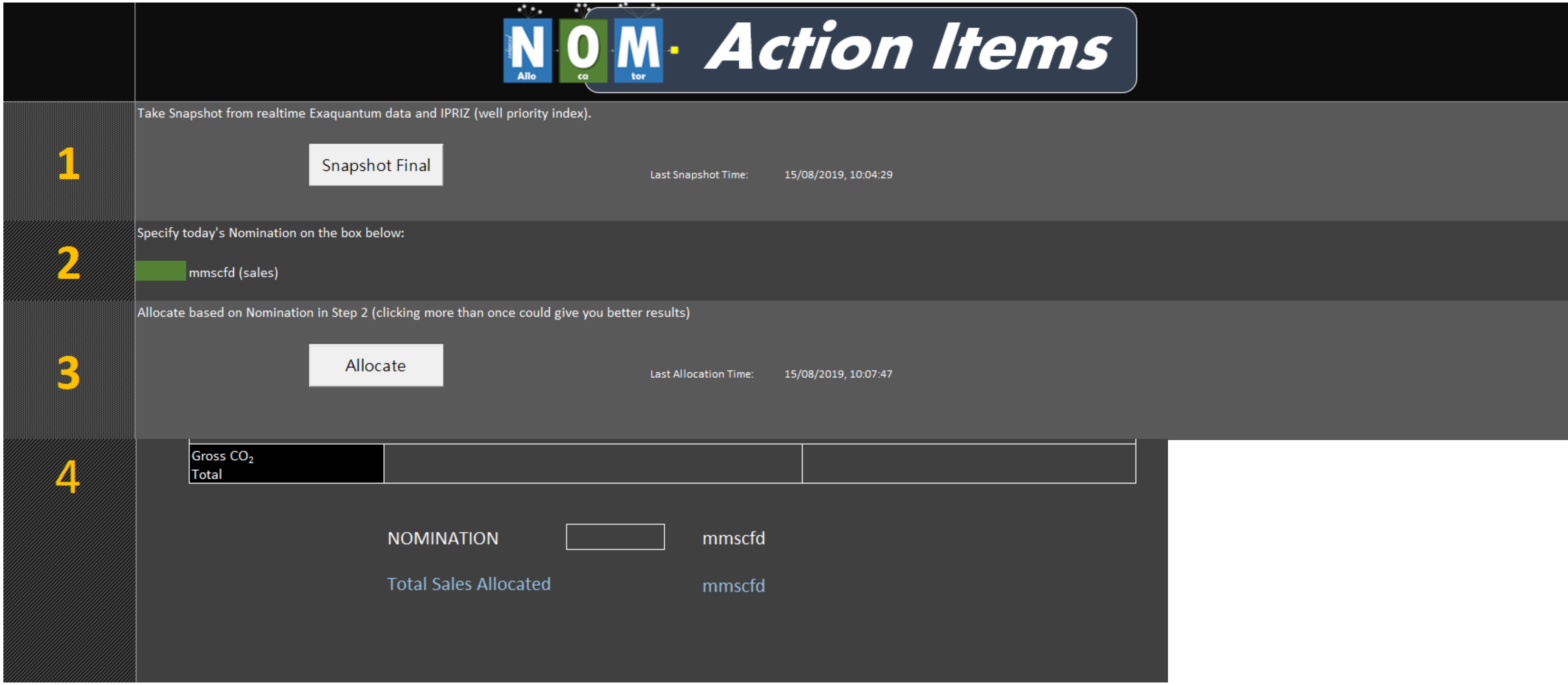
Setting constraints:

```
SolverAdd cellRef:=Worksheets("ProdAlloc").Range("$I$34:$I$161"), relation:=1, formulaText:=Worksheets("ProdAlloc").Range("$H$34:$H$161") 'control
SolverAdd cellRef:=Worksheets("ProdAlloc").Range("$I$34:$I$161"), relation:=3, formulaText:=Worksheets("ProdAlloc").Range("$G$34:$G$161") 'control

SolverAdd cellRef:=Worksheets("ProdAlloc").Range("$I$5"), relation:=3, formulaText:=Worksheets("ProdAlloc").Range("$I$4") 'co2 min constraint
```

- Sometimes facility engineers would manually intervene depending on situations.
- This requires some adjustments in the calculation.
- At later time, they might request to turn off this feature.

```
'revised variables
Dim rBLS As Double, rBMA As Double, rBMB As Double, rSYA As Double, rSYB As Double
Dim offBumiU As Double, offSuriyaU As Double, offBlsU As Double

'specify addition
addBumi = **
addSY = **
addBLS = **

'-- **** Unit (add ** mmscfd to mimic actual shrinkage factor)
ms = Worksheets("EASY").Cells(25, 6) 'msfr
gs = Worksheets("ProdAlloc").Cells(12, 10) 'computed gross (i.e. numerical solution)

If (ms - gs) > addBumi Then
    Worksheets("EASY").Cells(25, 5) = gs + addBumi
Else
    Worksheets("EASY").Cells(25, 5) = ms
End If

'-- **** Unit (add ** mmscfd to mimic actual shrinkage factor)
gs = Worksheets("ProdAlloc").Cells(13, 10)
ms = Worksheets("EASY").Cells(26, 6)
If (ms - gs) > addSY Then
    Worksheets("EASY").Cells(26, 5) = gs + addSY
Else
    Worksheets("EASY").Cells(26, 5) = ms
    delSY = gs + addSY - ms 'the remaining from addSY
End If

'-- ***** Unit (add ** mmscfd to mimic actual shrinkage factor)
gs = Worksheets("ProdAlloc").Cells(14, 10)
ms = Worksheets("EASY").Cells(27, 6)
If (ms - gs) > addBLS Then
    Worksheets("EASY").Cells(27, 5) = gs + addBLS
Else
    Worksheets("EASY").Cells(27, 5) = ms
    delBLS = gs + addBLS - ms 'the remaining from addBLS
End If
```

Interface (for offshore personnel)



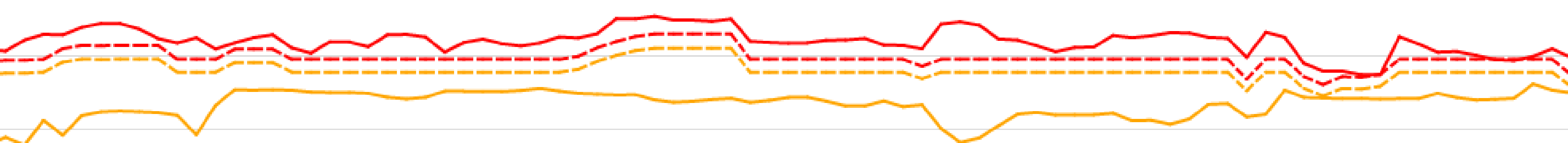
Automated email

Production Date: 11-Feb-2022
Total Actual Sales Gas= MMSCFD
Total Nomination Gas= MMSCFD

Unit:
Actual sales gas MMSCFD vs target sales gas MMSCFD. Variance= %

Unit:
Actual sales gas MMSCFD vs target sales gas MMSCFD. Variance= %

Unit:
Actual sales gas MMSCFD vs target sales gas MMSCFD. Variance= %

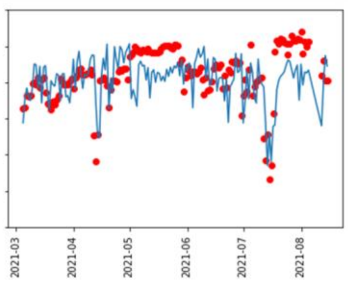


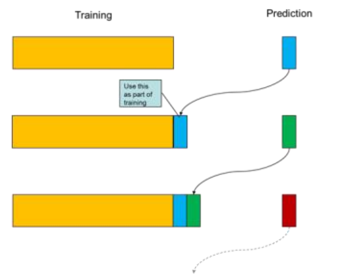
Daily tracking on the website: constantly monitored by General Manager’s Office / Corporate Planning

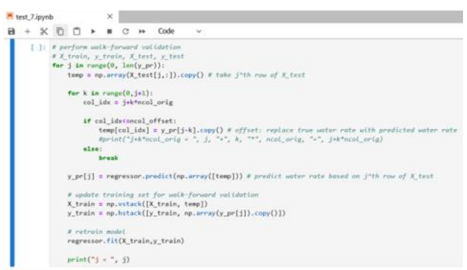
Future improvement

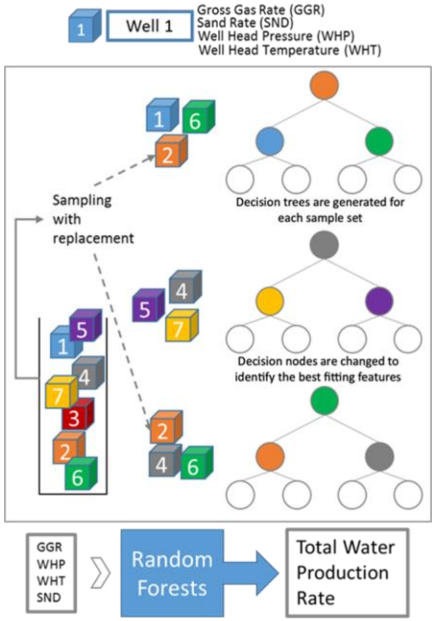
- The facility has limited water and sand handling capacity.
- Currently still doing research in establishing machine learning-based relationship between well measurements and topside water and sand measurements.

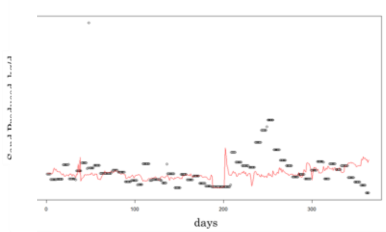
```
[1252]: mse = ((y_test - y_pr)**2).mean()
        Rsq = np.corrcoef(y_test,y_pr)

        print("RMSE = ", np.sqrt(mse), " bbl/day")
        print("R2 = ", Rsq)

        RMSE =                    bbl/day
        R2 =  [[1.          0.43247048]
         [0.43247048 1.        ]]

[1253]: plt.scatter(X_test_date, y_test, color="red")
        plt.plot(X_test_date, y_pr)
        plt.xticks(rotation=90)
        plt.ylim([10000,22000])
        plt.show()
```





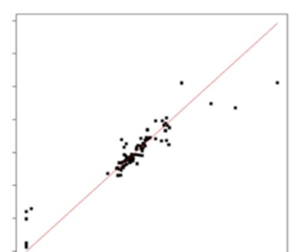






$$c_1 w_{1,ASD}(t) + c_2 w_{2,ASD}(t) + \cdots c_N w_{N,ASD}(t) = \sum_i c_i w_{i,ASD}(t) \rightarrow Q_{sand}(t)$$

Well	Parameter	% Influence
15	WHT	8.9
9	GGR	8.2
15	WHP	7.1
89	WHP	6.6
16	WHP	6.4
71	GGR	6.3
11	WHP	6.0
9	WHT	5.8
71	WHT	5.6
37	WHP	5.6



- Automatic choke sizing
  - How to deal with unexpected behaviors?
    - Well behavior
    - Unplanned facility shutdown (compressor trip, etc)
- Coupling with Integrated Reservoir Modeling such as GAP (by PETEX) for better physics; pressure dynamics, etc.

Summary

- Objectives
  - Meet daily sales gas demand
  - Meet CO_2 specification
  - Meet unit partners' requirement
  - Take care of sensitive wells
  - Do not exceed facility's sand/water handling capacity