

Paper No: SPE-180710-MS. Predicting SAGD ESP Intake Temperature

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Outline

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- SAGD Subcool Definition and Importance
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- Summary

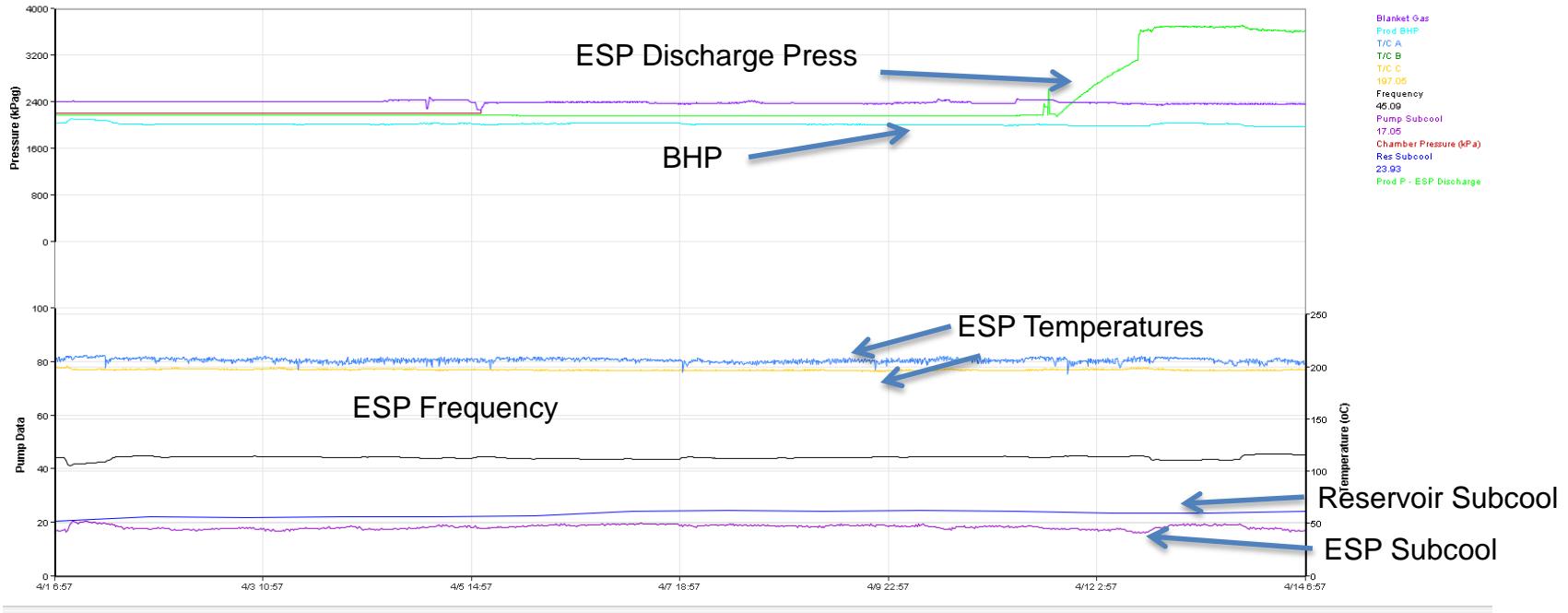
Study Goal

Developing a formula predicting the ESP intake temperature and subcool in production wells for supporting production automation and optimization.

ESP Temperature and Subcools

- Reservoir Subcool = $T_{sat}(resP) - T(intake)$
 - Target 20C
- Pump Subcool = $T_{sat}(BHP) - T(intake)$
- **Importance:** Maintaining well reliability/integrity and optimize well production and steam injection

ESP Temperature and Subcool



Intake Temperature Multivariate Formula

Based on:

- Bottomhole pressure (P),
- Steam Injection rate (S),
- Production rate corresponding to:
 - ESP frequency (F)
 - Pump rate (Pr)

Numerical Uncertainties to Overcome

Standard statistical practices poorly handle multivariate data with long time periods during which parameters are regulated and kept constant.

A typical standard forecasting model developed using the actual temperature will forecast a constant value equal to an average value.

A new modeling approach had to be developed.

Basis of Numerical Solution

A two-stage formula is based on Ideal Gas Law (**PV=nRT**) with lagged non-dimensional parameter ratios augmented with:

- Pump Rate (Pr),
- Pump Frequency (F),
- Steam Injection Rates (S),

during the last 50 minutes (five 10-min intervals).

Augmented Ideal Gas Law Formula

$$P * V * Pr * F = n * S * T$$

Annotation:

P – Pressure

T – Temperature

Pr – Median Pump Rate represents the pump size

V – Chamber Gas Volume is affected by Pr and F

S – Steam Injection Rate

F – ESP Frequency

n – Number of Moles is affected by S

Non-Temperature Ratio

A general form of the intake temperature ratio at time index (*i*) is a function of ratios of other parameters as follows:

$$T(i)/T(i-1) = \text{Ratio } (i, i-1) = f\{P(i)*Pr(i)*Fi*S(i-1)\} / \{P(i-1)*Pr(i-1)*F(i-1)*S(i)\}$$

The right hand side of the equation represent the Non-Temperature Ratio.

We assume the chamber volume (V) and number of moles (n) do not change in 10-min time intervals. Thus, their ratios were eliminated.

Non-Temperature Ratio Modeling

- The intake temperature prediction is a 2-stage process

1st Stage: A multivariate multiplicative model was built to predict the ratio at time (*i*) with lagged ratios taken at the 5 previous 10 minute time intervals *i-1, i-2, i-3, i-4, i-5*:

$$\text{Ratio}(0, i-1) = C0 * \text{Ratio}(i-1, i-2)^{C1} * \text{Ratio}(i-2, i-3)^{C2} * \text{Ratio}(i-3, i-4)^{C3} * \text{Ratio}(i-4, i-5)^{C4}$$

Where C0, C1-C4 were the estimated multivariate regression coefficients.

The Intake Temperature Estimate from the Non-Temperature Ratio

2nd Stage:

1st step: Predicted Ratio(i, i-1) is equivalent to the temperature ratio $T(i)/T(i-1)$ thus,

2nd step: The Intake temperature is estimated from

$$Ti = \text{Predicted Ratio } (i, i-1) * T (i-1)$$

All-Pad Formula

Ratio(i, i-1):

$$R01 = 10^{-0.000823} * R12^{-0.5067} * R23^{-0.2776} * R34^{-0.1594} * R45^{-0.0622}$$

and

$$T0 = R01 * T1$$

Where:

T0 – Current estimated temperature

T1 – Actual temperature 10 minutes prior

T2 – Actual temperature 20 minutes prior.... etc

Validation (1st step Ratio Estimates)

PAD	RMSE (error)	C0* (requires anti-log conversion)	C1	C2	C3	C4	Error degrees of freedom	R-squared
1	0.0481	-0.0009	-0.5916	-0.3243	-0.1951	-0.0837	1,798,098	0.41
2	0.0428	-0.0006	-0.4128	-0.2279	-0.1165	-0.0483	839,675	0.22
3	0.0438	-0.0008	-0.4129	-0.1437	-0.1292	-0.0501	781,198	0.2
4	0.0449	-0.0008	-0.4793	-0.2305	-0.1049	-0.0379	1,271,288	0.28
6	0.0390	-0.0004	-0.3889	-0.2581	-0.1437	-0.0904	374,010	0.15
5	0.0717	-0.0022	-0.5560	-0.3993	-0.2360	-0.0968	301,107	0.41
7	0.0430	-0.0005	-0.3762	-0.1796	-0.1038	-0.0425	552,209	0.14
8	0.0358	0.0001	-0.4331	-0.2615	-0.1837	-0.0647	142,486	0.17
1,2,3,4,5,7,8 (No_Pad6)	0.0473	-0.0009	-0.5096	-0.2785	-0.1597	-0.0615	5,686,091	0.31
As above + PAD6	0.0469	-0.0008	-0.5067	-0.2776	-0.1594	-0.0622	6,060,106	0.31

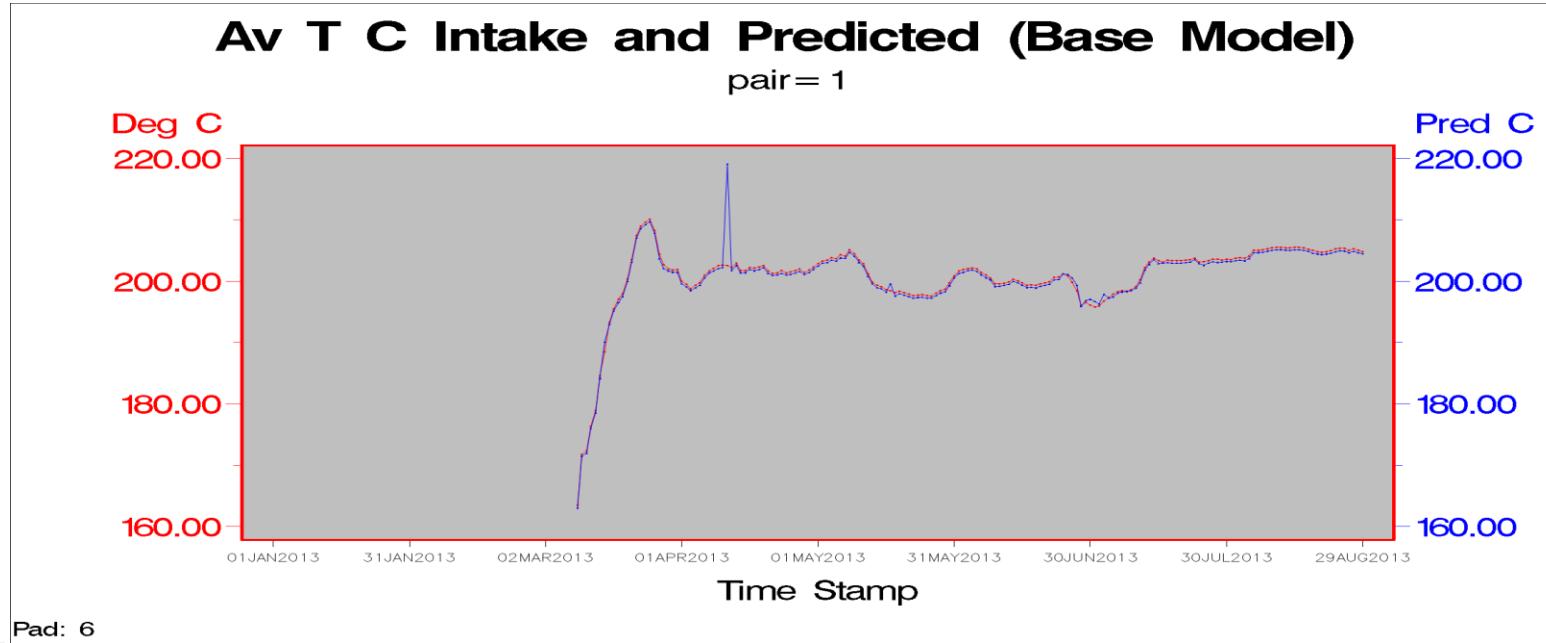
Validation-1st step.

Parameter Estimates and their Significance

Variable	Parameter Estimate	Standard Error	t Value	Pr > t
C0	-0.00082302	0.00001904	-43.23	<.0001
C1	-0.50669	0.00031102	-1629.1	<.0001
C2	-0.27758	0.00033841	-820.24	<.0001
C3	-0.15942	0.00033261	-479.30	<.0001
C4	-0.06218	0.00029362	-211.76	<.0001

Validation Example No1 – 2nd step

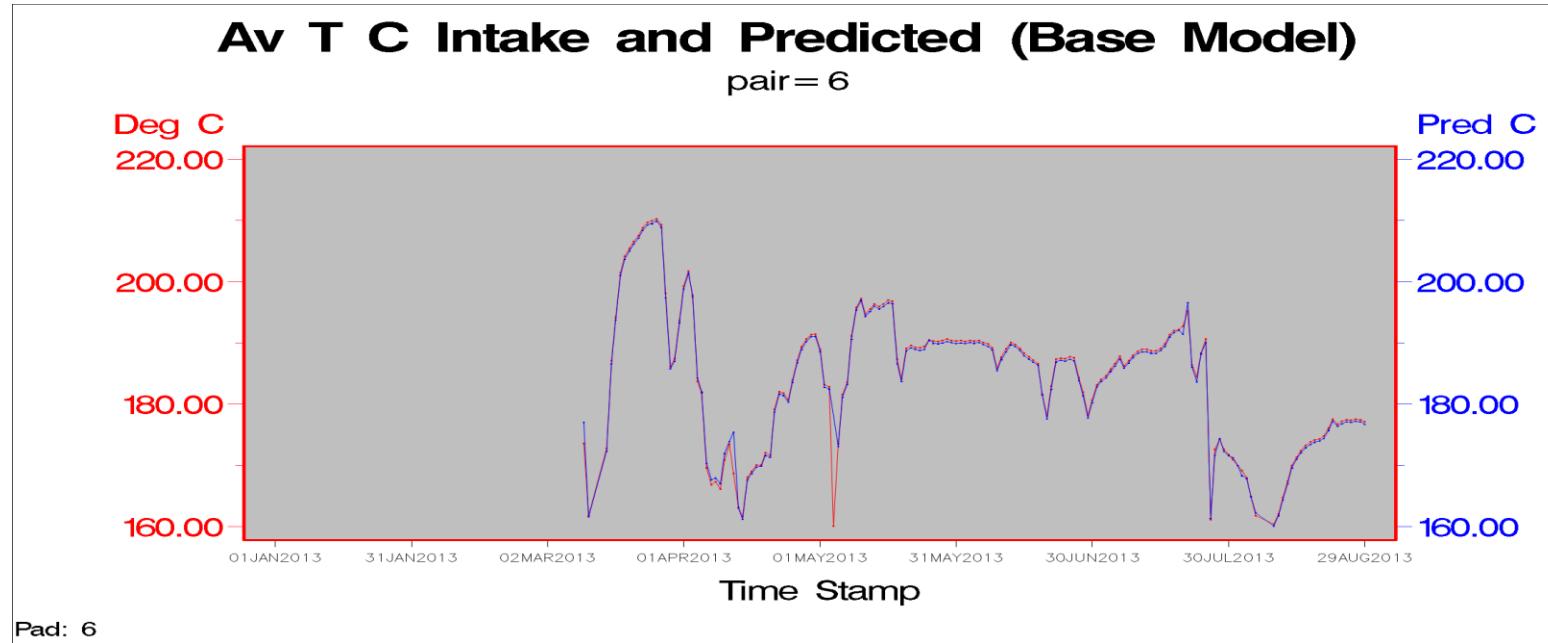
Temperature Predictions vs Actual



Pad: 6

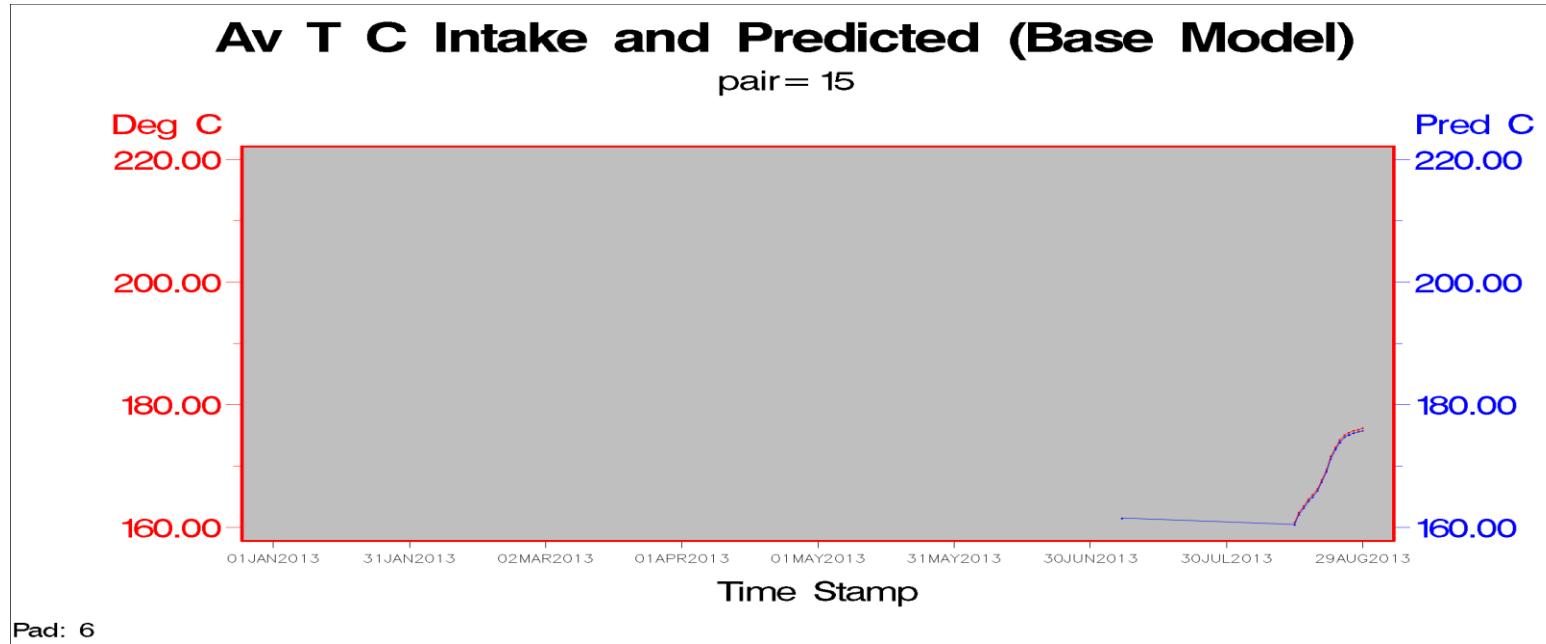
Validation Example No 2 – 2nd step

Temperature Predictions vs Actual



Validation Example No 3 – 2nd step

Temperature Predictions vs Actual



Summary

- A Time Lagged PVT Ratio Formula was developed and tested for predicting an ESP's intake temperature in SAGD wells for the purposes of automating ESP operation based on ESP temperature and subcool parameters
- The two-step formula is based on augmented The Ideal Gas Law and ratios of parameters, which represented non-dimensional terms.
- Specifically, it uses pump frequency, pump size, steam injection rates, and BHP from the last five 10-minute interval step values, and one step back the intake temperature value.
- Validation process has shown that the formula is very robust, consistent, and can be applied across all well pairs and pads (mature and new pads).

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Calgary, Alberta, Canada
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Thanks to Suncor!



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Questions ?

Analytics Leads to
Evolution



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