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RESULTS OF THE AIR INLEAKAGE TEST DEMONSTRATED AT THE PHEF FOR THE SALT PROCESS CELL (U)

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**RESULTS OF THE AIR INLEAKAGE TEST
DEMONSTRATED AT THE PHEF FOR THE SALT PROCESS CELL (U)**

SUMMARY

Air leaks into the salt processing cells (SPC) vessels because they are maintained at a slight negative pressure with respect to the cell. The Process Operating Procedure (POP)# 27-355-506 was written at DWPF to measure air inleakage of the PRFT, PR, OE and OECT.

DWPF requested SRL to demonstrate the Air Inleakage Test at the PHEF. The purpose of implementing the test at the PHEF was to:

- (1) Determine if the existing DWPF Process Operating Procedure (POP) algorithm provides a reliable tool to conduct the test, and
- (2) if the existing method proves to be inadequate, then develop a new method to conduct the test.

The existing POP did not perform satisfactorily during PHEF demonstrations. Although its failure was in part due to the small molecular difference between air and the PHEF inertant (nitrogen), the POP is not expected to be adequate even with CO₂ as the inertant. Two tests were conducted at the PHEF using a new method [2] with promising results. The method and test results are summarized in this report.

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Air Inleakage Test Using DWPF POP:Test Algorithm

The test is done by performing a calculation to estimate the oxygen concentration in each of the four tanks in the SPC. These include the Precipitate Reactor (PR), the Precipitate Reactor Feed Tank (PRFT), the Organic Evaporator (OE), and the Organic Evaporator Condensate Tank (OECT).

Two oxygen analyzers monitor the combined exhaust stream of the above mentioned vessels and serve as the primary protection against the high oxygen concentrations. There are software and hardware interlocks associated with the analyzers that will put the SPC in a safe mode.

This POP is more than an independent check against the Oxygen analysers. The POP calculates the O₂ concentration in the individual vessels. This calculation is critical since it is possible to have O₂ concentration above the MOC in a portion of the system vessels and below MOC at the SCVC exit. The most likely scenerio that would cause this discrepancy would be large inleakage into one vessel and low inleakage into the systems other vesels.

The main steps of the algorithm are summarized below. The algorithm

- (1) Computes the average vessel CO₂ purge flow and exhaust flow over average minutes.
- (2) Calculates the density of the vapor in the vessel from the average CO₂ purge and exhaust flow.
- (3) Calculates the density of the vapor in the vessel on a benzene free basis.
- (4) Calculates the approximate oxygen concentration in the vessel from the benzene free basis density of the vessel.
- (5) When the oxygen concentration is less than the referenced maximum oxygen concentrator allowed for the vessel, the test is considered complete.

Test Results

The test conducted at the PHEF measured the nitrogen purge at the PR inlet and the Vent Condenser vapor outlet and the oxygen at the VC exit. The Vent Condenser vapor exit flow was measured with a Kurz flow transmitter and oxygen was measured with a gas chromatograph. The DWPF POP test was inconclusive at PHEF because of the inertant nitrogen density being very close to air, the inability of the Kurz transmitter to read accurately at the low flows and the small difference between flow values.

New Test Method Developed at the PHEF:

The new air inleakage test algorithm is described in reference [2]. It is assumed that the composition at the Kurz transmitter would not change due to change in the vacuum. This assumption relies on steps being performed quickly enough so that the composition does not change. The test outline for DWPF is described below. The test conducted at the PHEF facility is described in Attachment A [1].

Test Outline For DWPF

The method outlined below represents the steps to carry out the testing of the new algorithm. Note that the method is generalized here. More detailed work is required to conduct the test for suggested vessels at DWPF.

The pressure meter should be zeroed before the test is conducted. Zero error is the deviation in the pressure transmitter at the reading of 0.0 inwc for the specified calibration range. If the transmitter can be zeroed then the zero error is removed. This deviation is incorporated in the algorithm as a correction factor to calculate the corrected flow. The deviation can be positive or negative.

It is very essential to characterize the air inleakage as a function of ΔP to use in the final correction step. Please refer to reference [2] for more details. The flow through the points of leakage at the PHEF is determined to be turbulent. The measured exponent for the ΔP term at PHEF is 0.425, which is slightly out of expected range [1]. It is believed that the low pressure drop at PHEF may be causing the flow coefficient to vary considerably. This could have the considerable effect on the exponent.

Step 1

- Set the Precipitate Reactor (PR) at -2 inwc. (Referred as reference pressure. Reference pressure can be -2,-3,-4 inwc).
- Set CO2 purge flow to the PR at 2 scfm.
(This flow could be DWPF process standby flow.)
- Allow the system to reach steady-state, where, the Oxygen Concentration would not change. (i.e it will take approximately two to three hours. This is to set up quiescent condition which is starting point for DWPF.)
- When the system comes to steady state, measure the following parameters.

Precipitate Reactor Pressure	(P1)	_____	inwc
Inlet CO2 purge flow to the PR	(F1)	_____	scfm
Flow at the PR exit	(F2)	_____	pph
Precipitate Reactor temperature	(T1)	_____	°C
Ambient temperature		_____	°C

Step 2

- With the PR pressure at -2 inwc, increase the inlet CO2 purge by 2 scfm. Due to increase in the flow, the PR pressure will fluctuate. As soon as the PR pressure settles out, measure the following parameters:

Precipitate Reactor pressure	(P2)	_____	inwc
Inlet CO2 purge flow to the PR	(F3)	_____	scfm
Flow at the PR exit	(F4)	_____	pph

The flowmeter response to the change in flow is

$$\frac{F4 - F2}{F3 - F1 * (273 + T1^{\circ}\text{K} / 273^{\circ}\text{K})} = X1 \text{ lbs/hr per acfm}$$

Step 3

- With the PR pressure at -2 inwc., decrease the inlet CO2 to 2 scfm. As soon as the PR pressure stabilizes, measure the following parameters. This step works as a meter calibration.

Precipitate Reactor Pressure	(P3)	_____	inwc
Inlet CO2 purge flow to the PR	(F5)	_____	scfm
Flow at the PR exit	(F6)	_____	pph

Note: Step 3 is not required except to verify to see if things go back to Step 1. F2 of Step 1 should be the same as F6 of Step 3.

Step 4

- This step requires to change the process pressure to change the air inleakage into the system. Increase the PR pressure to -12 inwc with the inlet CO2 purge flow at 2 scfm. After the PR pressure stabilizes to -12 inwc., measure the following parameters.

Precipitate reactor pressure	(P4)	_____	inwc
Inlet CO2 purge flow to the PR	(F7)	_____	scfm
Flow at the PR exit	(F8)	_____	pph

From step 3 and 4, calculate the difference in air inleakage caused by the increased vacuum.

$$\frac{(F8 - F6) \text{ lbs/hr}}{X1 \text{ lbs/hr per acfm}} = X2 \text{ ft}^3/\text{min}$$

The next step is to calculate the air inleakage at initial condition of -2 inwc. Assume turbulent flow which is proportional to the square root of the pressures. The exponent for the ΔP term must be derived for the DWPF [2].

$$\frac{X2 \text{ ft}^3/\text{min}}{\sqrt{P4/P1 - 1}} = X3 \text{ ft}^3/\text{min}$$

Any error detected while zeroing the meter should be incorporated in the above equation for P4 and P1. Please refer attachment A for more details.

Correcting back to standard conditions, the calculated air inleakage is

$$X3 \text{ ft}^3/\text{min} * \frac{273 \text{ }^\circ\text{K}}{273 + T1^\circ\text{K}} = X4 \text{ scfm}$$

and the calculated O2 concentration is

$$\frac{21\% * X4 \text{ scfm}}{X4 \text{ scfm} + F1 \text{ scfm}} = \% \text{ O2}$$

TEST RESULTS:

Two tests were conducted with the new algorithm at the PHEF. Test 1 and 2 were conducted at the reference pressure of -2 and -4 inwc respectively. Data of the tests are documented in Table 1 below. Please refer Attachment A for variable descriptions and steps of the test.

Table 1:

Step	Measured variables	Test 1	Test 2
1	P1, inwc	2.0	4.0
	F1, pph	40.7	40.0
	F2, pph	48.9	50.2
	C1, vol%	4.00	4.38
2	P2, inwc	2.0	3.9
	F3, pph	60.2	60.1
	F4, pph	70.8	71.5
	C2, vol%	4.00	4.38
3	P3, inwc	2.0	4.0
	F5, pph	41.2	41.2
	F6, pph	47.8	50.2
	C3, vol%	3.98	4.49
4	P4, inwc	12.1	12.0
	F7, pph	40.1	41.1
	F8, pph	58.8	55.6
	C4, vol%	3.81	4.60
5	P5, inwc	12.1	12.0
	F9, pph	40.5	40.9
	F10, pph	60.3	54.7
	C5, vol%	7.22	6.19

The PHEF test calculations are shown in Attachment A and summarized in Table 2 below.

TABLE 2:

Test	Measurd ^A O2 conc % wt (C1)	Calcu. ^B Fpred1, pph	Corre. Cal ^C Fpred2, pph	Calcu. ^D O2 Con; % (C6)	Corre. ^E Calcu. O2,% (C7)	% error ^F in Calcu. O2, %	%error in ^G Corr.Calc. O2, %
1	4.55	7.89	8.67	3.78	4.09	-16.92	-10.11
2	4.96	8.78	9.29	4.18	4.38	-15.72	-11.69

Where,

- A. Measured O2 concentration computed in weight %.
- B. Calculated Air Flow (Fpred1) based on the corrected air flow.
- C. Corrected Calculated Air Flow (Fpred2) based on the transmitter zero error.
- D. Calculated Oxygen concentration, wt% (C6) from Fpred1.
- E. Corrected Calculated Oxygen Concentration wt% (C7) from Fpred2
- F. % error in Calculated Oxygen Concentration (C6) compared to measured O2 concentration (C1).
- G. % error in Corrected Calculated Oxygen Concentration (C7) compared to measured O2 concentration (C1).

Conclusion:

The method was tested at -2 and -4 inwc of reference pressure. Based on the two test results, it seems that the suggested method works. The procedure was mainly evaluated at 40 pph of nitrogen purge to the PR. The Kurz flow transmitter failure recently, prevented to test the method at low purge rate (less than 40 pph). The flow through the points of leakage at the PHEF is determined to be turbulent. The measured exponent for the ΔP term at PHEF is 0.425, which is slightly out of expected range. Therefore, It is essential to characterize the air inleakage as a function of ΔP for DWPF.

References:

1. H. B. Shah, LABORATORY NOTEBOOKS, DPSTN-4671 AND WSRC-NB-90-178.
2. R. A. Jacobs, "RESPONSE OF DWPF THERMAL FLOWMETERS TO COMPOSITION CHANGE- EFFECT ON O2 DETERMINATION IN SPC", Savannah River Site Document, WSRC-TR-92-0069, February 3, 1992.

Attachment A

The method and algorithm tested at PHEF are described below. In order to counter check the algorithm, the system was allowed to reach steady-state after a six fold increase in the vacuum. Note that this step is not required at DWPF. During the test at the PHEF,

- (1) Organic Evaporator (OE) and Organic Evaporator Condenser Decanter (OECD) were valved out.
- (2) The Precipitate Reactor (PR) vacuum breakers were valved out.
- (3) All the level probe purges were shut off.
- (4) The PR pressure transmitter was zeroed before the test.

Step 1

- Precipitate Reactor (PR) was set at -2 inwc. (referred as reference pressure).
- The nitrogen purge flow to the PR was maintained at 40 pph.
- Air was bleed into the system such that the Oxygen Concentration at the Vent Condenser exit would be a minimum of 4%.
- System was allowed to reach steady-state, where the Oxygen Concentration did not change. (it took approximately two to three hours.)
- When the system reached steady state, following parameters were measured.

Precipitate Reactor Pressure	(P1)	_____	inwc
Inlet N2 purge flow to the PR	(F1)	_____	pph
Flow at the vent condenser exit	(F2)	_____	pph
Oxygen concentration at VC exit	(C1)	_____	vol%
Precipitate Reactor temperature		_____	°C
Ambient temperature		_____	°C

Step 2

- At the PR pressure of -2 inwc, increased the inlet nitrogen purge to 60 pph. After the PR pressure stabilized, following parameters were measured:

Precipitate Reactor pressure	(P2)	_____	inwc
Inlet N2 purge flow to the PR	(F3)	_____	pph
Flow at the vent condenser exit	(F4)	_____	pph
Oxygen concentration at VC exit	(C2)	_____	vol%

Step 3

- With the PR pressure at -2 inwc., decreased the inlet nitrogen to 40 pph. After the PR pressure stabilized, following parameters were measured.

Precipitate Reactor Pressure	(P3)	_____	inwc
Inlet N2 purge flow to the PR	(F5)	_____	pph
Flow at the vent condenser exit	(F6)	_____	pph
Oxygen concentration at VC exit	(C3)	_____	vol%

Step 4

- Increased the PR pressure to -12 inwc with the inlet nitrogen purge flow at 40 pph. After the PR pressure stabilized to -12 inwc., following parameters were measured.

Precipitate reactor pressure	(P4)	_____	inwc
Inlet N2 purge flow to the PR	(F7)	_____	pph
Flow at the vent condenser exit	(F8)	_____	pph
Oxygen concentration at VC exit	(C4)	_____	vol%

Step 5

- The system was allowed to arrive at steady-state at -12 inwc. At steady state, following parameters were measured.

Precipitate Reactor Pressure	(P5)	_____	inwc
Inlet N2 purge flow to the PR	(F9)	_____	pph
Flow at the VC exit	(F10)	_____	pph
Oxygen concentration at VC exit	(C5)	_____	vol%
Precipitate Reactor temperature		_____	°C
Ambient temperature		_____	°C

CALCULATIONS:

The computations below represent the Air Inleakage Test #1 conducted at PHEF [1].

- Calculate air flow (X1) from Nitrogen purge to the PR @ -2 inwc (P1) and @ 40 pph (F1).

$$\text{Oxygen Concentration (C1)} = 4.00\% \text{ Vol} = 4.5455 \% \text{ weight}$$

$$X1 = \text{air flow in pph}$$

$$\frac{0.233X1}{F1 + X1} = 0.045455$$

$$X1 = 9.86 \text{ pph}$$

Calculate air flow (X2) from Nitrogen purge to the PR @ -12 inwc (P5) and @40 pph (F9).

$$\text{Oxygen Concentration (C5)} = 7.22\% \text{ Vol} = 8.1672 \% \text{ weight}$$

$$X2 = \text{air flow in pph}$$

$$\frac{0.233X_2}{F_9 + X_2} = 0.081672$$

$$X_2 = 21.86 \text{ pph}$$

$$\begin{aligned} \Delta \text{ Flow} &= X_2 - X_1 \\ &= 21.86 - 9.86 = 12.00 \text{ pph} \end{aligned}$$

- (2) Calculate predicted Flow from difference in pressure.

$$\begin{aligned} F_{\text{pred from } \Delta \text{ Flow}} &= \frac{(X_2 - X_1)}{(P_5/P_1)^{0.425} - 1} \\ &= \frac{12.0}{(12/2)^{0.425} - 1} \\ &= 8.28 \text{ pph} \end{aligned}$$

A 0.3 inch zero error of Pressure Transmitter was detected before the start up of the test.

$$\begin{aligned} \text{Corrected } F_{\text{pred}} &= \frac{(X_2 - X_1)}{(P_5/P_1)^{0.425} - 1} \\ &= \frac{12.0}{(12.3/2.3)^{0.425} - 1} \\ &= 9.14 \text{ pph} \end{aligned}$$

- (3) Calculate vapor density in the PR from change in the purge rate and the exhaust flow.

$$\begin{aligned} \text{Volu. Purge FR } (\Delta V^*) &= [(F_3 - F_1)/N_2 \text{ MW}] * (359 \text{ ft}^3/\text{lbmole}) * (T_2/T_1^{\circ}\text{K}) \\ &= (60.2 - 40.7/28) * 359 * 298/273 = 273 \text{ ft}^3/\text{h} \end{aligned}$$

$$\begin{aligned} \text{Where, } T_2 &= \text{PR temperature, } ^{\circ}\text{K} \\ T_1 &= 273 ^{\circ}\text{K} \end{aligned}$$

$$\begin{aligned} \text{Vapor density} &= \frac{(F_4 - F_2)}{\Delta V^*} \\ &= 70.8 - 48.9/273 \\ &= 0.08022 \text{ lbs/ft}^3 \\ &= 12.47 \text{ ft}^3/\text{lbs} \end{aligned}$$

- (4) Calculate corrected air flow based on the vapor density and air density.

$$\begin{aligned} \text{Volu. Air flowrate} &= (F_8 - F_2) * \text{Vapor density} \\ &= (58.8 - 48.9) * 12.47 = 123.45 \text{ ft}^3/\text{hr} \end{aligned}$$

$$\begin{aligned} \text{Air density} &= \frac{M_{\text{Wair}} * 273}{359 * (\text{Ambient Temp.} + 273^{\circ}\text{K})} \end{aligned}$$

$$= 0.07278 \text{ lbs/ft}^3$$

Where,

$$\begin{aligned} \text{MW Air} &= 29 \text{ Lb/Lbmole} \\ \text{Ambient Temp } ^\circ\text{K} &= 30 \text{ } ^\circ\text{C} \end{aligned}$$

$$\begin{aligned} \text{Corrected } \Delta \text{ air flow} &= (\text{Volumetric air flowrate}) (\text{Air density}) \\ &= 123.45 * 0.07278 \\ &= 8.98 \text{ pph} \end{aligned}$$

- (5) Compute the Calculated Predicted Flow based on the corrected air flow.

$$\begin{aligned} \text{Calculated Flow, } F_{\text{Pred1}} &= \frac{\text{Corrected } \Delta \text{Air}}{(P_4/P_1)^{0.425} - 1} \\ &= \frac{8.98}{(12/2)^{0.425} - 1} = 7.89 \text{ pph} \dots\dots\dots (a) \end{aligned}$$

For 0.3 inwc zero error of pressure transmitter

Corrected Calculated

$$\begin{aligned} \text{Flow, } F_{\text{Pred2}} &= \frac{\text{Corrected } \Delta \text{air}}{(P_4/P_1)^{0.425} - 1} \\ &= \frac{8.98}{(12.3/2.3)^{0.425} - 1} \\ &= 8.67 \text{ pph} \dots\dots\dots (b) \end{aligned}$$

- (6) Compute the Calculated Oxygen Concentration based on the calculated predicted flow.

From equation a

$$\begin{aligned} \text{Calculated Oxygen (C6)} &= \frac{0.233 * F_{\text{Pred1}}}{F_1 + F_{\text{Pred1}}} \\ &= \frac{0.233 * 7.89}{40.7 + 7.89} \\ &= 3.78\% \text{ W} \end{aligned}$$

From equation b

$$\begin{aligned} \text{Corrected Calculated (C7)} &= \frac{0.233 * F_{\text{Pred2}}}{F_1 + F_{\text{Pred2}}} \\ \text{Oxygen} &= \frac{0.233 * 8.67}{40.7 + 8.67} \\ &= 4.09\% \text{ W} \end{aligned}$$

(7) Actual Oxygen Concentration (C1) Measured @ VC exit = 4.55%W

$$\begin{aligned}\text{Error in Calculated Oxygen} &= +/\frac{(C1-C6)}{C1} * 100 \\ &= (4.55 - 3.78) / 4.55 * 100 \\ &= -16.92\%\end{aligned}$$

$$\begin{aligned}\text{Error in Corrected calculated Oxygen} &= +/\frac{(C1-C7)}{C1} * 100 \\ &= (4.55 - 4.09) / 4.55 * 100 \\ &= -10.11\%\end{aligned}$$

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