MOTIVA

MOTIVA PAMC Sulfiding Low Temperature TGTU Catalyst

Team Members	Special Thanks
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Port Arthur Manufacturing Complex Sulfiding Low Temperature TGTU Catalyst

Abstract

In November 2023, Motiva performed the TGTU sulfiding procedure presented and discussed at Brimstone 2023 by ASRL, Rob Marriott, Chris Lavery, and Michael Huffmaster. This Sulfiding Procedure for Low Temperature TGTU Catalyst utilizes the sulfiding reaction exotherm while also preventing H2S starvation in the lower part of the reactor bed while sulfiding. With Reactor Inlet Temperature at ~165°F, sulfiding H2S (acid gas) was first introduced observing an exotherm followed by the introduction of H2. Reactor Inlet Temperature was then slowly ramped up while controlling the sulfiding exotherm with changes in sulfiding AG flow and H2 flow. With Reactor Inlet Temperatures in the 300-315°F range, the desired 575-600°F reactor bed temperatures were achieved thus completing the sulfiding steps. Performance of the TGTU Reactor has been very good since startup.

Background

The Motiva Port Arthur Refinery is part of the Port Arthur Manufacturing Complex processing over 650 MBPD of crude oil and total of >725 MBPD of feedstocks making it the largest Refinery in the Americas and 7th largest in the world. The Sulfur Processing Facility is one of the largest in the world that is part of a Refinery at ~2500 LTPD. There are 6 SRU's and 5 TGTU's processing the Sulfur for the Refinery's requirements.

To improve energy efficiency, the 5 TGTU's have been changed out from C234 to either C834 or C934 during the latest turnarounds. C934 has been installed once it was commercially available. The oldest TGTU's (TGTU1 and TGTU2) also have a combination of steam preheater with hot oil heater. The newest TGTU's use 600 psig superheated steam for preheat.

The C934 Low Temperature Catalyst offers the potential to shutdown the Hot Oil Heaters on TGTU1 and TGTU2 due to the lower Reactor Inlet Temperature (RIT) requirements. Catalyst sulfiding and end-of-life

RIT requirements may need the Hot Oil Heater to remain in service or change the heater to 600 psig superheated steam as another option.

Brimstone 2023 included presentations and research papers by ASRL, Rob Marriott, Chris Lavery, and Michael Huffmaster discussing an alternative catalyst sulfiding procedure that could utilize the TGTU Catalyst Sulfiding Exotherm to assist the TGTU Reactor Preheater in providing the required duty/temperature for sulfiding. This approach could also potentially prevent H2S starvation in the bottom of the bed while sulfiding thus improving catalyst activity after sulfiding.

After discussions internally and with ASRL, this alternative approach was approved for the oldest and smallest TGTU1 Catalytic Reactor. TGTU1 receives SRU Tail Gas from two SRU's using a combination of steam preheat exchanger and hot oil heat exchanger.

In November 2023, the sulfiding of the TGTU1 Low Temperature Catalyst was successfully performed with the procedure discussed at Brimstone 2023. With low RIT of ~165°F, H2S was first introduced (acid gas) observing an exotherm. Once complete, H2 was added while controlling the exotherm. RIT was then slowly ramped up to the 300-315°F range. The desired 560-615°F reactor temperature profile was achieved and held for 5-6 hours thus achieving the complete sulfiding steps. Performance of the TGTU Reactor has been very good since startup.

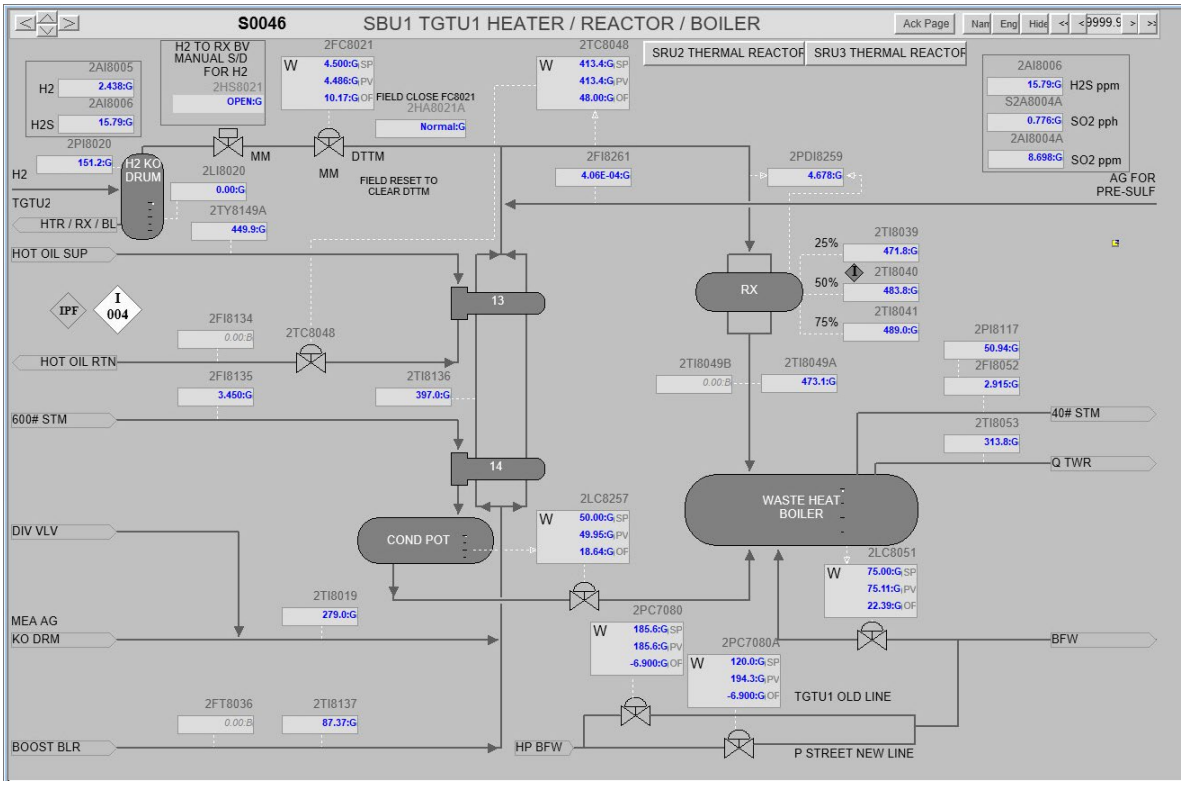
Sulfiding Low Temperature TGTU Catalyst – Lessons Learned

There were two attempts of the Low Temperature Sulfiding Procedure with H2S and H2. The second attempt was very successful.

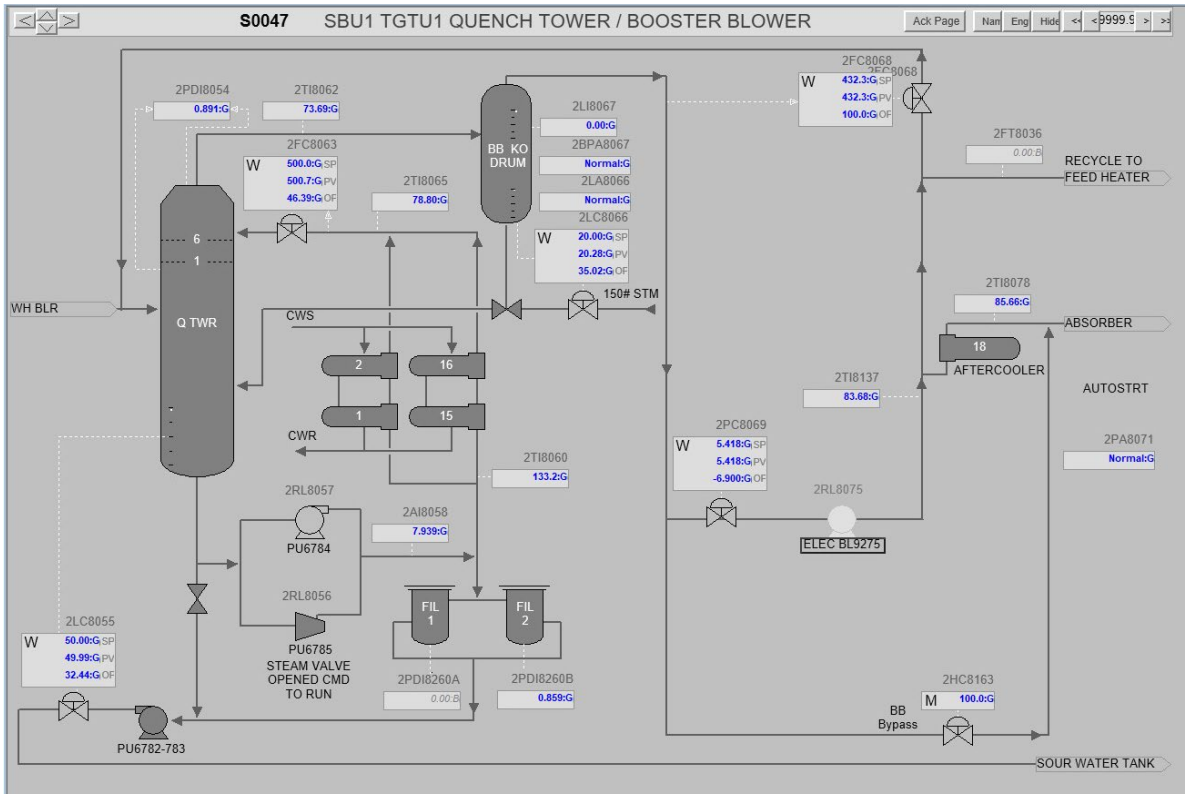
The first attempt observed a very strong exotherm which immediately required halting sulfiding to cool the Reactor, regroup, and start with a lower RIT. The first controlled test of this procedure started with RIT <300°F, introduction of Sulfiding H2S, ramp-up of RIT to ~440°F, and then introduction of H2. The observed exotherm was very strong requiring sulfiding to be stopped and cooling of the reactor.

After seeing the strong exotherm that could be obtained, the decision was made by the Team to add both H2S and H2 while at low RIT and then slowly ramp the RIT to observe the desired Reactor Bed Temperatures, which proved very successful. Reduction of H2 and/or H2S flows would be used to control the exotherm. During the first attempt, the Team proved that the exotherm could be quickly controlled by adjusting the H2S and H2.

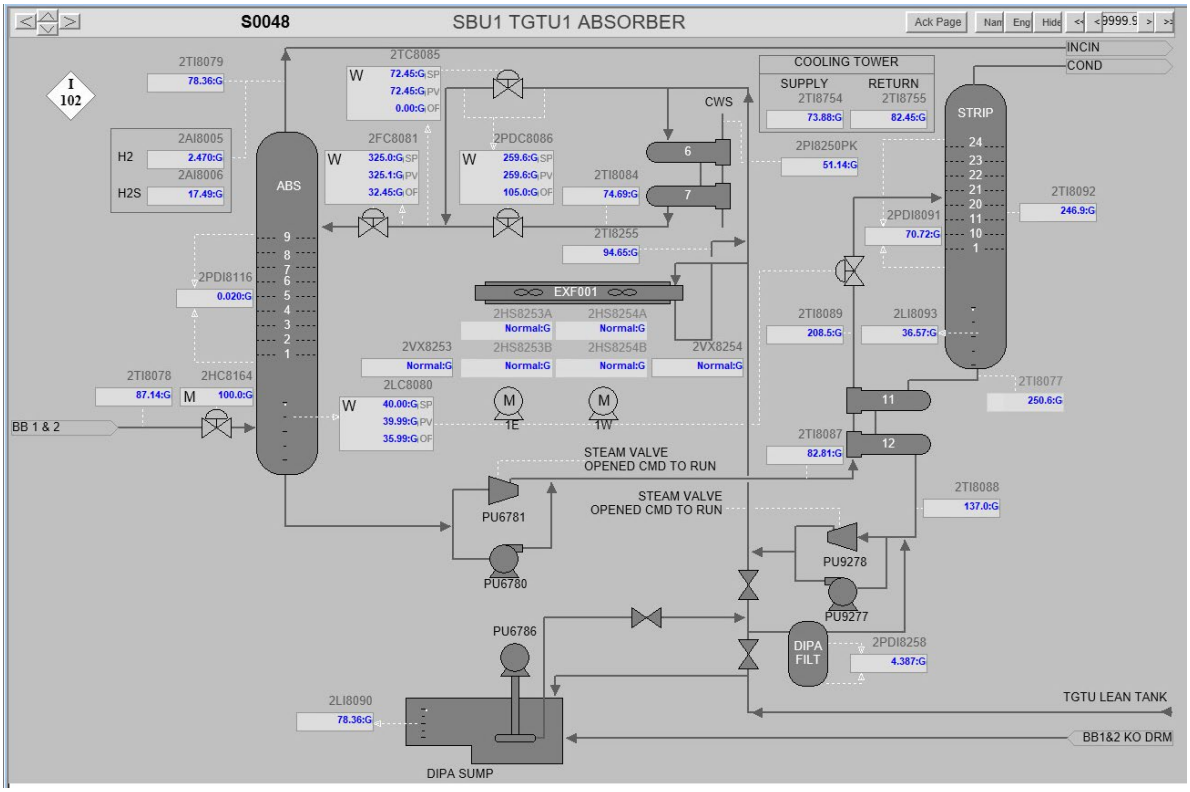
TGTU1 Steam Heat Exchanger, Hot Oil Heat Exchanger, Reactor, and Waste Heat Boiler



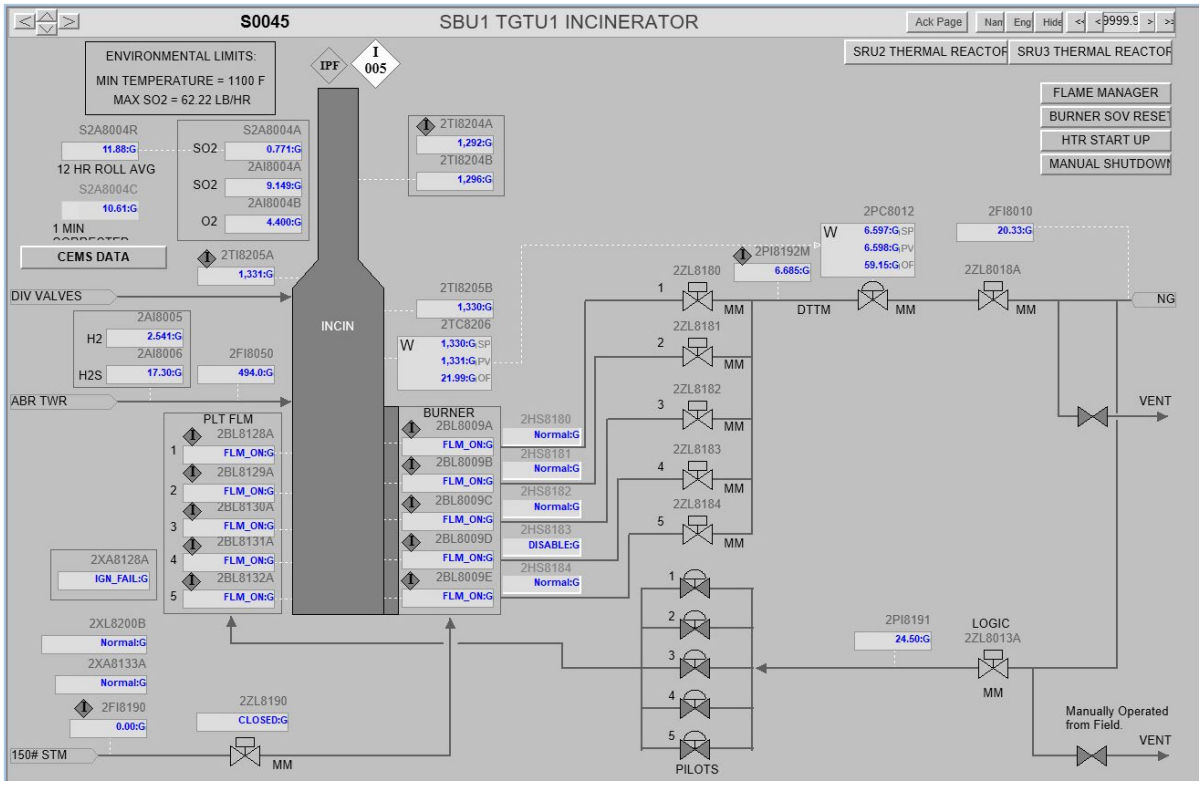
TGTU1 Quench Tower



TGTU1 Absorber and Regenerator with Recycle Acid Gas



TGTU1 Incinerator



Sulfiding Low Temperature TGTU Catalyst - Timeline

- Nov 4th
    - 7:00 PM RIT ~165°F, SRU in Natural Gas sweep Tail Gas through TGTU, Sulfiding AG 10MSFCH
    - 8:30 PM Sulfiding AG increased to 15 MSCFH
    - 9:00 PM TGTU AG Recycle increase observed and Absorber H2S observed
- Nov 5th
    - 02:00 AM H2 Introduced at 5 MSCFH
    - 03:30 AM RIT slow ramp-up initiated from ~165°F, increased Sulfiding AG to 15 MSCFH
    - 05:45 AM RIT 275°F, 10% Bed Exotherm observed
    - 06:30 AM RIT 282°F, strong 10% Bed exotherm, reduced Sulfiding AG to 10.5 MSCFH
    - 07:00 AM RIT 288°F, 10%/50% Bed exotherms
    - 07:35 AM RIT 290°F, 10%/50% Bed exotherms, reduced Sulfiding AG to 8.5 MSCFH
    - 08:30 AM RIT 300°F, 10%/50%/75% Bed exotherms, increased H2 to 8 MSCF with observed H2 reduction
    - 09:30 AM RIT 308°F, 10%/50%/75% Bed strong exotherms, reduced Sulfiding AG to 5.8 MSCFH and H2 to 3.5 MSCFH
    - 10:30 AM RIT 313°F, 10%/50%/75%/ROT Bed exotherms, maintained Sulfiding AG at 5.8 MSCFH and reduced H2 to 0.0 MSCFH
    - 11:15 AM 10% Bed Exotherm peaked and turned
    - 11:30 AM RIT 310°F, re-introduced H2 at 1.8 MSCFH and slowly ramped up to 5.0 MSCFH
    - 8:30 PM SRU2 AAG introduction, reduced Sulfiding AG
    - 11:55 PM SRU3 AAG introduction

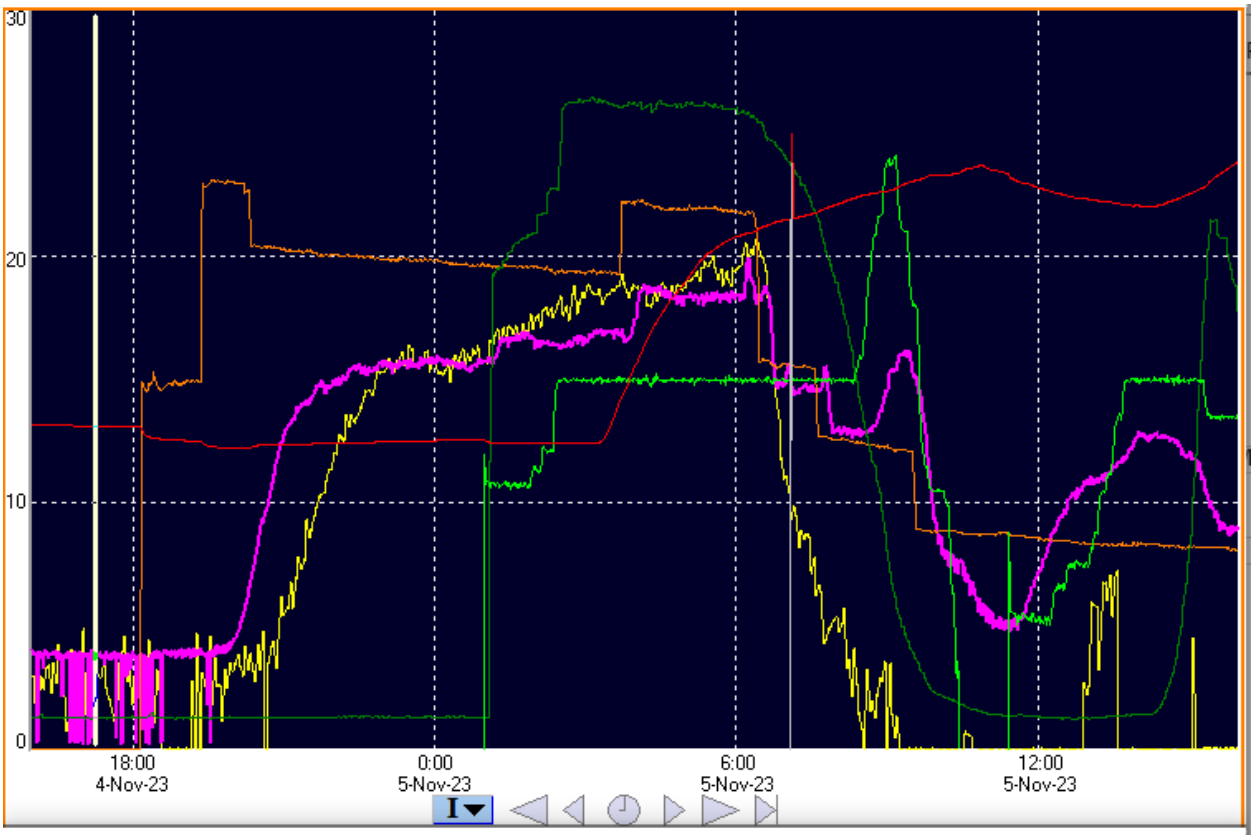
Sulfiding Low Temperature TGTU Catalyst - Timeline (continued)

Nov 4th

6:15 PM, RIT ~175°F,

SRU in Natural Gas sweep

Tail Gas through TGTU1



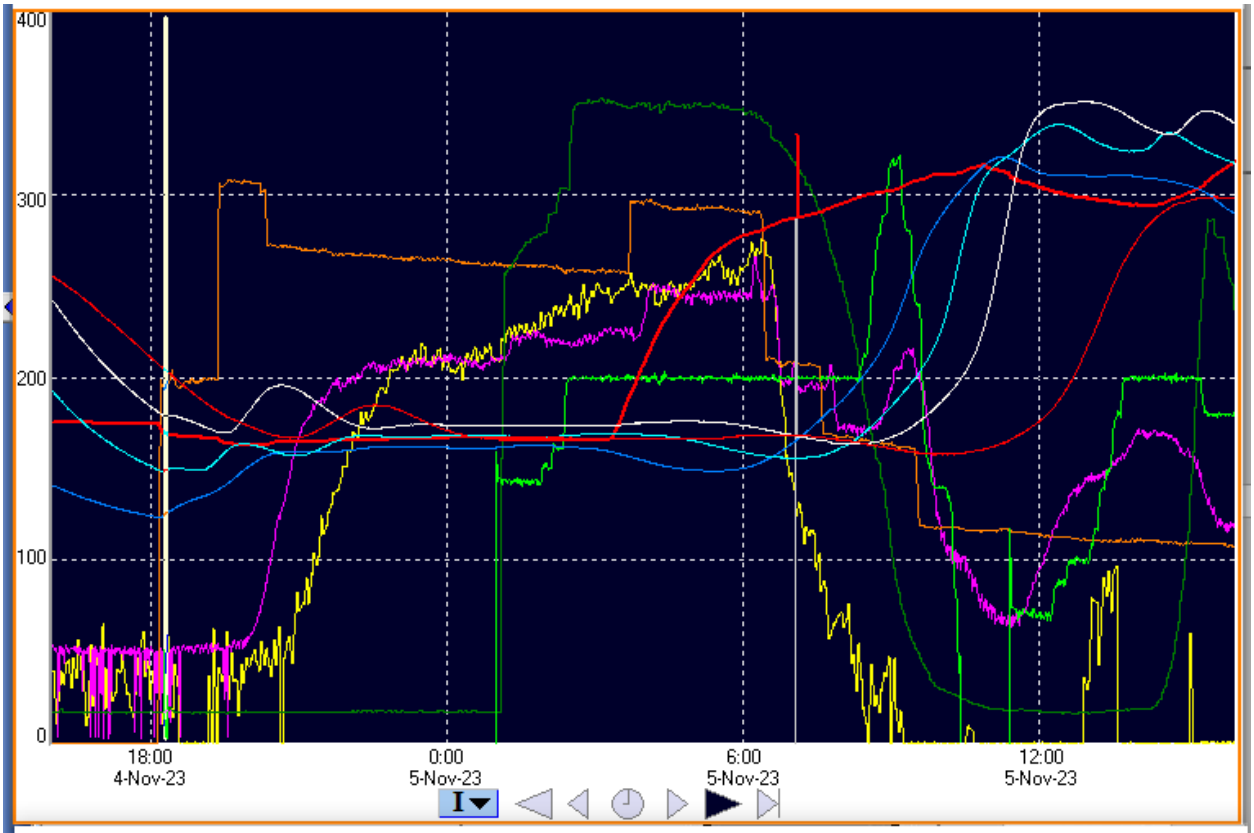
Detail for on 4-Nov-23 18:15

Point Name	Point Description	Eng Units	Value:Qual	Low ... High
2AI8006.PV@PARPI	ABSORBER OFFGAS PCT H2S	PPM	5.521:G	0 ... 80
2FI8102.PV@PARPI	H2S RECYCLE TO SRU	MSCFH	3.912:G	0 ... 30
2FI8261.PV@PARPI	ACID GAS FOR PRESUFIDING	MSCFH	0.002:G	0 ... 20
2AI8005.PV@PARPI	ABSORBER OFFGAS PCT H2	PCT	0.209:G	0 ... 5
2FC8021.PV@PARPI	HYDROGEN TO CAT REACTOR	MSCFH	-2.367:G	0 ... 10
2TC8048.PV@PARPI	CAT REACTOR INLET	DEGF	175.0:G	0 ... 400

Sulfiding Low Temperature TGTU Catalyst - Timeline (continued)

Nov 4th

7:00 PM, Sulfiding AG 10 MSFCH



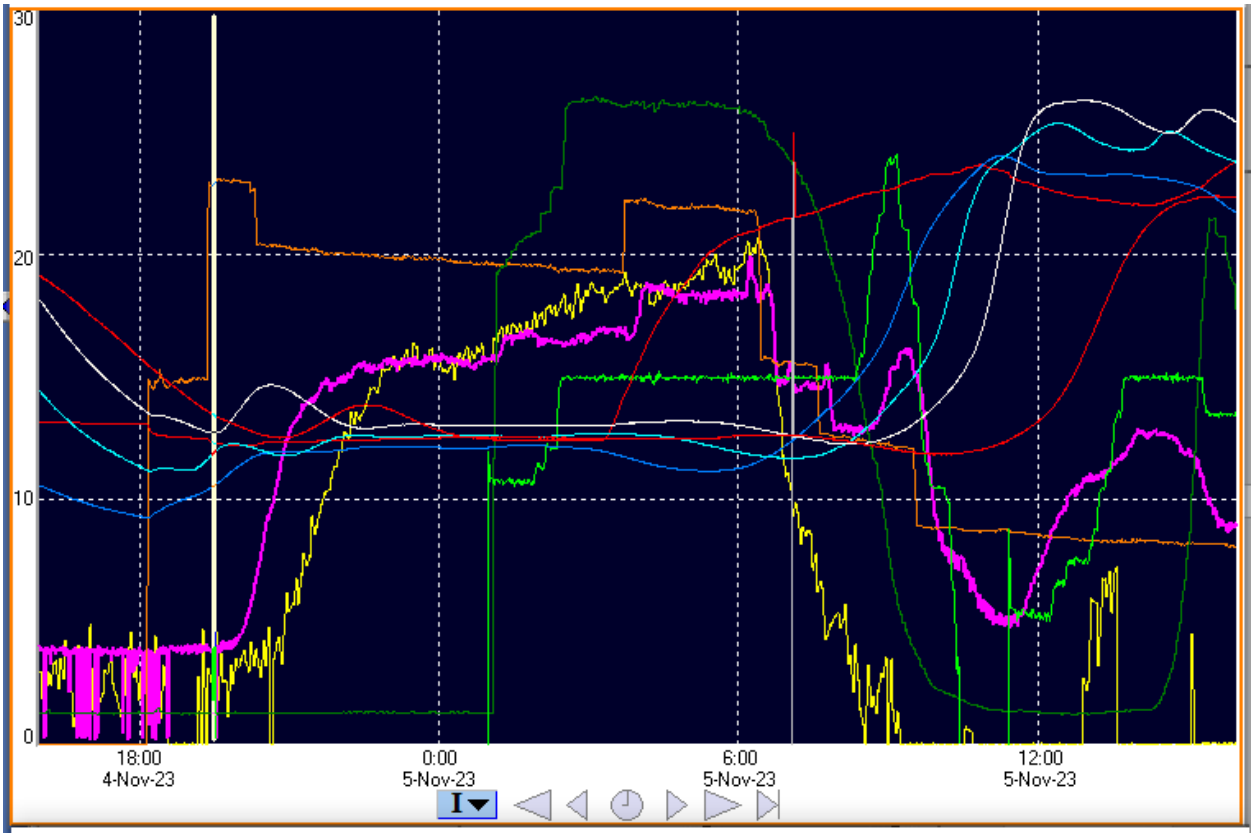
Detail for on 4-Nov-23 19:17

Point Name	Point Description	Eng Units	Value:Qual	Low ... High
2AI8006.PV@PARPI	ABSORBER OFFGAS PCT H2S	PPM	7.735:G	0 ... 80
2FI8102.PV@PARPI	H2S RECYCLE TO SRU	MSCFH	0.243:G	0 ... 30
2FI8261.PV@PARPI	ACID GAS FOR PRESUFIDING	MSCFH	9.726:G	0 ... 20
2AI8005.PV@PARPI	ABSORBER OFFGAS PCT H2	PCT	0.219:G	0 ... 5
2FC8021.PV@PARPI	HYDROGEN TO CAT REACTOR	MSCFH	-2.375:G	0 ... 10
2TC8048.PV@PARPI	CAT REACTOR INLET	DEGF	169.6:G	0 ... 400
2TI8039.PV@PARPI	CAT REACTOR- 25% LEVEL	DEGF	219.9:G	0 ... 700
2TI8040.PV@PARPI	CAT REACTOR- 50% LEVEL	DEGF	261.5:G	0 ... 700
2TI8041.PV@PARPI	CAT REACTOR- 75% LEVEL	DEGF	313.5:G	0 ... 700
2TI8049A.PV@PARPI	CAT RX OUTLET TEMP	DEGF	357.9:G	0 ... 700

Sulfiding Low Temperature TGTU Catalyst - Timeline (continued)

Nov 4th

8:30 PM, Sulfiding AG increased to 15 MSCFH



Detail for on 4-Nov-23 20:29

Point Name	Point Description	Eng Units	Value:Qual	Low ... High
2AI8006.PV@PARPI	ABSORBER OFFGAS PCT H2S	PPM	7.336:G	0 ... 80
2FI8102.PV@PARPI	H2S RECYCLE TO SRU	MSCFH	2.482:G	0 ... 30
2FI8261.PV@PARPI	ACID GAS FOR PRESUFIDING	MSCFH	15.29:G	0 ... 20
2AI8005.PV@PARPI	ABSORBER OFFGAS PCT H2	PCT	0.212:G	0 ... 5
2FC8021.PV@PARPI	HYDROGEN TO CAT REACTOR	MSCFH	-2.326:G	0 ... 10
2TC8048.PV@PARPI	CAT REACTOR INLET	DEGF	164.4:G	0 ... 400
2TI8039.PV@PARPI	CAT REACTOR- 25% LEVEL	DEGF	246.6:G	0 ... 700
2TI8040.PV@PARPI	CAT REACTOR- 50% LEVEL	DEGF	278.1:G	0 ... 700
2TI8041.PV@PARPI	CAT REACTOR- 75% LEVEL	DEGF	297.4:G	0 ... 700
2TI8049A.PV@PARPI	CAT RX OUTLET TEMP	DEGF	314.8:G	0 ... 700

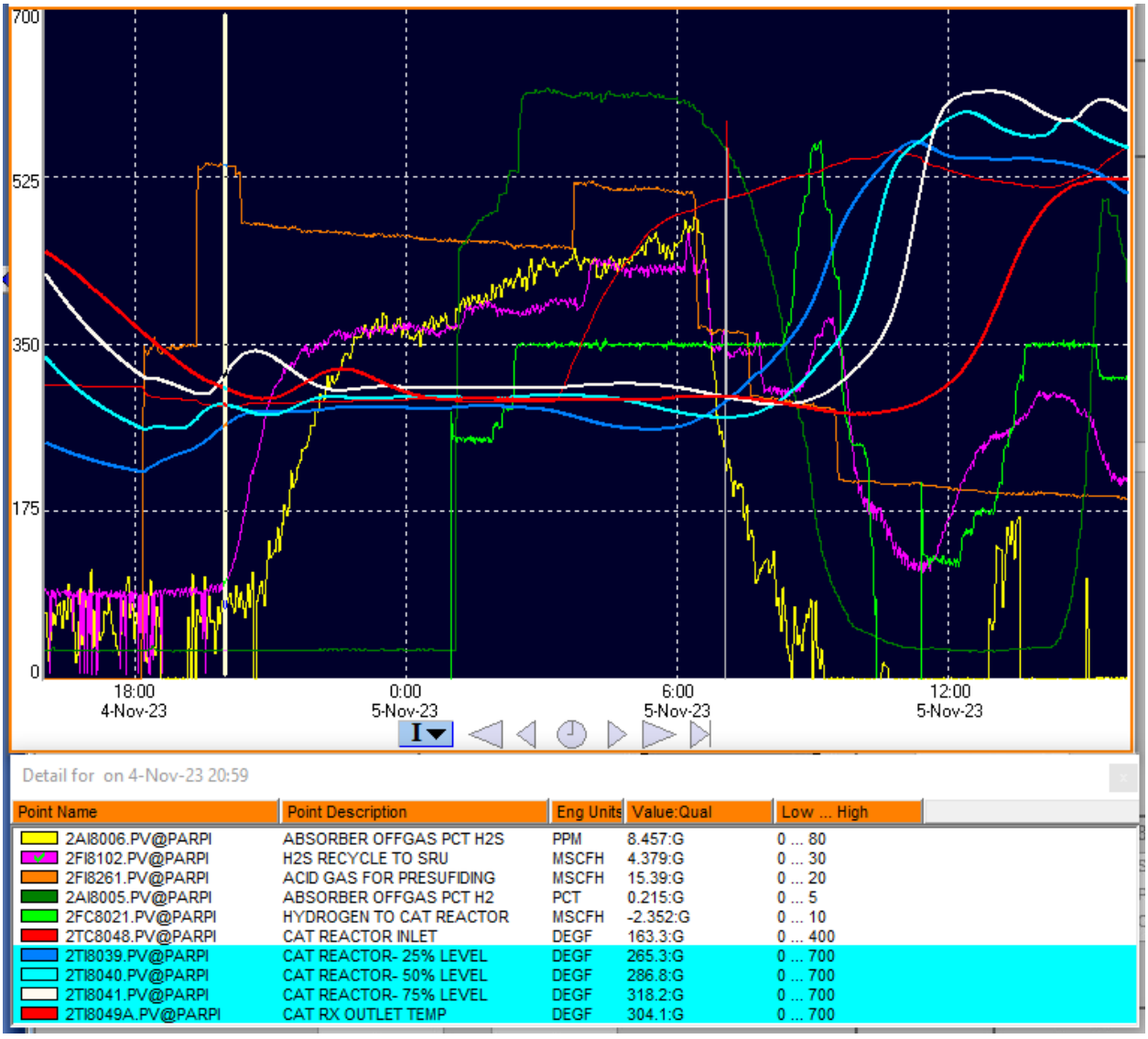
Sulfiding Low Temperature TGTU Catalyst - Timeline (continued)

Nov 4th

9:00 PM

TGTU AG Recycle increase observed

Absorber OH H2S observed



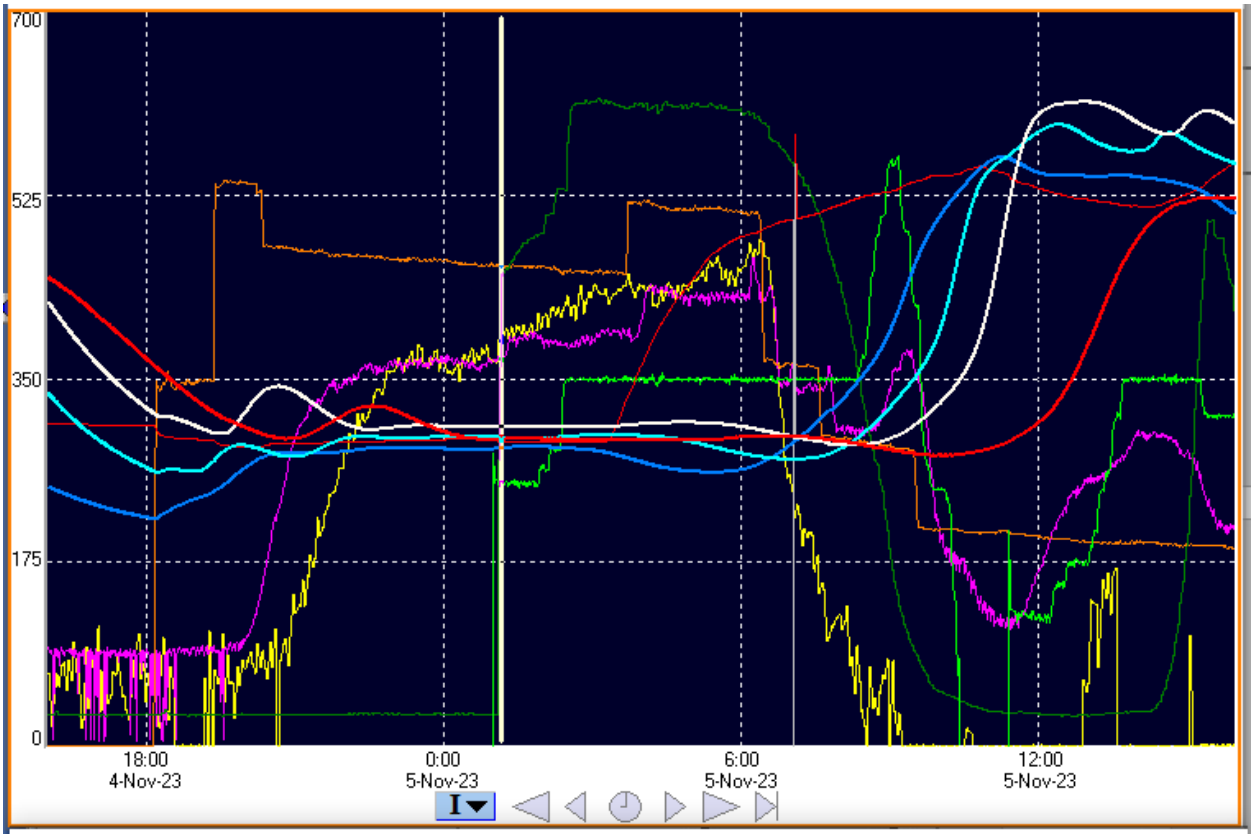
Detail for on 4-Nov-23 20:59

Point Name	Point Description	Eng Units	Value:Qual	Low ... High
2AI8006.PV@PARPI	ABSORBER OFFGAS PCT H2S	PPM	8.457:G	0 ... 80
2FI8102.PV@PARPI	H2S RECYCLE TO SRU	MSCFH	4.379:G	0 ... 30
2FI8261.PV@PARPI	ACID GAS FOR PRESUFIDING	MSCFH	15.39:G	0 ... 20
2AI8005.PV@PARPI	ABSORBER OFFGAS PCT H2	PCT	0.215:G	0 ... 5
2FC8021.PV@PARPI	HYDROGEN TO CAT REACTOR	MSCFH	-2.352:G	0 ... 10
2TC8048.PV@PARPI	CAT REACTOR INLET	DEGF	163.3:G	0 ... 400
2TI8039.PV@PARPI	CAT REACTOR- 25% LEVEL	DEGF	265.3:G	0 ... 700
2TI8040.PV@PARPI	CAT REACTOR- 50% LEVEL	DEGF	286.8:G	0 ... 700
2TI8041.PV@PARPI	CAT REACTOR- 75% LEVEL	DEGF	318.2:G	0 ... 700
2TI8049A.PV@PARPI	CAT RX OUTLET TEMP	DEGF	304.1:G	0 ... 700

Sulfiding Low Temperature TGTU Catalyst - Timeline (continued)

Nov 5th

02:00 AM, H2 Introduced at 5 MSCFH



Detail for on 5-Nov-23 2:09

Point Name	Point Description	Eng Units	Value:Qual	Low ... High
2AI8006.PV@PARPI	ABSORBER OFFGAS PCT H2S	PPM	43.85:G	0 ... 80
2FI8102.PV@PARPI	H2S RECYCLE TO SRU	MSCFH	15.69:G	0 ... 30
2FI8261.PV@PARPI	ACID GAS FOR PRESUFIDING	MSCFH	13.08:G	0 ... 20
2AI8005.PV@PARPI	ABSORBER OFFGAS PCT H2	PCT	3.211:G	0 ... 5
2FC8021.PV@PARPI	HYDROGEN TO CAT REACTOR	MSCFH	3.608:G	0 ... 10
2TC8048.PV@PARPI	CAT REACTOR INLET	DEGF	166.2:G	0 ... 400
2TI8039.PV@PARPI	CAT REACTOR- 25% LEVEL	DEGF	283.8:G	0 ... 700
2TI8040.PV@PARPI	CAT REACTOR- 50% LEVEL	DEGF	294.4:G	0 ... 700
2TI8041.PV@PARPI	CAT REACTOR- 75% LEVEL	DEGF	304.7:G	0 ... 700
2TI8049A.PV@PARPI	CAT RX OUTLET TEMP	DEGF	292.7:G	0 ... 700

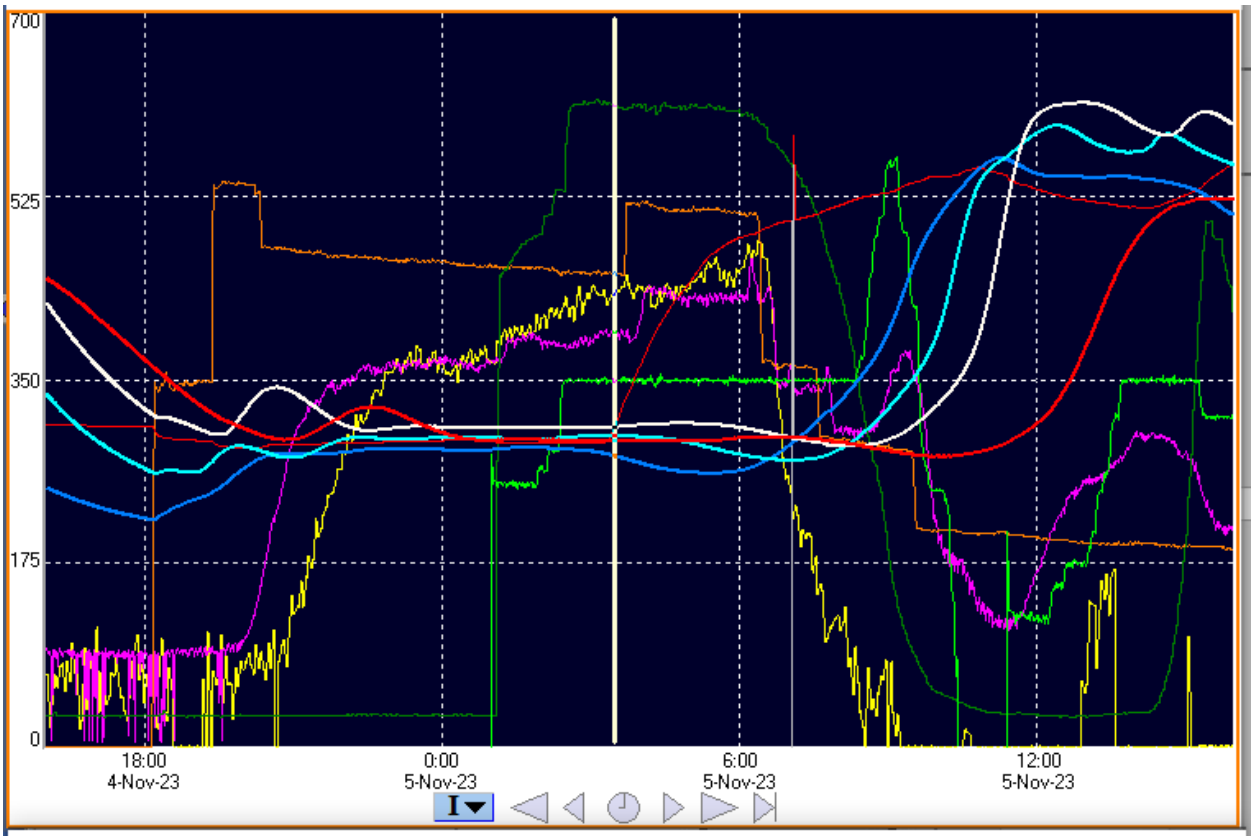
Sulfiding Low Temperature TGTU Catalyst - Timeline (continued)

Nov 5th

03:30 AM

RIT slow ramp-up initiated from ~165°F

Sulfiding AG increased to 15 MSCFH



Detail for on 5-Nov-23 3:30

Point Name	Point Description	Eng Units	Value:Qual	Low ... High
2AI8006.PV@PARPI	ABSORBER OFFGAS PCT H2S	PPM	49.32:G	0 ... 80
2FI8102.PV@PARPI	H2S RECYCLE TO SRU	MSCFH	16.95:G	0 ... 30
2FI8261.PV@PARPI	ACID GAS FOR PRESUFIDING	MSCFH	12.95:G	0 ... 20
2AI8005.PV@PARPI	ABSORBER OFFGAS PCT H2	PCT	4.373:G	0 ... 5
2FC8021.PV@PARPI	HYDROGEN TO CAT REACTOR	MSCFH	4.988:G	0 ... 10
2TC8048.PV@PARPI	CAT REACTOR INLET	DEGF	174.6:G	0 ... 400
2TI8039.PV@PARPI	CAT REACTOR- 25% LEVEL	DEGF	277.5:G	0 ... 700
2TI8040.PV@PARPI	CAT REACTOR- 50% LEVEL	DEGF	297.0:G	0 ... 700
2TI8041.PV@PARPI	CAT REACTOR- 75% LEVEL	DEGF	305.2:G	0 ... 700
2TI8049A.PV@PARPI	CAT RX OUTLET TEMP	DEGF	291.8:G	0 ... 700

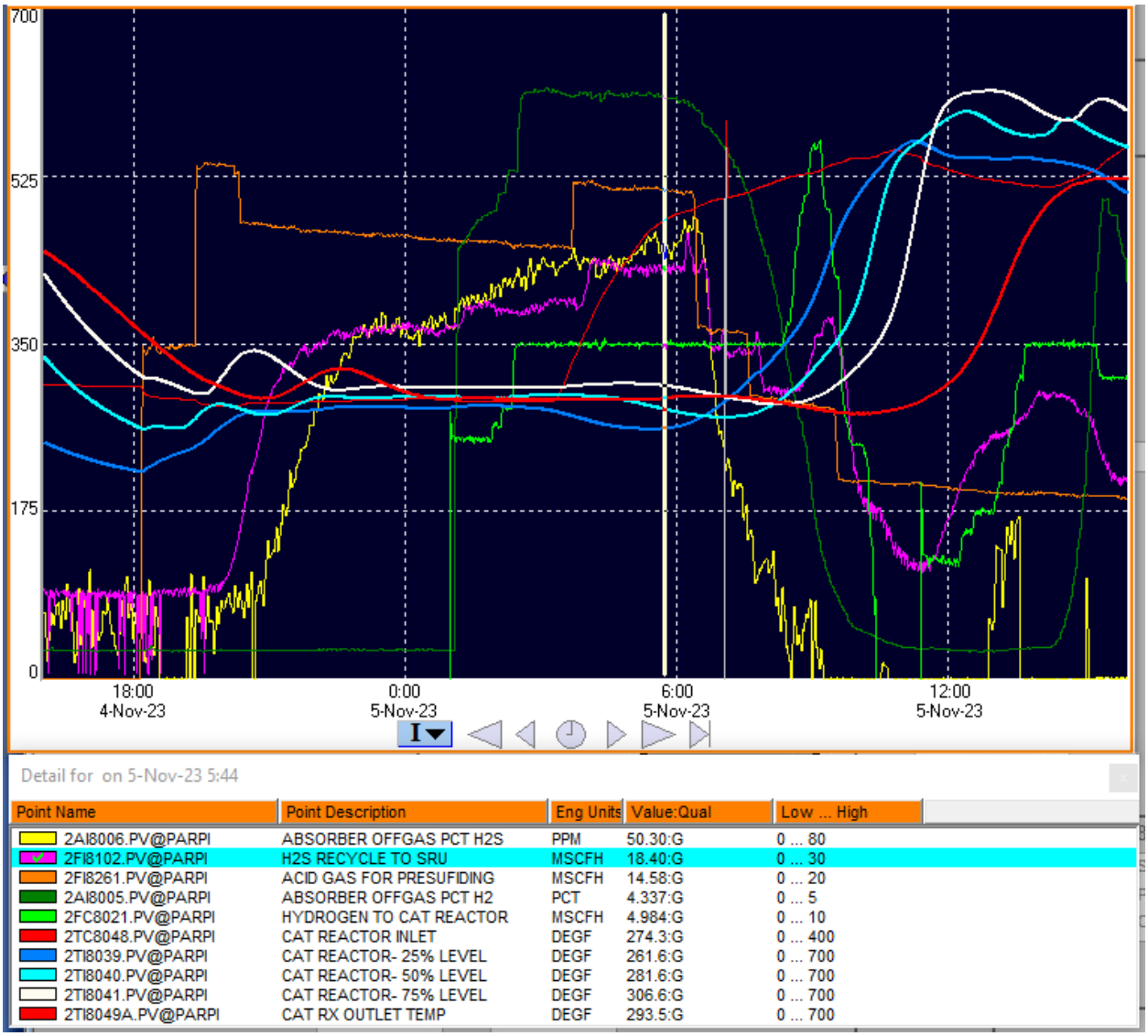
Sulfiding Low Temperature TGTU Catalyst - Timeline (continued)

Nov 5th

05:45 AM

RIT 275°F

10% Bed Exotherm observed



Detail for on 5-Nov-23 5:44

Point Name	Point Description	Eng Units	Value:Qual	Low ... High
2AI8006.PV@PARPI	ABSORBER OFFGAS PCT H2S	PPM	50.30:G	0 ... 80
2FI8102.PV@PARPI	H2S RECYCLE TO SRU	MSCFH	18.40:G	0 ... 30
2FI8261.PV@PARPI	ACID GAS FOR PRESUFIDING	MSCFH	14.58:G	0 ... 20
2AI8005.PV@PARPI	ABSORBER OFFGAS PCT H2	PCT	4.337:G	0 ... 5
2FC8021.PV@PARPI	HYDROGEN TO CAT REACTOR	MSCFH	4.984:G	0 ... 10
2TC8048.PV@PARPI	CAT REACTOR INLET	DEGF	274.3:G	0 ... 400
2TI8039.PV@PARPI	CAT REACTOR- 25% LEVEL	DEGF	261.6:G	0 ... 700
2TI8040.PV@PARPI	CAT REACTOR- 50% LEVEL	DEGF	281.6:G	0 ... 700
2TI8041.PV@PARPI	CAT REACTOR- 75% LEVEL	DEGF	306.6:G	0 ... 700
2TI8049A.PV@PARPI	CAT RX OUTLET TEMP	DEGF	293.5:G	0 ... 700

Sulfiding Low Temperature TGTU Catalyst - Timeline (continued)

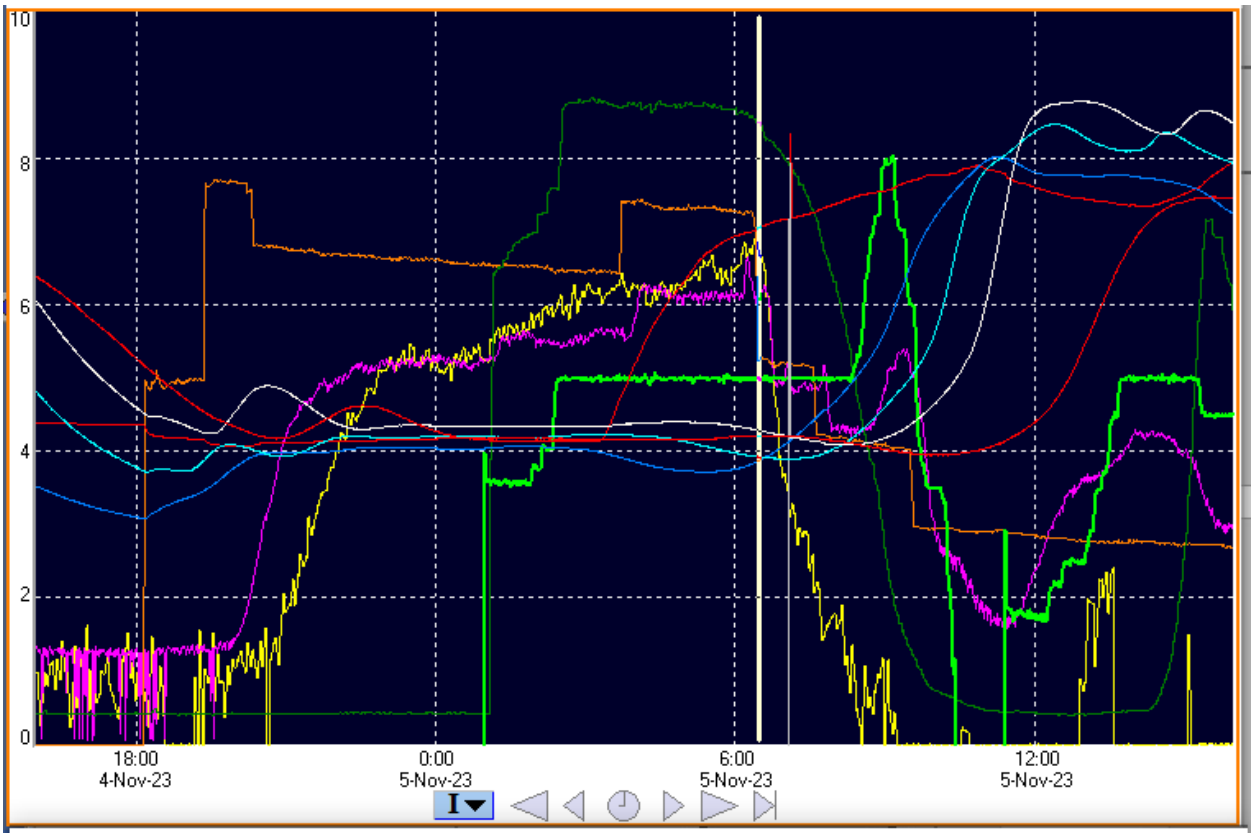
Nov 5th

06:30 AM

RIT 282°F

Strong 10% Bed exotherm starting

Reduced Sulfiding AG to 10.5 MSCFH



Detail for on 5-Nov-23 6:30

Point Name	Point Description	Eng Units	Value:Qual	Low ... High
2AI8006.PV@PARPI	ABSORBER OFFGAS PCT H2S	PPM	53.53:G	0 ... 80
2FI8102.PV@PARPI	H2S RECYCLE TO SRU	MSCFH	18.29:G	0 ... 30
2FI8261.PV@PARPI	ACID GAS FOR PRESUFIDING	MSCFH	10.52:G	0 ... 20
2AI8005.PV@PARPI	ABSORBER OFFGAS PCT H2	PCT	4.245:G	0 ... 5
2FC8021.PV@PARPI	HYDROGEN TO CAT REACTOR	MSCFH	4.992:G	0 ... 10
2TC8048.PV@PARPI	CAT REACTOR INLET	DEGF	282.4:G	0 ... 400
2TI8039.PV@PARPI	CAT REACTOR- 25% LEVEL	DEGF	271.8:G	0 ... 700
2TI8040.PV@PARPI	CAT REACTOR- 50% LEVEL	DEGF	275.2:G	0 ... 700
2TI8041.PV@PARPI	CAT REACTOR- 75% LEVEL	DEGF	300.4:G	0 ... 700
2TI8049A.PV@PARPI	CAT RX OUTLET TEMP	DEGF	295.7:G	0 ... 700

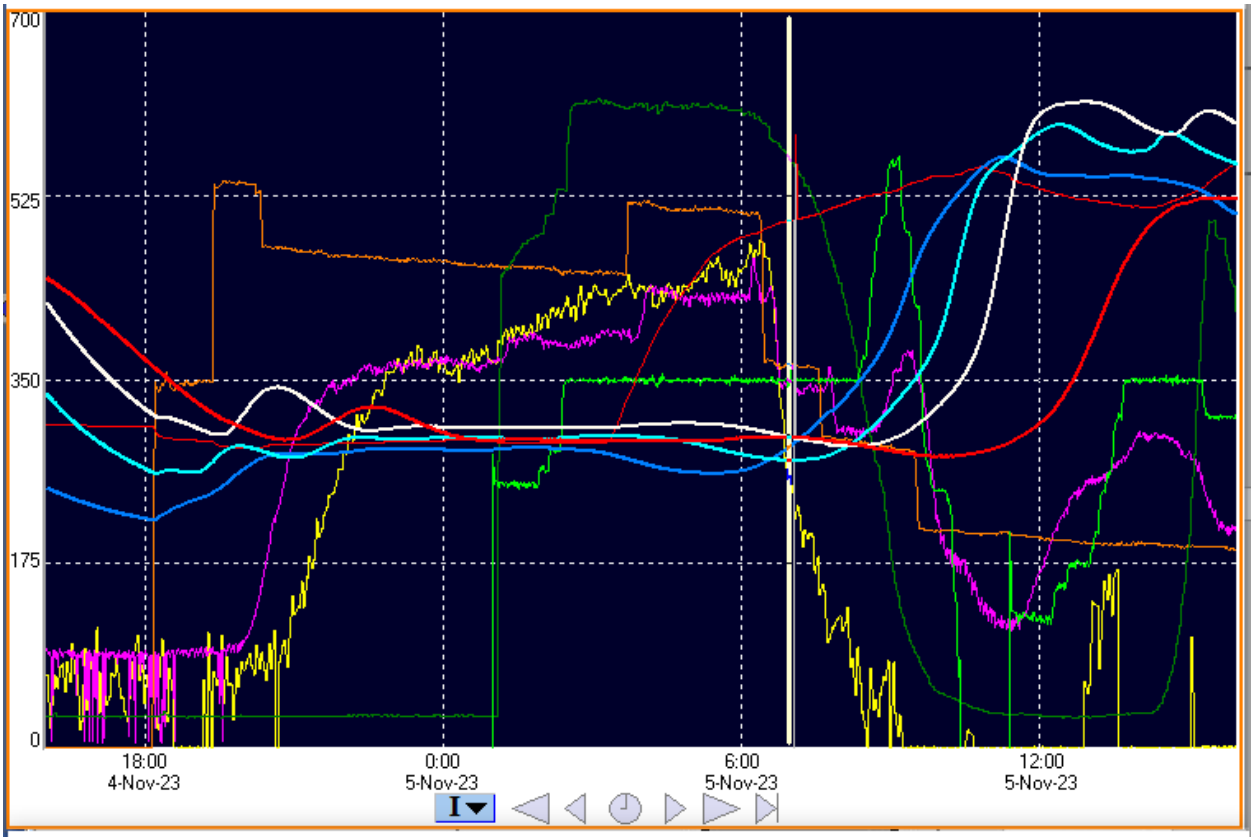
Sulfiding Low Temperature TGTU Catalyst - Timeline (continued)

Nov 5th

07:00 AM

RIT 288°F

10%/50% Bed exotherms



Detail for on 5-Nov-23 7:00

Point Name	Point Description	Eng Units	Value:Qual	Low ... High
2AI8006.PV@PARPI	ABSORBER OFFGAS PCT H2S	PPM	29.43:G	0 ... 80
2FI8102.PV@PARPI	H2S RECYCLE TO SRU	MSCFH	14.99:G	0 ... 30
2FI8261.PV@PARPI	ACID GAS FOR PRESUFIDING	MSCFH	10.42:G	0 ... 20
2AI8005.PV@PARPI	ABSORBER OFFGAS PCT H2	PCT	3.999:G	0 ... 5
2FC8021.PV@PARPI	HYDROGEN TO CAT REACTOR	MSCFH	4.987:G	0 ... 10
2TC8048.PV@PARPI	CAT REACTOR INLET	DEGF	286.7:G	0 ... 400
2TI8039.PV@PARPI	CAT REACTOR- 25% LEVEL	DEGF	286.7:G	0 ... 700
2TI8040.PV@PARPI	CAT REACTOR- 50% LEVEL	DEGF	273.5:G	0 ... 700
2TI8041.PV@PARPI	CAT REACTOR- 75% LEVEL	DEGF	295.7:G	0 ... 700
2TI8049A.PV@PARPI	CAT RX OUTLET TEMP	DEGF	295.2:G	0 ... 700

Sulfiding Low Temperature TGTU Catalyst - Timeline (continued)

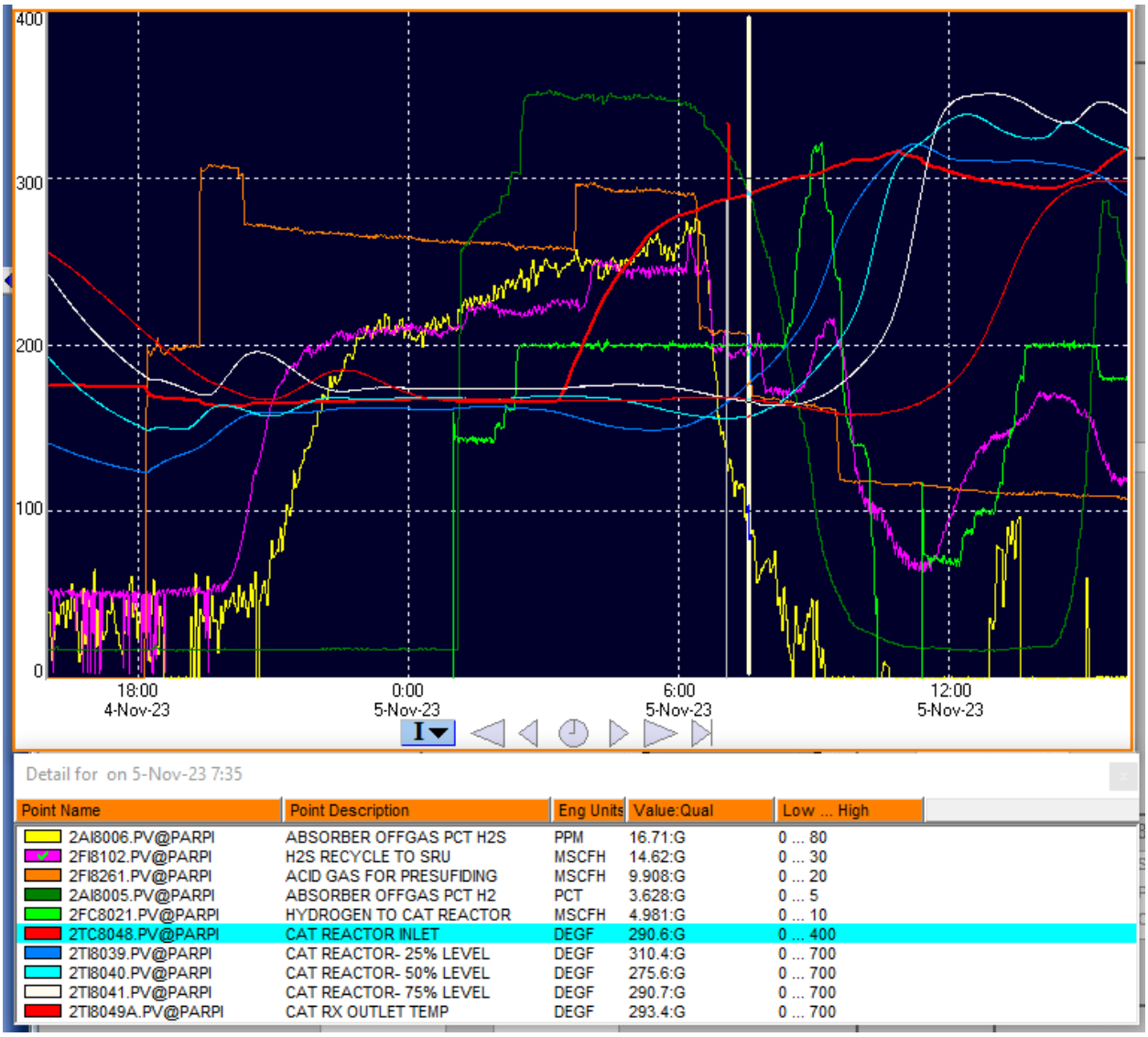
Nov 5th

07:35 AM

RIT 290°F

10%/50% Bed exotherms

Reduced Sulfiding AG to 8.5 MSCFH



Sulfiding Low Temperature TGTU Catalyst - Timeline (continued)

Nov 5th

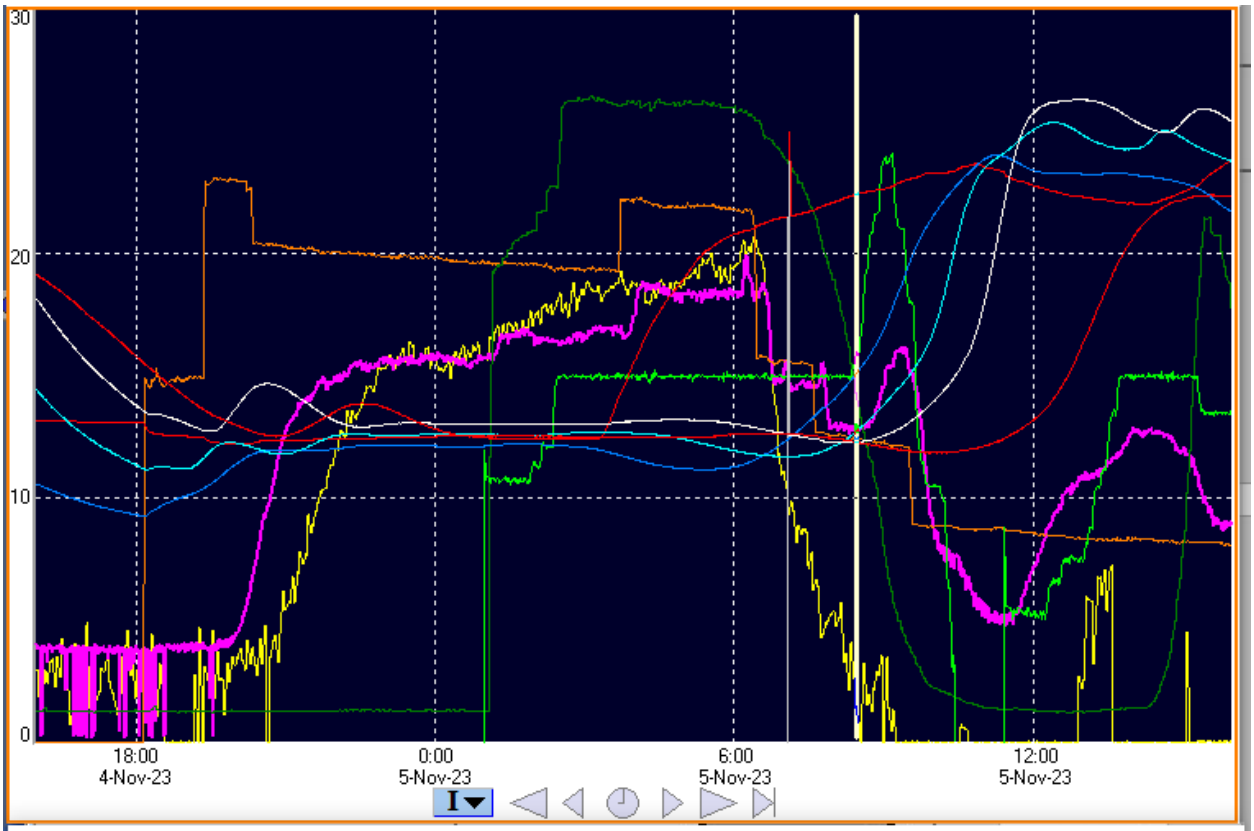
08:30 AM

RIT 300°F

10%/50%/75% Bed exotherms

Observe H2 concentration reduction at Absorber OH

Increased H2 to 8 MSCF



Detail for on 5-Nov-23 8:29

Point Name	Point Description	Eng Units	Value:Qual	Low ... High
2AI8006.PV@PARPI	ABSORBER OFFGAS PCT H2S	PPM	2.643:G	0 ... 80
2FI8102.PV@PARPI	H2S RECYCLE TO SRU	MSCFH	12.83:G	0 ... 30
2FI8261.PV@PARPI	ACID GAS FOR PRESUFIDING	MSCFH	8.305:G	0 ... 20
2AI8005.PV@PARPI	ABSORBER OFFGAS PCT H2	PCT	2.314:G	0 ... 5
2FC8021.PV@PARPI	HYDROGEN TO CAT REACTOR	MSCFH	5.319:G	0 ... 10
2TC8048.PV@PARPI	CAT REACTOR INLET	DEGF	299.8:G	0 ... 400
2TI8039.PV@PARPI	CAT REACTOR- 25% LEVEL	DEGF	353.8:G	0 ... 700
2TI8040.PV@PARPI	CAT REACTOR- 50% LEVEL	DEGF	298.1:G	0 ... 700
2TI8041.PV@PARPI	CAT REACTOR- 75% LEVEL	DEGF	287.5:G	0 ... 700
2TI8049A.PV@PARPI	CAT RX OUTLET TEMP	DEGF	287.1:G	0 ... 700

Sulfiding Low Temperature TGTU Catalyst - Timeline (continued)

Nov 5th

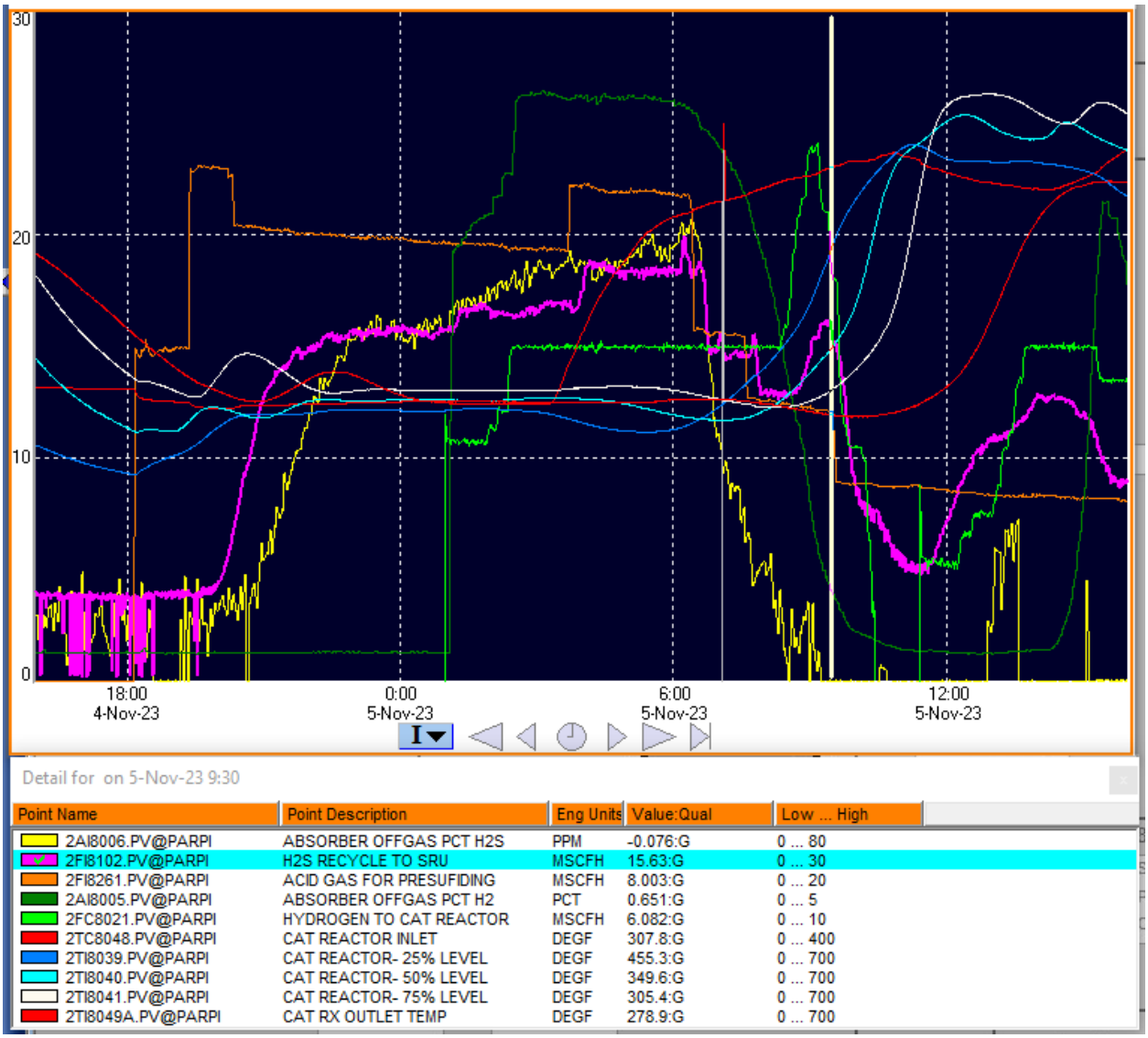
09:30 AM

RIT 308°F

10%/50%/75% **STRONG** Bed exotherms

Reduced Sulfiding AG to 5.8 MSCFH

Reduced H2 to 3.5 MSCFH



Sulfiding Low Temperature TGTU Catalyst - Timeline (continued)

Nov 5th

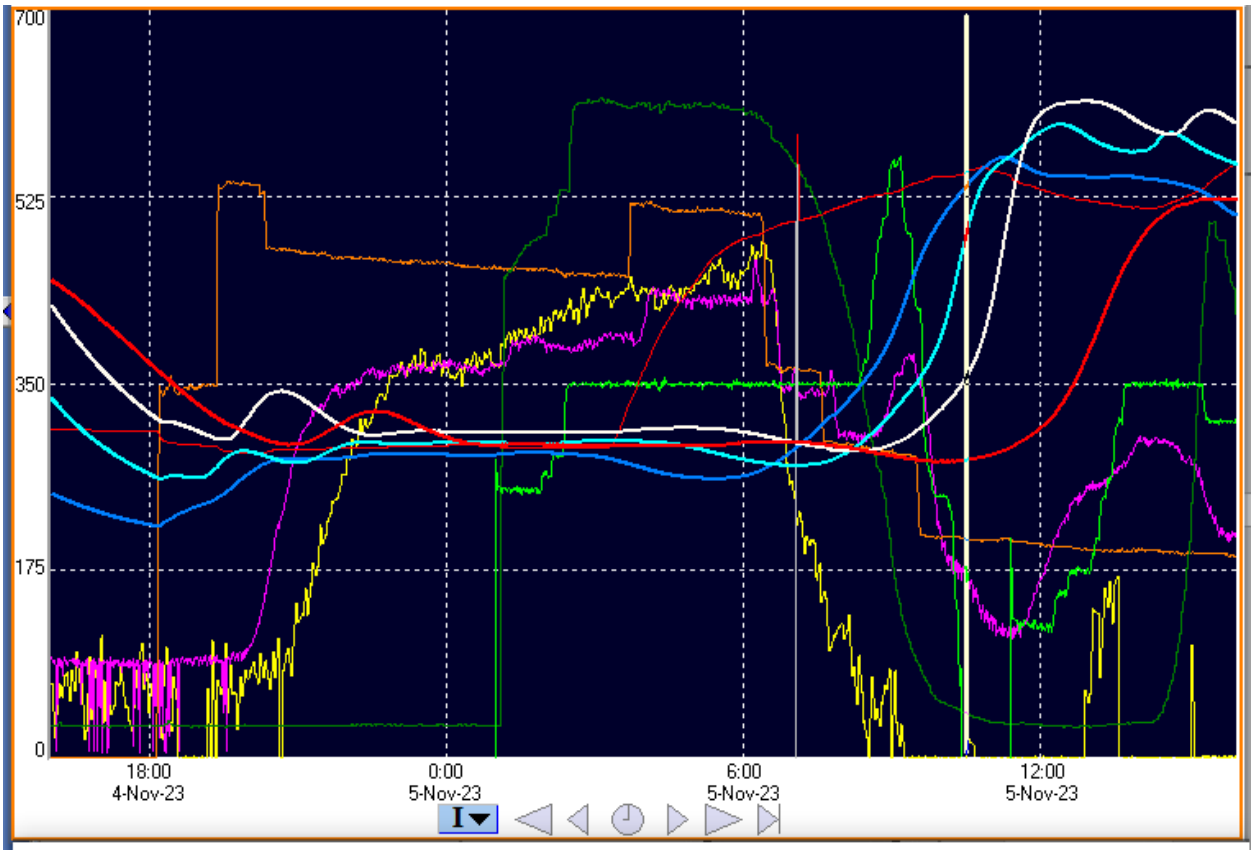
10:30 AM

RIT 313°F

10%/50%/75%/ROT **STRONG** Bed exotherms

Maintained Sulfiding AG at 5.8 MSCFH

Reduced H2 to 0.0 MSCFH to turn the exotherm



Detail for on 5-Nov-23 10:31

Point Name	Point Description	Eng Units	Value:Qual	Low ... High
2AI8006.PV@PARPI	ABSORBER OFFGAS PCT H2S	PPM	0.047:G	0 ... 80
2FI8102.PV@PARPI	H2S RECYCLE TO SRU	MSCFH	7.461:G	0 ... 30
2FI8261.PV@PARPI	ACID GAS FOR PRESUFIDING	MSCFH	5.842:G	0 ... 20
2AI8005.PV@PARPI	ABSORBER OFFGAS PCT H2	PCT	0.297:G	0 ... 5
2FC8021.PV@PARPI	HYDROGEN TO CAT REACTOR	MSCFH	-1.592:G	0 ... 10
2TC8048.PV@PARPI	CAT REACTOR INLET	DEGF	313.7:G	0 ... 400
2TI8039.PV@PARPI	CAT REACTOR- 25% LEVEL	DEGF	534.9:G	0 ... 700
2TI8040.PV@PARPI	CAT REACTOR- 50% LEVEL	DEGF	486.9:G	0 ... 700
2TI8041.PV@PARPI	CAT REACTOR- 75% LEVEL	DEGF	355.3:G	0 ... 700
2TI8049A.PV@PARPI	CAT RX OUTLET TEMP	DEGF	278.5:G	0 ... 700

Sulfiding Low Temperature TGTU Catalyst - Timeline (continued)

Nov 5th

11:15 AM

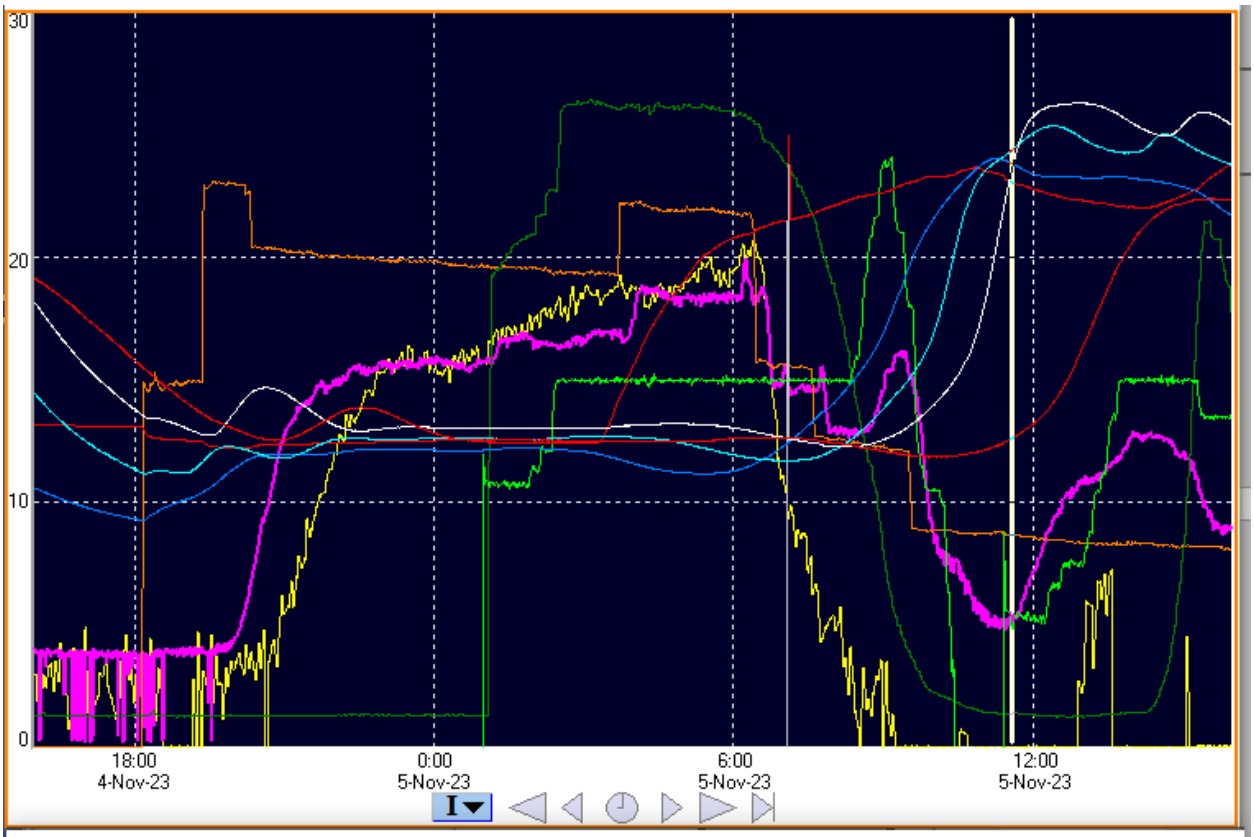
10% Bed Exotherm **peaked and turned**

11:30 AM

RIT 310°F

Re-introduced H2 at 1.8 MSCFH

Slowly ramped H2 up to 5.0 MSCFH



Detail for on 5-Nov-23 11:36

Point Name	Point Description	Eng Units	Value:Qual	Low ... High
2AI8006.PV@PARPI	ABSORBER OFFGAS PCT H2S	PPM	-0.041:G	0 ... 80
2FI8102.PV@PARPI	H2S RECYCLE TO SRU	MSCFH	5.018:G	0 ... 30
2FI8261.PV@PARPI	ACID GAS FOR PRESUFIDING	MSCFH	5.781:G	0 ... 20
2AI8005.PV@PARPI	ABSORBER OFFGAS PCT H2	PCT	0.230:G	0 ... 5
2FC8021.PV@PARPI	HYDROGEN TO CAT REACTOR	MSCFH	1.712:G	0 ... 10
2TC8048.PV@PARPI	CAT REACTOR INLET	DEGF	308.0:G	0 ... 400
2TI8039.PV@PARPI	CAT REACTOR- 25% LEVEL	DEGF	557.0:G	0 ... 700
2TI8040.PV@PARPI	CAT REACTOR- 50% LEVEL	DEGF	570.6:G	0 ... 700
2TI8041.PV@PARPI	CAT REACTOR- 75% LEVEL	DEGF	553.7:G	0 ... 700
2TI8049A.PV@PARPI	CAT RX OUTLET TEMP	DEGF	295.1:G	0 ... 700

Sulfiding Low Temperature TGTU Catalyst - Timeline (continued)

Nov 5th

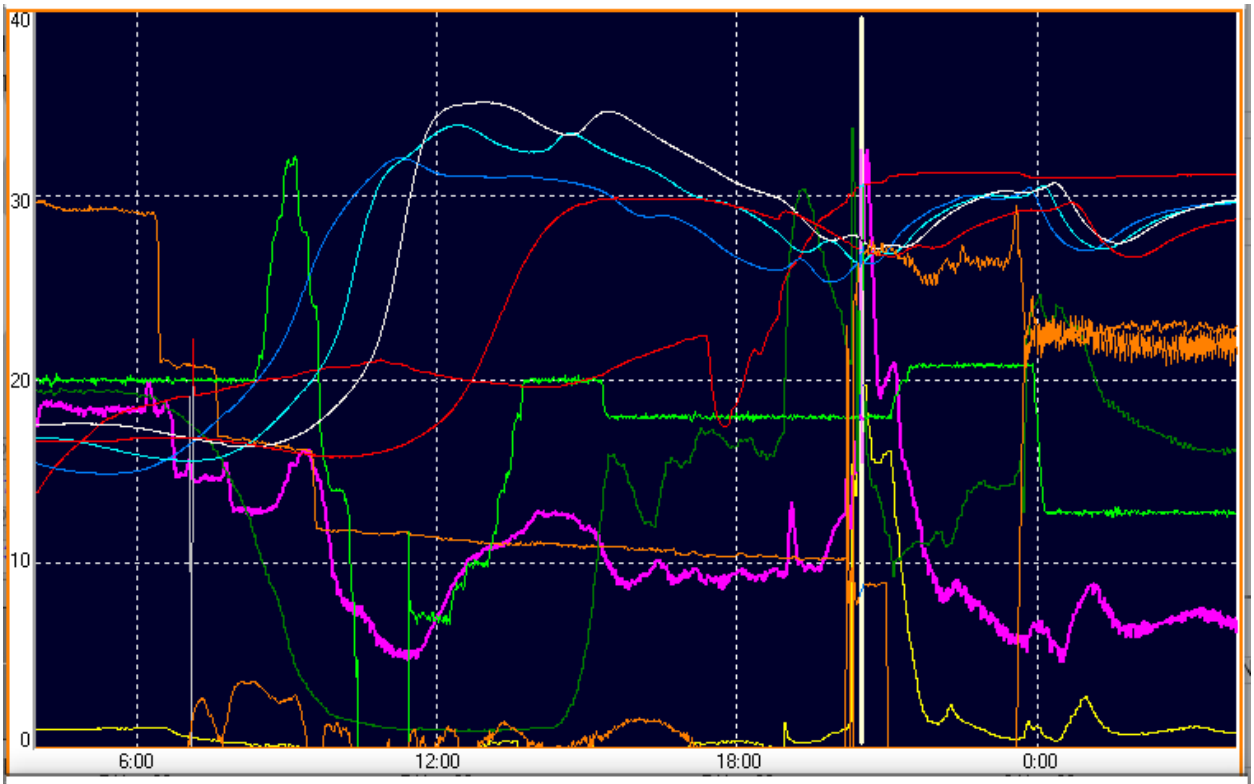
20:30 (8:30 PM)

SRU2 AAG introduction

Reduced Sulfiding AG

21:00 (9:00 PM)

Stopped Sulfiding AG



Detail for on 5-Nov-23 20:30

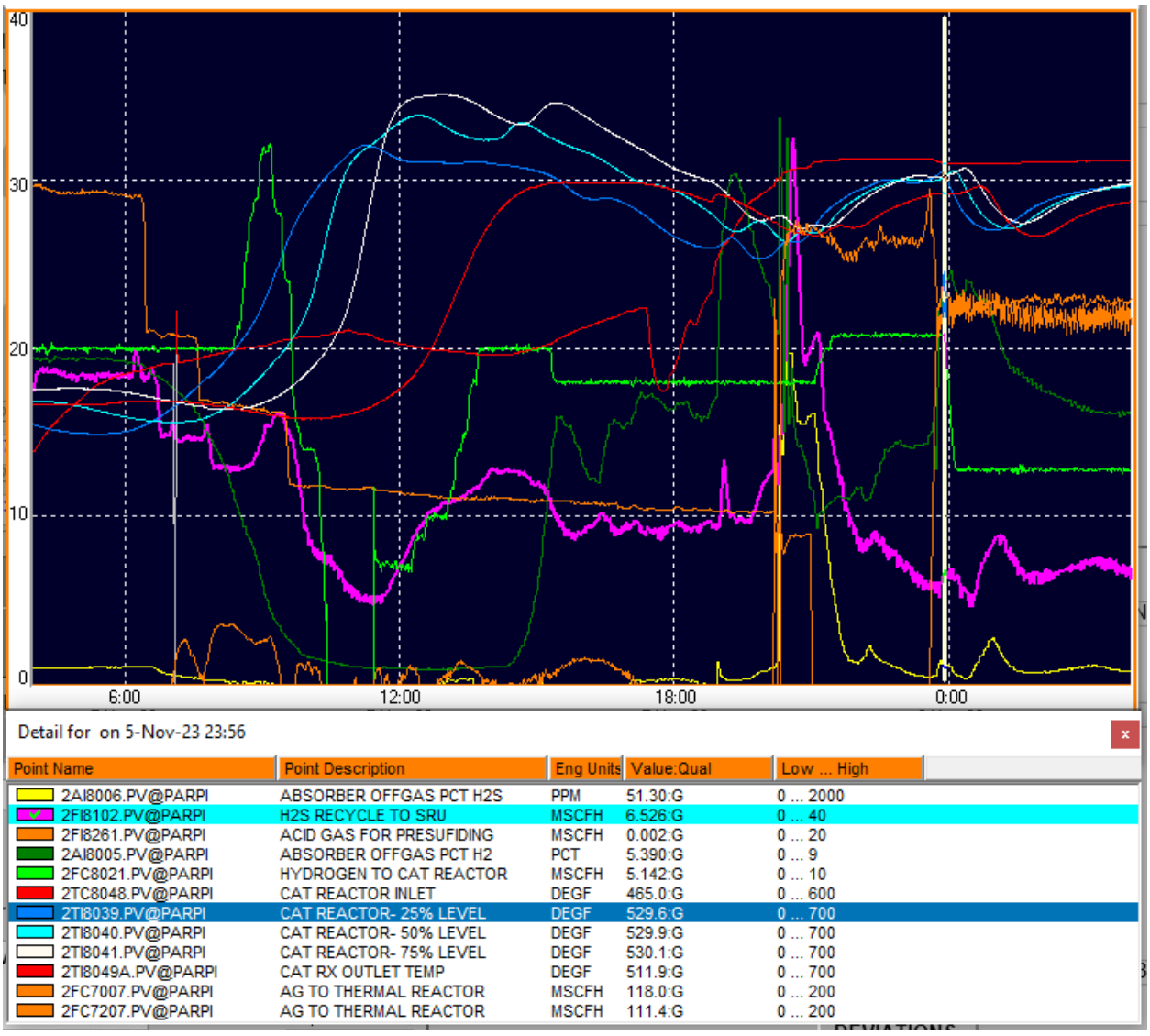
Point Name	Point Description	Eng Units	Value:Qual	Low ... High
2AI8006.PV@PARPI	ABSORBER OFFGAS PCT H2S	PPM	987.0:G	0 ... 2000
2FI8102.PV@PARPI	H2S RECYCLE TO SRU	MSCFH	25.58:G	0 ... 40
2FI8261.PV@PARPI	ACID GAS FOR PRESUFIDING	MSCFH	4.344:G	0 ... 20
2AI8005.PV@PARPI	ABSORBER OFFGAS PCT H2	PCT	3.495:G	0 ... 9
2FC8021.PV@PARPI	HYDROGEN TO CAT REACTOR	MSCFH	4.489:G	0 ... 10
2TC8048.PV@PARPI	CAT REACTOR INLET	DEGF	459.1:G	0 ... 600
2TI8039.PV@PARPI	CAT REACTOR- 25% LEVEL	DEGF	461.7:G	0 ... 700
2TI8040.PV@PARPI	CAT REACTOR- 50% LEVEL	DEGF	462.5:G	0 ... 700
2TI8041.PV@PARPI	CAT REACTOR- 75% LEVEL	DEGF	483.4:G	0 ... 700
2TI8049A.PV@PARPI	CAT RX OUTLET TEMP	DEGF	473.2:G	0 ... 700
2FC7007.PV@PARPI	AG TO THERMAL REACTOR	MSCFH	135.4:G	0 ... 200
2FC7207.PV@PARPI	AG TO THERMAL REACTOR	MSCFH	0.00:G	0 ... 200

Sulfiding Low Temperature TGTU Catalyst - Timeline (continued)

Nov 5th

23:55 (11:55 PM)

SRU3 AAG introduction



Detail for on 5-Nov-23 23:56

Point Name	Point Description	Eng Units	Value:Qual	Low ... High
2AI8006.PV@PARPI	ABSORBER OFFGAS PCT H2S	PPM	51.30:G	0 ... 2000
2FI8102.PV@PARPI	H2S RECYCLE TO SRU	MSCFH	6.526:G	0 ... 40
2FI8261.PV@PARPI	ACID GAS FOR PRESUFIDING	MSCFH	0.002:G	0 ... 20
2AI8005.PV@PARPI	ABSORBER OFFGAS PCT H2	PCT	5.390:G	0 ... 9
2FC8021.PV@PARPI	HYDROGEN TO CAT REACTOR	MSCFH	5.142:G	0 ... 10
2TC8048.PV@PARPI	CAT REACTOR INLET	DEGF	465.0:G	0 ... 600
2TI8039.PV@PARPI	CAT REACTOR- 25% LEVEL	DEGF	529.6:G	0 ... 700
2TI8040.PV@PARPI	CAT REACTOR- 50% LEVEL	DEGF	529.9:G	0 ... 700
2TI8041.PV@PARPI	CAT REACTOR- 75% LEVEL	DEGF	530.1:G	0 ... 700
2TI8049A.PV@PARPI	CAT RX OUTLET TEMP	DEGF	511.9:G	0 ... 700
2FC7007.PV@PARPI	AG TO THERMAL REACTOR	MSCFH	118.0:G	0 ... 200
2FC7207.PV@PARPI	AG TO THERMAL REACTOR	MSCFH	111.4:G	0 ... 200

Sulfiding Low Temperature TGTU Catalyst - Timeline (continued)

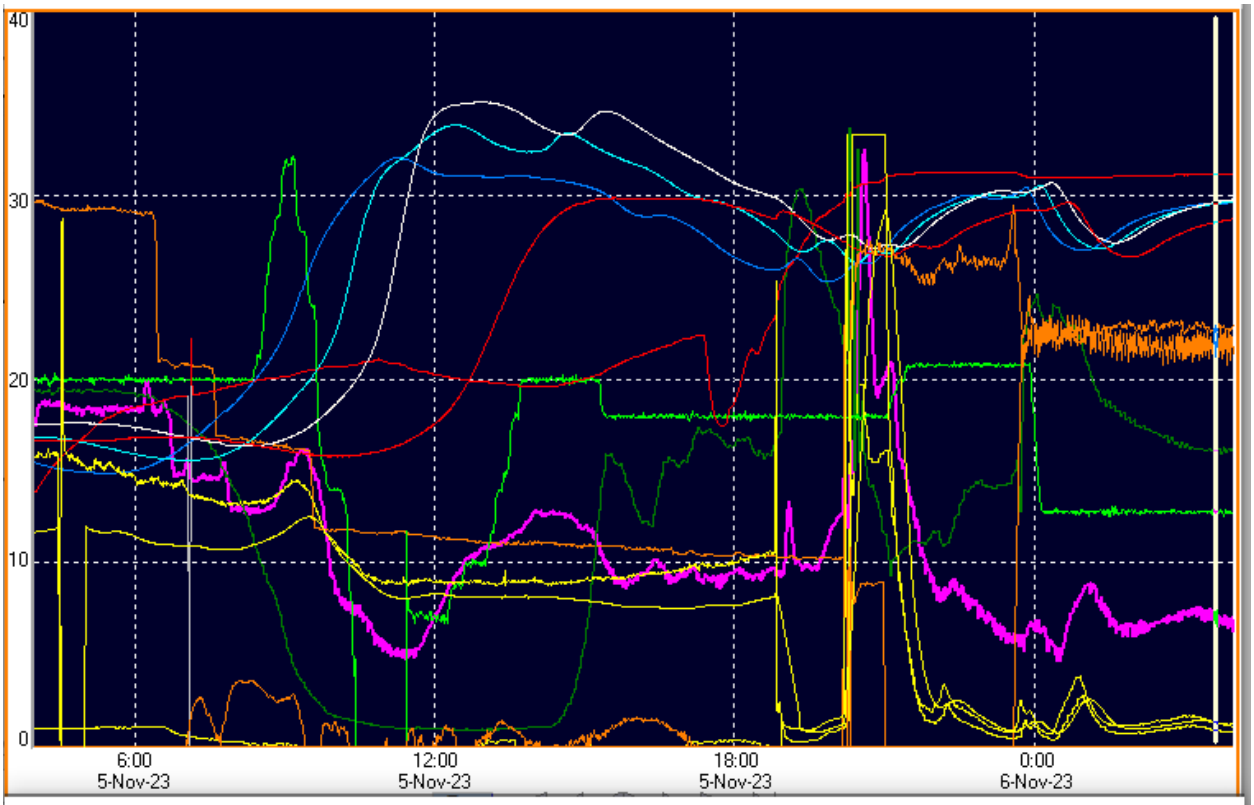
Nov 6th

03:40 AM

Incinerator Emissions within Environmental Limits

~20 ppm

1.5 lb/hr SO2



Detail for on 6-Nov-23 3:40

Point Name	Point Description	Eng Units	Value:Qual	Low ... High
2AI8006.PV@PARPI	ABSORBER OFFGAS PCT H2S	PPM	45.66:G	0 ... 2000
2FI8102.PV@PARPI	H2S RECYCLE TO SRU	MSCFH	7.330:G	0 ... 40
2FI8261.PV@PARPI	ACID GAS FOR PRESUFIDING	MSCFH	0.001:G	0 ... 20
2AI8005.PV@PARPI	ABSORBER OFFGAS PCT H2	PCT	3.630:G	0 ... 9
2FC8021.PV@PARPI	HYDROGEN TO CAT REACTOR	MSCFH	3.198:G	0 ... 10
2TC8048.PV@PARPI	CAT REACTOR INLET	DEGF	467.7:G	0 ... 600
2TI8039.PV@PARPI	CAT REACTOR- 25% LEVEL	DEGF	518.3:G	0 ... 700
2TI8040.PV@PARPI	CAT REACTOR- 50% LEVEL	DEGF	517.9:G	0 ... 700
2TI8041.PV@PARPI	CAT REACTOR- 75% LEVEL	DEGF	519.5:G	0 ... 700
2TI8049A.PV@PARPI	CAT RX OUTLET TEMP	DEGF	500.5:G	0 ... 700
2FC7007.PV@PARPI	AG TO THERMAL REACTOR	MSCFH	113.9:G	0 ... 200
2FC7207.PV@PARPI	AG TO THERMAL REACTOR	MSCFH	110.5:G	0 ... 200
2AI8004A.PV@PARPI	STACK SO2 ANALYZER	PPM	19.55:G	0 ... 600
S2A8004A.PV@PARPI	TGTU1 STACK SULFUR OXIDE	LB/HR	1.627:G	0 ... 50

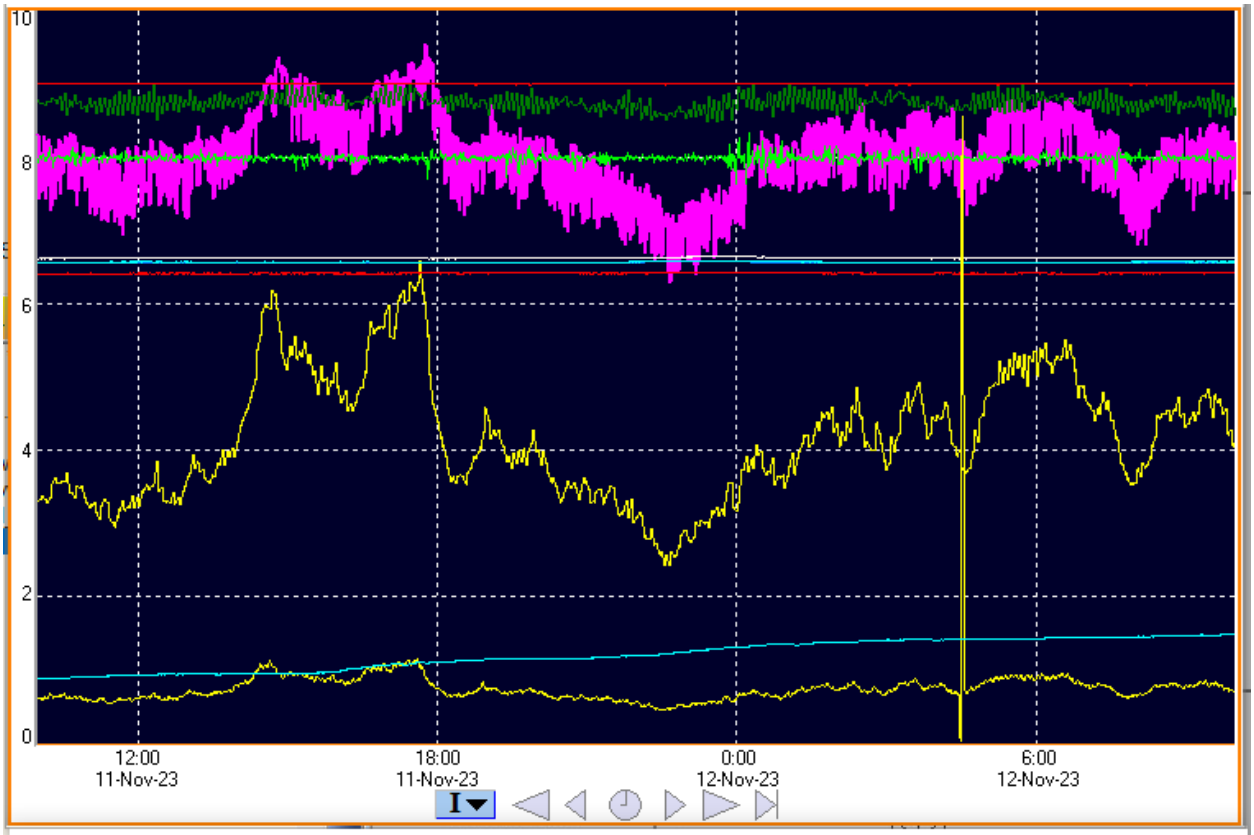
Sulfiding Low Temperature TGTU Catalyst – Timeline (continued)

Nov 10th

22:00 (10:00 PM)

Operating well

pH added to trend



Detail for on 10-Nov-23 22:03

Point Name	Point Description	Eng Units	Value:Qual	Low ... High
2AI8006.PV@PARPI	ABSORBER OFFGAS PCT H2S	PPM	47.41:G	0 ... 200
2FI8102.PV@PARPI	H2S RECYCLE TO SRU	MSCFH	7.756:G	0 ... 10
2FI8261.PV@PARPI	ACID GAS FOR PRESUFIDING	MSCFH	0.00:G	0 ... 0.02
2AI8005.PV@PARPI	ABSORBER OFFGAS PCT H2	PCT	5.195:G	0 ... 6
2FC8021.PV@PARPI	HYDROGEN TO CAT REACTOR	MSCFH	3.227:G	0 ... 4
2TC8048.PV@PARPI	CAT REACTOR INLET	DEGF	450.4:G	0 ... 500
2TI8039.PV@PARPI	CAT REACTOR- 25% LEVEL	DEGF	459.7:G	0 ... 700
2TI8040.PV@PARPI	CAT REACTOR- 50% LEVEL	DEGF	460.2:G	0 ... 700
2TI8041.PV@PARPI	CAT REACTOR- 75% LEVEL	DEGF	464.0:G	0 ... 700
2TI8049A.PV@PARPI	CAT RX OUTLET TEMP	DEGF	448.9:G	0 ... 700
2AI8004A.PV@PARPI	STACK SO2 ANALYZER	PPM	22.49:G	0 ... 500
2AI8058.PV@PARPI	QUENCH WATER PH ANALYZER	PH	7.685:G	7 ... 14

Sulfiding Low Temperature TGTU Catalyst – Lessons Learned

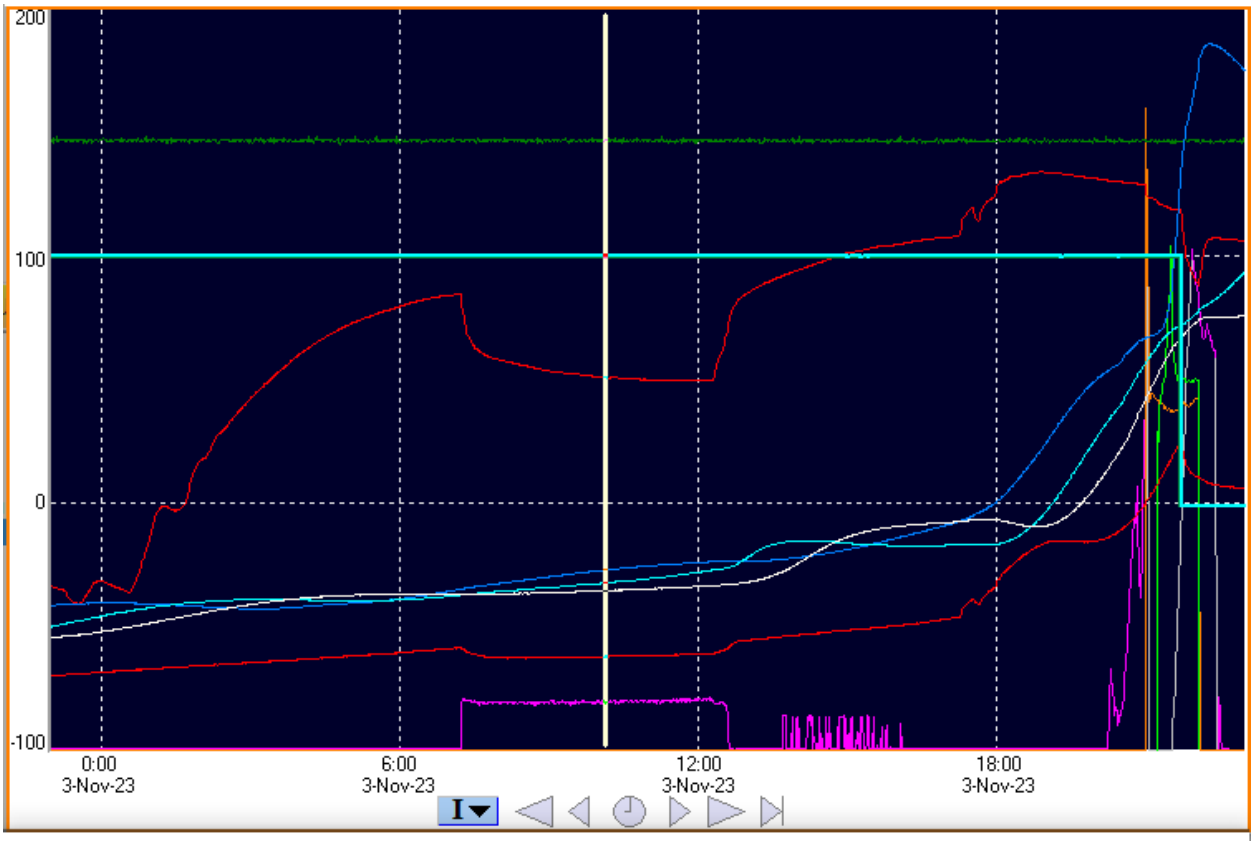
- The first attempt observed a very strong exotherm which immediately required halting sulfiding to cool the Reactor, regroup, and start with a lower RIT.
- The first controlled test of this procedure started with RIT <300°F, introduction of Sulfiding H2S, ramp-up of RIT to ~440°F, and then introduction of H2.
- The observed exotherm was very strong requiring sulfiding to be stopped and cooling of the reactor.
- After seeing the strong exotherm that could be obtained, the decision was to add both H2S and H2 while at low RIT and then slowly ramp the RIT to observe the desired Reactor Bed Temperatures, which proved very successful.
- We also proved that the exotherm could be quickly controlled by adjusting the H2S and H2.

Sulfiding Low Temperature TGTU Catalyst – 1st Attempt Timeline

Nov 3rd

RIT slow ramp up

Small flow Sulfiding AG



Detail for on 3-Nov-23 10:09

Point Name	Point Description	Eng Units	Value:Qual	Low ... High
2AI8006.PV@PARPI	ABSORBER OFFGAS PCT H2S	PPM	10.31:G	-10 ... 0
2FI8102.PV@PARPI	H2S RECYCLE TO SRU	MSCFH	5.269:G	0 ... 80
2FI8261.PV@PARPI	ACID GAS FOR PRESUFIDING	MSCFH	0.00:G	0 ... 20
2AI8005.PV@PARPI	ABSORBER OFFGAS PCT H2	PCT	0.412:G	0 ... 0.5
2FC8021.PV@PARPI	HYDROGEN TO CAT REACTOR	MSCFH	-2.491:G	0 ... 8
2TC8048.PV@PARPI	CAT REACTOR INLET	DEGF	302.0:G	0 ... 600
2TI8039.PV@PARPI	CAT REACTOR- 25% LEVEL	DEGF	207.1:G	0 ... 850
2TI8040.PV@PARPI	CAT REACTOR- 50% LEVEL	DEGF	192.3:G	0 ... 850
2TI8041.PV@PARPI	CAT REACTOR- 75% LEVEL	DEGF	183.1:G	0 ... 850
2TI8049A.PV@PARPI	CAT RX OUTLET TEMP	DEGF	107.7:G	0 ... 850
2ZI8000.PV@PARPI	SRU2 GAS TO TGTU1 FD HTR	PCT	99.95:G	-100 ... 200
2ZI8002.PV@PARPI	SRU3 TO TGTU1 DV POSITN	PCT	100.2:G	-100 ... 200

Sulfiding Low Temperature TGTU Catalyst – 1st Attempt Timeline

Nov 3rd

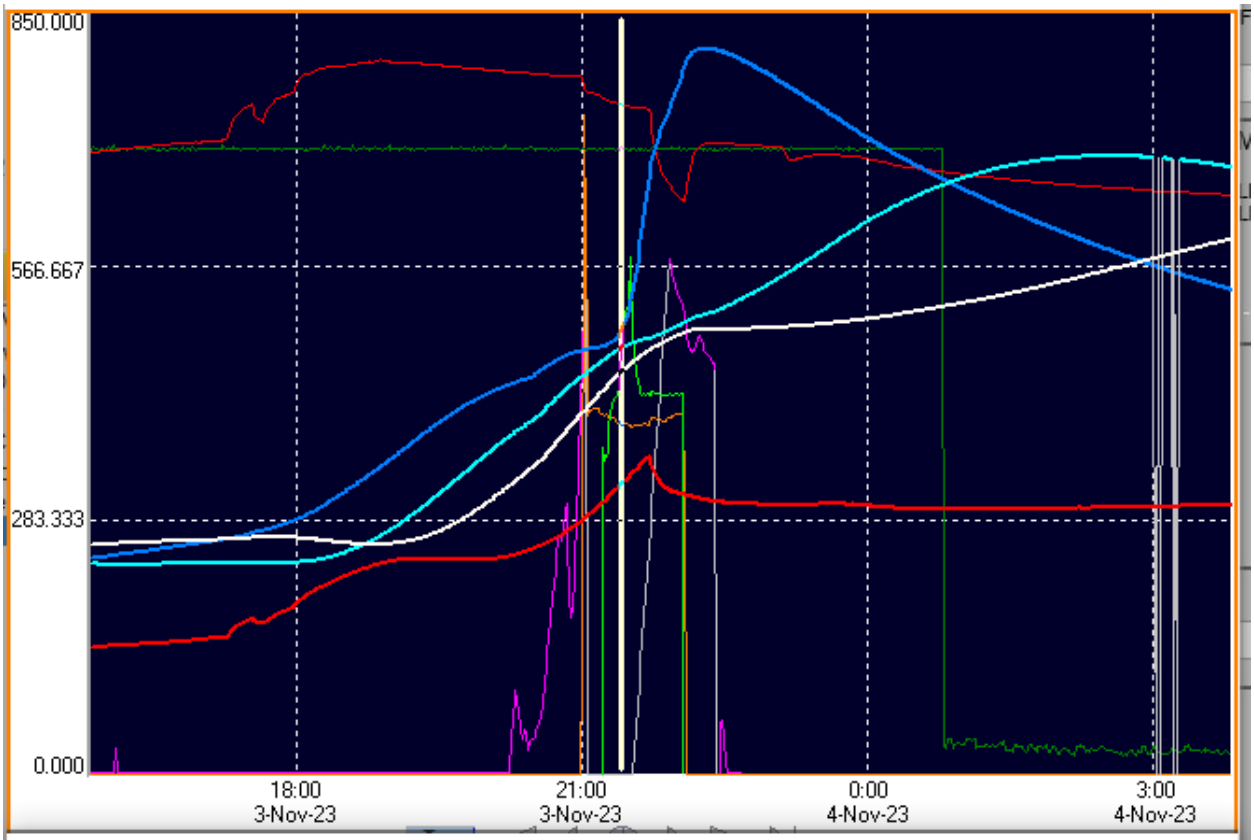
21:25 (9:25 PM)

RIT ~340°F

Sulfiding AG increased

H2 introduced

Very strong 10% Bed exotherm starting to be observed



Detail for on 3-Nov-23 21:25

Point Name	Point Description	Eng Units	Value:Qual	Low ... High
2AI8006.PV@PARPI	ABSORBER OFFGAS PCT H2S	PPM	10.35:G	-10 ... 0
2FI8102.PV@PARPI	H2S RECYCLE TO SRU	MSCFH	0.00:B	0 ... 80
2FI8261.PV@PARPI	ACID GAS FOR PRESUFIDING	MSCFH	9.203:G	0 ... 20
2AI8005.PV@PARPI	ABSORBER OFFGAS PCT H2	PCT	0.412:G	0 ... 0.5
2FC8021.PV@PARPI	HYDROGEN TO CAT REACTOR	MSCFH	4.366:G	0 ... 8
2TC8048.PV@PARPI	CAT REACTOR INLET	DEGF	440.8:G	0 ... 500
2TI8039.PV@PARPI	CAT REACTOR- 25% LEVEL	DEGF	495.0:G	0 ... 850
2TI8040.PV@PARPI	CAT REACTOR- 50% LEVEL	DEGF	476.9:G	0 ... 850
2TI8041.PV@PARPI	CAT REACTOR- 75% LEVEL	DEGF	450.1:G	0 ... 850
2TI8049A.PV@PARPI	CAT RX OUTLET TEMP	DEGF	324.4:G	0 ... 850

Sulfiding Low Temperature TGTU Catalyst – 1st Attempt Timeline

Nov 3rd

22:00 (10:00 PM)

Very strong 10% Bed exotherm

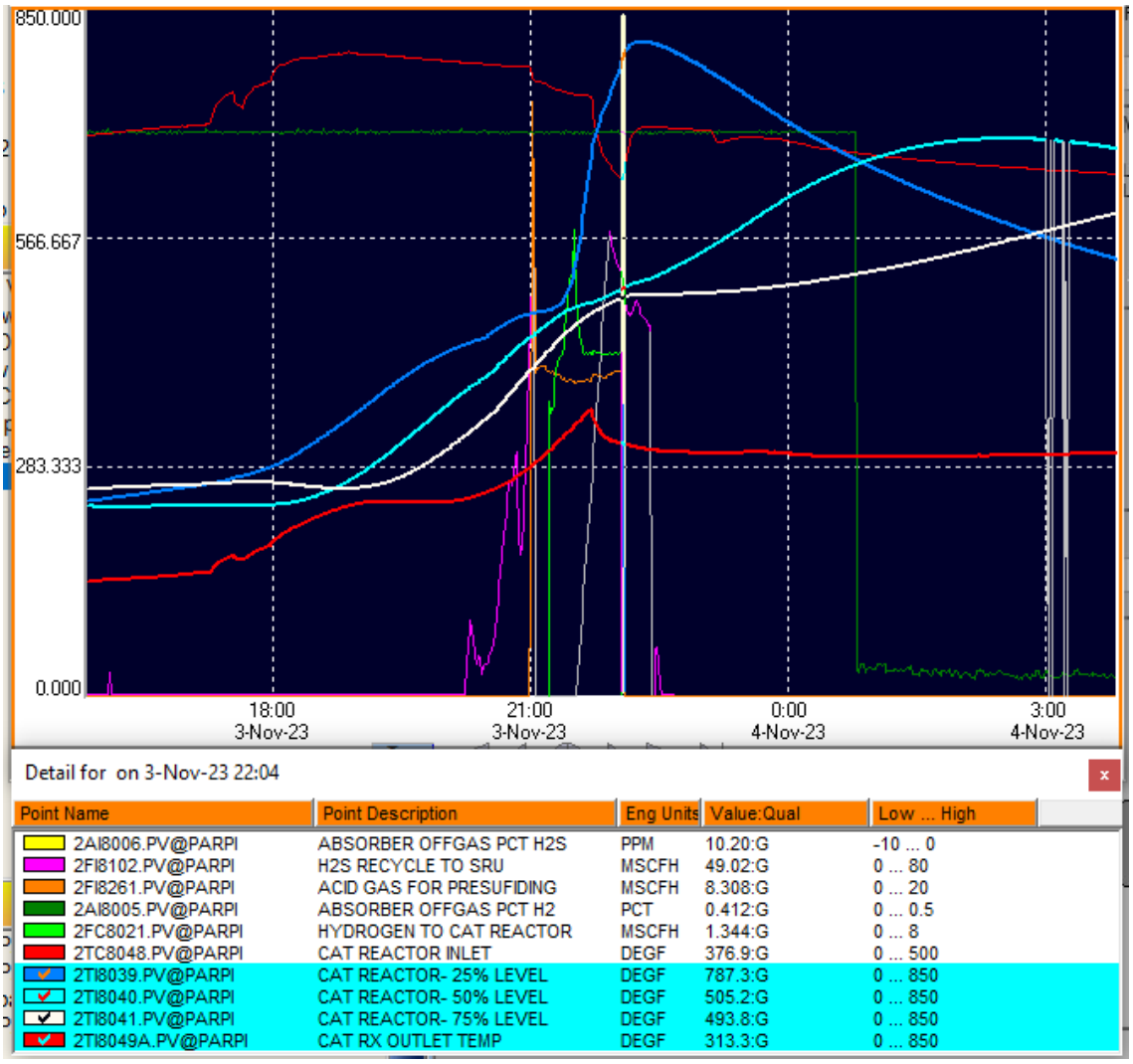
Sulfiding AG stopped

H2 stopped

Reactor cooldown initiated

Exotherm immediately peaked and turned.

Cooldown continued and regrouped until following day



Point Name	Point Description	Eng Units	Value:Qual	Low ... High
2AI8006.PV@PARPI	ABSORBER OFFGAS PCT H2S	PPM	10.20:G	-10 ... 0
2FI8102.PV@PARPI	H2S RECYCLE TO SRU	MSCFH	49.02:G	0 ... 80
2FI8261.PV@PARPI	ACID GAS FOR PRESUFIDING	MSCFH	8.308:G	0 ... 20
2AI8005.PV@PARPI	ABSORBER OFFGAS PCT H2	PCT	0.412:G	0 ... 0.5
2FC8021.PV@PARPI	HYDROGEN TO CAT REACTOR	MSCFH	1.344:G	0 ... 8
2TC8048.PV@PARPI	CAT REACTOR INLET	DEGF	376.9:G	0 ... 500
2TI8039.PV@PARPI	CAT REACTOR- 25% LEVEL	DEGF	787.3:G	0 ... 850
2TI8040.PV@PARPI	CAT REACTOR- 50% LEVEL	DEGF	505.2:G	0 ... 850
2TI8041.PV@PARPI	CAT REACTOR- 75% LEVEL	DEGF	493.8:G	0 ... 850
2TI8049A.PV@PARPI	CAT RX OUTLET TEMP	DEGF	313.3:G	0 ... 850

Sulfiding Low Temperature TGTU Catalyst - Summary

- Sulfiding Low Temperature TGTU Catalyst with this approach accomplished the two objectives.
    - Maintained H2S throughout the Reactor while sulfiding thus preventing H2S starvation.
    - Reached desired Reactor Bed Temperatures >600°F with Reactor Inlet Temperature <315°F.
- Special thank you to ASRL, Rob Marriott, Chris Lavery, and Michael Huffmaster.

References

1) **UNDERSTANDING THE FORMATION OF AND HANDLING OF H2S AND SO2 EMISSIONS FROM LIQUID SULPHUR DURING STORAGE AND TRANSPORTATION** – Sulphur Seminar 1999 –Jan A. Lagas, Stork Engineers & Contractors B.V.; P.D. Clark, G.D. Butlin and E. Fitzpatrick, Alberta Sulphur Research Ltd.; M.L.J.A. Wetzels and W.S. Kijlstra, Shell Global Solutions