START-UP EXPERIENCE FOR VALUE RECOVERY FROM CCR NET GAS AT YANBU' REFINERY

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Abstract

Yanbu' Refinery (YR) recently converted its Semi-Regenerative Platformer unit to the UOP-licensed Continuous Catalytic Regenerative (CCR) Platforming process. To recover value from CCR net gas, an LPG Recovery Unit, utilizing a new to Saudi Aramco technology, was installed to maximize LPG recovery and to increase the hydrogen purity of the net gas for use in the new Diesel Hydro-Treater unit. This paper will describe how the enhanced absorption process was incorporated at YR to complement the existing Saturate Gas Conditioning Unit, and share the experience with the start-up and operations of the LPG Recovery Unit. The recovered, higher-value LPG is separated in the existing debutanizer column. A new three-stage propane refrigeration system is used to chill the CCR net gas to maximize LPG recovery.

Introduction

The original fixed-bed platformer unit has been operational at Yanbu' Refinery (YR) since 1983. With a view to: (a) increase the unleaded gasoline production by 8 MBD; (b) upgrade YR product value by allowing light straight run naphtha and butanes to blend in the gasoline pool; (c) reduce requirement for expensive MTBE purchases; and (d) improve reliability, safety, and efficiency by reducing unit downtime, YR elected to transform the 38 MBD capacity UOP fixed-bed Platformer to a 40 MBD capacity UOP-licensed Continuous Catalytic Regenerative (CCR) Platformer system.

As part of the reforming process, the CCR system produces a net gas that is rich in C_3+ LPG and hydrogen. To maximize propane recovery from excess net gas and existing Sat Gas debutanizer overhead, the licensed LPG Recovery System, from Advanced Extraction Technologies, Inc. (AET), was selected because of its effectiveness in achieving very high propane recoveries (96+%) from about 10 kg/cm^{2}g *(151 psig)* off-gases without requiring feed gas compression. This paper presents the incorporation of new-to-Saudi Aramco technology and shares the start-up challenges and experiences with the AET LPG Recovery Unit at YR that started up during June-July 2006.

LPG Recovery Technology

The typical AET Process LPG Recovery Unit technology, as shown in Figure 1, utilizes a C_5+ solvent for absorption of C_3+ LPG components from a refinery off-gas stream. The selection of C_5+ solvent is based on the fact that it has low molecular weight, which reduces the solvent circulation, and it has a low vapor pressure, which reduces the solvent loss.

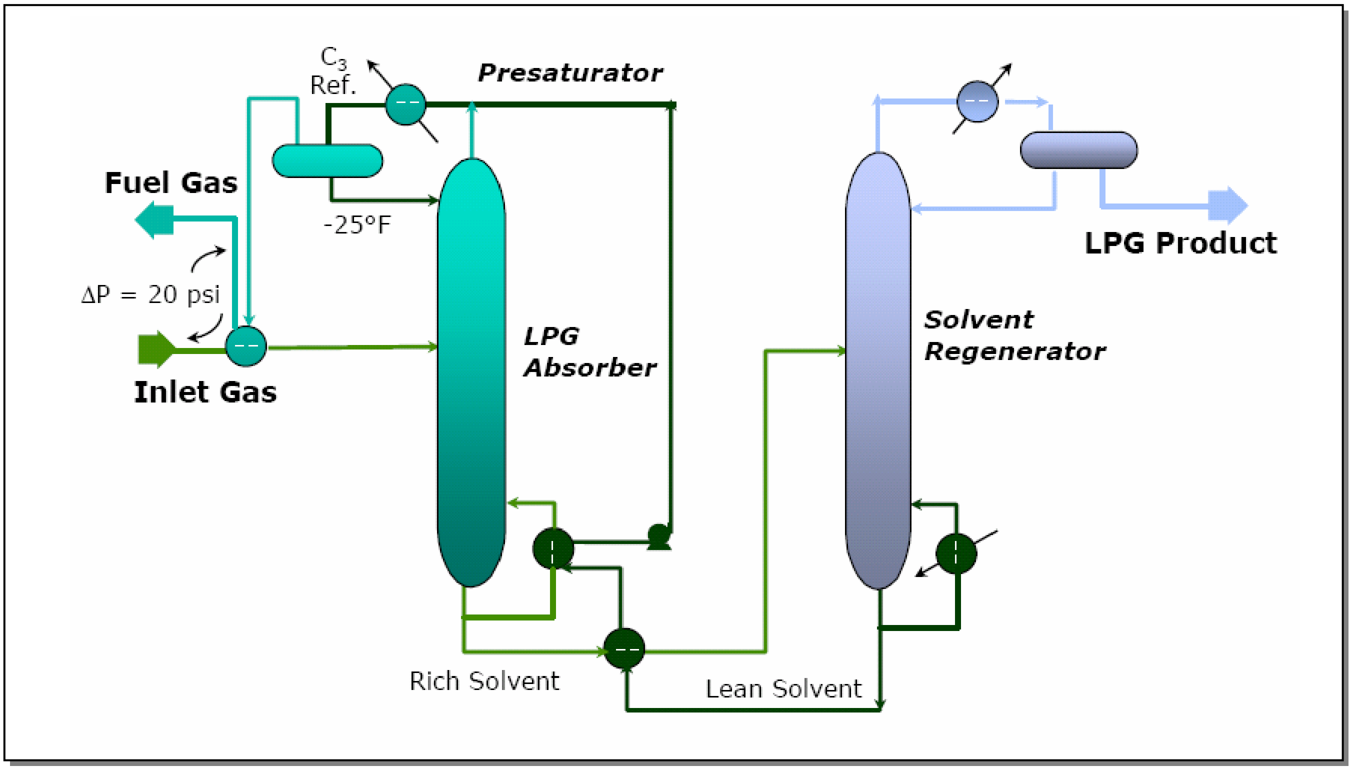

Figure 1 - AET Process LPG Recovery Unit [1]

In the AET Process, this absorption effectiveness is further enhanced by pre-saturating the lean C_5+ solvent with the "*undesired*" hydrogen and methane present in the inlet refinery off-gas that essentially forms the fuel gas, and is available at the overhead of the LPG absorber since the propane and butanes are removed from the off-gas inlet gas in the absorber column. The pre-saturated solvent at about -25°F, separated from the hydrogen/methane fuel gas, is pumped to the top of the absorber. This hydrogen/methane pre-saturated solvent upon entering the absorber focuses on absorbing only the propane and butanes.

As shown, the LPG absorber is reboiled at the bottom to ensure that the recovered propane-plus LPG meets the specification content for all light-ends present in the inlet refinery off-gas. The rich solvent from the bottom of the LPG absorber is fractionated in the solvent regenerator to separate the absorbed C_3/C_4 LPG as an overhead product and the bottoms being the C_5+ lean solvent product. By virtue of separation of C_3/C_4 LPG overhead, the solvent regenerator operation is similar to that of a debutanizer column. Therefore, any new AET process facility requires an LPG absorber column and a debutanizer-regenerator column.

[1] Adapted from AET web site: www.aet.com

LPG Recovery at Yanbu' Refinery

Since YR already had a debutanizer column as part of its Sat Gas Concentration Unit V14, alternatives were considered to eliminate the need for installing a new debutanizer column just for the new LPG absorber. Instead of securing a new segregated C_5+ stream for the lean solvent service, the stabilized platformate, which is a C_5+ product, available from the bottom of the existing debutanizer column was considered as the preferred lean solvent for the AET Process. Unfortunately, the solvent circulation rate of the stabilized platformate as lean solvent to achieve the 96+% propane recovery from the expected CCR net gas flow was large enough to require a larger diameter debutanizer column.

To utilize the existing debutanizer column in place, a part of the unstabilized platformate feed to the debutanizer was re-directed to the new LPG absorber to absorb some of the LPG from the CCR net gases. The remaining LPG present in CCR gases was absorbed by circulating a part of the stabilized platformate from the bottom of the existing debutanizer as the lean solvent for the LPG absorber. Doing so essentially splits the total C_5+ solvent requirement for the desired high propane recovery. The challenge of using the unstabilized platformate feed, which is essentially saturated with propane and butanes, as a bulk solvent for part of LPG absorption through the new LPG absorber, was overcome by chilling the unstabilized platformate to a significantly lower temperature of -29°C. The LPG absorber configuration at YR CCR system is shown in Figure 2.

To minimize platformate loss from the overhead of the absorber, and to increase the LPG absorption efficiency, the stabilized platformate solvent stream is pre-saturated with hydrogen, methane and ethane by mixing with the overhead gases from the LPG absorber and chilling to about -29°C *(-20°F)*. The chilled gases are separated from the chilled solvent stream in a presat separator. The pre-saturated lean solvent is pumped to the top of the LPG absorber column.

The unstabilized *(bulk solvent)* and stabilized debutanizer bottoms *(lean solvent)* Platformate streams are precooled by exchanging cold energy from the absorber bottoms stream and then chilled by propane refrigerant to -29°C *(-20°F)*. The CCR net gas is combined with the recycled overhead gases from the debutanizer and deethanizer columns to form the combined feed to the LPG absorber. The combined gas stream is first precooled by exchanging cold energy with the propane-free light-end gases *(hydrogen, methane and ethane)* and then chilled to -29°C *(-20°F)* before entering the LPG absorber column near the bottom. The upward flowing chilled gases are counter-currently contacted with the downward flowing pre-saturated lean solvent which absorbs the propane-plus components from the gases. The cold rich solvent from the bottom of the LPG absorber is pumped and warmed against the unstabilized and stabilized Platformate solvent streams and then flows to the unstabilized Platformate feed stream to the existing debutanizer joining at a point downstream of the take-off point for the unstabilized solvent.

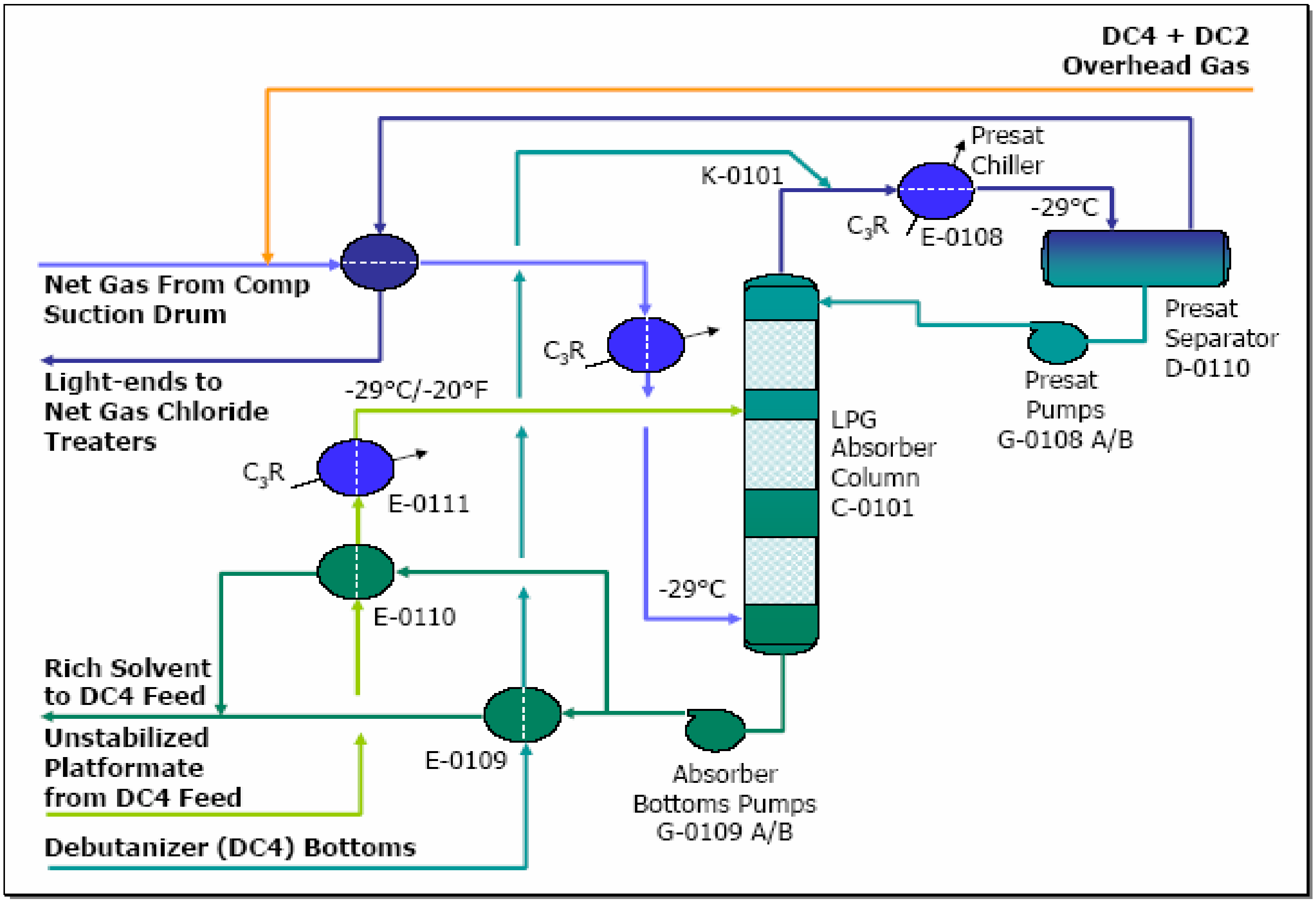

Figure 2 - LPG Absorber Configuration at Yanbu' Refinery

As may be noted by comparison of Figures 1 and 2 that the LPG absorber incorporated at YR does not have a reboiler. This simpler absorber design takes advantage of the availability of a deethanizer column as part of the Sat Gas Concentration Unit, which takes feed from the overhead of the debutanizer column to meet the ethane specification of the C_3/C_4 product.

As shown in Figure 3, at the debutanizer overhead the uncondensed light-ends are separated from the condensable C_3/C_4 mixture. The overhead net liquid C_3/C_4 product is further fractionated in deethanizer column followed by depropanizer column to produce propane and mixed butanes products.

The separated light-ends from the overhead of the debutanizer (DC4) column along with the separated ethane and lighter from the overhead of deethanizer (DC2) column are recycled back to the LPG absorber of Figure 2 to recover any contained propane and heavier hydrocarbons.

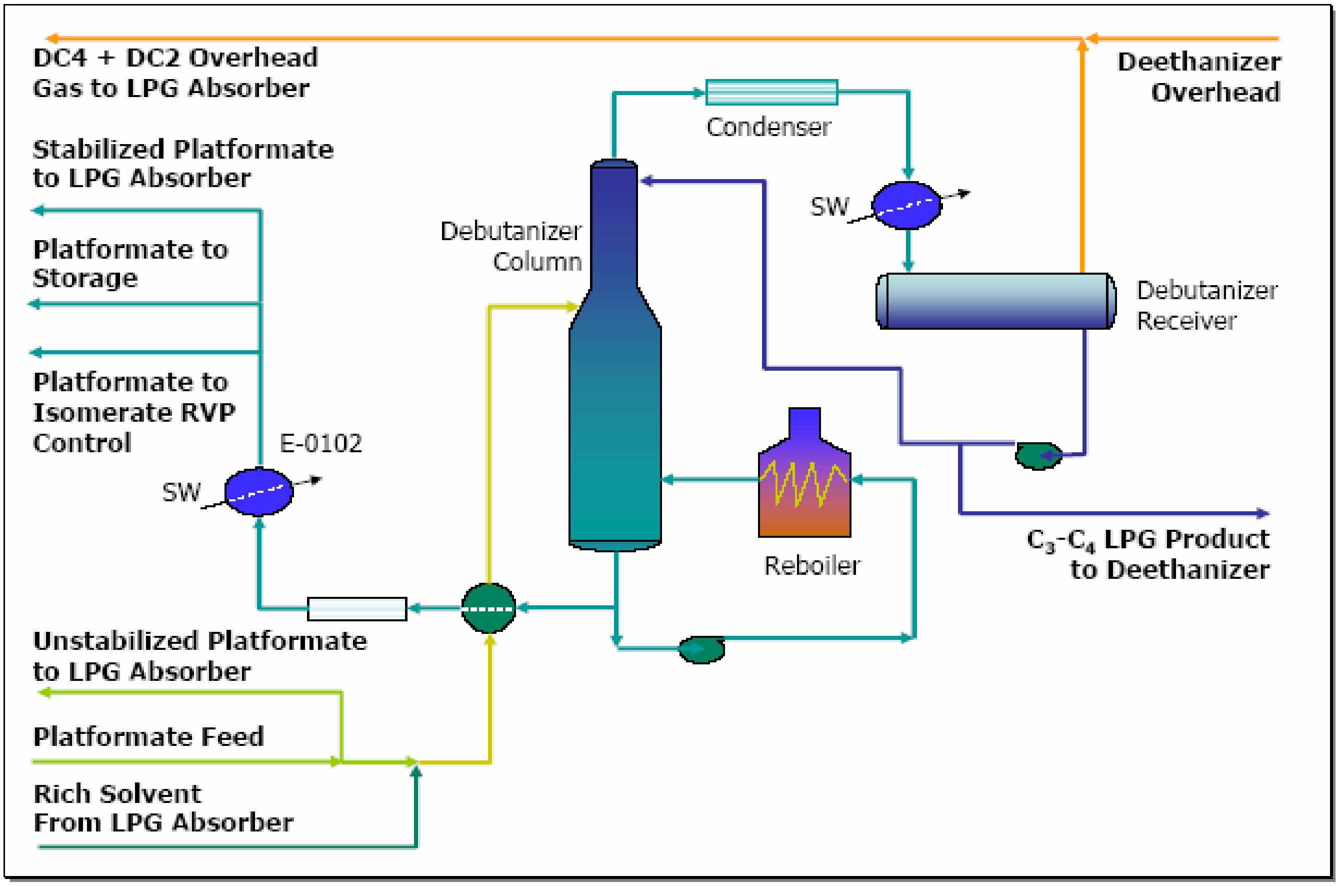

Figure 3 - Modified Debutanizer Configuration at Yanbu' Refinery

To handle increased processing load within the existing debutanizer column, modifications to existing equipment were as follows:

- Addition of series heat transfer surface to the feed/bottoms exchanger.
- Addition of parallel heat transfer surface to the bottoms product sea water cooler.
- Addition of new overhead sea water trim condenser.
- Replacement of overhead product and reflux pump.

Within the existing deethanizer system, the deethanizer feed pumps were replaced. Within the depropanizer system, the overhead air cooled condenser was replaced with a sea water shell and tube condenser, and the overhead net propane product cooler was replaced with a larger heat exchanger.

Propane Refrigeration Cycle

To provide the required chilling a propane refrigeration system is required. Figure 4 summarizes the closed loop three-stage propane refrigeration cycle to provide the necessary chilling for the unstabilized and stabilized Platformate solvent streams and the CCR net gas feed to the LPG absorber.

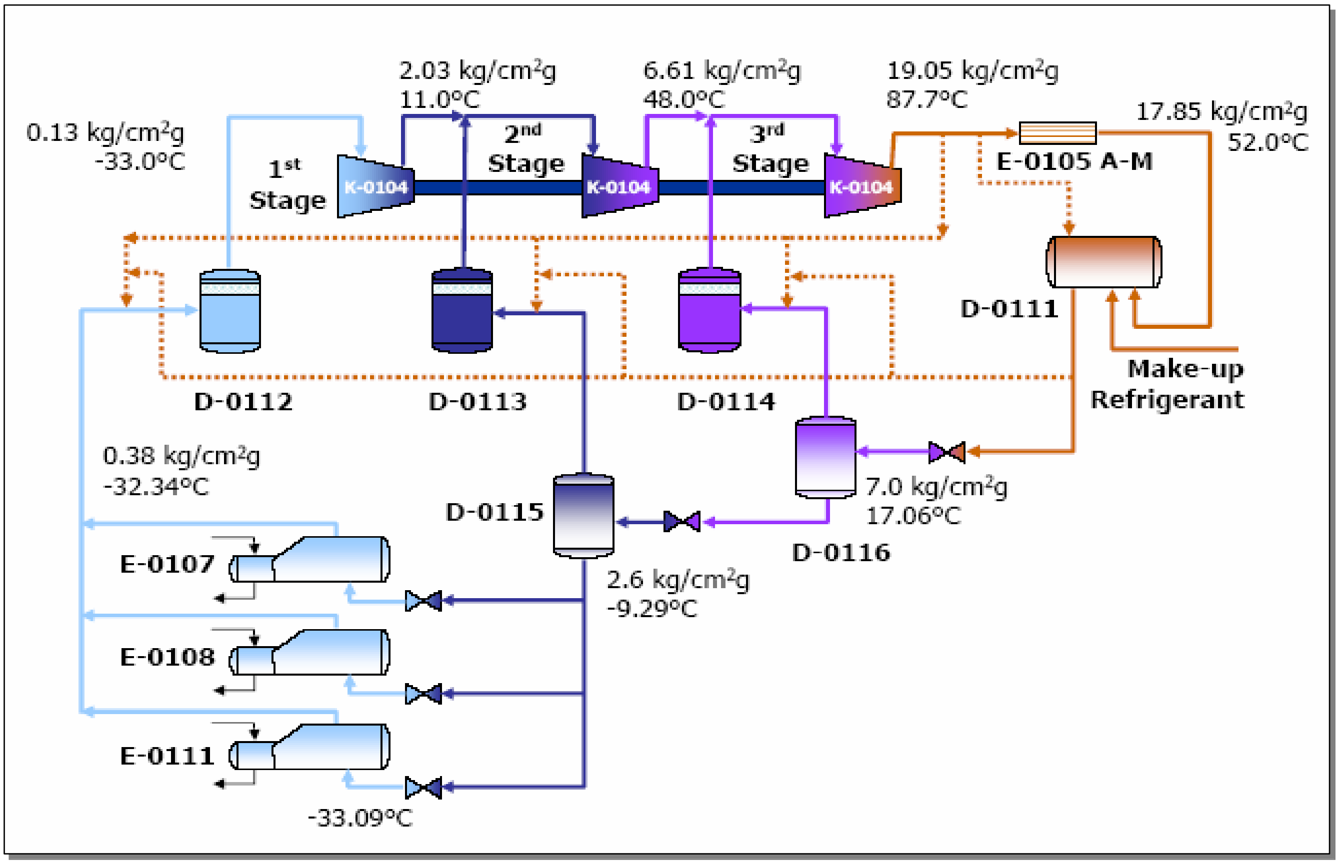

Figure 4 – Three-Stage Propane Refrigeration Cycle for LPG Recovery

All of the three process services, namely the Feed Gas Chiller E-0107, Platformate Chiller E-0111 and the Presat Chiller E-0108 chill the respective process streams to about -29°C *(-20°F)* using the -33°C *(-27°F)* propane refrigerant. The vaporized propane from the chillers enters the 1st stage of the Propane Compressor K-0104 through the 1st stage suction drum D-0112. The LP Economizer D-0115 and HP Economizer D-0116 reduce the refrigerant compressor horsepower by separating the 2nd stage side load flashed vapors at -9°C *(15°F)* and 3rd stage side load flashed vapors at 17°C *(63°F)*, respectively. The compressed propane refrigerant vapors are condensed by air cooled condenser E-0105 and returned to the propane accumulator D-0111.

As shown via the dotted line in Figure 4, the refrigerant compressor's anti-surge system controls the flow of the hot discharge propane and the quench liquid propane to the 1st, 2nd and 3rd Stage Suction Drums D-0112, D-0113 and D-0114, respectively.

Overall Design Performance

Because of the integration of the LPG absorber *Unit V11* with the debutanizer/deethanizer/depropanizer columns of the Sat Gas Concentration *Unit V14*, it is quite cumbersome to ascertain the material recovery performance of the LPG absorber system. By drawing an envelope around the integrated system, the LPG recovery is determined by analyzing the two gas streams summarized in Table 1.

Table 1 – Overall Material Performance

Component	Combined CCR Net & Unit V14 Gases		Product Gas to DHT/Fuel Gas		Products Yield	
					Gas Product	
	Kg-mol/h	*Mol%*	*Kg-mol/h*	*Mol%*	*Recovery, %*	*Flow, Nm³/h*
Hydrogen	2,170.20	73.62	2,168.31	88.63	99.9	48,601
Methane	107.15	3.63	104.21	4.26	**Liquids Products**	
Ethane	245.38	8.32	165.84	6.78	Recovery, %	Flow, US BPD
Propane	239.75	8.13	3.37	0.14	98.6	3,277
Iso-Butane	52.04	1.77	0.22	0.01	99.6	853
n-Butane	62.29	2.11	0.79	0.03	98.7	951
Iso-Pentane	22.91	0.78	2.29	0.09	90.0	380
n-Pentane	12.62	0.43	0.70	0.03	94.5	217
C_6+	35.41	1.20	0.64	0.03	98.2	719
TOTAL	2,947.75	100.00	2,446.37	100.00		6,398
Flow, Nm^3/h	69,700		57,845			

Pre-Commissioning Activities

This unit was constructed as part of the YR platformer revamp project BI-3538. Upon completion of the mechanical construction of this unit, the following pre-commissioning activities had been undertaken:

1. A total of 120 hydro-tests were completed.
2. A total of 280 instrumentation loop were checked.
3. The eight (8) refrigeration loops were chemically cleaned.
4. Propane compressor lube oil system had been flushed.
5. A total of 31 equipment were boxed up.
6. A total of 22 motors were unclipped and run for 4 hours.
7. The instrumentation connection had been completed reinstated.

Subsequent to the completion of above pre-commissioning activities as part of mechanical completion, additional start-up pre-commissioning activities were as follows:

1. The refrigerant and lube oil circulation system was purged, evacuated and dried out with nitrogen to -40°C dew point.
2. The absorber system was purged and dried out by nitrogen to -40°C dew point.
3. All control valves where stroked and functionally tested.

4. All PZV were commissioned.
5. Refrigeration loop was filled with propane and samples collected to confirm the system dew point to be < -40°C.

LPG Recovery Process Start-up

Having completed all the commissioning activities as described above, and with the previously established operation of the debutanizer column which was producing a C_5+ Platformate product meeting the C_4 and lighter content specification, it was determined that the available initial CCR net gas flow on June 18, 2006 was about 33,000 Nm^3/h *(29.6 MMSCFD)*. Therefore, first the flow of unstabilized platformate *(bulk solvent)* from the feed to the debutanizer column was initiated at the rate of about 38 m^3/h *(167 US gpm)*. Once the level in the bottom of the LPG Absorber Column C-0101 was established at about 60% level transmitter (LT) range, the Absorber Bottoms Pump G-109B was started to circulate the bulk solvent through the two solvent cross-exchangers back to the debutanizer column feed.

After about an hour of the established circulation for the bulk solvent, flow of the debutanizer bottoms *(lean solvent)* stream was initiated at the rate of about 34 m^3/h *(150 US gpm)*. After filling the piping and exchangers, the lean solvent level began to increase in the Presat Separator D-0110. When the level was established at about 60% of the LT range, the Presat Pump G-0108A was started to transfer the solvent to the top of the absorber column. Within 20 minutes from the start of the G-0108A pump, level in the bottom of the absorber started to increase, thereby indicating that the two solvent circulations loops had been completed. The level transmitter controlling the flow from the discharge of the absorber bottoms pump G-0109B was switched to auto control.

With no gas flow through the absorber system, upon establishment of the lean solvent circulation, the column pressure started to decrease from an initial pressure of about 10 kg/cm^2g *(142 psig)* to about 8.6 kg/cm^2g *(122 psig)*. This indicated slight absorption of the hydrocarbons even at warm solvent temperatures on the order of 37°C *(98°F)*. To re-establish the pressure within the column to the CCR net gas compressor suction drum pressure without flowing gas through the LPG recovery unit, the inlet isolation valve was re-opened. The isolation valve blocking the flow from the LPG absorber overhead to the fuel gas system remained closed. With the circulating warm solvent the pressure increased and stabilized at about 9.8 kg/cm^2g *(139 psig)*.

While establishing the aforementioned two solvent circulation circuits several level and flow instrumentation calibration issues were identified.

- ***First Circuit***: between debutanizer feed → cross-exchanger E-0110 → platformate chiller E-0111 → LPG absorber C-0101 → absorber bottoms pump G-0109B → cross-exchangers E-0110 & E-0109 → debutanizer feed
- ***Second Circuit***: cool debutanizer bottoms from E-0102 → cross-exchanger E-0109 → mixer K-0101 → presat chiller E-0108 → presat separator D-0110 → presat pump G-0108A → LPG absorber C-0101 → absorber bottoms pump G-0109B → cross-exchangers E-0110 & E-0109 → debutanizer feed

Before attempting to start the propane refrigeration system, all instrumentation calibration issues were addressed over the following 24 hours.

Subsequently, the flow of CCR net gas through the LPG recovery process was initiated by opening the isolation valve at the outlet of the absorption system and closing the bypass isolation valve around the LPG recovery unit.

Propane Refrigeration System Start-up

With the established cooling load through the tube side of three chillers, start-up of the refrigeration system could now be commenced. The unfamiliarity of the refrigeration cycle within the refining industry as a whole was a significant challenge for the operations team in developing the feel for starting and controlling the three-stage, closed loop propane refrigeration system.

Table 2 summarizes the twelve compressor trips and the respective lessons learned that eventually resulted in a successful start-up of the three-stage centrifugal compressor and the closed loop refrigeration cycle at YR.

While the comparable quench-based suction drum configuration is quite extensively used at Saudi Aramco's gas processing facilities, one of the recurring problem in the start-up at YR had been managing and controlling the liquid levels in the various suction drums.

The hydrocarbon processing industry at large uses significantly sized refrigeration systems without the need to add quench liquid into the compressor suction drums by simply routing the anti-surge hot gas from the compressor discharge through a sparger line below the tube bundle in kettle chillers and in the economizer drums where liquid refrigerant is normally present. Doing so not only avoids the potential imbalance between the anti-surge gas flows and quench liquid temperature control valves, it also assures that the compressor suction drums remain dry and thus prevent compressor trips from high liquid level. Such a system at YR would have significantly simplified the start-up of the refrigerant compressor.

Throughout the compressor start-up attempts, starting flow of refrigerant vapors as quickly as possible into the refrigerant compressor to keep the discharge temperature within limits, and trying to close the anti-surge gas and liquid quench flows to reduce overloading the compressor motor was emphasized. A sudden realization after the twelfth trip that the inlet feed gas from the CCR unit was only about ⅓ the design gas flow and analysis of the compressor surge flows revealed that as long as the inlet gas flow from the CCR unit was less than 88% of the design flow for the LPG Recovery Unit, the installed refrigeration compressor will always have its anti-surge valve open.

This paved the way to change the start-up focus from trying to close the anti-surge valve to managing the introduction of available refrigerant vapors generated by the process streams through the chillers. This was the final straw that led to the successful start-up of the refrigeration system and within about five hours of continued integrated operation of the process-refrigeration systems, all temperatures reached their expected settings.

Table 2 – Propane Compressor K-0104 Start-up Trip History & Lessons Learned

TRIP NO.	TRIP TYPE OR SYMPTOM	LESSON LEARNED OR FOLLOW-UP ACTION TAKEN
1	High Vibration	Bypass trip setting during initial start-up.
2	High Amperage Load	Watch amperage indication to prevent overloading the compressor motor.
3	High-High Level 1st stage suction drum	Fix and calibrate LTs and FTs for accurate display on DCS screen.
4	High Discharge Temperature	1. Bypass current trip setting of 95°C and watch discharge temperature to not exceed vendor recommended limit of about 150°C. 2. Change start-up procedure to introduce chiller vapors into the compressor as quickly as possible.
5	Loss of Level Indication in Suction Drums and trip from High-High Level	Refill LTs with glycol and place plugs to prevent loss of fluid in LT legs.
6	Loss of suction pressure	DO NOT start compressor with isolation valves (ZV) OPEN on discharge and three suction stages.
7	High Discharge Pressure from cascading discharge temperature with discharge pressure	Avoid cascading discharge pressure and temperature until unit is stabilized and close in desired settings and the cascading configuration is checked and fixed.
8	Low suction pressure	Avoid imbalance from opening 5% of suction PV when compared to opening 30% discharge PV. Increase suction and discharge openings in equal increments.
9	Amperage overload from LP Economizer PV opening from 5% → 33%	Avoid rapid opening of LP and HP Economizer PVs.
10	3rd stage suction drum High-High level	Unreliable level transmitter operation. Avoid compressor operation until level indication is reliably displayed on DCS screen.
11	1st stage suction High-High level due to stuck 1st stage anti-surge valve and loss of suction pressure trip	1. Check, fix and recalibrate the 1st stage anti-surge valve and assure its operation. 2. Do not open drain valve too quickly. 3. Assure flow from 2″ hot sparger gas line in suction drums to assure imbalanced quench liquid is vaporized.
12	1. 3rd stage anti-surge valve stuck…3rd stage suction High-High level 2. 1st stage anti-surge valve stayed open throughout	1. Fix solenoid and recalibrate the 3rd stage anti-surge valve functionality. 2. Recognize that the anti-surge valves will remain open at inlet gas flow from CCR < 88% of design flow to the LPG Recovery unit.
SUCCESSFUL START-UP		

A representative DCS display snapshot of the process flow is shown in Figure 5 and that of the refrigeration system in Figure 6.

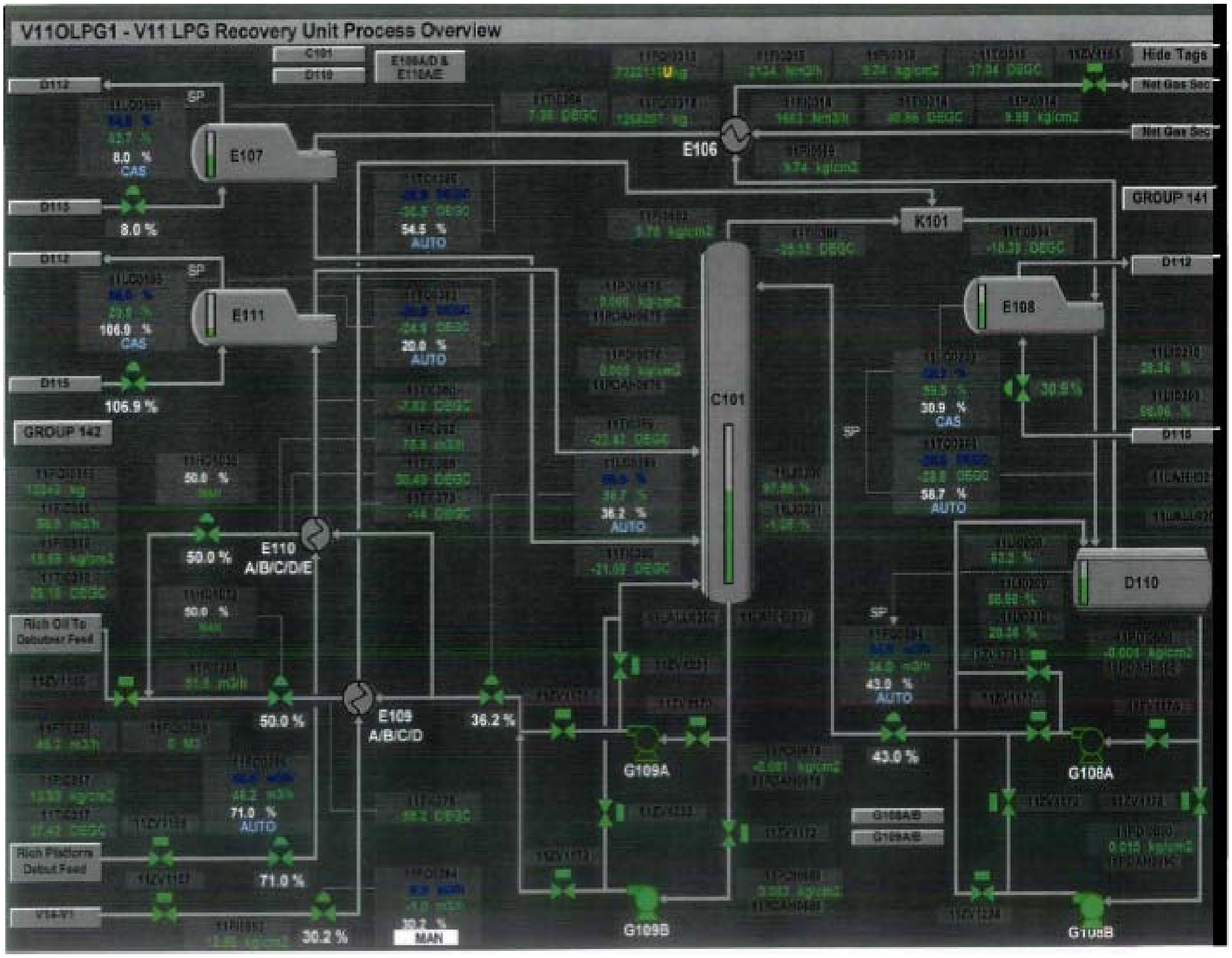

Figure 5 – LPG Recovery Unit Process Overview after Refrigeration Start-up

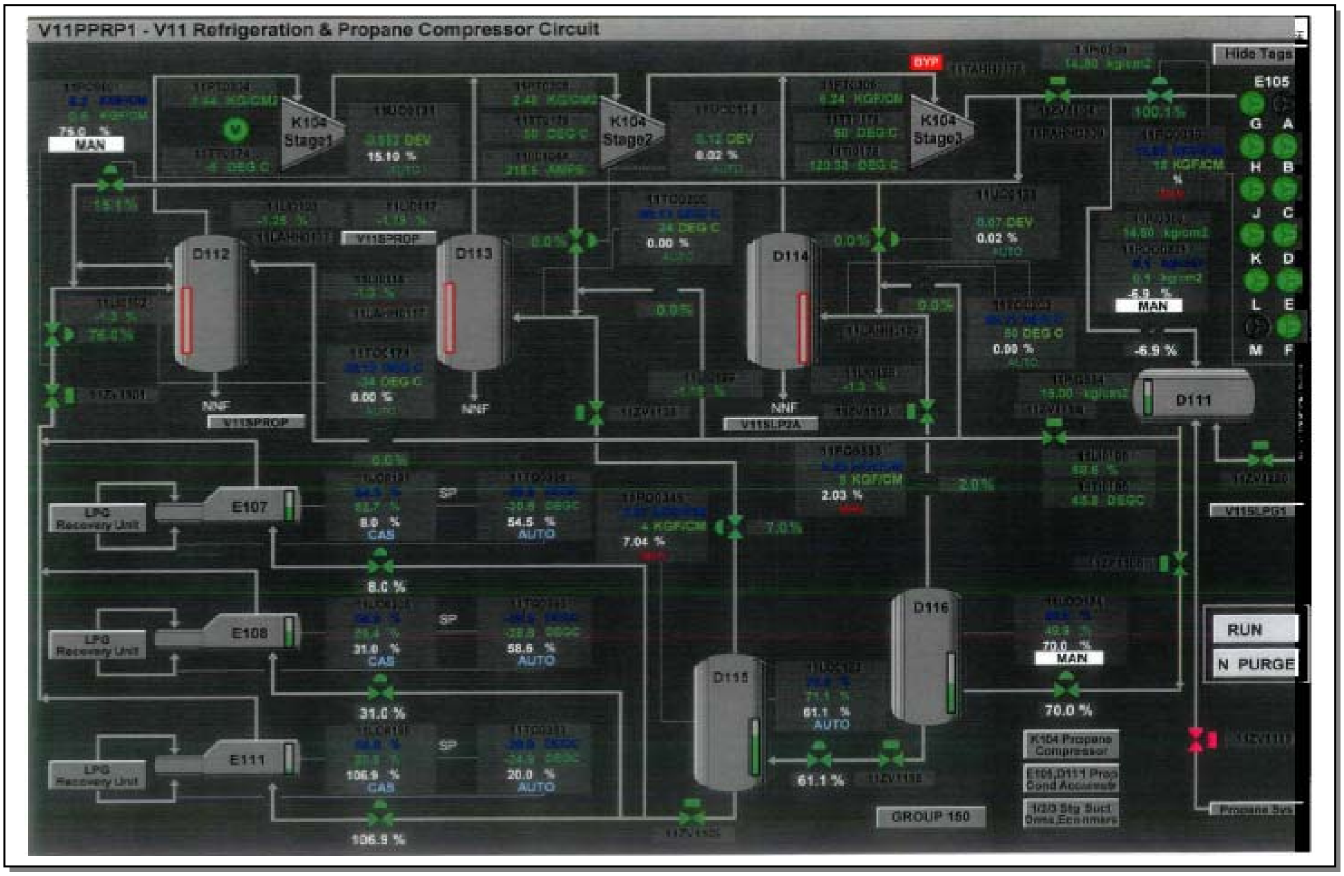

Figure 6 – Propane Refrigeration Compressor Circuit after Start-up

Conclusions

The new-to Saudi Aramco AET LPG Recovery Process was successfully incorporated at Yanbu' Refinery (YR) to utilize the Gas Concentration Unit's existing debutanizer and deethanizer columns in place to maximize LPG recovery from CCR net gas. Due to unfamiliarity of the refinery personnel with the closed loop, multistage propane refrigeration cycle, steady learning from each compressor trip led to eventual successful start-up of not only the propane refrigeration compressor but also the integrated process-refrigeration system. Most of the compressor trips were related to high liquid level in compressor suction drums caused by the imbalance of the anti-surge gas flow and its associated liquid propane quench flow. The operation of the integrated LPG recovery facility is very easy, stable, and flexible to gas flow and composition changes. Should the refrigeration compressor accidentally trip, the LPG recovery process can continue to operate stably and await restart of the refrigeration compressor. The operation of the YR unit has successfully demonstrated turndown to 30% of the design inlet gas flow capacity. With this start-up, YR has successfully pioneered the incorporation of colder temperatures within a refining environment to maximize recovery of value from its hydrocarbon resources.