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BP Chemicals
Selective Olefin Recovery

Process Optimization Studies
Economics of SOR for Grassroot Plants
and for KG Expansion

April, 1996

STONE & WEBSTER ENGINEERING
HOUSTON, TEXAS
1.0 INTRODUCTION

This interim report has been prepared as a followup to the January 1996 JDAG meeting. The report presents the results of various studies which evaluate the impact of process design changes on the overall SOR economics for cracked gas olefin recovery. The changes were made to either complete portions of the design that were missing or overlooked, or to improve and/or optimize the SOR process.

A grass-roots propane-feed 350,000 MTA plant with a conventional recovery system was adopted as the study basis, and was compared with SOR systems of various sizes up to 350,000 MTA. This approach was taken to determine if SOR plants could be competitive with larger plants utilizing conventional recovery systems.

Second phase KG expansion by 50,000-150,000 MTA ethylene was reexamined in view of the SOR process optimization. As was done in Stone & Webster’s December 1995 study, an SOR system was compared with an ARS expansion.

Following the directives given at the JDAG meeting, the following changes to the SOR process design were incorporated:

(1) Feed was changed to 100% propane with cracking at high severity to maximize conversion, since the SOR process does not recycle unconverted feed.

(2) Front end acetylene hydrogenation was increased to hydrogenate all of the acetylenes, including all of the MAPD. A guard bed was added to protect against acetylenes breakthrough. The back end C3 hydrogenation system was eliminated.

(3) Ethylene and propylene recoveries were increased by utilizing a leaner solution, and by increasing the solution circulation to reduce the olefin loadings in the rich solution. In addition, C4s recovery was increased to nearly 100%.

Time did not allow for studies to be completed for pyridine recovery, higher temperature stripping, increased product purities, and increased heat recovery. These studies will be completed in the May-June 1996 time frame.
2.0 EXECUTIVE SUMMARY

2.1 SOR PROCESS OPTIMIZATION

Olefin recoveries were increased over the 98% ethylene, 90% propylene recoveries used in Stone & Webster's December 1995 report. This was primarily accomplished by modifying the lean and rich solution loadings.

Higher absorber pressures were examined to determine if there was an optimum. Absorber pressures of 4.1, 6.9, and 15.9 bar g (60, 100, and 230 psig) were studied, based on estimated pressures using 2, 3, and 4 stages of cracked gas compression.

The absorber temperature was maintained at 30°C (86°F) to avoid refrigeration.

The results of the SOR process optimization study are presented in Section 3.0, and are summarized in the following table:

<table>
<thead>
<tr>
<th>Stages of Cracked Gas Compression</th>
<th>Absorber Pressure (bar g)</th>
<th>Range of Ethylene Recoveries (%)</th>
<th>Range of Propylene Recoveries (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>4.1</td>
<td>98.0-98.6</td>
<td>78.0-96.5</td>
</tr>
<tr>
<td>3</td>
<td>6.9</td>
<td>98.5-99.5</td>
<td>91.7-97.0</td>
</tr>
<tr>
<td>4</td>
<td>15.9</td>
<td>99.4-99.6</td>
<td>97.9-98.6</td>
</tr>
</tbody>
</table>

If the absorber is not limited by the number of contacting stages, olefin recoveries at a given pressure will be a function of the lean and rich solution loadings. Design olefin recoveries were selected based on non-rigorous optimization of the lean and rich loadings as follows:

<table>
<thead>
<tr>
<th>Stages of C.G. Compression</th>
<th>Absorber Pressure (bar g)</th>
<th>Design Ethylene Recovery (%)</th>
<th>Design Propylene Recovery (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>4.1</td>
<td>98.5</td>
<td>93.0</td>
</tr>
<tr>
<td>3</td>
<td>6.9</td>
<td>99.0</td>
<td>97.0</td>
</tr>
<tr>
<td>4</td>
<td>15.9</td>
<td>99.5</td>
<td>98.5</td>
</tr>
</tbody>
</table>

These recoveries are a marked improvement over the 98% ethylene, 90% propylene used as the basis for economic evaluations in the December 1995 study report.

As a result of these higher olefin recoveries, the SOR process shows improved economics over conventional cryogenic distillation technology. Economic evaluations made at different absorber pressures are summarized as follows:

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In each case, SOR shows a 30-34% installed cost savings and a 16-20% net operating cost savings over a conventional recovery system. (Net operating cost savings includes an adjustment for differences in product recoveries). The above data appear to imply that an optimum could exist for three stages of cracked gas compression.

To further analyze the optimum SOR design, an additional comparison was made in Section 3.0, comparing each of the SOR systems with one another on a total plant basis. (Since the material balances are slightly different for each of the SOR cases, adjustments for installed cost and operating cost differences of the slightly different front ends were required for this comparison.) The results of this latter SOR optimization comparison are summarized in the following table:

<table>
<thead>
<tr>
<th>Stages of C.G. Compression</th>
<th>Absorber Pressure (bar g)</th>
<th>SOR Savings in Installed Cost (%)</th>
<th>SOR Savings in Net Operating Cost (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>4.1</td>
<td>34</td>
<td>16</td>
</tr>
<tr>
<td>3</td>
<td>6.9</td>
<td>33</td>
<td>20</td>
</tr>
<tr>
<td>4</td>
<td>15.9</td>
<td>30</td>
<td>18</td>
</tr>
</tbody>
</table>

| Stages of C.G. Compression | Absorber Pressure (bar g) | Installed Front End Cost, $MM | Installed SOR System Cost, $MM | Total Plant Installed Cost, $MM | Increase in Total Installed Cost relative to base case, $MM | Propane Feed Value, $MM/yr | Total Product Value, $MM/yr | Gross Margin, $MM/yr | Front End Variable Cost, $MM/yr | SOR System Variable Cost, $MM/yr | Total Variable Operating Cost, $MM/yr | Increase in Total Variable Cost relative to base case, $MM/yr | Net Margin, $MM/yr | Increase (decrease) in net margin relative to base case, $MM/yr | Payout relative to base case, years |
|----------------------------|---------------------------|-------------------------------|-------------------------------|-------------------------------|---------------------------------|-----------------------------|---------------------------|-----------------------------|-------------------------------|-------------------------------|-------------------------------|---------------------------------|-----------------------------|-----------------------------------------------------------------------------------|
| 2                          | 4.1                       | 62.7                          | 82.5                          | 145.2                         | ---                             | 140.3                        | 277.9                     | 137.6                       | 14.07                          | 14.21                          | 28.28                          | ---                             | 109.3                        | ---                             | 2.4 (6.6)                         |
The results of this analysis indicate that three stages of compression are optimum, provided that the absorber offgas is not required at a higher pressure. If it were, offgas compression would be required, and the optimum number of compression stages could increase. If the offgas is used as low pressure fuel gas, three stages are optimum, and is in fact preferred over two stages even if two stages are sufficient to deliver the offgas without further compression. If, however, the offgas is used as methanol plant feed to a steam reformer, for example, four stages of compression would probably be optimum.

2.2 ECONOMICS OF GRASSROOT SOR UNITS

Various size propane-fed grassroot olefin plants incorporating SOR units were examined to determine how SOR plants compare with large conventional plants. For the SOR cases, an "optimized" three stage compression design was used with recoveries of 99.0% on ethylene, 97.0% on propylene, and 100% on C4s.

For this analysis, ethylene production cost was used as a representative economic variable. The economics of SOR have been predicated on the absorber offgas having fuel gas value. The results of this study are presented in Section 4.0 and are summarized graphically in Figure 2.2. The results may be summarized as follows:

(1) At equivalent capacities of 350,000 MTA ethylene, the ethylene production cost is 16-17% lower with SOR, as compared with a conventional plant.

(2) At a capacity of 150,000 MTA, SOR has a 1-5% lower ethylene production cost, as compared with a 350,000 MTA conventional plant.

(3) SOR plants slightly smaller than 150,000 MTA can also be competitive. The breakeven SOR plant size (defined as that plant size which has the same ethylene production cost as a 350,000 MTA conventional plant) ranges from 120,000 to 140,000 MTA, depending upon the level of fixed costs.

(4) The above conclusions are insensitive to the level of fixed costs.

The overall conclusion of this study is that very small SOR plants are expected to be competitive with large olefin plants using conventional recovery technology.
Figure 2.2 - Difference in Prod’n Cost
Relative to 350,000 MTA Convent’l Plant

- 15% Fixed Costs
- 20% Fixed Costs
- 25% Fixed Costs

SOR Plant Capacity, MTA Ethylene (Thousands)

Difference in Ethylene Prod’n Cost (%)
2.3 ECONOMICS OF SOR FOR KG EXPANSION

The KG expansion study is presented in Section 5.0. For a second phase expansion by 50,000-150,000MTA ethylene, SOR has a lower installed cost (18 % less), but a significantly higher operating cost (36 % greater) as compared with an ARS expansion. The higher SOR operating cost mainly results from the differences in ethylene and propylene yields and unconverted propane utilization and valuation between the two alternates.

Based on the assumptions in Section 5.0, the payout of an ARS expansion as compared to an SOR expansion is 3.9 years for a 150,000 MTA expansion and 5.7 years for a 50,000 MTA expansion. For this calculation, quench water has been valued at half the LP steam value, and absorber offgas has been valued at fuel gas value.

If quench water were valued at zero, the payout of an ARS expansion as compared to an SOR expansion would be about 11 years for a 150,000 MTA expansion and about 17 years for a 50,000 MTA expansion. For quench water valued at LP steam value, the payouts would be 2.5 years for 150,000 MTA and 3.5 years for 50,000 MTA.

A one-furnace ARS expansion (90,000 MTA) will have payouts relative to SOR intermediate between the 50,000 and 150,000 MTA cases: 3 years for quench water valued at LP steam value, 5 years for quench water valued at half LP steam value, and 14 years for zero value quench water.

The conclusions of this analysis are, therefore:

(1) SOR competitiveness for any expansion is extremely sensitive to quench water valuation. For a 50,000-150,000MTA expansion of KG, SOR will be more attractive than ARS at zero value quench water. For quench water valued at LP steam value, ARS is attractive at the larger (150,000 MTA) capacity increment. At intermediate quench water valuations, SOR is still more attractive than ARS.

(2) For a one-furnace 90,000 MTA expansion, payouts for ARS range from 3 to 14 years, depending upon quench water valuation. SOR is more attractive than ARS for all but the highest quench water valuations.
2.4 CONCLUSIONS

The following conclusions may be drawn from this study:

(1) SOR olefin recoveries approaching 100% are possible by a combination of lower lean solution loading (improved stripping), lower rich solution loading (greater solution circulation), and increased absorber pressure.

(2) As a result of the improved olefin recoveries, the economics of SOR for cracked gas olefin recovery are improved over the economics presented in Stone & Webster's December 1995 report. Savings over conventional recovery systems of 16-17% in ethylene production cost are expected for a grass roots SOR unit. The economics of SOR are contingent on the absorber offgas having fuel gas value.

(3) The optimum absorber pressure will depend upon how the offgas is utilized. For those applications where the offgas is required at less than 7 bar g, three stage cracked gas compression with absorption at about 7 bar g will probably be optimal. The offgas would then be let down to user pressure. For applications requiring high pressure offgas, it will most likely pay to use four stage cracked gas compression with absorption at about 17 bar g. The resulting higher olefin recoveries will make this option attractive, as opposed to absorption at a lower pressure with compression of the offgas.

(4) It should be able to produce polymer-grade ethylene and propylene products by a combination of increased absorber presstripping and minor changes to the distillation section design. Product purity studies have been deferred to May-June 1996.

(5) Recycle of pyridine/water solutions should provide a feasible approach to reducing pyridine losses to an acceptable level while minimizing product contamination and pyridine makeup. The required facilities are not expected to impact the SOR economics significantly. Pyridine studies have been deferred to May-June 1996.

(6) There may be room for some optimization of SOR heat recovery, further improving its economics.

(7) Smaller (120,000-150,000 MTA) SOR olefin plants are expected to be competitive with larger (350,000 MTA) plants using conventional cryogenic distillation technology. This advantage could open up a new market for small SOR olefin plants located closer to end users.

(8) SOR competitiveness for KG expansion is extremely sensitive to quench water
valuation. For a 50,000-150,000MTA expansion, SOR is more attractive than ARS at zero value quench water and for quench water valued at half LP steam value. For quench water valued at LP steam value, ARS is attractive for a 150,000 MTA expansion. For a one-furnace expansion (90,000 MTA), SOR will be more attractive than ARS for all but the highest quench water valuations.

As for the grassroots studies, absorber offgas was assumed to have fuel gas value. In general, SOR will not have the overwhelmingly attractive economics for expansions, as it does for grassroots applications.

2.5 RECOMMENDATIONS

Stone & Webster recommends that BP Chemicals proceeds with its current program of additional development for the cracked gas SOR process, with support on engineering tasks by Stone & Webster.

The Antoine coefficients for ethylene and propylene vapor pressures should be checked by BPC against the latest experimental data and revised if necessary. Stone & Webster could then assess the impact of any revisions to the coefficients on the SOR process design and economics.

Key VLE data needed to assess the feasibility of the SOR process should be given priority. Critical data requirements include VLE data for 1-butene, cis- and trans-2-butene, isobutylene, 1,3-butadiene, propadiene, and carbon monoxide. Once this data is developed, Stone & Webster will assess its impact on product purities and the feasibility of the solution reclaiming operation.

The value of KG quench water for process evaluation should be determined, and the economics reevaluated.

Stone & Webster should complete its studies on product purities, solution stripping, pyridine recovery, and heat recovery optimization in the May-June timeframe.

If the technical and economic feasibility of the process are confirmed, Stone & Webster recommends that BPC proceed with the pilot plant/commercial demonstration program as outlined in the January 1996 JDAG meeting.