Pipe Network Evaluation for "X" Field Production Optimization

(Evaluasi Jaringan Pipa Untuk Optimasi Produksi Lapangan “X”)

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Abstract
Fields “X” is an old field in the South East Sumatra Block. The area was developed using ten platforms. One main problems on this field is the disruption of some wells productivity due to flow constraints in the piping network. The objective of this paper is to evaluate the pipeline network for area "X1" using simulation model. The simulation results show that there are bottlenecking and backpressure problems in the network. By fixing the problems, total oil production in this area can be increased up to 19 percent or 1,006.2 BOPD higher than initial condition.

Keywords: Pipeline Network, Bottlenecking, Back Pressure, Production Optimization

I. INTRODUCTION

Field “X” is a mature field that is included in the South East Sumatra Block. The pipeline network in the “X1” area has been developed since the field was produced in 1974. The area was developed using ten platforms, namely Sundari-A, Sundari-B, Yvone-A, Yvone-B, Krisna-A, Krisna-B, Krisna-C, Krisna-D, Krisna-E and Krisna-P. Until now there have been 90 producing wells through these 10 platforms. Oil production is mostly derived from the carbonate reservoir of the Baturaja Formation which is divided into two units, namely the Upper Baturaja Unit (Krisna D and E) and the Lower Baturaja Unit (Krisna A, B, C, and E), and only a small portion comes from sandstones Talang Akar Formation.

Currently, the inspection of production fluid flow is done manually, by analyzing wellhead pressure change to the increase or decrease of production flow rate at separator and storage station. All platforms are in the offshore area with a considerable distance between platforms in average of 25,365 ft. The limitation of sea transportation as a link between platforms becomes an obstacle to the inspection of production fluid flow. This process takes one to two days considering the distance between well head and production facility platform (separator) and storage station. The farthest distance of well head to the production facility platform is 87,300 ft.

One main problem on this field is the disruption of some wells productivity due to flow constraints in the pipeline network or better known as bottlenecking. Bottlenecking results in a high pressure drop in the pipe segment that connects two or more pipes behind it so as if the flow is narrowed which will then provide high back pressure to the wellhead. It may lead to some problems such pipe abrasion, corrosion, and rupture. To overcome this, a model that resembles field conditions needs to be made so it can be simulated. There are two common ways of repairs the bottlenecking, by replacing the bottleneck-affected pipe with a new pipe that has an optimum inner diameter, or adding a parallel pipe next to the pipe affected by the bottlenecking. A result comparison of the two methods is made to determine the best solution [1-5].

A network modeling can simulate various production optimization scenarios to reduce the
risk of trial and error compared to directly carried out in the pipeline network, as well as simulations of the current pipeline network readiness in case there is an increase or decrease in production rate [6].

Pipeline network modeling has been applied to other areas in the south of the "X1" Area "X" Field, and no significant back pressure problems were found. However, the model is useful in making simulations of production rate optimization scenarios and looking at the ability of the network when there is an increase or decrease in production. Accurate pipeline modeling is required because small amounts of fluid flow can significantly impact pressures in a large gathering system [7–8].

In this paper the "X1" Area pipeline network model was evaluated to identify whether bottlenecking and back pressure problems occur in the pipeline network and to determine the optimal condition.

II. METHOD

The work flow research is shown in Figure 1. The work procedures performed to evaluate the production network optimization in this study are as follows:

1. Collecting field data such as well test production data, reservoir data, fluid data, and pressure data on risers at each platform.
2. Collecting technical design data and technical specifications from wells and pipeline networks, namely data wellbore diagrams, pipeline network layout diagrams, technical specification data from pipelines and fluid flow diagrams on each related platform.
3. Modeling and simulation of each production well and pipeline in Area "X1" using the WellFlo and ReO applications.
4. Performing production rate matching and network matching against pressures between field data and data from the WellFlo and ReO 2014 pipeline network simulation results.
5. Conducting analysis on pipelines such as nodal analysis, well performance analysis, pressure drop analysis per foot and production optimization analysis.
6. Conducting pipeline network optimization scenarios by increasing or decreasing fluid pressure through choke control of the wellhead and riser pipes in the pipeline network to increase the optimal production rate.

Data required in the production and pipeline network model are:

1. Trajectory data as true vertical depth (TVD), measure depth (MD), and slope angles of wells.
2. Completion diagram that is the data of layers of rock that are skipped, perforation, production casing, screen, blank pipe, packer, tubing, ESP pump.
3. Reservoir data, namely fluid properties data in the form of reservoir pressure, volume and temperature, and rock formation (PVT).
4. Production data from the well test conducted on the separator. Production data that is used as a reference is production data dated January 27, 2016, considering to the active production wells during that period was above the average of 41 active wells.
5. Well performance data that is obtained from simulation results on the production well model.
6. Pipeline data consist of pipeline material specification, length, diameter, thickness, water depth, and coating material.
7. Fluid data as fluid flowing in the pipeline obtained from the simulation results of the production well model.
8. Pressure riser data is the pressure of the riser out and into the platform.
9. Subsea pipeline layout data.

The equipment used in evaluating this area pipeline network is the WellFlo 2011 and ReO 2014 software.

III. RESULTS AND DISCUSSION

The stages of modeling and simulation begin with making simulation models, matching, and analysis. Modeling for production well simulation in Area "X1" using the WellFlo application. Modeling and matching of production wells begins with the preparation of data, modeling, and validation or matching the results of simulations against field data. The data needed is trajectory data (Table 1), PVT data (Table 2), reservoir and production data (Table 3), and completion data (Figure 2).

Figure 3 shows the pipeline network scheme in the "X1" Area. The "X1" Area pipeline network connects ten platforms starting from the S-B, S-A, Y-B, Y-A, K-E, K-A, K-D, K-C, K-B platforms. Fluid flow starts from the fluid in the S-B platform to the S-A platform, the S-B and S-A fluid flows join then flows to the Y-A platform. Y-B bridge fluid flow also flows towards Y-A. Fluid flow from the Y-A platform and the K-E platform then flows to the K-A platform. Fluid flow collected in the K-A platform flows towards the K-B platform. Fluid flow from the K-D and K-C platforms, each flows to the K-B platform. All the fluid collected in the K-B platform flows to the K-P platform to be processed using a separator. Fluid separation oil in the K-P platform separator is flowed back to the K-B platform to be forwarded to the C-P platform as the end point of fluid flow in the "X1" Area.

Well performance matching is done with the WellFlo application. Matching conditions are met when the inflow performance curve is crossed with...
the outflow performance curve at a flow rate that is consistent with production data. In Figure 3, the intersection point between the inflow and outflow curves occurs at an operating pressure of 2,433.46 psia and a liquid flow rate of 1,201.9 BFPD.

Similar method was applied for other 41 wells, resulted on matching between actual and simulation data for the production flow and pressure as shown in Table 4. The table shows that the average of percentage difference liquid flow rate was 0.03% with a maximum difference of 0.15% in KA-03: BR wells, and average of bottomhole pressure is 3.2% with a maximum difference of 5.8% in KC-10: BR wells.

Pipeline modeling for network simulations in the "X1" Area using the ReO application. Figure 4 is a complete picture of the pipeline network model in the "X1" Area. The pipeline connects ten platforms starting from the S-B, S-A, Y-B, Y-A, K-E, K-A, K-D, K-C, K-B, K-P platforms. The final point of liquid production is processed at the K-B process platform, while the end point of this area is the C-P platform. Table 5 and Table 6 show the pipe size and fluid properties respectively. In addition to modeling the pipeline between platforms, a pipeline network between wells is also modeled on each platform. Figure 5 shows the pipeline network between wells on the S-B platform.

The results of pressure and oil rate matching at each platform with the ReO2014 application are shown in Table 7. The table shows the average pressure difference of 0.95%, where the highest difference in pressure is 1.14% at K-B-03 wells. The average oil rate difference is 5.16% with the biggest oil rate difference of 8.49% in well S-A-01 that may be caused by inaccurate of well data. The latest well test was conducted more than 1 month from the reference date of this production simulation, January 27, 2016.

The results of the riser pressure and the oil rate matching are shown in Table 8. Simulation results the average pressure matching difference is 1.5% with the largest matching difference of the pressure of 3.3% on the C-P platform. While the average of oil rate difference matching is 3.1% with the biggest oil rate difference matching of 6.8% at the Y-B Out platform.

Matching results showed that bottlenecking was occurred in three segments, called segment 3, segment 6, and segment 8, thus the simulation was proposed to close the well on the S-A platform before the pipeline bottlenecking position, with the scenarios below:

a. Close 1 well in S-A platform
b. Close 2 wells in S-A platform

Scenario 1 was conducted by shutting down one well S-A-01 (1043 BFPD) at S-A platform. Final lockdown output was 11,342.59 BOPD press 29 psia. The simulation results shows that the pipeline network are still able to run and increasing oil rate more than 10% on other four wells in S-A platform.

Scenario 2 was conducted by shutting down two wells with the smallest fluid flow rate at the S-A platform. The well that was turned off: S-A-01 (1043 BFPD) and S-A-08 (1027 BFPD). Final lockdown output was 11,342.59 BOPD press 29 psia. By shutting down two S-A-01 and S-A-08 production wells the production target of 11,342.59 BOPD and 29 psia cannot be achieved.

Simulation result shows that the production target cannot be achieved when the shut-in wells have a total fluid rate of more than 1500 BFPD. The pipeline network optimization scenario was carried out by opening pressure choke at wellhead, and pipes inlet and outlet at each platform. Figure 6 presents the result of the optimization scenario on the matching simulation.

In addition, if the pressure value of optimization scenario is higher than the pressure value of the matching simulation, the pipeline condition can still be optimized by increasing the production pressure to increase production rate. However, if the pressure value of the optimization scenario results is lower than the pressure value of the matching simulation, the pipeline condition is no longer optimal, and tends to blockage in the fluid flow rate in the pipe segment, this confirms the bottlenecking in the pipe segment.

From the above results, it can be seen that the bottlenecking occurs on three segments, segment 3 (KE to KA), segment 6 (KA to KB), and segment 8 (KC to KB), thus simulation of pipeline network optimization suggests to reduce the pressure on the segments to increase production rate.

Table 9 shows that to increase the production rate can be done by reducing wellhead pressure, in order to obtain production increase in average of 22.4 BOPD or 18% higher than initial production of 134.5 BOPD in average. High pressure on the wellhead indicates the occurrence of back pressure in the pipeline network, back pressure will inhibit the overall oil production rate. To reduce the pressure on the wellhead, some efforts should be made to reduce the separator pressure at the block station production facility. Thus, the result of the study indicates that the second hypothesis is accepted, namely there are bottlenecking and back pressure problems in the pipeline network in the "X1" Area "X" Field.

The oil production rate of the "X1" area is 6,205.9 BOPD, which is smaller than the total production rate at the wellhead of 6,433 BOPD, as the affect of production rate loss in the pipeline network. The optimization in the pipeline network shows an increase in oil production of 1,006.2 BOPD or 19% higher than initial production rate of
the "X1" Area. Thus, the result of the study indicates that the third hypothesis is accepted, namely the simulation modeling on pipeline network can increase the optimum oil production rate.

IV. CONCLUSIONS
After evaluating and optimizing the "X1" Area pipeline network, it can be concluded as follows:
1. Pipeline network and production wells in "X1" Area can be modeled with an average of pressure differences by 1.5%, and biggest pressure matching difference in 3.3%, while the matching average of oil rate difference is 3.1% with the biggest oil rate difference matching oil in 6.8%.
2. Bottlenecking problems were found in three segments; segment 3 (KE to KA), segment 6 (KA to KB, and segment 8 (KC to KB), thus some efforts need to be made to reduce the pressure on the pipeline segment contained bottlenecking includes: pipeline pigging, pipeline replacement with larger diameters, or parallel pipeline additional.
3. Back pressure was found in the majority of production wells in the "X1" Area pipeline network, so efforts to reduce the pressure at the block station of production facilities need to be done.
4. An optimization scenario simulation results for back pressure and bottlenecking problems show an increase in production rate of 1,006.2 BOPD or 19% higher compare to initial production rate.

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Figure 1. Procedure of Research

Start

Data Processing and Preparation

Well Model Matching

Pipe Network Model Matching

Running Optimum Scenario Analysis

End
Table 1. Trajectory Data of S-A-06 Well

| MD, ft | TVD, ft | Deviation Angle, degree |
|--------|---------|-------------------------|
| 400.0  | 400.0   | 0.0                     |
| 863.0  | 862.9   | 1.1                     |
| 985.0  | 984.8   | 2.7                     |
| 1077.0 | 1076.5  | 4.7                     |
| 1137.0 | 1136.1  | 6.5                     |
| 1262.0 | 1259.6  | 8.8                     |
| 1325.0 | 1321.5  | 10.8                    |
| 1388.0 | 1383.1  | 12.0                    |
| 1420.0 | 1414.3  | 13.0                    |
| 1503.0 | 1494.8  | 14.1                    |
| 1661.0 | 1646.5  | 16.3                    |
| 1817.0 | 1793.7  | 19.3                    |
| 1981.0 | 1949.1  | 18.7                    |
| 2068.0 | 2029.2  | 23.0                    |
| 2131.0 | 2083.7  | 30.0                    |

| MD, ft | TVD, ft | Deviation Angle, degree |
|--------|---------|-------------------------|
| 2194.0 | 2137.2  | 31.9                    |
| 2288.0 | 2215.2  | 34.0                    |
| 2383.0 | 2291.4  | 36.6                    |
| 2414.0 | 2315.7  | 38.5                    |
| 2479.0 | 2365.9  | 39.4                    |
| 2575.0 | 2439.6  | 39.9                    |
| 2732.0 | 2560.1  | 39.9                    |
| 2984.0 | 2753.5  | 39.9                    |
| 3298.0 | 2994.9  | 39.7                    |
| 3612.0 | 3237.2  | 39.5                    |
| 3929.0 | 3481.8  | 39.5                    |
| 4242.0 | 3724.2  | 39.2                    |
| 4557.0 | 3970.7  | 38.5                    |
| 4872.0 | 4219.3  | 37.9                    |
| 5172.0 | 4461.2  | 36.3                    |

Table 2. PVT Data

| Formation | Pb | GOR, scf/stb | Boi | Bgi, cf/scf | SGO | SGG | Tr, °F | Type of Reservoir Drive |
|-----------|----|--------------|-----|-------------|-----|-----|-------|------------------------|
| K, UBRF   | 400.0 | 0.0 | 2194.0 | - | 32 | 0.80 | 208 | Solution Gas Drive |
| K, LBRF   | 862.9 | 1.1 | 2288.0 | - | 36 | 0.80 | 211 | Partial Water Drive |
| K, TAF    | 984.8 | 2.7 | 2383.0 | 0.01 | 37.6 | 0.77 | 220 | Solution Gas/Water Drive |
| Y, BRF    | 1076.5 | 4.7 | 2414.0 | - | 36 | 0.86 | 211 | Water Drive & Solution Gas Drive |
| Y, TAF    | 1136.1 | 6.5 | 2479.0 | - | 34 | - | 215 | Water Drive & Solution Gas Drive |
| S, TAF    | 2083.7 | 30.0 | 5172.0 | - | 24.3 | 0.64 | 230 | Strong Water Drive |

Table 3. Production Data

| Platform | Status | Test Date    | BFPD | BSW % | BOPD | BWPD | MCFD | GOR | PBHP | PBHT | FLT |
|----------|--------|--------------|------|-------|------|------|------|-----|------|------|-----|
| S-01     | P*     | 26-12-2015   | 1,043| 97.00 | 31   | 1,012| 47   | 1,501| -    | -    | 192 |
| S-05     | P      | 10-01-2016   | 2,299| 94.00 | 138  | 2,161| 43   | 312  | 600  | 207  | 204 |
| S-06     | P      | 20-12-2015   | 1,202| 87.00 | 156  | 1,046| 44   | 281  | -    | -    | 196 |
| S-08     | P      | 24-12-2015   | 1,027| 96.00 | 41   | 986  | 42   | 1,022| 386  | 215  | 198 |
| S-09     | P      | 19-12-2015   | 3,120| 93.00 | 218  | 2,902| 57   | 261  | 624  | 208  | 202 |
| S-10     | P      | 22-12-2015   | 3,092| 92.00 | 247  | 2,845| 43   | 174  | 411  | 210  | 214 |
| S-11     | S*     | 23-03-2015   | 1,530| 95.00 | 76   | 1,453| 30   | 392  | 900  | 208  | 189 |
| S-13     | P      | 27-01-2016   | 4,787| 96.00 | 191  | 4,596| 42   | 219  | 699  | 205  | 204 |
| S-14     | P      | 28-12-2015   | 1,599| 93.00 | 112  | 1,487| 35   | 312  | -    | -    | 196 |

*P = Production, S = Shut-in
| Platform/Well Name | Actual | Simulated | % Difference |
|-------------------|--------|-----------|--------------|
| K-A               |        |           |              |
| K-A-01            | 553    | 1,133     | 547.30       |
|                   |        |           | 1,134.0      | 1.0 | 0.09 |
| K-A-03            | 295    | 662       | 282.35       |
|                   |        |           | 663.0        | 4.3 | 0.15 |
| K-A-05            | 511    | 692       | 489.72       |
|                   |        |           | 691.0        | 4.2 | 0.14 |
| K-A-07            | 232    | 471       | 224.70       |
|                   |        |           | 471.5        | 3.1 | 0.11 |
| K-A-09            | 507    | 954       | 487.70       |
|                   |        |           | 954.0        | 3.8 | 0.00 |
| K-B               |        |           |              |
| K-B-01            | 610    | 927       | 606.00       |
|                   |        |           | 927.5        | 0.7 | 0.05 |
| K-B-03            | 1284   | 813       | 1276.60      |
|                   |        |           | 813.5        | 0.6 | 0.06 |
| K-B-05            | 588    | 1,192     | 586.68       |
|                   |        |           | 1,192        | 0.2 | 0.02 |
| K-B-09            | 639    | 1,486     | 618.30       |
|                   |        |           | 1,486        | 3.2 | 0.01 |
| K-C               |        |           |              |
| K-C-02            | 452    | 1,940     | 441.00       |
|                   |        |           | 1,940        | 2.4 | 0.02 |
| K-C-04            | 561    | 1,087     | 545.70       |
|                   |        |           | 1,087        | 2.7 | 0.00 |
| K-C-10            | 279    | 921       | 262.88       |
|                   |        |           | 921.0        | 5.8 | 0.01 |
| K-C-11            | 475    | 739       | 478.40       |
|                   |        |           | 739.0        | 0.7 | 0.00 |
| K-D               |        |           |              |
| K-D-01            | 269    | 379       | 259.95       |
|                   |        |           | 379.0        | 3.4 | 0.00 |
| K-D-06            | 315    | 572       | 297.73       |
|                   |        |           | 572.0        | 5.5 | 0.02 |
| K-D-07            | 307    | 1,910     | 293.90       |
|                   |        |           | 1,910.0      | 4.3 | 0.00 |
| K-D-09            | 242    | 703       | 234.10       |
|                   |        |           | 703.0        | 3.3 | 0.01 |
| K-E               |        |           |              |
| K-E-01            | 586    | 1,616     | 569.50       |
|                   |        |           | 1,615.8      | 2.8 | 0.01 |
| K-E-03            | 386    | 153       | 379.40       |
|                   |        |           | 152.8        | 1.7 | 0.13 |
| K-E-05            | 316    | 191       | 314.90       |
|                   |        |           | 191.0        | 0.3 | 0.00 |
| K-E-09            | 404    | 1,663     | 383.60       |
|                   |        |           | 1,663.0      | 5.0 | 0.01 |
| S-A               |        |           |              |
| S-A-01            | 862    | 1,043     | 826.90       |
|                   |        |           | 1,042.9      | 4.1 | 0.01 |
| S-A-05            | 615    | 2,299     | 583.50       |
|                   |        |           | 2,298.7      | 5.1 | 0.02 |
| S-A-06            | 807    | 1,202     | 770.70       |
|                   |        |           | 1,202.2      | 4.5 | 0.02 |
| S-A-08            | 386    | 1,027     | 376.30       |
|                   |        |           | 1,027.0      | 2.5 | 0.02 |
| S-A-09            | 639    | 3,120     | 617.30       |
|                   |        |           | 3,120.1      | 3.4 | 0.01 |
| S-A-10            | 426    | 3,092     | 417.60       |
|                   |        |           | 3,092.1      | 2.0 | 0.01 |
| S-A-13            | 714    | 4,787     | 692.40       |
|                   |        |           | 4,787.5      | 3.0 | 0.01 |
| S-A-14            | 873    | 1,599     | 844.30       |
|                   |        |           | 1,589.9      | 3.3 | 0.01 |
| S-B               |        |           |              |
| S-B-01            | 923    | 896       | 889.40       |
|                   |        |           | 896.0        | 3.6 | 0.00 |
| S-B-04            | 875    | 2,102     | 853.80       |
|                   |        |           | 2,102.1      | 2.4 | 0.02 |
| S-B-05            | 906    | 1,520     | 891.10       |
|                   |        |           | 1,520.0      | 1.6 | 0.01 |
| S-B-06            | 825    | 1,639     | 797.40       |
|                   |        |           | 1,639.1      | 3.3 | 0.01 |
| S-B-07            | 812    | 1,509     | 772.65       |
|                   |        |           | 1,508.9      | 4.8 | 0.01 |
| S-B-08            | 621    | 1,523     | 595.30       |
|                   |        |           | 1,523.1      | 4.1 | 0.01 |
| Y-A               |        |           |              |
| Y-A-05            | 261    | 446       | 250.40       |
|                   |        |           | 446.0        | 4.1 | 0.01 |
| Y-A-06            | 234    | 445       | 225.60       |
|                   |        |           | 445.0        | 3.6 | 0.01 |
| Y-B               |        |           |              |
| Y-B-05            | 489    | 1,358     | 468.50       |
|                   |        |           | 1,358.3      | 4.2 | 0.02 |
| Y-B-06            | 356    | 1,149     | 339.40       |
|                   |        |           | 1,149.1      | 4.7 | 0.01 |
| Y-B-08            | 624    | 283       | 593.60       |
|                   |        |           | 283.0        | 4.9 | 0.00 |
| Y-B-10            | 480    | 145       | 457.60       |
|                   |        |           | 145.0        | 4.7 | 0.02 |
| Average Difference|        |           |              |
|                   |        |           | 3.2          | 0.03|      |
Figure 2. Diagram of S-06 Well

Figure 3. Nodal Analysis of S-06 Well
Figure 4. Pipeline Network of “X1” Area

Figure 5. Pipeline Network between Wells in S-B Platform
Table 5. Seabed Pipe of “X1” Area

| Segment | Route From | To | Pipe Code | Material Specification | Outside Diameter, in. | Inside Diameter, in. | Pipe Length, in. | Weight/unit, lb |
|---------|------------|----|-----------|------------------------|-----------------------|---------------------|-----------------|----------------|
| 1       | S-B        | S-A | Pipe_1_12 | ERW/API5LX42           | 12.6                  | 12                  | 4,065           | 39.36          |
| 2       | S-A        | Y-A | Pipe_1_13 | ERW/API5LX42           | 12.6                  | 12                  | 62,274          | 39.36          |
| 3       | K-E        | K-A | Pipe_1_14 | ERW/API5LX42           | 12.6                  | 12                  | 4,975           | 39.36          |
| 4       | Y-B        | Y-A | Pipe_3    | ERW/API5LX42           | 12.6                  | 12                  | 16,731          | 38.75          |
| 5       | Y-A        | K-A | Pipe_4    | ERW/API5LX42           | 17                    | 16                  | 11,711          | 90.06          |
| 6       | K-A        | K-B | Pipe_6    | ERW/API5LX42           | 17                    | 16                  | 9,250           | 88.00          |
| 7       | K-D        | K-B | Pipe_3_1  | ERW/API5LX42           | 17                    | 16                  | 15,953          | 88.00          |
| 8       | K-C        | K-B | Pipe_1_15 | ERW/API5LX42           | 12.8                  | 12                  | 7,381           | 52.91          |
| 9       | K-B        | C-P | Pipe_2    | ERW/API5LX42           | 20                    | 19                  | 95,943          | 104.0          |

Table 6. Pressure and Flow Rate of Pipe Network

| Platform | Parameter | Data |
|----------|-----------|------|
| S-B      | Fluid flow rate, bfpd | 765.0 |
|          | Outlet pressure to S-A, psi | 315.0 |
| S-A      | Fluid flow rate, bfpd | 1,901.0 |
|          | Inlet pressure from S-B, psi | 310.0 |
|          | Outlet pressure to Y-A, psi | 300.0 |
| Y-B      | Fluid flow rate, bfpd | 1,168.0 |
|          | Outlet pressure to Y-A, psi | 180.0 |
| Y-A      | Fluid flow rate, bfpd | 3,171.0 |
|          | Inlet pressure from S-A, psi | 145.0 |
|          | Inlet pressure from Y-B, psi | 145.0 |
|          | Outlet pressure to K-A, psi | 140.0 |
| K-E      | Fluid flow rate, bfpd | 225.0 |
|          | Outlet pressure to K-A, psi | 145.0 |
| K-A      | Fluid flow rate, bfpd | 3,742.0 |
|          | Inlet pressure from Y-A, psi | 115.0 |
|          | Inlet pressure from K-E, psi | 115.0 |
|          | Outlet pressure to K-B, psi | 110.0 |
| K-D      | Fluid flow rate, bfpd | 803.0 |
|          | Outlet pressure to K-B, psi | 115.0 |
| K-C      | Fluid flow rate, bfpd | 344.0 |
|          | Outlet pressure to K-B, psi | 115.0 |
| CBU      | Fluid flow rate, bfpd | 6,254.0 |
|          | Outlet pressure to K-B, psi | 63.5 |
| K-B      | Fluid flow rate, bfpd | 11,218.0 |
|          | Inlet pressure from K-A, psi | 64.0 |
|          | Inlet pressure from K-D, psi | 63.0 |
|          | Inlet pressure from K-C, psi | 64.5 |
|          | Inlet pressure from CBU, psi | 63.5 |
|          | Outlet pressure to C-P, psi | 70.0 |
| C-P      | Fluid flow rate, bfpd | 11,218.0 |
|          | Inlet pressure from K-B, psi | 30.0 |
Table 7. Pressure and Flowrate Matching Result for Each Well

| Platform/Well | Pwh, psia |          |        |              | q, bfpd |          |        |
|--------------|-----------|----------|--------|-------------|---------|----------|--------|
|              | Actual    | Matching | %Δ     | Actual       | Matching | %Δ       |        |
| S-A          |           |          |        |              |         |          |        |
| S-A-01       | 607.7     | 613.8    | 1.01   | 32.0         | 34.7    | 8.49     |
| S-A-05       | 755.9     | 763.0    | 0.95   | 138.0        | 145.5   | 5.46     |
| S-A-06       | 765.7     | 758.0    | -1.01  | 156.3        | 165.0   | 5.58     |
| S-A-08       | 686.7     | 694.0    | 1.06   | 41.1         | 42.8    | 4.30     |
| S-A-09       | 686.7     | 694.0    | 1.06   | 218.4        | 231.4   | 5.95     |
| S-A-10       | 765.7     | 773.4    | 1.00   | 247.4        | 261.6   | 5.78     |
| S-A-13       | 716.3     | 724.0    | 1.07   | 191.5        | 204.5   | 6.81     |
| S-A-14       | 647.2     | 653.7    | 1.01   | 111.9        | 118.6   | 5.92     |
| S-B          |           |          |        |              |         |          |        |
| S-B-01       | 686.7     | 679.8    | -1.01  | 125.4        | 132.7   | 5.77     |
| S-B-04       | 380.5     | 376.7    | -1.00  | 231.2        | 244.5   | 5.74     |
| S-B-05       | 558.3     | 563.9    | 1.00   | 76.0         | 80.4    | 5.77     |
| S-B-06       | 676.8     | 671.0    | -0.86  | 180.3        | 193.5   | 7.35     |
| S-B-07       | 864.5     | 857.8    | -0.77  | 45.3         | 48.7    | 7.48     |
| S-B-08       | 538.5     | 543.9    | 1.00   | 106.6        | 110.4   | 3.51     |
| Y-A          |           |          |        |              |         |          |        |
| Y-A-05       | 647.2     | 654.0    | 1.05   | 22.3         | 23.7    | 6.11     |
| Y-A-06       | 370.6     | 374.0    | 0.91   | 80.1         | 85.5    | 6.76     |
| Y-B          |           |          |        |              |         |          |        |
| Y-B-03       | 775.6     | 783.0    | 0.95   | 601.0        | 650.4   | 8.21     |
| Y-B-04       | 351.1     | 355.0    | 1.11   | 356.2        | 378.9   | 6.37     |
| Y-B-08       | 312.6     | 313.1    | 0.18   | 127.3        | 130.1   | 2.15     |
| Y-B-10       | 262.3     | 260.0    | -0.88  | 100.0        | 102.8   | 2.75     |
| K-A          |           |          |        |              |         |          |        |
| K-A-01       | 775.6     | 768.0    | -0.98  | 79.3         | 82.6    | 4.15     |
| K-A-03       | 508.9     | 504.0    | -0.96  | 132.4        | 136.5   | 3.07     |
| K-A-05       | 370.6     | 367.0    | -0.97  | 34.6         | 35.0    | 1.29     |
| K-A-07       | 637.3     | 631.0    | -0.99  | 33.0         | 35.6    | 7.88     |
| K-A-09       | 459.5     | 455.0    | -0.98  | 66.8         | 69.5    | 4.02     |
| K-B          |           |          |        |              |         |          |        |
| K-B-03       | 192.8     | 195.0    | 1.14   | 40.6         | 42.8    | 5.36     |
| K-B-05       | 627.4     | 634.0    | 1.05   | 47.7         | 47.7    | 0.09     |
| K-B-09       | 874.4     | 883.0    | 0.98   | 93.0         | 97.9    | 5.30     |
| K-B-10       | 943.5     | 934.0    | -1.01  | 145.0        | 155.8   | 7.43     |
| K-C          |           |          |        |              |         |          |        |
| K-C-02       | 815.1     | 823.0    | 0.97   | 126.0        | 129.3   | 2.60     |
| K-C-04       | 731.2     | 738.0    | 0.94   | 145.0        | 153.2   | 5.64     |
| K-C-10       | 429.9     | 434.0    | 0.96   | 64.5         | 66.4    | 2.97     |
| K-C-11       | 825.0     | 833.0    | 0.97   | 23.0         | 24.7    | 7.39     |
| K-D          |           |          |        |              |         |          |        |
| K-D-01       | 469.4     | 465.0    | -0.94  | 201.0        | 193.2   | 3.88     |
| K-D-06/ST    | 489.1     | 484.0    | -1.05  | 85.8         | 85.6    | -0.19    |
| K-D-07       | 420.0     | 424.0    | 0.95   | 152.8        | 159.6   | 4.45     |
| K-D-09       | 854.6     | 846.0    | -1.01  | 344.5        | 373.7   | 8.47     |
| K-E          |           |          |        |              |         |          |        |
| K-E-01       | 1.062.1   | 1.062.5  | 0.04   | 97.0         | 104.4   | 7.63     |
| K-E-04       | 647.2     | 641.0    | -0.96  | 64.3         | 68.0    | 5.88     |
| K-E-05       | 489.1     | 484.0    | -1.05  | 30.6         | 31.3    | 2.35     |
| K-E-11       | 607.7     | 614.0    | 1.04   | 35.0         | 36.9    | 5.40     |
| Average Difference | 0.95 | 5.16 |
### Table 8. Pressure and Flowrate Matching Result for Each Platform

| Platform       | Pwh, psia  |           | %Δ  |
|----------------|------------|-----------|-----|
|                | Actual     | Matching  |     |
| S-B out        | 315.0      | 317.1     | 0.7 |
| S-A in S-B     | 310.0      | 303.0     | 2.3 |
| S-A out        | 300.0      | 303.0     | 1.0 |
| Y-B out        | 180.0      | 178.0     | 1.1 |
| Y-A in Y-B     | 145.0      | 144.1     | 0.6 |
| Y-A in S-A     | 145.0      | 144.1     | 0.6 |
| Y-A out        | 140.0      | 144.1     | 2.9 |
| K-E out        | 145.0      | 146.0     | 0.7 |
| K-A in Y-A     | 115.0      | 113.5     | 1.3 |
| K-A in K-E     | 115.0      | 113.5     | 1.3 |
| K-A out        | 110.0      | 113.5     | 3.2 |
| K-C out        | 115.0      | 114.8     | 0.2 |
| K-D out        | 115.0      | 114.8     | 0.2 |
| K-B in K-A     | 64.0       | 66.0      | 3.1 |
| K-B in K-C     | 64.5       | 66.0      | 2.3 |
| K-B in K-D     | 63.0       | 62.0      | 1.6 |
| K-B out        | 70.0       | 71.0      | 1.4 |
| C-P in         | 30.0       | 29.0      | 3.3 |
| Average Difference |               |           | 1.5 |
| Maximum Difference |               |           | 3.3 |

| Platform       | q, bfpd    |           | %Δ  |
|----------------|------------|-----------|-----|
|                | Actual     | Matching  |     |
| S-B out        | 765.0      | 801.2     | 4.73|
| S-A out        | 1,901.0    | 1,982.8   | 4.30|
| Y-B out        | 1,168.0    | 1,247.4   | 6.80|
| Y-A out        | 3,171.0    | 3,248.0   | 2.43|
| K-E out        | 225.0      | 232.4     | 3.29|
| K-A out        | 3,742.0    | 3,825.1   | 2.22|
| K-C out        | 344.0      | 354.9     | 3.16|
| K-D out        | 803.0      | 795.2     | 0.97|
| K-B out        | 11,218     | 11,393    | 1.56|
| C-P in         | 11,218     | 11,344    | 1.12|
| Average Difference |               |           | 3.1 |
| Maximum Difference |               |           | 6.8 |
| Platform/Well | Pwh, psia |  |  | q, bfpd |  |  |
|---------------|-----------|---|---|--------|---|---|
|               | Matching  | Optimized | %Δ | Matching | Optimized | %Δ |
| S-A           |           |           |    |          |          |    |
| S-A-01        | 613.8     | 370.7     | -40| 34.7     | 41.6     | 20 |
| S-A-05        | 763.0     | 370.7     | -51| 145.5    | 188.4    | 29 |
| S-A-06        | 758.0     | 370.7     | -51| 165.0    | 202.2    | 23 |
| S-A-08        | 694.0     | 370.7     | -47| 42.8     | 56.5     | 32 |
| S-A-09        | 694.0     | 370.7     | -47| 231.4    | 252.1    | 9  |
| S-A-10        | 773.4     | 370.7     | -52| 261.6    | 294.0    | 12 |
| S-A-13        | 724.0     | 370.7     | -49| 204.5    | 244.5    | 20 |
| S-A-14        | 653.7     | 404.2     | -38| 118.6    | 124.4    | 5  |
| S-B           |           |           |    |          |          |    |
| S-B-01        | 679.8     | 391.3     | -42| 132.7    | 158.8    | 20 |
| S-B-04        | 376.7     | 391.3     | 4  | 244.5    | 238.9    | -2 |
| S-B-05        | 563.9     | 391.3     | -31| 80.4     | 89.7     | 12 |
| S-B-06        | 671.0     | 391.3     | -42| 193.5    | 289.7    | 50 |
| S-B-07        | 857.8     | 391.3     | -54| 48.7     | 72.9     | 50 |
| S-B-08        | 543.9     | 391.3     | -28| 110.4    | 126.2    | 14 |
| Y-A           |           |           |    |          |          |    |
| Y-A-05        | 654.0     | 145.7     | -78| 23.7     | 34.7     | 47 |
| Y-A-06        | 374.0     | 145.7     | -61| 85.5     | 90.5     | 6  |
| Y-B           |           |           |    |          |          |    |
| Y-B-03        | 783.0     | 189.2     | -76| 650.4    | 734.5    | 13 |
| Y-B-04        | 355.0     | 189.2     | -47| 378.9    | 424.3    | 12 |
| Y-B-08        | 313.1     | 189.2     | -40| 130.1    | 151.2    | 16 |
| Y-B-10        | 260.0     | 189.2     | -27| 102.8    | 129.2    | 26 |
| K-A           |           |           |    |          |          |    |
| K-A-01        | 768.0     | 100.7     | -87| 82.6     | 110.9    | 34 |
| K-A-03        | 504.0     | 100.7     | -80| 136.5    | 169.3    | 24 |
| K-A-05        | 367.0     | 100.7     | -73| 35.0     | 37.7     | 8  |
| K-A-07        | 631.0     | 100.7     | -84| 35.6     | 38.9     | 9  |
| K-A-09        | 455.0     | 100.7     | -78| 69.5     | 76.0     | 9  |
| K-B           |           |           |    |          |          |    |
| K-B-03        | 195.0     | 207.0     | 6  | 42.3     | 42.6     | -1 |
| K-B-05        | 634.0     | 207.0     | -6 | 47.7     | 76.3     | 60 |
| K-B-09        | 883.0     | 500.6     | -43| 97.9     | 102.3    | 4  |
| K-B-01        | 934.0     | 207.0     | -78| 155.8    | 184.4    | 18 |
| K-C           |           |           |    |          |          |    |
| K-C-02        | 823.0     | 108.4     | -87| 129.3    | 154.5    | 19 |
| K-C-04        | 738.0     | 270.4     | -63| 153.2    | 203.2    | 33 |
| K-C-10        | 434.0     | 108.4     | -75| 66.4     | 69.2     | 4  |
| K-C-11        | 833.0     | 453.9     | -46| 24.7     | 27.5     | 8  |
| K-D           |           |           |    |          |          |    |
| K-D-01        | 465.0     | 241.7     | -48| 193.2    | 226.0    | 17 |
| K-D-06/ST     | 484.0     | 241.7     | -50| 85.6     | 102.7    | 20 |
| K-D-07        | 424.0     | 447.0     | 5  | 159.6    | 159.1    | -0.3|
| K-D-09        | 846.0     | 241.7     | -71| 373.7    | 429.9    | 15 |
| K-E           |           |           |    |          |          |    |
| K-E-01        | 1,062.5   | 447.4     | -58| 104.4    | 119.3    | 14 |
| K-E-04        | 641.0     | 145.4     | -77| 68.0     | 87.7     | 29 |
| K-E-05        | 484.0     | 145.4     | -70| 31.3     | 32.8     | 5  |
| K-E-11        | 614.0     | 438.8     | -29| 36.9     | 39.7     | 7  |
Figure 6. Optimization Result of Riser Pressure

| S-B | Matching | Optimum | % Δ |
|-----|----------|---------|-----|
| 317.14 | 391.3 | 23.4% |

| S-A | Matching | Optimum | % Δ |
|-----|----------|---------|-----|
| 303 | 370.7 | 22.4 |

| Y-B | Matching | Optimum | % Δ |
|-----|----------|---------|-----|
| 178 | 189.2 | 6.3 |

| Y-A | Matching | Optimum | % Δ |
|-----|----------|---------|-----|
| 144.1 | 145.7 | 1.1 |

| K-E | Matching | Optimum | % Δ |
|-----|----------|---------|-----|
| 146 | 145.4 | -0.4 |

| K-A | Matching | Optimum | % Δ |
|-----|----------|---------|-----|
| 113.5 | 100.7 | -11.3 |

| K-D | Matching | Optimum | % Δ |
|-----|----------|---------|-----|
| 114.8 | 241.7 | 110.6 |

| K-B | Matching | Optimum | % Δ |
|-----|----------|---------|-----|
| 62 | 207.0 | 233.9 |

| CBU | Matching | Optimum | % Δ |
|-----|----------|---------|-----|
| 207 | 156 | 24.6 |

| K-C | Matching | Optimum | % Δ |
|-----|----------|---------|-----|
| 114.8 | 108.4 | -5.5 |

| C-P | Matching | Optimum | % Δ |
|-----|----------|---------|-----|
| 29 | 14.7 | 49.3 |