The CNPC Liaohe Oilfield Shuguang Oil Production Plant—located some 560 km east-northeast of Beijing—used conventional oil-removal techniques to treat contaminated water generated during oil extraction before reinjecting the produced water into the oilfield reservoir. Over time, though, the reservoir had become nearly saturated and could no longer receive reinjected water. The Design Institute for CNPC Liaohe Oilfield Shuguang (DI), therefore, developed a plan to implement additional produced water treatment measures and discharge the newly treated water into the Raoyang River, a tributary of the Liao River.

In May 2015, however, China’s Ministry of Environmental Protection implemented revised discharge limits for the refinery and petrochemical industries. The new standards established some of the most stringent effluent quality limits in the world. To meet the standards, the DI designed a robust, four-train activated sludge treatment system to help remove water soluble organics (WSOs) followed by multimedia filtration.

Yet the produced water generated by the Shuguang plant proved difficult to treat. The water chemistry contains large amounts of WSOs (measured as chemical oxygen demand or COD) resistant to biological treatment. Despite the best efforts of the new wastewater plant’s operating teams, the new system could not reliably achieve the discharge standard of 50 mg/l COD. The DI approached Siemens Water
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Solutions for help in designing modifications to the treatment plant that would produce effluent quality consistently meeting the extremely challenging COD limit.

**Solutions start with good science**

Table 1 presents the produced water feed characteristics and final treated effluent target concentrations required for discharge to the Raoyang River.

Siemens’ team of field services personnel conducted a bench-scale proof-of-concept study using final effluent samples from the wastewater treatment plant. Additionally, samples of the Liaohe produced water and treated effluent were shipped to Siemens Water Solutions headquarters in Wisconsin, USA, to validate the work performed in the field and develop the upgrade plan. The headquarters of Siemens Water Solutions hosts a complete 1000 m² pilot testing plant supported by more than 500 m³ of analytical testing laboratories, making it suitable for the analysis of industrial, municipal, and even hazardous wastewaters, waters, and sludges.

Validation work consisted of bench-scale PACT treatability testing and laboratory analyses to screen powdered activated carbon types and dose, as well as process modelling to determine the optimum configuration of process trains needed to achieve the required treatment at the lowest possible cost.

Based on the testing performed in the field and in validation bench-scale testing results, Siemens recommended that the Shuguang Wastewater Treatment Plant be upgraded to a True 2-Stage (T2S) PACT system. The existing 4-train activated sludge layout provided the flexibility needed to easily convert the wastewater treatment system to a 2-Stage PACT process: three parallel trains of 1st Stage PACT followed by one train of 2nd Stage PACT. Capital improvements included the addition of a 2nd Stage Clarifier, powdered activated carbon storage and delivery, and diffused aeration upgrades.

**Good science is also good business**

The treatability study not only proved that the Siemens PACT technology could meet these stringent discharge standards, but it also provided supporting data used by Siemens to offer a process performance guarantee for the upgrade.

Siemens drew on its experience gained from more than 100 PACT systems supplied globally to develop a retrofit plan that economically incorporated PACT technology using existing Shuguang Wastewater Treatment Plant infrastructure and equipment.

**Treatment advantages**

Powdered activated carbon offers customers several advantages for the treatment of effluent water when compared with granular activated carbon beds:

- First, powdered activated carbon costs less than granulated carbon.
- Second, because it is powdered instead of granulated, it offers more active surface area per equivalent mass than granules do.
- Third, powdered carbon interacts more efficiently and thoroughly with treated water inside the tank, and the required dose can be tailored to the precise discharge requirement.

**How the system works**

- Powdered activated carbon solids flow counter-current to the wastewater flow. Virgin carbon dose is first applied to the 2nd Stage PACT; waste carbon solids from the 2nd Stage are transported to the 1st Stage PACT, where additional COD adsorption occurs in equilibrium with the higher concentration of 1st Stage recalcitrant COD (Figure 2).
- De-oiled wastewater enters the 1st Stage PACT, consisting of three parallel aeration tanks followed by two parallel clarifiers.

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**Table 1. Shuguang Wastewater Treatment Plant Influent and Effluent Characteristics.**

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit</th>
<th>Influent</th>
<th>Required effluent</th>
</tr>
</thead>
<tbody>
<tr>
<td>COD</td>
<td>mg/l</td>
<td>≤ 700</td>
<td>≤ 50</td>
</tr>
<tr>
<td>BOD₅</td>
<td>mg/l</td>
<td>≥ 140</td>
<td>≤ 10</td>
</tr>
<tr>
<td>Oil</td>
<td>mg/l</td>
<td>10</td>
<td>≤ 3</td>
</tr>
<tr>
<td>NH₃-N</td>
<td>mg/l</td>
<td>≤ 20</td>
<td>≤ 8</td>
</tr>
<tr>
<td>TOC</td>
<td>mg/l</td>
<td>-</td>
<td>≤ 20</td>
</tr>
</tbody>
</table>

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![Figure 1. Upgraded Shuguang Oil Production Plant PACT® treatment facility.](image1)

![Figure 2. Liaohe PACT® True 2 Stage (T2S).](image2)

![Figure 3. Liaohe Oilfield Shuguang PACT T2S Wastewater Treatment Plant performance (note: trend lines represent 5 day moving averages).](image3)
Return activated sludge recycle maintains the total mixed liquor suspended solids (MLSS) at 12,000 mg/l concentration. A portion of this recycle is wasted from the process and dewatered for disposal. 1st Stage Clarifier effluent discharges to the lift station from where it is pumped to the inlet of the 2nd Stage PACT. The 2nd Stage PACT, consisting of a single set of aeration tank and clarifier, receives virgin carbon dosing, resulting in maximum recalcitrant COD removal. Return activated sludge recycle maintains the MLSS concentration at 15,000 mg/l; a portion of this recycle is wasted to the 1st Stage PACT. The wastewater exits the 2nd Stage Aeration Tanks into the 2nd Stage Clarifier where the final solid/liquid separation occurs.

- 2nd Stage Clarifier effluent discharges to existing pressure sand filters and discharges to the Raoyang River.

Performance results
Effluent COD performance results following the PACT T2S upgrade are shown in Figure 3. Despite the variability that occurs in feed COD – often well above the design level of 700 mg/l – the PACT T2S has been able to achieve consistent compliance with the 50 mg/l COD limit. Even with a spike of feed COD nearly 200% of design concentration, the PACT T2S effluent maintained performance with 95% COD removal and effluent returning to normal within days of the event.

Operational support
Siemens Water Solutions’ approach to treating this produced water challenge included complete sales, installation guidance, training and service support. The most economical programme was sought, which in the DI’s case included retrofitting and adapting existing equipment to a PACT process. Training CNPC’s staff to maintain successful operations at full flow rates – meeting guaranteed performance targets on an ongoing basis – was an integral part of Siemens’ startup process. Additional services for support during emergencies, or changes in effluent specifications, or in the characteristics of the produced water are available as needed – as an additional service – for the life of the system.

Conclusion
The DI was challenged to meet China’s new petrochemical industry standards for discharge to surface waters. Siemens Water Solutions collaborated with the DI to develop a solution path that maximised the use of existing infrastructure and equipment by implementing Siemens PACT T2S. A treatability study conducted in Siemens’ analytical laboratories – using actual produced water from the Liaohe Shuguang Oilfield – proved that a 2-stage, powdered activated carbon treatment solution would meet the strict new standards. Data generated during the study enabled both performance and operating carbon cost guarantees to be provided to the DI, minimising future operating and financial risks to the client.

Figure 4. PACT® T2S™ effluent.