

THERMOCHEM QUALIFICATIONS FOR STEAM PURITY AND STEAM QUALITY MEASUREMENT AND OPTIMIZATION

Thermochem is a vertically integrated consultancy, service, and OEM instrument firm working primarily in the geothermal energy industry. TCI specializes in analytical chemistry, instrumentation, chemical engineering, process chemistry, power plant performance testing, well testing, and geochemistry. TCI has 30 years' experience in steam purification process design, testing and optimization for the geothermal energy industry. Examples of major projects related to steam purity/quality Thermochem has performed are summarized below:

Design of the Steam Wash System Corrosion and Mitigation Process at the Aidlin Power Plant, The Geysers, for Mission Power Engineering to control HCl and gathering system corrosion (Hirtz, 1990), on-going monitoring and optimization for Calpine, 1990 – present.

Steam Wash Performance Testing and Optimization, Corrosion Mitigation Process Design at all plants in The Geysers, for Unocal, PG&E, Geo Operator Corp. CCPA, Calpine, NCPA, Santa Fe, and SMUD, 1990 – present.

Steam Wash Performance Testing and Optimization, Corrosion Mitigation Process Design for Salton Sea Region 2, Unit 5, for CalEnergy, 2001.

Steam Wash Performance Testing and Optimization at the Salton Sea Region 2 Vulcan Plant turbo-expander cycle, for CalEnergy, 2002.

Preparation of Employer's Requirements for Steam Scrubber and Wash Systems at Kawerau geothermal plant, New Zealand, for Mighty River Power, 2007.

Steam Wash Performance Testing, Optimization and Investigation of Turbine Scaling at the Hudson Ranch I geothermal plant, Salton Sea, for EnergySource, 2013.

Steam Wash and Monitoring System Design and Performance Testing during commissioning of Olkaria expansion project Units 1AU and Unit IV, for Hyundai Engineering, 2014 and 2015.

Steam Wash Performance Testing, Optimization and Retrofit Design to Mitigate Scaling at the Te Mihi geothermal plant, New Zealand, for Contact Energy, 2015.

Steam Wash Performance Testing, Optimization and Retrofit Design to Mitigate Scaling at the Kizildere II geothermal plant, Turkey, for Zorlu Energy, 2015.

Steam Wash Performance Testing and Optimization during commissioning of the Alasehir geothermal plant, Turkey, for Zorlu Energy, 2015.

Steam Wash Performance Testing and Optimization during commissioning of the Kizildere III Unit 1 geothermal plant, Turkey, for Zorlu Energy, 2017.

Steam Wash Performance Testing and Optimization during commissioning of the Kizildere III Unit 2 geothermal plant, Turkey, for Zorlu Energy, 2018.

Steam Purity and Quality Testing, Investigation into Excessive Brine Carry-over at the Silangkitang Unit I geothermal plant, Indonesia, for Sarulla Operations Ltd., 2017.

Steam Purity and Quality Performance Testing, at the Silangkitang Unit I geothermal plant, Indonesia, for HDEC and Sarulla Operations Ltd., 2017 - 2018.

Steam Purity and Quality Performance Testing, at the Namora Langit Unit I and II geothermal plants, Indonesia, for HDEC, 2017 - 2018.

Design and Fabrication of On-line Steam Purity Analyzers at the Silangkitang Unit I and the Namora Langit Unit I and II geothermal plants, Indonesia, for HDEC, 2017 - 2018.

Steam Purity and Quality Performance Testing, at the Karaha Bodas geothermal plant, Indonesia, for General Electric, 2018.

Steam Purity and Quality Performance Testing, at the Muaralaboh geothermal plant, Indonesia, for Supreme Energy, 2019 – 2020.

Steam Purity Testing and Investigation of Turbine Scaling, at the Darajat Unit 1 geothermal plant, Indonesia, for Star Energy and Jacobs Engineering, 2019.

Thermochem Team Primary Experts and Relevant Experience

Senior Process Chemist

Dr. Darrell Gallup, Ph.D., Senior Process Chemist employed by Thermochem, has a Ph.D. from Utah State University and previously worked for Unocal and Chevron. Darrell has 35 years' experience in production optimization for the petroleum industry, beginning with Texaco, Unocal and then Chevron, finally with Thermochem, Inc. in 2010. He is an internationally recognized authority on oil and gas production, chemistry, flow assurance, geothermal energy production, water treatment and environmental processes. His "hands-on" problem solving and process development philosophy (Laboratory / Pilot / Demonstration / Commercialization) has delivered an impressive track record of success in solving complex process chemistry and engineering problems. Dr. Gallup is the Inventor of the pH-modification process that was originally patented by Unocal and used at the Salton Sea. He is also very familiar with Crystallizer – Clarifier (CRC) technology and the steam purity and corrosion issues at the Salton Sea. Dr. Gallup is the author of over 80 technical papers and several book chapters, numerous presentations to technical and industry forums, inventor of over 50 US patents and foreign counterparts, with several patents pending.

Senior Chemical Process Engineer

Paul von Hirtz is the President of Thermochem, Inc. and Commissioner of PT. Thermochem, Indonesia. Paul has a BS degree in chemistry and minor in Physics from Sonoma State University. He is the chairman of ASTM committee E44.15 which develops and standardizes testing procedures for the geothermal energy industry. Mr. von Hirtz is an editorial board member for the Geoscience journal *Geothermics*, and a board member of the International Geothermal Association. For 32 years, Mr. von Hirtz has specialized in geothermal well testing operations and the design of testing equipment for two-phase flow streams.

His expertise is in single- and two-phase flow, steam purity and quality measurement, steam scrubbing and separation techniques. He has extensive experience in pilot-plant and full-scale testing for the evaluation and development of chemical processes. Mr. von Hirtz has developed instrumentation and chemical processes for geothermal energy production such as H₂S abatement, silica scale control, continuous non-condensable gas monitors, two-phase high-temperature wellbore samplers, removal of HCl from superheated steam, on-line steam quality and purity monitors and is the inventor of the TFT[®] process for two-phase flow measurement. As a chemical engineer with a background in analytical chemistry, Mr. von Hirtz understands the limitations inherent in physical and chemical measurements and how to improve data quality when necessary. He is very experienced in chemical process modeling, propagated error analysis and sensitivity studies, and understanding of complex chemical process systems involving multiple data sources.

Thermochem Instrumentation and Equipment Supply Experience

Thermochem experience in supplying steam purity and quality instrumentation and equipment is summarized in the table below.

Thermochem Steam Quality / Purity and Multi-Nozzle Isokinetic Probe Installation Record

| Power Plant | Year | Country | Units Installed | Warranty Claims |
|----------------------|------|-------------|-------------------------|-----------------|
| Salton Sea Unit 5 | 2002 | USA | 2 HP, 1 SP, 1 LP, 2 VLP | none |
| North Lake Energy | 2003 | USA | 1 HP | none |
| Darajat Unit III | 2006 | Indonesia | 2 HP | none |
| Germencik | 2008 | Turkey | 1 HP, 1 LP | none |
| San Jacinto Phase I | 2010 | Nicaragua | 1 HP | none |
| Lahendong | 2010 | Indonesia | 3 HP | none |
| Ulubelu | 2011 | Indonesia | 4 HP | none |
| San Jacinto Phase II | 2012 | Nicaragua | 1 HP | none |
| Alaşehir | 2014 | Turkey | 1 HP, 2 LP | none |
| Darajat Unit II | 2015 | Indonesia | 1 HP | none |
| Sarulla SIL | 2016 | Indonesia | 1 HP | none |
| Sarulla NIL | 2016 | Indonesia | 2 HP | none |
| Tongonan EDC | 2016 | Philippines | 2 HP | none |
| Kizildere III UI | 2016 | Turkey | 3 HP, 2 IP, 2 LP | none |
| Tongonan EDC | 2017 | Philippines | 4 HP | none |
| Kizildere III UII | 2017 | Turkey | 3 HP, 2 IP, 2 LP | none |
| Darajat Unit I | 2019 | Indonesia | 1 HP | none |
| Tongonan EDC | 2019 | Philippines | 2 HP | none |
| Rantau Dedap | 2020 | Indonesia | 2 HP, 2 LP | none |

References

- The American Society of Mechanical Engineers, PTC-19.11 "Steam and Water Sampling, Conditioning, and Analysis in the Power Cycle", 2008
- American Society for Testing and Materials, Method D 1066-97, "Standard Practice for Sampling Steam", 2001
- American Society for Testing and Materials, Method D 1066-06, "Standard Practice for Sampling Steam", 2007
- American Society for Testing and Materials, Method D 1192-70 (Reapproved 1977), "Standard Specification for Equipment for Sampling Water and Steam"
- Peña, J. M., and Campbell, H. E., (1987); "Steam Wetness Measurement Using a Transversable Retractable Probe", Geothermal Resources Council TRANSACTIONS, Vol. 11, October 1987, pp. 53-58
- Hirtz, P. N., Miller, J., and Prabhu, E. (1990); "Operational Results of a Dry-Steam Resource Chloride Corrosion Mitigation System", Geothermal Resources Council TRANSACTIONS, Vol. 14, Part II, August 1990, pp. 1667-1675
- Hirtz, P. N., Buck, C. L., and Kunzman, R. J. (1991); "Current Techniques in Acid-Chloride Corrosion Control and Monitoring at The Geysers", Proceedings, Sixteenth Workshop on Geothermal Reservoir Engineering., Stanford Geothermal Program, Stanford, CA, Workshop Report SGP-TR-134, pp. 83-95
- Stockman, E., McLean, D., Mathur, R., Jonas, O., and Hirtz, P. (1993), "Measuring Steam Impurities in a Geothermal Pipeline System Using Real Time Instrumentation", Geothermal Resources Council TRANSACTIONS, Vol. 17
- von Hirtz, P. N., and Kunzman, R. J. (2019); "Advanced On-Line Steam Purity Analyzer for Geothermal Power Plants", Geothermal Resources Council TRANSACTIONS, Vol. 43.
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