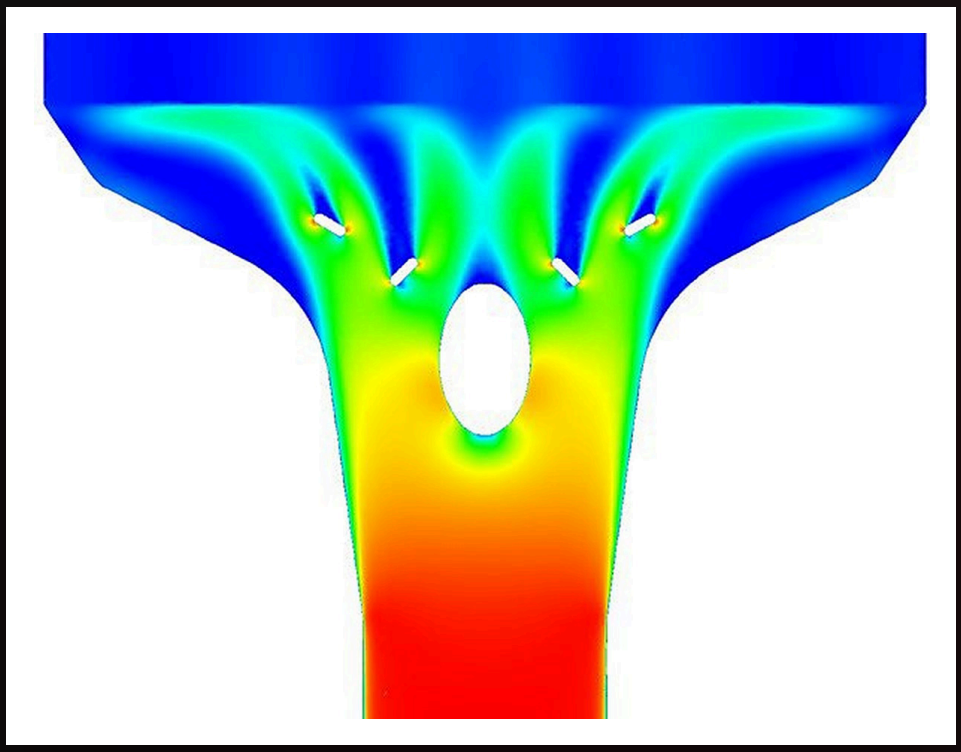
KnightHawk Engineering, Inc.

CASE STUDY
RESEARCH & DEVELOPMENT



ON THE COVER Velocity field through a transfer line exchanger inlet, redesigned with KHE's Intrabody Flow Distributor.

Engineering the Unproven

ADVANCEMENTS IN THE RESEARCH AND DEVELOPMENT OF NOVEL TECHNOLOGY

Thirty-five years of multidisciplinary engineering, from molten-salt energy storage to a 30,000-barrel-a-day reactor, told in twelve studies of ideas made real.

INTRODUCTION

Thirty-Five Years at the Frontier

Where industry's hardest problems meet a laboratory, a materials lab, and an uncommon way of thinking.

Since 1991, KnightHawk Engineering, Inc. (KHE) has provided specialty engineering and design services from its home in Houston, Texas, applying a unique and proprietary multidisciplinary approach to problems that resist conventional solutions. Our clients range from some of the largest multinational corporations in the world to start-ups bringing entirely new technologies to market. Complementing the engineering practice is the KnightHawk Materials Lab (KML), a specialty materials laboratory supporting materials analysis, testing, and prototyping, closing the loop between what is modeled and what is made.

Focused principally on the petrochemical and energy industries, KHE has extensive experience in the failure analysis of operating plants, optimization and troubleshooting, emission management, multiphase reactor design, and fitness-for-service (FFS) assessments, enabling the critical decision of whether to run-as-is, repair, or replace critical equipment. Our highly experienced and qualified analysts apply numerical methods, finite element analysis (FEA) and computational fluid dynamics (CFD), to execute projects that often arrive on an emergency basis and must be resolved within a short turnaround.

The same rigor that keeps the most advanced reactors in industry running is what allows us to build the ones that do not yet exist.

It is this depth of experience in supporting the operation and maintenance of complex, large-scale commercial equipment, including the most advanced reactors and processes in industry, that allows KHE to bring the same rigor to the development of new, cutting-edge technologies and products addressing the problems industry faces today. Across that work, KHE provides concept development, independent third-party opinions, recommendations, feasibility assessments, and prototyping services.

The twelve studies that follow describe, in more detail, representative projects and the technologies behind them: what was asked, how it was modeled, and what the models made possible.

1991

Founded in Houston, Texas, serving the petrochemical and energy industries

KML

KnightHawk Materials Lab: in-house materials analysis, testing, and prototyping

30,000 BBL/DAY

Single-reactor capacity reached through CFD-led scale-up (Study 02)

THE TECHNOLOGY PORTFOLIO

Seven Fields of Development

Concept development, third-party opinion, feasibility, and prototyping, across the technologies reshaping energy and the environment.

01 HYDROGEN
Advanced non-catalytic reforming for hydrogen production, including hydrogen-torch and microwave processes.

02 GAS-TO-LIQUIDS
Third-generation slurry-phase bubbling-bed, three-phase reactors for gas-to-liquids (GTL) conversion.

03 BIOMASS
Fluidized-bed gasifiers for renewable biomass processing.

04 WASTE-TO-ENERGY
Reactors and processes for municipal solid waste-to-energy, including anaerobic, landfill, sewage, wastewater, leachate, and hazardous industrial waste streams.

05 PROPULSION
High-test peroxide (HTP) reactors for energy and propulsion.

06 ENHANCED OIL RECOVERY
Modular direct-injection reactors for enhanced oil recovery using superheated steam and flue gas.

07 EMISSIONS
Low-NOx thermal oxidizers for waste-energy integration and the destruction of waste gases and wastewaters.

The Toolkit

COMPUTATIONAL FLUID DYNAMICS | FINITE ELEMENT ANALYSIS | DISCRETE ELEMENT MODELING | RAPID PROTOTYPING | MATERIALS LABORATORY

01

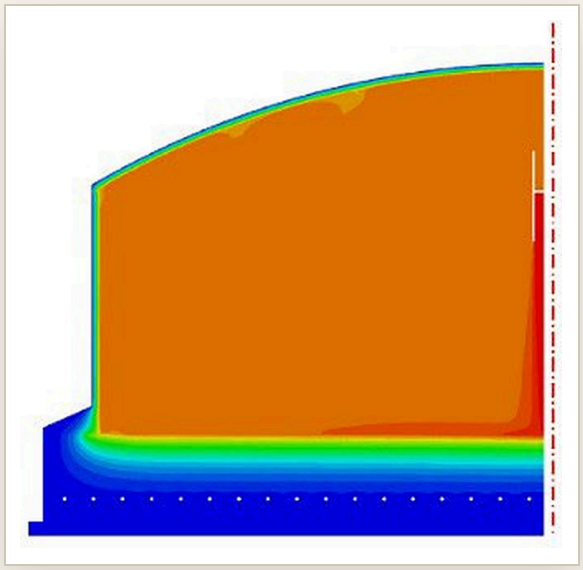


FIG. 1 Temperature field through a molten-salt storage tank, its foundation, and the surrounding soil.

SOLAR POWER · THERMAL ENERGY STORAGE

Holding the Sun Overnight

Millions of gallons of molten salt, modeled across months and years, keep a solar plant generating long after dark.

Thermal energy storage (TES) in large industrial tanks holding millions of gallons of molten salt allows heat captured from solar fields to generate power through the night and under cloudy skies. KHE applied CFD and FEA to evaluate heat losses to the ambient air, to the foundation, and to the surrounding soil over periods of months and years.

The same models yielded valuable insight into the tanks' cooling and preheat cycles, protecting the walls, roof, and floor from differential thermal growth during the shutdown and start-up actions required for inspection and maintenance.

CFD FEA TRANSIENT THERMAL

02

GAS-TO-LIQUIDS · FISCHER-TROPSCH SYNTHESIS

Thirty Thousand Barrels a Day from a Single Vessel

A 180-foot bubbling-bed reactor, taken from laboratory to commercial scale with three-phase, transient CFD.

The slurry-phase reactor (SPR), a bubbling-bed reactor that converts syngas into liquid products, hosts a highly exothermic process that must nonetheless be held near-isothermal. Fischer-Tropsch (FT) reactions of syngas proceed in the presence of a novel catalyst to produce high-quality liquid fuel products. Large reactors, in this instance 30 ft in diameter and 180 ft tall, were packed with proprietary gas-distribution, cooling, gas-liquid-solid separation, and mixing-circulation systems.

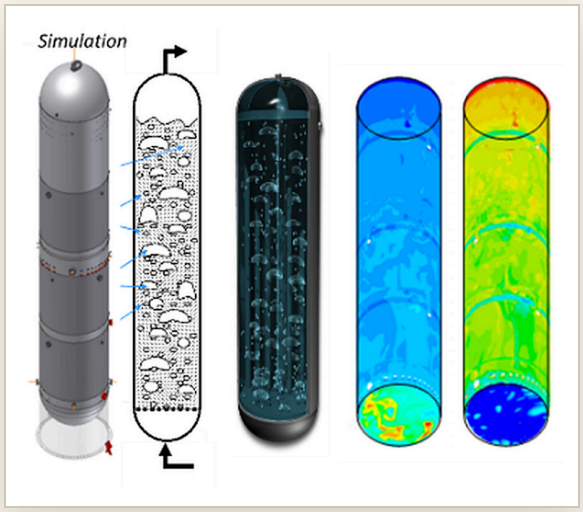


FIG. 2 From schematic to simulation: gas holdup, velocity, and catalyst distribution through the slurry-phase reactor.

CFD, FEA, and rapid prototyping greatly accelerated scale-up from the laboratory, through piloting, to commercial development, and intensified single-reactor capacity to more than 30,000 barrels per day, or 500 MW of steam duty. The analysis included a transient, three-dimensional, three-phase CFD model (syngas, waxy liquid, and catalyst solids) with reactions, circulation, and heat removal, evaluating flow, thermal behavior, species, erosion, and catalyst attrition among the parameters governing the system and its interactions.

CFD FEA RAPID PROTOTYPING SCALE-UP

03

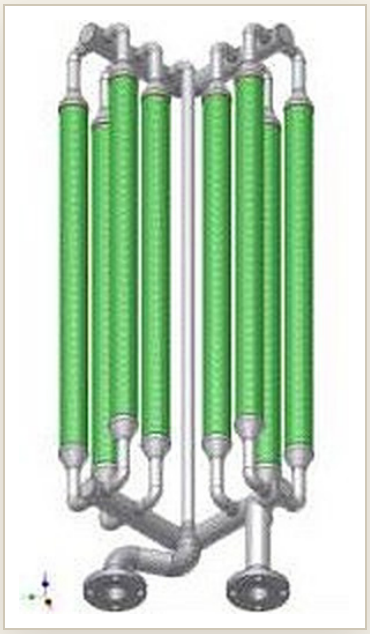


FIG. 3 Candle-filter assembly with parallel headers and multi-stage pulse distribution.

PROCESS SEPARATION · FILTRATION

Timing the Pulse

Optimizing the backpressure pulse that clears a filter cake, so every candle in the series clears at once.

New technologies within filtration systems were developed and evaluated to optimize cycle time and the sequence and intensity of the backpressure pulses used to dislodge filter cake, ensuring optimal filtration flux.

The analysis resolved the transient pressure pulse through multi-staged orifice plates, designed to distribute flow evenly across parallel headers and to deliver equal pulsation to candle-type filters arranged in series.

CFD | TRANSIENT PRESSURE | FLOW DISTRIBUTION

Across every study in this collection the same instinct applies: resolve the physics first, and the design decisions follow.

04

LABORATORY REACTORS · SCALE-UP

Perfect Mixing, Measured

A stirred micro-reactor, resolved down to the agitator blade, to shorten the road from bench to commercial design.

Continuously stirred tank micro-reactors are used in the laboratory to simulate a wide variety of processes. In this reactor, perfect mixing is achieved, with the reactants uniformly distributed throughout the vessel.

KHE applied numerical analysis to evaluate the complete reactor, including its two-stage agitators, baffle plates, and cooling jacket, resolving flows and catalyst concentrations, reaction rate, residence time, and output composition. The result accelerates testing from laboratory scale toward the design of large commercial reactors.

CFD | MIXING | RESIDENCE TIME

FIG. 4 Particle tracks around a two-stage agitator in a continuously stirred micro-reactor.

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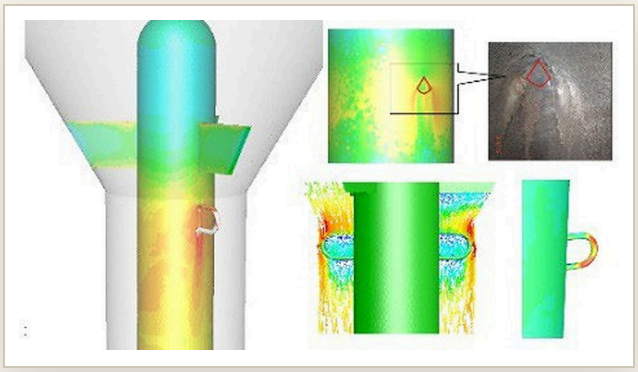

FIG. 5 Predicted erosion pattern at the internals, alongside the damage observed in the field (inset).

EQUIPMENT LIFE · MATERIALS

Predicting Where Metal Wears

The erosion the model forecast is the erosion the field revealed.

Erosion of internals can severely limit the service life of equipment. CFD was applied to evaluate erosion rates, resolving flow velocity, impingement angles, and slurry-wall interactions. The erosion observed in the field closely matched the predictions from the model.

Alternatives were then evaluated to reduce erosion rates and to apply hardened materials selectively, ensuring protection against erosion damage in service.

CFD | EROSION MODELING | MATERIALS SELECTION

A model earns its keep when the field confirms it. The erosion that CFD predicted was the erosion found on the metal.

06

HEAT TRANSFER · TWO-PHASE FLOW

Finding the Quiet Zones

Where the flow slows and recirculates, fouling begins. CFD finds those zones before the deposits do.

Baffled heat exchangers in two-phase flow are prone to fouling in low-flow and recirculation zones. This fouling degrades heat-transfer efficiency, raises pressure drop, and can demand significant downtime for cleaning.

CFD was applied to evaluate the flow patterns through the bundle and to identify the zones at greatest risk of fouling, informing both the operation and the design of the exchanger.

CFD | FOULING ASSESSMENT | HEAT EXCHANGERS

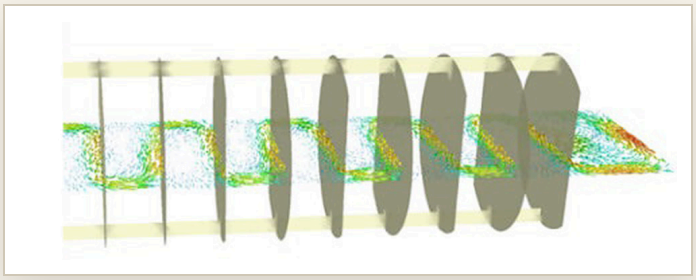

FIG. 6 Flow paths through a baffled shell-and-tube exchanger, revealing the recirculation pockets behind each baffle.

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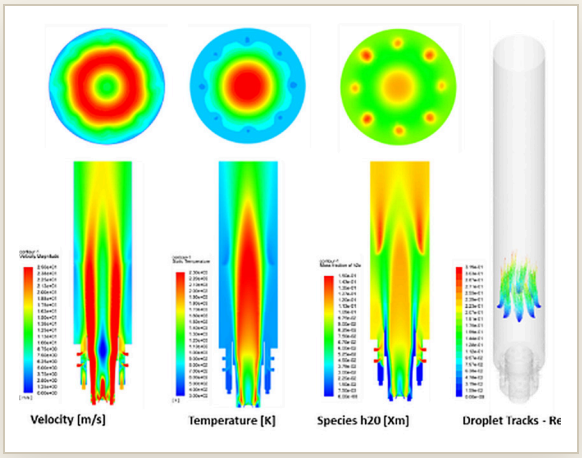

FIG. 7 Velocity, temperature, water-vapor species, and droplet tracks through the thermal oxidizer.

EMISSIONS · WASTE DESTRUCTION

Engineering Complete Destruction

Burner, waste gas, and atomized liquid, resolved together to guarantee the residence time, temperature, and mixing that destruction demands.

Waste liquids and waste gases can be destroyed in thermal oxidizers with very high destruction efficiency. In this analysis it was essential to accurately resolve the flow and temperature fields produced by the burners; the injection of waste gases and their resulting reactions; and the injection and atomization of waste liquids, their dispersion, and droplet destruction through adequate residence time, temperature, and turbulent mixing.

Species transport and volumetric reactions, radiation, and discrete-phase droplet injection were all included in the assessment.

CFD | COMBUSTION | DISCRETE PHASE | RADIATION

08

GASIFICATION · PARTICLE MECHANICS

Every Particle Accounted For

Laser-scanned particles, modeled one by one, explain why a gasifier bed segregates, and how to stop it.

Discrete Element Modeling (DEM) is a specialized field of CFD in which particle-particle, particle-wall, and particle-fluid interactions are evaluated individually. For a commercial coal gasifier, the particles were characterized by laser scanning and modeled as multi-spherical assemblies, representing angular and elongated particles with true contact radii.

The model evaluated particle interactions, rotation, and the segregation of coarser particles to the periphery by rolling while finer particles percolated through the bed. Development on pilot-scale cold models was rapidly scaled to commercial application and proved highly successful: segregation was mitigated by a mass-flow, static flow distributor delivering a uniform particle distribution and homogeneous gas flow through the packed bed.

DEM | CFD | PILOT SCALE-UP

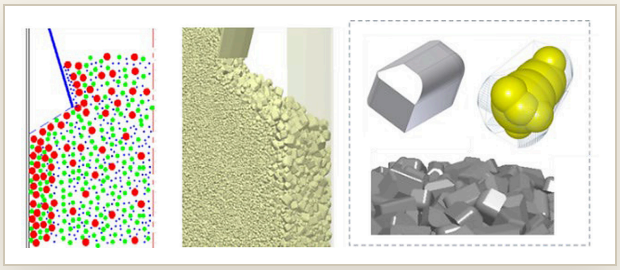

FIG. 8 Laser-scanned particles modeled as multi-sphere assemblies, and the segregation of coarse and fine fractions through the bed.

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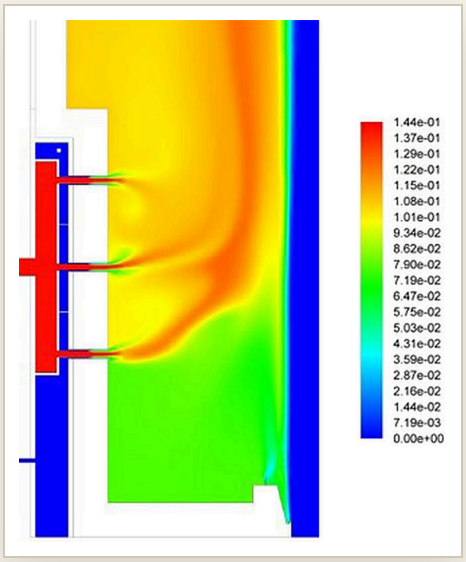

FIG. 9 Temperature field through the injection chamber, from 70 °F at the wall to 2,927 °F in the core.

INJECTION SYSTEMS · CONDENSATION CONTROL

Staying Above the Dew Point

A long-standing condensation problem, resolved by seeing exactly where water vapor met a cold wall.

Where gases carrying a partial pressure of steam enter injection chambers, any wall below the dew point presents a risk of condensation, liquid-phase accumulation, and the formation of slugs.

KHE applied CFD using a two-dimensional axisymmetric method, including swirl, species transport, reactions, radiation, and discrete-phase droplet injection, to evaluate the mass fraction of water vapor and the droplet destruction efficiency. Long-standing condensation problems in this equipment were successfully mitigated.

CFD | AXISYMMETRIC | SPECIES TRANSPORT

10

GASIFICATION · RENEWABLES

Turning Waste Streams into Syngas

Biomass, sludge, fine coal, and solid waste, gasified in a single reactor modeled in its full three-dimensional domain.

A fluidized-bed gasifier converts a wide variety of biomass, sludges, fine coal, solid wastes, and other hydrocarbon-bearing streams, often of low energy value, into syngas for power generation and liquid-fuel production. CFD was applied to approximate the pyrolysis of solid particles subjected to heating, partial oxidation, and gasification reactions, while FEA evaluated the elastic-plastic material properties required for high-temperature operation.

Mixing efficiency, residence times, particle tracks, and gas composition were evaluated in the assessment and optimization of the reactor. The analysis encompassed the full three-dimensional domain, with injection ports for solids, oxygen, and steam, species transport with reactions, and radiation.

CFD | FEA | PYROLYSIS | HIGH-TEMPERATURE MATERIALS

> *Often of low energy value, often simply waste: the streams a fluidized bed turns into fuel.*

11

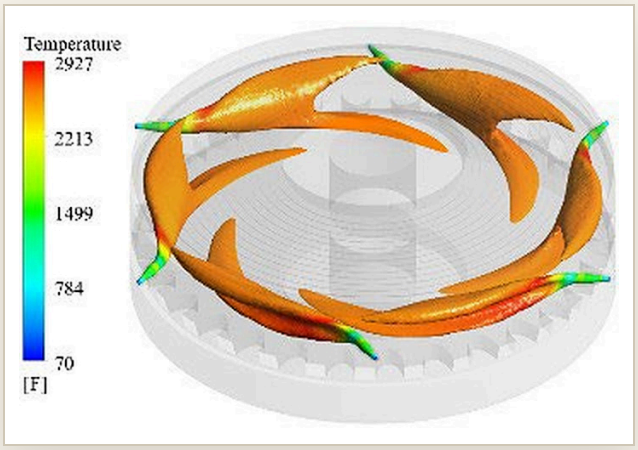

FIG. 11 Thermal field across the rotating scrapers and hearth of a multi-hearth calciner.

SOLIDS PROCESSING · REFRACTORY FURNACES

Heat Through Stone

Thermal gradients through arched refractory domes, evaluated for both failure and optimization.

A multi-hearth calciner is a special class of furnace: a central rotating shaft with scrapers, multiple stacked vertical chambers or hearths, and burners injecting heat and flue gas peripherally for countercurrent flow. It serves solids-treatment applications such as calcination, catalyst regeneration, drying, and devolatilization.

CFD and thermal-structural FEA were applied to evaluate the heat gradients through the arched refractory domes and walls, in both failure assessment and optimization of the furnace.

CFD | THERMAL-STRUCTURAL FEA | REFRACTORY

12

ETHYLENE · TRANSFER LINE EXCHANGERS

A Better Way In

An Intrabody Flow Distributor, custom-sized to end impingement and coking at the tubesheet without adding a single inch of pressure drop.

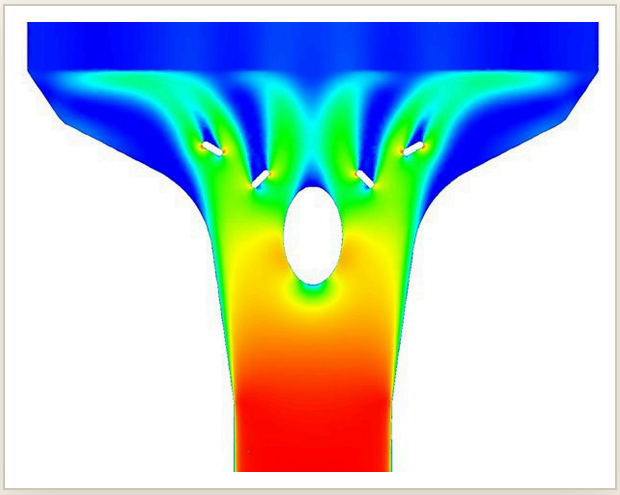

FIG. 12 Velocity field through the TLE inlet with the Intrabody Flow Distributor in place.

Transfer line exchangers (TLEs), a class of heat exchanger used for the rapid cooling of cracked gases from an upstream furnace, are commonly found in ethylene production facilities. Their inlet tubesheets are subject to very high velocities, coking build-up, rapid expansion and maldistribution of flow, and erosion of the tubesheet and tubes.

KHE custom-sized an Intrabody Flow Distributor (IFD), optimizing the refractory shape, the IFD center body, and the size, angles, and locations of the flow vanes so as not to increase pressure drop while minimizing or eliminating flow recirculation, mitigating center impingement, and improving distribution to the peripheral tubes. Coking was reduced significantly, extending run times between cleaning shutdowns; erosion of the tubesheet and inlet tubes decreased; and thermal performance improved with the improved flow distribution.

CFD | FLOW DISTRIBUTION | PROPRIETARY DESIGN

AFTERWORD

The Measure of an Idea

Every technology in this collection began as a question: can it be built, will it hold, and what will it do at full scale? KnightHawk Engineering answers those questions with the same disciplines it applies to the most demanding operating equipment in industry, so that the first time a new reactor runs, it runs as predicted.

From concept development and independent opinion through feasibility, analysis, and prototyping in our own materials laboratory, KHE partners with the companies and founders who are defining what comes next.

KnightHawk Engineering, Inc.

Houston, Texas · www.knighthawk.com

Specialist in Failure Analysis, Troubleshooting and Design of Static and Rotating Equipment

KNIGHTHAWK MATERIALS LAB (KML) · MATERIALS ANALYSIS, TESTING, AND PROTOTYPING