Cogeneration Performance Project

October 23, 2014

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Industrial Mentor: Jeff Armstrong, FlexEnergy

Agenda

1. Who is FlexEnergy?
2. UTSR Fellowship Project: Cogeneration

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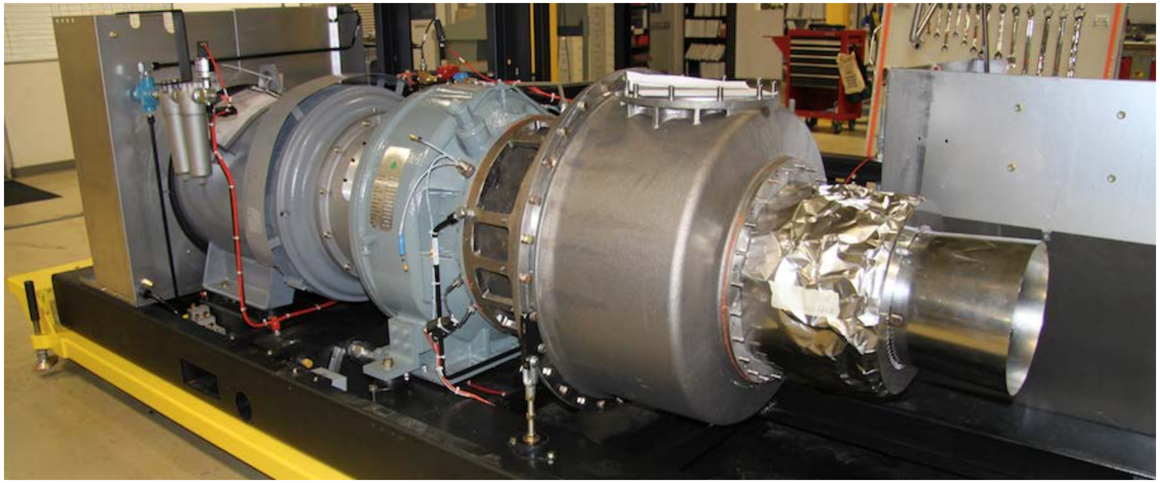
2. UTSR Fellowship Project: Cogeneration

OVERVIEW

- FlexEnergy produces 250 and 333 kW gas-fired turbines (over 3 million operating hours)
- Developed by Ingersoll Rand as a derivative of the Dresser-Rand KG2 (oilfield focused machine)
- Flex offers the only "micro" turbine built like larger, more robust turbine generators
- Flex turbines use synchronous generators, not high speed alternators, providing significantly more kVA & transient load capability than power electronics micro-turbines



Key Product Attributes…

High availability in multiple applications

+

Low annual maintenance time

+

Ease of deployment

+

Co & tri generation capabilities

+

Utility power independence

+

Compliance with emissions legislation

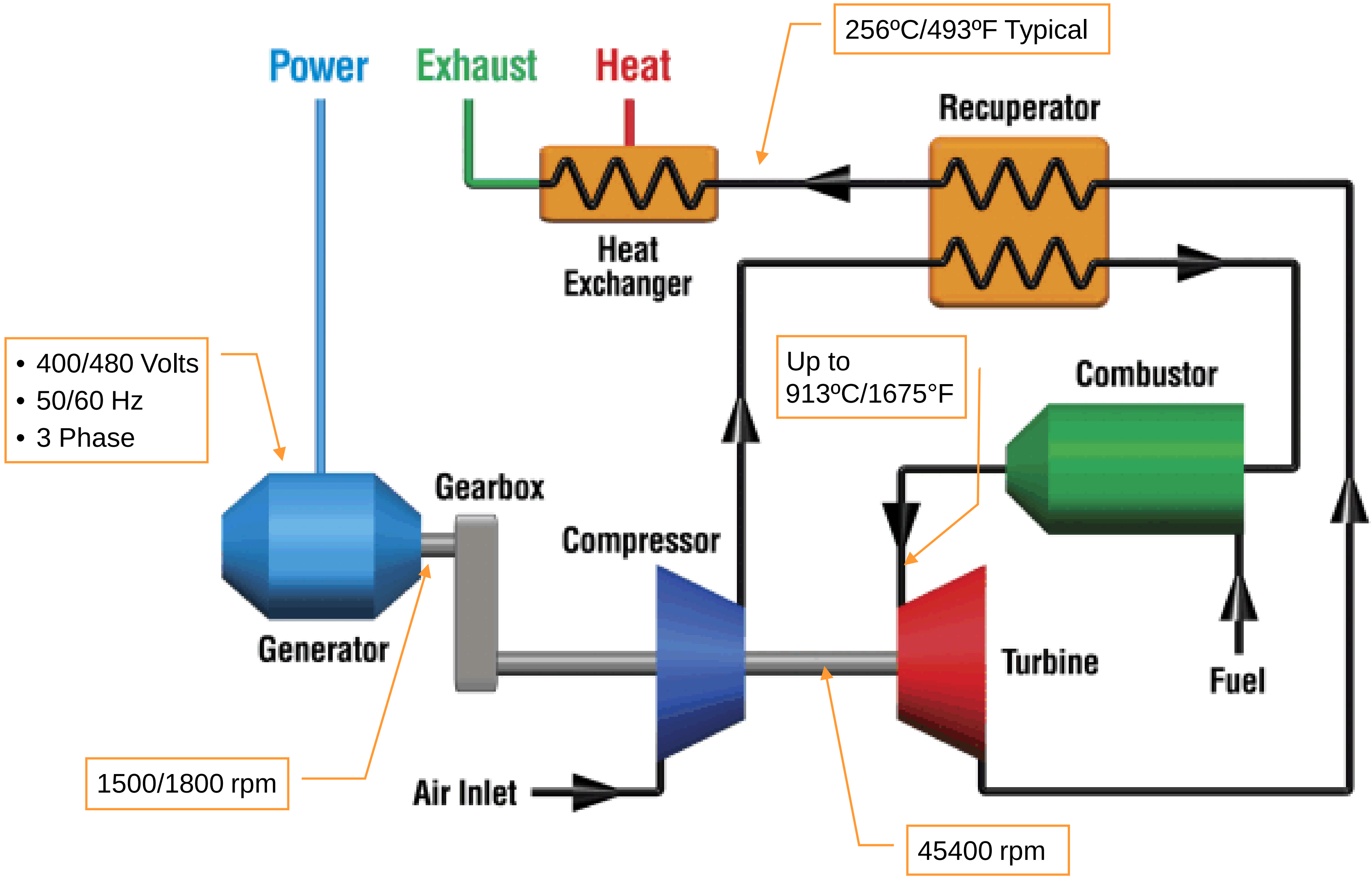
=

Increased productivity – CHP generation

Lower operating costs

Environmentally Friendly

FLEXENERGY TURBINE CYCLE DIAGRAM



FLEX TURBINE™ MT250 & MT333

Rugged Turbine Engine

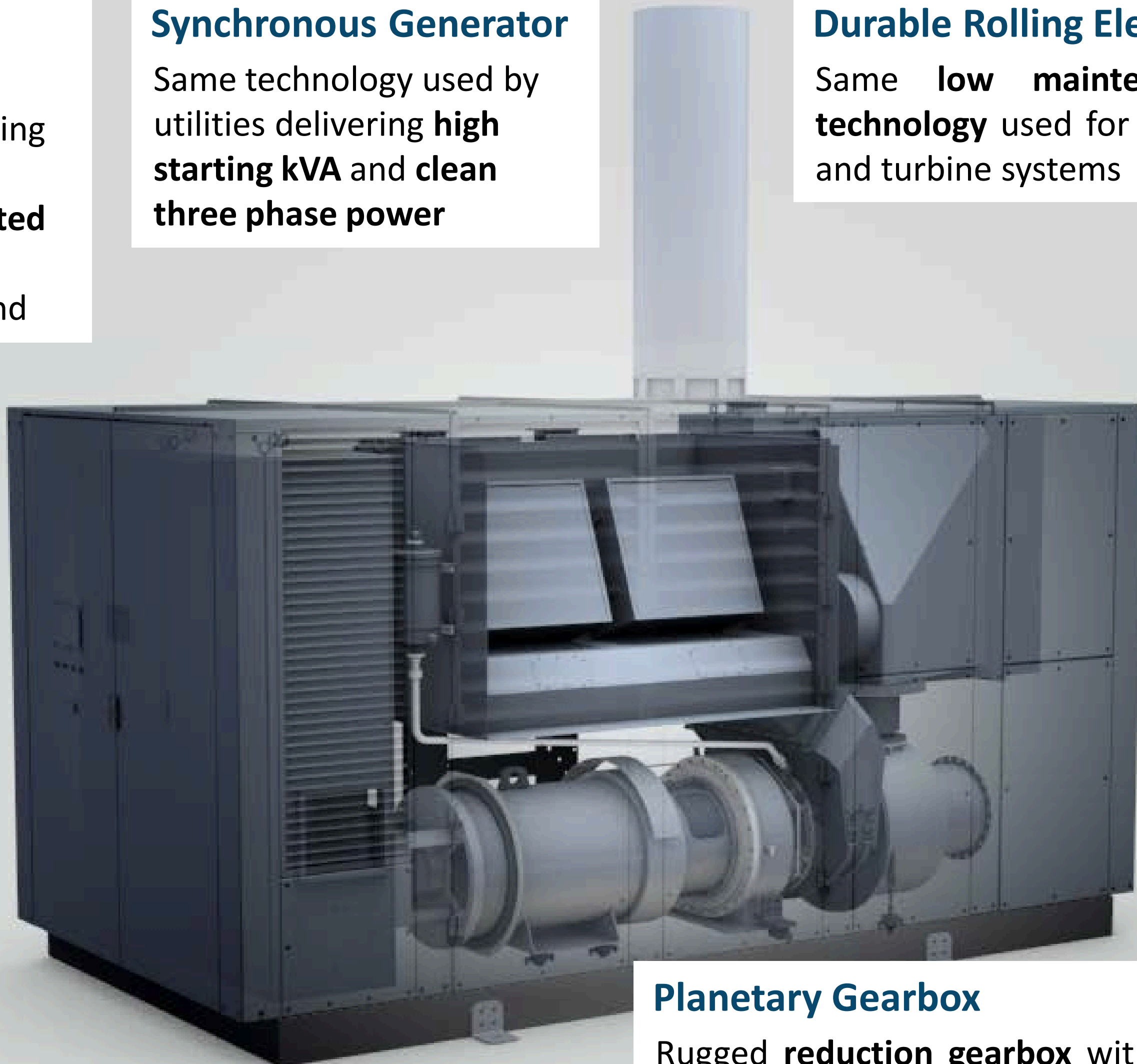
Back-to-back rotating components and **proven oil-lubricated bearings** with all bearings at cold end

Synchronous Generator

Same technology used by utilities delivering **high starting kVA** and **clean three phase power**

Durable Rolling Element Bearings

Same **low maintenance, high reliability technology** used for high performance engine and turbine systems



Patented Combustor

Dry low NOx easily meets and **exceeds the most stringent regulations**

Patented Recuperator

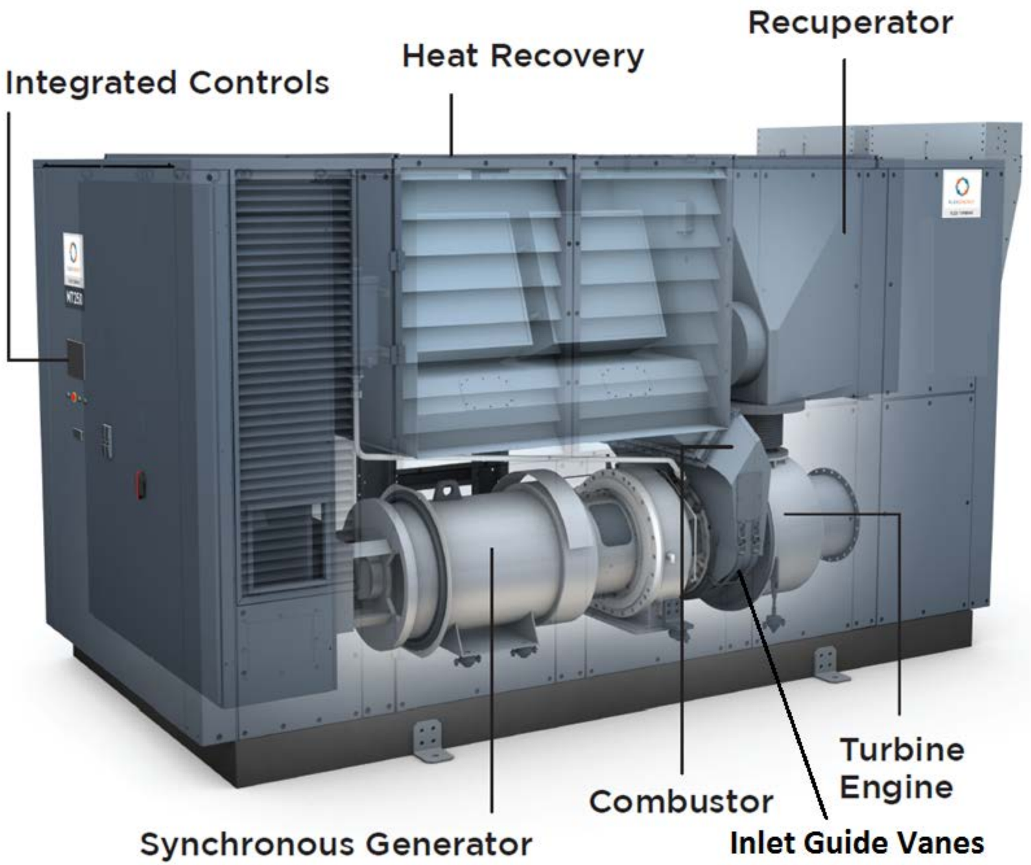
Critical to high efficiency and considered **best-in-class**

Planetary Gearbox

Rugged **reduction gearbox** with **soft coupling** drives generator at synchronous speed

FLEX TURBINE™ MT333

A 333kW gas turbine engine-driven power system

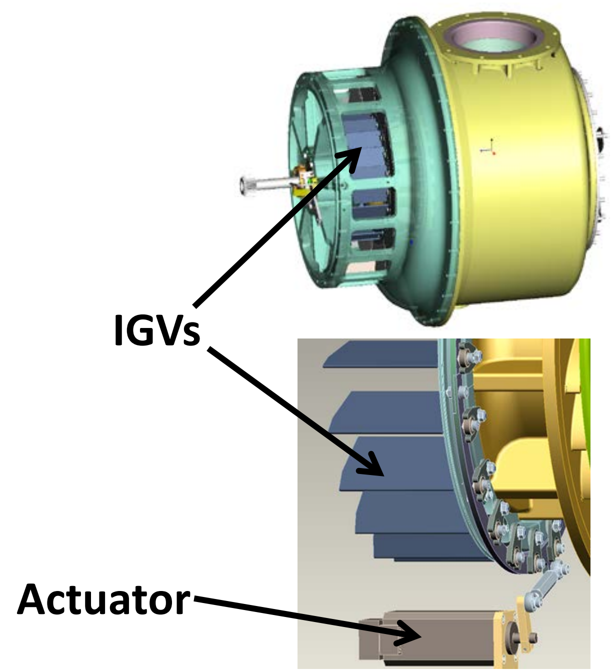


Key Features

- Uprated core engine derived from MT250
- High load starting capability up to 125 HP DOL

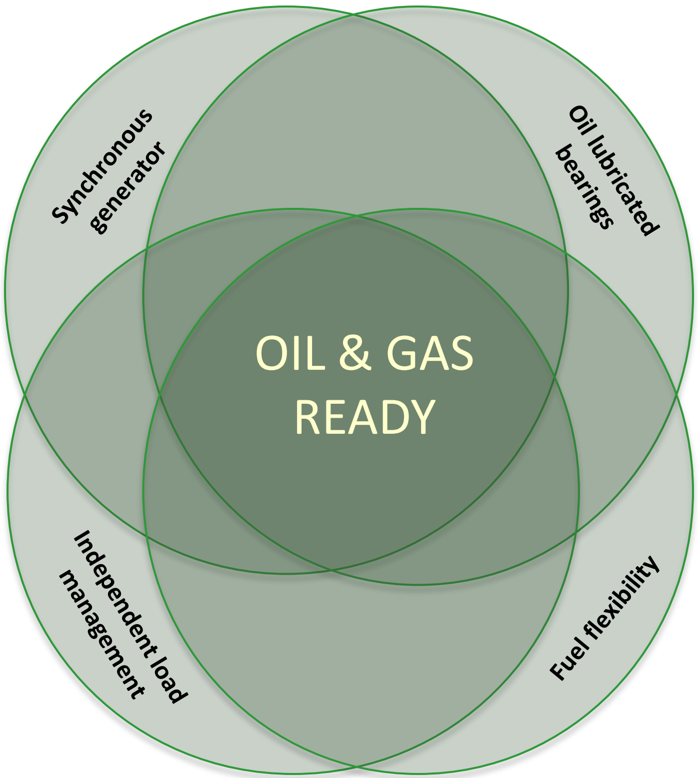
Inlet Guide Vanes

- Increases efficiency at part-load conditions
- Ideal for off-grid load and fuel following



MATCHING TURBINE TECHNOLOGY TO APPLICATION

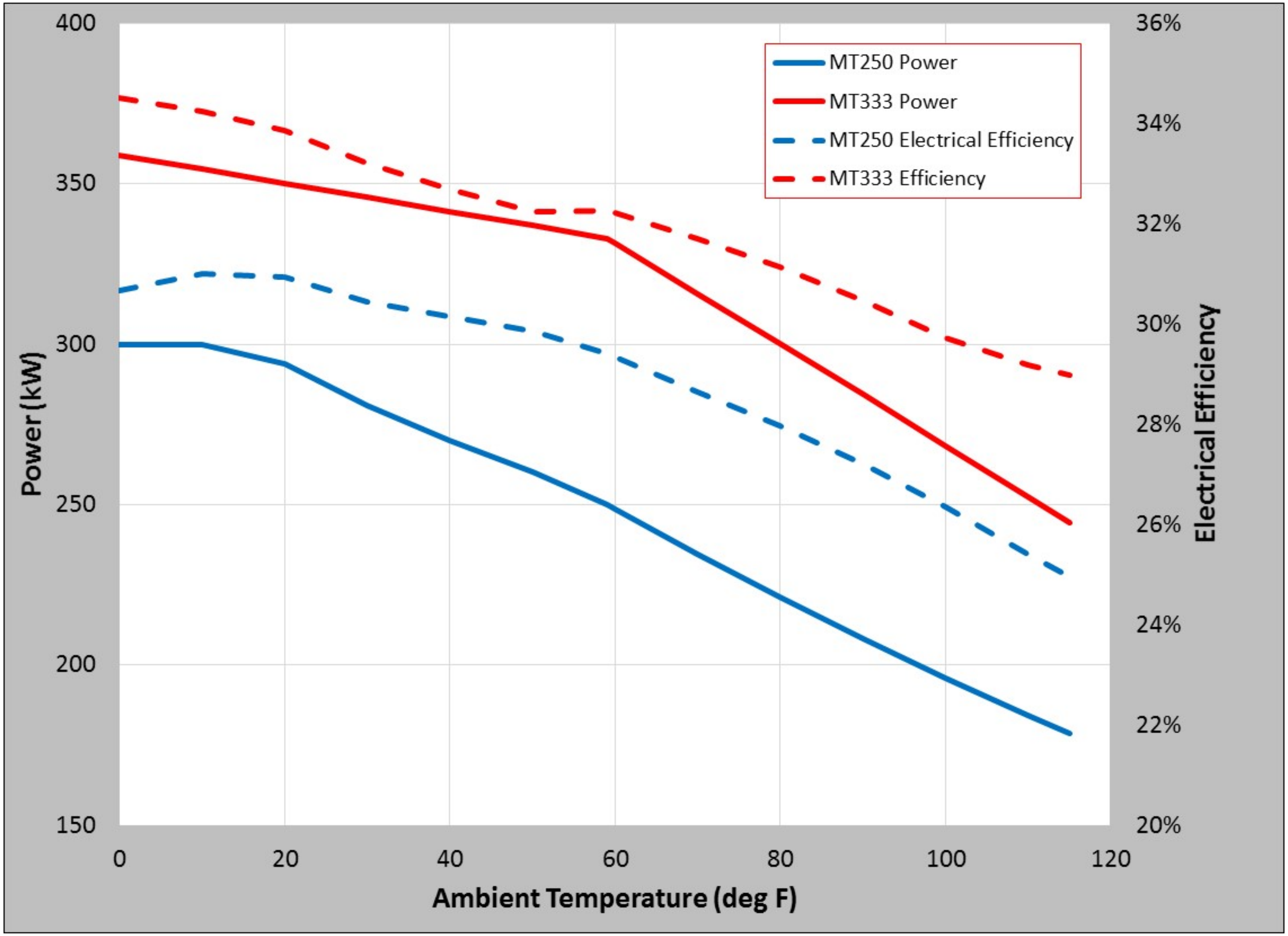
What constitutes "Oil & Gas Ready"?



Manufacturer	Generation Technology	Speed reduction gearbox?	Bearings	Load management independent of battery?
Rolls Royce	SYNCHRONOUS	YES	OIL LUBRICATED	YES
GE	SYNCHRONOUS	YES	OIL LUBRICATED	YES
Seimens	SYNCHRONOUS	YES	OIL LUBRICATED	YES
Solar	SYNCHRONOUS	YES	OIL LUBRICATED	YES
Dresser Rand	SYNCHRONOUS	YES	OIL LUBRICATED	YES
Flex	SYNCHRONOUS	YES	OIL LUBRICATED	YES
Other Micros	HIGH SPEED ALTERNATOR	NO	AIR	NO

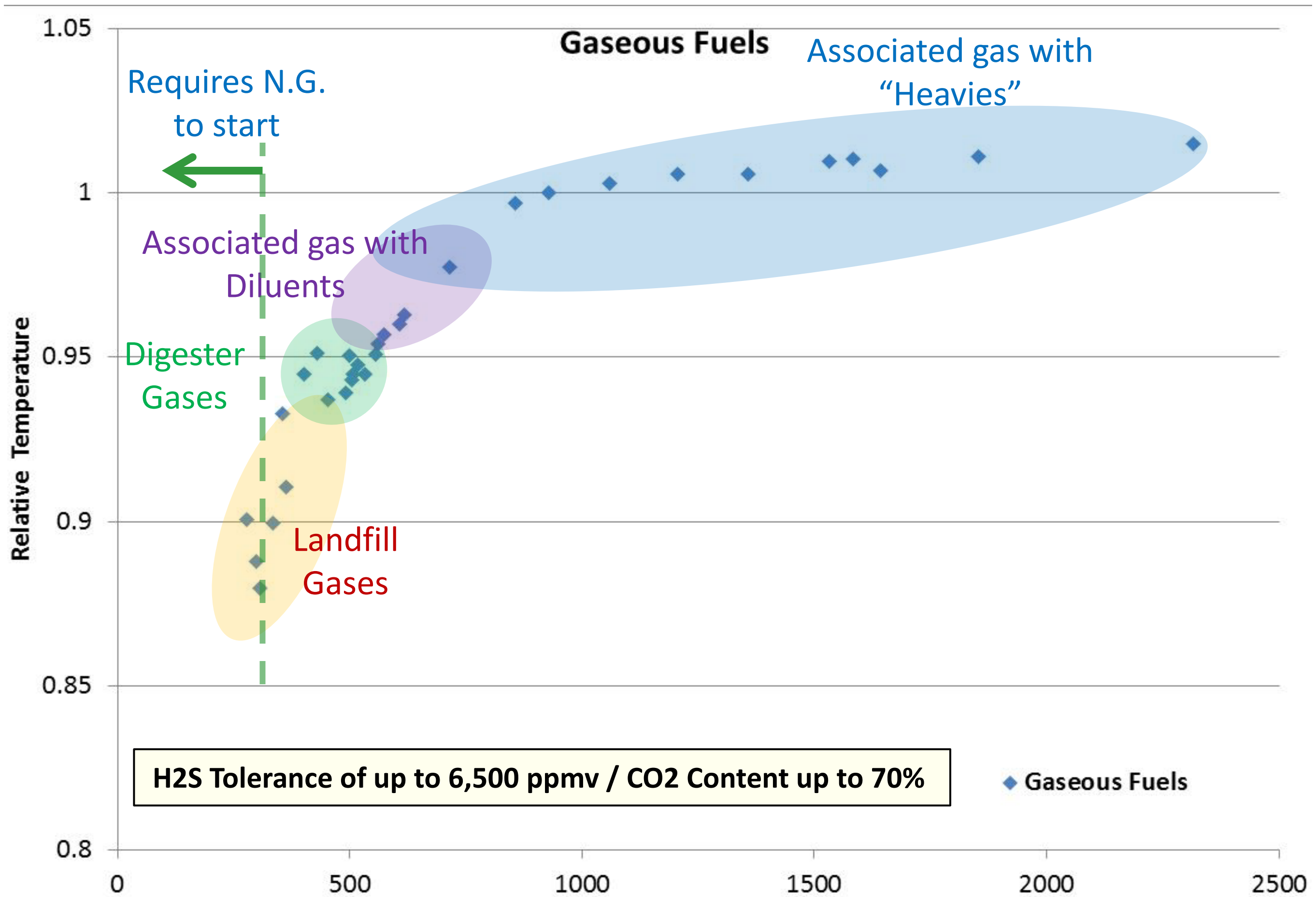
FlexEnergy is the ONLY 'micro' turbine generator that shares the same technology as larger gas turbine generators.

Turbine Electrical Performance



Note: Does not include fuel gas booster parasitic
Deduct 3.5% per 1000 ft (305 m)

COMBUSTOR OPTIONS BRING FUEL FLEXIBILITY



Fuel Lower Heating Value (Btu/ft3); dry basis at 14.7 psi (101 kPa) and 59F (15C)

Agenda

1. **Who is FlexEnergy?**

2. **UTSR Fellowship Project: Cogeneration**

Motivation for Project

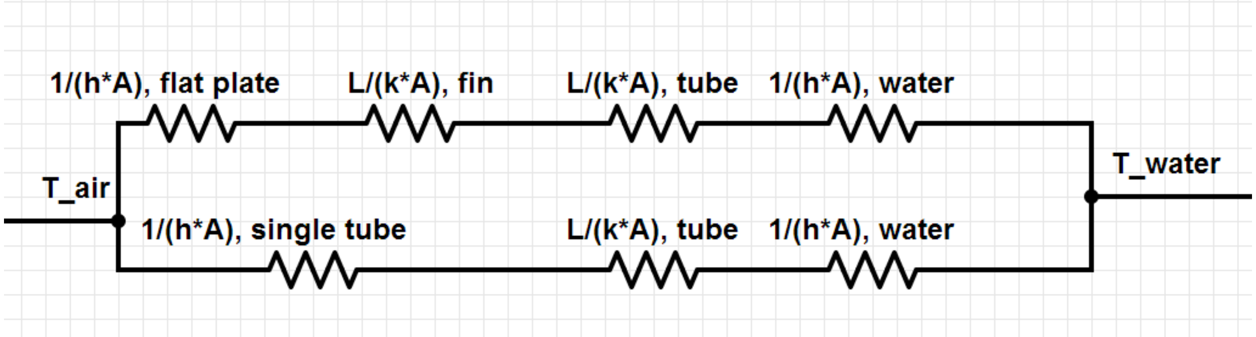
- New MT333 has higher mass flow:
  - Decrease DP of cogeneration heat exchanger
  - Maintain HX within turbine enclosure
- CHP Efficiency Incentives aggressive:
  - Public Utility Regulatory Policies Act (PURPA):
    - Requires 42.5% LHV combined efficiency with only ½ of cogenerated heat
  - California SGIP:
    - Requires 60% HHV combined efficiency (~66% LHV)
  - Massachusetts' CHP Program initiative:
    - Requires 60% HHV combined efficiency (~66% LHV)
  - European Directive 2004/8/EC (2004.02.11):
    - Requires 75% LHV combined efficiency

Project Approach

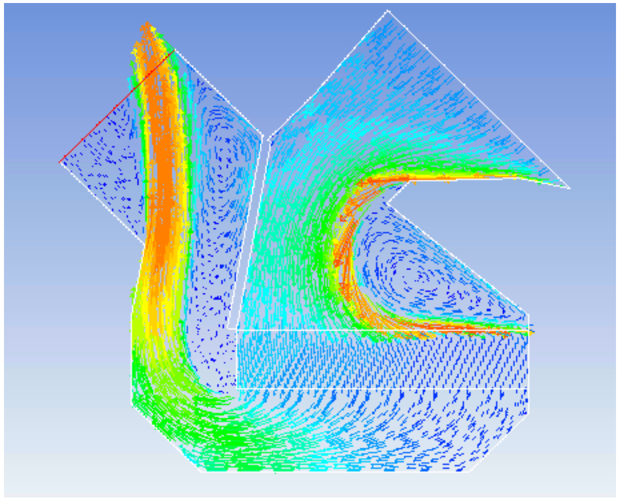
- Calibrate model of existing cogen HX
- Identify Improved design

Project Overview

- **Engineering Equation Solver (EES) heat exchanger model.**



- Computational Fluid Dynamics



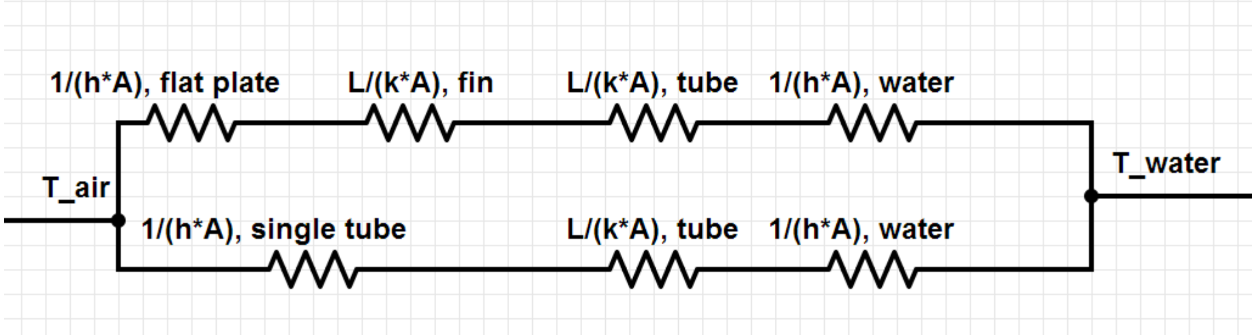
NTU-ε Model

$$NTU = \frac{UA}{C_{\min}}$$

$$C_{\min} = \dot{m} * Cp$$

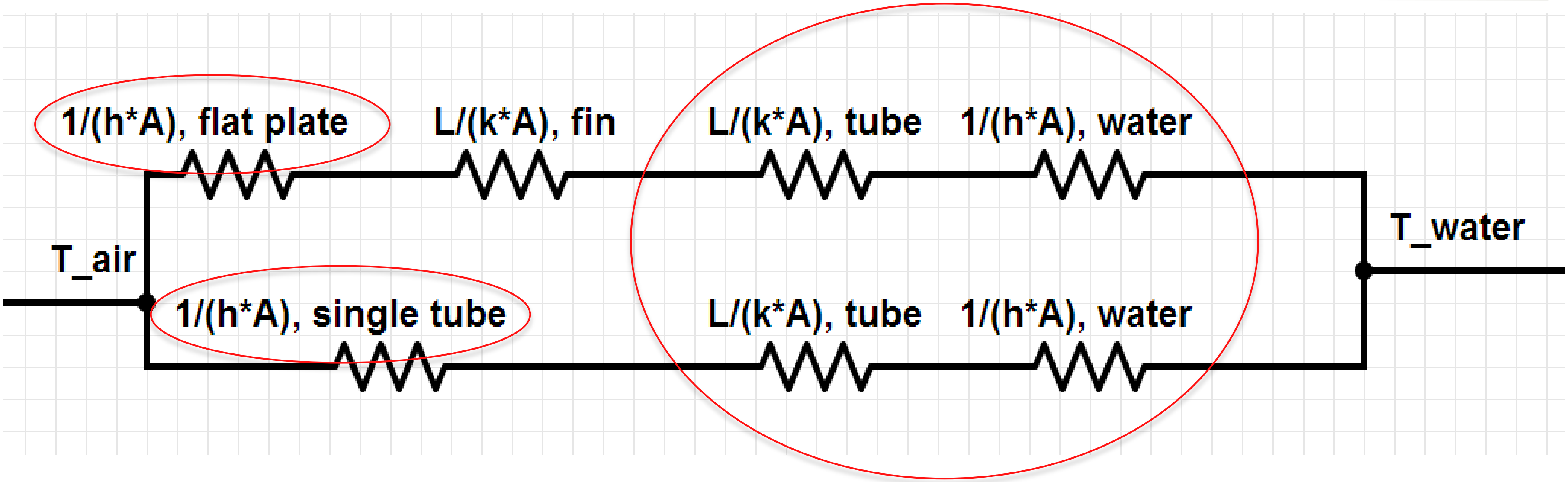
$$UA = \frac{1}{R_{eq}}$$

Thermal circuit, R_{unit}

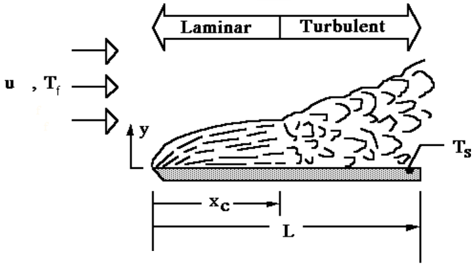


$$R_{eq} = \frac{R_{unit}}{N_{fins} * N_{tubes} * N_{rows}}$$

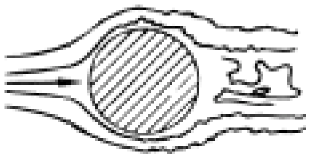
Improving the Thermal Circuit - Candidates



- Flat plate correlation

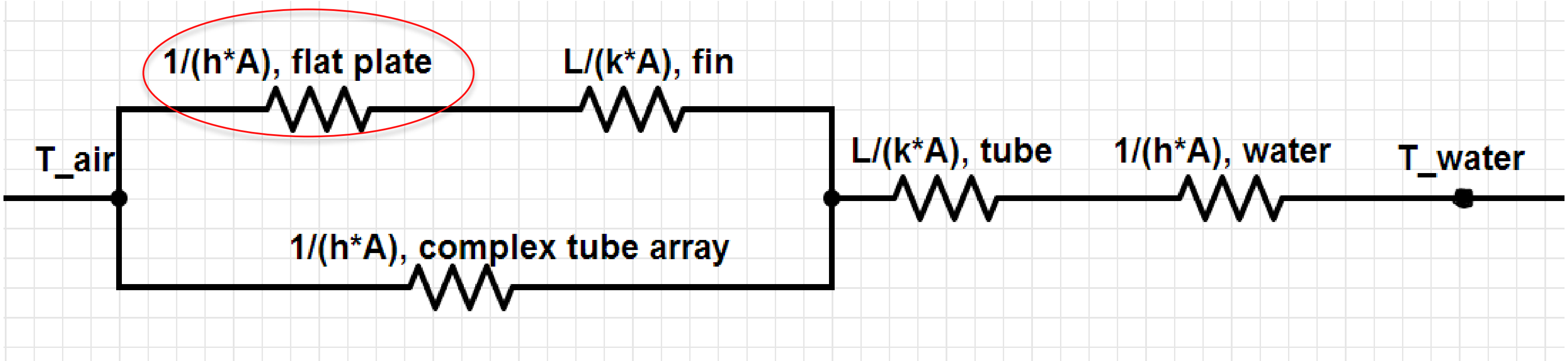


- Single tube correlation



- Circuit in parallel with itself

Modified Thermal Circuit



- Tube correlation changed to Chilton-Colburn analogy of finned banks of tubes.
- No suitable replacements were found for flat plate correlation.

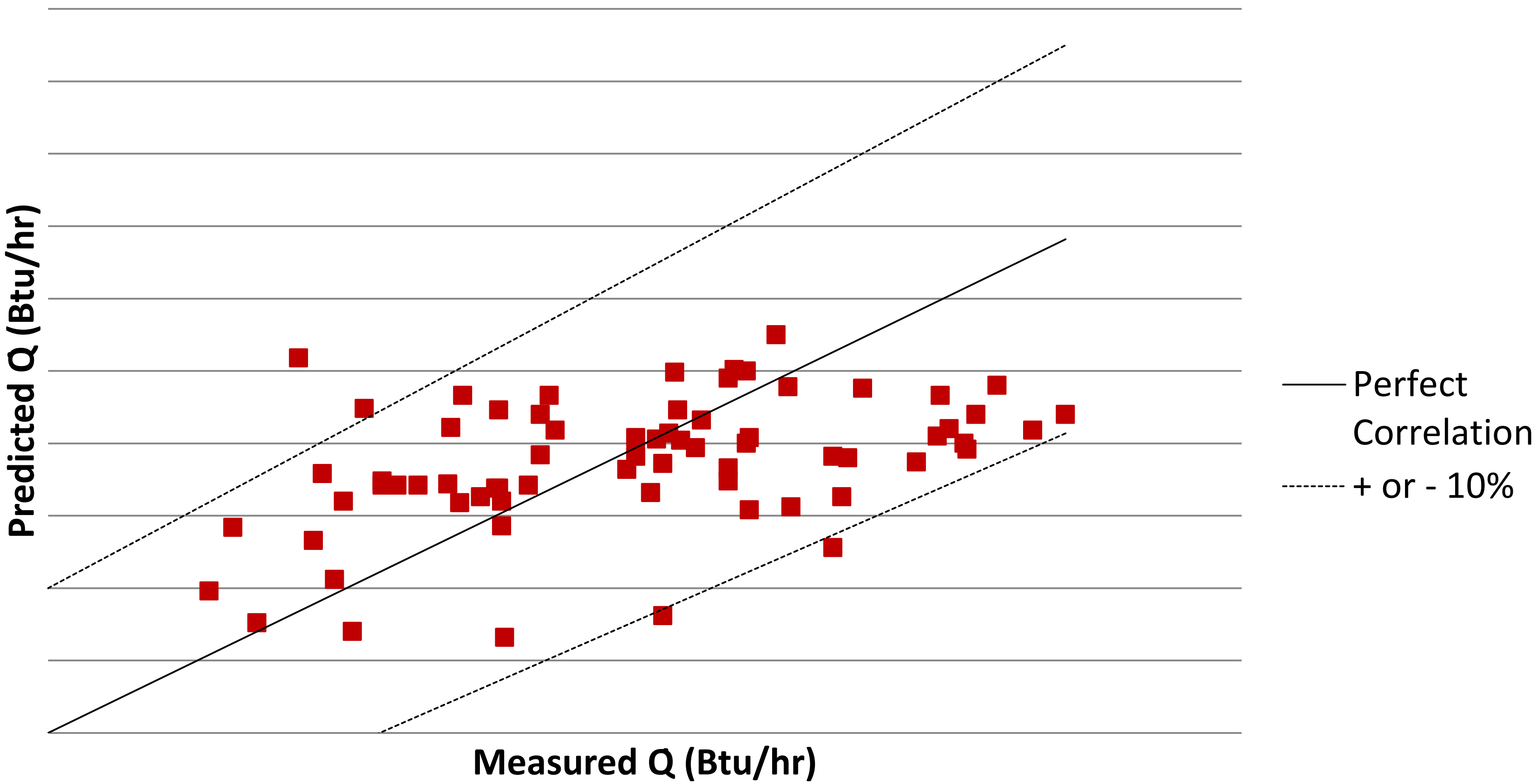
Modeling the Leak

- Model continued to over-predict empirical data by 4%, on average.
- To compensate, air leaking past the heat exchanger was modeled using the correlation:

$$\dot{m}_{leak} = A_{effective} * \sqrt{(\Delta P / P_{amb}) / 1.991}$$

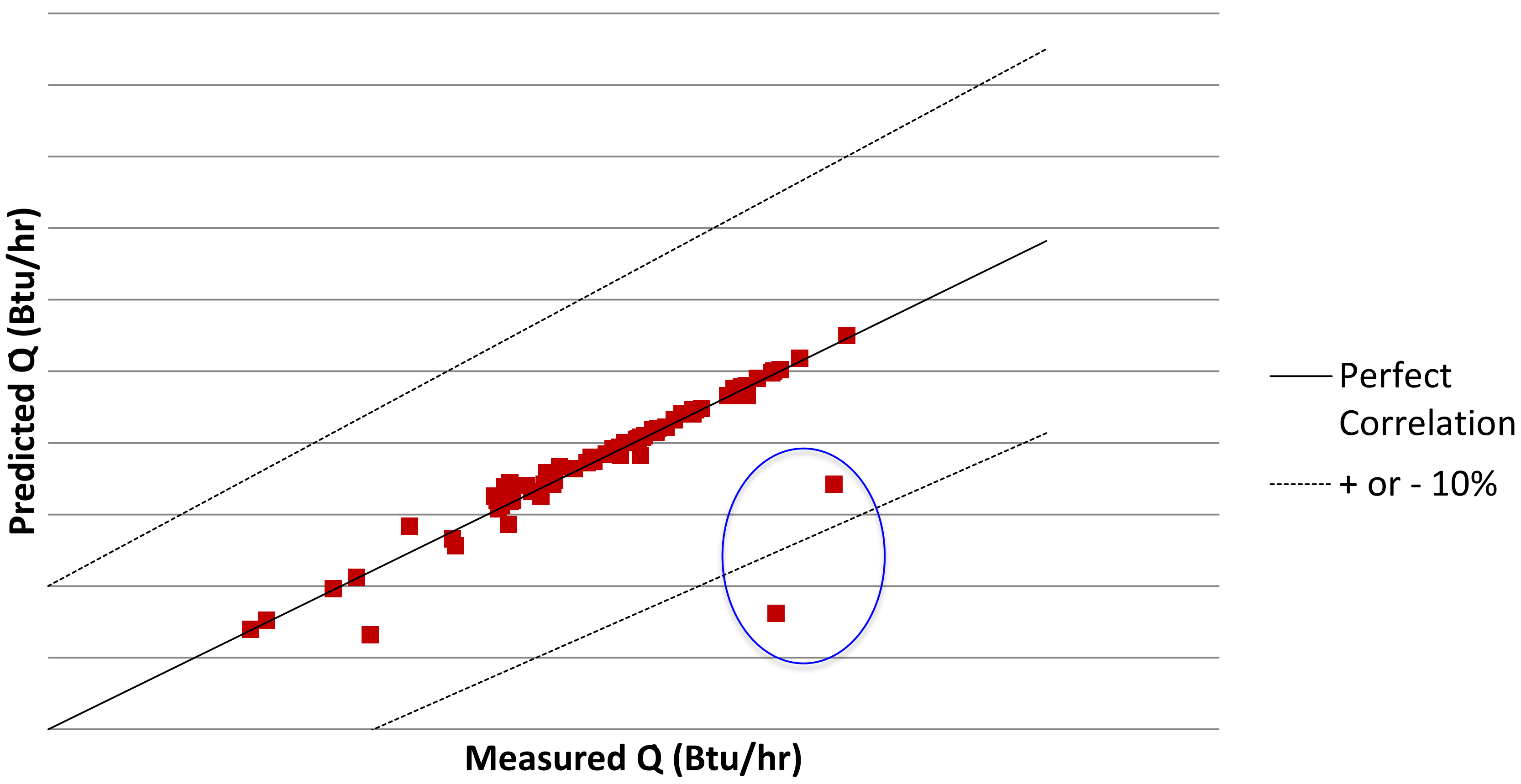
- $A_{effective}$ was chosen such that the models predictions were reduced by 4%, to more closely match the empirical data.

Empirical and Modeled Values



$$\dot{Q} = \dot{m} * Cp * \Delta T_{water}$$

ΔTwater → ΔTair

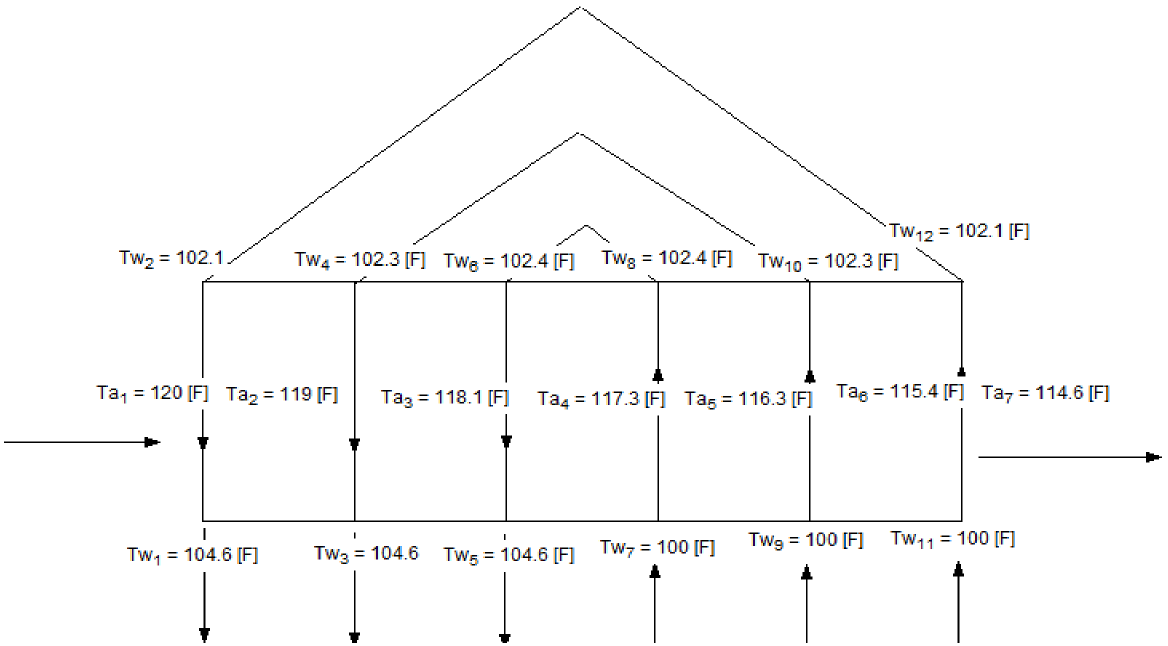


Energy Balance – A New Approach

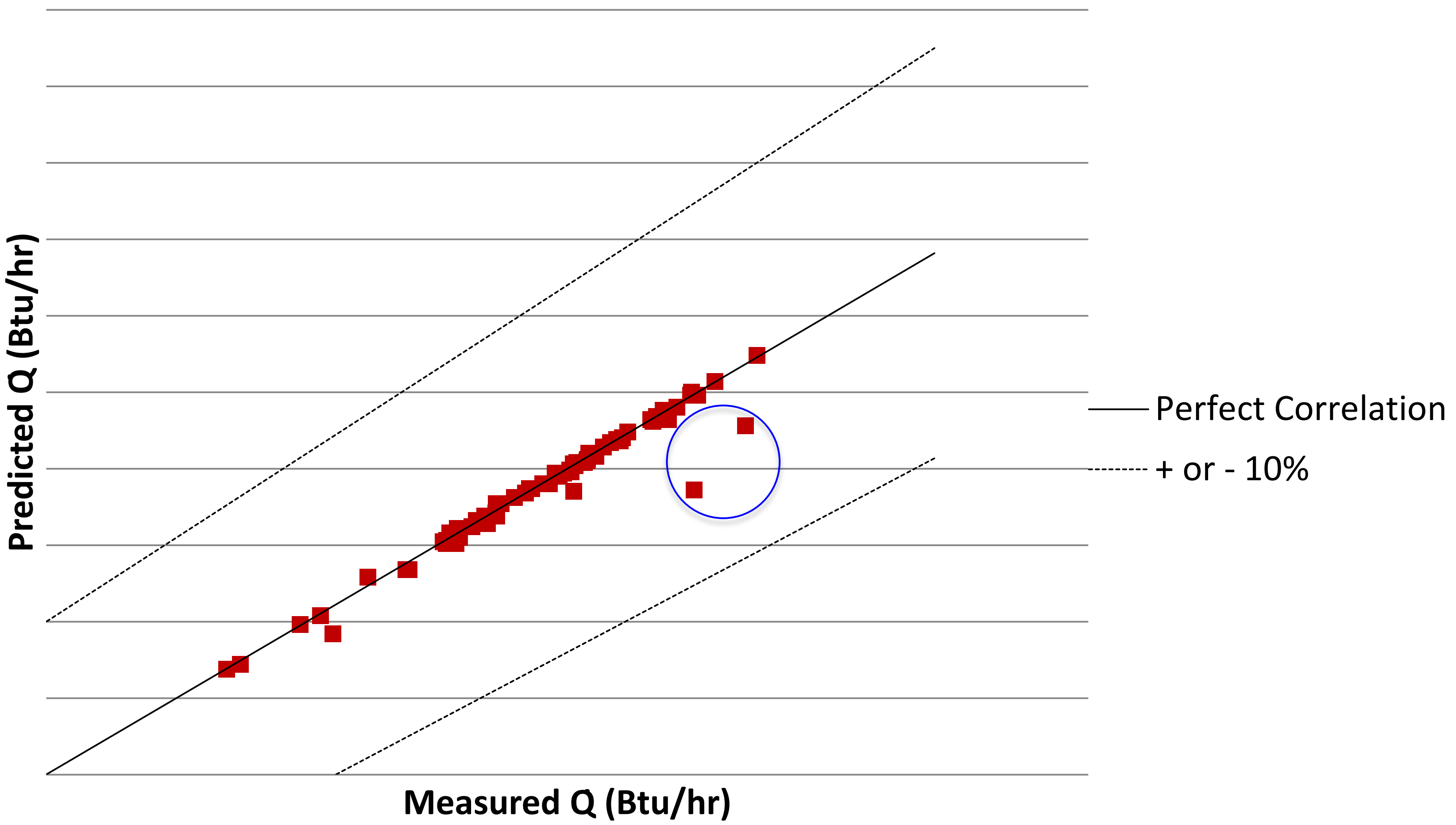
$$\dot{Q} = \dot{m} * Cp * \Delta T_{water}, \quad \dot{Q} = -\dot{m} * Cp * \Delta T_{air}, \quad \dot{Q} = \frac{T_{air} - T_{water}}{R_{row}}$$

$$R_{row} = \frac{R_{unit}}{N_{fins} * N_{tubes}}$$

6 row, 2 pass

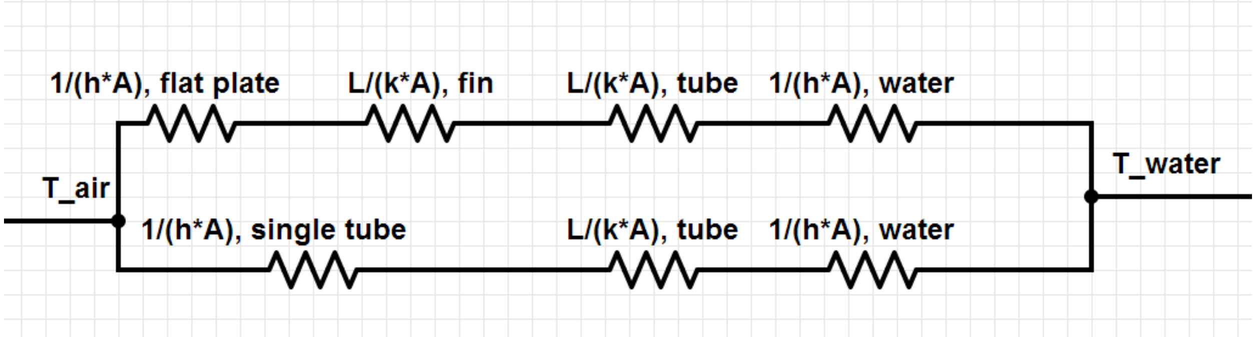


Empirical and Modeled Values

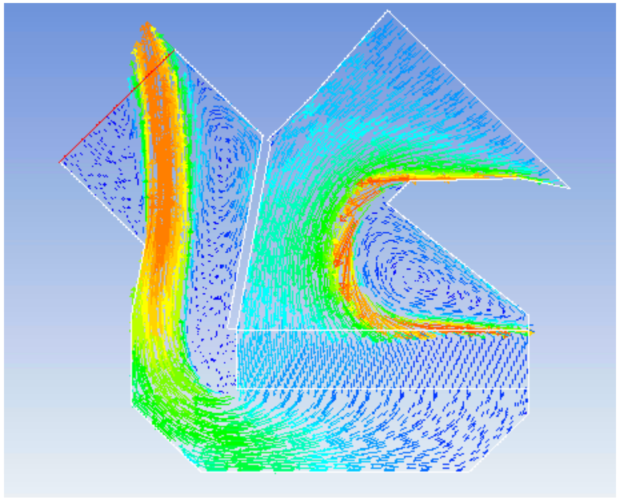


Project Overview

- Engineering Equation Solver (EES) heat exchanger model.



- **Computational Fluid Dynamics**



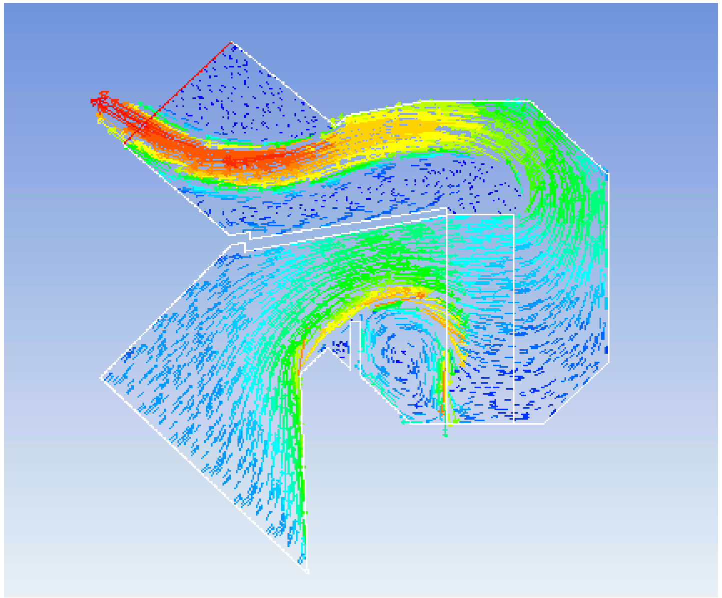
CFD Modeling

- Realizable k-Epsilon
- Mass flow Inlet
- Pressure Outlet
- HX — Porous, Laminar Zone
- HX — Negative Heat “Source”
- Color/arrow length depicts velocity
- Over 50 Geometries tested

Pressure Drop (ΔP) Calculations

- ΔP data is proprietary
- All ΔP data in this report are relative. They are based off of the current cogen configuration
- ΔP refers to total pressure
- ΔP refers to ΔP across the entire geometry, excluding the HX.

$$\Delta P_{relative} = \frac{\Delta P}{\Delta P_{current}} * 100$$

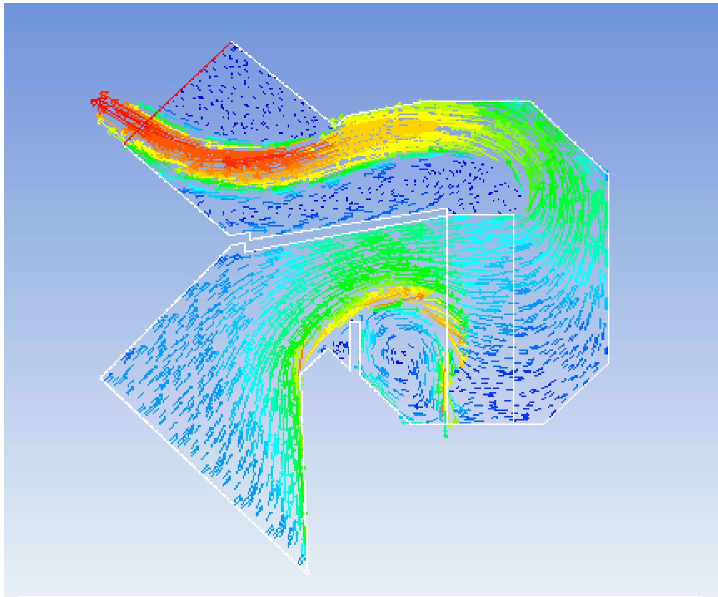


Current Cogen Configuration

Grid Independence Study

- CFD models are not grid independent.
- This table refers to percentage change of values resulting from doubling the previous density.

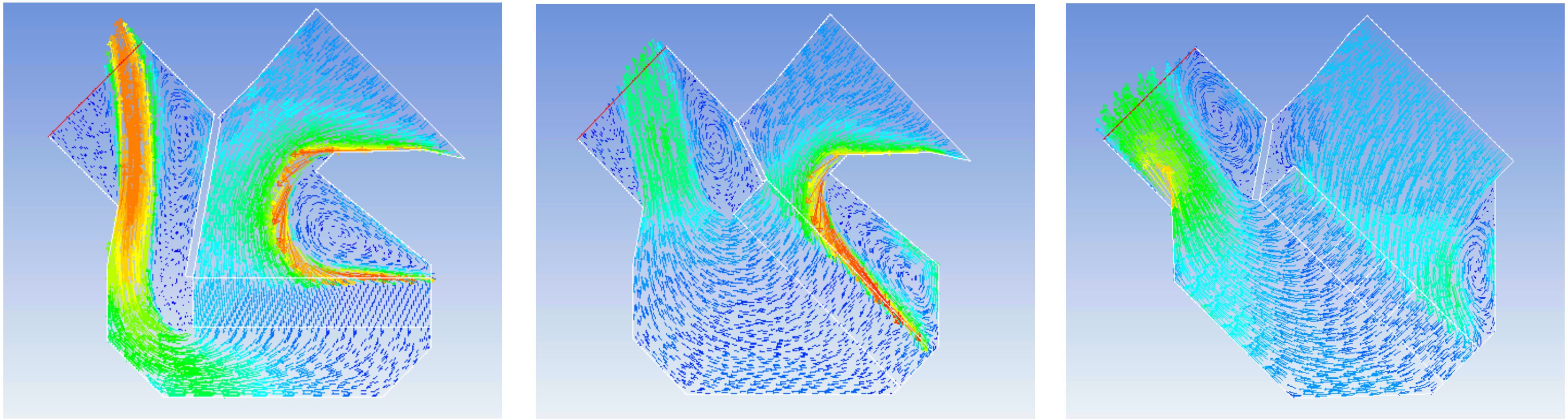
	2x	4x
Inlet ΔP	-45%	29%
Outlet ΔP	32%	50%
Total non-HX ΔP	-5%	42%



Current Cogen Configuration

- Most models in this report are “4x” grid density.

3 Main Design Considerations



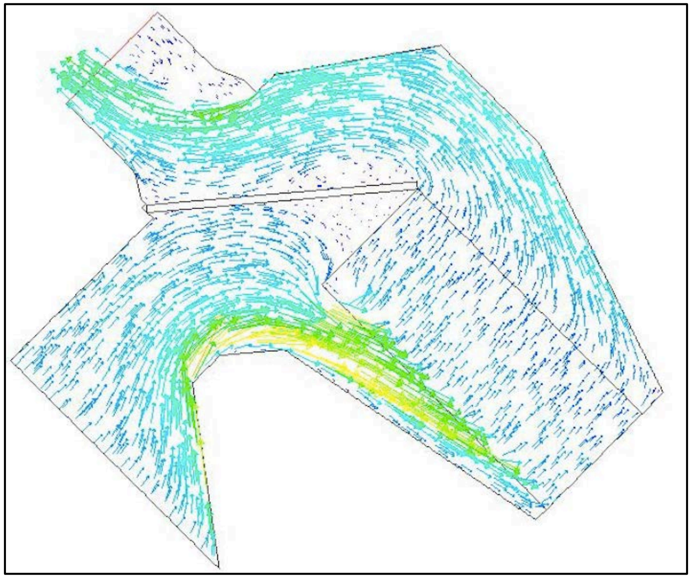
Center Pivot ΔP = 45 | Front Pivot ΔP = 65 | Back Pivot, ΔP = 8

- The back/front pivot designs were rejected for two reasons:

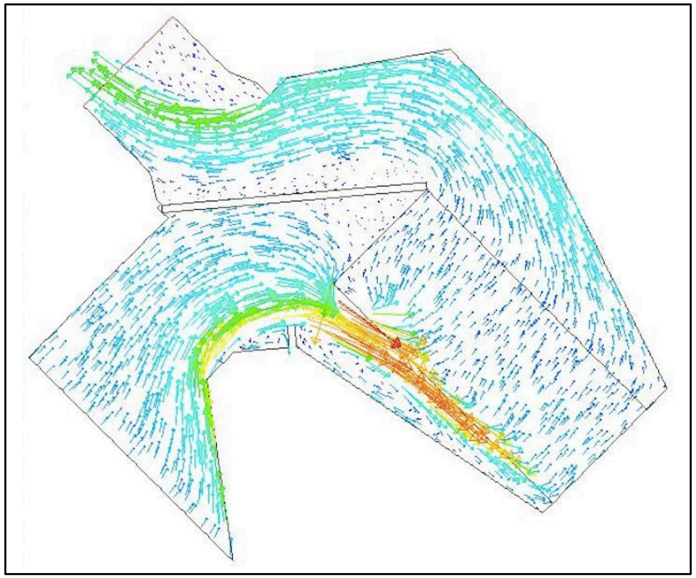
1. High damper door torque
2. Undesired heat transfer when in “closed” position.

New Considerations

- At this point in the design stage, it was determined that a deeper HX would be required.
- Decided to quantify the independent effect of a flow-tripping “lip”.



Center Pivot with thick HX, ΔP = 52

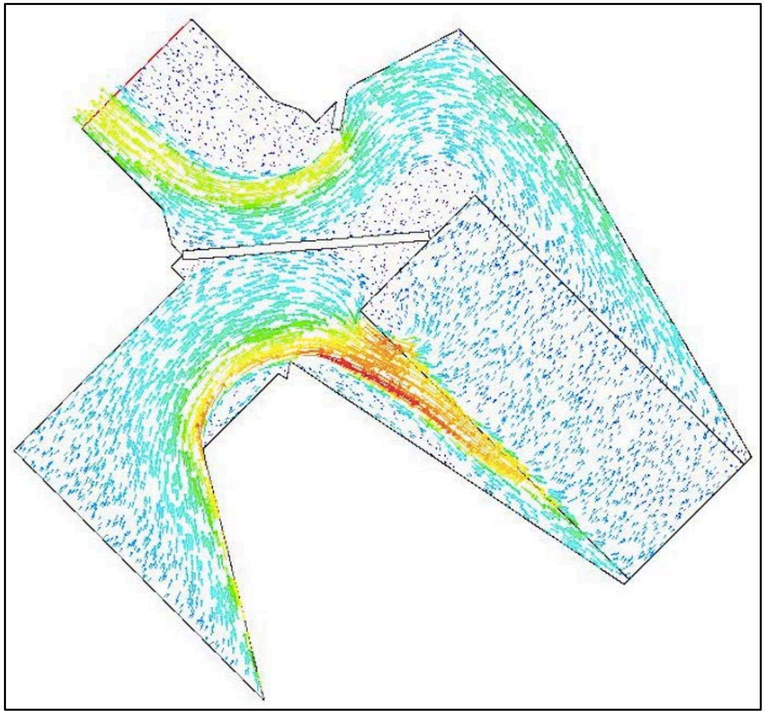


Added lip, ΔP = 91

Final Design

Other designs had better ΔP. However, this geometry was superior because of other considerations:

- Small damper torque
- Fits desired size of HX
- Damper closes completely
- Accommodates the geometric constraints of the remainder of the MT333.



Final Design, ΔP = 95

Conclusion

As a result of the UTSR fellowship, a number of objectives were achieved:

- The HX model was refined and calibrated
- ΔP was predicted for various geometries
- A final HX size was selected
- A final cogen geometry was designed

Acknowledgements

- FlexEnergy, Inc.
- UTSR Fellowship Program
- Special Thanks to
  - Jeffrey Armstrong, Chris Bolin, John Alday, Nikolai Kozulin, Corey Bergeron, Mike Carney, Tom Hackett, Bob Megee, Brian Finstad, and Greg Arbo, all of FlexEnergy.
  - Dr. Steven Gorrell, Brigham Young University

Questions?

- If I don't know the answer, then I reserve the right to pretend that it's proprietary information.