The Verdicorp ORC Turbine

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* Verdicorp Inc.   ** Danfoss Turbocor Compressors

Verdicorp
ENVIRONMENTAL TECHNOLOGIES

Verdicorp

- 1993- Ron Conry founded Turbocor as an R&D company in Australia
- 1999- Turbocor moves to Montreal, Canada
- 2003- Turbocor launches oil-free, high efficiency, direct drive centrifugal compressors for refrigeration industry
- 2004- Danfoss Turbocor Compressors as 50/50 Joint Venture with Danfoss of Denmark
- 2007- Turbocor relocates to Tallahassee, FL
- 2009- Verdicorp founded by Ron Conry to take technologies developed for Turbocor, into areas other than refrigeration
- 2010- With many of the original development team, offices formed in Tallahassee, Melbourne and New York
- 2011- Turbocor on track to produce over 6,000 compressors a year, with over 20,000 compressors in the field

Low Temperature ORC Applications

- Technical viability
  - Performance
  - Reliability
  - Compact Footprint
- Commercial viability
  - System cost
    - Expander cost
  - Scalable Manufacturing
  - Service & Support System

Technical Direction

- Adapt an existing, reliable machine
- Base machine design (Danfoss Turbocor)
  - Two stage, variable speed centrifugal compressor
  - Un-shrouded impellers
  - Designed for HFC-134a
- Conversion to
  - Single stage, variable speed turbo-expander
  - Shrouded rotor
  - Designed for HFC-245fa
- Verdicorp has exclusive Worldwide license to all technologies in Danfoss Turbocor Compressors
- Development team made up of many from original team

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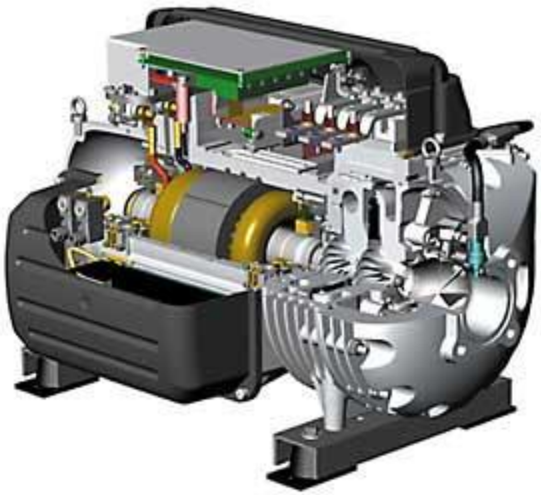
ENVIRONMENTAL TECHNOLOGIES

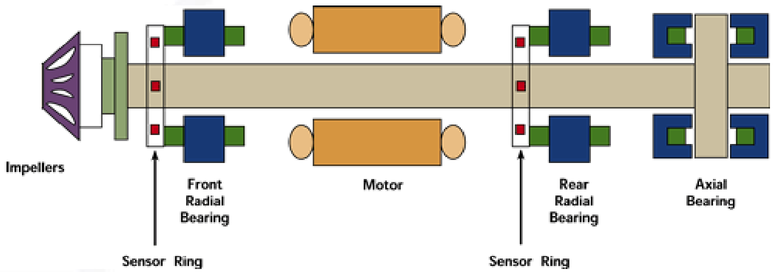
Danfoss Turbocor Compressors



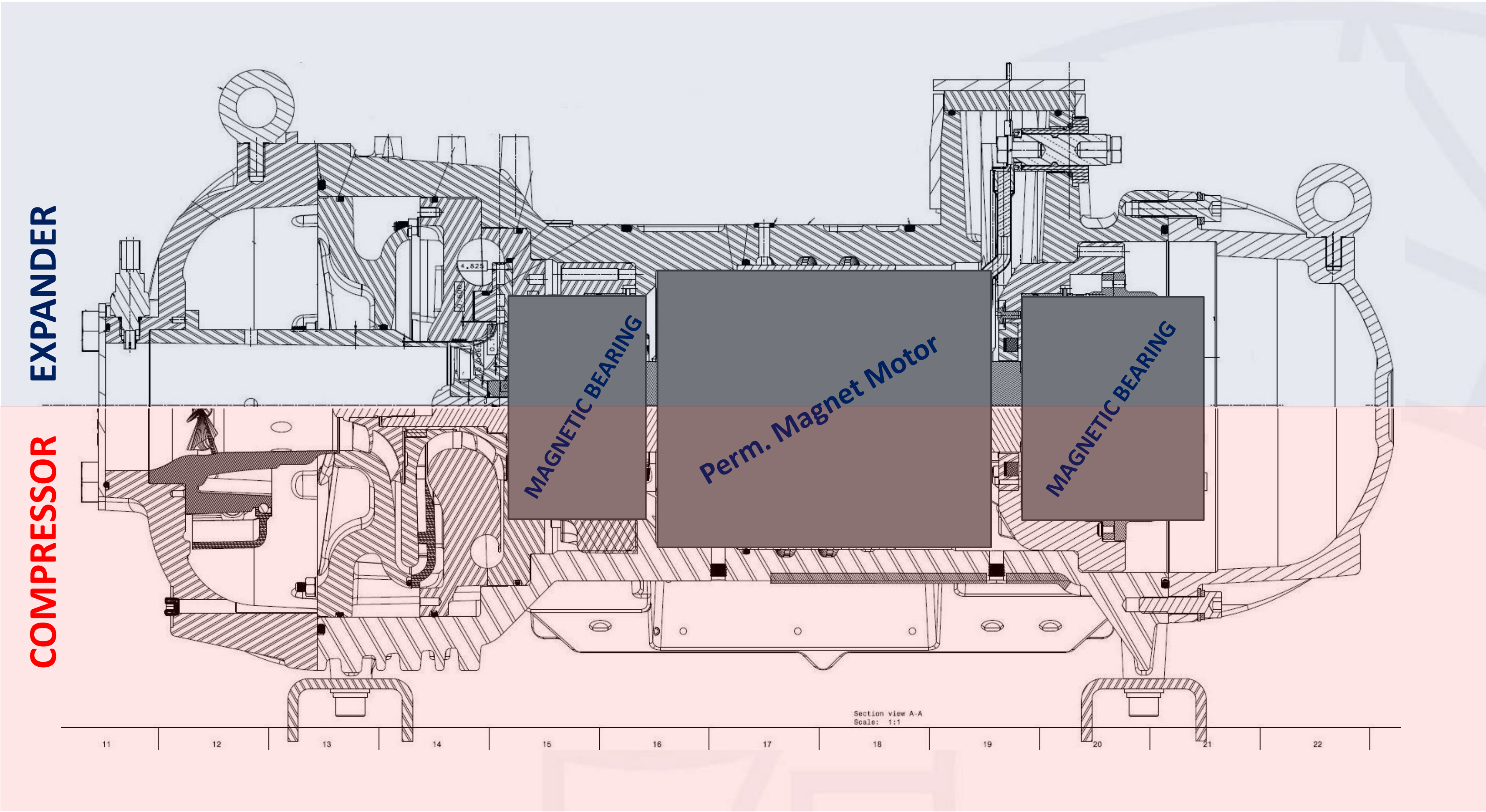
- **Outstanding energy efficiency**
- **Totally oil-free operation**
- **Extended equipment life with minimal scheduled maintenance**
  - Solid-state electronics,
  - no lubrication and no metal-to-metal contact of rotating components.
- **High Speed Operation**
- **Onboard digital controls and power electronics**
  - Enables effective monitoring, control and self-diagnosis/correction of system operation.
- **Exceptionally quiet operation**: 70dBA
- **Compact**: ½ the footprint and ¼ the weight relative to screw machines.

Magnetic Bearings

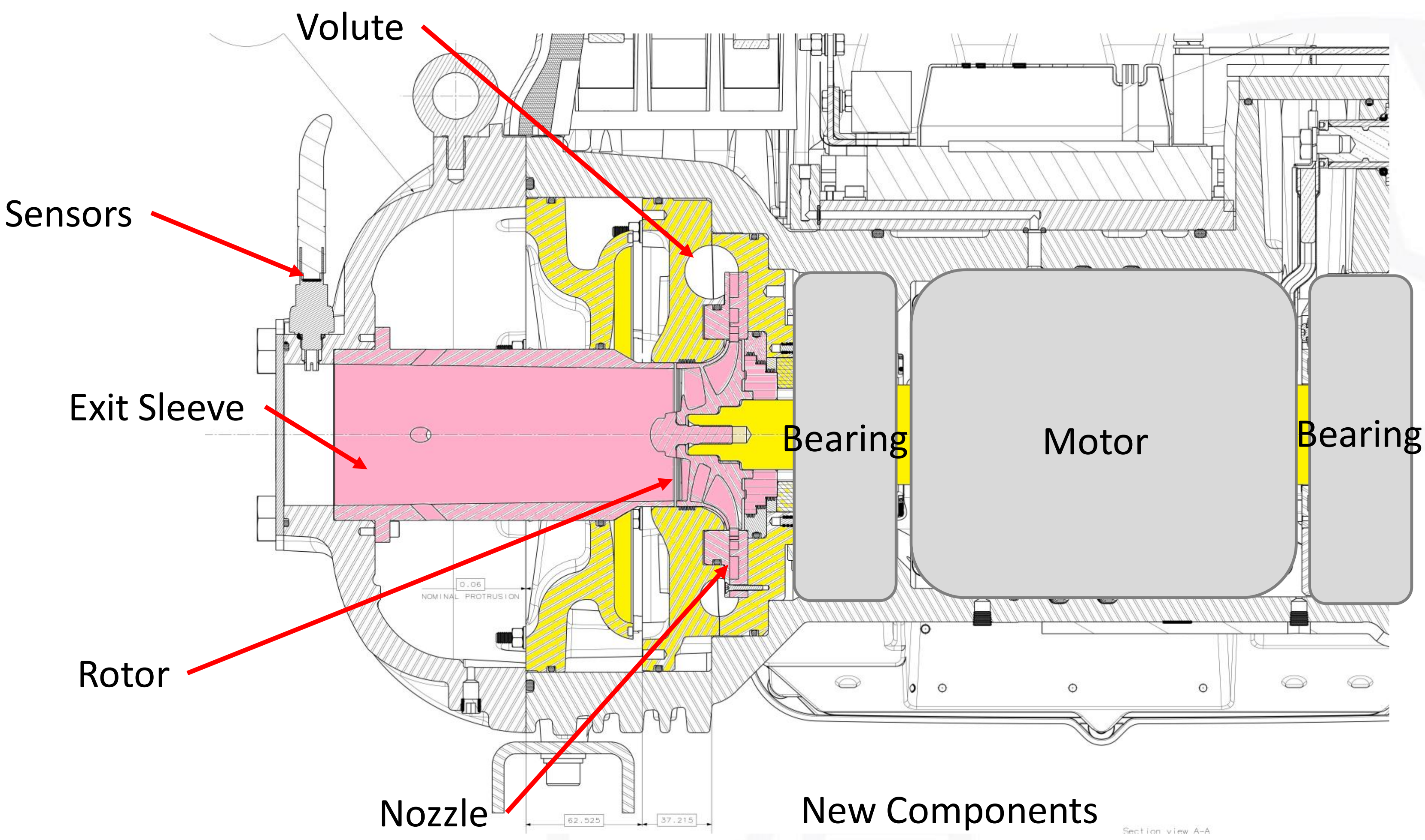
- Rotor shafts and impellers levitate during rotation and float on a magnetic cushion.
- Two radial and one axial magnetic bearing are employed.
- Bearing sensors feed back real-time orbit information to digitally controlled bearings.
- Centered rotation is instantaneously self-corrected and maintained.
- When not powered, the rotor is supported by carbon composite, touchdown bearings designed for years of use.
- Minimal losses due to non-lubricated, non-contact operation
- High speed operation means high power density.



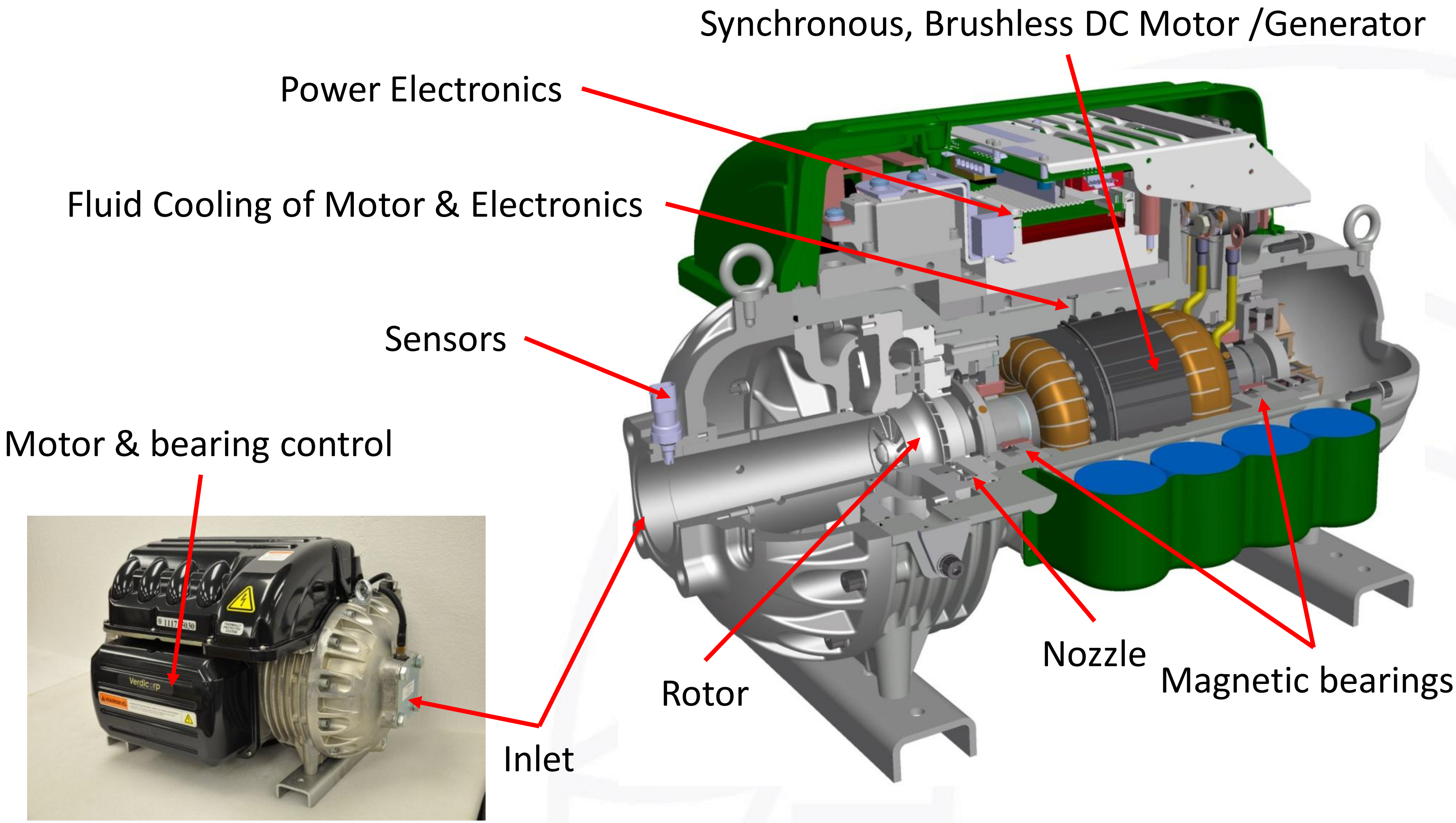
Compressor – Expander Comparison



Aerodynamic Components



Technology


Synchronous, Brushless DC Motor /Generator
Power Electronics
Fluid Cooling of Motor & Electronics
Sensors
Motor & bearing control
Inlet
Rotor
Nozzle
Magnetic bearings

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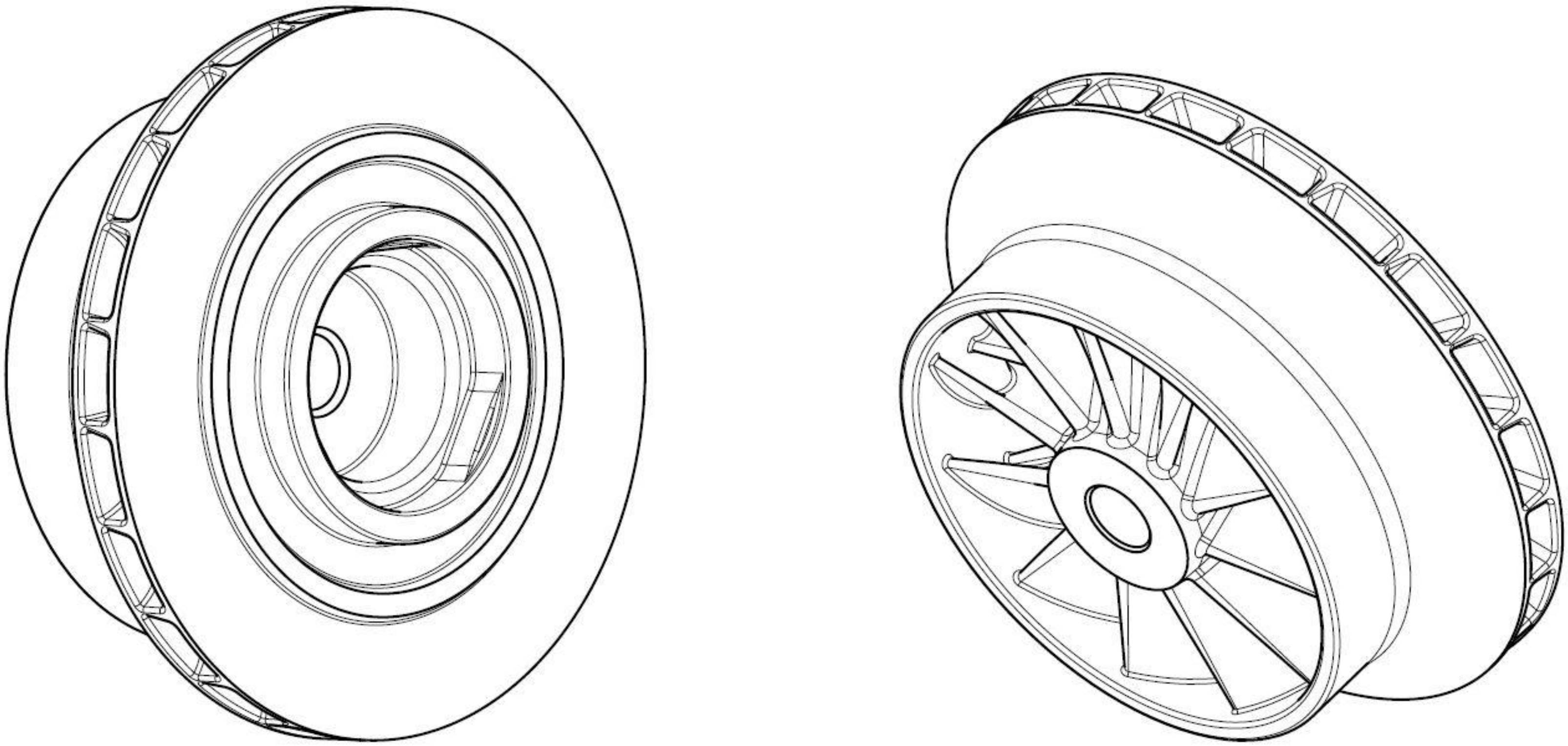
Shrouded Rotor

- Sturdy rotor design



Family of Expanders

- Nozzle – Rotor combinations for a family of Expanders
  - 30kW,
  - 45kW,
  - 60kW,
  - 75kW and
  - 90kW
- New family up to 180kW systems

Cooling System

- Hermetically sealed motor / rotor system
- The motor and power electronics are cooled internally using the working fluid
- A small part of the fluid from the condenser pump outlet is expanded to cool the motor & electronics
- Expanded vapor is re-introduced into the discharge stream

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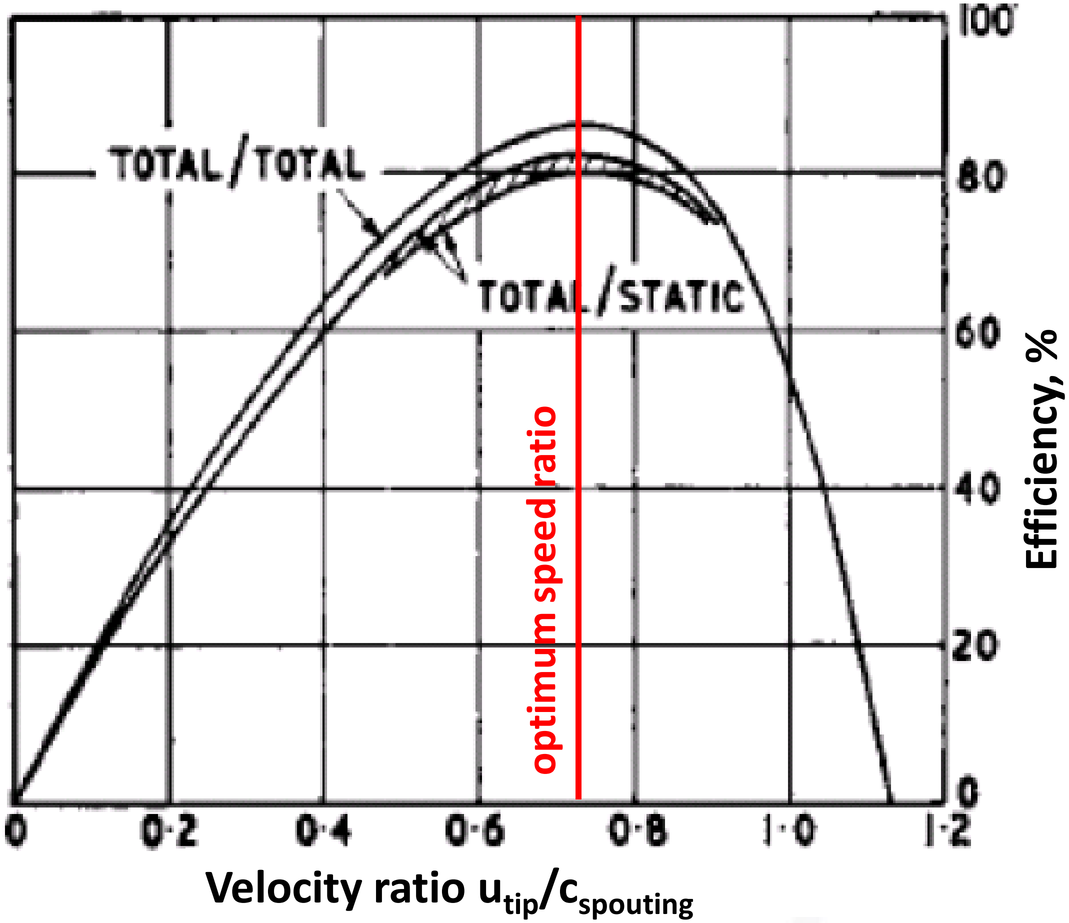
Operational Experience

- Started testing prototypes in 2009
- Alpha testing under actual operating conditions started in Q2- 2010
- Alpha testing completed Q4- 2010
- A number of field trial units are currently running at Beta sites
- Beta testing expected to be completed Q4- 2011

Turbine efficiency as a function of ratio of rotor tip speed u_{tip} over spouting velocity $c_{spouting}$

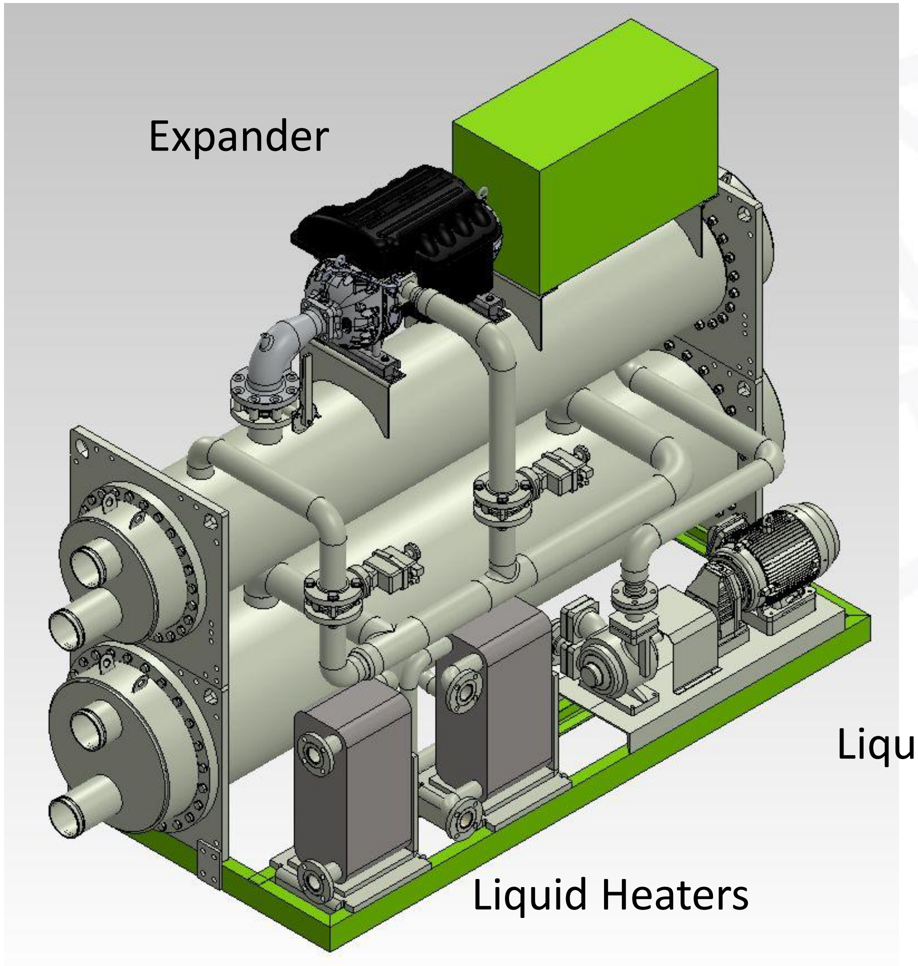


From Hiett, G. F. and Johnston, I. H. 'Experiments concerning the aerodynamic performance of inward flow radial turbines'. Proc Inst Mech Engrs (1963-64). Vol 178 pg 31 (ii)

Advantages of variable speed

- Spouting velocity changes with ambient temperature. Turbine peak efficiency is maintained at off-design conditions by changing RPM
- Permanent magnet generator / inverter combination allows grid independent operation

ORC System Overview
TE-75



Summary

- Compact, reliable ORC Turbine design
- Variable speed, high efficiency motor- generator
- Fluid-cooled, integral power & control electronics
- Oil-free, magnetic bearings for high speed and efficiency
- Backed by technology & cost-effective manufacturing proven in large volume refrigeration compressors
- Modular design for wide power ranges