DEVELOPMENT OF PREMIUM EFFICIENCY CENTRIFUGAL COMPRESSOR FOR MIDDLE EAST DISTRICT COOLING APPLICATIONS TO PROVIDE HIGH RELIABILITY / EFFICIENCY / SERVICIABILITY

24-25th October, 2017
INTERNATIONAL DISTRICT COOLING AND HEATING CONFERENCE
DOHA, QATAR
Background
Chiller operations - Compared to Standard Comfort Cooling conditions (AHRI)

1. Lower chilled water temperature to take into account thermal dispersion through distribution piping
2. Higher evaporator water delta-T to reduce water flow rate and system water pressure drops
3. Higher operating lift (due to higher wet bulb temperature)
MIDDLE EAST TYPICAL DISTRICT COOLING CONDITIONS

District Cooling plants require also chillers the ability to operate at below typical adverse conditions:

4. Low delta-T syndrome
   - Forces more chillers to operate at part loads;
   - Increase in Opex for DC provider since plant efficiency is reduced;
   - Impedes full utilization of plant installed capacity.

5. Higher Entering cooling water temperature vs design
   - In case of failure of a Cooling Tower, the header temperature of water leaving the tower will rise affecting all the chillers;
   - During summer, make-up water from utility provider can be as high as 113F / 45degC
GLOBAL ENERGY MARKET

The electric energy market price has been growing in the last years even in the Middle East region and such a growth is expected to continue in the next coming years.

District Cooling investments must look at future energy cost as well. As energy demands and costs rise, District Cooling plants for offices, industry and homes need to be increasingly efficient, reliable and sustainable.
ENVIRONMENT

Most of human activities are based on the use of equipment which impacts the Earth’s ecosystem through direct/indirect CO2 emissions.

Demand for natural resources must not overcome the Earth’s capability to regenerate.

The equipment (incl. HVAC systems) must generate the lowest possible carbon footprint, meaning the lowest amount of CO2 emissions.

Several regulations are introducing mandatory and stringent requirements on the Energy-Related-Products’ design in order to achieve challenging global targets of CO2 reduction in the next decades, as per the agreements from Global Climate Conferences - Latest MOP28 Kigali (Ruanda), October 2016 -
New 3000TR Centrifugal Compressor
NEW CENTRIFUGAL COMPRESSOR

New 3000TR Centrifugal Compressor specifically designed for District Cooling applications

SUITABILITY TO APPLICATION

Capability to provide reliable and stable operations at required District Cooling operating conditions

HIGH ENERGY EFFICIENCY

Chiller COP: 0.63kW/TR @ Zero Tolerance

- Lower running costs
- Fast return of investment
- Sustainability: Overall low carbon footprint «...from cradle to grave»
NEW CENTRIFUGAL COMPRESSOR

OVERVIEW

1° STAGE

MOTOR

MAIN SUCTION

2° STAGE

DISCHARGE

MOTOR

INTERSTAGE PIPING

MOTOR DRIVEN INLET GUIDE VANES (IGV)

MOTOR DRIVEN VARIABLE DIFFUSER (DDC)

Integral Oil tank with submerged pump to supply lubricating oil

Motor cooling by liquid refrigerant
NEW CENTRIFUGAL COMPRESSOR

FEATURES & BENEFITS

- Two stage economized cycle
- Back-To-Back Impeller
- Optimized Impeller Geometry
- Variable diffuser

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- Optimized Impeller Geometry
- Variable diffuser

- Few parts, IGV-DDC moved by electric motor, rollin bearings, oil cooling

RELIABILITY

STABILITY

EFFICIENCY & ENVI. IMPACT

SERVICEABILITY
Compressor
Design features
TWO-STAGE ECONOMIZED CYCLE

Standard cycle

Economized cycle

- Under high lift conditions the economizer allows **higher cooling capacity** (up to +10%) and **efficiency**
- Also **better reliability** and compressor durability thanks to reduced mechanical stress, as the lift is distributed on two impellers.
Impellers are mounted on same rotating shaft and oriented to same direction. The resulting axial load is supported by a thrust bearing.

**High bearing stress**

Impellers are oriented to opposite directions. Thrust load reduction by 67%

**Improved reliability**

**Lower mechanical losses**

**Longer bearing life**
OPTIMIZATION OF IMPELLER GEOMETRY

Impeller geometry has been optimized in order to **enlarge the compressor stability range (A-B curve) and also the efficiency**, thus to grant chiller operations at full and part loads even in adverse conditions.

Design items:
- Fully machined impeller with backwards blades
- Outlet blade angle
- Blades number and thickness
- Leading edge geometry

The gas flow has been simulated by **Computational Fluid Dynamics (CFD) codes** for both 1\textsuperscript{st} and 2\textsuperscript{nd} stage and prediction has been then verified with tests conducted on prototypes.
OPTIMIZATION OF IMPELLER GEOMETRY

The impeller is fully machined - surface has very low roughness: + 2% advantage in efficiency vs conventional casting.

Blades are oriented backwards in order to grant better efficiency...

V1: Impeller tip speed  V2: Radial velocity of gas  R: Resultant velocity

...indeed:
• resultant velocity and friction losses are lower.
• power needed by the impeller is lower
The larger the impeller outlet blade angle the lower the min flow at which surge occurs.

Such an angle has been increased in order to enlarge the compressor stability range vs conventional impeller.
OPTIMIZATION OF IMPELLER GEOMETRY

BLADES NUMBER AND THICKNESS

High nr of blades allows load reduction on each blade, therefore blade thickness can be reduced.

Beneficial effects on efficiency and wider stability range.

Compressor design:
• Total nr of blades has been increased by the addition of intermediate splitter blades.
• Blade thickness has been reduced.
• Length of splitter blades has been increased by inclining them upstream to better drive the gas flow between full and splitter blades.
Shape modified from arc to ellipse to improve flow pattern inside the impeller by suppressing sudden acceleration and deceleration at the edge.
DIFFUSER (VANELESS VS VANED)

Kinetic energy at impeller outlet is converted into pressure energy through the diffuser.

Vaneless diffuser has been selected since allows wider operating range and also good off-design point efficiency.

Vaneless diffuser helps also to lower sound level at diffuser.

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<thead>
<tr>
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<th>Operation Range</th>
<th>Design Point Efficiency</th>
<th>Off- Design Point Efficiency</th>
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<tbody>
<tr>
<td>Vaneless Diffuser</td>
<td>✅</td>
<td>✅</td>
<td>✅</td>
</tr>
<tr>
<td>Vaned Diffuser</td>
<td>✗</td>
<td>✅</td>
<td>✗</td>
</tr>
</tbody>
</table>
DIFFUSER (DDC = DISCHARGE DIFFUSER CONTROL)

**Conventional** fixed geometry

**Variable** Diffuser

Discharge Diffuser Control avoids surging and provides **10% efficiency increase at part loads** vs hot gas by-pass
INTERSTAGE PIPING (ECONOMIZER)

Piping shape has been designed to avoid any backflow and ensure good mix of high temperature gas from 1\textsuperscript{st} stage and low temperature gas from economizer in order to prevent any efficiency loss at 2\textsuperscript{nd} stage.
RESULTS - EFFICIENCY

Pressure level between 1\textsuperscript{st} and 2\textsuperscript{nd} stage has been set in order to enhance the economized cycle and overall chiller performance.
COMPRESSOR DESIGN - CONCLUSIONS

THE GOAL HAS BEEN ACHIEVED!

MAX STABILITY VS SURGE/CHOKE: SAFE OPERATIONS ALSO WITH HIGHER CEWT VS DESIGN

OPTIMIZED OVERALL EFFICIENCY - 0.63KW/TR @ ME CONDITIONS
From Compressor to Chiller

WCT-series, optimized for District Cooling applications

3000TR Cooling Capacity @ Middle East DC conditions
0.63kW/TR Zero Tolerance

57/41F
93/107F

WCT - Chiller overview
Stadium in Qatar

9 SCF pairs of WCT chillers /Technical Data at full load:

- Cooling capacity: 9 x 5800Tons @ Zero Tolerance
- Evaporator water: 57F / 41F
- Condenser water: 95F / 109F
- Efficiency: 0.633 kW/TR @ Zero Tolerance

<table>
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<tr>
<th>PERFORMANCE TESTS (Constant CEWT)</th>
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<tbody>
<tr>
<td>Test conditions</td>
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<tr>
<td>% Load</td>
</tr>
<tr>
<td>100</td>
</tr>
<tr>
<td>75</td>
</tr>
<tr>
<td>50</td>
</tr>
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<td>22</td>
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Future-ready (new refrigerants)

**MOP 28 – Kigali amendment**

**HFC Phase-down schedule for Bahrain, India, Iran, Iraq, Kuwait, Oman, Pakistan, Qatar, Saudi Arabia and UAE**

<table>
<thead>
<tr>
<th>Period</th>
<th>Percentage</th>
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<tr>
<td>2028 to 2031</td>
<td>100%</td>
</tr>
<tr>
<td>2032 to 2036</td>
<td>90%</td>
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<tr>
<td>2037 to 2041</td>
<td>80%</td>
</tr>
<tr>
<td>2042 to 2046</td>
<td>70%</td>
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<tr>
<td>2047 and thereafter</td>
<td>15%</td>
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- No Phase Out planned for HFCs, incl. R134a. The process requires a gradual reduction of HFCs’ consumption.
- Daikin/Daikin Chemicals is also a producer of refrigerants and is working to provide:
  - Retrofit package for existing installed R-134a WCT units
  - WCT new series, fitted with low GWP refrigerant.

![WCT series - R134a -](image)
THANK YOU