POWER REGENERATION
UPGRADING OF VAPOUR
COMPRESSION REFRIGERATION
PLANTS

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CRYOGENIC PROCESSES
PRODUCTION OF COOL METAPHOR

Work in

High Temperature

Gravity

Heat

Low Temperature

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\[ CP \approx 1\, \text{kW} \div 10\, \text{MW} \]

\[ CP = m_c \cdot F \]

\[ P_c = m_c \cdot L_c = CP \cdot L_c / F = CP / COP \]

\[ COP = F / L_c \]

\[ CP = \text{Const.} \]

\[ F' > F \quad \text{and} \quad P_c' < P_c \]

\[ m_c' < m_c \quad \text{and} \quad \text{COP}' > \text{COP} \]
Refrigeration Energy Consumption & Emissions

Electricity

<table>
<thead>
<tr>
<th>Country</th>
<th>Production (GkWh)</th>
<th>For Cool (GkWh)</th>
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</thead>
<tbody>
<tr>
<td>WORLD</td>
<td>20408</td>
<td>3061</td>
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<td>1003</td>
<td>231</td>
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</tbody>
</table>

Refrigeration Energy Consumption

Worldwide 17%
Industrialized Countries 24%
Worldwide CO2 Emissions 4.5%

+ millions of fossil fuel litres: cars, trucks, boats & ships
How to Save Power

MANY ATTEMPTS TO SAVE POWER

- BIOGRAPHY MAJOR TENTATIVE

- ADDITIONAL CONDENSATE SUBCOOLING AND PRESSURE AMPLIFICATION VIA INTERNAL PROCESSES
HOW TO SAVE POWER IN COLD ENERGY PROJECT
HOW TO SAVE POWER

- Recuperated work
- Saved work
- Regenerated cycle work
SAVE VIA POWER REGENERATION
ADDITIONAL CONDENSATE SUBCOOLING AND PRESSURE AMPLIFICATION VIA INTERNAL PROCESSES
SAVE VIA POWER REGENERATION
COLD ENERGY PROJECT TASKS

OPTIMIZATION PROCEDURE:

• CONSTRAINTS:
  - COOL POWER
    1. \( P_c = P_{csc} = \text{Const.} \);
    2. \( d\text{pm}=V_c\times\text{rpm0}=\text{Const} \)
  - WORKING FLUID (REFRIGERANT) R404a;
  - BOUNDARY QUANTITIES \( TC = +40 \, ^\circ\text{C} \) \( TE = -40 \, ^\circ\text{C} \);
  - NUMBER OF BLEEDS 1, 2, ..., EQUIPPED WITH ONE OR MORE CEG;
  - MACHINERY AND EQUIPMENT TECHNOLOGY

• VARIABLES OF THE INTERNAL POWER REGENERATION CYCLES:
  - MASS FLOW RATES;
  - BLEED PRESSURES & TEMPERATURES: (p & T);
  - TURBOMACHINERY TECHNOLOGY: SHAPES, VELOCITIES; SIZES.
SELECTION OF TURBOMACHINES SIMILITUDE CONCEPTS

SPECIFIC SPEED,

$$\omega_s = \frac{\omega \sqrt{V}}{(\Delta H_s)^{\frac{1}{4}}}$$

SPECIFIC DIAMETER

$$D_s = \frac{D(\Delta H_s)^{\frac{1}{4}}}{\sqrt{V}}$$

RELATIONSHIP AMONG THEM

$$f_{0s}(\omega_s, D_s') = 0$$

RELATED TO EFFICIENCY $$\eta'$$ BY THE SPECIFIC SPEED

$$f_s(\omega_s, \eta') = 0$$

EXPANDER $$\omega_s * D_s$$ LEADS

$$\frac{U}{C_{sp}} = \frac{\pi \cdot D \cdot n}{60 \cdot \sqrt{2 \cdot \Delta H_s}}$$

0.6 - 0.85

Rey not relevant
Mach relevant
sound speed:

- refrigerant 140-165 m/s
- air comp 340-380 m/s
- exhaust turbine 600-700 m/s

SHAFT DIAMETER RELATED TO THE TORQUE
CETT DATABASE

REFRIGERANT COMPRESSOR
krpm 40
D_C = 70 mm
DP_C = 80 kPa
Diffuser leads to use rotor exit pressure as degree of freedom for optimization purposes.

Modification of the blade height to meet the mass conservation.
TEST BENCH CONDITIONS ARE CONTROLLED BY # 6 P.I.D. REGULATORS
Compressor wheel, front and rear disks
REFRIGERATION PLANT EQUIPPED WITH RECIPROCATING COMPRESSOR TESTS

Vdm = CONST

CP [kW], Pmc [kW], krpm

PS1 [kPa]

COP

Pmc CAL  Pc CAL  Pmc NF  krpm NF
Pc NF  Pc TEST  Pmc TEST  krpm TEST
COP TEST  COP NF  COP CAL
CONCLUSIONS

Cryogenic plant power consumption can be reduced by means of direct power regeneration performed by means of internal sub-cycles including a CEG.

Saved power for optimum designed and matched systems is expected to be higher than 20% - 22% in respect to that of the Simple Cycle for condenser and evaporator temperatures equal to +40 and -40 °C.

The adoption of CETT for Compressor Expander Group has led to economic and high performance behaviour. The increasing of the pressure at the Main Compressor inlet has been demonstrated.

Moreover, some evaluations on the possibility of using the liquid refrigerant R404a as lubricant for the ball bearing cartridge have been made. Tests have been carried out and the response is positive. The adoption of hybrid ball bearings seems the most adequate for this application.
The End