Refrigeration Plant Energy Efficiency.

*How to minimize running costs!*

Dr Michael Bellstedt
Minus40 Pty Ltd
Sydney
Refrigeration in the meat industry

- Refrigeration – the largest, yet most neglected power user!
- The energy and carbon cost threats
- Synthetic refrigerants – get out now!
- Energy efficiency
  - Where is power used?
  - Importance of plant stability
  - Overview of energy savings opportunities
- Conclusions and Recommendations
- Government finance and funding
Energy
Refrigeration in meat industry

- Used everywhere....
  - Office air-conditioning
  - Boning and processing rooms
  - Carcass chillers and holding chillers
  - Freezer rooms
  - Blast chillers and freezers
  - Plate freezers (carton and offal)
- 30% to 70% of site power consumption!!!!
- Yet in many cases refrigeration plant technologies from ‘70s and ‘80s
NSW Business Electricity Prices 1995 - 2020
(2009/10 $)

Historical electricity price
Low carbon price
High carbon price

91% rise
79% rise

Year

Electricity Price (c/kWh)
## Power cost impact

<table>
<thead>
<tr>
<th></th>
<th>Small</th>
<th>Medium</th>
<th>Large</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Annual consumption</strong></td>
<td>5 GWh</td>
<td>10 GWh</td>
<td>25 GWh</td>
</tr>
<tr>
<td><strong>2011 annual cost</strong></td>
<td>$500,000</td>
<td>$1,000,000</td>
<td>$2,500,000</td>
</tr>
<tr>
<td><strong>2015 annual cost</strong></td>
<td>$750,000</td>
<td>$1,500,000</td>
<td>$3,750,000</td>
</tr>
<tr>
<td><strong>Increase</strong></td>
<td>$250,000</td>
<td>$500,000</td>
<td>$1,250,000</td>
</tr>
</tbody>
</table>

Investing in power savings is a really good idea!!!
Refrigerants overview

- **Ammonia** – high efficiency, environmentally benign, special design requirements
- **Carbon dioxide** – low temperatures, environmentally benign, special design requirements
- **Synthetics (R22, R404a, R134a)** – commonly used for small systems, often low efficiency, environmentally problematic
Choice of refrigerant and system

COP DIFFERENCES BETWEEN R717 & R404A WITH AMBIENT TEMPERATURE

Ammonia, evaporative condenser, liquid recirculated

R404a: air-cooled condenser, direct expansion

R404a systems 30-70% LESS efficient
Ammonia and synthetic refrigerants: Energy efficiency

- Ammonia systems generally exceed most synthetic refrigerant systems in fundamental cycle efficiency.
- Many system options well suited to ammonia are not feasible for synthetic refrigerant systems (e.g. flooded evaporators).
- Most ammonia systems use evaporative condensers, whilst synthetic systems generally use air-cooled condensers.
- Synthetic refrigerant systems use direct expansion (DX) for nearly all evaporators – this restricts low condensing pressures, a key energy saving technique.
- Therefore many energy efficiency options presented here are not applicable to synthetic refrigerant systems, or of limited application.
Carbon levy on synthetic refrigerants?

- As of 1 July 2012, an additional levy of $23/carbon ton will be charged on imported synthetic refrigerants.
- Synthetic refrigerants are intense global warming gases with very high Global Warming Potential (GWP).
- R404A has a GWP of 3,300 – 1kg of R404A = 3,300kgs of CO₂.
- Therefore an additional levy of $75/kg will be charged on R404A!
  - A typical small CR system with 50kg of refrigerant would attract $3,750 in levies alone when re-charged.
- This will cause a significant disincentive to use high GWP refrigerants after 1 July 2012.
## Global Warming Potentials

<table>
<thead>
<tr>
<th>Refrigerant</th>
<th>100yr GWP</th>
</tr>
</thead>
<tbody>
<tr>
<td>R717 (Ammonia)</td>
<td>0</td>
</tr>
<tr>
<td>R744 (CO$_2$)</td>
<td>1</td>
</tr>
<tr>
<td>R404a</td>
<td>3,862</td>
</tr>
<tr>
<td>R134a</td>
<td>1,410</td>
</tr>
<tr>
<td>R22</td>
<td>1,780</td>
</tr>
</tbody>
</table>

Releasing 1kg of R404a = 3,862 kgs of CO$_2$!

= emissions of 1 car driven 15-20,000km!!
### Effect of Carbon Tax on R404A

<table>
<thead>
<tr>
<th>Costs / kg</th>
<th>Tax rate / ton CO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$0</td>
</tr>
<tr>
<td>Base cost</td>
<td>$30</td>
</tr>
<tr>
<td>Carbon Tax</td>
<td>$0</td>
</tr>
<tr>
<td>Handling cost</td>
<td>$0</td>
</tr>
<tr>
<td>Nett cost</td>
<td>$30</td>
</tr>
<tr>
<td>% increase</td>
<td>0%</td>
</tr>
</tbody>
</table>
Impact on R404A plant running costs

- Typical HFC leakage 20%/annum
- 500-2,000kgs R404A typical for many sites
- Hence 100-400kgs leakage per annum
- Currently $3,000 to $12,000 annual refrigerant costs
- At $30/ton carbon tax, this will increase to $22,000 to $88,000 per annum.
- A major leak causing full refrigerant loss could cost >$400,000 in one hit!!
Ammonia

Freon
Energy Savings Opportunities
## Refrigeration energy savings opportunities

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Typical plant</th>
<th>Optimized plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable head pressure</td>
<td>12%</td>
<td>3%</td>
</tr>
<tr>
<td>Compressor control</td>
<td>15%</td>
<td>5%</td>
</tr>
<tr>
<td>Remote control optimisation</td>
<td>8%</td>
<td>5%</td>
</tr>
<tr>
<td>Heat recovery</td>
<td>2%</td>
<td>0%</td>
</tr>
<tr>
<td>Defrost management</td>
<td>2%</td>
<td>1%</td>
</tr>
<tr>
<td>Variable cold store temperatures</td>
<td>2%</td>
<td>0%</td>
</tr>
<tr>
<td>Variable evaporator fan speeds</td>
<td>2%</td>
<td>0%</td>
</tr>
<tr>
<td>Condensate sub-cooling</td>
<td>4%</td>
<td>2%</td>
</tr>
<tr>
<td>Design review</td>
<td>10%</td>
<td>2%</td>
</tr>
<tr>
<td>Maintenance review</td>
<td>2%</td>
<td>0%</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>45%</strong></td>
<td><strong>18%</strong></td>
</tr>
</tbody>
</table>
Where is the energy used?

Single stage indirect refrigeration system:
Refrigeration Plant stability – first priority

- Plant stability: stable operating conditions + smooth response to changes
- Stable operation = efficient operation.
- Instabilities caused by:
  - On/off condenser fan operation
  - Simple level control mechanism on vessels
  - Compressor cycling in response to load changes
  - Poor control strategies
- Hence achieving STABLE plant operation is generally a pre-requisite to effective reduction of energy use.
Plant stability – discharge pressures

Plant controlled by on/off condenser fan operation
Plant stability – impact on remaining plant

Discharge pressure oscillates

Suction pressure also oscillates

Compressor load state responds to pressure fluctuations
1) - Fans
Saving fan power with a VSD

- Fan power
- Air flow

- Speed control
- Staged control

Savings due to VSD

100%
Fan VSD savings

- 10kW fan motor
- Run fan 50% of the time = 5kW average use
- Run fan at 50% fan speed = 1.25kW average use
- Save 3.75 kW = $5,000/annum
- 10kW VSD costs <<$5,000!!!
Variable evaporator fan speeds

Most evaporator fans run 24/7

Alternatives:
• Fit VSDs to fans (one VSD per evaporator)
• Reduce fan speed when doors closed say >30 minutes
• Reduce fan speed at night/on weekends
• Run low speed (20%), then pulse speed to 70% to mix air
Evaporator fans on VSD

- Freezer evaporator fan motor – 1.5 kW
- Refrigeration power required to remove heat – 0.75 kW, hence 2.25 kW total
- Annual power costs for 24/7 operation: $3,000!
- Use VSD at 70% average fan speed – 0.5 kW fan power + 0.25 kW = 0.75 kW total
- Annual power costs for 24/7 operation: $1,000!
- Annual savings: $2,000 PER FAN!!
2) – Variable head pressure
Variable head pressure control

- Compressor power reduces 2-3% per 1ºC reduction in condensing temperature
- Many plants run at constant head pressure setpoint throughout the year
- At cool ambient and/or part load conditions, significant savings can be achieved by allowing head pressure to reduce
- Additional savings achievable by operating condenser fans at variable speed, rather than staging fans
Compressor + condenser fan
Summer conditions

Minimum total power
Compressor + condenser fan
Winter conditions

Minimum total power
Example: VHPC with ambient sensor (left) and VSDs on condensers (below)
3) – Compressor control
Screw compressor capacity control
Slide vs variable speed

![Graph showing the relationship between Compressor Power and Part-Load Ratio for both fixed and variable speed operations. The graph includes equations for calculating power.]

Compressor Power [kWₑ]

Part-Load Ratio

Compressor Power [kWₑ]

Part-Load Ratio

Fixed Speed

Variable Speed

Equations:

\[ kW_{\text{fixed speed}} = 16.1126 + 31.152 \cdot \text{PLR} + 52.4817 \cdot \text{PLR}^2 \]

\[ kW_{\text{variable speed}} = 45.0225 + 23.0802 \cdot \text{PLR} + 32.0556 \cdot \text{PLR}^2 \]

Courtesy: University of Wisconsin
Unloaded screw compressor

Problem: Compressor at 70% slide position!

Solution: VSDs for screw compressors
Two-compressor plant

efficient loading

Single compressor operation

Dual compressor operation

C1 @ 100%; 50Hz
C1 @ 100%; 28Hz
C1 @ 100%; 25Hz
C2 @ 75%
C2 @ 100%
C1 OFF;
C2 OFF

0-100% loading

Mode A
Mode B
Mode C
Mode D

Two-compressor plant
efficient loading
Two-compressor plant
efficient unloading

Single compressor operation

Dual compressor operation

C1 @ 100%; 50Hz
C1 @ 100%; 28Hz
C1 @ 100%; 25Hz
C2 @ 75 %
C2 @ 100 %
C1 OFF;     
C2 OFF
100-0% unloading

100-0% unloading
Slide position transducers on Hitachi (l) and Stal (below)
4) – Remote optimization
The plant control challenge

- Operating conditions vary
  - Summer/winter ambient conditions
  - Production changes
  - Seasonal production
  - Day/night/weekend operation

- Optimum operating conditions are a moving target
  - Changing plant operating conditions
  - Changing services costs and rates
  - Plant changes and improvements
Principle of remote control optimisation

- PLC contains standard site programming
- PLC serviced by local personnel
- Server turned off during service or troubleshooting work
- Energy saver algorithms on server, cannot be affected by PLC changes
- Verification easily done by comparing performance with server ON and OFF
5) – Heat recovery
Heat recovery

- Freezer room subfloor heating (<20ºC)
- Domestic Hot Water/ Hand wash (40ºC)
- Space heating (40-60ºC)
- Washdown water (55-60ºC)
- CIP, sterilisation (80-90ºC)
- Boiler feedwater (any)
## Temperature levels

<table>
<thead>
<tr>
<th></th>
<th>Freon</th>
<th>Ammonia</th>
<th>Oil cooling</th>
<th>Heat pump</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slab heating (&lt;20ºC)</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>DHW (40ºC)</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>○</td>
</tr>
<tr>
<td>Space heating (40-60ºC)</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>○</td>
</tr>
<tr>
<td>Washwater (55-65ºC)</td>
<td>○</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>CIP (80-90ºC)</td>
<td></td>
<td></td>
<td></td>
<td>●</td>
</tr>
</tbody>
</table>
Heat recovery from ammonia systems

- Three options, each with pro’s and con’s:
  - Low stage discharge
  - High stage discharge
  - Oil coolers

- More heat available from high stage discharge, but
- Heat recovery from low stage discharge REDUCES power consumption
- Analysis required to find best solution for each site
Heat recovery with high stage desuperheater
Heat recovery with low stage desuperheater
6) – Condensate subcooling
Liquid refrigerant sub-cooling

Compressor

Condenser

Evaporator

Expansion device

Sub-cool liquid HERE before expansion
Condensate sub-cooling with feedwater

Compressor

Evaporator

Expansion device

Evaporative Condenser

Mains water
Condensate sub-cooling with feedwater

**COP IMPROVEMENT DUE TO CONDENSATE SUB COOLING**

- COP IMPROVEMENT [%]
- TOWN WATER TEMPERATURE [°C]

- 20°C COND TEMP
- 25°C COND TEMP
- 30°C COND TEMP
- 35°C COND TEMP
7) – Economizer on screw compressors
Economizer on screw compressor
Economized refrigeration system

Compressors

Liquid receiver

Condenser

Accumulator

Economiser
Economizer sub-cooling - COP

Economizer effect on COP

Condensing Temperature: $T_c[\degree C]$ vs. COP increase

- $T_s=-25\degree C$
- $T_s=-20\degree C$
- $T_s=-15\degree C$
- $T_s=-10\degree C$
- $T_s=-5\degree C$
Economizer sub-cooling - kWR

Economizer effect on Capacity

Condensing Temperature: Tc[℃]

Capacity increase

- Ts=-25°C
- Ts=-20°C
- Ts=-15°C
- Ts=-10°C
- Ts=-5°C
8) – Suction splitting
Suction splitting

- Split suction lines to run higher temperature loads at higher suction pressure
  - Eg. Blast freezers and holding freezers
  - Eg. Chiller rooms and processing rooms
EFFECT OF SUCTION TEMPERATURE ON COP OF A 2 STAGE PLANT

10 °C increase in suction temperature = 18% compressor energy saving
EFFECT OF SUCTION TEMPERATURE ON COP OF A SINGLE STAGE PLANT

5 °C increase in suction temperature = 18% compressor energy saving
9) – remove liquid injection oil cooling
Liquid injection oil cooling on screw compressors

**Problem:** LI oil cooling reduces efficiency

**Solution:** Water cooled oil cooling
Liquid injection oil cooling

Liquid Injection vs. water cooled oil cooling

% of increase

Suction Temperature: $T_s[^\circ C]$

COP  Capacity
10) – defrost relief
Defrost relief
- into suction line
Defrost relief

- into intercooler
Effect of defrost on low stage compressor

Compressor loaded to 100% during the 7 PM defrost cycle

Compressor loaded to 75% during the 10 PM defrost cycle
11) – non-condensable control
Auto air purging well done

- Condenser with purge pots and individual purge lines
Air purging

Old gas purgers

Manual gas purging

Solution: Autopurgers
12) – water removal
Water accumulation

- Water enters with air, but accumulates in the system
- Accumulates on the low temperature side, generally in accumulator/surge vessels
- Reduces suction pressure required to achieve setpoint evaporation temperature
- Some devices (ice cream churns) act to remove water.
- Otherwise water purger required.
Effect of water on energy efficiency
13) – oil feed rate optimisation
Oil regulation valve on screw compressor
Oil feed to screw compressors

- Industrial screw compressors require an oil feed into the compression space to seal the clearances and ensure compression.
- Insufficient oil flow – poor efficiency
- Excessive oil flow – can cause overcompression or even hydraulic locking
- Generally compressor discharge temperature used to adjust oil flow rates
- Incorrect adjustment can cause significant inefficiencies
Oil feed to screw compressors

![Graph showing the relationship between oil feed rate, COP, oil temperature, and compressor failure.](image)
Oil feed to screw compressors
- some concerns

- Different optimum flow for low- and high-stage operation
  - Same size compressor, different oil flow rates
- Different flow rates depending on compressor speed
  - Risk of hydraulic lock at low compressor speeds
  - Variable oil feed required / proportional control
- Oil flow should be adjusted on swing compressor
  - Switchover arrangement on oil feed needed
  - Two reg valves at different flow settings
- Oil flow may depend on condensing pressure
  - Variable head pressure control may require variable oil flow
14) – “bottleneck” removal
Typical “Bottlenecks”

- Undersized suction/discharge lines, or unnecessary line obstructions
  - Reduces suction, increases discharge pressure at compressor
- Undersized evaporators/condensers
  - Decreases suction, increases condensing temp
- Direct expansion evaporators
  - Limits variable head pressure control options
- Excessively long wet/dry suction lines
  - Reduces suction pressure at compressor
- Poorly designed wet suction risers
  - Reduces suction pressure at compressor
- Redundant suction regulation valves
  - Reduces suction pressure at compressor
Example: Poor suction line installation

Two stop lines in series!!

Redundant valve not removed from suction line
Bottlenecks in discharge lines

Line reductions fitted to existing discharge line:
Excessive gas velocities

Redundant valves not removed from discharge line
Reducing discharge line pressure drops

**EFFECT OF DISCHARGE LINE PRESSURE DROP ON COP OF A REFRIGERATION PLANT**

- **INCREASE IN COP [%]**
  - 0%
  - 2%
  - 4%
  - 6%
  - 8%
  - 10%
  - 12%
  - 14%
  - 16%
  - 18%

- **REDUCTION IN DISCHARGE LINE PRESSURE DROP [kPa]**
  - 0
  - 50
  - 100
  - 200

- **TEMPERATURE CONDITIONS**
  - 25°C COND TEMP
  - 30°C COND TEMP
  - 35°C COND TEMP
Conclusions and Recommendations

• Analyse your plant for energy savings opportunities – there are many!
• Opportunities not feasible a few years ago are now viable due to higher power costs
• Many opportunities are available at relatively minor cost, or require controls upgrade only
• Implement viable opportunities NOW
• Convert Freon systems to ammonia plant
• Apply for government money – there is a lot going around!
Government Finance and Funding

- NSW Energy Saver Program
- NSW Energy Saving Scheme
- Low Carbon Australia
- Clean Technology Investment Program
- Government funding scenario for Example Abattoir
NSW Energy Saver Program

- 70% subsidy for Energy Audit
- 30 hours engineering support for implementation
- $20,000 discretionary Early Adopter Funding for projects >$100,000

Limitations:
- NSW sites only
- Not applicable to EEO companies
- Suitable for sites spending $60K+ p.a. on electricity
NSW Energy Saving Scheme

- Energy Savings Certificates [ESCs] created for energy savings projects.
- ESCs can be traded for CASH
- Typical $500k Energy Efficiency project can attract ESCs worth $10,000 to $30,000

Limitations:
- NSW only, all sites
Low Carbon Australia

• Low Interest Finance for Energy Savings projects
• Operational Leases
• Financial Leases
• On-power-bill financing
• Direct loans up to 50%

Limitations:
• All sites in Australia
• Not applicable to greenfield sites
• Must satisfy carbon reduction criteria
Clean Technology Investment Program

- 33% or 50% of capital cost of Energy Efficiency project as GRANT (Grants < $10M)

Site gets:
- 50%, if company turnover <$100M and requested funding <$500,000
- 33%, for all other grants up to $10M

Limitations
- All sites in Australia
- Manufacturing industry only, esp food (= all meat works)
- Must satisfy carbon reduction criteria
Government funding scenario for Example abattoir

- Total project cost for Energy Efficiency projects on site: $250,000
- Energy savings estimated at $93,000 power per annum, 2.7 year simple payback.
- Further engineering costs are applied to fully scope the project and accurately estimate the savings, say $30,000
- Example applies for a low interest loan from Low Carbon Australia (up to 50%), repayable over 5 years
- Example obtains a capital grant from the Clean Technology Investment Program
- Example expends another $15,000 on application fees and compliance costs
Government funding scenario for Example abattoir

<table>
<thead>
<tr>
<th>Cost item</th>
<th>With support</th>
<th>Without support</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project capital cost</td>
<td>$250,000</td>
<td>$250,000</td>
</tr>
<tr>
<td>Plus prior engineering</td>
<td>$30,000</td>
<td>$30,000</td>
</tr>
<tr>
<td>Application and compliance costs</td>
<td>$15,000</td>
<td>$0</td>
</tr>
<tr>
<td>Less LCA finance</td>
<td>($147,500)</td>
<td>$0</td>
</tr>
<tr>
<td>Less CTIP grant</td>
<td>($147,500)</td>
<td>$0</td>
</tr>
<tr>
<td>Nett project cost (Capex)</td>
<td>$0</td>
<td>$280,000</td>
</tr>
<tr>
<td>Annual power cost saving</td>
<td>$93,000</td>
<td>$93,000</td>
</tr>
<tr>
<td>Less annual LCA repayment</td>
<td>($17,000)</td>
<td>$0</td>
</tr>
<tr>
<td>Nett annual saving</td>
<td>$76,000</td>
<td>$93,000</td>
</tr>
<tr>
<td>Simple payback on Capex</td>
<td>0</td>
<td>3.01</td>
</tr>
</tbody>
</table>
Any Questions???