AM-cover®

The new system for magnesium melt protection

developing technologies for the future
The Search for Alternatives to SF$_6$ (1)

- **Key drivers**: environmental, & cost pressures
- **Fluorine**: identified as the key chemical component of SF$_6$
- **Search**: other fluorine-bearing gases as SF$_6$ alternatives?
- **Alternative Gases**:
  - CFC (Chlorofluorocarbon)
  - HCFC (Hydrochlorofluorocarbon)
  - HFC (Hydrofluorocarbon)
  - PFC (Perfluorocarbon)
  - Inorganic Fluorides (e.g. BF$_3$, SiF$_4$)
The Search for Alternatives to $\text{SF}_6$ (2)

- CFCs rejected due to Ozone Depleting Potentials (ODP)
- HCFCs rejected due to the advanced stage of production phase-out (Montreal Protocol)
- PFCs rejected due to high Global Warming Potential (GWP)
- Inorganic Fluorides toxic and expensive
- HFCs have no ODP and some have low GWPs
The Search for Alternatives to SF$_6$ (3)

- Selected HFC-134a for further study:
  - Cost competitive (~ 1/3 to 1/2 the cost of SF$_6$)
  - Low GWP (1320 compared to 22450 for SF$_6$)
  - Readily available
  - Non-toxic

Chemical Name: 1,1,1,2-tetrafluoroethane

Chemical Formula: CF$_3$CH$_2$F

HFC-134a mixed with carrier gas is AM-cover™
AM-cover®
The Basics of this Protective Atmosphere

► Volume concentrations of active agent HFC-134a in carrier gas are similar to the range used for SF$_6$
  – Volume % HFC-134a ~ 0.05% to 0.5%

► Recommended carrier gas
  – **Nitrogen**
    • Bulk
    • N$_2$ generator (membrane removes H$_2$O and most of the O$_2$ from air)
  – **CO$_2$**
    • Significant improvement in effectiveness of reactive agent (lower % required @constant temp)
    • Significant increase in effective temperature of protective atmosphere
    • Even with (CO$_2$ GWP of 1) total GHE reduction by using alternative to SF$_6$ > 95%
  – **Dry air**
    • Not Recommended
      – If not “dry” higher levels of HF have been experienced
    • Dew point < -40 deg
Melt Protection: AM-cover Compared to SF$_6$
(Baseline from Commercial Scale Trials for IMA SF$_6$ Alternatives Study)

► Commercial Scale Trials
  – Furnace – 500 kg “bath tub”, 0.5 m$^2$ surface area
  – Reagent Concentration – 0.05% (500ppm)
  – Alloy – AM50
  – Temperatures – 680 deg C and 710 deg C
  – Flow Rates for Atmosphere – 2.5, 5, 10, & 20 l/min
  – Tightly Sealed Furnace Cover
  – Good Distribution via Perimeter Ring
Minimum Supply of Protective Atmosphere Required

**SF₆ - .05% (500ppm)**
CO₂ + 5% Air AM50 @ 680 °C
10 l/min

**HFC134a – .05% (500ppm)**
CO₂ + 5% Air AM50 @ 680 °C
5 l/min

Acceptable!
Minimum Supply of Protective Atmosphere Required

**SF₆** -
CO₂ + 5% Air AM50 @ 680 °C
5 l/min

**HFC134a** –
CO₂ + 5% Air AM50 @ 680 °C
2.5 l/min

Not Acceptable!
Melt Protection: AM-cover Compared to SF$_6$
(Baseline from Commercial Scale Trials for IMA SF$_6$ Alternatives Study)

- Gas Flow Required for AM50B Protection

<table>
<thead>
<tr>
<th>Active Agent, Temp, and Carrier Gas Flow (l/min)</th>
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<tr>
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<tr>
<td>Temp (°C)</td>
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<tr>
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<tr>
<td>680</td>
</tr>
<tr>
<td>710</td>
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</table>
Melt protection with AM-cover®

- Provides excellent protection in molten magnesium operations
- Simple gas delivery system but needs to be tailored to each application
  - Same delivery principle as SF₆
- Once the surface film is formed, it is very stable

Pure magnesium protected with AM-cover
Delivery System for AM-cover®

► Relatively Simple Delivery System

- Same principles used for SF$_6$
- Flow of HFC-134a and carrier gas from sources controlled via rotameter, mass flow controller, etc.
  - Lower cylinder pressure of HFC-134a vs. SF$_6$ must be considered
    - Is volume output of balanced system adequate?
  - Easy to customize system for size considerations, automation, safety back-up
- Basic SF$_6$ systems can sometimes be converted by recalibration of or changing flow / pressure controller for active agent
- No additional safety precautions for storage & placement other than those already in place for SF$_6$
Distribution Over Melt is Important with AM-cover®

Protection Area is Smaller with AM-cover®

- Lower thermal stability
- Lower density
- AM-cover may require improved distribution system
“Memory-Effect”

Melts protected with AM-cover & SF₆

Cover gas protection removed

AM-cover surface remains protected

- Reduced dross during furnace tending
- Reduced burning of Mg adhering to tools & equipment removed from melt
- Reduced burning of dross when removed increases its value
HPDC with AM-cover®
Commercial trial results for European 1350 tonne cold chamber with 2 tonne melt/dosing furnace

- Carrier gas with both SF$_6$ & HFC-134a was Nitrogen
- With cover gas optimized the daily cost of gas reduced by 40% with AM-cover compared to SF$_6$
  - Lower concentration plus lower cost
- Dross reduced by 50%
- Significant reduction in smoke generation
HPDC with AM-cover®

Commercial trial results for European 1350 tonne cold chamber with 2 tonne melt/dosing furnace

GHG Emissions with Optimised AM-cover and SF₆

- 1.72 kg / day SF₆ to produce 4 tonnes castings
  - Using SF₆ GWP = 22200, daily GHG = 38.2 tonne CO₂
- 0.65 kg / day HFC-134a to produce 4 tonnes castings
  - Using HFC-134a GWP = 1600, daily GHG = 1.1 tonne CO₂
- Reduction in Greenhouse Gas Emissions = 97%
  - Assumes degradation = 0%
Ingot Casting with AM-cover®

► Surface Appearance is Critical Quality Issue
  – Brightness
  – Discoloration
  – Burn Marks, Oxidation

► Ingot Conveyors
  – Area Requiring Protection is Large
  – Tight Enclosure is Hard to Achieve
    • Systems Tend to be More Open than Furnace Enclosures
    • Volume Flows of Atmosphere Tend to be High
Ingot Casting with AM-cover®
Production Scale Experience at Company A

► Conditions
- Alloys: AM50A, AZ91D
- Melt Temperature: 690° C
- Carrier Gas: CO₂
- Flow Rate of Atmosphere: Same as with CO₂ / SF₆
- Distribution System: Multiple Outlets / Good Coverage of Solidifying Surfaces

► Results
- Surface Quality: Equal or Better than with CO₂ / SF₆
- % HFC-134a Required for Equal Surface Quality = ½ of % SF₆
- Corrosion of Conveyor No More Severe than with SF₆
  • Measured via Mild Steel Test Plates
- HF Levels in Working Environment Well Below TLV
Ingot Casting with AM-cover®
Production Scale Experience at Company A

► Relative Cost Comparison (Normalized)

<table>
<thead>
<tr>
<th></th>
<th>CO(_2) / SF(_6)</th>
<th>CO(_2) / HFC-134a</th>
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<tbody>
<tr>
<td>Flow Rate</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Concentration</td>
<td>1</td>
<td>0.55 to 0.78</td>
</tr>
<tr>
<td>Cost</td>
<td>1</td>
<td>0.36 to 0.43</td>
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► Relative GHG Emissions (Normalized)

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<td>1</td>
<td>0.02</td>
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Ingot Casting with AM-cover®
Production Scale Experience at Company B

► Conditions
  – Alloy: AZ91D
  – Melt Temperature: 665° C
  – Carrier Gas: 50% Dry Air : 50% CO₂
  – Flow Rate of Atmosphere: Same as with CO₂ : Air / SF₆
  – Distribution System: Multiple Outlets / Good Coverage of Solidifying Surfaces

► Results
  – Surface Quality Equal or Better than with CO₂ : Air / SF₆
  – Equal Results on Surface Quality were Obtained with Reduced HFC-134a concentration
    • SF₆ = 1.2%
    • HFC-134a = 0.5%
## Ingot Casting with AM-cover®

### Production Scale Experience at Company B

- **Relative Cost Comparison (Normalized)**

<table>
<thead>
<tr>
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<th>CO₂ : Air / SF₆</th>
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<tr>
<td>Flow Rate</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Concentration (Agent)</td>
<td>1</td>
<td>0.42</td>
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<tr>
<td>Cost</td>
<td>1</td>
<td>0.21</td>
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- **Relative GHG Emissions (Normalized)**

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Commercial use of AM-cover®

► Following successful commercial testing of AM-cover, a number of companies have converted their existing SF$_6$ cover gas system to AM-cover:
  • two USA diecasters
  • two European diecasters
  • one European recycler

► Evaluation trials have been completed with:
  • two USA diecasters
  • six European diecasters
  • two Asian diecasters
  • one European & one North American recycler
Environmental Issues

- GWP of AM-cover is \textit{17 times less} than SF$_6$ (1320 vs. 22450)
- Atmospheric lifetime of AM-cover is \textit{228 times less} than SF$_6$ (14 years compared to 3200 years for SF$_6$)
- Replacing 1kg of SF$_6$ with 1kg of AM-cover reduces the Greenhouse Gas emissions by 93% (CO$_2$-equivalent)
- Further reductions in Greenhouse Gas emissions can be achieved with optimisation of AM-cover to the customer’s system
- Recent trials conducted by US EPA confirm that replacing SF$_6$ with AM-cover reduces Greenhouse Gas emissions by >99% (CO$_2$-equivalent)
Health and Safety Issues

- HFC-134a and SF$_6$ decompose to produce HF
- HF release extensively studied by AMT/CAST in laboratory and plant trials
- Negligible HF in surrounding working environment with an optimised AM-cover system
- When crucible door is opened, slight HF spike occurs above TLV
- HF level quickly falls below TLV via dilution by air
Commercial Issues

- CAST has granted AMT exclusive rights to sub-license AM-cover for all molten magnesium processing
- Customers must sign a commercial license before using AM-cover
- Comprehensive commercial documentation package delivered to customer upon signing the license
- Licensees pay a royalty based on production, consumption of HFC-134a, other considerations
- Royalties returned to CAST to fund further research
- AMT Marketing staff following a set protocol for implementation of AM-cover
Other applications tested

- Squeeze casting
- Investment casting
- Ingot casting
- Sand casting
Conclusion

► AM-cover is a viable replacement for SF$_6$

✓ Cost effective
✓ Superior melt protection
✓ Applicable to a wide range of processes
✓ Significant reduction in Greenhouse Gas emissions
✓ Correct implementation can ensure safe use
✓ Potential for significant revenue from Carbon Credits
www.am-technologies.com.au