Thermal Vacuum Power from the Sun

China Solar Cooling Week, Shanghai, 27th of March 2015

High-Vacuum Flat Solar Thermal Panels for:

- air-conditioning
- industrial process heat
Thermal Vacuum Power Charged™ Products

TVP solar thermal panels take full advantage of high-vacuum insulation in a planar layout, achieving high efficiencies up to 200°C without concentration.

Thermal Vacuum Power Charged™ panels capture both direct and diffuse light maximizing the amount of sun energy converted to thermal. Energy output is increased by at least 30%.

TVP Solar owns 11 patents protecting breakthrough core technology, products and manufacturing.
Solar KeyMark Certified Best Performance

Highest efficiency up to 200°C in any light condition thanks to high-vacuum insulation

Traditional flat plate fiberglass insulation

TVP Solar flat panels high-vacuum insulation
Main Differentiating Factor: Diffuse, Polluted Light Capture

Clouds, humidity, dust, pollution, and sand contribute heavily to diffuse light

- Thermal Vacuum Power Charged™ panels capture both direct and diffuse light.
- Even in high irradiance locations, diffuse light represents a significant portion of annual solar energy input due to clouds and pollution.
- Increasing the efficiency of a solar collector by concentration reduces diffuse light capturing by the inverse of the concentrating factor due to optical laws.
- Diffuse light also plays a significant role at dawn and at dusk, due to low-angle light scattering, impacting solar field energy production.

Source: METEONORM
Zero Maintenance: No Significant Effect By Dust & Dirt

Uniquely proven in-field with measured results published at IEA SHC Task Meetings

TVP panels do not require precision cleaning due to both direct and diffuse light capture, making them key to supplying solar thermal in hazy, dusty, polluted, humid climates.

TVP panels use inexpensive, standard stationary support structures which do not require any maintenance, otherwise mandatory for concentrator tracking systems.
Solar Assisted Air Conditioning: Both 2E & 1E VAM

Driving standard absorption chillers (recommended hybrid configuration for 24/7)

Solar thermal energy feeds an absorption chiller instigating thermodynamic condensation process, then supplying a secondary circuit of cold water into a building.

Solar energy covers peak load and most daylight cooling needs; hybridizing with an auxiliary burner using traditional combustible (natural gas, bio-diesel, etc) for 24/7 smooth operations.

- TVP panels have the highest sun-to-cool peak efficiency: up to 78% @ 180°C (2E VAM), up to 50% @ 95°C (1E VAM).
- Optionally providing year-round dual savings: cooling in summer, heating in winter (with sanitary hot water for free).
- Compact stationary solar field with minimum footprint, adaptable to any rooftop.
### Energetics: Consistent and Predictable

MT-Power energy production & thermal efficiency depend on irradiance

<table>
<thead>
<tr>
<th>Global Horizontal Irradiance (GHI)</th>
<th>60</th>
<th>95</th>
<th>110</th>
<th>120</th>
<th>130</th>
<th>140</th>
<th>150</th>
<th>165</th>
<th>180</th>
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<tbody>
<tr>
<td>2,217 kWh/m²/year</td>
<td>1,727</td>
<td>1,528</td>
<td>1,427</td>
<td>1,355</td>
<td>1,279</td>
<td>1,200</td>
<td>1,118</td>
<td>1,034</td>
<td>861</td>
<td>773</td>
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<tr>
<td>2,117 kWh/m²/year</td>
<td>1,702</td>
<td>1,502</td>
<td>1,401</td>
<td>1,330</td>
<td>1,255</td>
<td>1,179</td>
<td>1,099</td>
<td>977</td>
<td>852</td>
<td>768</td>
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<tr>
<td>1,988 kWh/m²/year</td>
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<td>1,363</td>
<td>1,266</td>
<td>1,297</td>
<td>1,125</td>
<td>1,050</td>
<td>974</td>
<td>857</td>
<td>738</td>
<td>659</td>
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<tr>
<td>1,957 kWh/m²/year</td>
<td>1,528</td>
<td>1,333</td>
<td>1,234</td>
<td>1,163</td>
<td>1,090</td>
<td>1,013</td>
<td>935</td>
<td>814</td>
<td>691</td>
<td>609</td>
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<tr>
<td>1,839 kWh/m²/year</td>
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<td>1,200</td>
<td>1,104</td>
<td>1,034</td>
<td>966</td>
<td>895</td>
<td>822</td>
<td>712</td>
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<tr>
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<td>1,184</td>
<td>1,086</td>
<td>1,017</td>
<td>947</td>
<td>875</td>
<td>802</td>
<td>692</td>
<td>583</td>
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<td>1,638 kWh/m²/year</td>
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<td>1,081</td>
<td>983</td>
<td>916</td>
<td>847</td>
<td>776</td>
<td>706</td>
<td>600</td>
<td>496</td>
<td>428</td>
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<tr>
<td>1,529 kWh/m²/year</td>
<td>1,187</td>
<td>992</td>
<td>900</td>
<td>836</td>
<td>772</td>
<td>706</td>
<td>641</td>
<td>544</td>
<td>449</td>
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<tr>
<td>1,444 kWh/m²/year</td>
<td>1,128</td>
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<td>839</td>
<td>775</td>
<td>710</td>
<td>644</td>
<td>579</td>
<td>484</td>
<td>393</td>
<td>335</td>
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<tr>
<td>1,325 kWh/m²/year</td>
<td>1,018</td>
<td>831</td>
<td>745</td>
<td>686</td>
<td>627</td>
<td>569</td>
<td>511</td>
<td>427</td>
<td>347</td>
<td>296</td>
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<tr>
<td>1,208 kWh/m²/year</td>
<td>884</td>
<td>706</td>
<td>627</td>
<td>573</td>
<td>520</td>
<td>468</td>
<td>417</td>
<td>343</td>
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<tr>
<td>1,112 kWh/m²/ann</td>
<td>811</td>
<td>637</td>
<td>559</td>
<td>508</td>
<td>457</td>
<td>407</td>
<td>359</td>
<td>290</td>
<td>228</td>
<td>190</td>
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</tbody>
</table>
Masdar City, Abu Dhabi, UAE: TVP Supplies up to 180°C
Case study 1: Solar Air Conditioning with double stage absorption chiller

### Masdar City, Abu Dhabi, UAE: Case Study Results

- Panels remained uncleaned throughout measurement year 2014
- Masdar SAC field by TVP has been in continuous operation since February 2012

<table>
<thead>
<tr>
<th>Operating Year: 2014</th>
<th>Input Energy on Collector Plane (kWh/m²/day)</th>
<th>Solar Field Average Daily Energy Produced (kWh/m²/day)</th>
<th>Solar Field System Efficiency</th>
<th>Solar Field Average Daily Energy Produced (kWh/day)</th>
</tr>
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<tbody>
<tr>
<td>January</td>
<td>4.89</td>
<td>2.09</td>
<td>43%</td>
<td>87.88</td>
</tr>
<tr>
<td>February</td>
<td>5.45</td>
<td>2.24</td>
<td>41%</td>
<td>94.02</td>
</tr>
<tr>
<td>March</td>
<td>5.52</td>
<td>2.28</td>
<td>41%</td>
<td>95.58</td>
</tr>
<tr>
<td>April</td>
<td>5.73</td>
<td>2.44</td>
<td>43%</td>
<td>102.34</td>
</tr>
<tr>
<td>May</td>
<td>4.74</td>
<td>1.74</td>
<td>37%</td>
<td>72.98</td>
</tr>
<tr>
<td>June</td>
<td>4.46</td>
<td>1.73</td>
<td>39%</td>
<td>72.58</td>
</tr>
<tr>
<td>July</td>
<td>4.68</td>
<td>1.84</td>
<td>39%</td>
<td>77.26</td>
</tr>
<tr>
<td>August</td>
<td>4.97</td>
<td>2.22</td>
<td>45%</td>
<td>93.19</td>
</tr>
<tr>
<td>September</td>
<td>5.52</td>
<td>2.48</td>
<td>45%</td>
<td>104.02</td>
</tr>
<tr>
<td>October</td>
<td>5.70</td>
<td>2.20</td>
<td>39%</td>
<td>92.59</td>
</tr>
<tr>
<td>November</td>
<td>4.87</td>
<td>2.07</td>
<td>42%</td>
<td>86.78</td>
</tr>
<tr>
<td>December</td>
<td>4.81</td>
<td>2.03</td>
<td>42%</td>
<td>85.29</td>
</tr>
<tr>
<td><strong>Month Average</strong></td>
<td><strong>5.11</strong></td>
<td><strong>2.11</strong></td>
<td><strong>41%</strong></td>
<td><strong>88.71</strong></td>
</tr>
<tr>
<td><strong>Year Total</strong></td>
<td><strong>1,865.56</strong></td>
<td><strong>770.92</strong></td>
<td><strong>41%</strong></td>
<td><strong>32,378.63</strong></td>
</tr>
</tbody>
</table>
Aramco, Dhahran, KSA: TVP Supplies up to 180°C
Aramco, Dhahran, KSA: Case Study Preliminary Results

Case study 2: Solar Air Conditioning with double stage absorption chiller

- Panels have not been cleaned since commissioning
- Commissioned Oct 2014
TVP Solar: New Developments for MT-Power

New release 4.3 for volume production introduced in Q4 2014

Improvements of new MT-Power 4.3 vs 3.22 currently installed in Aramco

- Doubled the panel size: 2m² vs 1m²
- Reduced weight: 25kg/m² vs 42kg/m² (-40%)
- New absorber design: 2 parallel flows (implementing patented return flow under high-vacuum) vs meander pipe
- New manufacturing of parts: molded vs laser cut
TVP Solar New Solar Field Layout: Embedded Return Piping (i)
### Simplified solar field balance of system

#### v.3.22 @ Masdar

#### New v. 4.3

### Benefits of new MT-Power 4.3:

- No external piping on panel strings and lower solar field balance of system cost
- Easier, quicker and cheaper installation
- Lower maintenance cost
- Higher system performance due to better insulation of return pipe via high-vacuum
TVP Solar New Solar Field Layout: Embedded Return Piping (iii)
Conclusions & Take-Aways

Conclusions

• Solar Cooling WORKS!!

• Solar energy by TVP consistently operates absorption chillers with predictable savings
  • in high-irradiance countries, 2E VAM can be driven up to 180°C
  • in low-irradiance countries, 1E VAM can be driven up to 95°C

• SAC by TVP operates in harsh environments (dirt, dust, pollution), without precision cleaning

• Implementing the patented return flow under high vacuum makes the solar field easy to install and maintain, even when using pressurized fluids (up to 14 bar)

Key Take-Aways

• Designed to operate at high temperature (up to 200°C) without concentrating mirrors

• Certified best performance up to 200°C

• It can work in China, ready to demonstrate it!
Effect of Dust Accumulation

Array Performance

- Daily Input Energy (kWh/m²)
- Relative Loss
- Linear (Relative Loss)

\[ y = -0.008x - 0.0046 \]
Case study 4: direct comparison with Compact Parabolic Trough and Compact Linear Fresnel

**Notes**

- Outclassing in efficiency and energy production
- Proven no need for cleaning
- Proven to resist to corrosive environments
Best Solar Thermal Collector

TVP panels outperforms concentrators (Parabolic Trough or Fresnel) up to 200°C

Key advantages vs concentrators:

- Highest thermal energy production, mainly due to diffuse light capture
- Highest solar-to-thermal conversion efficiency
- Maintenance-free: no precision cleaning or repair to mechanical parts (no tracking systems)
- Easier transportation, installation and integration
- Long-lasting durability
- Lowest cost profile