Technologies of HTR-PM Plant and its economic potential

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25 August 2015
Contents

- **HTR-PM**: High Temperature gas-cooled Reactor Pebble-bed Module
  - **HTR-PM DPP**: twin-module demonstration power plant, a unit with power of 200 MWe
  - **HTR-PM 600**: Hexa-module commercial unit with power of 600 MWe
- **HTR-PM DPP**: basis, design, progress
- **HTR-PM 600**: design, features
- Analysis of economic potential
HTR-10 – basis of HTR-PM

- 1986: “National High Technology Program (863)”
- 1992: Approved
- 1995: Started construction
- 2000: Reached first criticality
- 2003: Operated in full power
## Design of HTR-10

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactor Power, MWth</td>
<td>10</td>
</tr>
<tr>
<td>Pressure, MPa</td>
<td>3</td>
</tr>
<tr>
<td>Reactor Inlet Temperature, °C</td>
<td>250</td>
</tr>
<tr>
<td>Reactor Outlet Temperature, °C</td>
<td>700</td>
</tr>
<tr>
<td>Fuel Elements Number</td>
<td>27000</td>
</tr>
</tbody>
</table>

- **Spherical fuel elements**
- **Max fuel elements temp. < 1600° C**
- **Passive residual heat removal**
- **Multi-pass charging mode**
- **Side by side arrangement**
- **All control rods in side reflectors**
Tests on HTR-10

- Loss of helium flow
- Turbine trip
- Loss of off-site power supply
- Helium blower trip without scram
- Reactivity insertion without scram
- Helium blower trip without closing outlet cut-off valve
**Technical Objectives of HTR-PM**

- **Demonstration of inherent safety features**
  - Practically exclude the need for off-site emergency plan

- **Demonstration of cost competitiveness**

- **Standardization and modularization**

- **Confirmation of proven technologies**
Overview of HTR-PM Design

Final technical solution in 2006

<table>
<thead>
<tr>
<th>Reactor &amp; SG</th>
<th>2 X 250 MW</th>
<th>Fuel enrich.</th>
<th>8.5%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary helium</td>
<td>250/ 750°C, 7 MPa</td>
<td>Avg. burn-up</td>
<td>90 MWd/ tU</td>
</tr>
<tr>
<td>Plant life-time</td>
<td>40 a</td>
<td>Main steam</td>
<td>567 °C/ 13.25 MPa</td>
</tr>
</tbody>
</table>
**Engineering Tests**

*Started construction in 2009 and finished in 2010*

*The laboratory overview*

*The facility is ready for test*

**Large-scale helium loop**
- **power**: 10 MW
- **tempt.**: 750 °C
- **pressure**: 7 MPa
- **coolant**: helium

**Full scale, under helium conditions**
- steam generator, one of the 19 units
- helium circulator
- fuel handling system
- control rods driving system
- small absorber balls reserve shutdown system
- helium purification system
- reactor protection system and control room
Reactor Pressure Vessel

- Height: 25m
- Diameter: 5.7m
- The key difficulty is the forge, with a weight 460 tons.

(Bottom vessel I)
(Top head)
(Bottom head & bottom vessel II)
Circulator design

- **Vertical layout**
- **Driven by electrical motor**
- **Single stage, centrifugal impeller**
- **Active magnetic bearing (AMB),**
  - no shaft penetration of vessel, no lubrication

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure rise</td>
<td>kPa</td>
<td>200</td>
</tr>
<tr>
<td>Temp. of helium</td>
<td>°C</td>
<td>250</td>
</tr>
<tr>
<td>Rotation speed</td>
<td>rpm</td>
<td>4,000</td>
</tr>
<tr>
<td>Electrical power</td>
<td>kW</td>
<td>4,500</td>
</tr>
</tbody>
</table>
Steam Generator

- **Vertical, counter flow, once-through type, helical tubes**

- **Middle size, multi-layer helical tube assemblies**

<table>
<thead>
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<th>Parameter</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power</td>
<td>MW</td>
<td>253</td>
</tr>
<tr>
<td>No. of Units</td>
<td></td>
<td>19</td>
</tr>
<tr>
<td>No. of tubes per unit</td>
<td></td>
<td>35</td>
</tr>
<tr>
<td>Total No. of Tubes</td>
<td></td>
<td>665</td>
</tr>
</tbody>
</table>
Reactivity control systems

- Two independent systems: rods plus small absorber spheres (SAS), located in side reflector
  - Primary: rods, 24, motor driven
  - Secondary: SAS, 6, falling by gravity, pneumatic conveyance
Fuel Handling System

- Charge and discharge fuel elements on line
- Separating out the broken FEs
- Measure burn-up of FE and screening out spent fuel
- Transfer spent FEs to storage tank
Progress of HTR-PM DPP

HTR-PM project location
Shidao Bay, Rongcheng City, Shandong Province, China.

The target to connect grid is 2017
Progress of HTR-PM DPP

- Engineering design, nearly finished
- Procurement, more than 95% finished
- Civil engineering, nearly finished
  - NI: reactor building, nuclear auxiliary building, spent fuel building, electrical building
  - CI: T/G building
- Installation engineering, ongoing
  - Installation of heavy components will start soon, RPV, CI, SG, blowers, in succession
Fuel fabrication

- In 2010, INET demo production facility, 100k/a, finished the first production
- In the end of 2014, irradiation test of fuels, Petten, Netherlands, finished, results are good
- Commercial fuel plant, 300k/a, commissioning test, to start production this year
**HTR-PM**: multi-module reactor steam turbine plant to properly address safety, cost and technology feasibility
Overall design of HTR-PM 600

- Each NSSS module, identical to those in DPP in order to use proven SSC in DPP and realize standardization.
- 6 NSSS identical modules, coupled to one steam turbine for generation, forming one unit.
- Maximally, auxiliary systems are shared by multiple modules.
- Two unit at a single site.
- Cogeneration is possible through steam extraction.
Nearly the same site footprint of PWR 600 plants.
Configuration of systems

- Systems non-shared among modules, i.e. one-to-one
  - NSSS (RPV, CI, SG, HGD, Blower, CRDM, SAS)
  - ESF (e.g. pressure relief system)
  - Auxiliary system (main steam and feedwater, helium purification)
  - Nuclear measurement, reactor protection,
  - Emergency power supply
Configuration of systems

- Systems shared among modules
  - HVAC in NI
  - FHS, Fresh fuel supply, Spent fuel storage
  - Other auxiliary process systems
  - Miscellaneous systems
  - MCR and DCS
  - Normal power supply
Analysis of economic potential

- Technical advantages of HTR-PM 600
  - Inherent safety (no core meltdown)
    - Capacity of emergency power supply system is small and allowed start-up time is longer
    - Elimination or simplification of emergency response, enhanced security
  - Simplicity: due to enhanced safety, safety-related systems and auxiliary systems are eliminated or simplified.
  - Use beyond electricity generation: unique feature
Purpose of this analysis

- Try to answer the question based on Chinese practice of HTR-PM DPP
  - Can HTR-PM 600 compete with normal PWR?
    - Commercially feasible?
Cost competitiveness

- Generally, capital cost is the most important factor influencing the generation cost of electricity.
- So, primarily focusing on the capital cost of HTR-PM 600.
Input for economic analysis

- Analysis has been done based on detailed costs databank for HTR-PM DPP and also the China’s PWR 600 (Generation II+ technology) projects
Economy-related characteristics

Disadvantage or negative factors

- Economy of scale
- The Size of module is limited by safety requirements

- SCC = Cost($)/Size(kWe)

- For HTR-PM 600, due to low power density, RPV is larger and heavier than that of PWR.
Economy-related characteristics

Advantages or positive factors

- **Economy of experience** (mass production, replication):
  - Learning curve. The curve will flatten out after about the 6-8 module. “On site” learning for civil and installation are remarkable
  - Bulk ordering. For a two unit plant, 12 PRV needed. When the number increases, the specific fixed cost decreases.
  - Serial fabrication of components.
Capital cost breakdown structure

- **Direct cost**
  - NI (civil, equipment, installation)
  - CI (civil, equipment, installation)
  - BOP (civil, equipment, installation)

- **Indirect and other cost**

- **First load of fuel**

- **Contingencies**

- **Taxes, etc.**
Elements of capital cost of HTR 600

In the total capital cost, more than 50% coming from NI
Composition of equipment in NI

- NI process system: ~85%
- HTR-PM 600

- NI process system: ~60%
- PWR 600
Composition of NI process systems of HTR 600

More than three quarter contributed by NSSS
Main equipment of NSSS

- RPV
- SG (internals & vessel)
- Core internals (metal, graphite, carbon)
- Blower
- FHS
- CRDM
- SAS
Potential to reduce cost of NSSS equipment

- Bulk ordering, 5-10%
- Increase of suppliers, 10 - 20%
- Domestic production, 20 - 30%
  - Graphite material
  - AMB, electrical penetration, valves, etc.
- Simplification and optimization, 5 - 10%
- Appropriate standards or codes
Evaluation of NSSS equipment cost

- Cost of equipment in DPP multiplied by factors based on actual shared/non-shared situation
- Revised the cost
  - taking commercial factors into account, such as bulk ordering, etc.
  - taking account of the technical progress for cost reduction which is realistic in near future, e.g. domestic production, etc.
Estimation of total capital cost

- Aspects much different from PWR
  - Main equipment cost, especially NSSS (addition)
  - Equipment cost of auxiliary systems (subtraction)

- Aspects similar to PWR
  - NI civil work, installation work (based on man-hour, difficulty factor)
  - Cl, BOP
  - First fuel (actual amount), contingencies
  - Other cost
  - Capacity factor, etc.
Evaluation result of total capital cost

- Based on above evaluation of main equipment costs, total capital cost can be estimated:
  - Specific capital cost of HTR-PM 600 is higher than PWR 600 (Generation II+). However, the difference is only about 15%.
  - Further sensitivity analysis show that, increase of 10% for the main equipment cost in NI will result in an increase of about 4% for total capital cost.
  - Taking account of the uncertainty of main equipment cost, the difference is still lower than 20%.
Concluding remarks

- **HTR-PM DPP** is being built in China and the conceptual design of HTR-PM 600 has been finished.

- Based on the cost data of HTR-PM DPP, analysis of economic competitiveness of HTR-PM 600 has been done. For the case of pure electricity generation, although the capital cost of HTR is higher than that of PWR, the difference is less than 20%.
Thank you for your attention!