DOE Virtual Receiver and Reactor Workshop

Nitrate Salt Receivers

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Nitrate Salt Selection

- Sandia National Laboratories, circa 1975, searched for a heat transfer fluid that was simultaneously suitable for energy collection, energy storage, and steam generation
- Goal was to find a fluid which has:
  - A high thermal stability (loss rate <0.01 percent/year) at the temperatures (at least 500 °C) required to operate a Rankine cycle at a commercially competitive efficiency (42+ percent)
  - A low vapor pressure (<100 Pa) such that the fluid could be stored in a tank operating at atmospheric pressure
  - A high chemical stability in contact with air (leaks don't lead to fires), and with water / steam (steam generator leaks do not degrade the fluid properties)
  - At 600 °C, acceptable corrosion rates (< 3 mm in 30 years) for 300-series stainless steel. At 400 °C, acceptable corrosion rates for carbon steel
  - A low cost (< $2/kg)
- No fluid ever studied satisfies all of these requirements, except nitrate salt

Nitrate Salt Selection - Continued

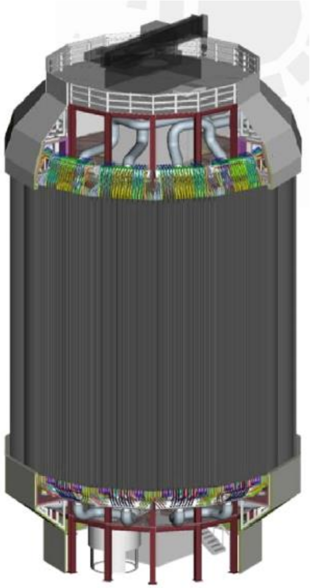
- Nitrate salt might be the best fluid, but it’s a user-hostile fluid
  - At temperatures above 240 °C, salt looks and acts just like dense water; however, at temperatures below 220 °C, salt is an excellent surrogate for concrete
  - Salt flows through any opening, no matter how small
  - Salt oxides all organic materials, including valve stem packings, pump mechanical seals, and the insulation on electric cables
  - Salt, if overheated by the electric heat tracing, decomposes to various oxides. Consequent corrosion rates can reach mm per month

Enabling Technologies

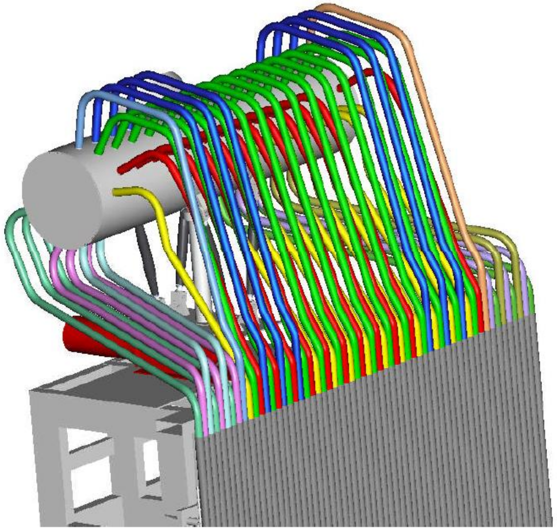
- Receiver tube material
  - Solid solution alloys, with nickel as the principal component
  - Candidates include Alloy 230 and Inconel 625LCF (low cycle fatigue)
  - Materials can tolerate 30,000 strain cycles, oscillating between compression and tension, at stresses beyond the yield point
  - Permits incident fluxes in the range of 650 kW/m^2 (outlet) to 1,200 kW/m^2 (inlet)
  - Favorable flux limits reduce the absorber area, which, in turn, reduces the radiation and the convection losses to a point where the receiver can achieve an efficiency that is commercially competitive (89+ percent)
- Salt pumps with lengths of 14+ m
  - Allows the main storage tanks to be used as pump sumps
  - Avoids pump sumps, located below grade, fed by gravity from the main storage tanks
  - Avoids a number of (financially disastrous) failure modes due to flooding of a sump

Commercial Receiver Designs

- External cylinder
  - Compromise between heliostat cosine efficiency and spillage losses
  - Moderate thermal conductivity of salt requires long heating length (150 m); 7 or 8 panels in series keep tube lengths within commercial feasibility

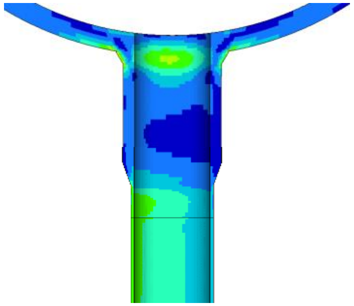


- Absorber panel
  - Flow distributed to, and collected from, tubes in parallel flow
  - Independent tubes accommodate lateral flux gradients
  - Jumper tubes allow automated welding

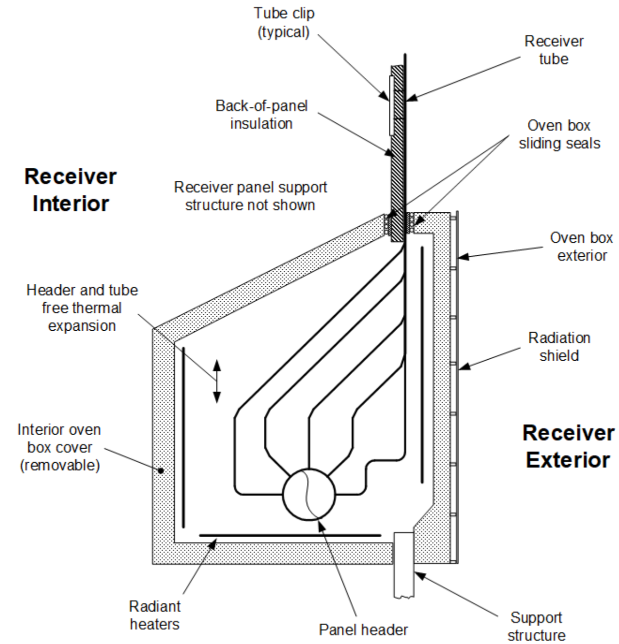


Commercial Receiver Designs - Continued

- Header and nozzle
  - Rates of temperature change can reach 6 °C/sec
  - Nozzles provide a transition in thickness (9.5 mm to 1.65 mm) to reduce transient stresses
  - Nozzles are plastically pulled from the header by a collet



- Header ovens
  - Radiant heaters preheat complex header and jumper tube geometries
  - Control of the convection losses from the oven is an art form



What's Working

- Principal performance parameters (photon-to-thermal conversion efficiency, availability, control system authority, pressure drop, preheat / fill / drain times) have been successfully demonstrated
- Nickel alloy tubes, particularly Alloy 230, are tolerating the damage due to the combined effects of creep and fatigue
- Selective surface coating on the tubes (Pyromark) offers good optical properties (93+ percent absorptivity) over an adequate period (3 years)
- Inlet vessel, with compressed air in the ullage space, adequately protects the receiver following a site power outage
- Throttle valves at the bottom of the downcomer are tolerating rates of temperature change as high as 6 °C/sec
- Reliable, multi-megawatt receiver pumps are commercially available

What's Not Working

- Heliostat slope and pointing errors often exceed the design budget (3 mrad)
  - A common result is spillage losses larger than planned, which reduces the annual energy collected by the receiver
  - Spillage losses can be reduced by shifting the heliostat aim points to locations closer to the receiver equator. However, this 1) increases the peak fluxes, 2) increases the tube strain, and 3) reduces the creep lifetime
- Trained, conscientious operators, willing to work for several years in a remote location, are too few for all of the commercial projects
  - Full control system automation has yet to be reached, due in part to:
    - Inaccurate instruments, unpredictable valves, and inadequate heat tracing
    - Various opinions regarding operating states and transitions
  - Operators are required, at times, to make ad hoc decisions that lead to 1) high transient stresses, 2) equipment failures, and 3) a loss in availability

Future Technical Advancements

- Few, at least in terms of the annual solar-to-electric efficiency
  - Current design temperature (565 °C) permits the use of air as the cover gas, provides a commercially feasible corrosion allowance (0.7 mm in 30 years), and provides competitive Rankine cycle efficiencies (44+ percent)
  - An increase in the design temperature to 600 to 625 °C can increase the cycle efficiency (46+ percent), but:
    - Higher fluid temperatures require a reduction in the design tube strain, which 1) reduces the incident flux, 2) increases the absorber area, and 3) reduces the receiver efficiency
    - Increases in the Rankine efficiency are achieved by higher live steam pressures (165 bar); however, 165 bar cycles are better suited to baseload, rather than cycling, operation
    - An O_2 - NO_2 mixture as the ullage gas in the storage tanks is required to limit the concentrations of nitrite ions, and in turn, oxide ions in the salt. In the absence of oxide control, an increase in the salt temperature of 35 °C increases the corrosion rates of stainless steel and nickel alloys by a factor of 10+. However, is it practical to use O_2 - NO_2 as the cover gas in a commercial project?

Future Technical Advancements - Continued

- Modest gains from improvements in technical features, such as the absorptivity of alternate selective coatings for the receiver
- Principal commercial deficit is currently plant availability, not receiver efficiency, thermal storage efficiency, or Rankine cycle efficiency
  - Sources of low availability (65 to 75 percent) are well understood
    - Primarily the hot salt tank
    - Followed by the salt steam generator
    - Followed by salt valves, either too many or incorrectly sized
  - Iterations on the design, particularly the process design, can improve the plant availability to match that of commercial parabolic trough projects (92+ percent)
  - Over the next 10+ years, the commercial gains from improving the plant availability outweigh the potential gains from improving the plant efficiency by perhaps two orders of magnitude

