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SOLAR THERMAL ENERGY RESEARCH GROUP

A hybrid dephlegmator for incorporation into an air-cooled steam condenser

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Fakulteit Ingenieurswese
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Overview

- Air-cooled condensers (ACCs): what, where, why?
- Hybrid (dry/wet) dephlegmator concept
- Performance evaluation
- Summary

Air-cooled condensers: what, where, why?

- In a basic steam turbine power producing cycle:
  - Energy is added to water in a boiler/heater to generate high pressure steam
  - The steam is expanded in a turbine to produce power
  - The low pressure steam from the turbine exhaust is condensed
  - The condensate is pumped back to the boiler/heater to complete the cycle

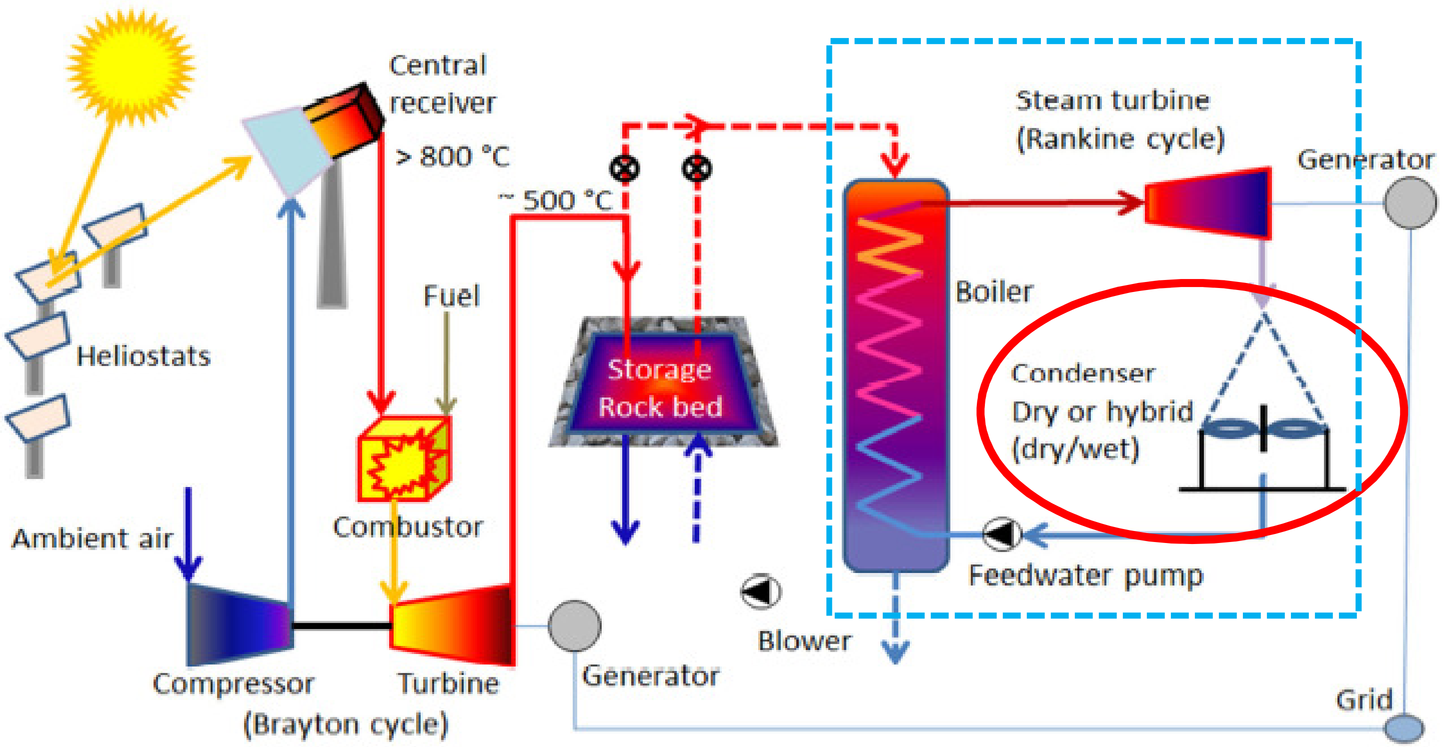

Image courtesy of www.eai.in

Air-cooled condensers: what, where, why?

- Wet cooling using evaporative condensers

  - Approximately ½ of all power plants in the U.S. use evaporative cooling[1]
  - The vast majority of operating solar thermal power plants are wet cooled[2]

1. Carney B, Feeley T, McNemar A. *NETL Power Plant Water Research Program*. EPRI Workshop on Advanced Thermoelectric Cooling Technologies 2008; Charlotte NC.
2. NREL 2010: http://www.nrel.gov/csp/solarpaces/project_detail.cfm/projectID=6

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ACCs at operating CSP plants (2010)

Name	Technology	Country	Turbine Capacity, MW	Cooling Method
Archimede	Parabolic Trough	Italy	5	Wet Cooling
Palma del Rio II	Parabolic Trough	Spain	50	Wet Cooling
Puerto Errado 1	Linear Fresnel reflector	Spain	1.4	Dry cooling
Alvarado 1	Parabolic Trough	Spain	50	Wet Cooling
Andasol - 1	Parabolic Trough	Spain	50	Wet Cooling
Andasol- 2	Parabolic Trough	Spain	50	Wet Cooling
Central Solar Termoelectria La Florida	Parabolic Trough	Spain	50	Wet Cooling
Extresol- 1	Parabolic Trough	Spain	50	Wet Cooling
Extresol-2	Parabolic Trough	Spain	50	Wet Cooling
Iibersol Ciudad Real(Puertollano)	Parabolic Trough	Spain	50	Wet Cooling
La Dehesa	Parabolic Trough	Spain	50	Wet Cooling
Majadas 1	Parabolic Trough	Spain	50	Wet Cooling
Manchasol-1	Parabolic Trough	Spain	50	Wet Cooling
Solnova 1	Parabolic Trough	Spain	50	Wet Cooling
Solnova 3	Parabolic Trough	Spain	50	Wet Cooling
solnova 4	Parabolic Trough	Spain	50	Wet Cooling
Planta Solar 10	power tower	Spain	11	Wet Cooling
Planta solar 20	power tower	Spain	20	Wet Cooling
Colorado Integrated Solar Project	Parabolic Trough	USA	2	Wet Cooling
Nevada Solar One	Parabolic Trough	USA	75	Wet Cooling
Saguaro Power Plant	Parabolic Trough	USA	1	Wet Cooling
Solar Electric Generating Station I	Parabolic Trough	USA	13.8	Wet Cooling
Solar Electric Generating Station II	Parabolic Trough	USA	30	Wet Cooling
Solar Electric Generating Station III	Parabolic Trough	USA	30	Wet Cooling
Solar Electric Generating IV	Parabolic Trough	USA	30	Wet Cooling
Solar Electric Generating V	Parabolic Trough	USA	30	Wet Cooling
Solar Electric Generating VI	Parabolic Trough	USA	30	Wet Cooling
Solar Electric Generating VII	Parabolic Trough	USA	30	Wet Cooling
Solar Electric Generating VIII	Parabolic Trough	USA	80	Wet Cooling
Solar Electric Generating Station IX	Parabolic Trough	USA	80	Wet Cooling
Sierra suntower	power tower	USA	5	Wet Cooling

2. http://www.nrel.gov/csp/solarpaces (last updates March 2010)

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Air-cooled condensers: what, where, why?

- Wet cooling using evaporative condensers

  - Approximately ½ of all power plants in the U.S. use evaporative cooling[1]
  - 36 of the 37 major operating solar thermal power plants are wet cooled[2]
  - Water intensive: >30 000 litres per day per MW installed[3]
  - Typically accounts for > 80 % of the water consumption at a plant[4]

The use of alternative means of cooling therefore holds the greatest potential for decreasing water consumption related to electricity production

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ACCs at CSP plants under construction (2010)

Name	Technology	Country	Turbine Capacity, MW	Cooling Method
ISCC Argelia	Parabolic Trough	Alegria	150	Dry cooling
ISCCS AL Kuraymat	Parabolic Trough	Egypt	140	
ISCC Morocco	Parabolic Trough	Morocco	470	Wet Cooling
Palma del Rio I	Parabolic Trough	Spain	50	Wet Cooling
Puerto Errado 2	Linear fresnel reflector	Spain	30	Dry cooling
Andasol -3	Parabolic Trough	Spain	50	
Andasol-4	Parabolic Trough	Spain	50	Wet Cooling
Arcosol 50	Parabolic Trough	Spain	50	Wet Cooling
El REBOSO 2 50-MW Solar thermal power plant	Parabolic Trough	Spain	50	Wet Cooling
Shams 1	Parabolic Trough	UAE	100	
Blythe Solar Power project	Parabolic Trough	USA	1000	Dry cooling
Genesis Solar Energy Project	Parabolic Trough	USA	250	Dry cooling
NextEra Beacon Solar Energy Project	Parabolic Trough	USA	250	
Solana Generating Station	Parabolic Trough	USA	280	
Brightsource Coyote Springs 1(PG&E 3)	Power tower	USA	200	
Brightsource Coyote Springs 2(PG&E 4)	Power tower	USA	200	
BrightSource PG&E 5	Power tower	USA	200	
BrightSource Pg&E6	Power tower	USA	200	
BrightSource PG &E7	Power tower	USA	200	
Crescent Dunes Solar Energy Project	Power tower	USA	110	Hybrid
Gaskell Sun tower	Power tower	USA	245	
Ivanpah Solar Electric Generating Station	Power tower	USA	392	Dry cooling
Rice Solar Energy Project	power tower	USA	150	Dry cooling
Imperial Valley- Solar Two	Dish/Engine	USA	750	

As the use of ACCs becomes more widespread it becomes increasingly important to ensure adequate and predictable performance under all operating conditions.

2. http://www.nrel.gov/csp/solarpaces (last updated March 2010)

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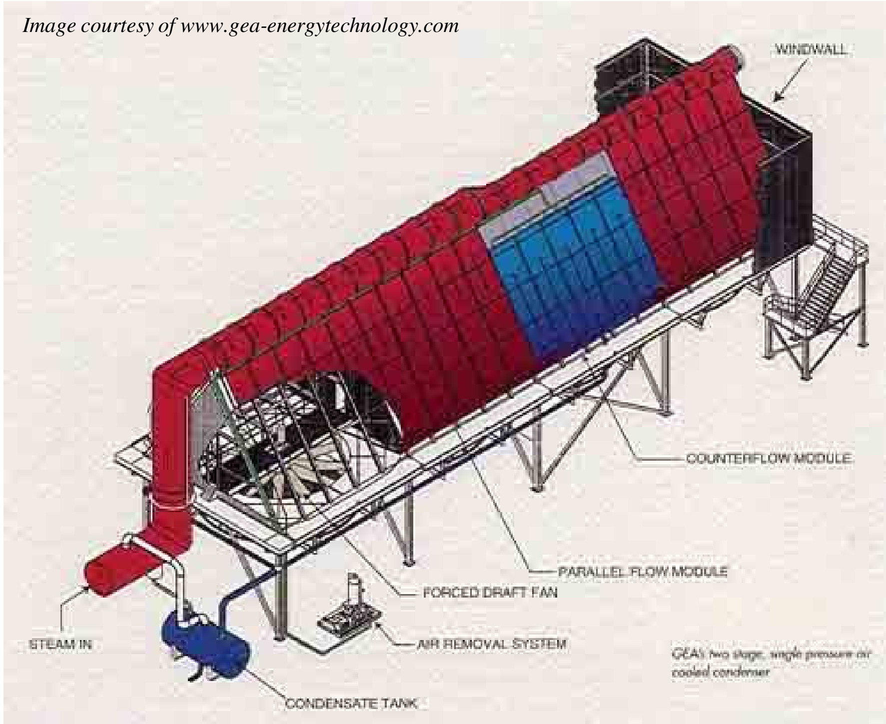
Air-cooled condensers: How do they work?



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Air-cooled condensers in South Africa

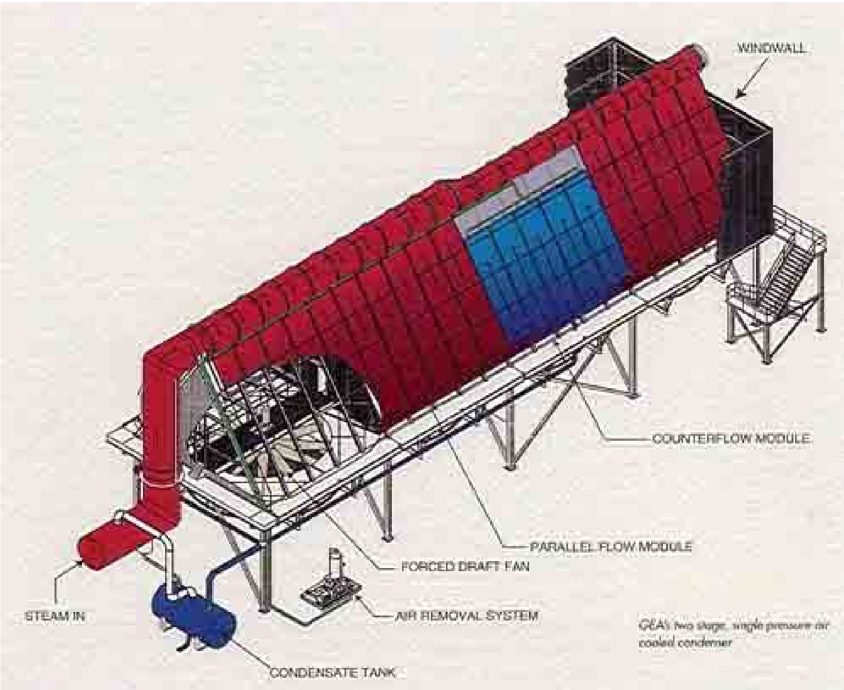
Air-cooled condensers: what, where, why?

- ACCs use ambient air to cool and condense the process fluid
- No water is directly consumed in the cooling process
  - ACCs are therefore an attractive option considering current global water security concerns
  - ACCs allow for flexibility in plant location
    - Location not constrained by proximity to water resources
    - Plants can be built nearer fuel/energy supplies or load centers → increased reliability and reduced transmission costs

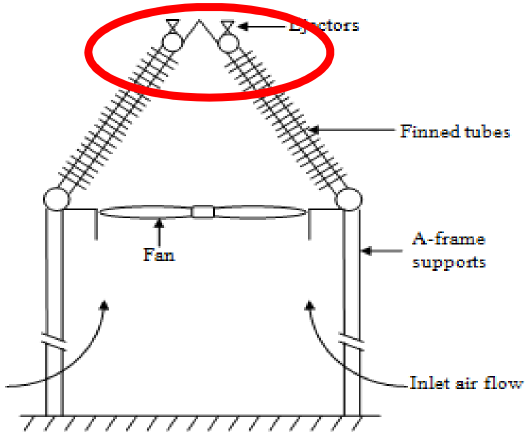
- ACCs experience a reduction in cooling effectiveness at high ambient temperatures
  - $Q \propto T_v - T_a$
- A dynamic relationship exists between condenser and turbine performance
- Reduced cooling effectiveness → decreased plant output on hot days

Hybrid (dry/wet) dephlegmator (HDWD)

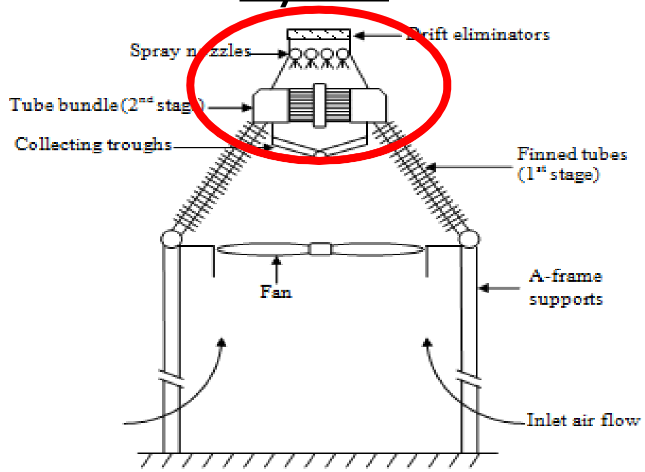
- Replace conventional dephlegmator with a HDWD
- Originally proposed by Heyns and Kröger[5]



Conventional

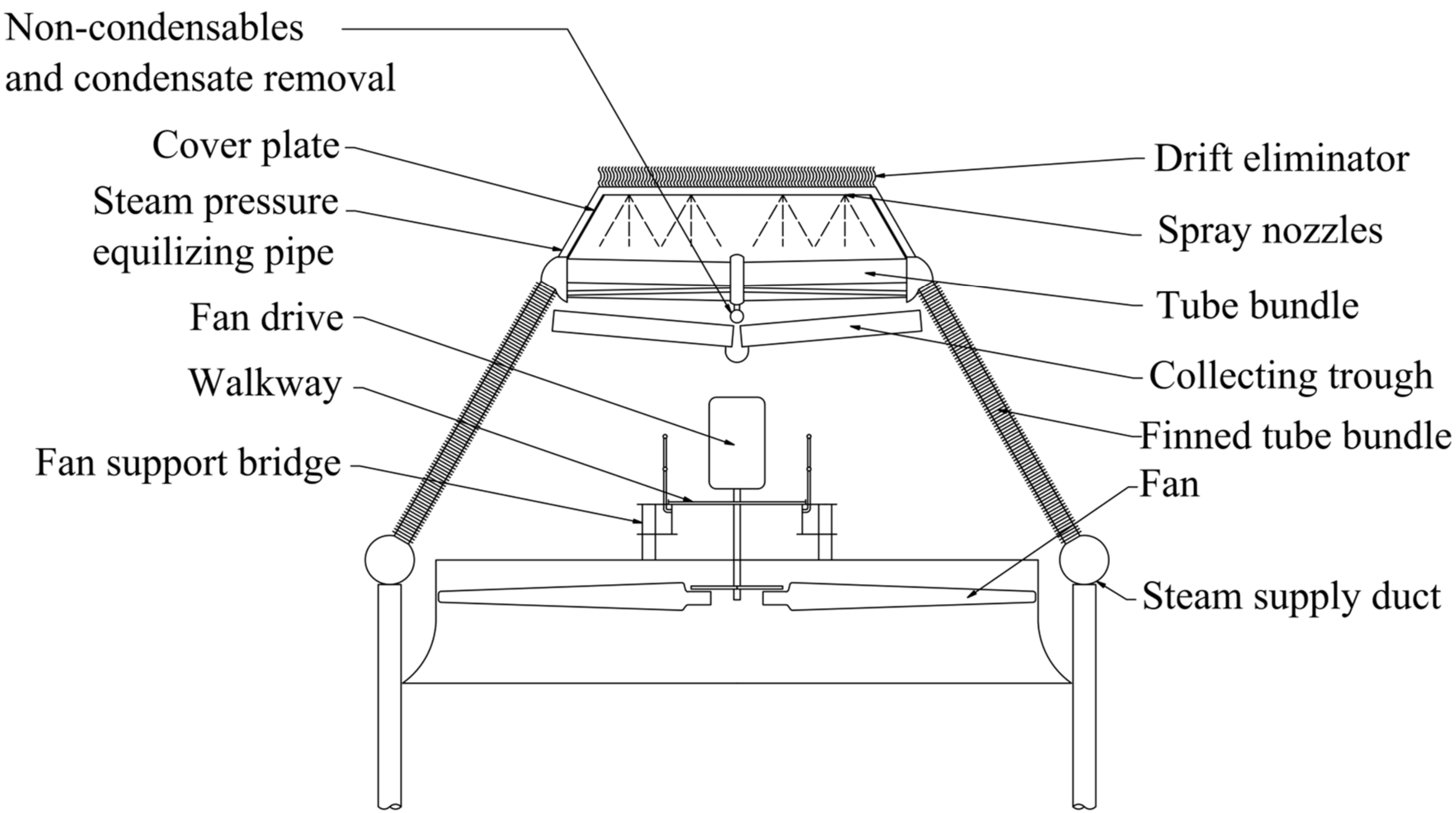


Hybrid



5. Heyns, J.A., Kröger, D.G., *Performance characteristics of an air-cooled steam condenser with a hybrid dephlegmator*, R&D Journal of the South African Institute of Mechanical Engineers, Vol. 28, pp. 31-36, 2012.

Hybrid (dry/wet) dephlegmator



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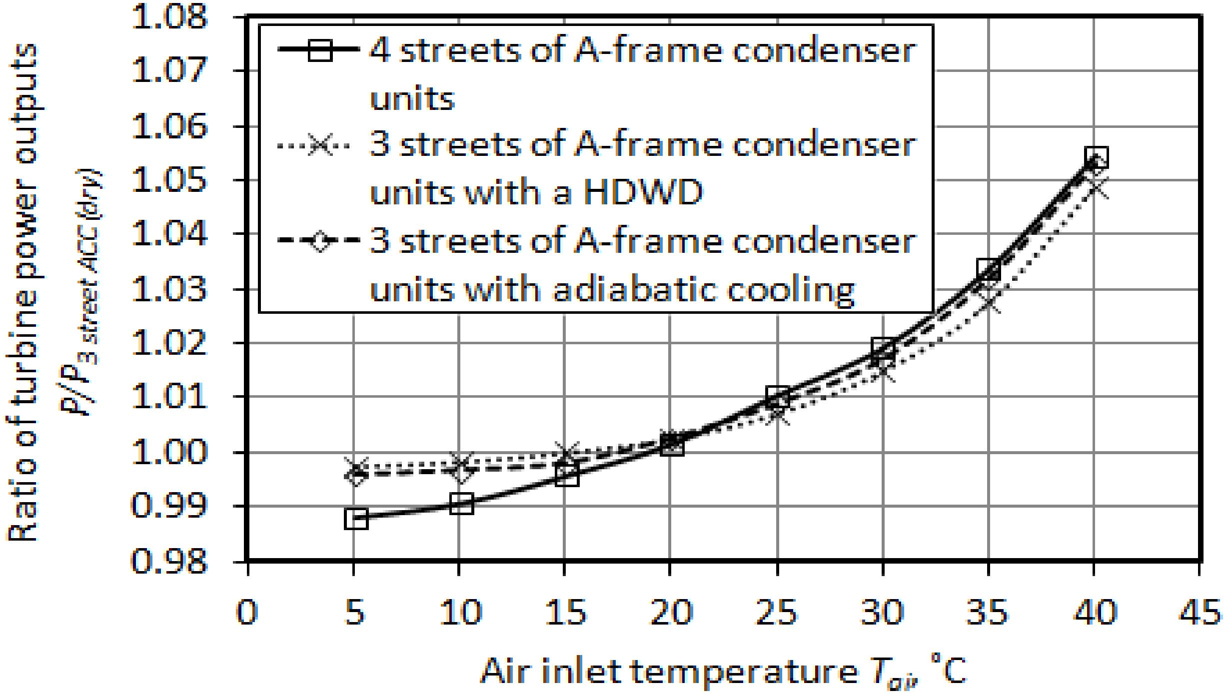
HDWD: Preliminary performance evaluation



- 3 street ACC with a HDWD (operating wet) provides the same turbine output benefits as:
  - A 33% over-sized ACC (4 streets vs 3) - at a much reduced cost
  - A conventional ACC with spray cooling enhancement – while consuming 20 % - 30 % less water and avoiding fouling and corrosion issues

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Summary

- While ACCs offer water consumption advantages over evaporative cooling towers they experience decreased performance during hot periods
- Alternative and enhancement strategies have thus far proven problematic
- A novel hybrid dephlegmator concept is proposed that:
  - Offers enhanced cooling performance (up 35 % increase for an entire ACC)
  - While consuming only a small amount of water
  - Is able to reduce the load on the ejector
  - Simple and cost effective
- The best configuration for the HDWD is under investigation
- Determining the exact performance characteristics of the HDWD forms the focus of current and future research

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