the Energy to Lead

Industrial Heat Pumps in Agricultural Drying Applications

> **Paul Glanville**
Senior Engineer, End Use Solutions,
Gas Technology Institute

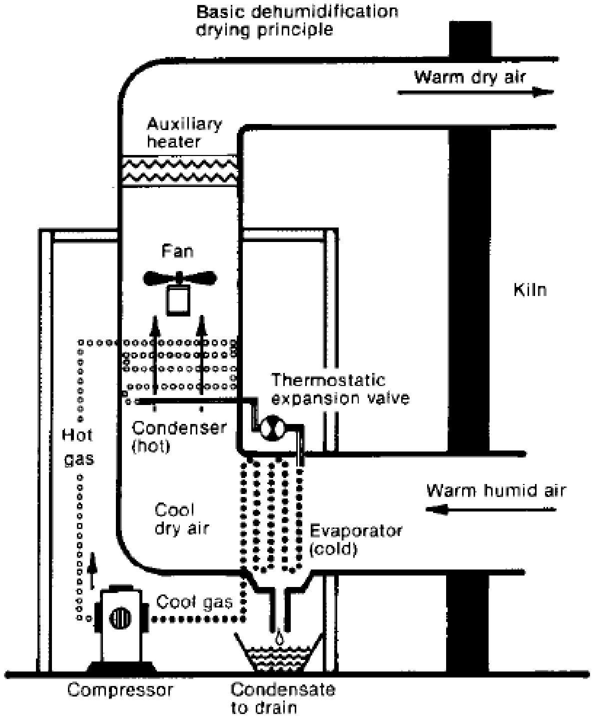
> International Gas Union Research Conference
18 September 2014

gti®

U.S. AGRICULTURAL DRYING

Opportunity for Thermal-Driven Heat Pumps

- Indirect drying is a significant natural gas load in North America, 5% of the U.S. Commercial and Industrial gas consumption.
- Drying step can consume between 50-70% of process energy to deliver finished product in agricultural and lumber applications.
- The same overall design has been in use for over 50 years, with a nominal efficiency of 35%, with advanced technologies reaching 82%-88%.
- The industry has explored vapor compression (VC) heat pump drying (HPD) since 1973, though market impact since has been limited – due to high relative cost of electricity at **6.5X that of natural gas** (US DOE – 2012).
- Thermally-driven HPD makes good sense, simultaneous heating and dehumidification with a lower temperature lift than other heat pump applications.



USDA Agricultural Handbook AH-188: *Dry Kiln Operator's Manual* (2001)
http://www.fpl.fs.fed.us/products/publications/several_pubs.php?grouping_id=101&header_id=p

U.S. AGRICULTURAL DRYING

Opportunity for Thermal-Driven Heat Pumps

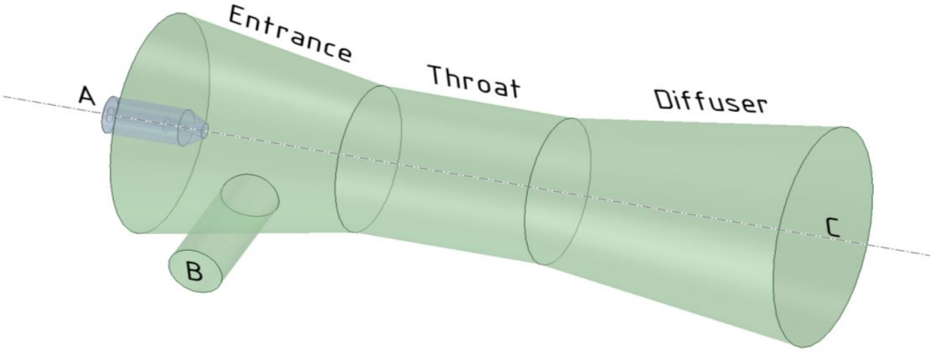
- To evaluate this opportunity, GTI is leading a team to develop and demonstrate a hybrid Gas-Fired Rotary Dryer with Integrated Heat Pump for Ag drying in California.
  - Drying fruits and vegetables in CA requires 1,815 GWh/year
- Team includes:
  - Manufacturers of Drum Dryer (GL&V) and Burners (Flynn)
  - HPD Technology Developer for Ejector Heat Pump (May-Ruben Thermal Solutions)
  - Food processer host site (Bean Drying)
  - CA Utility Partners

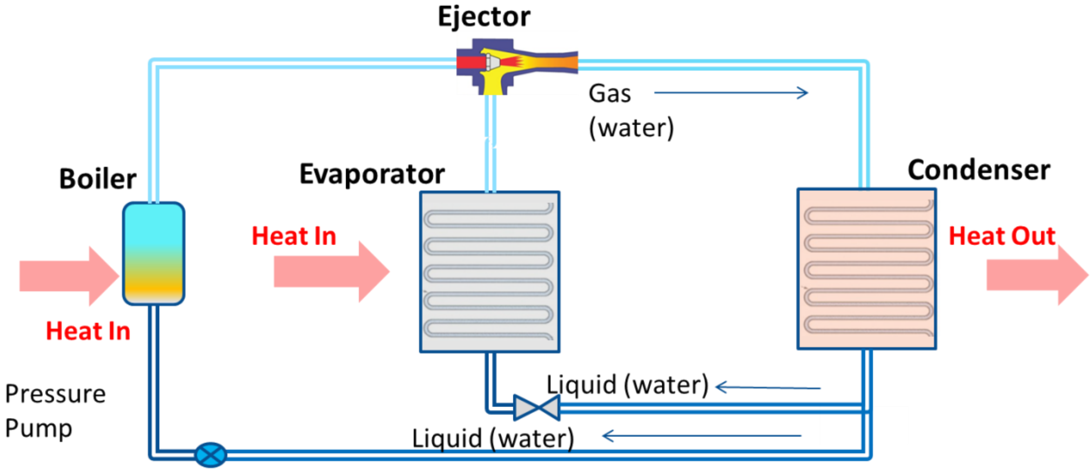
GTI Drum dryer demonstration in paper drying facility

EJECTOR HPD SYSTEM CONCEPT

Ejector Heat Pumps, Then…

- As a ‘thermo-compressor’, ejectors can compress a low pressure gas or saturated vapor with a high pressure fluid.
- Simple system for compression when steam or waste heat is available, standard ejectors were used for refrigeration & ice production since 19th Century.
- Standard systems had $\mathrm{COP}_{\mathrm{cooling}} < 0.3$, small entrainment ratios, not common today



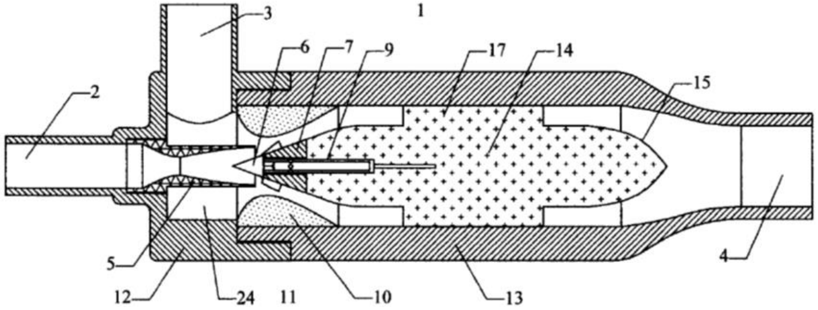


EJECTOR HPD SYSTEM CONCEPT

Ejector Heat Pumps, Then…

Two major problems limit ejector performance:

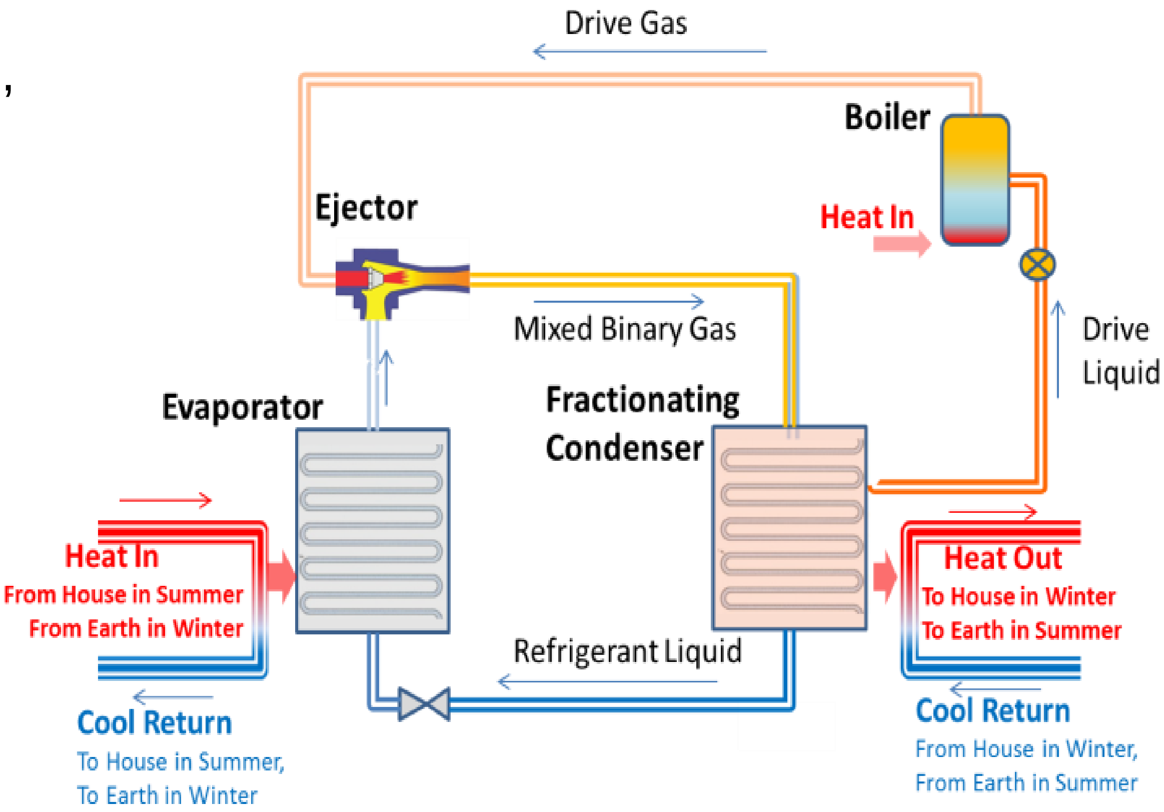
- Single working fluid needed for two distinct jobs, compromises by doing both poorly.
  - **Refrigeration –** Fluid must have a high enthalpy of vaporization for near isothermal phase change in condenser/evaporator. Heat transfer efficiency & capacity drop when non-isothermal.
  - **Ejector Entrainment–** Fluid must ***not*** have a high enthalpy of vaporization to boil easily in the generator, improving COP. Also, entrainment is aided when the molecular mass of the drive fluid exceeds that c
- Principle method of compressing refrigerant during entrainment is *momentum exchange*, inefficient turbulent mixing. *Pressure exchange* is much better, with the drive fluid providing "mechanical" compression.



Garris, C. A., GWU "Pressure Exchanging Ejector and Methods of Use". U.S. Patent 6,138,456.

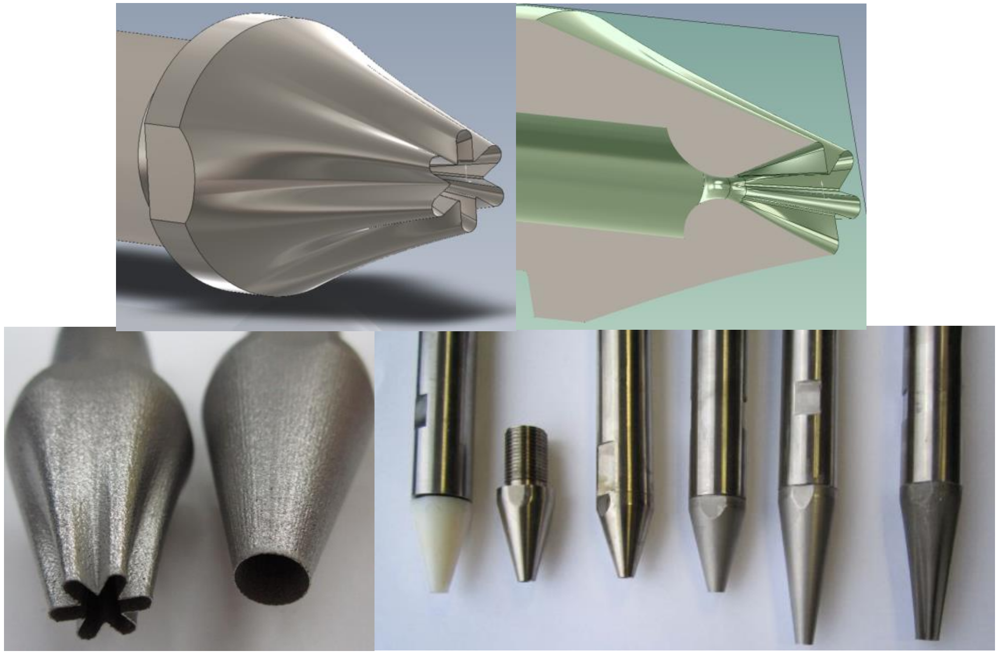
Ejector Heat Pumps, Now

- May-Ruben Thermal Solutions has developed the Binary Fluid Ejector (BFE) heat pump, for non-incremental improvement over standard ejectors:
  - **Two fluids, engineered for respective roles**
  - Novel nozzle designs to promote pressure energy exchange, static designs with vortex columns or, in later possible developments, dynamic with oscillating nozzle



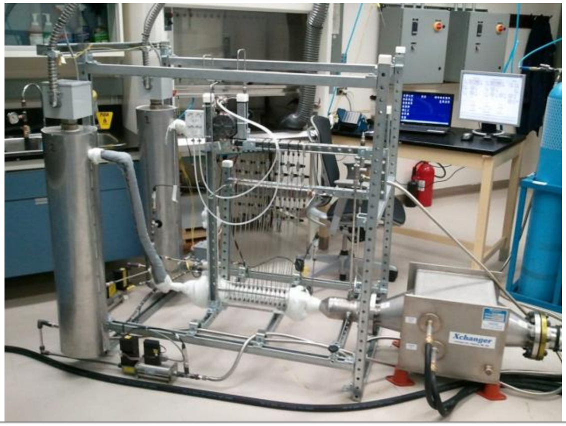
Ejector Heat Pumps, Now

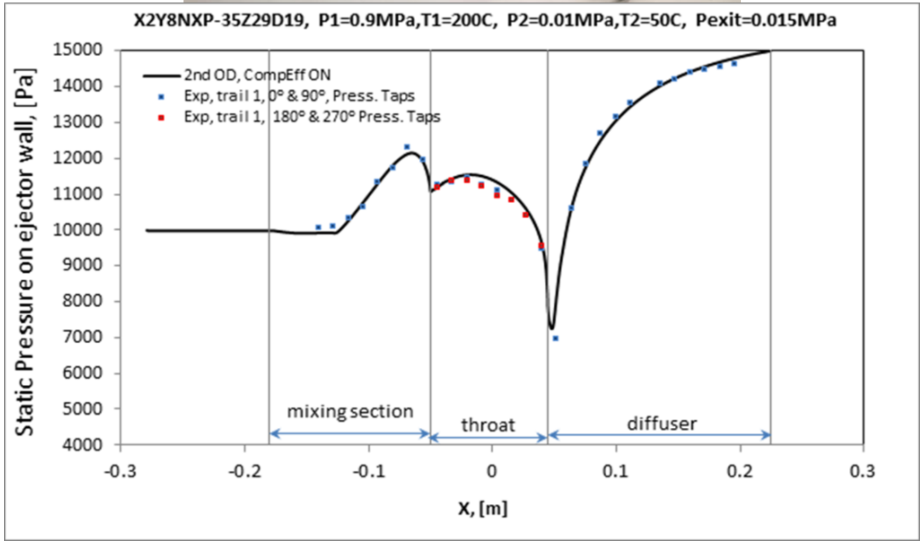
- May-Ruben Thermal Solutions has developed the Binary Fluid Ejector (BFE) heat pump, for non-incremental improvement over standard ejectors:
  - Two fluids, engineered for respective roles
  - **Novel nozzle designs to promote pressure energy exchange, static designs with vortex columns or, in later possible developments, dynamic with oscillating nozzle**



Ejector Heat Pumps, Now

- Initially focusing on desalination, extensive combination of parametric analysis with experimentally-validated CFD simulation and testing with inert gases in ejector test rig completed:
  - Entrainment ratios and estimated COPs, when extrapolated to seasonal temp. lifts show exceeding heating/cooling COPs of 2.0/0.9 may be feasible.
  - Depending on ultimate fluid pair selection, operating pressures may be quite moderate (<< 100 psi/0.7 MPa).
  - With quick startup, ejectors may be deployed in parallel for modulation





Example of CFD model calibration with inert gas

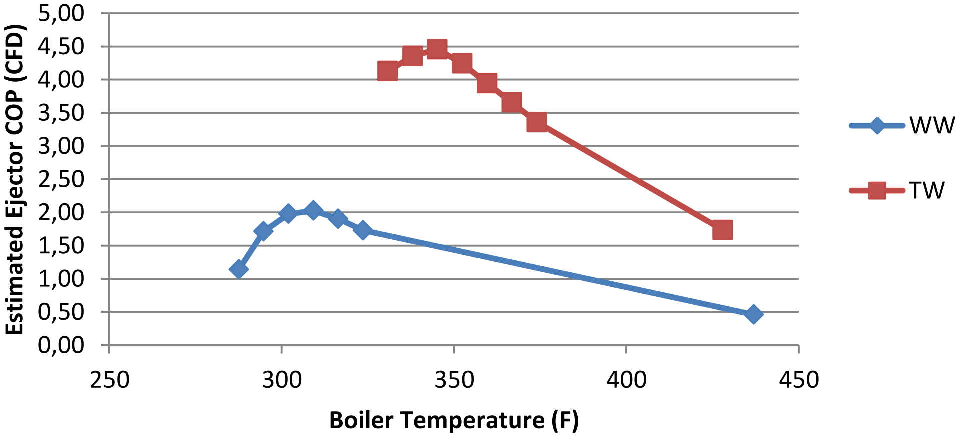
EJECTOR HPD SYSTEM CONCEPT

Ejector Heat Pumps, Now

- Simplified analysis shows critical impact of binary fluid selection and ejector design, guides optimization process and performance estimates:
  - Entrainment ratio (m_R/m_D) is largely a function of the nozzle design and ratio of fluid MW
  - f_h is a function of fluid selection and operating conditions

$$COP = \frac{Q_{evaporator}}{Q_{boiler} + W_{pump}} = \omega \frac{\left(h_{s,out} - h_{s,in}\right)_{evap}}{\left(h_{p,out} - h_{p,in}\right)_{boiler} + \frac{\left(P_{p,out} - P_{p,in}\right)_{pump}}{\rho_{avg,in\ out}}}$$

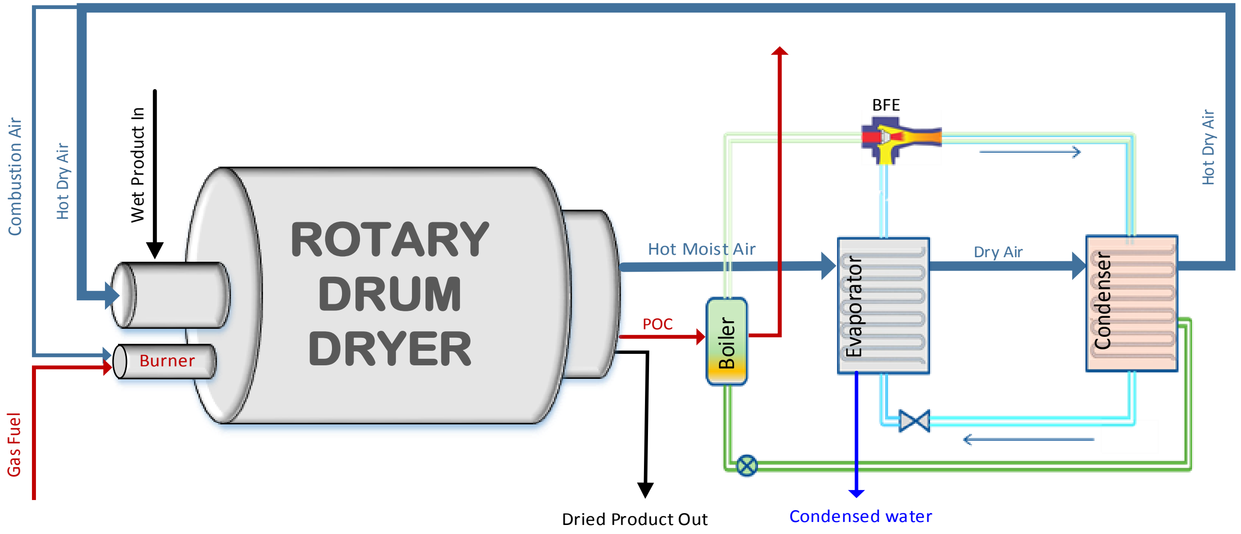
$$\boxed{COP = \omega \frac{Hv_{Evap} + \overline{Cp_1}\left(T_{Cond} - T_{Evap}\right)}{Hv_{Boil} + \overline{Cp_2}\left(T_{Boil} - T_{Cond}\right)} = \omega\ f_h}$$



GAS-FIRED HPD IN CALIFORNIA

Next Steps in the Development

- While early-stage development, with remaining technical risks, opportunity is large:
  - Energy savings versus standard gas drying.
  - Capital and operating cost savings versus existing HPD options.
- RD&D program initiating now.



Heat Source	Output Energy (MWh)	COP	Input Energy Required (MWh)	Annual** Energy Cost ($)	% Cost Savings vs gas heat	Annual Cost Savings ($) vs gas heat
Direct Fired Gas	1	0.8	1.25	$ 233,235	-	-
Electric HP	1	4.0	0.25	$ 197,100	**15%**	$ 36,135
BFE HP	1	2.0	0.50	$ 93,294	**60%**	$ 139,941

***based on natural gas rate $0.22/m3 and electrical rate of $0.09/kWhr at annual operations of 350 days/year*

Connect With Us

Contact:
Paul Glanville, PE
Senior Engineer,
End Use Solutions

847-768-0782
paul.glanville@gastechnology.org

Gas Technology Institute

1700 S Mount Prospect Rd,
Des Plaines, IL 60018, USA

www.gastechnology.org

@gastechnology