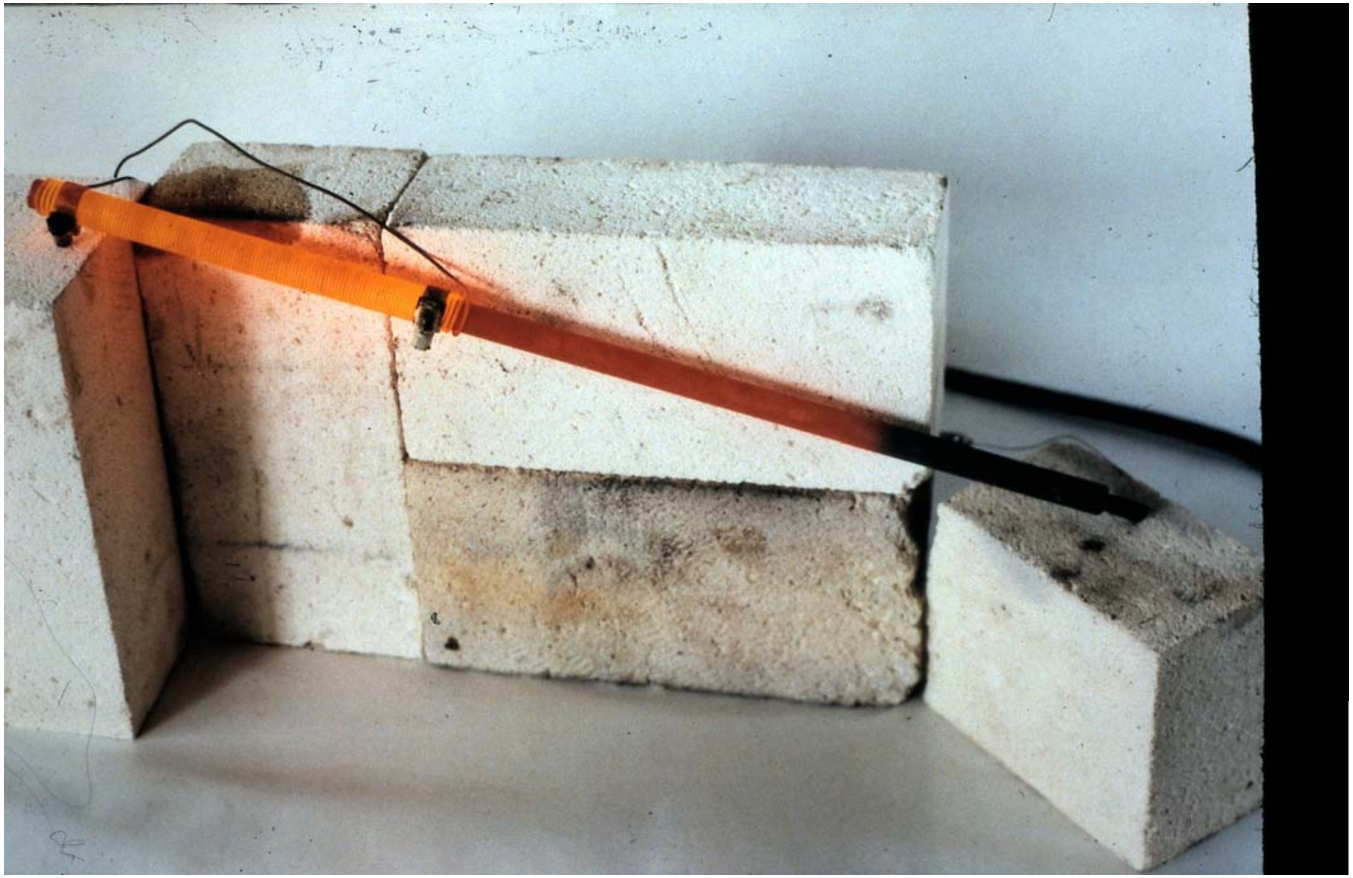
HEAT PIPES FOR CONTROL

CAN THEY BE USED IN CHEMICAL REACTORS?

David Reay

A Sodium Heat Pipe I Made Some Time Ago Introduces the Concept



And this is Developed into an 'Active Feedback Controlled VCHP'

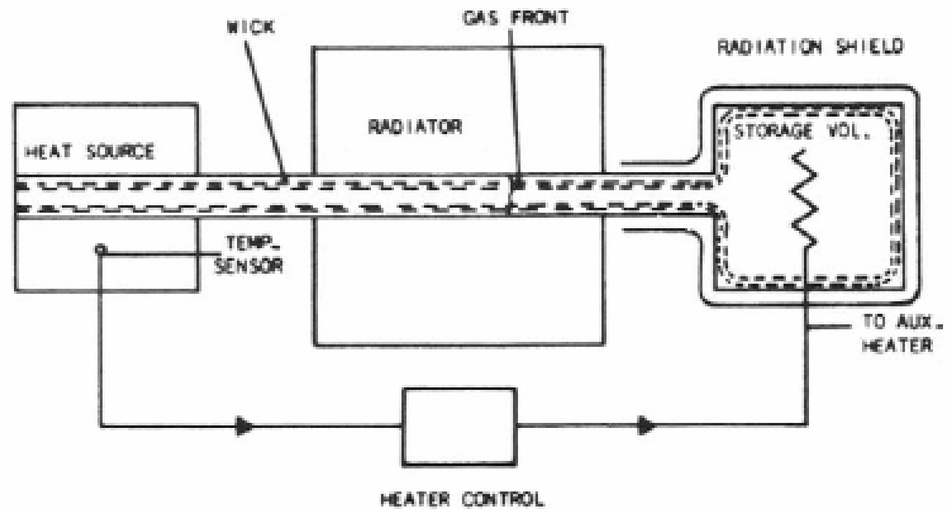
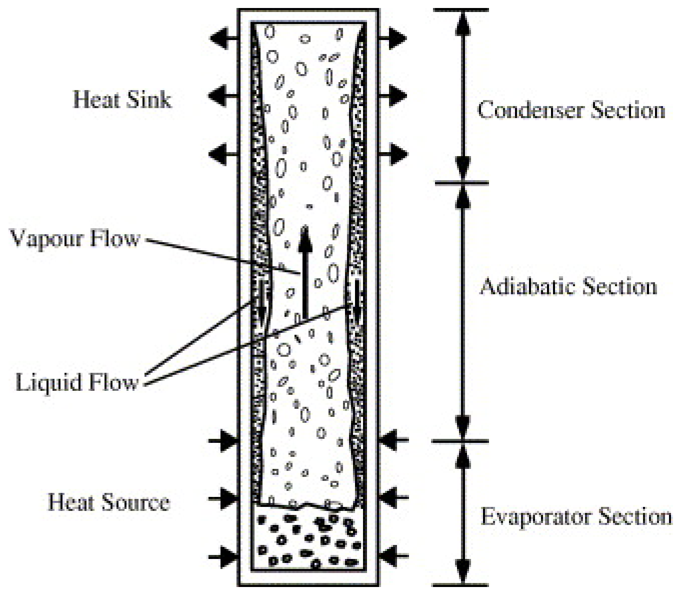
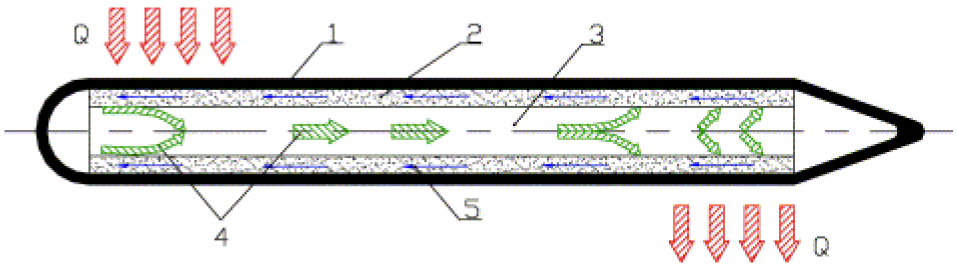


Fig. 6.5 Active feedback-controlled variable conductance heat pipe.

Which controls the source (reactor) temperature to +-1Deg.C

Back to Basics - Thermosyphons & Heat Pipes: What are they?

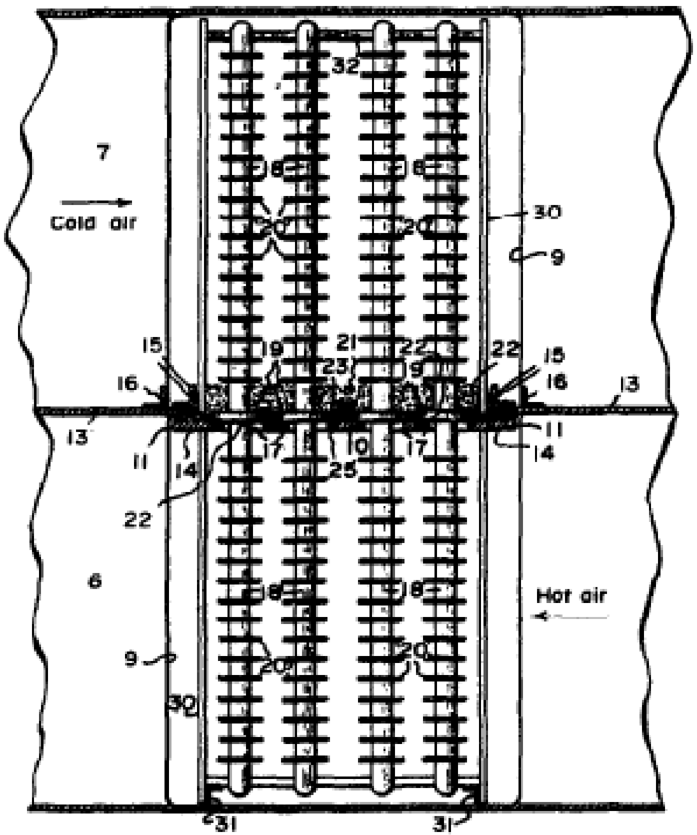




Conventional heat pipe schematic. (1) HP case, (2) porous wick, (3) vapour channel, (4) vapour, and (5) liquid.

Thermosyphon (Gravity-assisted liquid transport)

A Little Bit of History



Perkins Tubes used to transfer heat from a hot air stream to a cold one – gas-gas heat recovery.

The Perkins tube is a thermosyphon – relies on gravity for liquid return

The Perkins Oven – use coal to bake bread without getting soot on the dough!

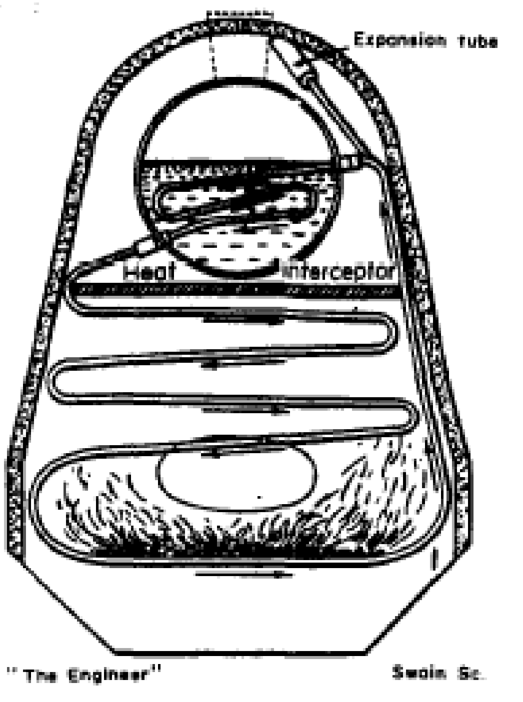
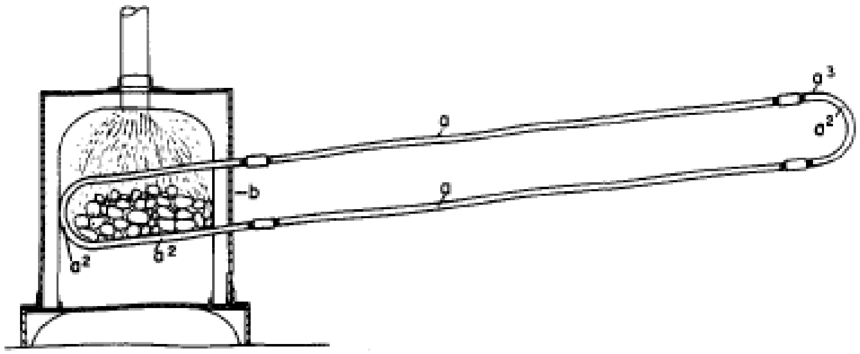


Fig. 3. Portable Perkins oven for army use.



Closer to Chemical Engineering – safety first!

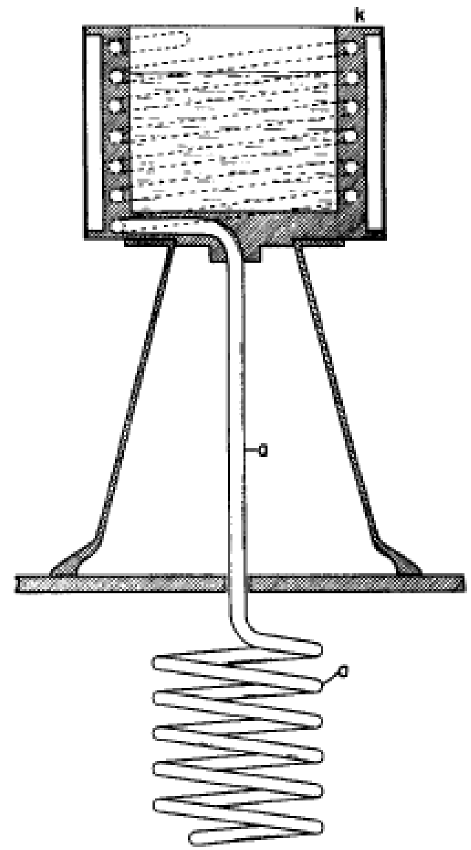


Fig. A9. A sectional elevation illustrating the application of our invention in warming or melting inflammable substances.

The current version of the Perkins Heat Exchanger

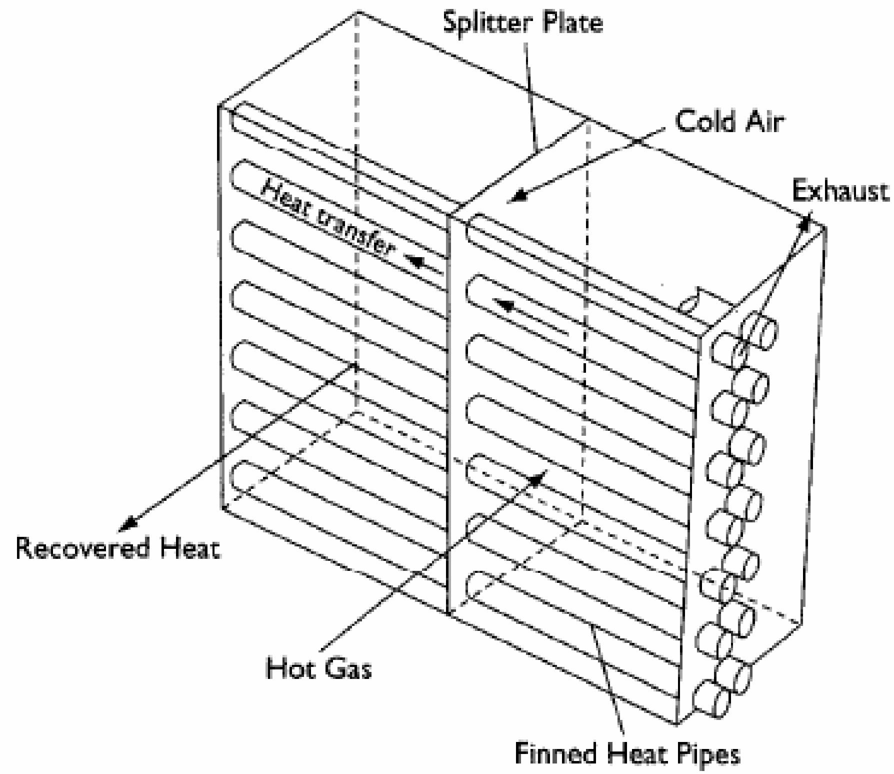


Fig. 7.18 Layout of a heat pipe heat exchanger showing means of heat transfer.

Heat Pipe Working Fluids

Table 3.1 Heat pipe working fluids

Medium	Melting point (°C)	Boiling point at atmos. press. (°C)	Useful range (°C)
Helium	−271	−261	−271 to −269
Nitrogen	−210	−196	−203 to −160
Ammonia	−78	−33	−60 to 100
Pentane	−130	28	−20 to 120
Acetone	−95	57	0 to 120
Methanol	−98	64	10 to 130
Flutec PP2[1]	−50	76	10 to 160
Ethanol	−112	78	0 to 130
Heptane	−90	98	0 to 150
Water	0	100	30 to 200
Toluene	−95	110	50 to 200
Flutec PP9[1]	−70	160	0 to 225
Thermex[2]	12	257	150 to 350
Mercury	−39	361	250 to 650
Caesium	29	670	450 to 900
Potassium	62	774	500 to 1000
Sodium	98	892	600 to 1200
Lithium	179	1340	1000 to 1800
Silver	960	2212	1800 to 2300

Note: (The useful operating temperature range is indicative only.) Full properties of most of the above are given in Appendix 1.

[1] Included for cases where electrical insulation is a requirement.

[2] Also known as Dowtherm A, an eutectic mixture of diphenyl ether and diphenyl.

Fluids can cover temperature ranges appropriate to most reactors.

Liquid metals used – eg sodium.

Comparison of fluid performance

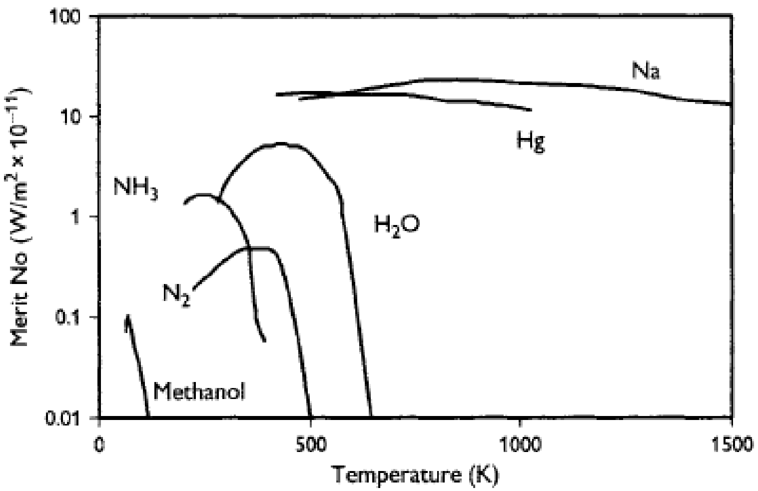


Fig. 2.36 Merit Number of selected working fluids.

Merit number compares relative heat transport capability of different working fluids.

Strong function of latent heat, surface tension, viscosity

Limitation to heat transport are several

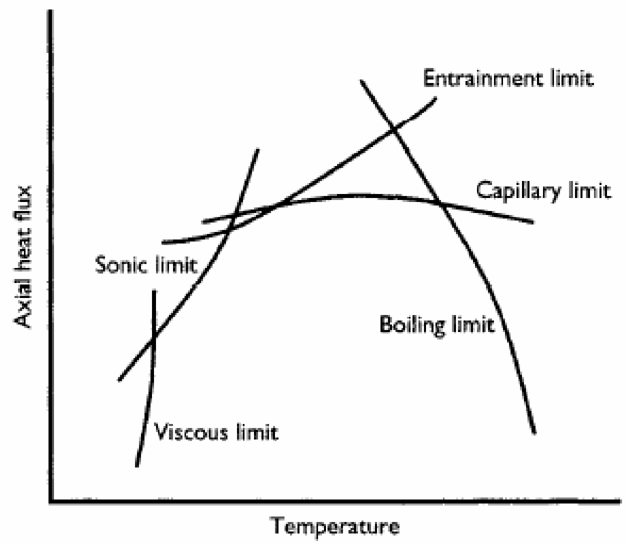


Fig. 2.1 Limitations to heat transport in a heat pipe.

Capillary limit affected by orientation of heat pipe & wick design.

The wick is a passive pump.

Sonic limit occurs when fluid density high (eg at low T)

Types of Heat Pipe

Variable conductance heat pipes
Thermal diodes
Pulsating (oscillating) heat pipes
Loop heat pipes (LHPs) and capillary pumped loops (CPLs)
Micro-heat pipes
Use of electrokinetic forces
Rotating heat pipes
Miscellaneous types – sorption heat pipe (SHP); magnetic fluid heat pipes

Applications as a Function of Heat Pipe Features

7.1 BROAD AREAS OF APPLICATION

In general, the applications come within a number of broad groups, each of which describes a property of the heat pipe. These groups are:

(i) Separation of heat source and sink
(ii) Temperature flattening, or isothermalisation
(iii) Heat flux transformation
(iv) Temperature control
(v) Thermal diodes and switches

Isothermalisation

Isothermalisation – or evening out of temperatures, is an inherent feature that may benefit reactors

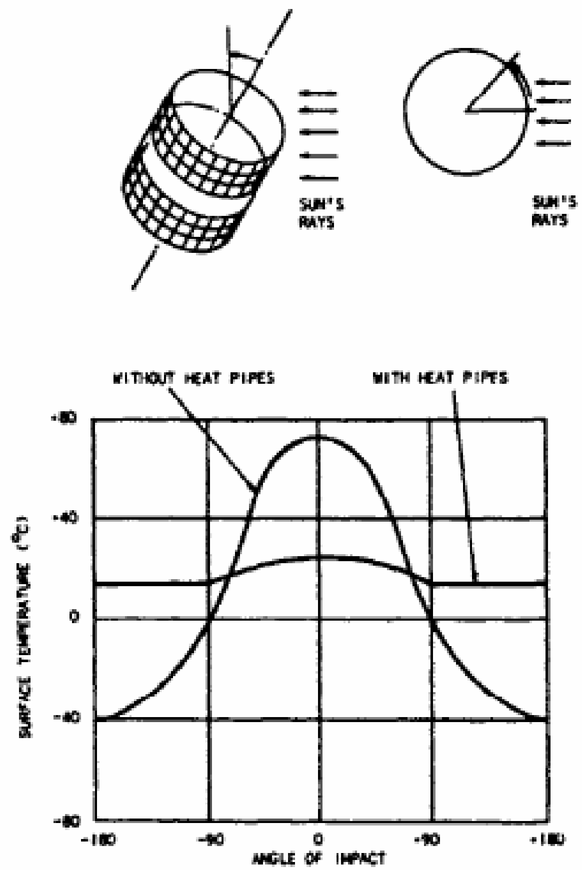


Fig. 7.1 Satellite isothermalisation (Courtesy Dornier Review).

Variable Conductance HP in a Reactor (Nuclear)

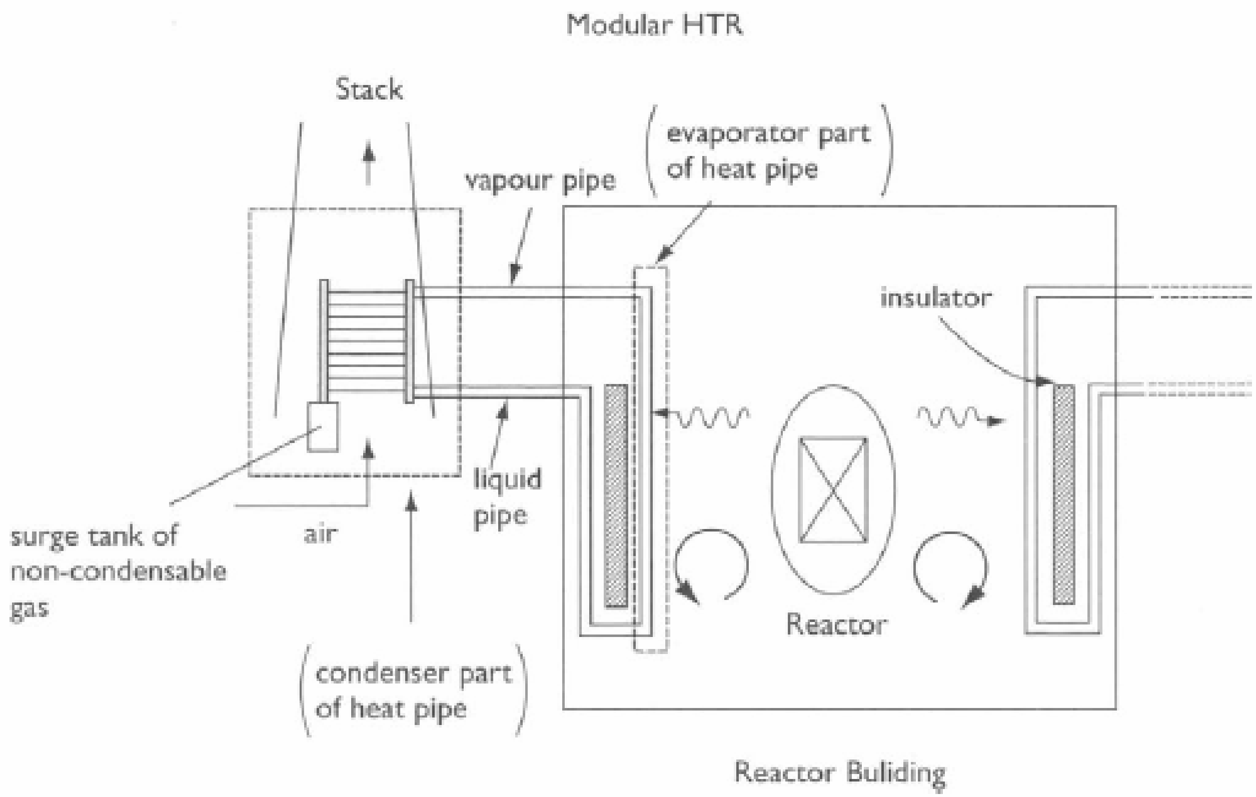


Fig. 7.6 Concept of VCHP decay heat removal system for the modular high temperature reactor [17].

Benefits in Chemical Reactors

Catalysts have been put on heat pipes, with surface reactions. The heat pipe is in ideal way of heat removal/input to the catalyst thereon.

The catalyst need not, of course, be applied directly onto the heat pipe in order to give benefits. Reay and Ramshaw [19] listed the following positive effects the heat pipe might have on catalytic behaviour:

- Isothermal operation where the heat pipe would be inherently safe for the removal of reaction hotspots (and coldspots), and, as here, for uniform heat input and isothermalisation.
- Capability to deal with high heat fluxes, both radial and axial. Liquid metal heat pipes can be used in high-temperature chemical reactors.
- Heat pipes have much faster response time to a thermal input than, say, a solid conductor. They can therefore be used to speed up the heating of a catalyst support structure (and the catalyst) easing light-off in combustion, as an example.

More possible benefits in Reactors

- A range of heat pipe working fluids can be selected to cover all temperatures envisaged in catalysis. In Chapter 5, a sodium heat pipe destined for catalytic reforming plant is illustrated.
- Variable conductance heat pipes (see Chapter 6) can be designed to maintain the temperature of catalysts near or on their surface at a constant temperature, independent of heat generation rates. This opportunity for reactor control could be highly important in temperature critical reactions.
- Heat pipes have already been used to even out temperature excursions in reactors, thereby increasing yield and hence reactor efficiency.
- Heat pipe surfaces have been plasma-sprayed with materials such as alumina and are therefore readily treatable as catalyst support members.

Chinese Chemical Heat Pipe Reactor

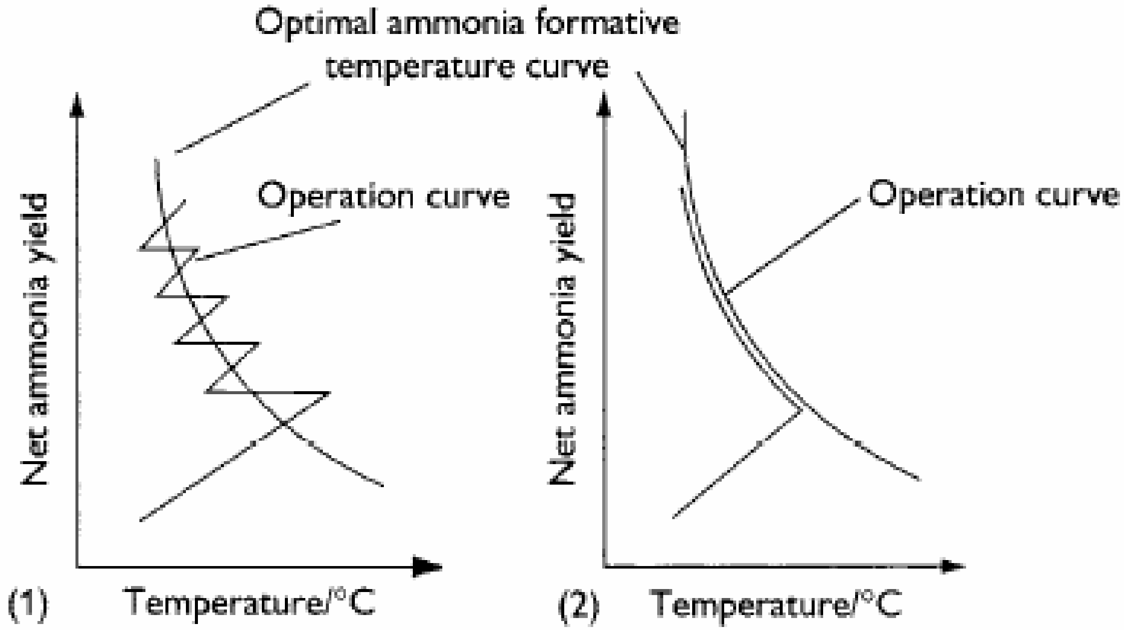


Fig. 7.11 Heat pipe reactor operation curves (China).

VCHP Concepts – Passive Control

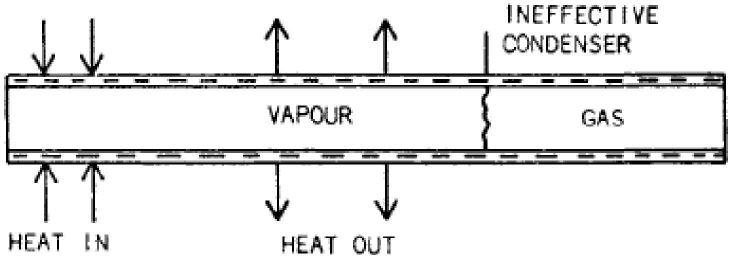


Fig. 6.1 Equilibrium state of a gas-loaded heat pipe.

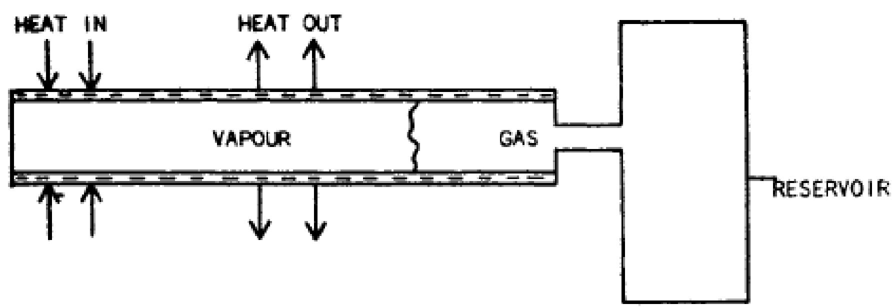


Fig. 6.2 Cold-reservoir variable conductance heat pipe.

VCHP – Passive Feedback Control

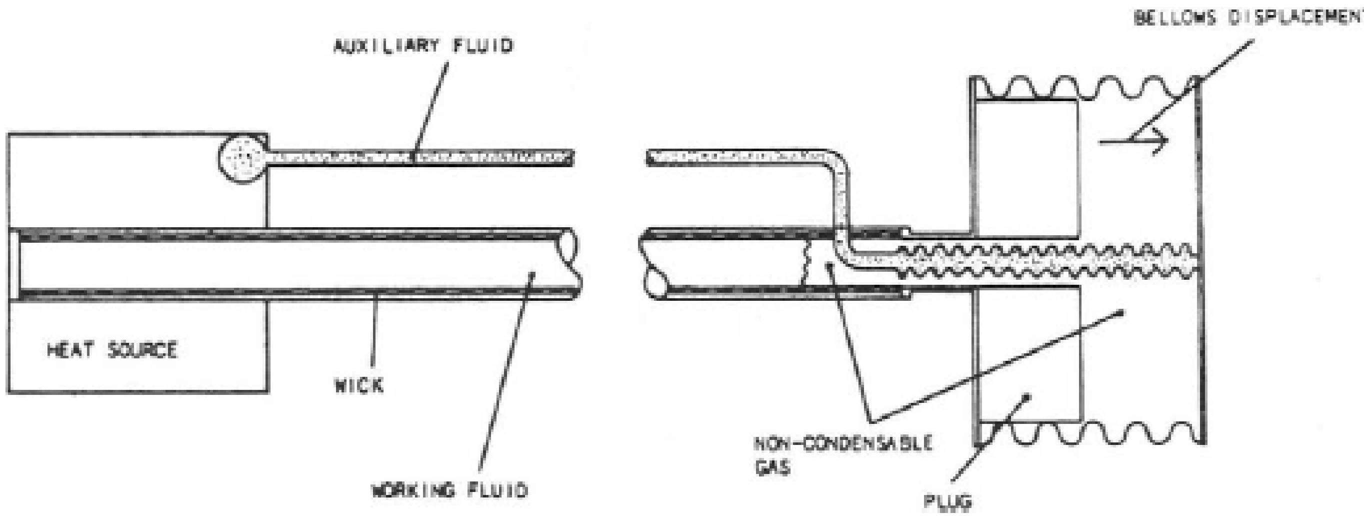


Fig. 6.6 Passive feedback-controlled variable conductance heat pipes.

VCHP – Active Feedback Control – as shown earlier

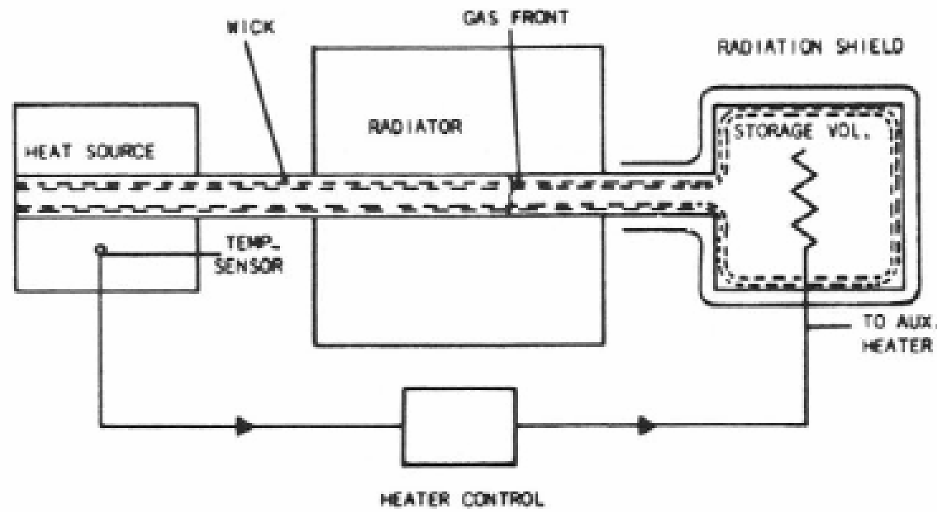


Fig. 6.5 Active feedback-controlled variable conductance heat pipe.

As with the SDR, rotation aids heat transfer and fluid transport

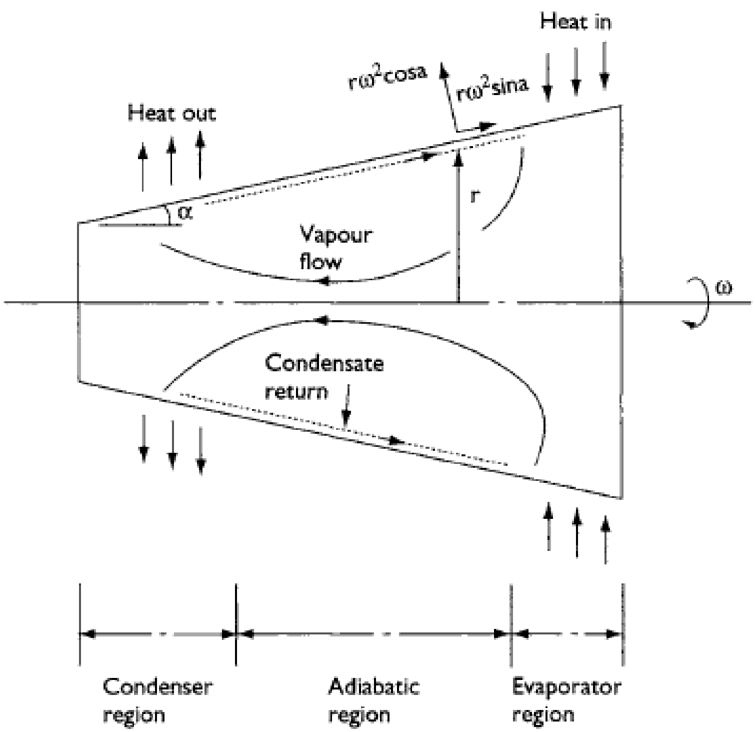


Fig. 6.40 Rotating heat pipe.

Used for cooling rotating machinery

Other rotating variants

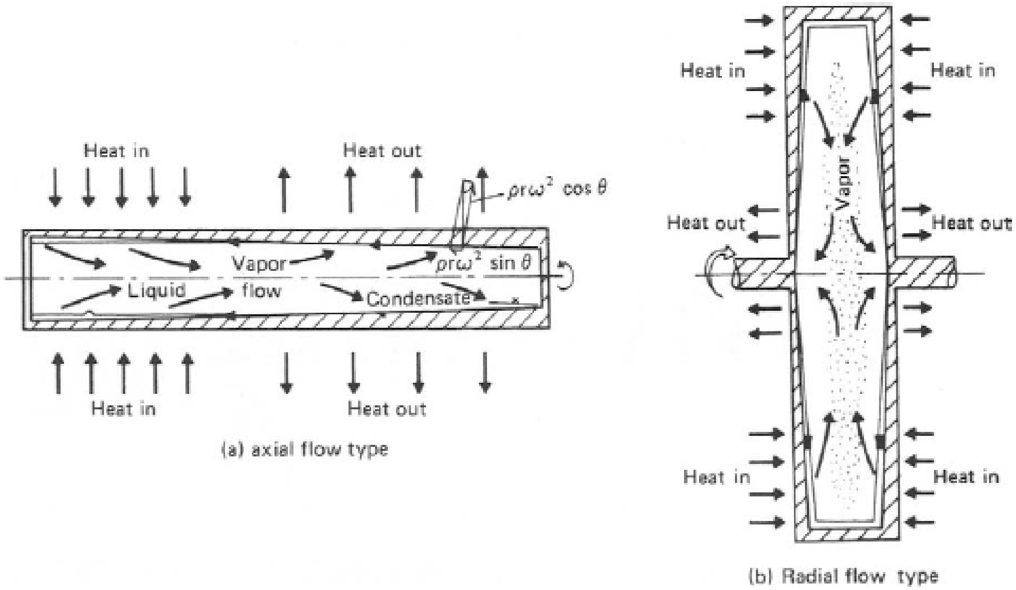


Fig. 6.45 The disc-shaped rotating heat pipe (b) [74].

In Conclusion

- The heat pipe, in its several variants, has many interesting heat transfer features.
- The heat pipe/thermosyphon could act to isothermalise reactor vessels, minimising uneven reaction rates.
- The ability to passively control temperatures at its evaporator could contribute to minimise excursions in endo- or exothermic reactions.
- The application of active feedback control can lead to precise temperature control.

- Newcastle University is able to collaborate with potential partners in bringing the technology into the marketplace.

Common wastewater treatment