THE FLASH EVAPORATOR FOR TRANSIENT HEAT LOADS

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INTRODUCTION

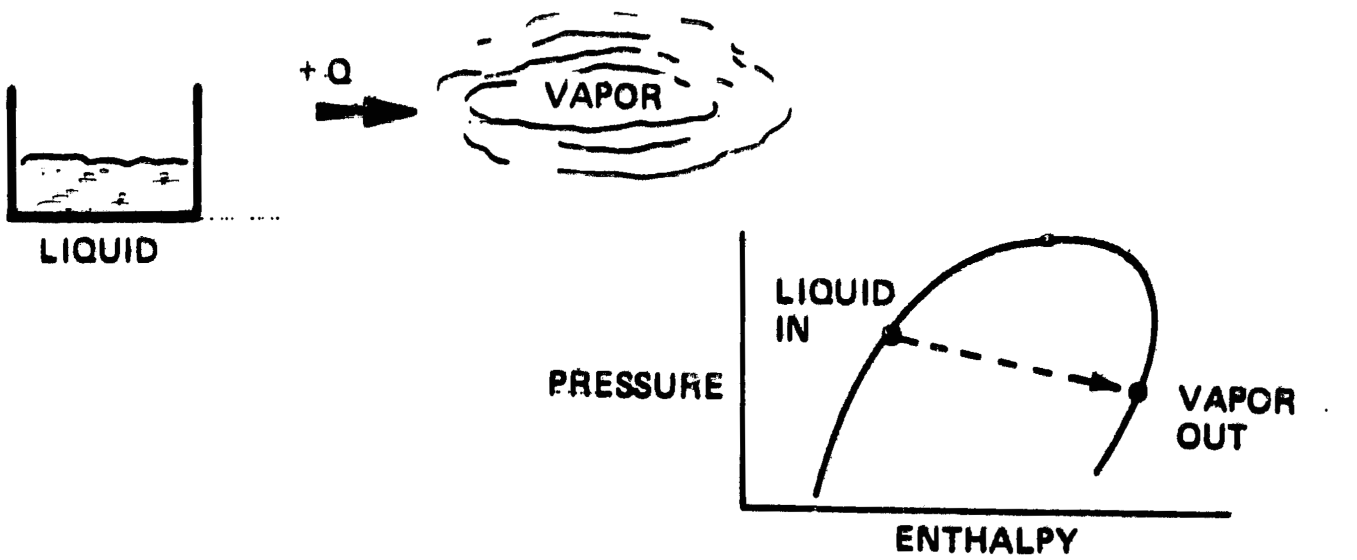
The thermal control system for the shuttle is being projected to include an expendable heat sink to augment the radiator and to provide primary heat rejection during atmospheric flight phases. Any device must demonstrate certain features to warrant its development for shuttle usage. These include high efficiency, capability to meet the high load transients as well as steady state, capability to respond quickly after dormant periods and to assume dormant operation, and sufficient simplicity to insure superior reliability. In addition to these requirements, it is attractive to obtain a single device which can utilize various evaporants. This document reports an investigation of the feasibility of a liquid spray flash evaporator concept intended to satisfy the objectives outlined.

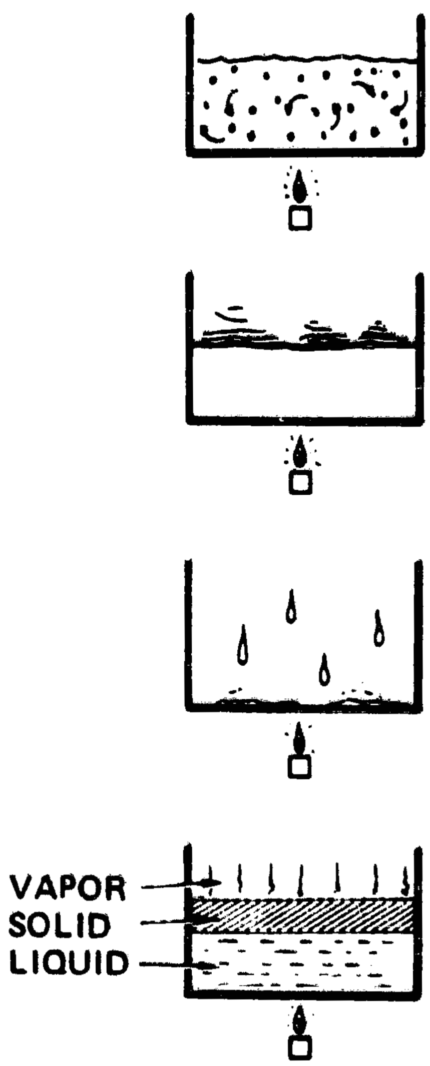
OBJECTIVES

1. Heat Load 0 - 25000 BTU/HR, inlet temperature ramps of 5 degrees per minute.
2. Outlet temperature range 35 to 45 F.
3. Evaporants H_2O, NH_3 or R-22 in pertinent pressure range.
4. Accelerations 0 - 4 g.
5. No backpressure control.
6. Heat rate control by supply rate modulation.
7. High enthalpy of vaporization.

VAPORIZATION PROCESSES

A liquid changes to a vapor with the addition of heat by any of several mechanisms. Devices associated with these mechanisms have associated with them a necessary rate control variable. In the case of the droplet evaporation device, the heat rate control by supply modulation is considered to be especially attractive from a simplicity standpoint when compared to backpressure control. It compares favorably with the sublimation device having an excellent rate control mechanism which is penalized to accommodate intermittent operation. Thus, it is attractive to pursue a device which evaporates liquids by the droplet evaporation mechanism. See Figure 1.





MECHANISM	RATE CONTROL VARIABLE
BOILING	BACKPRESSURE
POOL EVAPORATION	BACKPRESSURE
DROPLET EVAPORATION	SUPPLY RATE
FREEZING & SUBLIMATING	ICE THICKNESS (SELF REGULATING)

Figure 1. Vaporization Processes

DROPLET IMPINGEMENT

Several phenomena may occur during single droplet impingement of a three phase, single component fluid. The particle could freeze in transit with a corresponding inability to efficiently vaporize it. The particle could impinge on the wall as a liquid and evaporate, boil gently, or boil violently. In either of the first two the entire droplet can evaporate efficiently, while a significant fraction of the liquid in the latter case could be ejected. Finally, the liquid could be supplied faster than the evaporation with accumulation resulting. The bounds of desired operation are considered violated when the droplets freeze or when accumulation is encountered. The violent boiling will probably result in a fluid selection criterion rather than a design problem. The limits of freezing and accumulation will be estimated using both experimental and analytical techniques. See Figure 2.

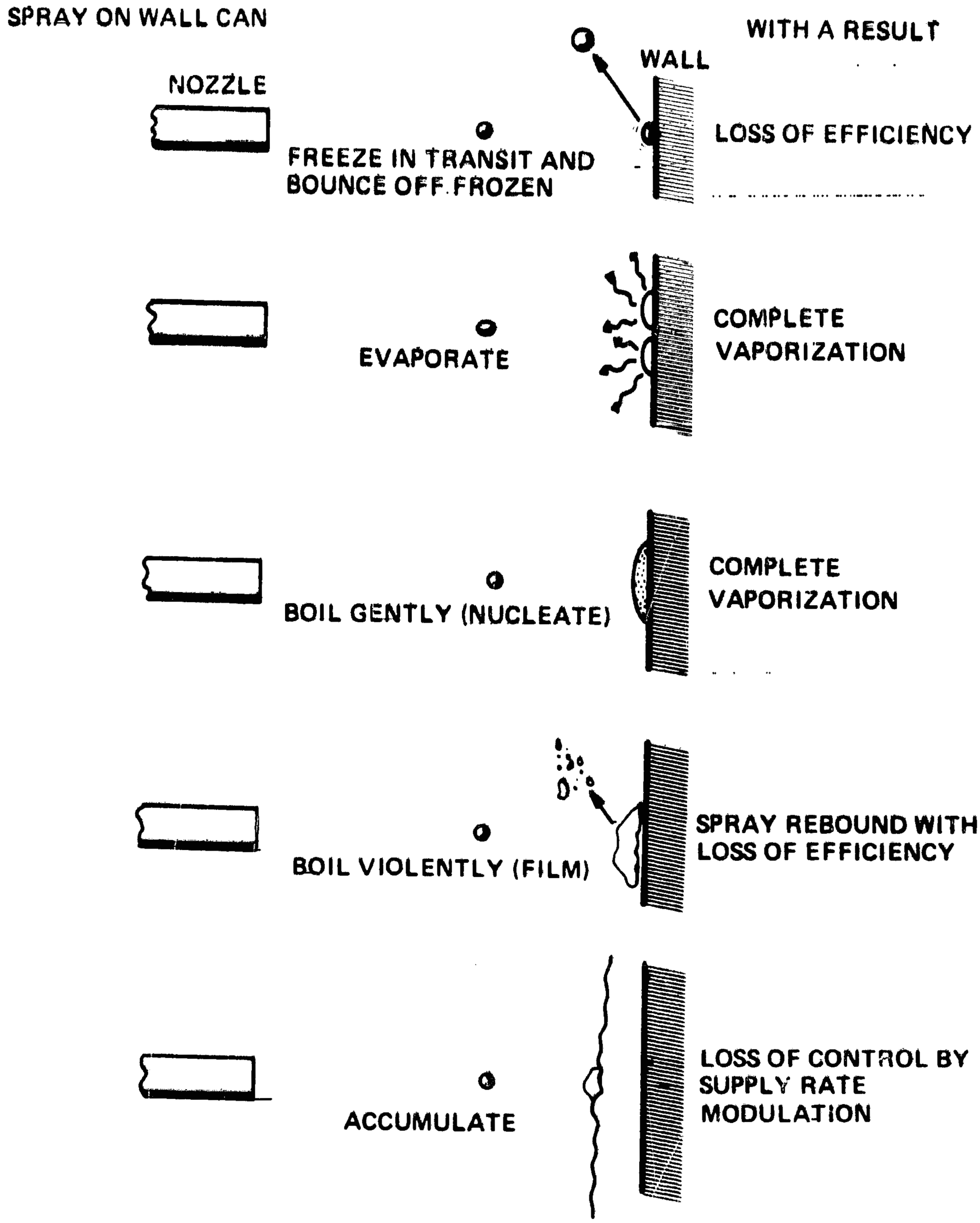


Figure 2. Droplet Impingement

WATER FREEZING CHARACTERISTICS

The time required to freeze a particle in flight may be analyzed using any of several approximate techniques. Figure 3 shows the length of time to complete freezing for water particles at various ambient conditions. The typical size of particles obtained from an atomizing nozzle is about 100 microns which would freeze in a distance of about one foot under vacuum conditions with a velocity of 50 feet per second. Raising the pressure from zero to a saturation temperature of 10°F produces nearly twice the distance to freezing. Thus, both the length of path, velocity, and ambient pressure have significant effects on the condition of the particle.

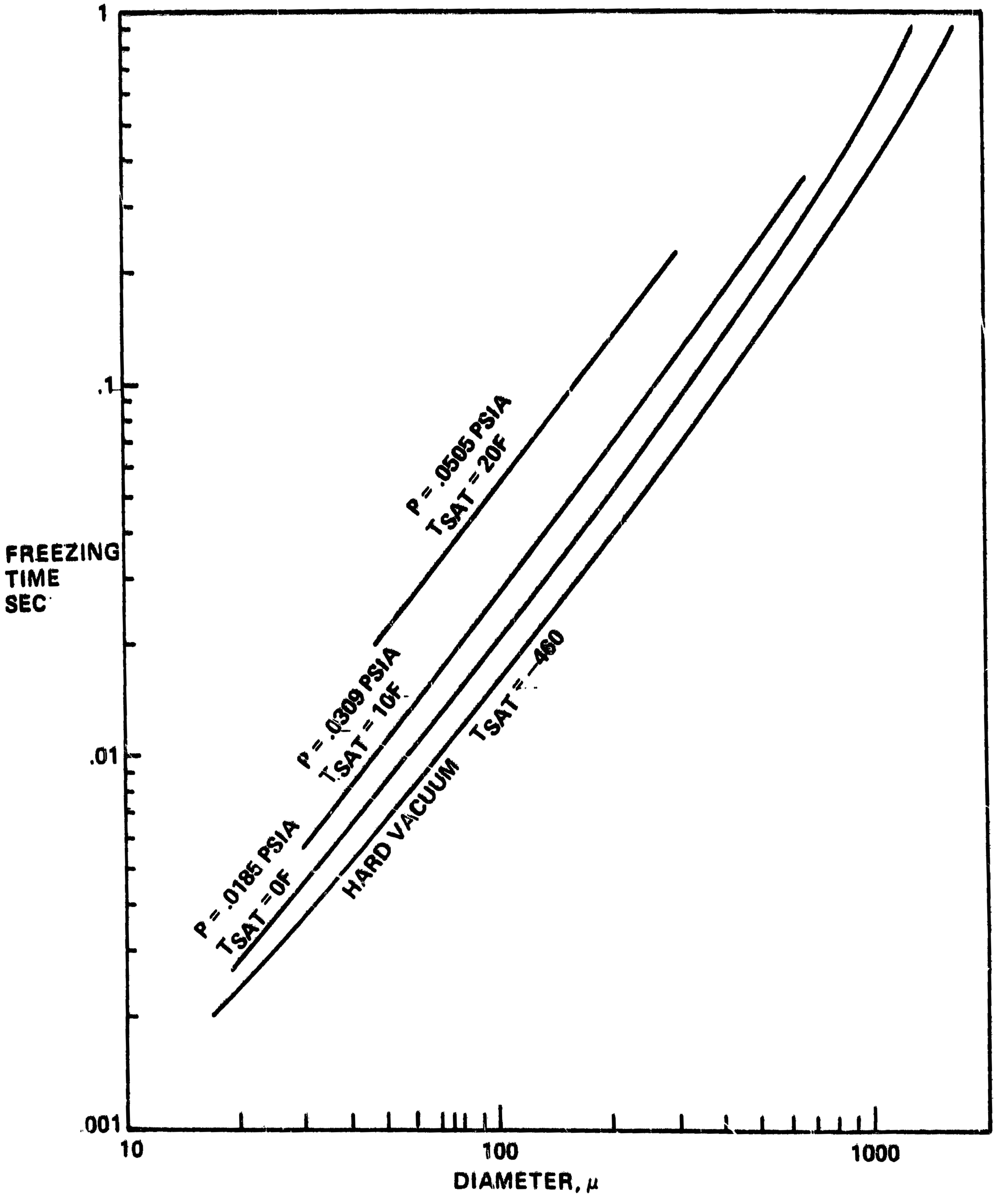


Figure 3. Water Freezing Characteristics

FLOODING TENDENCY OF SUPPLY VERSUS EVAPORATION RATES

The possible flooding of the evaporator surface has been analyzed by evaluating the characteristic supply time and evaporation time. See Figure 4. The characteristic supply time may be calculated as the time required to produce an equal number of particles and targets. These targets are a size such that a particle at target center will be hit by a second particle when the latter falls within the target. The characteristic evaporation time is calculated from a direct heat transfer solution. The evaporator is expected to flood whenever the supply time is less than the evaporation time. The excess in supply time over evaporation time provides for margin against variations in supply flux, etc. Within the range of droplet sizes expected, a one square foot evaporator is more than adequate to prevent flooding for water. The only evaporants (R-22, NH_3) have relatively similar characteristics.

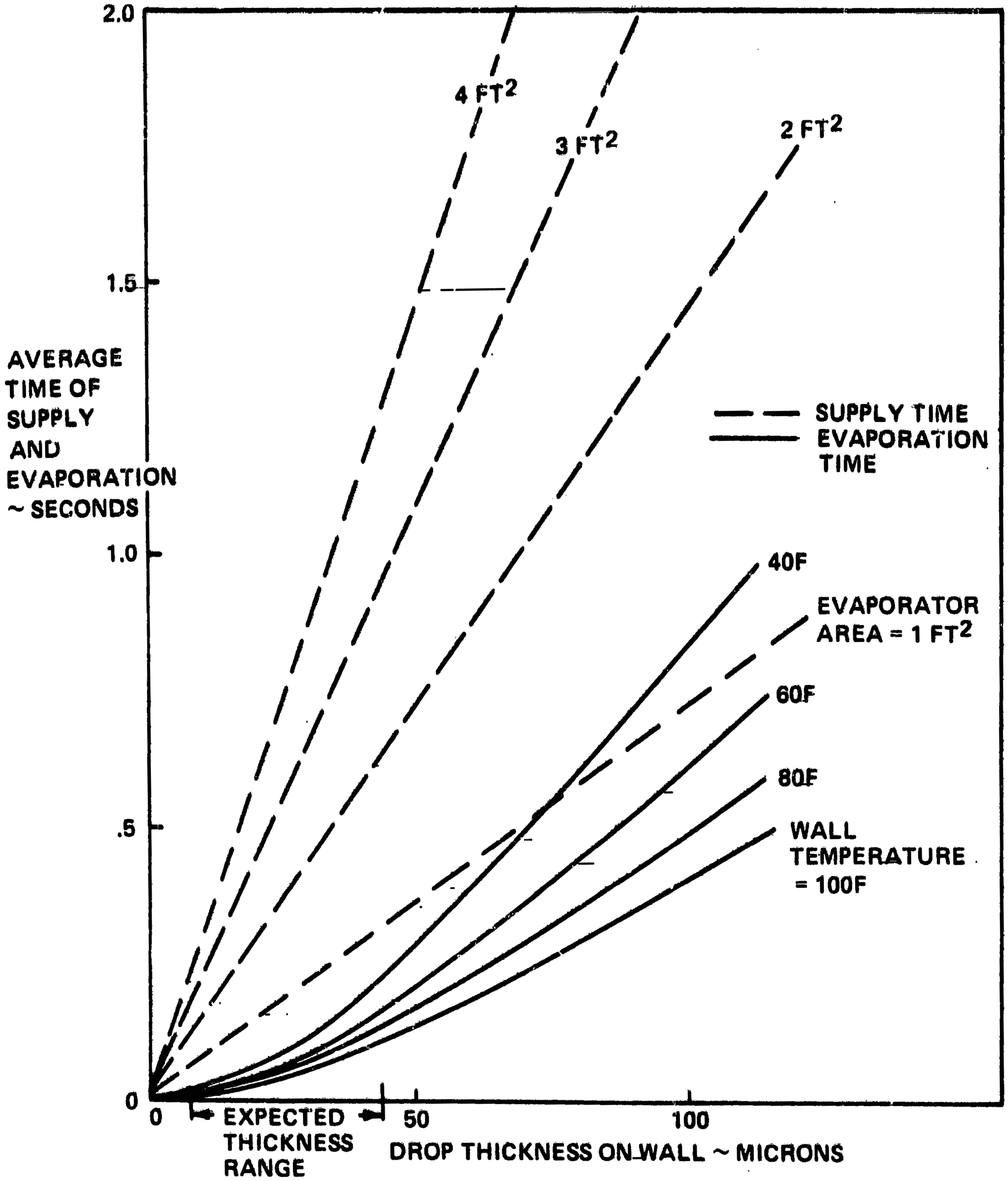


Figure 4. Flooding Tendency of Supply Versus Evaporations Rates

LIMITS OF DESIRED OPERATION

From the foregoing, the range of evaporator size and particle size may be calculated in which the evaporator will have the postulated single droplet evaporation mode. The parameters listed have such a strong effect (particularly the ambient pressure) that many sets of charts would be required to completely describe the situation. Particle freezing is a more formidable problem since the sizes at which the spray accumulates are actually much less than can be accommodated by the transport side heat transfer. This transport side design impact is the strongest sizing parameter in the system and will be illustrated shortly. See Figure 5.

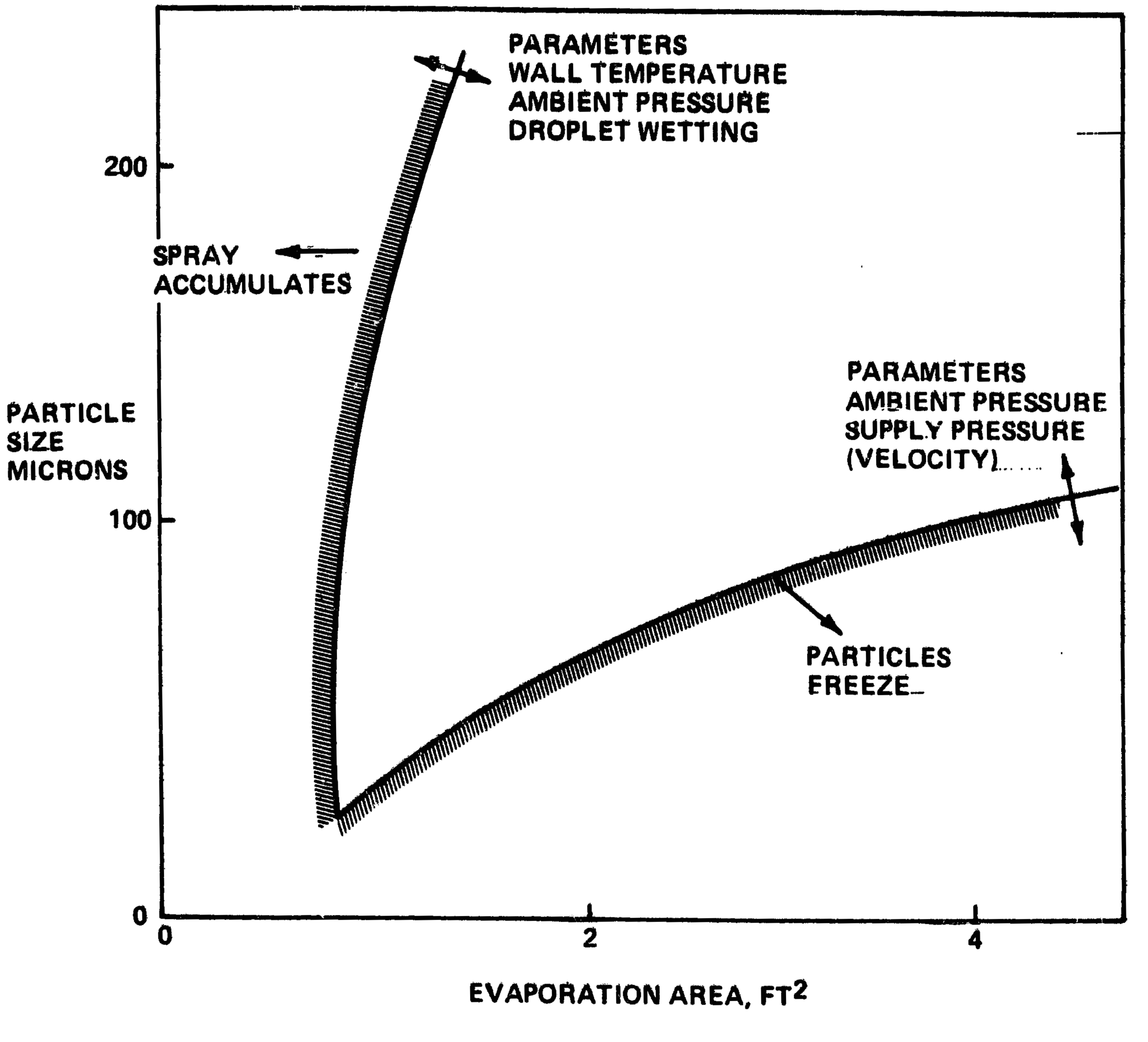


Figure 5. Limits of Desired Operation

EXPLORATORY TEST

An experiment was contrived to evaluate the effect of the basic parameters. The test objective was to establish the efficiency potential which each evaporant, to evaluate 4g effects, and to gain insight into operational problems associated with nozzle freezing, etc. The energy used to evaporate the fluid was extracted from the heat storage of a heavy test article. The simulated evaporator at a uniform high temperature was sprayed for a short interval and then allowed to reach equilibrium. The energy release calculated from before and after temperatures was divided by the expended evaporant weight to yield the enthalpy of evaporation actually obtained. This enthalpy could then be analyzed according to the appropriate parameters to account for the losses. See Figure 6.

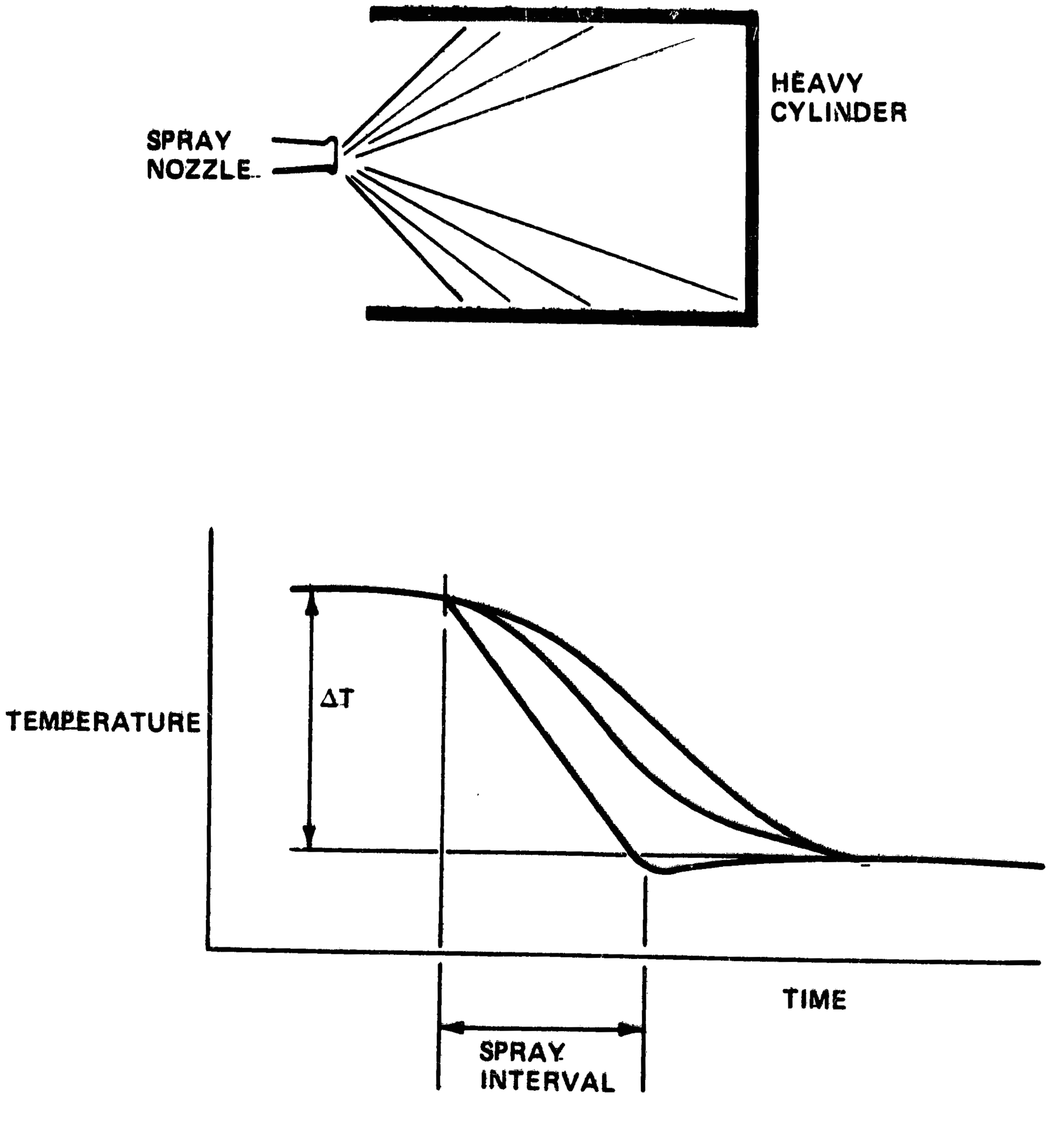


Figure 6. Exploratory Test

EXPLORATORY TEST RESULTS

The exploratory test results for water were found to form two relatively distinct data groups. At low ambient pressure, particles were observed to rebound from the evaporator wall, suggesting, together with the measured low efficiency, that the particle freezing had caused a reduction in efficiency. At higher ambient pressures, the efficiency was observed to decrease when the wall temperature approached the saturation temperature. This result is interpreted to indicate some flooding during the run. See Figure 7.

While reasonably high liquid use efficiencies were obtained with water, both the Freon 22 and NH_3 never achieved high efficiency. Some of the cause for this loss was a direct carryover of liquid droplets entrained in the vapor flow.

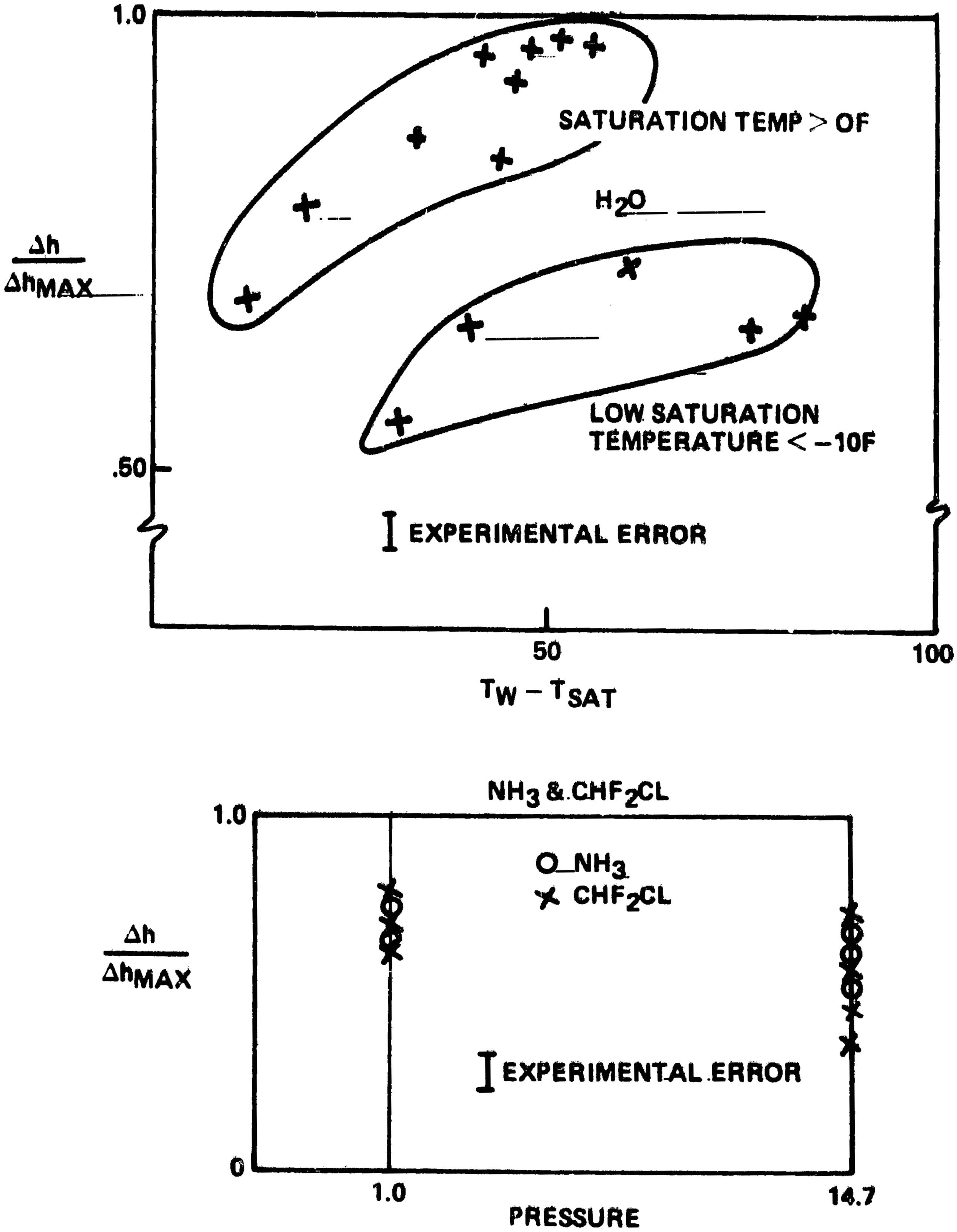


Figure 7. Exploratory Test Results

TRANSPORT FLUID SIDE DESIGN

A simple heat transfer and pressure drop calculation for the series tube evaporator heat exchange surface yields a result as illustrated in Figure 8. The transport fluid in this calculation is Freon 21 which is anticipated for the shuttle application. A similar plot results for water but tends to lower values of pressure drop and temperature difference.

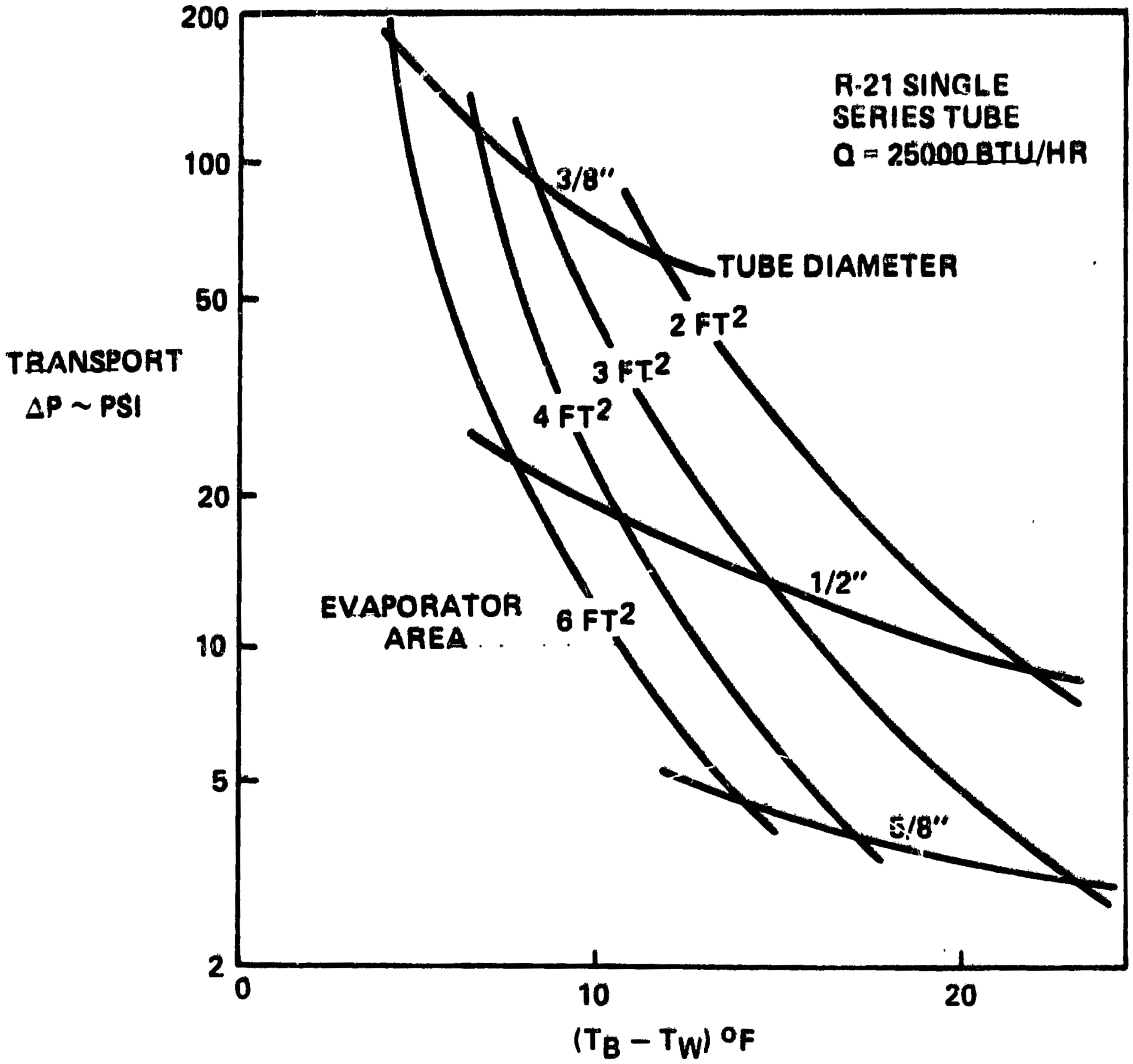


Figure 8. Transport Fluid Side Design

PARALLEL FLOW PATH OPTIMIZATION

A calculation of the previous type can be made for multiple tubes in parallel flow for Freon 21 transport fluid. By choosing the unique value of tube size and evaporator area which yield a selected pressure drop and temperature difference, one may determine the number of paths which yields the smallest evaporator. From such an exercise the area is found to be about 4 square feet for the 25000 BTU/HR device. This area could be decreased somewhat if an increased fin effect could be incorporated into the heat exchange surface. See Figure 9.

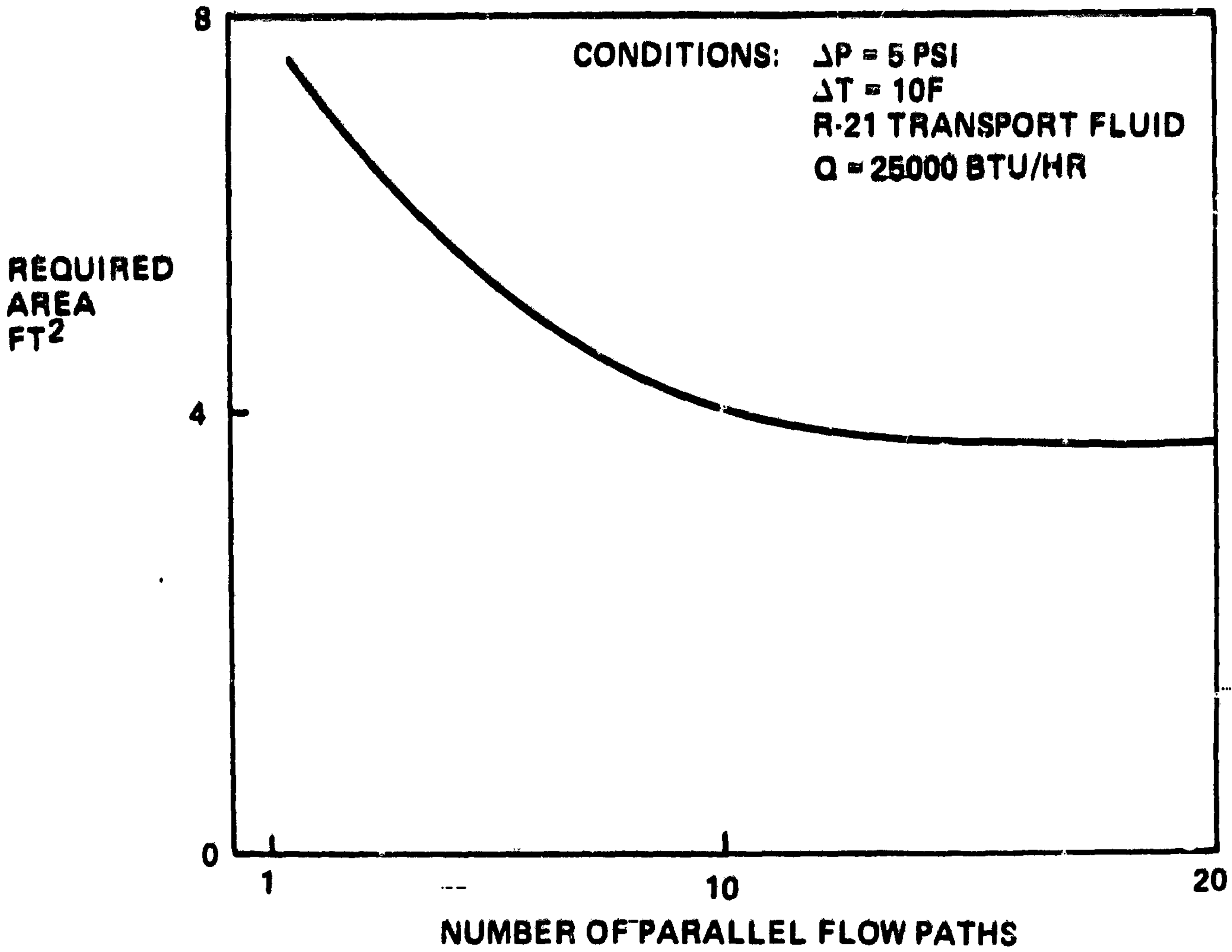
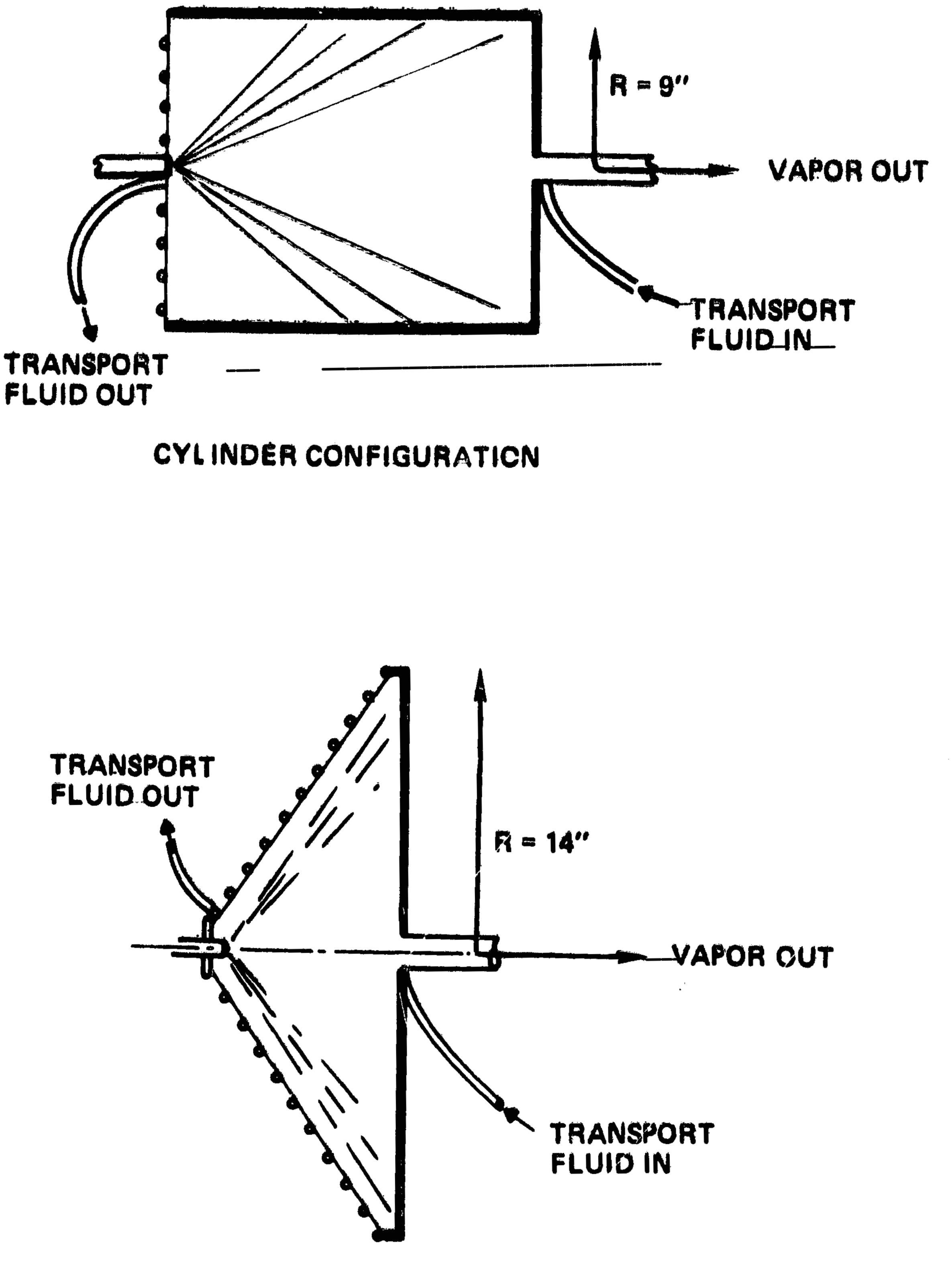


Figure 9. Parallel Flow Path Optimization

EVAPORATOR CONFIGURATIONS

With the addition of the transport fluid loop considerations, a pair of evaporators was constructed. See Figure 10. The active area of these evaporators was about 4 square feet with the anticipated spray pattern. Each of these evaporators is a fabricable configuration, and each tends to skew the spray flow differently allowing for differences in spray distribution. To provide the ambient pressure required for high efficiency, an exit hole was sized to choke the flow supplied at the desired pressure.



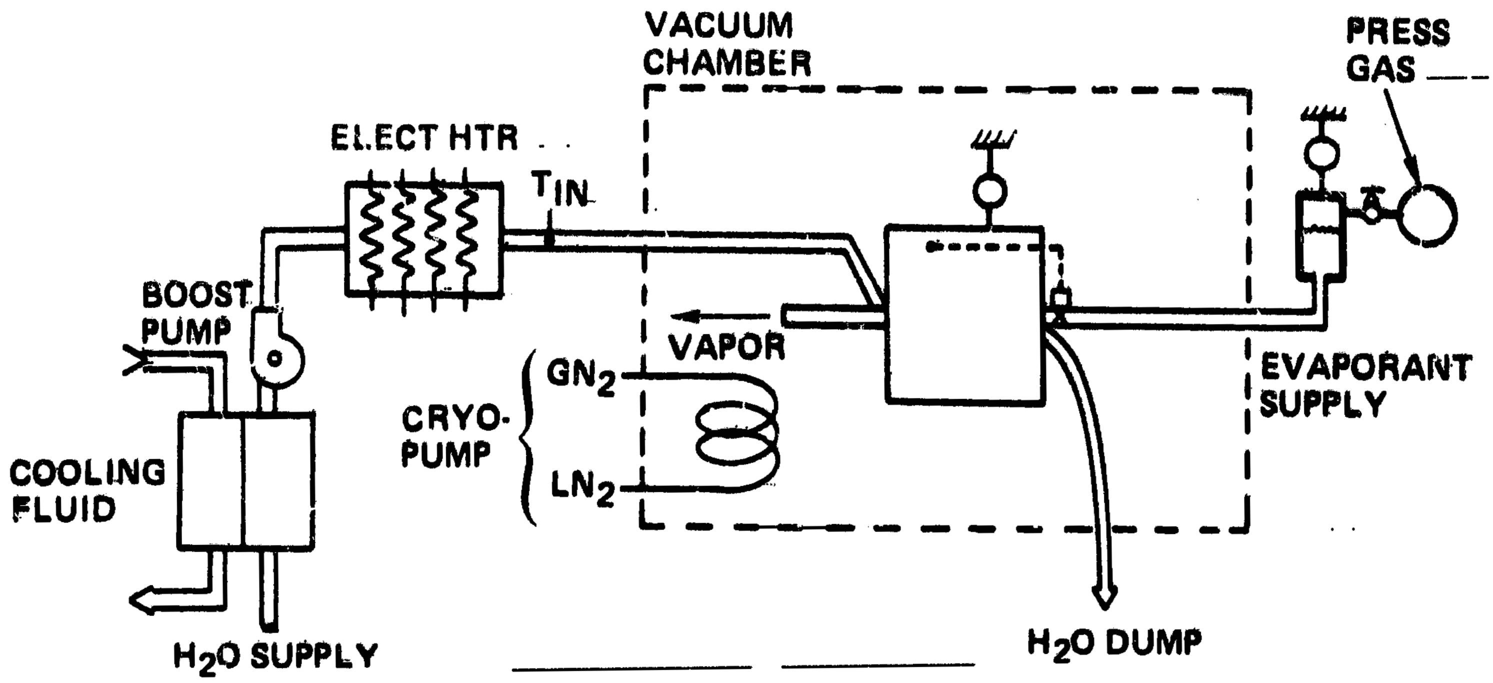
CYLINDER CONFIGURATION

PLATE CONFIGURATION

Figure 10. Evaporator Configurations

TEST SETUP AND CONDITIONS

The evaporators were installed in a vacuum chamber which was maintained at low pressure primarily by a liquid nitrogen cryopump. Test cell pressures below 0.02 psia assured choking of the exit port during operation. Actual pressures ranged between 10 and 1000 microns Hg (.0002 and .02 psia) except during exceptional circumstances. The water used as transport fluid was preconditioned by a cooling fluid and an electrical heater to achieve one of the two illustrated inlet temperature profiles. The evaporant was supplied using a pressurant gas at regulated pressure. See Figure 11.



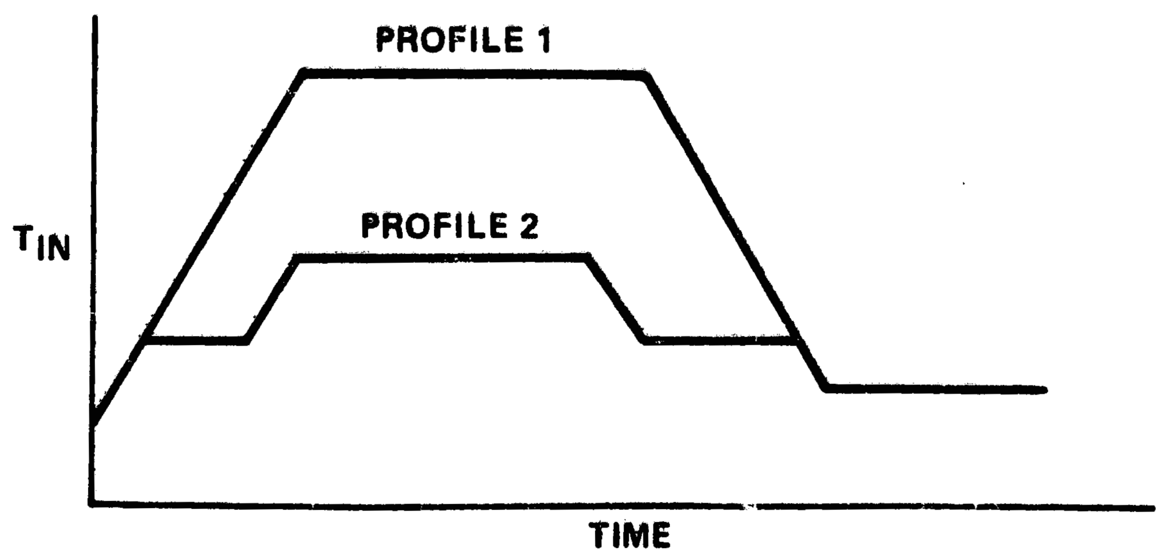


Figure 11. Test Setup and Conditions

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CYLINDER TEST INSTALLATION

The non-insulated cylindrical evaporator is shown installed in the chamber in Figure 12. Construction detail of the evaporator showing the rectangular tubing welded together is shown clearly. At the right is the evaporant supply line and valve, while on the left is a plexiglas tube simulating the vapor vent line. This tube accumulated up to an estimated 1/8 inch frost during testing. The evaporator was suspended from a load cell which could detect a one ounce accumulation within the evaporator.

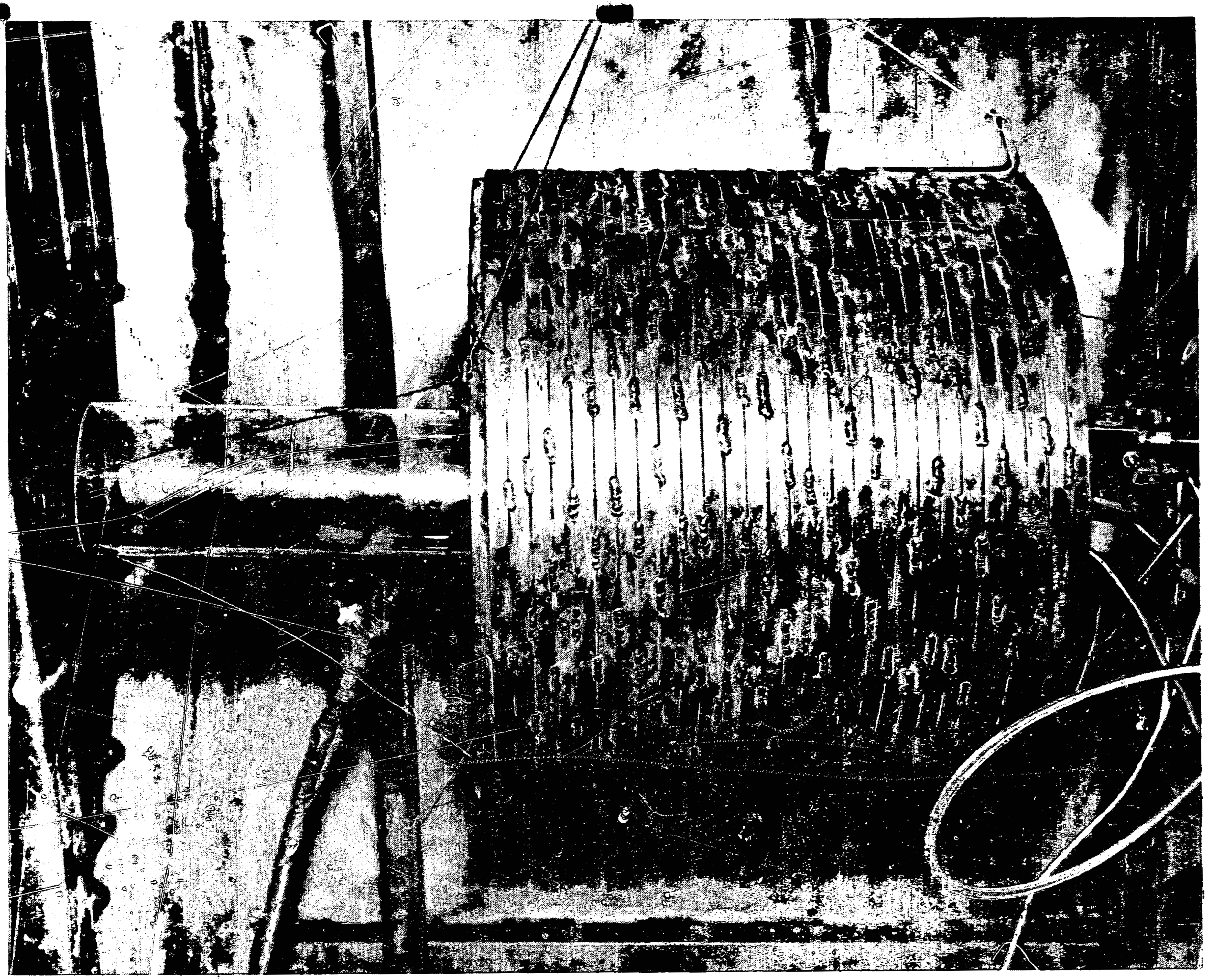
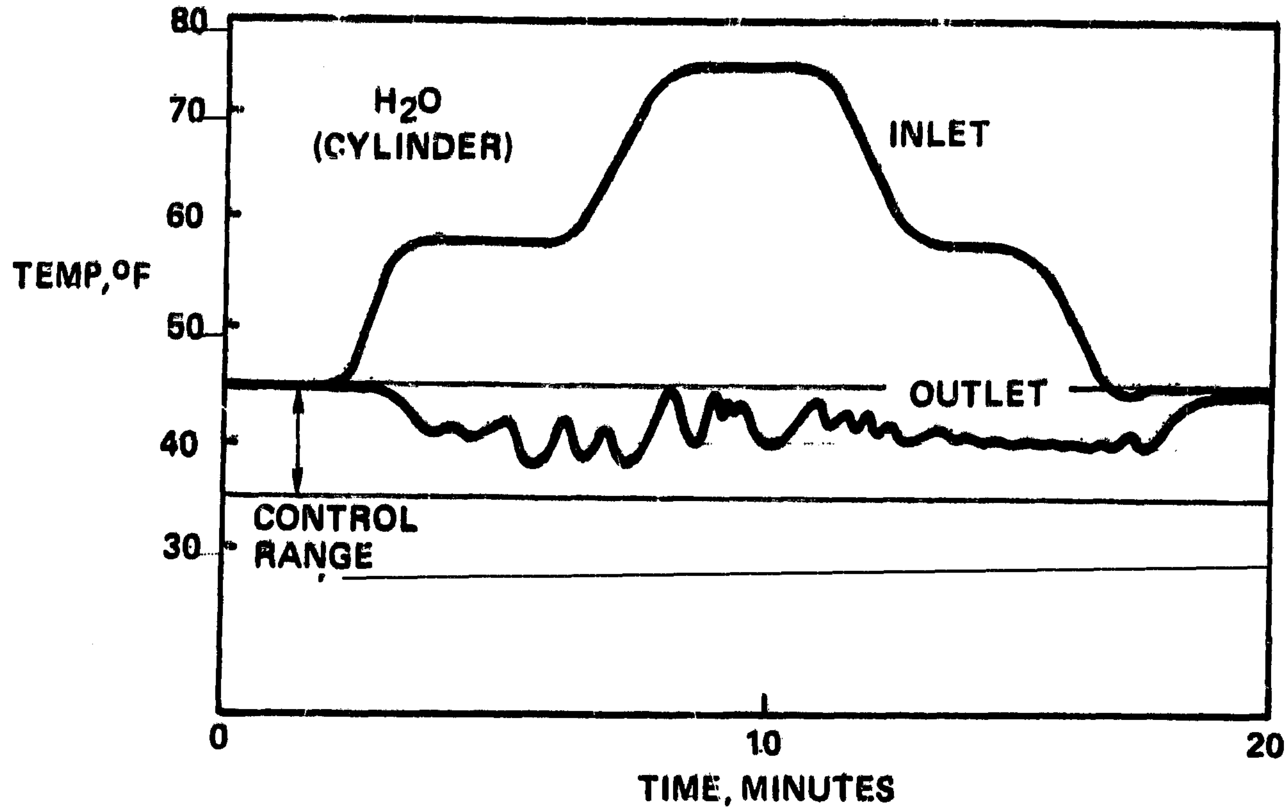


Figure 12. Cylinder Test Installation

TYPICAL RESULTS: H_2O

Results for water are as anticipated, with the evaporator's outlet temperature bounded between 35 and 45 degrees. An average of all results obtained indicates that about 93 percent of the injected water was evaporated at the predicted enthalpy rise. The only problem during testing was associated with evaporant freezing on the nozzle. This problem was circumvented by a gas nozzle purge of the liquid hold up, or by simply replacing stainless steel with a brass nozzle. Heating the nozzle was not effective in eliminating freezing. See Figure 13.



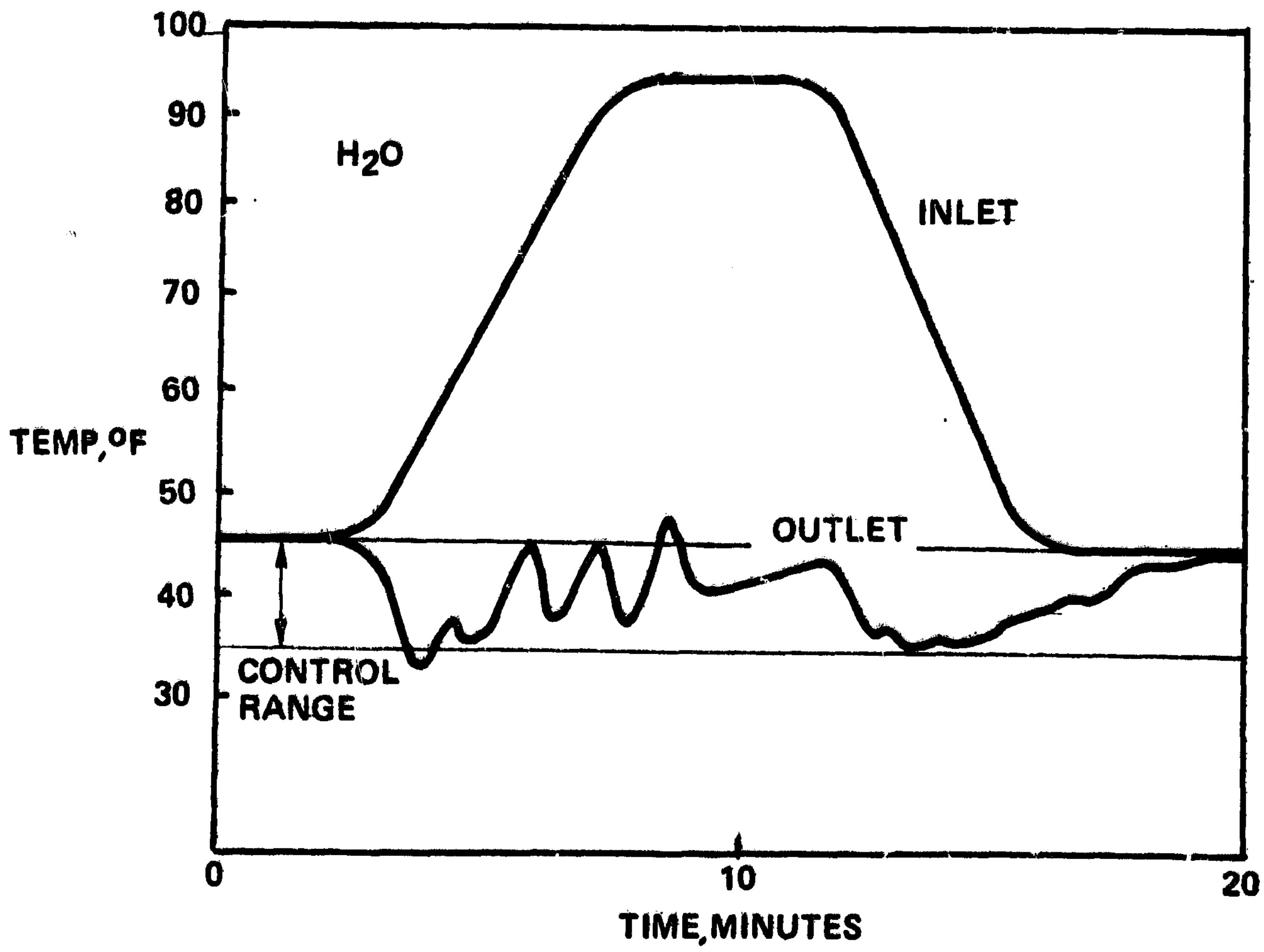
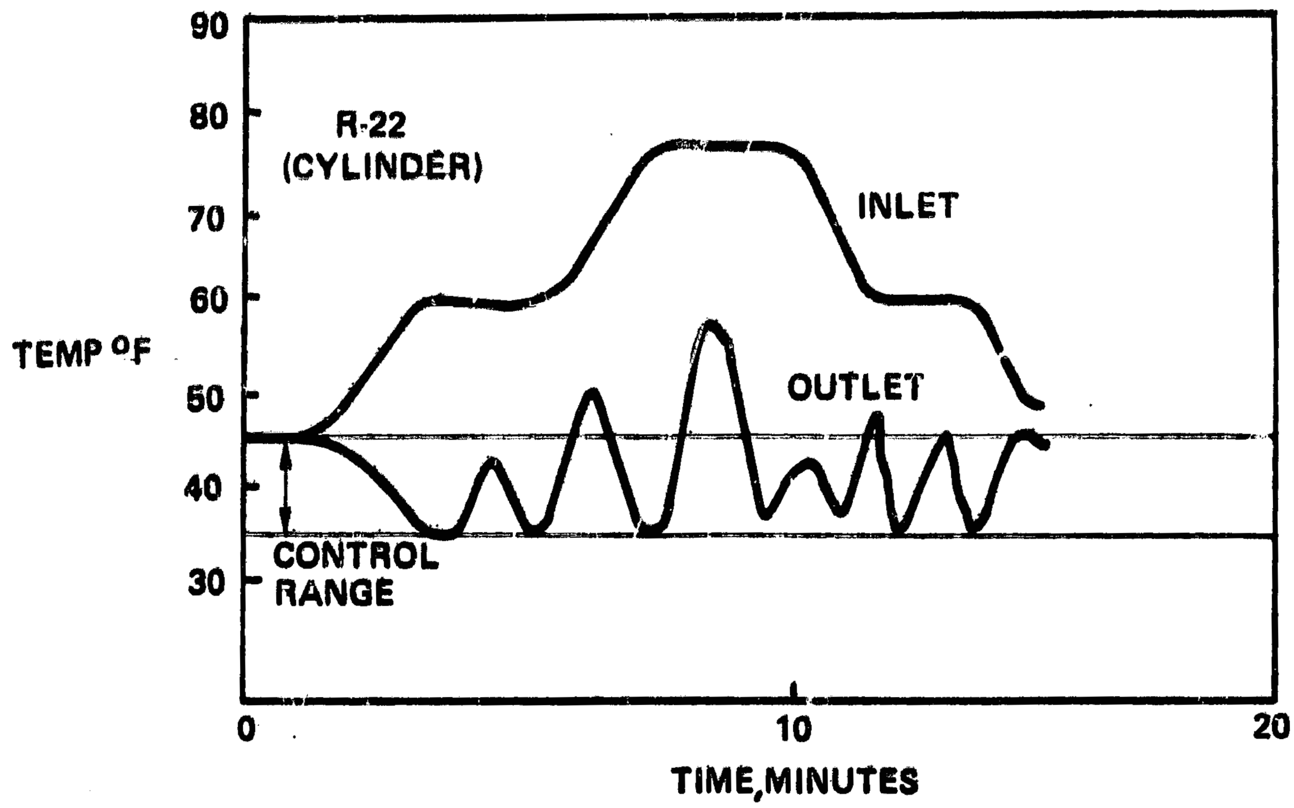


Figure 13. Typical Results: H_2O

TYPICAL RESULTS: R_{22} OR NH_3

Results for Freon 22 and Ammonia were similar to each other, with each having spray distributions which were disturbed significantly by vapor flow paths. The outlet (and interior) temperatures varied over wider ranges and incipient freezing of the transport fluid occurred in two modes. First, at low load the highest cooling position drops rapidly to freezing while the outlet is comparatively warm. As the cool pulse nears the outlet, the interior sensor is quite warm so that recycling to "on" may produce freezing at the outlet. This freezing was eliminated on all but one configuration by dual sensor control. However, the outlet temperature swings past the prescribed 35 to 45 degree control range. Some type of predetermined pulse length control could be expected to easily eliminate these swings if they are found to be excessive. Also, the use of Freon 21 as transport fluid is expected to result in lower amplitude temperature variations. See Figure 14.



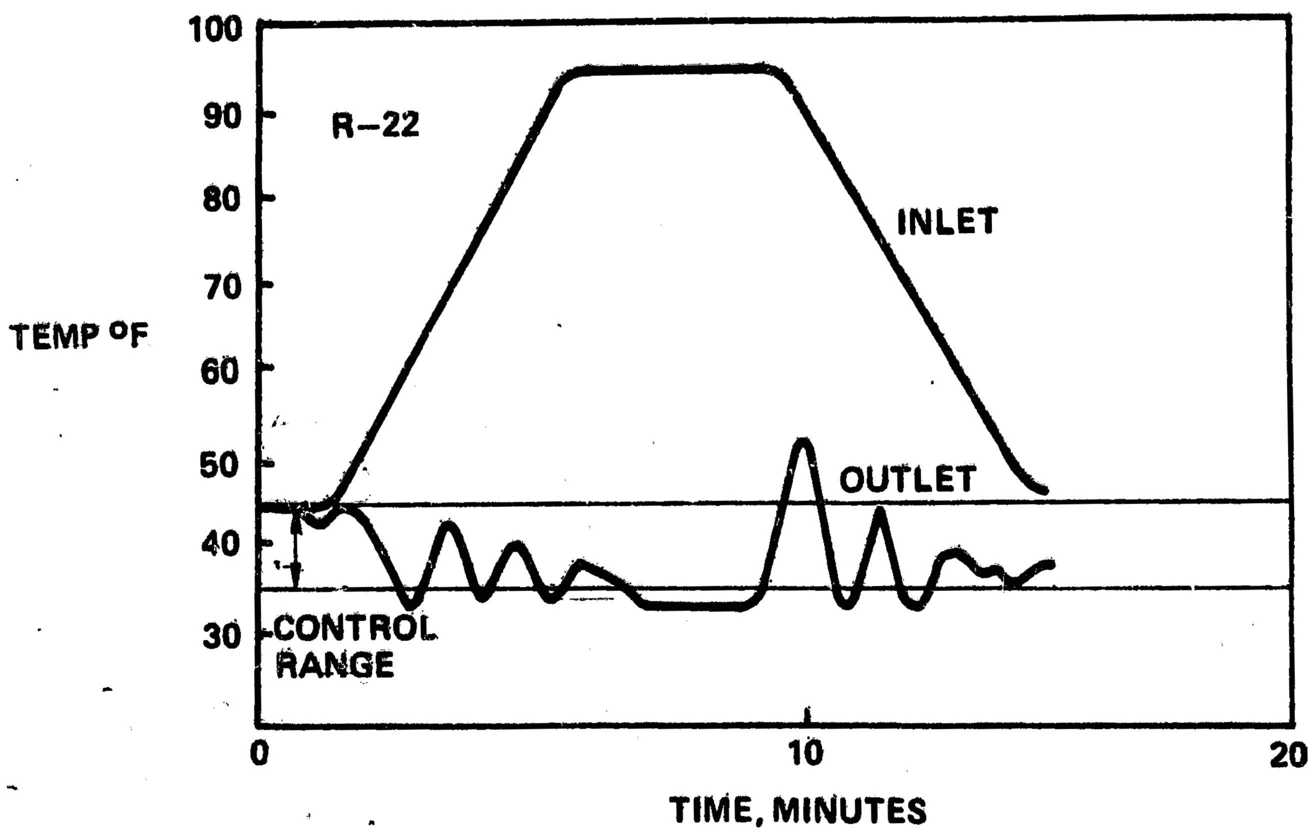


Figure 14. Typical Results: R_{22} or NH_3

SIGNIFICANT RESULTS

1. High enthalpy of vaporization achieved in single device for three evaporants.

   H_2O: 9 Runs, $\Delta h = 965$ BTU/LB (93%)

   R-22: 5 Runs, $\Delta h = 62.5$ BTU/LB (90%)

   NH_3: 4 Runs, $\Delta h = 357$ BTU/LB (80%)

2. No penalty associated with response from and assumption of quiesent condition.
3. Demonstrated capability of inlet temperature ramps up to 8 degrees per minutes.
4. Supply rate modulation control demonstrated.
5. Overloads of 75 percent demonstrated.
6. Demonstrated outlet temperature range 34 to 46 for water, 33 to 60 for R-22, 34 to 55 for NH_3.
7. Acceleration (mean) of 1 to 3.3 g documented in preliminary test, with at most a moderate efficiency loss.

CONCLUSIONS

In conclusion, this program has indicated the feasibility of a spraying flash evaporator with

1. High efficiency capability.
2. Operation without active back pressure control.
3. Control by supply rate modulation for heat load transients.
4. Capability to assume dormant operation with instant reactivation.
5. Operation with multiple evaporants in a single device.

It is recommended that the development of the evaporator concept be continued, toward providing availability for shuttle incorporation.