BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D. C. 20024

B70 06044

SUBJECT: The Skylab Humidity Problem and Several Possible Solutions - Case 620

DATE: June 15, 1970

FROM: J. J. Sakolosky

ABSTRACT

As the result of a medical requirement to decrease the level of carbon dioxide in the Skylab, a second operating molecular sieve has been added to the Airlock Module environmental control system. A secondary effect of this change is a drop in the nominal humidity level to a dew point of approximately 30°F. A humidity level corresponding to a dew point less than 40°F is unacceptable. The addition of a humidifier to the Skylab environmental control system provides one possible solution. However, if none of the water removed from the atmosphere is recycled, the stored water supply for a humidifier rapidly becomes excessive. Even when water recovered from the condensing heat exchangers is recycled to the humidifier, the resulting configuration is more than twice as heavy as Command Module lithium hydroxide for 140 mission days. The dew point temperatures that result when the CM lithium hydroxide system is used fall within the allowable medical requirements.

N79-73084

(NASA-CR-110730) THE SKYLAB HUMIDITY PROBLEM AND SEVERAL POSSIBLE SOLUTIONS (Bellcomm, Inc.) 12 p

Unclas
00/54 11819

BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D. C. 20024

B70 06044

SUBJECT: The Skylab Humidity Problem and Several Possible Solutions - Case 620

DATE: June 15, 1970

FROM: J. J. Sakolosky

MEMORANDUM FOR FILE

Introduction

A recently defined medical requirement to reduce the carbon dioxide level in the Skylab to less than 3 mm Hg has led to the addition of a second operating molecular sieve in the Airlock Module. The new system configuration also includes a spare molecular sieve. In addition, the nominal flow rate through each molecular sieve has been increased from 10 lbs/hr to 15 lbs/hr (6 ft^3/min to 9 ft^3/min). A secondary effect of the above changes has been to decrease the humidity level in the Skylab to an unacceptable level. If the medical requirements on the humidity level cannot be relaxed, then some significant hardware changes in the Skylab environmental control system will be required.

Current Skylab Humidity Levels

For this analysis, the significant water removal sources are the condensing heat exchangers (CHX) and the molecular sieves. Water lost overboard through atmospheric leakage is ignored. Cabin atmospheric flow through one condensing heat exchanger/molecular sieve system is illustrated in Figure 1. The second system is identical to the one shown. Water does not condense in the heat exchanger until the dew point of the cabin atmosphere is greater than 40°F. Air flowing out of the molecular sieves is assumed to be dry. Based on Reference 1, the equations for water vapor partial pressure when two molecular sieves and two condensing heat exchangers are operating are given below. The equations assume a well-mixed Skylab atmosphere at a constant temperature.

1. Dew Point $\leq$ 40°F

$$p(t) = \frac{RTG}{FM}\left(1-e^{-Ft/V}\right)$$

2. Dew Point > 40°F

$$p(t) = \frac{G+1.326}{14.26}\left[1 + \left(\frac{14.26p_o}{G+1.326} - 1\right) e^{-14.26\ RTt/VM}\right]$$

where $p(t)$ = water vapor partial pressure, psia

R = ideal gas constant = 10.73 psia ft^3/mole °R

T = atmospheric temperature = 530°R (70°F)

G = water generation rate, lbs/hr

F = volumetric flow rate through both molecular sieves = 1080 ft^3/hr

M = molecular weight of water = 18 lbs/mole

V = volume of Skylab = 12199 ft^3

p_o = water vapor partial pressure at a dew point of 40°F = .122 psi

t = time in hours

The above equations have been used to determine the humidity level in the Skylab for a water generation rate of 6.6 lbs/day (2.2 lbs/man/day). This corresponds approximately to the insensible water generated by three men each working at a metabolic rate of 450 Btu/hr and not sweating. Figure 2 indicates that the equilibrium water vapor partial pressure is approximately .081 psia. This corresponds to a dew point temperature of 30°F. The dashed lines of Figure 2, corresponding to equilibrium dew points of 40°F, 45°F, and 50°F, illustrate the humidity profiles which would result from water generation rates of 10.0 lbs/day, 18.6 lbs/day, and 27.3 lbs/day. These higher water generation rates would apply only if the activity profile resulted in considerable sweating; they cannot be maintained for long periods.

Stored Water Requirements of a Skylab Humidifier

A typical metabolic profile for the Skylab missions indicates that the water generated by the crew will not be sufficient to meet the minimum humidity requirements. The addition of a humidifier to the Airlock Module environmental control system provides a possible solution to this problem. The weight of the associated water supply grows quickly with mission duration, but the possibility exists to utilize the water removed by the condensing heat exchangers as an input to the humidifier.*

Figure 3A displays the daily water removal rate of the molecular sieves and the condensing heat exchangers as a function of the atmospheric dew point temperature. The water removed by the two molecular sieves is constant at 10 lbs/day for atmospheric dew points greater than 40°F. This reflects the assumption that the dew point of the air flowing out of the condensing heat exchangers remains constant at 40°F. At cabin dew point temperatures of 46°F and greater, the condensing heat exchangers become the predominant means for removing water from the cabin atmosphere.

In Figure 3B the amount of stored water which would be required by a humidifier to produce a given atmospheric dew point temperature is shown. The curves assume a crew water generation rate of 6.6 lbs/3 men/day and a total of 140 mission days (the total for the three Skylab missions). The solid line applies to the case when none of the water removed from the atmosphere is saved. When water condensed in the heat exchangers is reclaimed and supplied to a humidifier, the dashed line results. The weights shown are those for water requirements only; no water storage penalties or tank weights are included.

Water recovery from the condensing heat exchangers would add complexity to the system, but it would result in a considerable decrease in the stored water requirement for the three Skylab missions. For example, without recovery approximately 2900 lbs of stored water are required to maintain a dew point of 50°F; if water from the condensing heat exchangers is recovered for use in the humidifier, the stored water requirement is reduced to about 500 pounds.

A Renewed Look at Lithium Hydroxide

Even in the case where water is recovered from the heat exchanger, the CO_2 removal/humidity control system weight and complexity have grown to the point where a re-evaluation of the system against a simpler concept is in order. In particular,

*With the addition of a water-save bed, which would be a major design change, water could also be recovered from the molecular sieves.

it might be prudent to compare on a weight basis the current baseline configuration plus humidifier and stored water supply to a system which utilizes lithium hydroxide (LiOH) to remove CO_2 from the cabin atmosphere. The assumption here is that the LiOH system that already exists in the Command Module is capable of controlling the CO_2 level in the Skylab; accordingly, that system will be used as a basis for the comparison. But before examining weights, it will be instructive to examine the humidity level resulting when LiOH is used for CO_2 removal.

Using the methods of Reference 1, the following equations describing the water vapor partial pressure can be determined.

1. Dew Point ≤ 40°F

$$p(t) = .026Gt$$

2. Dew Point > 40°F, Two CHX's Operating

$$p(t) = \frac{G+1.742}{14.26}\left[1 + \left(\frac{14.26p_o}{G+1.742} - 1\right) e^{-14.26RTt/VM}\right]$$

3. Dew Point > 40°F, One CHX Operating

$$p(t) = \frac{G+.871}{7.13}\left[1 + \left(\frac{7.13p_o}{G+.871} - 1\right) e^{-7.13RTt/VM}\right]$$

Water and heat are generated by the chemical reaction occurring when CO_2 is absorbed by LiOH. For each pound of CO_2 absorbed, 875 Btu's of sensible heat and .409 lbs of water are produced. Thus for a three man crew generating 6.75 lbs/day of CO_2, 5900 Btu's/day and 2.76 lbs H_2O/day are generated in the CM.* The water generation rate, G, in the above equations will therefore be the sum of the crew water generation rate plus the water generated by the LiOH system.

---

*Note that operation of the suit loop compressor (85 w average power) will generate an additional 7200 Btu's/day in the CM. This additional heat load could serve to ease the condensation problems in the Command Module.

Figure 4 illustrates the resulting humidity levels when the crew water generation rate is 6.6 lbs/3 men/day. The solid curve is for the case when two condensing heat exchangers provide the water removal source; the dashed line results when only one AM condensing heat exchanger is operating. The respective equilibrium dew point temperatures are 45.5°F and 50.5°F. At a higher crew water generation rate of 15.6 lbs/3 men/day (includes considerable sweating by the crew), the equilibrium dew point temperature would be about 50°F with two condensing heat exchangers operating and 57°F with one condensing heat exchanger operating.

Table I lists the component and total weights for each system. For the LiOH system, only the cartridge weight and the LiOH storage structure weight have been listed since the basic system is already installed in the Command Module. The LiOH cartridges are from the Apollo program and weigh 4.5 lbs each. One cartridge is capable of absorbing the CO_2 generated by three men for 12 hours. The weight of the storage structure has been estimated. Hardware weight, desorption atmosphere losses, stored water requirements, and tankage penalties have been included in the weight attributed to the molecular sieve/humidifier system. The total weight of this system is more than twice that of the LiOH system. This results mainly from desorption and low humidity penalties which are almost five times greater than the hardware weight of the three molecular sieves.

Discussion

Both of the above alternatives for increasing the humidity level in the Skylab require significant hardware changes from the previous baseline. Based on weight and complexity, the LiOH system is the most desirable of the two alternatives. If it is found that the CM LiOH system is unable to meet Skylab requirements, then the old AAP LiOH system that was located in the Airlock Module offers another alternative.

From an engineering point of view, the most attractive solution to the humidity problem is a relaxation of the medical requirements on both carbon dioxide level and humidity level so that the previous configuration of one operating molecular sieve could be re-adopted. This avenue should be explored before making a decision requiring new hardware changes.

1022-JJS-cf

J. J. Sakolosky

J. J. Sakolosky

Attachments
- References
- Figures 1-4
- Table I

BELLCOMM, INC.

REFERENCES

1. "Initial Humidity Buildup in the AAP Cluster," Bellcomm Memorandum for File, J. J. Sakolosky, July 25, 1969.

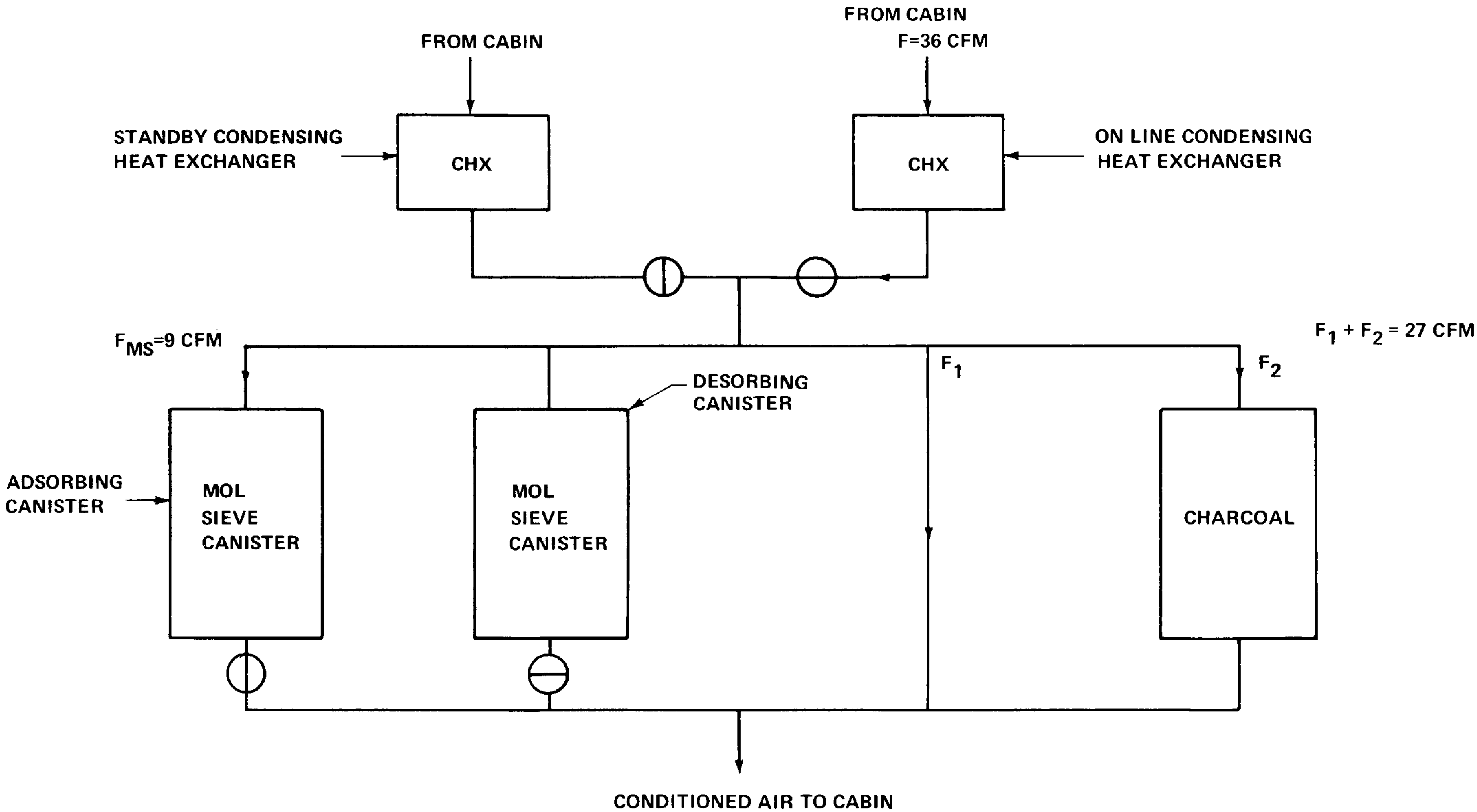

FIGURE 1 - FLOW SCHEMATIC FOR EACH CONDENSING HEAT EXCHANGER/MOLECULAR SIEVE SYSTEM

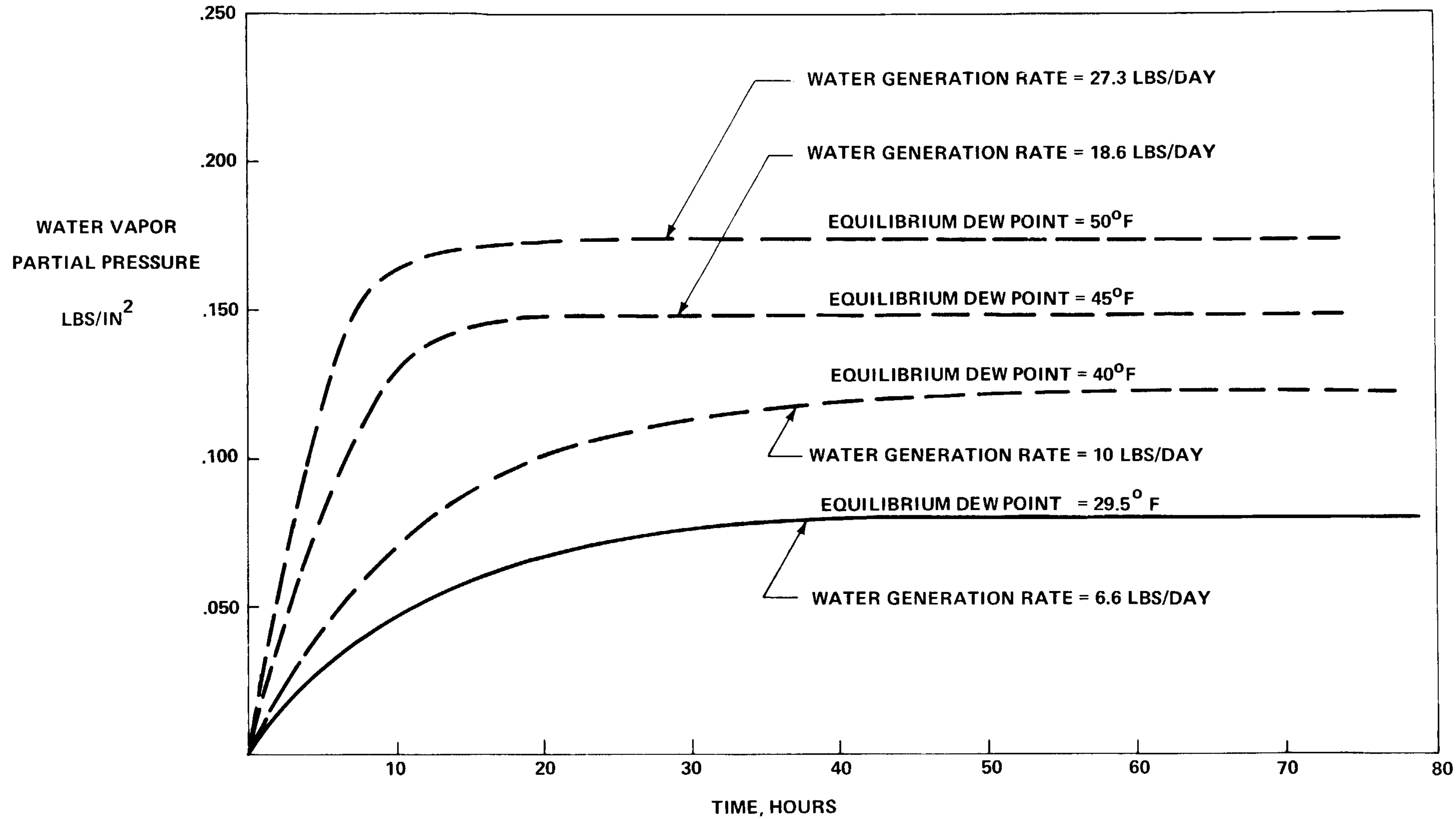

FIGURE 2. SKYLAB DEW POINT TEMPERATURES FOR VARIOUS WATER GENERATION RATES

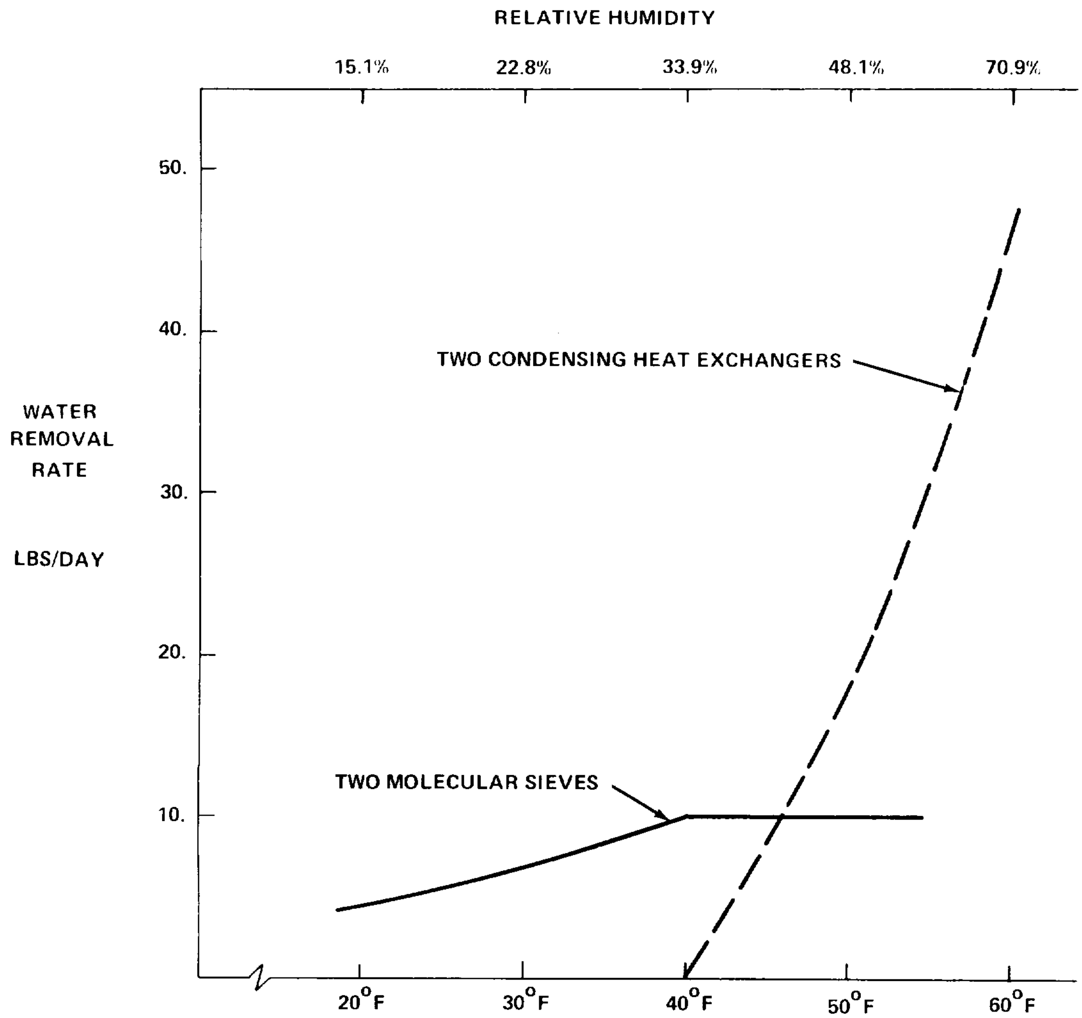

FIGURE 3A. WATER REMOVAL RATE OF TWO MOLECULAR SIEVES AND TWO CONDENSING HEAT EXCHANGERS AS A FUNCTION OF DEW POINT TEMPERATURE

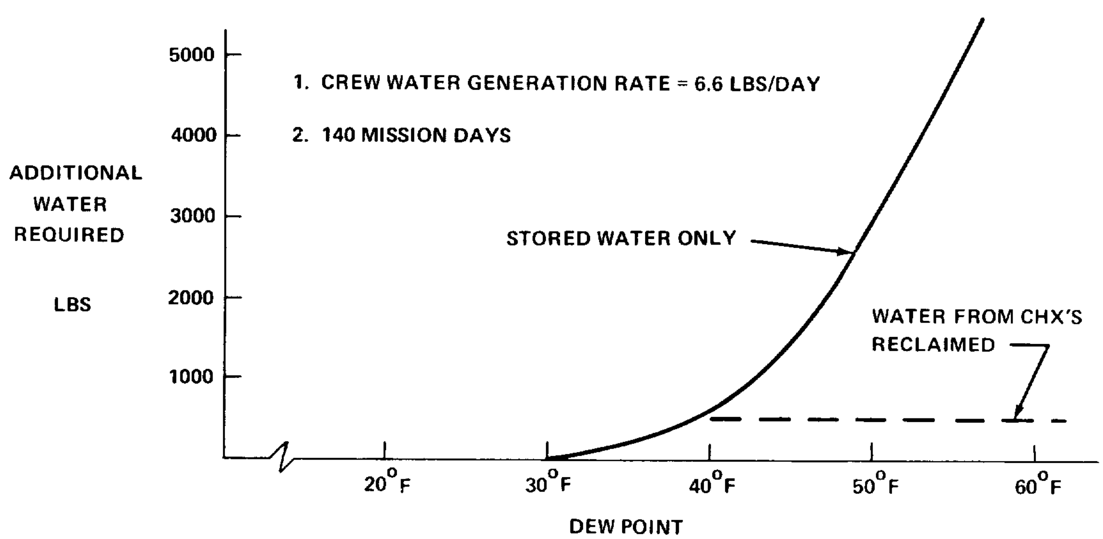

FIGURE 3B. STORED WATER REQUIRED TO MAINTAIN A GIVEN DEW POINT TEMPERATURE IN THE SKYLAB FOR 140 MISSION DAYS

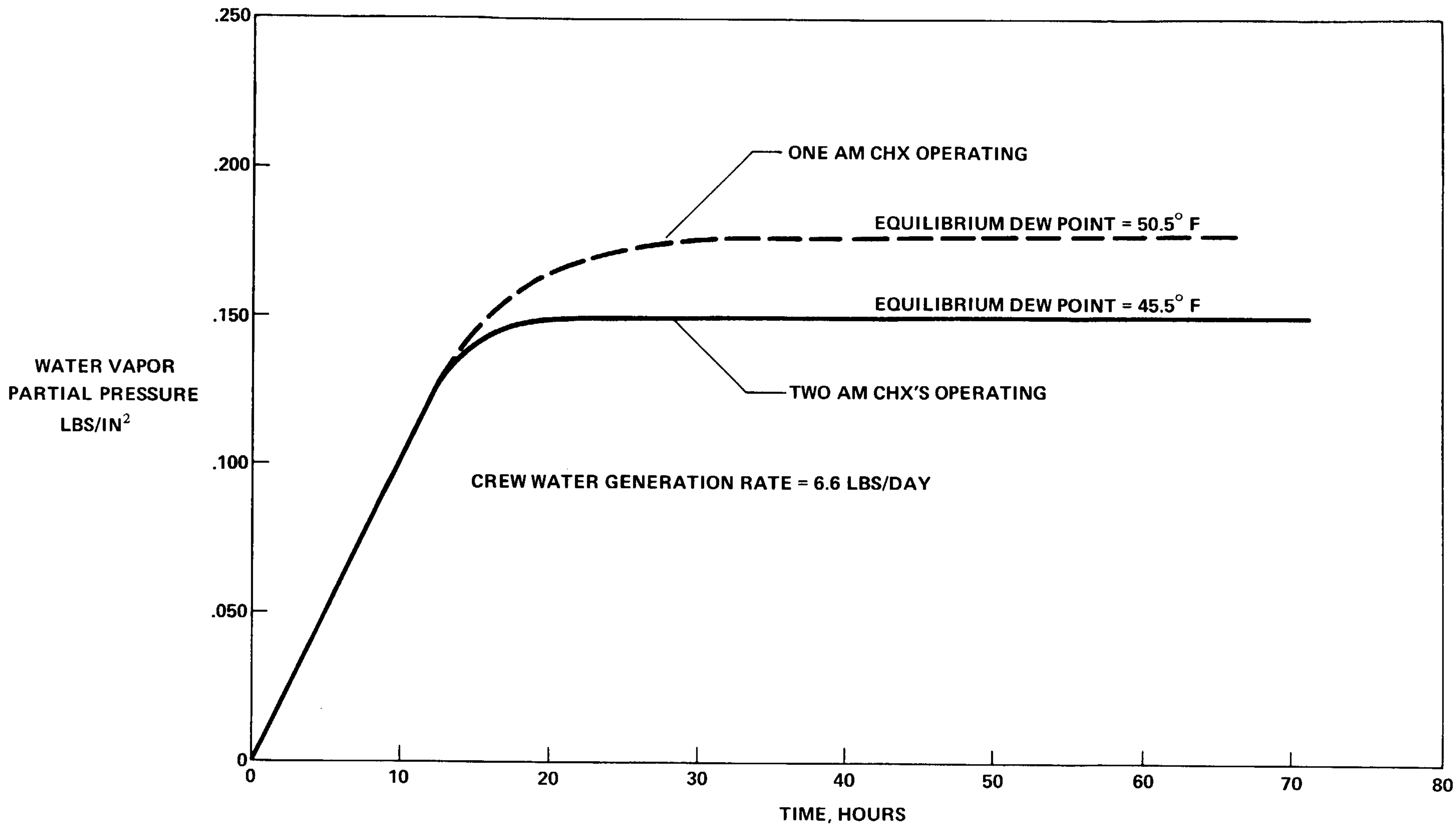

FIGURE 4 - SKYLAB HUMIDITY LEVELS WHEN LiOH IS USED FOR CO_2 REMOVAL

TABLE I. WEIGHT COMPARISON OF MOLECULAR SIEVE/HUMIDIFIER SYSTEM AND LiOH SYSTEM FOR CO_2 REMOVAL AND HUMIDITY CONTROL (140 MISSION DAYS)

Molecular Sieve/Humidifier System		LiOH System	
3 Molecular Sieves	540.0 LBS	280 LiOH Cartridges	1260 LBS
8 Charcoal Canisters	104.0	LiOH Storage Structure	100.0
N_2 Desorption Loss	526.0	TOTAL:	1360.0 LBS
O_2 Desorption Loss	398.0		
N_2 Tankage Penalty	916.0		
O_2 Tankage Penalty	---		
H_2O for Humidifier	500.0		
H_2O Tankage Penalty	250.0		
Humidifier (Estimated)	30.0		
TOTAL:	3264.0 LBS		

BELLCOMM, INC.

Subject: The Skylab Humidity Problem and Several Possible Solutions - Case 620

From: J. J. Sakolosky

Distribution List

NASA Headquarters

H. Cohen/MLR
J. H. Disher/MLD
W. B. Evans/MLO
R. M. Farrell/MMS
J. P. Field, Jr./MLP
T. E. Hanes/MLA
T. A. Keegan/MA-2
E. J. McLaughlin/MMS
M. Savage/MLT
W. C. Schneider/ML

MSC

C. A. Berry/DA
C. N. Crews/KS
R. L. Frost/KS
K. S. Kleinknecht/PA
C. K. Williams/KS

MSFC

L. F. Belew/PM-AA-MGR
G. D. Hardy/PM-AA-EI
J. W. Littles/S&E-ASTN-PFA
J. W. Thomas/PM-AA-EI

Bellcomm

A. P. Boysen
D. R. Hagner
W. G. Heffron
B. T. Howard
J. Z. Menard
J. M. Nervik
I. M. Ross
P. F. Sennewald
J. W. Timko
R. L. Wagner
M. P. Wilson
Departments 2031, 2034 Supervision
Department 1024 File
Division 101 Supervision
Division 102
Central Files
Library