29 Jan 1993

Performance Analysis for the CCN Collection Apparatus

Deborah K. Bircher

PERFORMANCE ANALYSIS FOR THE CCN COLLECTION APPARATUS

Deborah K. Bircher
Cloud Physics
Mechanical Engineering Department

ABSTRACT

This paper concerns the performance testing of a system to collect and chemically analyze cloud condensation nuclei (CCN). These are the atmospheric particles which nucleate cloud drops.

The air is humidified by passage through the "haze chamber", consisting of parallel vertical plates that are covered with cotton cloth and are kept wet by water supplied at the top edge. The plates are adiabatic , and should equilibrate in temperature at the wet bulb temperature of the incoming air. Measurements of the plate temperature with eighty thermocouples indicate behavior consistent with theory.

Another part of the system is called the CFD (continuous flow diffusion chamber). This consists of isothermal parallel wet plates with two cold plates at 18 C and one hot plate at 23 C. The hot plate contains twelve electric heaters which can be individually adjusted to achieve an isothermal hot plate. Measurements of the hot plate temperatures with 40 thermocouples show that the plate was isothermal within an accuracy of 1 C.

INTRODUCTION

The focus of this research project has been to identify the chemical composition of cloud condensation nuclei (CCN). CCN are atmospheric particulates that produce freely growing water drops when exposed to super saturations such as are found in clouds. The interest is in determining what chemical components cause an increase in the concentration of CCN.

The equipment used to collect samples includes two steady flow chambers, one of which, the haze chamber, subjects the sample to 100% relative humidity, the other, the CFD chamber, subjects the sample to a relative humidity of 101%. The drops grown in the haze chamber and the larger drops grown in the CFD chamber are inertialy separated from the air streams using devices called "impactors". The air flowing through the impactors make a high speed turn such that the inertia of the particles causes them to deviate from the air stream. Filters are then used to trap the particulates and the sample is analyzed for chemical content. Figure 1 shows a representation of the equipment used.

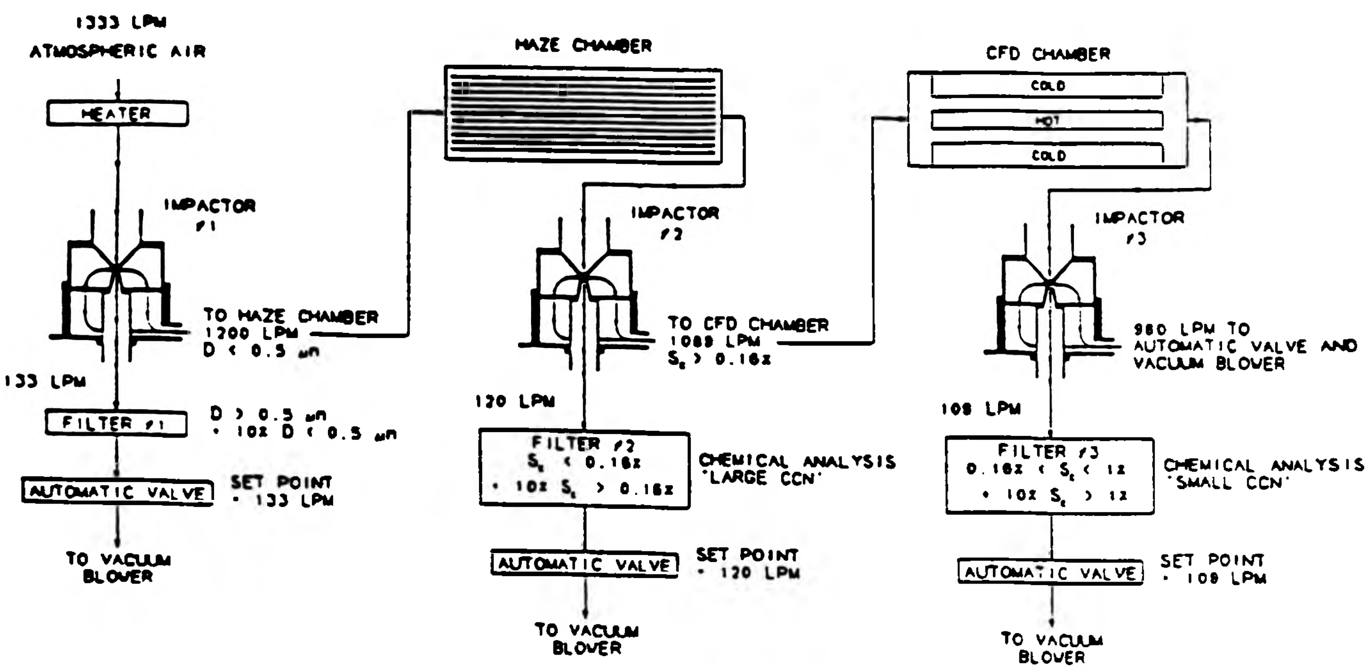

Figure 1. Flow diagram of CCN collection system.

Haze chamber:

Within the haze chamber there are twelve aluminum plates, 4 ft. by 12 ft., spaced .375 inches apart. Each plate is covered with cotton cloth and wetted with a continuous supply of water. The temperature within the haze chamber should equal the wet bulb temperature of the incoming air. To control the haze chamber temperature there is a heater upstream of the haze chamber. This heater is automatically controlled such that the wet bulb temperature at the heater exit is constant even though the heater inlet temperature is varying with time, due to the temporal fluctuations in the atmospheric temperature and relative humidity.

The first problem discussed is the selection of a wet bulb temperature setting for the heater, with consideration given to three limiting factors; (1) A heating capacity of 195 F could not be exceeded, (2) Cooling of the incoming air could not take place with the present design system, (3) And the wet bulb temperature range had to be flexible enough to encompass a range of atmospheric temperatures and relative humidities. Figure 2 shows typical atmospheric conditions for St. Louis, Mo. Each line represents the mean values for a particular month, and the two ends of each line shows conditions at 7 am and 12 pm.

Heat is supplied to the haze chamber plates by heat transfer from the air flow. Theory indicates that the plates will be nearly isothermal after reaching equilibrium, [Chen & Sparrow Ref. #1].The second problem presented is to show the temperature distribution of the haze chamber plates, and to confirm that they operate in an

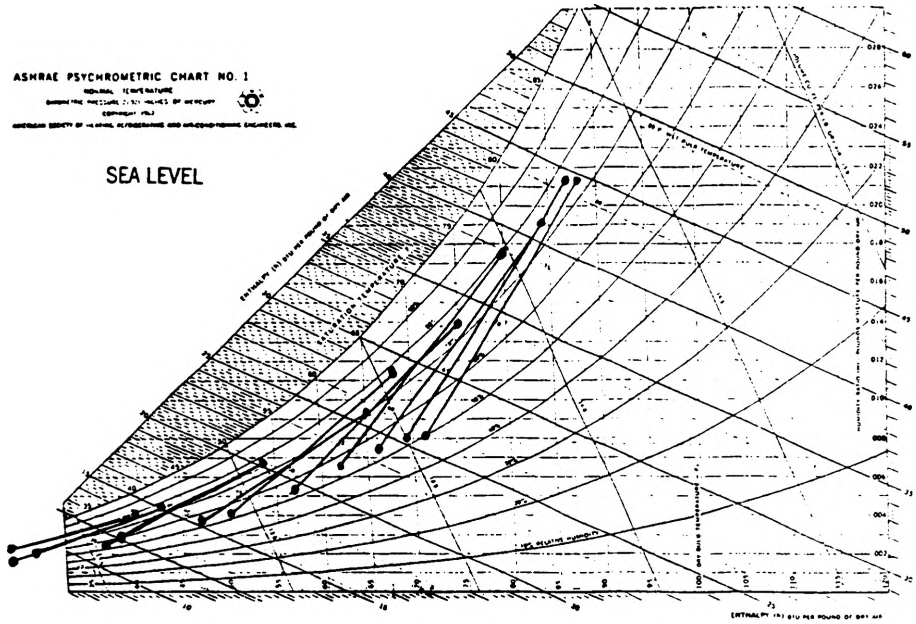

Figure 2. Characteristic temperature distribution for St. Louis, Mo. Data source (ref. #2)

approximately isothermal state. To do this eighty thermocouples were made and sewn onto the fabric of the twelve plates, temperature readings were then taken and charted.

An analysis of the dimensionless temperature parameter;

$$T = (Tw - Tf) / (To - Tf) \quad (1)$$

where;

Tf = The temperature of the plates downstream.
To = The temperature of the heated air at the inlet.
Tw = The temperature of the plates at the inlet.

was performed on data. From the analytical solution of the problem T was found to be -.05. [Chen & Sparrow, 1969, Ref. #1]. A comparison is made of the theoretical solution with the actual data taken.

CFD:

The last subject discussed is the thermodynamic processes occurring in the CFD chamber. The environment in the CFD is also approximately isothermal. The CFD chamber contains one hot plate and two cold plates. The cold plate has water that circulates within it where the temperature of the water is 5 C cooler than the temperature of the hot plate. Initially the CFD chamber hot plate was designed to operate at the same temperature as the haze chamber, but because a pressure drop preceding the inlet of the CFD chamber, at impactor #2 (fig. 1), the new vapor pressure did not correspond with a fully saturated condition. From thermodynamic tables a new operating temperature is selected the plates.

RESULTS

To find the wet bulb temperature for the haze chamber, wet bulb temperature ranges of 25 C, 28 C, and 33 C of figures 3,4 and 5 respectively were compared with local atmospheric conditions. From figure 2, the atmospheric conditions range from -4.4 C (24 F) to 31.1 C (88 F) with corresponding relative humidities of 50% to 79%, since these figures were averaged values, additional data (for July weather) was also taken in the lab. Lab data showed very high relative humidities of greater than 90% in the cooler early morning hours and lower humidities of 30% and 40% in the hot afternoon hours.

All of the local psychometric data fall within figures 3 but

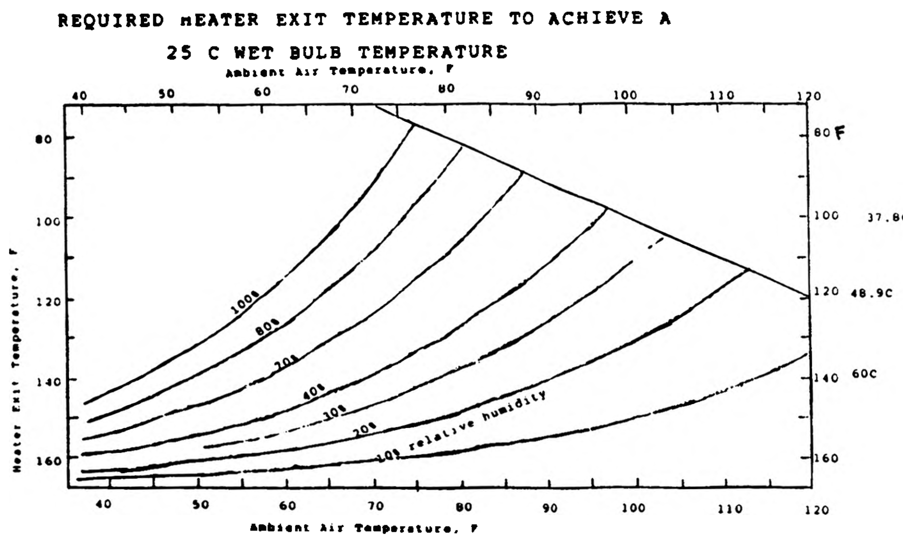

Figure 3. Wet bulb temperature range for 25 C.

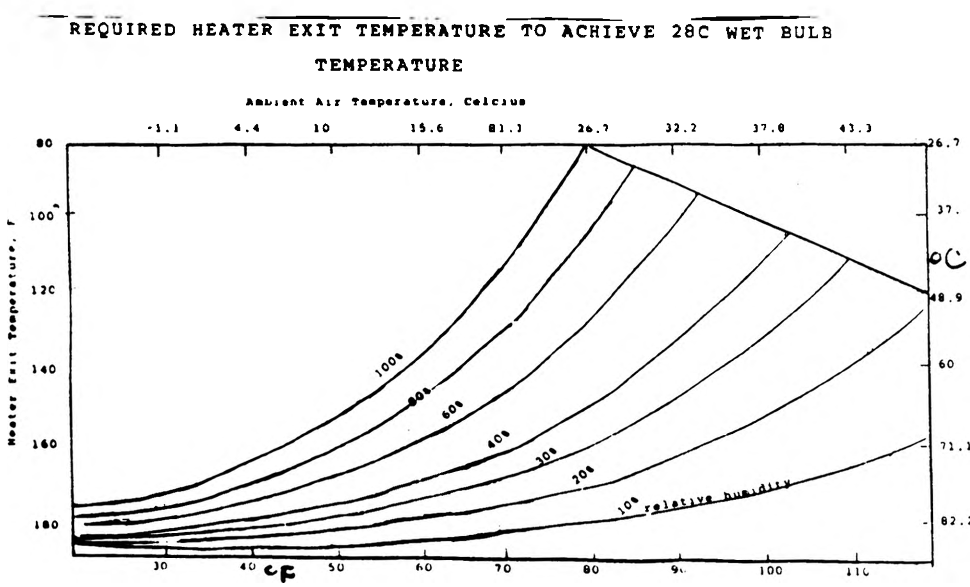

Figure 4. Wet bulb temperature range for 28 C.

figures 4,and 5 become restrictive in summer weather. The wet bulb temperature of figure 5, of 33 C, does not encompass the range of temperatures and relative humidities above a heating capacity of

90.6 C (195F). This range of temperatures which are typical for Missouri are included in the acceptable operating ranges for figures 3 and 4.

In figures 3,4, and 5 the region in the upper right hand corners would require cooling to maintain the respective wet bulb temperatures. Figure 3, 4, and 5 shows that cooling would start at about 72.5 F, 75 F, and 91 F and creates a region where the

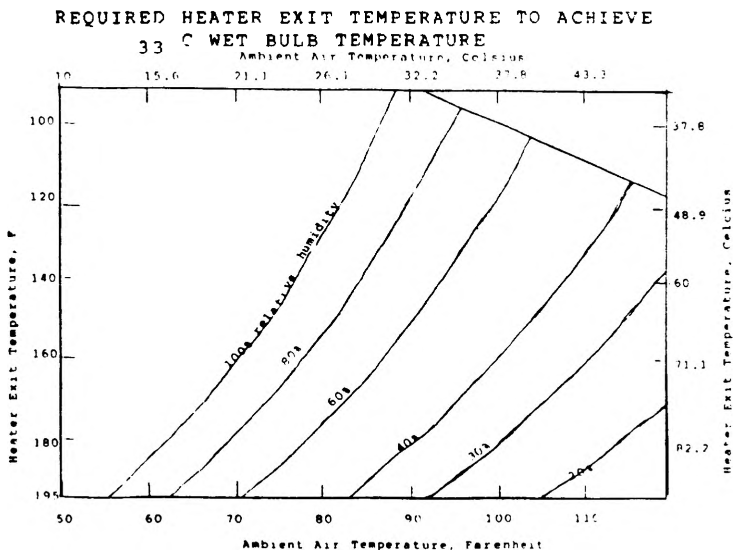

Figure 5. Wet bulb temperature range for 33 C.

relative humidities decrease from 100%. For summer conditions a 25 C wet bulb temperature will not be acceptable, because cooling will be required at temperatures and relative humidities that are common for summer weather. Although from figures 3 and 4 it can be seen that both wet bulb temperatures would be acceptable for winter weather.

Temperature readings for the thermocouples in the haze chamber were taken and recorded as in figure 6. Because of space limitations the temperature distribution of only one plate will be shown here. Comparison of the temperature distribution of each plate in the haze chamber showed that the measured temperature is slightly lower at the inlet side of the haze chamber which is in

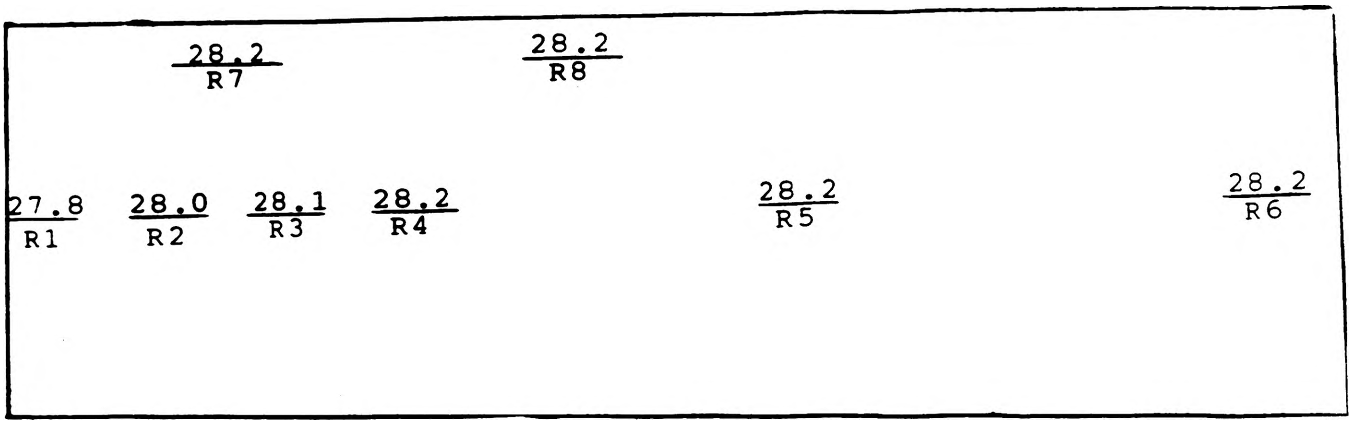

Figure 6. Temperature distribution of the plates in the haze chamber.

agreement with the analysis by Chen and Sparrow. From the actual solution of the problem T was found to oscillate about -.05, where Tw and Tf were obtained by averaging the temperature values across the twelve plates. The oscillation occurring because the value of To is dependent upon the cyclical nature of the heater at the air inlet. As a result T had typical values fluctuating between -.03 to -.06 when the system was at equilibrium.

The error for the temperature data due to the inaccuracies of the thermocouples is believed to be approximately 2/10 C. Another concern as a source of error has resulted from the temperature recording device giving misrepresentative temperature readings.

Referring to figure 1, air entering the haze chamber exits at atmospheric pressure and undergoes a throttling process across impactor #2. A pressure drop of approximately 7"Hg was seen across the impactor. From thermodynamic saturation tables the corresponding vapor pressure at 28 C, is equal to .03782 psia.

.03782 * (23"Hg./30"Hg.) = .028995 psia. (2)

From the ratio of the total pressures multiplied by the vapor pressure, the new vapor pressure upstream of the CFD is found. Again, going to the thermodynamic saturation tables the new operating temperature of the hot plate was obtained for a vapor pressure of .028995 psia, which is 23 C, and it follows from the initial design that the temperature for the cold plate be 18.0 C. Before the hot plate temperature was turned down, previous graphs showed large uneven temperature distributions which did not respond to increases in heating capacity. Recent data taken shows an even temperature distribution that does not fluctuate more than one degree.

CONCLUSION

The results show that the plates in both the haze chamber and the CFD have temperature distributions which are basically uniform and can be considered to operate in an approximately isothermal state.

Psychometric data charts indicate that the optimum wet bulb temperature range for the present summer weather conditions in the haze chamber is 28 C. Winter weather could be tolerated at either 25 or 28 C but will save money on equipment operating costs at 25 C during cooler months.

CFD operating temperatures selected from thermodynamic analysis are 23 C for the hot plate and 18 C for the cold plates.

ACKNOWLEDGMENTS

Dr. D.J. Alofs. Faculty advisor. Cloud Physics. Mechanical Engineering Department.

This work is sponsored by The University of Missouri-Rolla, OURE.

REFERENCES

1. Sparrow, E.M., and T.S. Chen (1969): Mutually dependent heat and mass transfer in laminar duct flow. AICHE Journal 15, 434-441.

2. "Climate guide of the World" by H.J. Cantrint. Copyright 1985. Published by Cannon publishers.