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**United States Department of Energy**

**Savannah River Site**

**Field Performance of a Slimline Turbomist Evaporator  
under Southeastern U. S. Climate Conditions (U)**

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## Table of Contents

1.0 Introduction.....	1
2.0 Evaporation principles .....	3
3.0 Experiment design and setup.....	6
4.0 Field testing and data.....	12
5.0 Predictive model.....	21
6.0 Forecast evaporation rates .....	25
7.0 Summary and conclusions.....	26
8.0 References.....	26

## Tables

Table 1	Adiabatic saturation calculation for SRS annual average climate conditions. ....	4
Table 2	Average climate conditions at the SRS over various time periods.....	5
Table 3	Spray rate projected for various nozzle core and orifice plate selections. ....	8
Table 4	Summary of Turbo-Mist field tests. ....	14
Table 5	Least-squares parameter estimation results.....	23
Table 6	Normalized evaporation and spray rates.....	23

## Figures

Figure 1	Vendor photographs of Slimline Turbo-Mist evaporator.....	2
Figure 2	Evaporative cooling potential as a function of temperature and relative humidity.....	5
Figure 3	Location of Turbo-Mist field test.....	9
Figure 4	Surveyed grid system for placement of fallback collection devices.....	10
Figure 5	Collection devices selected for measuring spray fallback .....	10
Figure 6	Rain gauge brands procured for SRS field testing. ....	11
Figure 7	Simplified Piping Configuration.....	11
Figure 8	Cross-plot of Clear and Yellow rain gauge data collected during field testing on 3/31/03.....	15
Figure 9	Cross-plot of White and Yellow rain gauge data collected during field testing on 3/31/03.....	15
Figure 10	Cross-plot of absorbent pad and "best" rain gauge fallback data collected during field testing on 3/31/03.....	16
Figure 11	Cross-plot of absorbent pad and rain gauge data collected from all applicable field tests.....	16
Figure 12	Spray fallback pattern for Turbo-Mist field test on 3/31/03.....	17
Figure 13	Spray fallback pattern for Turbo-Mist field test on 4/29/03.....	17
Figure 14	Spray fallback pattern for Turbo-Mist field test on 5/1/03.....	18
Figure 15	Spray fallback pattern for Turbo-Mist field test on 5/14/03.....	18

Figure 16 Spray fallback pattern for Turbo-Mist field test on 6/25/03.....19  
Figure 17 Spray fallback pattern for Turbo-Mist field test on 6/26/03.....19  
Figure 18 Spray fallback pattern for Turbo-Mist field test on 7/24/03.....20  
Figure 19 Spray fallback pattern for Turbo-Mist field test on 8/11/03.....20  
Figure 20 Normalized evaporation and spray rates.....24

Appendices

Appendix A – Data and analysis for Turbo-Mist field test on 3/31/03.....27  
Appendix B – Data and analysis for Turbo-Mist field test on 4/29/03 .....31  
Appendix C – Data and analysis for Turbo-Mist field test on 5/1/03.....35  
Appendix D – Data and analysis for Turbo-Mist field test on 5/14/03.....39  
Appendix E – Data and analysis for Turbo-Mist field test on 6/25/03 .....43  
Appendix F – Data and analysis for Turbo-Mist field test on 6/26/03 .....47  
Appendix G – Data and analysis for Turbo-Mist field test on 7/24/03 .....51  
Appendix H – Data and analysis for Turbo-Mist field test on 8/11/03 .....55

## Field Performance of a Slimline Turbomist Evaporator under Southeastern U. S. Climate Conditions

### 1.0 INTRODUCTION

A recent study of evaporation technologies for treating F- and H-area groundwater contaminated with radionuclides and metals (Flach 2002) suggested that spray evaporation might be a viable alternative or supplemental technique for managing tritiated groundwater at the Mixed Waste Management Facility (MWMF). The particular technology of interest in this study is the Slimline Manufacturing Ltd. Turbo-Mist Evaporator, which uses a powerful blower and high-pressure spray nozzles to propel a fine mist into the air at high air and water flowrates (Figure 1). The evaporator relies on the sensible heat that can be extracted from low (<100%) humidity air to drive evaporation. Incoming "dry" air is brought into contact with the spray field through a combination of the mechanical blower and natural wind, and simultaneously cooled and humidified through evaporative cooling. Because the energy for evaporation comes from a natural source, the overall cost is low compared to evaporation by direct heating.

In general, spray evaporation provides a method for reducing wastewater volume and concentrating contaminants. A concentrated waste stream can usually be treated more economically than a higher volume stream containing the same waste loading. At the MWMF Southwest Plume, a phytoremediation system has been constructed to remediate groundwater contaminated principally with tritium. Contaminated groundwater is collected ahead of a sheet pile dam constructed below natural seeps. The water is then distributed through an extensive spray irrigation system in the surrounding forest. Irrigation rates are adjusted to maximize evapotranspiration while minimizing infiltration past the root zone to the water table. Drought conditions in recent years have been favorable to system performance, and enabled the current irrigation field to meet demand. However, in wetter years and during winter months when evapotranspiration rates are low, the capacity of the irrigation field may not be adequate. In this situation a spray evaporator could potentially provide additional capacity to counter lower irrigation field capacity. The focus of the field evaluation is measuring the performance of the Turbo-Mist evaporator under SRS climate conditions for potential deployment at the MWMF.

Evaporation rate is affected by a number of factors including, the flowrate, temperature and humidity of the air contacting the spray field, and the spatial distribution, residence time, and size of spray droplets. Hot, dry, and windy conditions are most favorable to the spray evaporation, and Turbo-Mist units have been commercially deployed with success at several arid or semi-arid locations in North America ([www.turbomist.com/cgi-bin/division.cgi?Wastewater](http://www.turbomist.com/cgi-bin/division.cgi?Wastewater)). Quantitative performance or design data for the more humid Southeast United States was not available from Slimline Manufacturing Ltd. during the previous study (Flach 2002). The main objectives of the present study were to 1) develop optimal configurations of the Slimline Turbo-Mist under a variety of SRS field conditions to achieve maximum evaporation and minimal spray fall-back, 2) accurately measure the evaporation and fall-back rates for the optimal configurations and common field conditions, and 3) develop a model capable of predicting Turbo-Mist performance under SRS field conditions with adequate accuracy for design purposes.

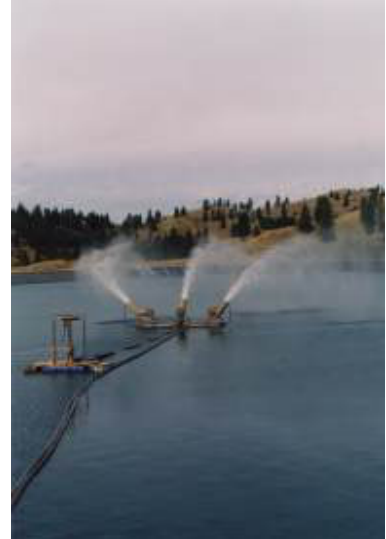


Figure 1 Vendor photographs of Slimline Turbo-Mist evaporator.

## 2.0 EVAPORATION PRINCIPLES

When “dry” (<100% humidity) air is brought into contact with liquid water, with no heat transfer to or from the overall system, liquid evaporates and air is cooled until thermodynamic equilibrium is reached (100% humidity). Such an operation is termed “adiabatic saturation”, and is the principle behind “swamp coolers” used for residential cooling in the Southwest US and agricultural cooling (e.g. poultry houses). The energy required to vaporize liquid water (latent heat of vaporization) is extracted from dry air through cooling (sensible heat). The amount of cooling as a function of temperature and relative humidity of the incoming air stream can be determined through application of the first law of thermodynamics, which states that enthalpy is conserved in a open system (cf. Reynolds and Perkins 1977). With minor approximation, the adiabatic saturation process can be described by:

$$h_{in}^* = (h_a + \gamma h_w)_{in} = (h_a + \gamma h_w)_{out} = h_{out}^* \quad (1)$$

where  $h^*$  = enthalpy of moist air per unit mass of dry air,  $h_a$  = enthalpy of dry air,  $h_w$  = enthalpy of water vapor,  $\gamma$  = specific humidity or humidity ratio (Reynolds and Perkins 1977 section 10-4). The thermodynamic properties of moist air can be readily computed from an ASHRAE handbook (e.g. American Society of Heating, Refrigerating and Air-Conditioning Engineers 1985) for equivalent source.

An example calculation is shown in Table 1, where the temperature and humidity of the incoming air stream have been set to the annual averages at the SRS, 65F and 68% (Hunter and Tatum 1997). For these conditions, the evaporative cooling is 6.6 °F. Figure 2 shows contours of constant evaporative cooling degrees resulting from various combinations of temperature and relative humidity. As illustrated by the plot, higher temperature and lower humidity produce more cooling and corresponding evaporation. Also shown in Figure 2 are seasonal average values of temperature and humidity at the SRS. Table 2 identifies the basis for these values and provides monthly average values as well.

Spray evaporation under atmospheric conditions is expected to be proportional to the cooling and evaporation amounts computed under adiabatic saturation conditions (Figure 2). For evaporation to be sustained, dry air (and water) must be continuously supplied to replenish the system. An energy balance expanding on equation (1) indicates that evaporation of initially dry air and evaporation of liquid water is proportional to the mass flowrate of dry air delivered to the system. For atmospheric spray evaporation, fresh air is delivered to the spray field through natural winds. Thus, the spray evaporation rate is also expected to be proportional to local wind speed. The overall dimensions of the spray field, and the distribution, residence time, and size of spray droplets within, are also expected to affect the evaporation rate. For example, the flowrate of dry air contacting the spray field is proportional to the cross-sectional area perpendicular to wind direction, in addition to wind speed.

In summary, spray evaporation under field conditions is expected to be proportional to the evaporative cooling potential based on adiabatic saturation and wind speed. Characteristics of the spray field will also affect the evaporation rate.

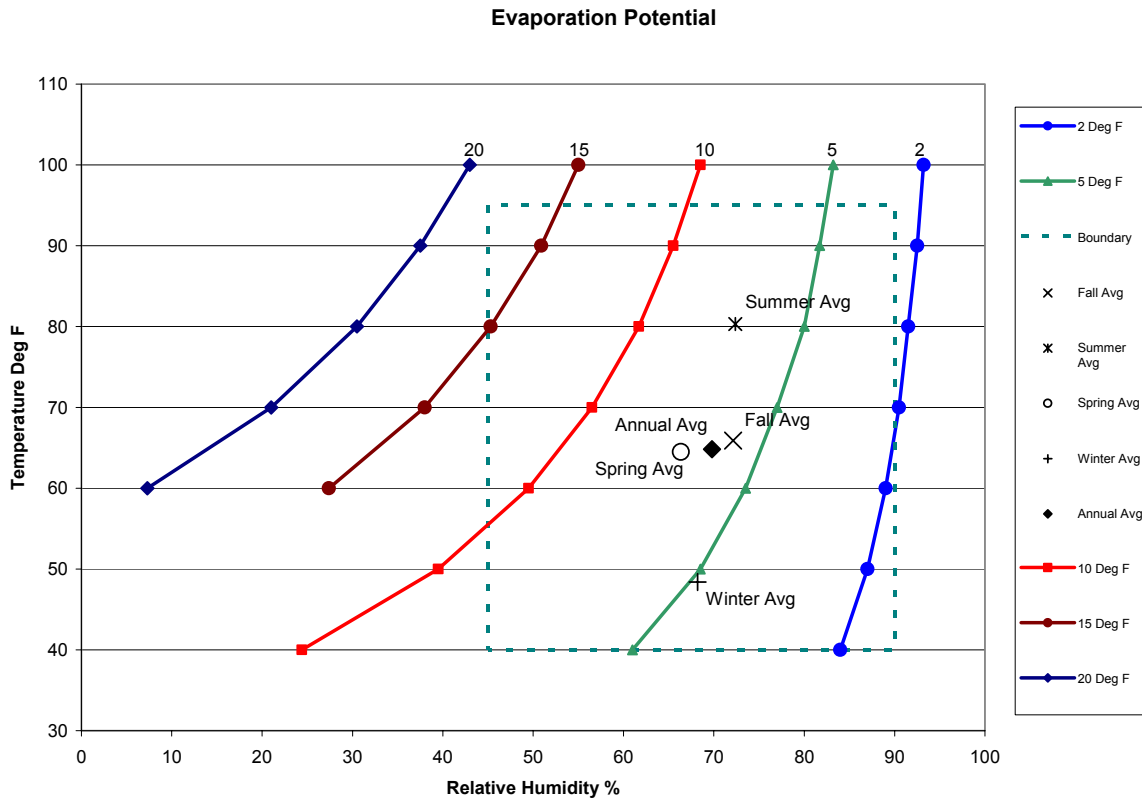
**Table 1      Adiabatic saturation calculation for SRS annual average climate conditions.**

<b>Adiabatic saturation / swamp cooler calculation using ASHRAE (1985) equations</b>					
<b>Constants</b>					
univ. gas const.	R	1545.33 ft-lbf/(lbmole-R)			source
molecular wt. air	M <sub>a</sub>	28.9645 lbm/lbmole			
air gas constant	R <sub>a</sub>	53.35 ft-lbf/(lbm-R)			
<b>Incoming air stream</b>					
pressure	p	14.7 psia			
temperature	t	65 F	18.3 C	524.67 R	
relative humidity	φ	68% unitless			
sat. pressure	p <sub>ws</sub>	0.3097 psia			eqn (4)
water vap. pres.	p <sub>w</sub>	0.2106 psia			eqn (22)
humidity ratio	W, γ	0.009040 unitless	63.28 grains/lbm <sub>a</sub>		eqn (20)
sat. humidity ratio	W <sub>s</sub>	0.013386 unitless			eqn (21)
deg. of saturation	μ	0.6753 unitless			eqn (10)
specific volume	v	13.42 ft <sup>3</sup> /lbm <sub>a</sub>			eqn (26)
		13.30 ft <sup>3</sup> /lbm			using (1+γ) factor and eqn (26)
		13.22 ft <sup>3</sup> /lbm			using ideal gas law
specific enthalpy	h	25.45 BTU/lbm <sub>a</sub>			eqn (30)
<b>Outgoing for adiabatic saturation/evaporation</b>					
pressure	p	14.7 psia			
temperature	t	58.35 F	14.6 C	518.02 R	
relative humidity	φ	100% unitless			
sat. pressure	p <sub>ws</sub>	0.2448 psia			eqn (4)
water vap. pres.	p <sub>w</sub>	0.2448 psia			eqn (22)
humidity ratio	W, γ	0.010532 lbm <sub>w</sub> /lbm <sub>a</sub>	73.72 grains/lbm <sub>a</sub>		eqn (20)
sat. humidity ratio	W <sub>s</sub>	0.010532 unitless			eqn (21)
deg. of saturation	μ	1.0000 unitless			eqn (10)
specific volume	v	13.28 ft <sup>3</sup> /lbm <sub>a</sub>			eqn (26)
		13.14 ft <sup>3</sup> /lbm			using (1+γ) factor and eqn (26)
		13.06 ft <sup>3</sup> /lbm			using ideal gas law
specific enthalpy	h	25.45 BTU/lbm <sub>a</sub>			eqn (30)
<b>Differences</b>					
temperature	Δt	-6.6 F			
relative humidity	Δφ	0.32 unitless			
enthalpy	Δh	0.00 BTU/lbm <sub>a</sub>			
humidity ratio	ΔW, Δγ	0.001492 lbm <sub>w</sub> /lbm <sub>a</sub>	10.44 grains/lbm <sub>a</sub>		

**Table 2** Average climate conditions at the SRS over various time periods.

Period	Temp (°F) T <sup>1</sup>	Relative Humidity (%) Ø <sup>2</sup>	Wind Speed (mph) V <sup>2</sup>
Annual	64.8	69.8	5.4
Winter	48.4	68.2	5.7
Spring	64.5	66.4	6.1
Summer	80.3	72.4	5.0
Fall	65.9	72.1	4.7
Dec	49.3	72.1	5.5
Jan	46.2	68.2	5.8
Feb	49.7	64.3	5.8
Mar	57	63.8	6.5
Apr	64.5	64.3	6.3
May	72.1	71.0	5.5
Jun	78.7	72.7	5.4
Jul	81.7	70.1	4.8
Aug	80.5	74.3	4.8
Sep	75.6	72.5	5.1
Oct	65.5	71.6	4.6
Nov	56.5	72.2	4.5

Note 1 Average of SRS data 1970-2000  
 Note 2 Average of SRS data 1997-2002



**Figure 2** Evaporative cooling potential as a function of temperature and relative humidity.

### 3.0 EXPERIMENT DESIGN AND SETUP

As stated in the Introduction, one objective of field testing was to identify optimal configurations of the Slimline Turbo-Mist evaporator. For potential deployment at the MWMF over dry land, high evaporation and little or no fallback are considered to be optimal. The unit can be configured with No. 25 or No. 45 nozzle cores, and nozzle orifice plates ranging from D2 through D14 in increasing orifice diameter. An orifice blank can be used if no flow is desired from a nozzle port. The manifold ring accommodates 30 nozzles. Other potential configuration controls are the manifold supply pressure to nozzles, and the inclination of the blower output tube. The air flowrate is fixed by the electric motor speed. Because the number of field tests was limited by budget and schedule considerations, and spray fallback on the F-seepage basin cap was limited by regulators to 25 gpm, not all possible configurations could be tested.

For SRS field testing, the air stream inclination was fixed at the maximum angle of 45 degrees to achieve maximum droplet loft, and the nozzle pressure was fixed at 100 psig. That left nozzle core and orifice plate selection as the attributes open for configuration optimization. Table 3 provides forecasts of the spray rate that will result from various combinations of number of nozzles, nozzle core and orifice plate at 100 psig based on vendor information. Spray rates less than or equal to 25 gpm (but at least 5 gpm) are highlighted as a conservative indicator of evaporator configurations that will avoid fallback exceeding 25 gpm. Turbo-Mist evaporation was roughly estimated from vendor information and engineering judgment to be on the order of 7 gpm for annual average SRS conditions in WSRC-TR-2002-00432. Optimal configurations were assumed to be those producing spray rates of this order of magnitude. From inspection of Table 3, 30 nozzles with orifice sizes D2 through D5 or D7 span the configurations that were anticipated to contain the optimal one for a given temperature and humidity.

To measure evaporator performance for a particular nozzle configuration and weather condition, a grid of collection devices was deployed at the F-seepage basin cap (Figure 3) to measure spray fallback. The evaporation rate was then computed as the measured spray rate minus the fallback rate. The surveyed grid system is depicted in Figure 4. A 20 ft square spacing was used in the center of the grid. Collection devices could be deployed at a variety of grid locations to handle particular weather conditions, primarily wind speed and direction. To handle a wide range of potential fallback amounts over the duration of a field test, both rain gauges and absorbent pads were used (Figure 5). Early testing indicated that rain gauges have a practical detection limit of roughly 0.1", and perhaps 0.2" is required for reasonable quantification. Absorbent pads can absorb and retain smaller amounts of fallback, approximately 0.2" and lower. Fallback is determined from the area, and dry and wet weights of the pad. Three brands of rain gauges (Figure 6) comprising two types (funnel/graduated cylinder and tipping bucket) were procured for the field testing. The Far View, All-Weather, and Onset gauges are commonly identified as the "Yellow", "Clear" and "White" gauges, respectively, on procedure, data, and calculation sheets.

Normal deployment of the Slimline Turbo-Mist evaporator allows for up to 15' of suction head, discharge flows in excess of 66 gpm, and additional water return for the self cleaning filter. To allow full flexibility for the testing, taking in consideration future deployments/test, the unit was

purchased from the vendor with the “as supplied water supply pump”. Because of the previously mentioned limitation of 25 gpm fall back limit for testing at this location, and wanting the flexibility to test at low flows, a bypass line was installed. The bypass line allowed for operation at discharge flows down to 5 gpm or less.

Figure 7 schematically illustrates the as-tested configuration of the Slimline Turbo-Mist evaporator at the F-seepage basin cap. Clean water was supplied to the unit via a 4 inch gravity feed PVC pipe. Flowmeters / totalizers were installed on the discharge line and bypass line to determine flows in the entire system. Pressure gauges were located on either side of the strainer and on the discharge line. An adjustable back pressure valve on the bypass line allowed for precise control of the system pressure.

Table 3 Spray rate projected for various nozzle core and orifice plate selections.

Orifice Disc #	Core	PSI	Capacity in GPM at the 100 PSI With xx Nozzles																													
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
D2	25	100	0.250	0.5	0.8	1.0	1.3	1.5	1.8	2.0	2.3	2.5	2.8	3.0	3.3	3.5	3.8	4.0	4.3	4.5	4.8	5.0	5.3	5.5	5.8	6.0	6.3	6.5	6.8	7.0	7.3	7.5
D3	25	100	0.290	0.6	0.9	1.2	1.5	1.7	2.0	2.3	2.6	2.9	3.2	3.5	3.8	4.1	4.4	4.6	4.9	5.2	5.5	5.8	6.1	6.4	6.7	7.0	7.3	7.5	7.8	8.1	8.4	8.7
D4	25	100	0.45	0.9	1.4	1.8	2.3	2.7	3.2	3.6	4.1	4.5	5.0	5.4	5.9	6.3	6.8	7.2	7.7	8.1	8.6	9.0	9.5	9.9	10.4	10.8	11.3	11.7	12.2	12.6	13.1	13.5
D5	25	100	0.54	1.1	1.6	2.2	2.7	3.2	3.8	4.3	4.9	5.4	5.9	6.5	7.0	7.6	8.1	8.6	9.2	9.7	10.3	10.8	11.3	11.9	12.4	13.0	13.5	14.0	14.6	15.1	15.7	16.2
D6	25	100	0.70	1.4	2.1	2.8	3.5	4.2	4.9	5.6	6.3	7.0	7.7	8.4	9.1	9.8	10.5	11.2	11.9	12.6	13.3	14.0	14.7	15.4	16.1	16.8	17.5	18.2	18.9	19.6	20.3	21.0
D7	25	100	0.81	1.6	2.4	3.2	4.1	4.9	5.7	6.5	7.3	8.1	8.9	9.7	10.5	11.3	12.2	13.0	13.8	14.6	15.4	16.2	17.0	17.8	18.6	19.4	20.3	21.1	21.9	22.7	23.5	24.3
D8	25	100	0.97	1.9	2.9	3.9	4.9	5.8	6.8	7.8	8.7	9.7	10.7	11.6	12.6	13.6	14.6	15.5	16.5	17.5	18.4	19.4	20.4	21.3	22.3	23.3	24.3	25.2	26.2	27.2	28.1	29.1
D10	25	100	1.21	2.4	3.6	4.8	6.1	7.3	8.5	9.7	10.9	12.1	13.3	14.5	15.7	16.9	18.2	19.4	20.6	21.8	23.0	24.2	25.4	26.6	27.8	29.0	30.3	31.5	32.7	33.9	35.1	36.3
D12	25	100	1.47	2.9	4.4	5.9	7.4	8.8	10.3	11.8	13.2	14.7	16.2	17.6	19.1	20.6	22.1	23.5	25.0	26.5	27.9	29.4	30.9	32.3	33.8	35.3	36.8	38.2	39.7	41.2	42.6	44.1
D14	25	100	1.65	3.3	5.0	6.6	8.3	9.9	11.6	13.2	14.9	16.5	18.2	19.8	21.5	23.1	24.8	26.4	28.1	29.7	31.4	33.0	34.7	36.3	38.0	39.6	41.3	42.9	44.6	46.2	47.9	49.5
D2	45	100	0.320	0.6	1.0	1.3	1.6	1.9	2.2	2.6	2.9	3.2	3.5	3.8	4.2	4.5	4.8	5.1	5.4	5.8	6.1	6.4	6.7	7.0	7.4	7.7	8.0	8.3	8.6	9.0	9.3	9.6
D3	45	100	0.360	0.7	1.1	1.4	1.8	2.2	2.5	2.9	3.2	3.6	4.0	4.3	4.7	5.0	5.4	5.8	6.1	6.5	6.8	7.2	7.6	7.9	8.3	8.6	9.0	9.4	9.7	10.1	10.4	10.8
D4	45	100	0.56	1.1	1.7	2.2	2.8	3.4	3.9	4.5	5.0	5.6	6.2	6.7	7.3	7.8	8.4	9.0	9.5	10.1	10.6	11.2	11.8	12.3	12.9	13.4	14.0	14.6	15.1	15.7	16.2	16.8
D5	45	100	0.71	1.4	2.1	2.8	3.6	4.3	5.0	5.7	6.4	7.1	7.8	8.5	9.2	9.9	10.7	11.4	12.1	12.8	13.5	14.2	14.9	15.6	16.3	17.0	17.8	18.5	19.2	19.9	20.6	21.3
D6	45	100	0.93	1.9	2.8	3.7	4.7	5.6	6.5	7.4	8.4	9.3	10.2	11.2	12.1	13.0	14.0	14.9	15.8	16.7	17.7	18.6	19.5	20.5	21.4	22.3	23.3	24.2	25.1	26.0	27.0	27.9
D7	45	100	1.11	2.2	3.3	4.4	5.6	6.7	7.8	8.9	10.0	11.1	12.2	13.3	14.4	15.5	16.7	17.8	18.9	20.0	21.1	22.2	23.3	24.4	25.5	26.6	27.8	28.9	30.0	31.1	32.2	33.3
D8	45	100	1.35	2.7	4.1	5.4	6.8	8.1	9.5	10.8	12.2	13.5	14.9	16.2	17.6	18.9	20.3	21.6	23.0	24.3	25.7	27.0	28.4	29.7	31.1	32.4	33.8	35.1	36.5	37.8	39.2	40.5
D10	45	100	1.77	3.5	5.3	7.1	8.9	10.6	12.4	14.2	15.9	17.7	19.5	21.2	23.0	24.8	26.6	28.3	30.1	31.9	33.6	35.4	37.2	38.9	40.7	42.5	44.3	46.0	47.8	49.6	51.3	53.1
D12	45	100	2.20	4.4	6.6	8.8	11.0	13.2	15.4	17.6	19.8	22.0	24.2	26.4	28.6	30.8	33.0	35.2	37.4	39.6	41.8	44.0	46.2	48.4	50.6	52.8	55.0	57.2	59.4	61.6	63.8	66.0
D14	45	100	2.45	4.9	7.4	9.8	12.3	14.7	17.2	19.6	22.1	24.5	27.0	29.4	31.9	34.3	36.8	39.2	41.7	44.1	46.6	49.0	51.5	53.9	56.4	58.8	61.3	63.7	66.2	68.6	71.1	73.5

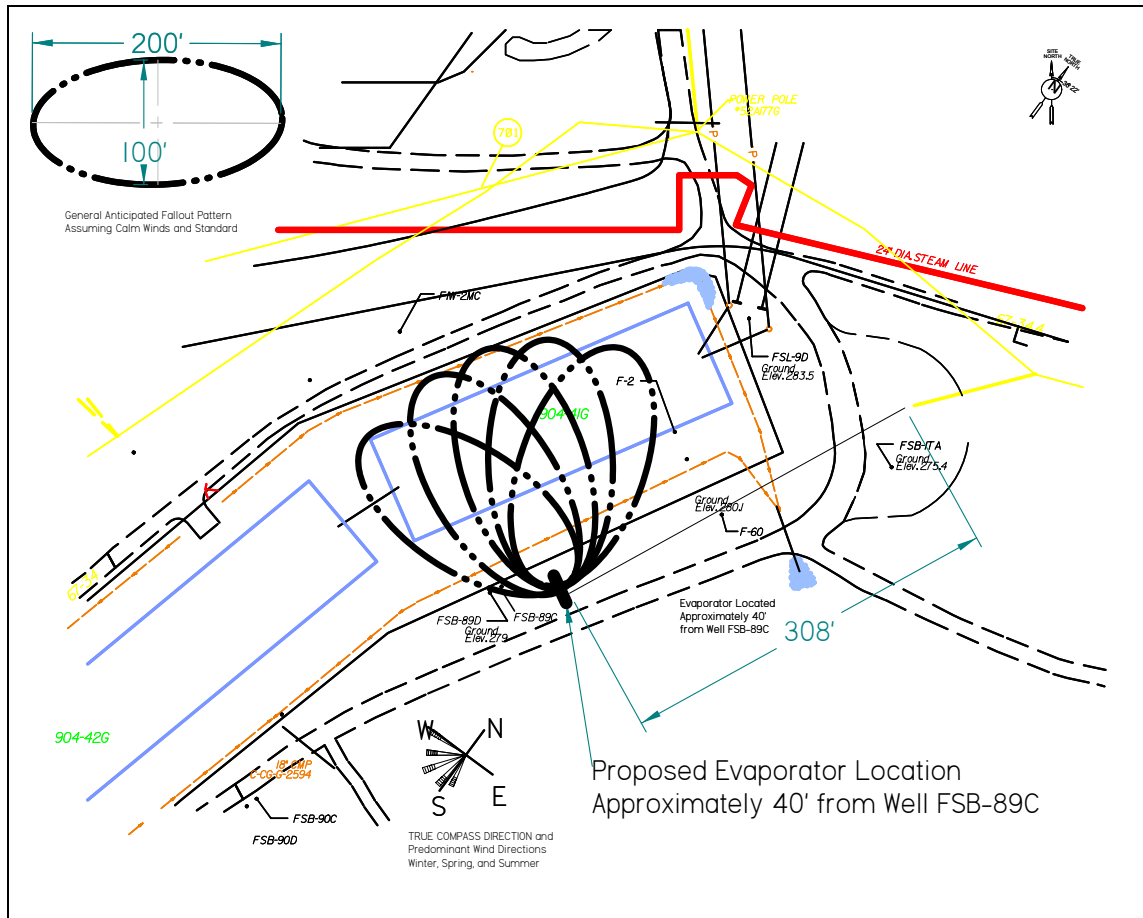


Figure 3 Location of Turbo-Mist field test.

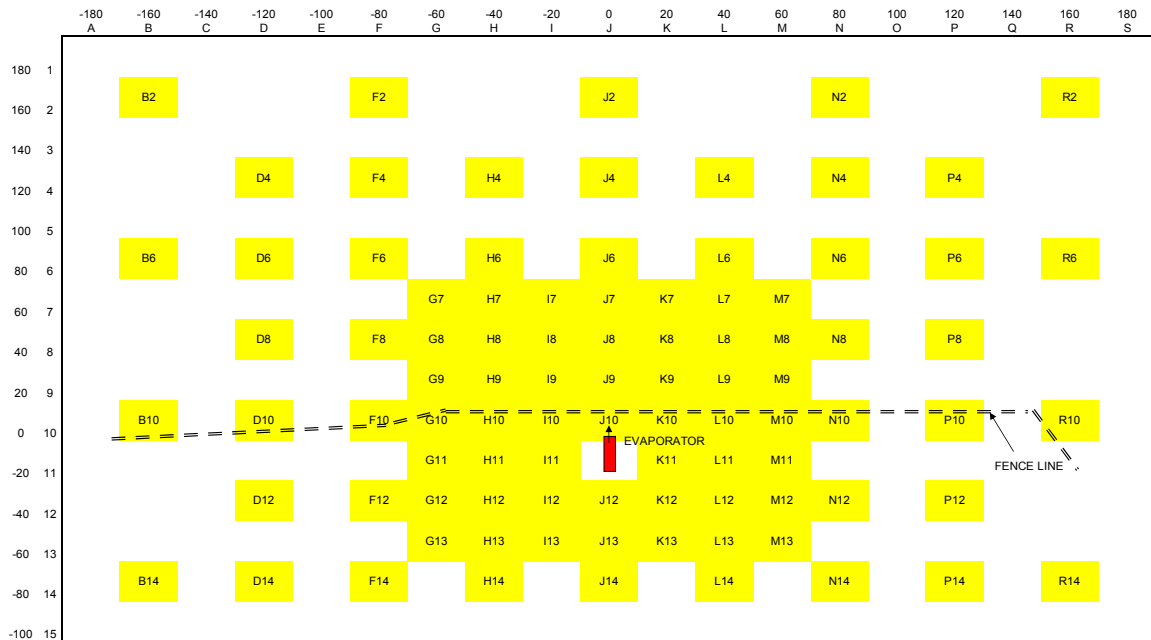


Figure 4 Surveyed grid system for placement of fallback collection devices.



Figure 5 Collection devices selected for measuring spray fallback



(a) Far View

(b) All-Weather

(c) Onset

Figure 6 Rain gauge brands procured for SRS field testing.

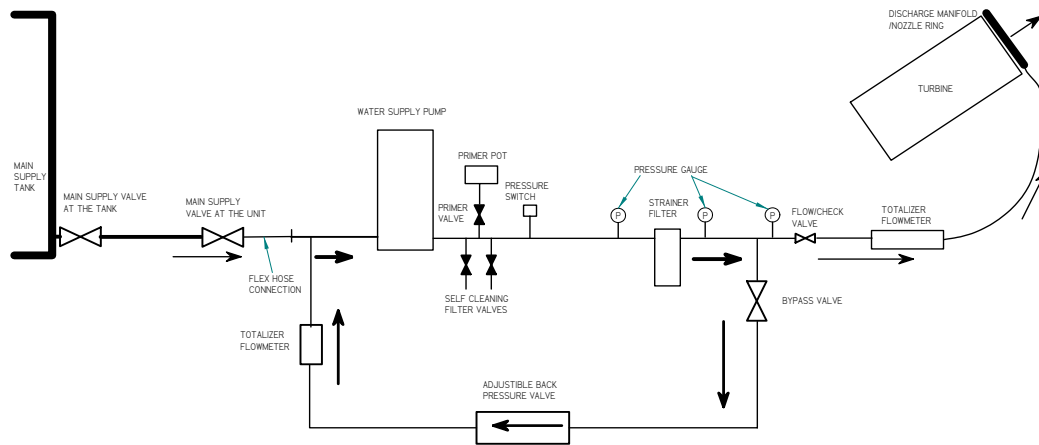


Figure 7 Simplified Piping Configuration

#### 4.0 FIELD TESTING AND DATA

Eight (8) field tests were conducted between March and August of 2003 (Table 4). Prior to the first test on March 31, a number of runs were performed to evaluate test equipment and experimental procedures, adequacy of the surveyed grid system, and performance of rain gauges. Qualitative observation of spray fallback from the initial runs suggested that the detection limit of rain gauges was at least 0.1". The fine mist produced from the D2 orifices with No. 25 cores during the initial runs would initially adhere to the rain gauge funnel (Far View and All-Weather) or debris screen (Onset). Only after a critical density of droplets had accumulated would droplets coalesce and fall into the graduated cylinder. This observation, and a realization that small amounts of fallback over a large area could be significant, lead to the use of absorbent pads in subsequent tests.

Spray fallback readings from co-located collection devices in the first formal test on March 31 were compared through the series of cross-plots shown in Figures 8-10. The Far-View/Yellow and All-Weather/Clear gauges appeared to be unbiased with respect to each other (Figure 8). The Onset/White gauge appeared to be biased low compared to the Far-View/Yellow (Figure 9) and All-Weather/Clear gauges. This was thought to be a result of the debris screen used in the tipping bucket design, which would retain water in holes through capillary suction. As a result, the Yellow and Clear gauges were used in subsequent tests. Comparison of the absorbent pads and Yellow gauges indicated that the pads are capable of reliably retaining fallback amounts up to 0.2" while at least 0.2" is needed with a rain gauge to avoid readings biased low (Figure 10).

The above observations lead to the following logic for assimilating data from multiple collection devices at individual grid locations:

1. Reading > 0.2" use rain gauge; otherwise use pad
2. Clear preferred over Yellow preferred over White

Readings from the Clear gauge are preferred over the Yellow gauge because the precision of the Clear gauge is 0.01" compared to 0.1" for the Yellow gauge. Figure 11 shows a cross-plot of data from absorbent pads and Yellow gauges across all tests. The plot suggests 0.25" as the optimal cut-off value in retrospect.

For each test a map of spray fallback was created by interpolating the point data from the preferred collection device at each grid location onto a regular 20' by 20' grid using a kriging algorithm embedded in Tecplot (Amtec Engineering, Inc.). Numerical integration of the kriged surface produced the total amount of spray fallback for a given test. The fallback rate was computed by dividing the fallback amount by the duration of the test. Detailed calculations for each test are provided in a Controlled Laboratory Notebook (WSRC-NB-2001-00167) and the Appendices.

Table 4 summarizes the evaporator configuration, average weather conditions, and spray fallback for each field test. Because testing was conducted from March through August, periods of rainfall were avoided, and daytime testing was preferred for logistical reasons, most tests were

conducted at relatively warm temperatures and moderate humidity. An exception was the 16 hr overnight test beginning at 4:21 PM on March 31 and ending at 8:58 AM on April 1, for which the average conditions were 38.3 °F, 72% relative humidity, and 1.9 mph wind speed. These conditions are unfavorable for evaporation and the evaporation rate was low.

Figures 12 through 19 shows the spatial distribution of fallback in inches per year for each test. Note that the contour scale varies between plots. For all but the last test using D8 orifice plates, the distribution of fallback was controlled by the prevailing wind direction and heavy fallback was confined to the immediate vicinity of the Turbo-Mist unit. Visual observations suggest this behavior was a result of the small droplet sizes produced by the D2 through D6 orifices. Small droplets have little inertia, and once blown into the atmosphere by the Turbo-Mist, are easily swept along with the natural winds. However, the larger droplets created by the D8 nozzle apparently have sufficient inertia to follow a trajectory in the direction the Turbo-Mist nozzle. In the August 11 test using the D8 orifice plates, the fallback pattern extended out from the unit in the direction of the air nozzle despite a differing prevailing wind direction.

**Table 4 Summary of Turbo-Mist field tests.**

Test date	Nozzle configuration			Performance		On-site weather			Central Shops 2/4 m tower			Central Shops 18 m tower		
	No.	Cores	Orifices	Spray rate	Evap.	Temp.	Relative humidity	Windspeed	Temp.	Relative humidity	Windspeed	Temp.	Relative humidity	Windspeed
				(gpm) Q	(gpm) E	(F) T	(%) φ	(mph) V	(F) T	(%) φ	(mph) V	(F) T	(%) φ	(mph) V
03/31/03	30	25	D2	6.1	1.81	38.3	72	1.9	39.5	69	2.9	43.1	54	4.4
04/29/03	30	25	D2	6.1	5.31	75.5	60	4.2	77.7	52	4.7	76.0	55	5.7
05/01/03	30	25	D5	15.7	6.49	75.9	67	4.0	78.2	56	7.0	76.7	59	8.8
05/14/03	30	25	D5	16.7	5.71	72.4	46	2.0	NA	NA	NA	NA	NA	NA
06/25/03	30	25	D5	16.2	8.31	87.7	42	2.7	87.9	41	3.7	86.4	41	3.9
06/26/03	27	45	D6	25.5	13.17	87.3	48	4.6	88.0	46	5.0	86.0	46	6.3
07/24/03	27	45	D6	26.1	11.36	82.5	62	3.0	85.0	56	4.4	81.0	59	5.0
08/11/03	30	45	D8	39.2	13.97	85.1	63	2.4	83.5	64	6.5	81.2	66	6.8

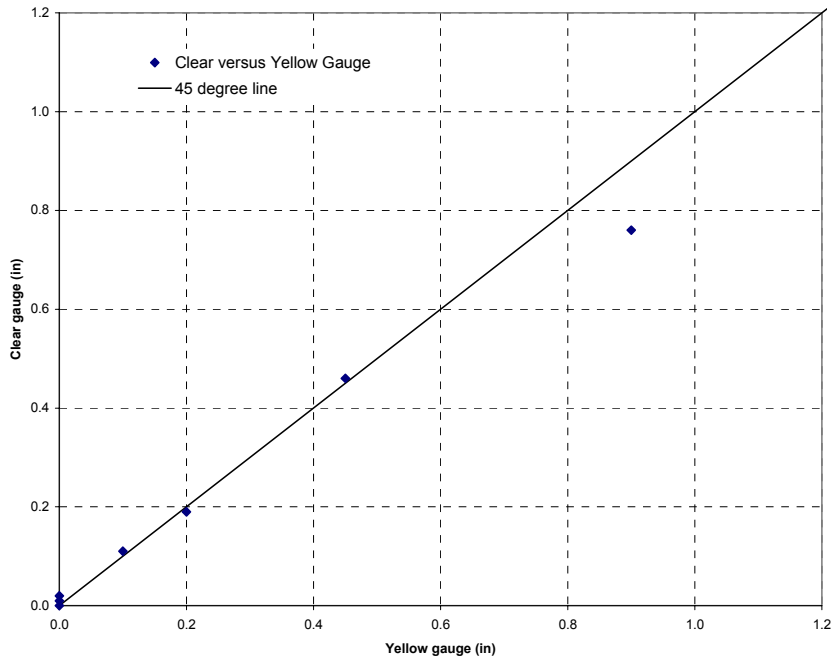


Figure 8 Cross-plot of Clear and Yellow rain gauge data collected during field testing on 3/31/03.

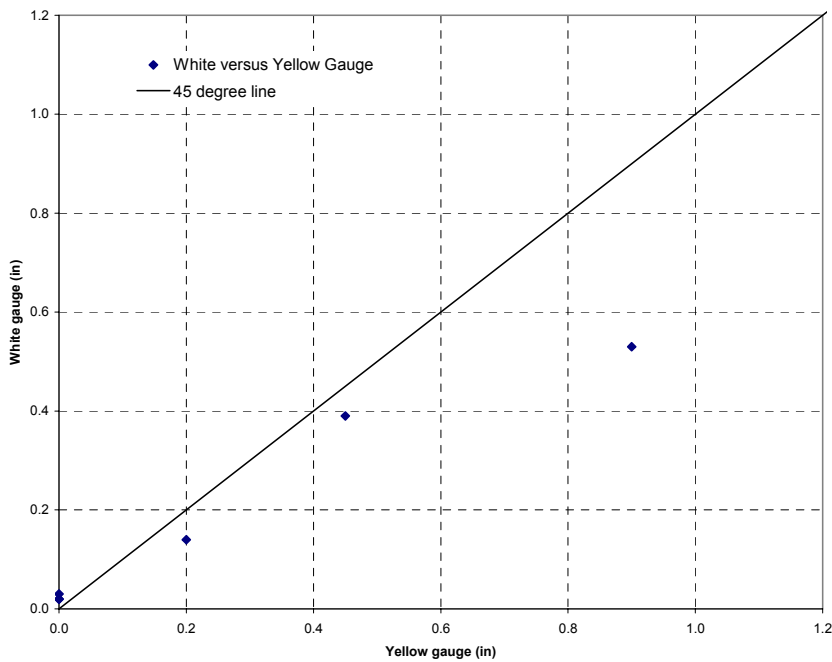
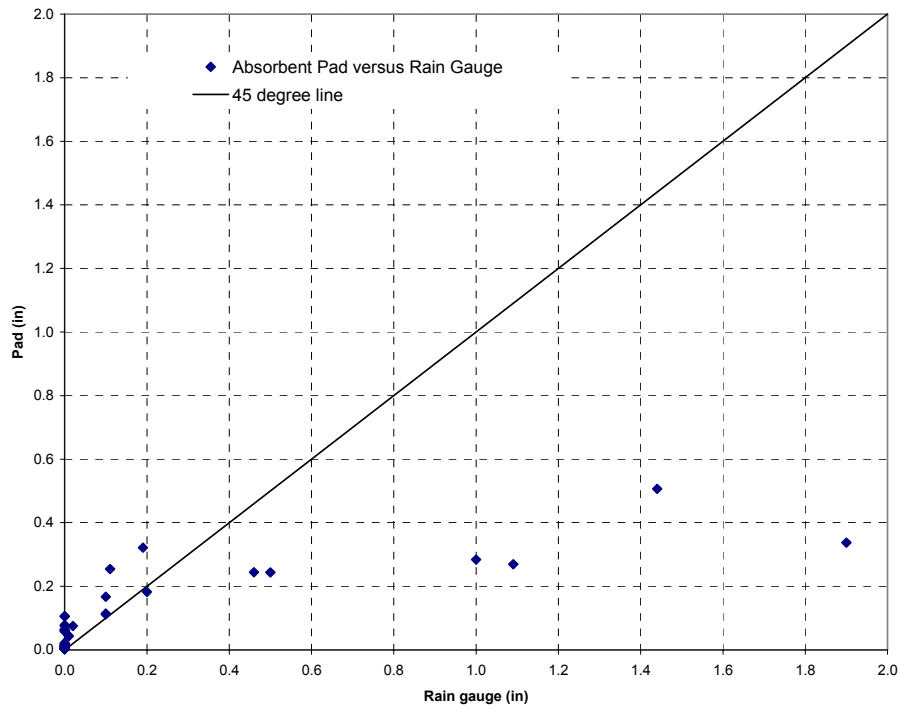
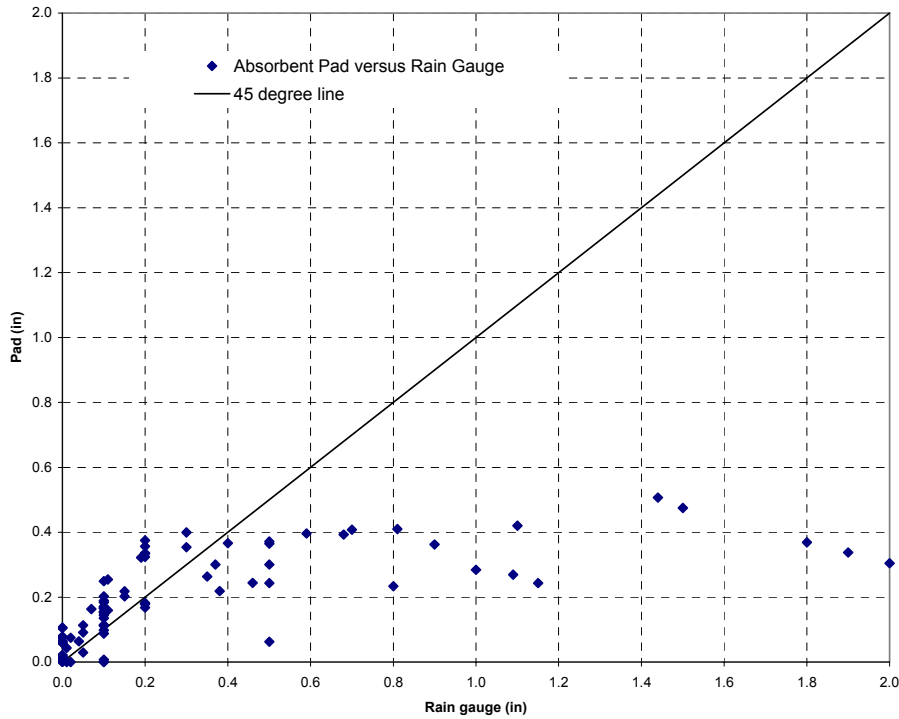


Figure 9 Cross-plot of White and Yellow rain gauge data collected during field testing on 3/31/03.



**Figure 10** Cross-plot of absorbent pad and "best" rain gauge fallback data collected during field testing on 3/31/03.



**Figure 11** Cross-plot of absorbent pad and rain gauge data collected from all applicable field tests.

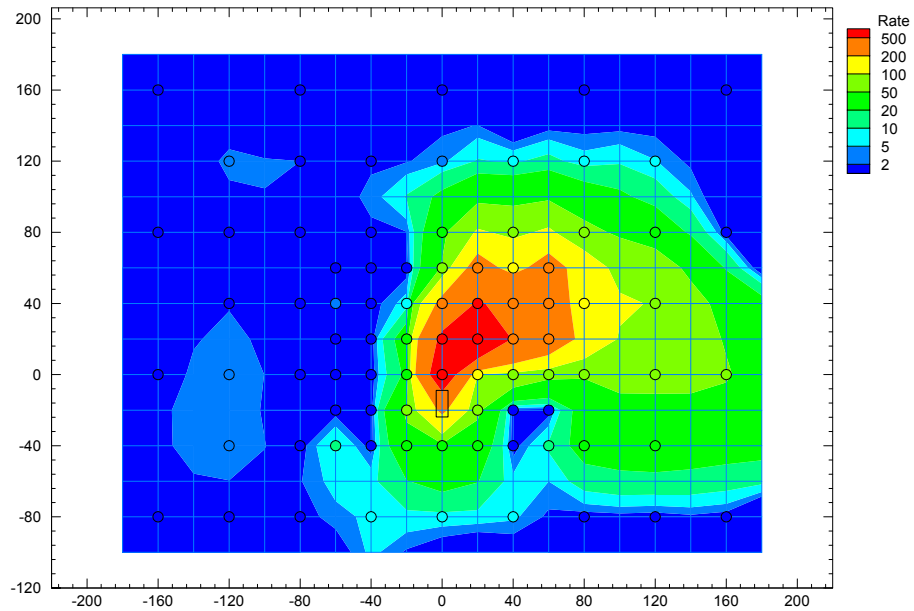


Figure 12 Spray fallback pattern for Turbo-Mist field test on 3/31/03.

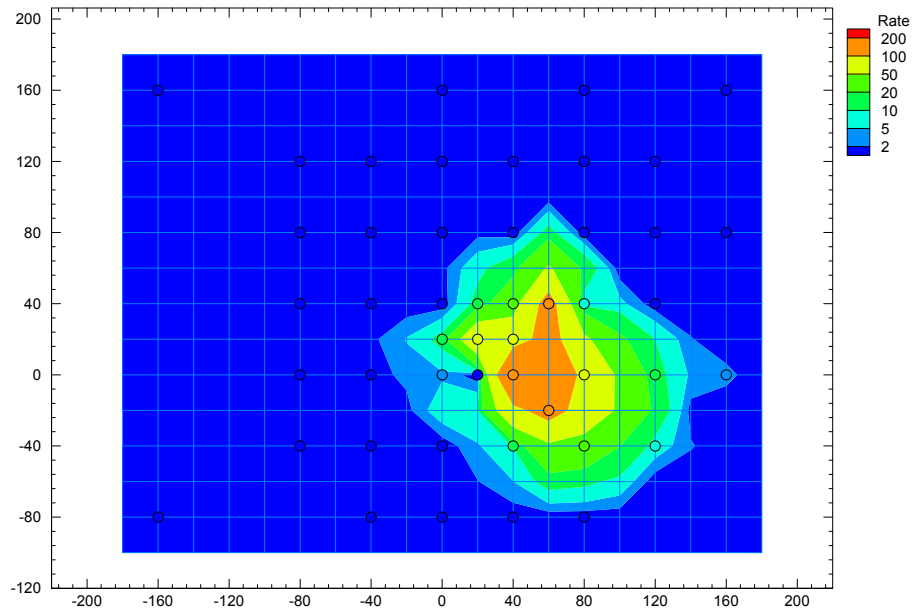


Figure 13 Spray fallback pattern for Turbo-Mist field test on 4/29/03.

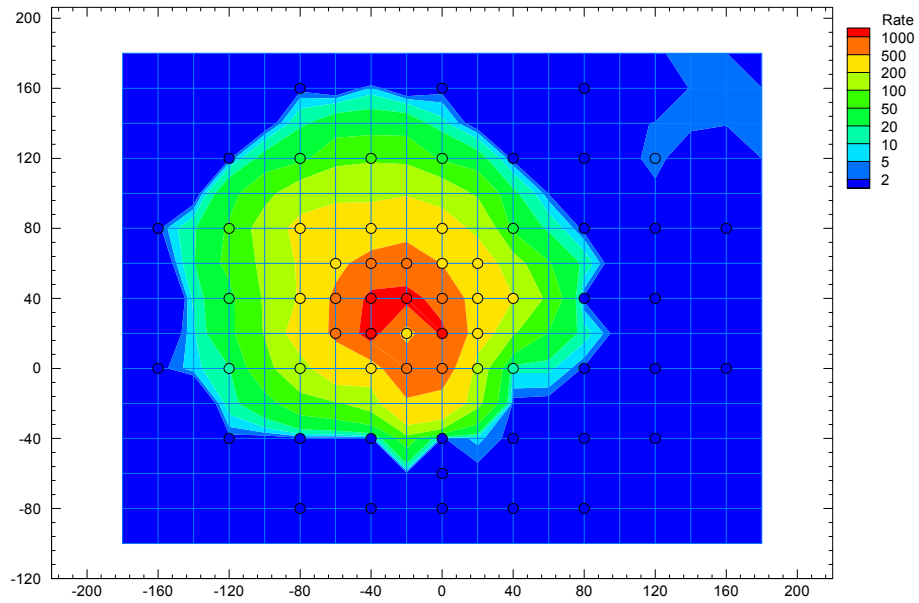


Figure 14 Spray fallback pattern for Turbo-Mist field test on 5/1/03.

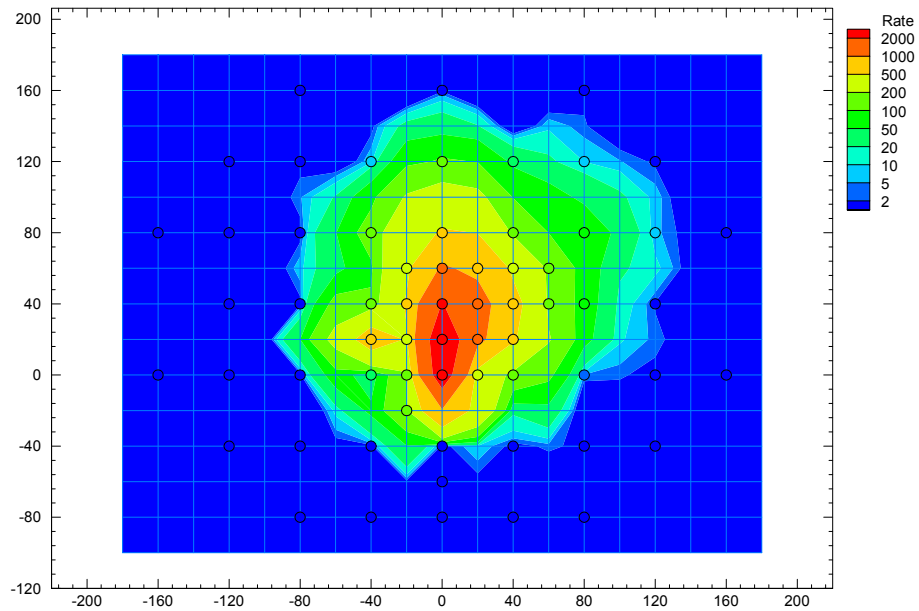


Figure 15 Spray fallback pattern for Turbo-Mist field test on 5/14/03.

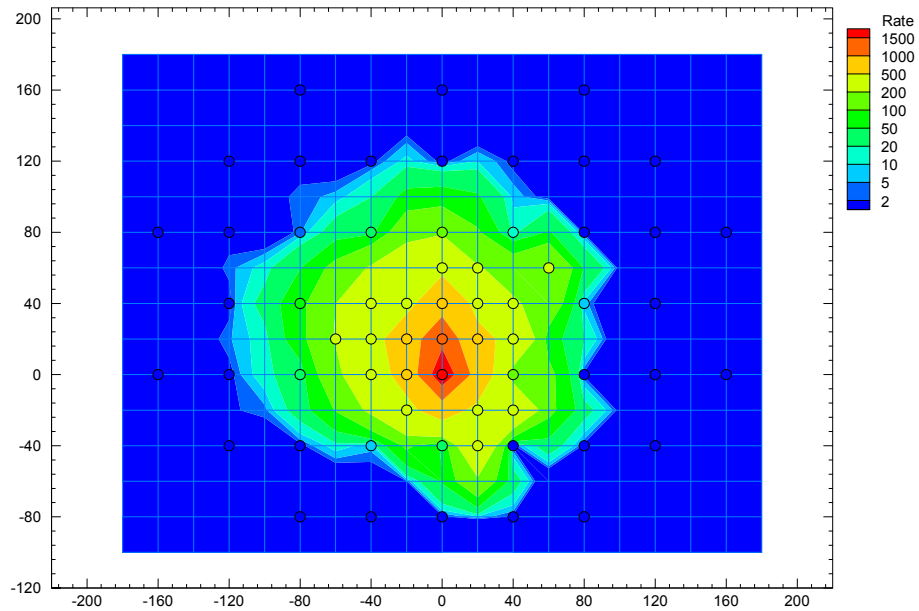


Figure 16 Spray fallback pattern for Turbo-Mist field test on 6/25/03.

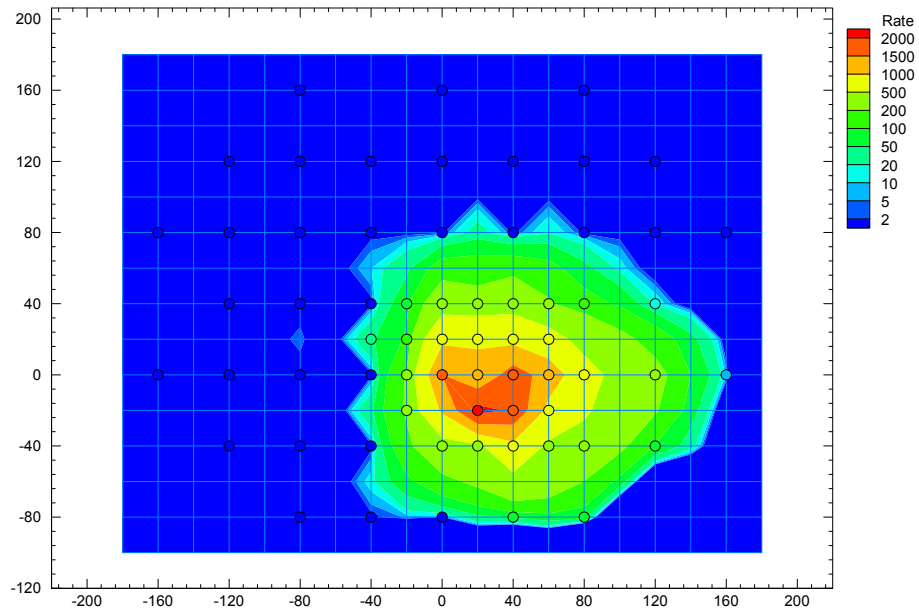


Figure 17 Spray fallback pattern for Turbo-Mist field test on 6/26/03.

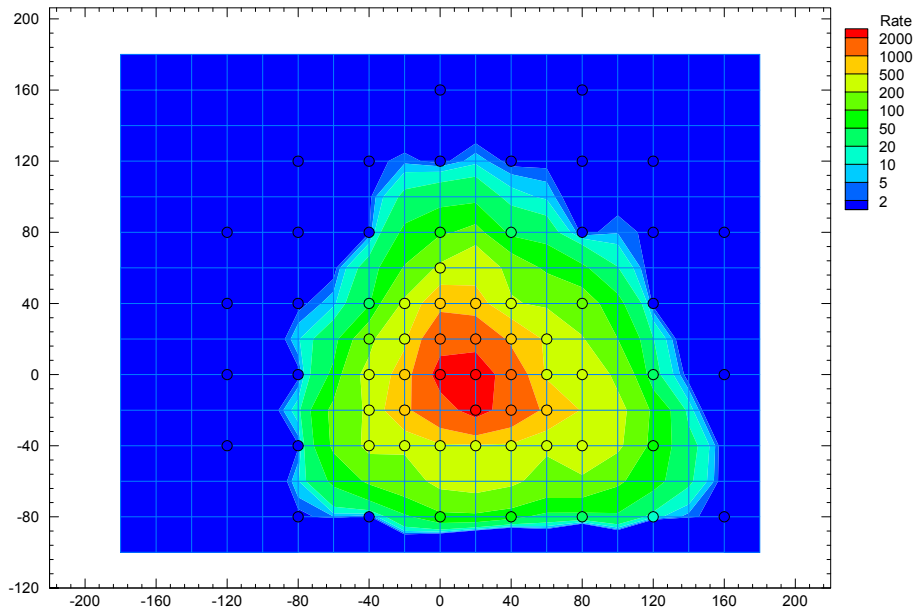


Figure 18 Spray fallback pattern for Turbo-Mist field test on 7/24/03.

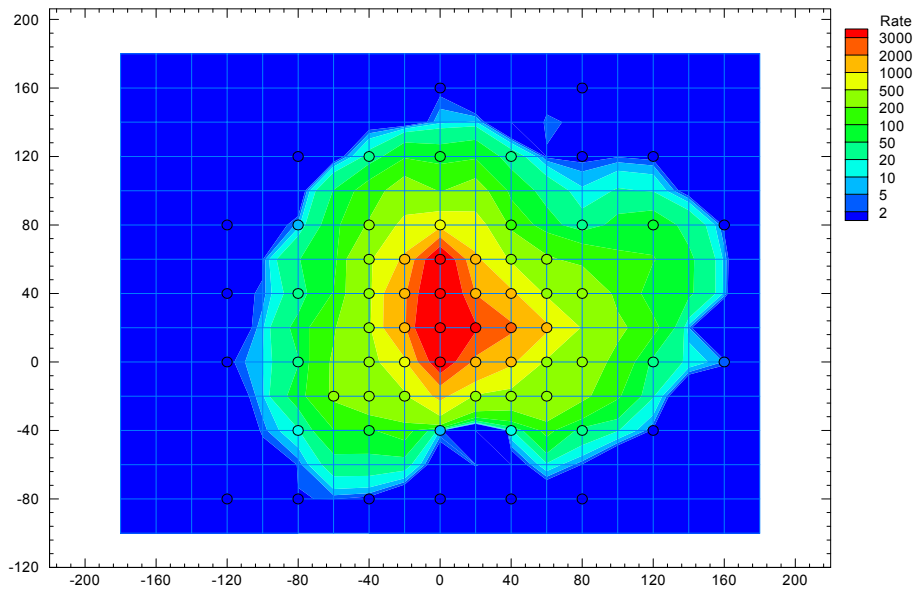


Figure 19 Spray fallback pattern for Turbo-Mist field test on 8/11/03.

## 5.0 PREDICTIVE MODEL

Because the collection of test data summarized in Table 4 only define Turbo-Mist performance under certain specific conditions, a model capable of predicting performance under arbitrary conditions is desired. Following the previously-stated expectation that the evaporation rate is largely proportional to the evaporative cooling potential based on adiabatic saturation and wind speed, the dimensional evaporation data in Table 4 are first normalized as

$$E' = \frac{E}{a \cdot EP \cdot V} \quad (2)$$

where  $E'$  = normalized evaporation rate (unitless),  $E$  = evaporation rate (gpm),  $EP$  = adiabatic saturation cooling degrees based on temperature and relative humidity ( $^{\circ}F$ ),  $V$  = wind speed (mph) and  $a$  = empirical constant to be determined (gpm/ $^{\circ}F$ -mph). Similarly, the spray rate is normalized as

$$Q' = \frac{Q}{a \cdot EP \cdot V} \quad (3)$$

where  $Q'$  = normalized spray rate (unitless),  $Q$  = spray rate (gpm).

The evaporation rate is zero when the spray rate is zero. Field data suggest the evaporation rate increases in proportion to spray rate initially, but levels off at higher spray rates. A non-dimensional functional form capturing this qualitative behavior is

$$E' = \frac{1}{1 + \frac{b}{Q'}} \quad (4)$$

where  $b$  is an empirical constant (unitless). The limiting behavior of equation (4) is

$$\begin{aligned} Q' \rightarrow 0 & \quad E' \rightarrow 0 \\ Q' \rightarrow \infty & \quad E' \rightarrow 1 \end{aligned}$$

In terms of dimensional parameters, equation (4) is equivalent to

$$E = \frac{1}{\frac{1}{a \cdot EP \cdot V} + \frac{b}{Q}} \quad (5)$$

with limits of

$$\begin{array}{ll} Q \rightarrow 0 & E \rightarrow 0 \\ Q \rightarrow \infty & E \rightarrow a \cdot EP \cdot V \end{array}$$

For each set of weather parameters, optimal values for the empirical constants a and b were determined using least-squares parameter fitting, as shown in Table 5. For these settings, the normalized evaporation and spray rates are listed in Table 6.

Normalized evaporation rate is plotted against normalized spray rate in Figure 20 based on weather data from the Central Shops 2/4 meter towers. Also shown in the figure is the predictive model defined by equation (4) and parameters in Table 5. The model fits the data reasonably well.

**Table 5 Least-squares parameter estimation results.**

Test date	Nozzle configuration			Performance		On-site weather			Central Shops 2/4 m tower			Central Shops 18 m tower		
	No.	Cores	Orifices	Spray rate (gpm)	Evap. (gpm)	Model (gpm)	Residual (gpm)	Residual <sup>2</sup> (gpm <sup>2</sup> )	Model (gpm)	Residual (gpm)	Residual <sup>2</sup> (gpm <sup>2</sup> )	Model (gpm)	Residual (gpm)	Residual <sup>2</sup> (gpm <sup>2</sup> )
				Q	E	E*	E*-E	(E*-E) <sup>2</sup>	E*	E*-E	(E*-E) <sup>2</sup>	E*	E*-E	(E*-E) <sup>2</sup>
03/31/03	30	25	D2	6.1	1.81	2.5	0.7	0.5	2.4	0.6	0.3	3.1	1.3	1.6
04/29/03	30	25	D2	6.1	5.31	3.3	-2.0	4.0	3.7	-1.6	2.7	3.5	-1.8	3.4
05/01/03	30	25	D5	15.7	6.49	7.5	1.0	1.0	8.5	2.0	4.0	8.3	1.8	3.1
05/14/03	30	25	D5	16.7	5.71	7.6	1.9	3.6						
06/25/03	30	25	D5	16.2	8.31	8.1	-0.2	0.0	8.3	0.0	0.0	8.1	-0.2	0.1
06/26/03	27	45	D6	25.5	13.17	12.7	-0.4	0.2	12.3	-0.9	0.8	12.5	-0.7	0.4
07/24/03	27	45	D6	26.1	11.36	11.0	-0.3	0.1	10.7	-0.6	0.4	10.7	-0.6	0.4
08/11/03	30	45	D8	39.2	13.97	13.5	-0.5	0.2	14.4	0.4	0.1	14.3	0.3	0.1
						1.38 a		9.6	0.49 a		8.3	0.56 a		9.1
						1.74 b			1.45 b			1.59 b		

**Table 6 Normalized evaporation and spray rates.**

Test date	Nozzle configuration			Performance		On-site weather			Central Shops 2/4 m tower			Central Shops 18 m tower		
	No.	Cores	Orifices	Spray rate (gpm)	Evap. (gpm)	Spray (unitless)	Evap. (unitless)	Model (unitless)	Spray (unitless)	Evap. (unitless)	Model (unitless)	Spray (unitless)	Evap. (unitless)	Model (unitless)
				Q	E	Q/a*EP*V	E/a*EP*V	E^a*EP*V	Q/a*EP*V	E/a*EP*V	E^a*EP*V	Q/a*EP*V	E/a*EP*V	E^a*EP*V
03/31/03	30	25	D2	6.1	1.81	0.68	0.20	0.28	1.13	0.34	0.44	0.39	0.12	0.20
04/29/03	30	25	D2	6.1	5.31	0.11	0.09	0.06	0.21	0.19	0.13	0.17	0.15	0.10
05/01/03	30	25	D5	15.7	6.49	0.35	0.14	0.17	0.40	0.16	0.22	0.31	0.13	0.16
05/14/03	30	25	D5	16.7	5.71	0.45	0.16	0.21						
06/25/03	30	25	D5	16.2	8.31	0.24	0.13	0.12	0.50	0.26	0.26	0.41	0.21	0.21
06/26/03	27	45	D6	25.5	13.17	0.26	0.13	0.13	0.63	0.33	0.30	0.45	0.23	0.22
07/24/03	27	45	D6	26.1	11.36	0.62	0.27	0.26	0.98	0.43	0.40	0.84	0.37	0.35
08/11/03	30	45	D8	39.2	13.97	1.16	0.41	0.40	1.28	0.46	0.47	1.15	0.41	0.42

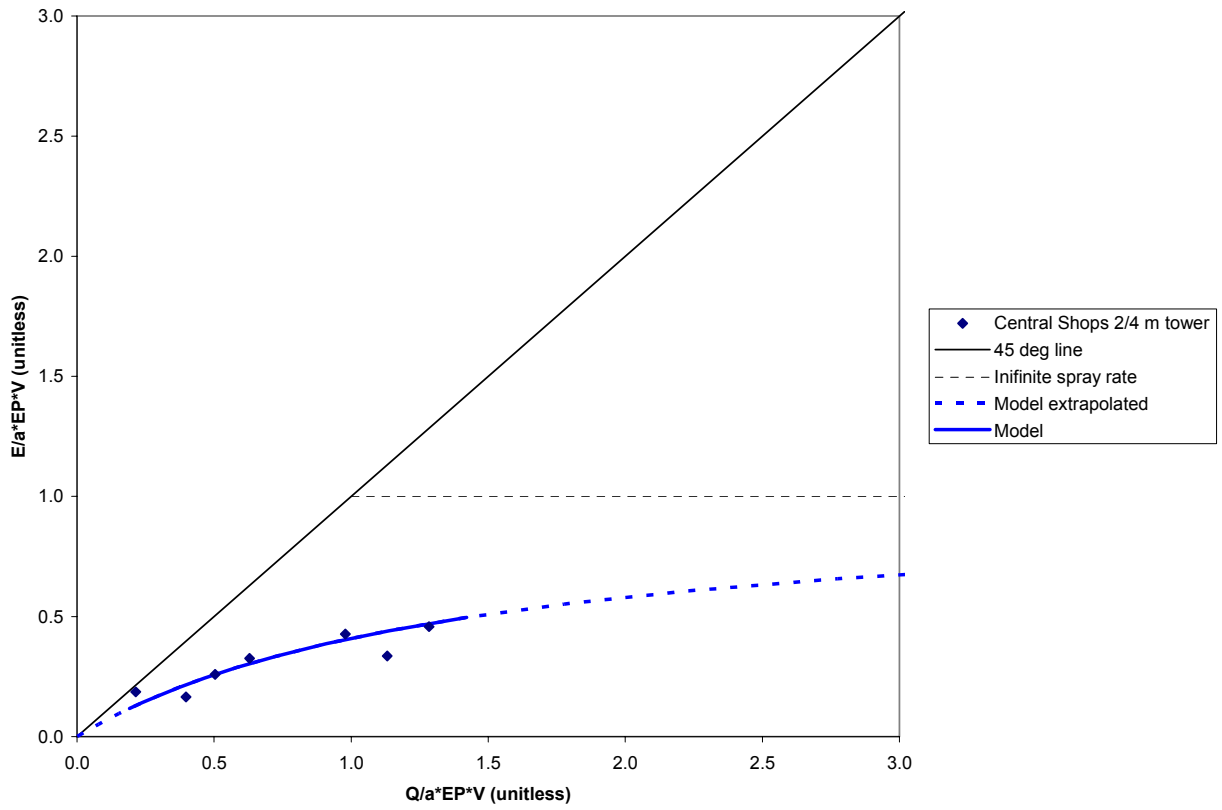
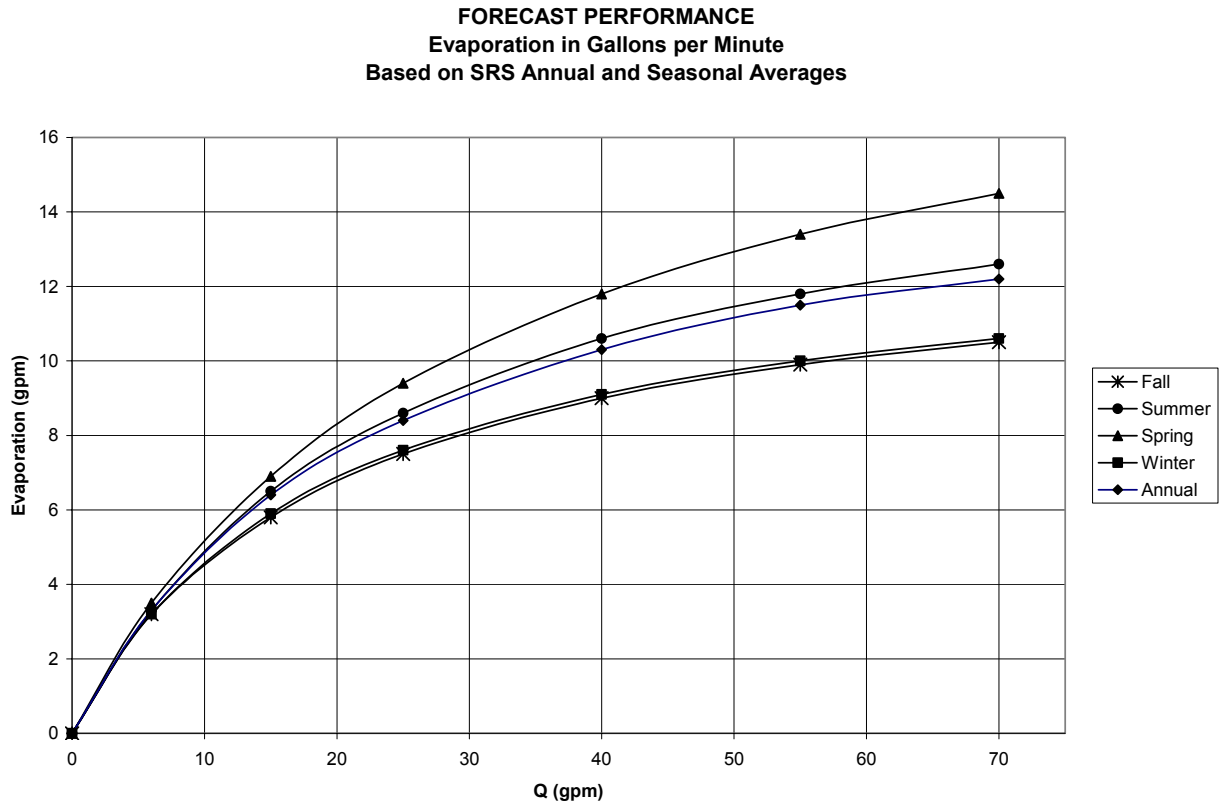


Figure 20 Normalized evaporation and spray rates.

## 6.0 FORECAST EVAPORATION RATES

The non-dimensional predictive model defined by equation (4) with  $a = 0.49 \text{ gpm}/^\circ\text{F}\text{-mph}$  and  $b = 1.45$  (Figure 20) can be translated into equivalent dimensional forms for specific weather conditions. Figure 21 shows predicted evaporation rates in gpm for annual and seasonal average weather conditions at the Savannah River Site and spray rate up to 70 gpm.



**Figure 21** Forecast long-term performance of the Turbo-Mist evaporator for annual and seasonal average weather conditions at the SRS.

## 7.0 SUMMARY AND CONCLUSIONS

The evaporation rate of spray from a Slimline Turbo-Mist evaporator is approximately proportional to the evaporative cooling potential of "dry" air based on temperature and humidity, and wind speed. As a secondary effort, the evaporation rate was also observed to increase with spray rate, to a point of diminishing increases. A model has been developed for predicting evaporation rate as a function of weather conditions and spray rate. Forecast performance of the Turbo-Mist evaporator under average temperature, humidity and wind speed conditions for the year and each season are plotted in Figure 21 as a function of spray rate (controlled by nozzle orifice selection). The fallback rate is the spray rate less the evaporation rate. If significant fallback is tolerable, an evaporation rate averaging about 12 gpm is estimated for operation at the SRS on a year-round basis.

## 8.0 REFERENCES

American Society of Heating, Refrigerating and Air-Conditioning Engineers, 1985, ASHRAE Handbook; 1985 Fundamentals, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta GA.

Controlled Laboratory Notebook WSRC-NB-2001-00167, assigned to G. P. Flach.

Hunter, C. H. and C. P. Tatum, 1997, Meteorological annual report for 1996 (U), WSRC-TR-97-0214.

Reynolds, W. C. and H. C. Perkins, 1977, *Engineering Thermodynamics*, McGraw-Hill, New York, 690 p.

Flach, G. P., 2002, Evaluation of Evaporation Technologies for Treating Contaminated Groundwater (U), WSRC-TR-2002-00432.

Appendix A – Data and analysis for Turbo-Mist field test on 3/31/03

30 No. 25 cores with D2 orifice plates

March 31 - April 1, 2003

30		Number of spray nozzles	0.001897 yr	Duration of test
25		Cores	0.6924 day	
D2		Orifices	16.62 hr	
3/31/03 16:21	37711.6813	Start of test	997 min	
6621 gal	m <sup>3</sup>	Nozzle flow totalizer	59820 sec	
5.1 gal/min	m <sup>3</sup> /hr	Nozzle flowrate - indicated	6036.5 gal	22.9 m <sup>3</sup> Spray volume
45120 gal	m <sup>3</sup>	Bypass flow totalizer	114530 gal	433.5 m <sup>3</sup> Bypass volume
116.1 gal/min	m <sup>3</sup> /hr	Bypass flowrate - indicated		
104 psi	Pa	P1	6.1 gal/min	1.38 m <sup>3</sup> /hr Spray flowrate
98 psi	Pa	P2	115 gal/min	26.1 m <sup>3</sup> /hr Bypass flowrate
100 psi	Pa	P3	21 in <sup>2</sup>	0.0135 m <sup>2</sup> Pad area
4/1/03 0:11	37712.0076	Midpoint	0.1458 ft <sup>2</sup>	
9483.1 gal	m <sup>3</sup>	Nozzle flow totalizer	3.35E-06 acre	
5.8 gal/min	m <sup>3</sup> /hr	Nozzle flowrate - indicated	480 volts	Voltage
99300 gal	m <sup>3</sup>	Bypass flow totalizer	36 amps	Current
114.2 gal/min	m <sup>3</sup> /hr	Bypass flowrate - indicated	29.9 kW	Power
100 psi	Pa	P1	38.3 F	3.49 C Temperature
99 psi	Pa	P2	72%	72% Relative humidity
100 psi	Pa	P3	1.9 mph	0.84 m/s Wind speed
4/1/03 8:58	37712.3736	End of test	226.27 deg	226.27 deg Wind direction
12657.5 gal	m <sup>3</sup>	Nozzle flow totalizer	6.05 gpm	Spray
6.1 gal/min	m <sup>3</sup> /hr	Nozzle flowrate - indicated	4.24 gpm	Fallback
159650 gal	m <sup>3</sup>	Bypass flow totalizer	<b>1.81 gpm</b>	<b>Evaporation</b>
116.1 gal/min	m <sup>3</sup> /hr	Bypass flowrate - indicated	30%	
102 psi	Pa	P1	29.9 kW	Power
98 psi	Pa	P2	0.08 \$/kW-hr	Energy cost
100 psi	Pa	P3	<b>0.022 \$/gal</b>	<b>Cost</b>
3 in		Pad width	0.056 \$/gal	Direct heating cost
7 in		Pad length	<b>39%</b>	<b>Relative cost</b>

Adiabatic saturation / swamp cooler calculation using ASHRAE (1985) equations						
<b>Constants</b>						<i>source</i>
univ. gas const.	R	1545.33 ft-lbf/(lbmole-R)				
molecular wt. air	M <sub>a</sub>	28.9645 lbm/lbmole				from eqn (24)
air gas constant	R <sub>a</sub>	53.35 ft-lbf/(lbm-R)				
<b>Incoming air stream</b>						
pressure	p	14.7 psia				
temperature	t	38.282 F	3.5 C	497.952 R	31Mar03 - 01Apr03 Field Test	
relative humidity	φ	0.72	unitless			
sat. pressure	p <sub>ws</sub>	0.1152 psia				eqn (4)
water vap. pres.	p <sub>w</sub>	0.0829 psia				eqn (22)
humidity ratio	W, γ	0.003528	unitless		24.69 grains/lbm <sub>a</sub>	eqn (20)
sat. humidity ratio	W <sub>s</sub>	0.004913		unitless		eqn (21)
deg. of saturation	μ	0.7180		unitless		eqn (10)
specific volume	v	12.62 ft <sup>3</sup> /lbm <sub>a</sub>				eqn (26)
		12.58 ft <sup>3</sup> /lbm				using (1+γ) factor and eqn (26)
		12.55 ft <sup>3</sup> /lbm				using ideal gas law
specific enthalpy	h	12.99 BTU/lbm <sub>a</sub>				eqn (30)
<b>Outgoing for adiabatic saturation/evaporation</b>						
pressure	p	14.7 psia				
temperature	t	34.88 F	1.6 C	494.55 R		
relative humidity	φ	1.00		unitless		
sat. pressure	p <sub>ws</sub>	0.1007 psia				eqn (4)
water vap. pres.	p <sub>w</sub>	0.1007 psia				eqn (22)
humidity ratio	W, γ	0.004291	lbm <sub>w</sub> /lbm <sub>a</sub>		30.03 grains/lbm <sub>a</sub>	eqn (20)
sat. humidity ratio	W <sub>s</sub>	0.004291		unitless		eqn (21)
deg. of saturation	μ	1.0000		unitless		eqn (10)
specific volume	v	12.55 ft <sup>3</sup> /lbm <sub>a</sub>				eqn (26)
		12.50 ft <sup>3</sup> /lbm				using (1+γ) factor and eqn (26)
		12.46 ft <sup>3</sup> /lbm				using ideal gas law
specific enthalpy	h	12.99 BTU/lbm <sub>a</sub>				eqn (30)
<b>Differences</b>						
temperature	Δt	-3.4 F				
relative humidity	Δφ	0.28		unitless		
enthalpy	Δh	0.00		BTU/lbm <sub>a</sub>		
humidity ratio	ΔW, Δγ	0.000763	lbm <sub>w</sub> /lbm <sub>a</sub>		5.34 grains/lbm <sub>a</sub>	
<b>Evaporation system parameters</b>						
Wind speed	v	1.9	mi/hr		2.76	ft/s
Height	h	35.0		ft		
Width	w	35.0		ft		
Xsec area	A	1225		ft <sup>2</sup>		
Incoming wet air vol. flow	Q	3376	ft <sup>3</sup> /s		2.0E+05	ft <sup>3</sup> /min (cfm)
Dry air mass flow	m <sub>a</sub>	267		lbm <sub>a</sub> /s		
Evaporation rate	m <sub>e</sub>	0.20	lbm <sub>w</sub> /s		12.25	lbm <sub>w</sub> /min
Liq. water density	ρ	62.3		lbm/ft <sup>3</sup>		@ 70F
Evaporation rate	Q <sub>e</sub>	0.003	ft <sup>3</sup> /s		1.47	gal/min
					88	gal/hr

Station ID	Yellow (in)	Clear (in)	White ID	Pad - Dry (g)	Pad - Wet (g)	White (in)
B2	0	nd	nd	nd	nd	nd
B6	0	nd	nd	nd	nd	nd
B10	0	nd	nd	nd	nd	nd
D4	0	nd	nd	14.3	15.8	nd
D6	0	nd	nd	14.3	15.2	nd
D8	0	nd	nd	14.5	15.7	nd
D10	0	nd	nd	14.4	17.3	nd
F2	0	nd	nd	nd	nd	nd
F4	0	nd	nd	14.0	15.3	nd
F6	0	nd	nd	14.6	15.7	nd
F8	0	nd	nd	nd	nd	nd
F10	0	nd	nd	nd	nd	nd
G7	0	nd	nd	nd	nd	nd
G8	0	nd	nd	14.3	15.7	nd
G9	T	nd	nd	nd	nd	nd
H4	0	nd	nd	14.4	15.4	nd
H6	0	nd	nd	14.3	15.2	nd
H7	0	nd	nd	nd	nd	nd
H8	0	T	TM-2	nd	nd	0.02
H9	T	nd	nd	nd	nd	nd
I7	0	nd	nd	nd	nd	nd
I8	0	nd	nd	14.8	19.4	nd
I9	T	nd	nd	14.4	34.5	nd
J2	0	nd	nd	nd	nd	nd
J4	0	nd	nd	14.3	16.9	nd
J6	T	nd	nd	14.7	41.7	nd
J7	0.1	nd	nd	nd	nd	nd
J8	0.45	0.46	TM-4	14.9	98.9	0.39
J9	1.3	1.09	TM-5	14.8	107.5	1.06
K7	0.5	nd	nd	nd	nd	nd
K8	1.0	nd	nd	14.3	112.0	nd
K9	1.9	nd	nd	14.4	130.6	nd
L4	0	nd	nd	14.4	20.3	nd
L6	0.1	nd	nd	14.9	72.4	nd
L7	0.3	nd	nd	nd	nd	nd
L8	0.9	0.76	TM-7	nd	nd	0.53
L9	0.9	nd	nd	nd	nd	nd
M7	0.5	nd	nd	nd	nd	nd
M8	0.5	nd	nd	14.0	97.8	nd
M9	0.6	nd	nd	nd	nd	nd
N2	0	nd	nd	nd	nd	nd
N4	0	nd	nd	13.8	18.3	nd
N6	0.1	nd	nd	14.3	53.7	nd
N8	0.3	nd	nd	nd	nd	nd
P4	0	nd	nd	14.8	18.2	nd
P6	T	nd	nd	14.3	36.2	nd
P8	0.2	nd	nd	14.4	77.1	nd
R2	0	nd	nd	nd	nd	nd
R6	0	nd	nd	nd	nd	nd
R10	0.1	nd	nd	nd	nd	nd

Station ID	Yellow (in)	Clear (in)	White ID	Pad - Dry (g)	Pad - Wet (g)	White (in)
B14	0	nd	nd	nd	nd	nd
D12	0	nd	nd	14.8	18.0	nd
D14	0	nd	nd	nd	nd	nd
F12	0	nd	nd	nd	nd	nd
F14	0	nd	nd	nd	nd	nd
G10	0	nd	nd	14.7	15.9	nd
G11	0	nd	nd	nd	nd	nd
G12	0	nd	nd	14.6	21.8	nd
G13	nd	nd	nd	nd	nd	nd
H10	0	nd	nd	nd	nd	nd
H11	0	nd	nd	nd	nd	nd
H12	T	nd	nd	nd	nd	nd
H13	nd	nd	nd	nd	nd	nd
H14	0	nd	nd	14.2	18.1	nd
I10	T	0.01	TM-6	14.5	29.6	0.03
I11	T	nd	nd	14.7	50.8	nd
I12	0	nd	nd	14.4	40.4	nd
I13	nd	nd	nd	nd	nd	nd
J10	nd	1.44	nd	14.7	189.0	nd
J11	nd	nd	nd	nd	nd	nd
J12	0	0.02	TM-3	14.5	40.3	0.02
J13	nd	nd	nd	nd	nd	nd
J14	0	nd	nd	14.7	19.8	nd
K10	0.20	0.19	TM-1	14.8	125.6	0.14
K11	T	nd	nd	14.9	51.4	nd
K12	0	nd	nd	14.7	36.9	nd
K13	nd	nd	nd	nd	nd	nd
L10	0.15	nd	nd	nd	nd	nd
L11	T	nd	nd	nd	nd	nd
L12	0	nd	nd	nd	nd	nd
L13	nd	nd	nd	nd	nd	nd
L14	0	nd	nd	14.3	18.1	nd
M10	0.10	0.11	nd	14.5	102.0	nd
M11	T	nd	nd	nd	nd	nd
M12	0	nd	nd	14.6	21.9	nd
M13	nd	nd	nd	nd	nd	nd
N10	0.10	nd	nd	nd	nd	nd
N12	0.05	nd	nd	nd	nd	nd
N14	0	nd	nd	nd	nd	nd
P10	0.10	nd	nd	14.6	53.0	nd
P12	T	nd	nd	14.7	35.3	nd
P14	T	nd	nd	nd	nd	nd
R14	T	nd	nd	nd	nd	nd

Appendix B – Data and analysis for Turbo-Mist field test on 4/29/03

30 No. 25 cores with D2 orifice plates

April 29, 2003

30		Number of spray nozzles	0.000812 yr	Duration of test
25		Cores	0.2965 day	
D2		Orifices	7.12 hr	
4/29/03 8:16	37740.3444	Start of test	427 min	
12681.2 gal	m <sup>3</sup>	T1-Nozzle flow totalizer	25620 sec	
5.8 gal/min	m <sup>3</sup> /hr	Nozzle flowrate - indicated	2614.8 gal	9.9 m <sup>3</sup> Spray volume
160030 gal	m <sup>3</sup>	T2-Bypass flow totalizer	47830 gal	181.1 m <sup>3</sup> Bypass volume
115 gal/min	m <sup>3</sup> /hr	Bypass flowrate - indicated		
106 psi	Pa	P1	6.1 gal/min	1.39 m <sup>3</sup> /hr Spray flowrate
100 psi	Pa	P2	112 gal/min	25.4 m <sup>3</sup> /hr Bypass flowrate
102 psi	Pa	P3	21 in <sup>2</sup>	0.0135 m <sup>2</sup> Pad area
4/29/03 11:41	37740.4868	Midpoint	0.1458 ft <sup>2</sup>	
13934.8 gal	m <sup>3</sup>	Nozzle flow totalizer	3.35E-06 acre	
6.5 gal/min	m <sup>3</sup> /hr	Nozzle flowrate - indicated	volts	Voltage
183000 gal	m <sup>3</sup>	Bypass flow totalizer	amps	Current
114.1 gal/min	m <sup>3</sup> /hr	Bypass flowrate - indicated	0.0 kW	Power
102 psi	Pa	P1	75.5 F	24.19 C Temperature
98 psi	Pa	P2	60%	60% Relative humidity
100 psi	Pa	P3	4.2 mph	1.86 m/s Wind speed
4/29/03 15:23	37740.641	End of test	209.056667 deg	209.06 deg Wind direction
15296 gal	m <sup>3</sup>	Nozzle flow totalizer	6.12 gpm	Spray
6.5 gal/min	m <sup>3</sup> /hr	Nozzle flowrate - indicated	0.81 gpm	Fallback
207860 gal	m <sup>3</sup>	Bypass flow totalizer	<b>5.31 gpm</b>	<b>Evaporation</b>
114.6 gal/min	m <sup>3</sup> /hr	Bypass flowrate - indicated	87%	
102 psi	Pa	P1	0.0 kW	Power
98 psi	Pa	P2	0.08 \$/kW-hr	Energy cost
100 psi	Pa	P3	<b>0.000 \$/gal</b>	<b>Cost</b>
3 in		Pad width	0.056 \$/gal	Direct heating cost
7 in		Pad length	<b>0%</b>	<b>Relative cost</b>

Adiabatic saturation / swamp cooler calculation using ASHRAE (1985) equations					
<b>Constants</b>					<i>source</i>
univ. gas const.	R	1545.33 ft-lbf/(lbmole-R)			
molecular wt. air	M <sub>a</sub>	28.9645 lbm/lbmole			from eqn (24)
air gas constant	R <sub>a</sub>	53.35 ft-lbf/(lbm-R)			
<b>Incoming air stream</b>					
pressure	p	14.7 psia			
temperature	t	75.542 F	24.2 C	535.212 R	29Apr03 Field Test
relative humidity	φ	0.60	unitless		
sat. pressure	p <sub>ws</sub>	0.4437 psia			eqn (4)
water vap. pres.	p <sub>w</sub>	0.2653 psia			eqn (22)
humidity ratio	W, γ	0.011430	unitless	80.01 grains/lbm <sub>a</sub>	eqn (20)
sat. humidity ratio	W <sub>s</sub>	0.019359	unitless		eqn (21)
deg. of saturation	μ	0.5904	unitless		eqn (10)
specific volume	v	13.74 ft <sup>3</sup> /lbm <sub>a</sub>			eqn (26)
		13.58 ft <sup>3</sup> /lbm			using (1+γ) factor and eqn (26)
		13.49 ft <sup>3</sup> /lbm			using ideal gas law
specific enthalpy	h	30.64 BTU/lbm <sub>a</sub>			eqn (30)
<b>Outgoing for adiabatic saturation/evaporation</b>					
pressure	p	14.7 psia			
temperature	t	65.59 F	18.7 C	525.26 R	
relative humidity	φ	1.00	unitless		
sat. pressure	p <sub>ws</sub>	0.3161 psia			eqn (4)
water vap. pres.	p <sub>w</sub>	0.3161 psia			eqn (22)
humidity ratio	W, γ	0.013668 lbm <sub>w</sub> /lbm <sub>a</sub>		95.68 grains/lbm <sub>a</sub>	eqn (20)
sat. humidity ratio	W <sub>s</sub>	0.013668	unitless		eqn (21)
deg. of saturation	μ	1.0000	unitless		eqn (10)
specific volume	v	13.53 ft <sup>3</sup> /lbm <sub>a</sub>			eqn (26)
		13.35 ft <sup>3</sup> /lbm			using (1+γ) factor and eqn (26)
		13.24 ft <sup>3</sup> /lbm			using ideal gas law
specific enthalpy	h	30.64 BTU/lbm <sub>a</sub>			eqn (30)
<b>Differences</b>					
temperature	Δt	-10.0 F			
relative humidity	Δφ	0.40	unitless		
enthalpy	Δh	0.00	BTU/lbm <sub>a</sub>		
humidity ratio	ΔW, Δγ	0.002238 lbm <sub>w</sub> /lbm <sub>a</sub>		15.67 grains/lbm <sub>a</sub>	
<b>Evaporation system parameters</b>					
Wind speed	v	4.2 mi/hr		6.12 ft/s	
Height	h	35.0 ft			
Width	w	35.0 ft			
Xsec area	A	1225 ft <sup>2</sup>			
Incoming wet air vol. flow	Q	7493 ft <sup>3</sup> /s		4.5E+05 ft <sup>3</sup> /min (cfm)	
Dry air mass flow	m <sub>a</sub>	545 lbm <sub>a</sub> /s			
Evaporation rate	m <sub>e</sub>	1.22 lbm <sub>w</sub> /s		73.24 lbm <sub>w</sub> /min	
Liq. water density	ρ	62.3 lbm/ft <sup>3</sup>			@ 70F
Evaporation rate	Q <sub>e</sub>	0.020 ft <sup>3</sup> /s		8.79 gal/min	528 gal/hr

Station ID	Yellow (in)	Clear (in)	White ID	Pad - Dry (g)	Pad - Wet (g)	White (in)
B2	0	nd	nd	14.5	14.5	nd
B6	0	nd	nd	nd	nd	nd
B10	0	nd	nd	nd	nd	nd
D4	0	nd	nd	nd	nd	nd
D6	0	nd	nd	nd	nd	nd
D8	0	nd	nd	nd	nd	nd
D10	0	nd	nd	nd	nd	nd
F2	0	nd	nd	nd	nd	nd
F4	0	nd	nd	14.8	14.8	nd
F6	0	nd	nd	14.2	14.2	nd
F8	T	nd	nd	14.8	14.8	nd
F10	0	nd	nd	14.5	14.5	nd
G7	T	nd	nd	nd	nd	nd
G8	T	nd	nd	nd	nd	nd
G9	0	nd	nd	nd	nd	nd
H4	0.1	nd	nd	14.5	14.5	nd
H6	0	nd	nd	14.5	14.5	nd
H7	T	nd	nd	nd	nd	nd
H8	T	nd	nd	14.8	14.8	0.02
H9	T	nd	nd	nd	nd	nd
I7	T	nd	nd	nd	nd	nd
I8	0	nd	nd	nd	nd	nd
I9	0	nd	nd	nd	nd	nd
J2	0	nd	nd	14.8	14.8	nd
J4	T	nd	nd	14.9	14.9	nd
J6	T	nd	nd	14.1	14.1	nd
J7	0	nd	nd	nd	nd	nd
J8	0	0.01	nd	14.6	14.6	nd
J9	0	0.01	nd	nd	nd	nd
K7	0	nd	nd	nd	nd	nd
K8	0	0.01	nd	nd	nd	nd
K9	T	0.07	nd	nd	nd	nd
L4	0	nd	nd	14.8	14.8	nd
L6	0	nd	nd	14.8	14.8	nd
L7	0	nd	nd	nd	nd	nd
L8	0.1	0.05	nd	14.5	24.5	nd
L9	0.15	0.06	nd	nd	nd	nd
M7	0	nd	nd	nd	nd	nd
M8	0.1	nd	nd	nd	nd	nd
M9	T	nd	nd	nd	nd	nd
N2	0	nd	nd	14.7	14.7	nd
N4	0	nd	nd	14.5	14.5	nd
N6	0	nd	nd	14.3	14.3	nd
N8	0	nd	nd	14.7	16.6	nd
P4	T	nd	nd	14.6	14.6	nd
P6	0	nd	nd	14.7	14.7	nd
P8	0	nd	nd	14.4	14.4	nd
R2	0	nd	nd	14.4	14.4	nd
R6	0	nd	nd	14.6	14.6	nd
R10	T	nd	nd	14.4	15.2	nd

Station ID	Yellow (in)	Clear (in)	White ID	Pad - Dry (g)	Pad - Wet (g)	White (in)
B14	0	nd	nd	14.5	14.5	nd
D12	0	nd	nd	nd	nd	nd
D14	0	nd	nd	nd	nd	nd
F12	0	nd	nd	14	14	nd
F14	0	nd	nd	nd	nd	nd
G10	0	nd	nd	nd	nd	nd
G11	0	nd	nd	nd	nd	nd
G12	0	nd	nd	nd	nd	nd
G13	0	nd	nd	nd	nd	nd
H10	0	nd	nd	14.4	14.6	nd
H11	0	nd	nd	nd	nd	nd
H12	0	nd	nd	14.6	14.6	nd
H13	0	nd	nd	nd	nd	nd
H14	0	nd	nd	14.4	14.4	nd
I10	0	nd	nd	nd	nd	nd
I11	0	nd	nd	nd	nd	nd
I12	0	nd	nd	nd	nd	nd
I13	0	nd	nd	nd	nd	nd
J10	0	nd	nd	14.9	16.1	nd
J11	0	nd	nd	nd	nd	nd
J12	0	nd	nd	15	15	nd
J13	0	nd	nd	nd	nd	nd
J14	0	nd	nd	14.7	14.7	nd
K10	T	T	nd	nd	nd	nd
K11	T	nd	nd	nd	nd	nd
K12	0	nd	nd	nd	nd	nd
K13	0	nd	nd	nd	nd	nd
L10	0.1	nd	nd	15.5	67.9	nd
L11	T	nd	nd	nd	nd	nd
L12	0	nd	nd	14.8	17.7	nd
L13	0	nd	nd	nd	nd	nd
L14	0	nd	nd	14.6	14.6	nd
M10	T	nd	nd	nd	nd	nd
M11	0.1	nd	nd	nd	nd	nd
M12	0	nd	nd	nd	nd	nd
M13	0	nd	nd	nd	nd	nd
N10	T	nd	nd	14.7	40.1	nd
N12	0	nd	nd	14.6	24.3	nd
N14	0	nd	nd	14.8	14.8	nd
P10	0	nd	nd	14.6	18.1	nd
P12	0	nd	nd	14.8	16.9	nd
P14	T	nd	nd	nd	nd	nd
R14	0	nd	nd	nd	nd	nd

Appendix C – Data and analysis for Turbo-Mist field test on 5/1/03

30 No. 25 cores with D5 orifice plates			1-May-03	
30		Number of spray nozzles	0.000713 yr	Duration of test
25		Cores	0.2604 day	
D5		Orifices	6.25 hr	
5/1/03 8:35	37742.3576	Start of test	375 min	
15340.6 gal	m <sup>3</sup>	T1-Nozzle flow totalizer	22500 sec	
15.9 gal/min	m <sup>3</sup> /hr	Nozzle flowrate - indicated	5867.3 gal	22.2 m <sup>3</sup> Spray volume
208207 gal	m <sup>3</sup>	T2-Bypass flow totalizer	40423 gal	153.0 m <sup>3</sup> Bypass volume
109.3 gal/min	m <sup>3</sup> /hr	Bypass flowrate - indicated		
98 psi	Pa	P1	15.6 gal/min	3.55 m <sup>3</sup> /hr Spray flowrate
94 psi	Pa	P2	108 gal/min	24.5 m <sup>3</sup> /hr Bypass flowrate
94 psi	Pa	P3	21 in <sup>2</sup>	0.0135 m <sup>2</sup> Pad area
5/1/03 11:36	37742.4833	Midpoint	0.1458 ft <sup>2</sup>	
18189 gal	m <sup>3</sup>	Nozzle flow totalizer	3.35E-06 acre	
15.9 gal/min	m <sup>3</sup> /hr	Nozzle flowrate - indicated	volts	Voltage
227910 gal	m <sup>3</sup>	Bypass flow totalizer	amps	Current
109.2 gal/min	m <sup>3</sup> /hr	Bypass flowrate - indicated	0.0 kW	Power
94 psi	Pa	P1	75.9 F	24.38 C Temperature
90 psi	Pa	P2	67%	67% Relative humidity
90 psi	Pa	P3	4.0 mph	1.80 m/s Wind speed
5/1/03 14:50	37742.6181	End of test	86.44 deg	86.44 deg Wind direction
21207.9 gal	m <sup>3</sup>	Nozzle flow totalizer	15.65 gpm	Spray
16.3 gal/min	m <sup>3</sup> /hr	Nozzle flowrate - indicated	9.16 gpm	Fallback
248630 gal	m <sup>3</sup>	Bypass flow totalizer	<b>6.49 gpm</b>	<b>Evaporation</b>
109.8 gal/min	m <sup>3</sup> /hr	Bypass flowrate - indicated	41%	
96 psi	Pa	P1	0.0 kW	Power
92 psi	Pa	P2	0.08 \$/kW-hr	Energy cost
92 psi	Pa	P3	<b>0.000 \$/gal</b>	<b>Cost</b>
3 in		Pad width	0.056 \$/gal	Direct heating cost
7 in		Pad length	<b>0%</b>	<b>Relative cost</b>

Adiabatic saturation / swamp cooler calculation using ASHRAE (1985) equations						
<b>Constants</b>						<i>source</i>
univ. gas const.	R	1545.33 ft-lbf/(lbmole-R)				
molecular wt. air	M <sub>a</sub>	28.9645 lbm/lbmole				from eqn (24)
air gas constant	R <sub>a</sub>	53.35 ft-lbf/(lbm-R)				
<b>Incoming air stream</b>						
pressure	p	14.7 psia				
temperature	t	75.884 F	24.4 C	535.554 R		01May03 Field Test
relative humidity	φ	0.67	unitless			
sat. pressure	p <sub>ws</sub>	0.4488 psia				eqn (4)
water vap. pres.	p <sub>w</sub>	0.2996 psia				eqn (22)
humidity ratio	W, γ	0.012939	unitless	90.57 grains/lbm <sub>a</sub>		eqn (20)
sat. humidity ratio	W <sub>s</sub>	0.019588	unitless			eqn (21)
deg. of saturation	μ	0.6606	unitless			eqn (10)
specific volume	v	13.78 ft <sup>3</sup> /lbm <sub>a</sub>				eqn (26)
		13.60 ft <sup>3</sup> /lbm				using (1+γ) factor and eqn (26)
		13.50 ft <sup>3</sup> /lbm				using ideal gas law
specific enthalpy	h	32.38 BTU/lbm <sub>a</sub>				eqn (30)
<b>Outgoing for adiabatic saturation/evaporation</b>						
pressure	p	14.7 psia				
temperature	t	67.77 F	19.9 C	527.44 R		
relative humidity	φ	1.00	unitless			
sat. pressure	p <sub>ws</sub>	0.3409 psia				eqn (4)
water vap. pres.	p <sub>w</sub>	0.3409 psia				eqn (22)
humidity ratio	W, γ	0.014767	lbm <sub>w</sub> /lbm <sub>a</sub>	103.37 grains/lbm <sub>a</sub>		eqn (20)
sat. humidity ratio	W <sub>s</sub>	0.014767	unitless			eqn (21)
deg. of saturation	μ	1.0000	unitless			eqn (10)
specific volume	v	13.61 ft <sup>3</sup> /lbm <sub>a</sub>				eqn (26)
		13.41 ft <sup>3</sup> /lbm				using (1+γ) factor and eqn (26)
		13.29 ft <sup>3</sup> /lbm				using ideal gas law
specific enthalpy	h	32.38 BTU/lbm <sub>a</sub>				eqn (30)
<b>Differences</b>						
temperature	Δt	-8.1 F				
relative humidity	Δφ	0.33	unitless			
enthalpy	Δh	0.00	BTU/lbm <sub>a</sub>			
humidity ratio	ΔW, Δγ	0.001827	lbm <sub>w</sub> /lbm <sub>a</sub>	12.79 grains/lbm <sub>a</sub>		
<b>Evaporation system parameters</b>						
Wind speed	v	4.0	mi/hr	5.91	ft/s	
Height	h	35.0	ft			
Width	w	35.0	ft			
Xsec area	A	1225	ft <sup>2</sup>			
Incoming wet air vol. flow	Q	7234	ft <sup>3</sup> /s	4.3E+05	ft <sup>3</sup> /min (cfm)	
Dry air mass flow	m <sub>a</sub>	525	lbm <sub>a</sub> /s			
Evaporation rate	m <sub>e</sub>	0.96	lbm <sub>w</sub> /s	57.56	lbm <sub>w</sub> /min	
Liq. water density	ρ	62.3	lbm/ft <sup>3</sup>			@ 70F
Evaporation rate	Q <sub>e</sub>	0.015	ft <sup>3</sup> /s	6.91	gal/min	415 gal/hr

Station ID	Yellow (in)	Clear (in)	White ID	Pad - Dry (g)	Pad - Wet (g)	White (in)
B2	0	nd	nd	nd	nd	nd
B6	0	nd	nd	14.5	14.6	nd
B10	0	nd	nd	14.5	14.5	nd
D4	0	nd	nd	14.5	14.7	nd
D6	0	nd	nd	14	27.4	nd
D8	T	nd	nd	14	23.6	nd
D10	0	nd	nd	14.5	19.2	nd
F2	0	nd	nd	14	14.1	nd
F4	0	nd	nd	14.5	24.1	nd
F6	0.1	nd	nd	14.5	73.4	nd
F8	0.15	nd	nd	15.5	85	nd
F10	T	nd	nd	14.5	52.3	nd
G7	0.3	nd	nd	nd	nd	nd
G8	0.4	nd	nd	nd	nd	nd
G9	0.4	nd	nd	nd	nd	nd
H4	nd	nd	nd	14.5	36.6	nd
H6	0.2	nd	nd	14.5	130.1	nd
H7	0.45	nd	nd	nd	nd	nd
H8	0.8	nd	nd	15	95.4	nd
H9	0.9	0.88	nd	nd	nd	nd
I7	0.5	nd	nd	nd	nd	nd
I8	1	0.83	nd	nd	nd	nd
I9	0.2	0.22	nd	nd	nd	nd
J2	0	nd	nd	14.5	14.5	nd
J4	0	nd	nd	14.5	25.3	nd
J6	0.2	nd	nd	14	125.4	nd
J7	0.35	nd	nd	nd	nd	nd
J8	0.7	0.59	nd	14.5	150.9	nd
J9	0.8	0.78	nd	nd	nd	nd
K7	0.15	0.21	nd	nd	nd	nd
K8	0.2	0.22	nd	nd	nd	nd
K9	0.2	nd	nd	nd	nd	nd
L4	0	nd	nd	14.5	14.5	nd
L6	0	nd	nd	14.5	24.4	nd
L7	0	nd	nd	nd	nd	nd
L8	0.1	nd	nd	14.5	64.2	nd
L9	T	nd	nd	nd	nd	nd
M7	0	nd	nd	nd	nd	nd
M8	0	nd	nd	nd	nd	nd
M9	0	nd	nd	nd	nd	nd
N2	0	nd	nd	14.5	14.5	nd
N4	0	nd	nd	14.5	14.6	nd
N6	0	nd	nd	15	15	nd
N8	0	nd	nd	14	14.2	nd
P4	0	nd	nd	14	14.7	nd
P6	0	nd	nd	14.5	14.5	nd
P8	0	nd	nd	14.5	14.6	nd
R2	0	nd	nd	nd	nd	nd
R6	0	nd	nd	14	14.1	nd
R10	0	nd	nd	14.5	14.5	nd

Station ID	Yellow (in)	Clear (in)	White ID	Pad - Dry (g)	Pad - Wet (g)	White (in)
B14	0	nd	nd	nd	nd	nd
D12	0	nd	nd	14.5	14.6	nd
D14	0	nd	nd	nd	nd	nd
F12	0	nd	nd	14	14.1	nd
F14	0	nd	nd	14.5	14.6	nd
G10	0	nd	nd	nd	nd	nd
G11	0	nd	nd	nd	nd	nd
G12	0	nd	nd	nd	nd	nd
G13	nd	nd	nd	nd	nd	nd
H10	0.2	nd	nd	14.5	137.1	nd
H11	0	nd	nd	nd	nd	nd
H12	0	nd	nd	14	14.1	nd
H13	nd	nd	nd	nd	nd	nd
H14	0	nd	nd	15	15	nd
I10	0.7	nd	nd	nd	nd	nd
I11	0	nd	nd	nd	nd	nd
I12	0	nd	nd	nd	nd	nd
I13	nd	nd	nd	nd	nd	nd
J10	0.5	nd	nd	14.5	140	nd
J11	nd	nd	nd	nd	nd	nd
J12	0	nd	nd	14	14.4	nd
J13	nd	nd	nd	14.5	14.5	nd
J14	0	nd	nd	14.5	14.5	nd
K10	0.1	nd	nd	nd	nd	nd
K11	0	nd	nd	nd	nd	nd
K12	0	nd	nd	nd	nd	nd
K13	nd	nd	nd	nd	nd	nd
L10	0	nd	nd	14.5	17.3	nd
L11	0	nd	nd	nd	nd	nd
L12	0	nd	nd	14.5	14.5	nd
L13	nd	nd	nd	nd	nd	nd
L14	0	nd	nd	14.5	14.5	nd
M10	0	nd	nd	nd	nd	nd
M11	0	nd	nd	nd	nd	nd
M12	0	nd	nd	nd	nd	nd
M13	nd	nd	nd	nd	nd	nd
N10	0	nd	nd	14	14.3	nd
N12	0	nd	nd	14.5	14.6	nd
N14	0	nd	nd	14.5	14.5	nd
P10	0	nd	nd	14.5	14.7	nd
P12	0	nd	nd	15	15	nd
P14	0	nd	nd	nd	nd	nd
R14	0	nd	nd	nd	nd	nd

Appendix D – Data and analysis for Turbo-Mist field test on 5/14/03

30 No. 25 cores with D5 orifice plates			14-May-03			
30		Number of spray nozzles	0.000557 yr		Duration of test	
25		Cores	0.2035 day			
D5		Orifices	4.88 hr			
5/14/03 10:07	37755.4215	Start of test	293 min			
21258.9 gal	m <sup>3</sup>	T1-Nozzle flow totalizer	17580 sec			
16.3 gal/min	m <sup>3</sup> /hr	Nozzle flowrate - indicated	4895.3 gal	18.5 m <sup>3</sup>	Spray volume	
248970 gal	m <sup>3</sup>	T2-Bypass flow totalizer	30480 gal	115.4 m <sup>3</sup>	Bypass volume	
109.8 gal/min	m <sup>3</sup> /hr	Bypass flowrate - indicated				
96 psi	Pa	P1	16.7 gal/min	3.79 m <sup>3</sup> /hr	Spray flowrate	
92 psi	Pa	P2	104 gal/min	23.6 m <sup>3</sup> /hr	Bypass flowrate	
92 psi	Pa	P3	21 in <sup>2</sup>	0.0135 m <sup>2</sup>	Pad area	
5/14/03 12:01	37755.5007	Midpoint	0.1458 ft <sup>2</sup>			
23186.5 gal	m <sup>3</sup>	Nozzle flow totalizer	3.35E-06 acre			
17 gal/min	m <sup>3</sup> /hr	Nozzle flowrate - indicated	490 volts		Voltage	
260960 gal	m <sup>3</sup>	Bypass flow totalizer	35 amps		Current	
104.2 gal/min	m <sup>3</sup> /hr	Bypass flowrate - indicated	29.7 kW		Power	
102 psi	Pa	P1	72.4 F	22.47 C	Temperature	
98 psi	Pa	P2	46%	46%	Relative humidity	
98 psi	Pa	P3	2.0 mph	0.91 m/s	Wind speed	
5/14/03 15:00	37755.625	End of test	136.20 deg	136.20 deg	Wind direction	
26154.2 gal	m <sup>3</sup>	Nozzle flow totalizer	16.71 gpm		Spray	
16.6 gal/min	m <sup>3</sup> /hr	Nozzle flowrate - indicated	11.00 gpm		Fallback	
279450 gal	m <sup>3</sup>	Bypass flow totalizer	<b>5.71 gpm</b>		<b>Evaporation</b>	
103.8 gal/min	m <sup>3</sup> /hr	Bypass flowrate - indicated	34%			
100 psi	Pa	P1	29.7 kW		Power	
96 psi	Pa	P2	0.08 \$/kW-hr		Energy cost	
96 psi	Pa	P3	<b>0.007 \$/gal</b>		<b>Cost</b>	
3 in		Pad width	0.056 \$/gal		Direct heating cost	
7 in		Pad length	<b>12%</b>		<b>Relative cost</b>	

Adiabatic saturation / swamp cooler calculation using ASHRAE (1985) equations						
<b>Constants</b>						<i>source</i>
univ. gas const.	R	1545.33 ft-lbf/(lbmole-R)				
molecular wt. air	M <sub>a</sub>	28.9645 lbm/lbmole				from eqn (24)
air gas constant	R <sub>a</sub>	53.35 ft-lbf/(lbm-R)				
<b>Incoming air stream</b>						
pressure	p	14.7 psia				
temperature	t	72.446 F	22.5 C	532.116 R		14May03 Field Test
relative humidity	φ	0.46	unitless			
sat. pressure	p <sub>ws</sub>	0.3999 psia				eqn (4)
water vap. pres.	p <sub>w</sub>	0.1839 psia				eqn (22)
humidity ratio	W, γ	0.007881	unitless	55.16 grains/lbm <sub>a</sub>		eqn (20)
sat. humidity ratio	W <sub>s</sub>	0.017394	unitless			eqn (21)
deg. of saturation	μ	0.4531	unitless			eqn (10)
specific volume	v	13.58 ft <sup>3</sup> /lbm <sub>a</sub>				eqn (26)
		13.48 ft <sup>3</sup> /lbm				using (1+γ) factor and eqn (26)
		13.41 ft <sup>3</sup> /lbm				using ideal gas law
specific enthalpy	h	26.00 BTU/lbm <sub>a</sub>				eqn (30)
<b>Outgoing for adiabatic saturation/evaporation</b>						
pressure	p	14.7 psia				
temperature	t	59.18 F	15.1 C	518.85 R		
relative humidity	φ	1.00	unitless			
sat. pressure	p <sub>ws</sub>	0.2521 psia				eqn (4)
water vap. pres.	p <sub>w</sub>	0.2521 psia				eqn (22)
humidity ratio	W, γ	0.010853	lbm <sub>w</sub> /lbm <sub>a</sub>	75.97 grains/lbm <sub>a</sub>		eqn (20)
sat. humidity ratio	W <sub>s</sub>	0.010853	unitless			eqn (21)
deg. of saturation	μ	1.0000	unitless			eqn (10)
specific volume	v	13.31 ft <sup>3</sup> /lbm <sub>a</sub>				eqn (26)
		13.16 ft <sup>3</sup> /lbm				using (1+γ) factor and eqn (26)
		13.08 ft <sup>3</sup> /lbm				using ideal gas law
specific enthalpy	h	26.00 BTU/lbm <sub>a</sub>				eqn (30)
<b>Differences</b>						
temperature	Δt	-13.3 F				
relative humidity	Δφ	0.54	unitless			
enthalpy	Δh	0.00	BTU/lbm <sub>a</sub>			
humidity ratio	ΔW, Δγ	0.002972	lbm <sub>w</sub> /lbm <sub>a</sub>	20.81 grains/lbm <sub>a</sub>		
<b>Evaporation system parameters</b>						
Wind speed	v	2.0	mi/hr	2.99	ft/s	
Height	h	35.0	ft			
Width	w	35.0	ft			
Xsec area	A	1225	ft <sup>2</sup>			
Incoming wet air vol. flow	Q	3657	ft <sup>3</sup> /s	2.2E+05	ft <sup>3</sup> /min (cfm)	
Dry air mass flow	m <sub>a</sub>	269	lbm <sub>a</sub> /s			
Evaporation rate	m <sub>e</sub>	0.80	lbm <sub>w</sub> /s	48.03	lbm <sub>w</sub> /min	
Liq. water density	ρ	62.3	lbm/ft <sup>3</sup>			@ 70F
Evaporation rate	Q <sub>e</sub>	0.013	ft <sup>3</sup> /s	5.77	gal/min	346 gal/hr

Station ID	Yellow (in)	Clear (in)	White ID	Pad - Dry (g)	Pad - Wet (g)	White (in)
B2	T	nd	nd	nd	nd	nd
B6	0	nd	nd	14.3	14.3	nd
B10	0	nd	nd	14.6	14.7	nd
D4	0	nd	nd	14.9	14.9	nd
D6	T	nd	nd	14.2	14.2	nd
D8	0	nd	nd	14.2	14.2	nd
D10	0	nd	nd	14.3	14.3	nd
F2	0	nd	nd	14.3	14.4	nd
F4	0	nd	nd	15	15	nd
F6	0	nd	nd	15.1	15.1	nd
F8	0	nd	nd	14.7	14.8	nd
F10	0	nd	nd	14.5	14.5	nd
G7	T	nd	nd	nd	nd	nd
G8	0	nd	nd	nd	nd	nd
G9	0	nd	nd	nd	nd	nd
H4	0	nd	nd	14.4	16	nd
H6	0	nd	nd	14.4	40.7	nd
H7	T	nd	nd	nd	nd	nd
H8	0.5	nd	nd	14.7	36.1	nd
H9	T	0.4	nd	nd	nd	nd
I7	0.25	nd	nd	nd	nd	nd
I8	0.35	0.3	nd	nd	nd	nd
I9	0.3	0.27	nd	nd	nd	nd
J2	0.1	nd	nd	14.8	15	nd
J4	0	nd	nd	14.2	35.1	nd
J6	0.3	nd	nd	14.6	136.3	nd
J7	0.6	nd	nd	nd	nd	nd
J8	1.3	1.15	nd	14.6	98.4	nd
J9	2	1.6	nd	nd	nd	nd
K7	0.5	nd	nd	nd	nd	nd
K8	0.75	0.7	nd	nd	nd	nd
K9	0.8	0.65	nd	nd	nd	nd
L4	0	nd	nd	14.4	22.4	nd
L6	0.1	nd	nd	14.4	84	nd
L7	0.25	nd	nd	nd	nd	nd
L8	0.35	nd	nd	14.1	104.7	nd
L9	0.3	nd	nd	nd	nd	nd
M7	0.1	nd	nd	nd	nd	nd
M8	0.1	nd	nd	nd	nd	nd
M9	T	nd	nd	nd	nd	nd
N2	0	nd	nd	14.8	14.9	nd
N4	T	nd	nd	14.6	16.5	nd
N6	T	nd	nd	14.2	30.6	nd
N8	0	nd	nd	14.5	28.5	nd
P4	0	nd	nd	14.4	14.6	nd
P6	0	nd	nd	14.7	15.9	nd
P8	0	nd	nd	14.8	15.1	nd
R2	0	nd	nd	nd	nd	nd
R6	0	nd	nd	14.5	14.5	nd
R10	0	nd	nd	14.3	14.3	nd

Station ID	Yellow (in)	Clear (in)	White ID	Pad - Dry (g)	Pad - Wet (g)	White (in)
B14	0	nd	nd	nd	nd	nd
D12	0	nd	nd	14.6	14.6	nd
D14	0	nd	nd	nd	nd	nd
F12	0	nd	nd	14.3	14.3	nd
F14	0	nd	nd	14.5	14.5	nd
G10	0	nd	nd	nd	nd	nd
G11	0	nd	nd	nd	nd	nd
G12	0	nd	nd	nd	nd	nd
G13	nd	nd	nd	nd	nd	nd
H10	T	T	nd	14.7	20	nd
H11	0	nd	nd	nd	nd	nd
H12	0	nd	nd	14.4	14.4	nd
H13	nd	nd	nd	nd	nd	nd
H14	0	nd	nd	14.4	14.4	nd
I10	0.1	nd	nd	nd	nd	nd
I11	0.1	nd	nd	nd	nd	nd
I12	0	nd	nd	nd	nd	nd
I13	nd	nd	nd	nd	nd	nd
J10	1.5	nd	nd	14.4	177.7	nd
J11	nd	nd	nd	nd	nd	nd
J12	0	nd	nd	14.5	14.5	nd
J13	nd	nd	nd	14.5	14.5	nd
J14	0	nd	nd	14.5	14.5	nd
K10	0.2	nd	nd	nd	nd	nd
K11	T	nd	nd	nd	nd	nd
K12	0	nd	nd	nd	nd	nd
K13	nd	nd	nd	nd	nd	nd
L10	0.1	0.05	nd	14.2	45.5	nd
L11	0	nd	nd	nd	nd	nd
L12	0	nd	nd	13.9	13.9	nd
L13	nd	nd	nd	nd	nd	nd
L14	0	nd	nd	14.4	14.4	nd
M10	T	nd	nd	nd	nd	nd
M11	0	nd	nd	nd	nd	nd
M12	0	nd	nd	nd	nd	nd
M13	nd	nd	nd	nd	nd	nd
N10	T	nd	nd	14.7	15.6	nd
N12	0	nd	nd	14.4	14.5	nd
N14	0	nd	nd	15	15	nd
P10	0	nd	nd	14.3	14.4	nd
P12	0	nd	nd	14.5	14.5	nd
P14	0	nd	nd	nd	nd	nd
R14	0	nd	nd	nd	nd	nd

Appendix E – Data and analysis for Turbo-Mist field test on 6/25/03

30 No. 25 cores with D5 orifice plates			25-Jun-03		
30		Number of spray nozzles	0.000479 yr		Duration of test
25		Cores	0.1750 day		
D5		Orifices	4.20 hr		
6/25/03 10:43	37797.4465	Start of test	252 min		
26238 gal	m <sup>3</sup>	T1-Nozzle flow totalizer	15120 sec		
16.6 gal/min	m <sup>3</sup> /hr	Nozzle flowrate - indicated	4071.4 gal	15.4 m <sup>3</sup>	Spray volume
279850 gal	m <sup>3</sup>	T2-Bypass flow totalizer	25660 gal	97.1 m <sup>3</sup>	Bypass volume
106.8 gal/min	m <sup>3</sup> /hr	Bypass flowrate - indicated			
102 psi	Pa	P1	16.2 gal/min	3.67 m <sup>3</sup> /hr	Spray flowrate
98 psi	Pa	P2	102 gal/min	23.1 m <sup>3</sup> /hr	Bypass flowrate
100 psi	Pa	P3	21 in <sup>2</sup>	0.0135 m <sup>2</sup>	Pad area
6/25/03 12:55	37797.5382	Midpoint	0.1458 ft <sup>2</sup>		
28413.8 gal	m <sup>3</sup>	Nozzle flow totalizer	3.35E-06 acre		
16.6 gal/min	m <sup>3</sup> /hr	Nozzle flowrate - indicated	480 volts		Voltage
293560 gal	m <sup>3</sup>	Bypass flow totalizer	35 amps		Current
104.9 gal/min	m <sup>3</sup> /hr	Bypass flowrate - indicated	29.1 kW		Power
100 psi	Pa	P1	87.7 F	30.95 C	Temperature
96 psi	Pa	P2	42%	42%	Relative humidity
98 psi	Pa	P3	2.7 mph	1.20 m/s	Wind speed
6/25/03 14:55	37797.6215	End of test	188.61 deg	188.61 deg	Wind direction
30309.4 gal	m <sup>3</sup>	Nozzle flow totalizer	16.16 gpm		Spray
16.3 gal/min	m <sup>3</sup> /hr	Nozzle flowrate - indicated	7.85 gpm		Fallback
305510 gal	m <sup>3</sup>	Bypass flow totalizer	<b>8.31 gpm</b>		<b>Evaporation</b>
104.7 gal/min	m <sup>3</sup> /hr	Bypass flowrate - indicated	51%		
100 psi	Pa	P1	29.1 kW		Power
96 psi	Pa	P2	0.08 \$/kW-hr		Energy cost
98 psi	Pa	P3	<b>0.005 \$/gal</b>		<b>Cost</b>
3 in		Pad width	0.056 \$/gal		Direct heating cost
7 in		Pad length	<b>8%</b>		<b>Relative cost</b>

Adiabatic saturation / swamp cooler calculation using ASHRAE (1985) equations						
<b>Constants</b>						<i>source</i>
univ. gas const.	R	1545.33 ft-lbf/(lbmole-R)				
molecular wt. air	M <sub>a</sub>	28.9645 lbm/lbmole				from eqn (24)
air gas constant	R <sub>a</sub>	53.35 ft-lbf/(lbm-R)				
<b>Incoming air stream</b>						
pressure	p	14.7 psia				
temperature	t	87.71 F	31.0 C	547.38 R	25Jun03 Field Test	
relative humidity	φ	0.42	unitless			
sat. pressure	p <sub>ws</sub>	0.6591 psia				eqn (4)
water vap. pres.	p <sub>w</sub>	0.2775 psia				eqn (22)
humidity ratio	W, γ	0.011966	unitless		83.76 grains/lbm <sub>a</sub>	eqn (20)
sat. humidity ratio	W <sub>s</sub>	0.029195		unitless		eqn (21)
deg. of saturation	μ	0.4099		unitless		eqn (10)
specific volume	v	14.06 ft <sup>3</sup> /lbm <sub>a</sub>				eqn (26)
		13.90 ft <sup>3</sup> /lbm				using (1+γ) factor and eqn (26)
		13.80 ft <sup>3</sup> /lbm				using ideal gas law
specific enthalpy	h	34.21 BTU/lbm <sub>a</sub>				eqn (30)
<b>Outgoing for adiabatic saturation/evaporation</b>						
pressure	p	14.7 psia				
temperature	t	69.96 F	21.1 C	529.63 R		
relative humidity	φ	1.00		unitless		
sat. pressure	p <sub>ws</sub>	0.3676 psia				eqn (4)
water vap. pres.	p <sub>w</sub>	0.3676 psia				eqn (22)
humidity ratio	W, γ	0.015952	lbm <sub>w</sub> /lbm <sub>a</sub>		111.66 grains/lbm <sub>a</sub>	eqn (20)
sat. humidity ratio	W <sub>s</sub>	0.015952		unitless		eqn (21)
deg. of saturation	μ	1.0000		unitless		eqn (10)
specific volume	v	13.69 ft <sup>3</sup> /lbm <sub>a</sub>				eqn (26)
		13.48 ft <sup>3</sup> /lbm				using (1+γ) factor and eqn (26)
		13.35 ft <sup>3</sup> /lbm				using ideal gas law
specific enthalpy	h	34.21 BTU/lbm <sub>a</sub>				eqn (30)
<b>Differences</b>						
temperature	Δt	-17.7 F				
relative humidity	Δφ	0.58		unitless		
enthalpy	Δh	0.00		BTU/lbm <sub>a</sub>		
humidity ratio	ΔW, Δγ	0.003986	lbm <sub>w</sub> /lbm <sub>a</sub>		27.90 grains/lbm <sub>a</sub>	
<b>Evaporation system parameters</b>						
Wind speed	v	2.7	mi/hr		3.94	ft/s
Height	h	35.0		ft		
Width	w	35.0		ft		
Xsec area	A	1225		ft <sup>2</sup>		
Incoming wet air vol. flow	Q	4823	ft <sup>3</sup> /s		2.9E+05	ft <sup>3</sup> /min (cfm)
Dry air mass flow	m <sub>a</sub>	343		lbm <sub>a</sub> /s		
Evaporation rate	m <sub>e</sub>	1.37	lbm <sub>w</sub> /s		82.03	lbm <sub>w</sub> /min
Liq. water density	ρ	62.3		lbm/ft <sup>3</sup>		@ 70F
Evaporation rate	Q <sub>e</sub>	0.022	ft <sup>3</sup> /s		9.85	gal/min
					591	gal/hr

Station ID	Yellow (in)	Clear (in)	White ID	Pad - Dry (g)	Pad - Wet (g)	White (in)
B2	nd	nd	nd	nd	nd	nd
B6	nd	nd	nd	14.2	14.2	nd
B10	nd	nd	nd	13.7	13.7	nd
D4	nd	nd	nd	14.4	14.4	nd
D6	nd	nd	nd	14.2	14.2	nd
D8	nd	nd	nd	14.1	14.1	nd
D10	nd	nd	nd	13.9	13.9	nd
F2	nd	nd	nd	14.4	14.4	nd
F4	nd	nd	nd	14.2	14.2	nd
F6	nd	nd	nd	14.3	15	nd
F8	0	nd	nd	15.1	28	nd
F10	0	nd	nd	14.1	19.6	nd
G7	0	nd	nd	nd	nd	nd
G8	0	nd	nd	nd	nd	nd
G9	0.1	nd	nd	nd	nd	nd
H4	0	nd	nd	14.2	14.2	nd
H6	T	nd	nd	14.6	20.9	nd
H7	T	nd	nd	nd	nd	nd
H8	0.1	nd	nd	13.8	78.6	nd
H9	0.2	0.17	nd	nd	nd	nd
I7	nd	nd	nd	nd	nd	nd
I8	0.2	0.19	nd	nd	nd	nd
I9	0.3	0.36	nd	nd	nd	nd
J2	nd	nd	nd	14	14	nd
J4	0	nd	nd	14.1	14.1	nd
J6	0.1	nd	nd	13.9	44.2	nd
J7	0.2	nd	nd	nd	nd	nd
J8	0.4	0.38	nd	14.6	89.9	nd
J9	0.7	0.65	nd	nd	nd	nd
K7	0.1	nd	nd	nd	nd	nd
K8	0.2	0.2	nd	nd	nd	nd
K9	0.4	0.28	nd	nd	nd	nd
L4	0	nd	nd	14.2	14.2	nd
L6	0.1	nd	nd	13.6	16.1	nd
L7	T	nd	nd	nd	nd	nd
L8	T	nd	nd	14.5	49.6	nd
L9	0.2	nd	nd	nd	nd	nd
M7	0.1	nd	nd	nd	nd	nd
M8	T	nd	nd	nd	nd	nd
M9	T	nd	nd	nd	nd	nd
N2	nd	nd	nd	14.4	14.4	nd
N4	nd	nd	nd	14.4	14.4	nd
N6	0	nd	nd	14.5	14.5	nd
N8	T	nd	nd	14.3	15.5	nd
P4	nd	nd	nd	14.5	14.5	nd
P6	nd	nd	nd	14.6	14.6	nd
P8	nd	nd	nd	14.2	14.2	nd
R2	nd	nd	nd	nd	nd	nd
R6	nd	nd	nd	13.9	13.9	nd
R10	nd	nd	nd	13.8	13.8	nd

Station ID	Yellow (in)	Clear (in)	White ID	Pad - Dry (g)	Pad - Wet (g)	White (in)
B14	T	nd	nd	nd	nd	nd
D12	nd	nd	nd	14.2	14.2	nd
D14	T	nd	nd	nd	nd	nd
F12	0	nd	nd	14	14	nd
F14	0	nd	nd	14.2	14.2	nd
G10	0	nd	nd	nd	nd	nd
G11	T	nd	nd	nd	nd	nd
G12	0	nd	nd	nd	nd	nd
G13	nd	nd	nd	nd	nd	nd
H10	0.1	0.07	nd	14.4	70.5	nd
H11	nd	nd	nd	nd	nd	nd
H12	0	nd	nd	14.4	15.5	nd
H13	nd	nd	nd	nd	nd	nd
H14	0	nd	nd	14.2	14.2	nd
I10	0.3	nd	nd	nd	nd	nd
I11	0.2	nd	nd	nd	nd	nd
I12	nd	nd	nd	nd	nd	nd
I13	nd	nd	nd	nd	nd	nd
J10	0.9	nd	nd	14.2	138.8	nd
J11	nd	nd	nd	nd	nd	nd
J12	nd	nd	nd	14	21.2	nd
J13	nd	nd	nd	nd	nd	nd
J14	0	nd	nd	14.4	14.4	nd
K10	nd	nd	nd	nd	nd	nd
K11	0.2	nd	nd	nd	nd	nd
K12	0.2	nd	nd	nd	nd	nd
K13	nd	nd	nd	nd	nd	nd
L10	T	0.04	nd	14.1	36.1	nd
L11	0.2	nd	nd	nd	nd	nd
L12	0	nd	nd	14	14	nd
L13	nd	nd	nd	nd	nd	nd
L14	0	nd	nd	14.1	14.1	nd
M10	0	nd	nd	nd	nd	nd
M11	0	nd	nd	nd	nd	nd
M12	0	nd	nd	nd	nd	nd
M13	nd	nd	nd	nd	nd	nd
N10	0	nd	nd	14	14.1	nd
N12	0	nd	nd	14.1	14.1	nd
N14	nd	nd	nd	14.3	14.3	nd
P10	0	nd	nd	14.2	14.2	nd
P12	nd	nd	nd	14.2	14.2	nd
P14	nd	nd	nd	nd	nd	nd
R14	nd	nd	nd	nd	nd	nd

Appendix F – Data and analysis for Turbo-Mist field test on 6/26/03

27 No. 45 cores with D6 orifice plates		26-Jun-03			
27		Number of spray nozzles		0.000464 yr	Duration of test
45		Cores		0.1694 day	
D6		Orifices		4.07 hr	
6/26/03 10:50	37798.4514	Start of test		244 min	
30418.4 gal	m <sup>3</sup>	T1-Nozzle flow totalizer		14640 sec	
26.1 gal/min	m <sup>3</sup> /hr	Nozzle flowrate - indicated		6211.4 gal	23.5 m <sup>3</sup> Spray volume
305990 gal	m <sup>3</sup>	T2-Bypass flow totalizer		22500 gal	85.2 m <sup>3</sup> Bypass volume
94.1 gal/min	m <sup>3</sup> /hr	Bypass flowrate - indicated			
104 psi	Pa	P1		25.5 gal/min	5.78 m <sup>3</sup> /hr Spray flowrate
100 psi	Pa	P2		92 gal/min	20.9 m <sup>3</sup> /hr Bypass flowrate
100 psi	Pa	P3		21 in <sup>2</sup>	0.0135 m <sup>2</sup> Pad area
6/26/03 13:00	37798.5417	Midpoint		0.1458 ft <sup>2</sup>	
33783.1 gal	m <sup>3</sup>	Nozzle flow totalizer		3.35E-06 acre	
26.1 gal/min	m <sup>3</sup> /hr	Nozzle flowrate - indicated		480 volts	Voltage
318180 gal	m <sup>3</sup>	Bypass flow totalizer		35 amps	Current
94.2 gal/min	m <sup>3</sup> /hr	Bypass flowrate - indicated		29.1 kW	Power
104 psi	Pa	P1		87.3 F	30.70 C Temperature
100 psi	Pa	P2		48%	48% Relative humidity
100 psi	Pa	P3		4.6 mph	2.04 m/s Wind speed
6/26/03 14:54	37798.6208	End of test		245.89 deg	245.89 deg Wind direction
36629.8 gal	m <sup>3</sup>	Nozzle flow totalizer		25.46 gpm	Spray
26.1 gal/min	m <sup>3</sup> /hr	Nozzle flowrate - indicated		12.28 gpm	Fallback
328490 gal	m <sup>3</sup>	Bypass flow totalizer		<b>13.17 gpm</b>	<b>Evaporation</b>
93.8 gal/min	m <sup>3</sup> /hr	Bypass flowrate - indicated		52%	
102 psi	Pa	P1		29.1 kW	Power
100 psi	Pa	P2		0.08 \$/kW-hr	Energy cost
100 psi	Pa	P3		<b>0.003 \$/gal</b>	<b>Cost</b>
3 in		Pad width		0.056 \$/gal	Direct heating cost
7 in		Pad length		<b>5%</b>	<b>Relative cost</b>

Adiabatic saturation / swamp cooler calculation using ASHRAE (1985) equations						
<b>Constants</b>						<i>source</i>
univ. gas const.	R	1545.33 ft-lbf/(lbmole-R)				
molecular wt. air	M <sub>a</sub>	28.9645 lbm/lbmole				from eqn (24)
air gas constant	R <sub>a</sub>	53.35 ft-lbf/(lbm-R)				
<b>Incoming air stream</b>						
pressure	p	14.7 psia				
temperature	t	87.259 F	30.7 C	546.929 R		26Jun03 Field Test
relative humidity	φ	0.48	unitless			
sat. pressure	p <sub>ws</sub>	0.6497 psia				eqn (4)
water vap. pres.	p <sub>w</sub>	0.3102 psia				eqn (22)
humidity ratio	W, γ	0.013409	unitless	93.87 grains/lbm <sub>a</sub>		eqn (20)
sat. humidity ratio	W <sub>s</sub>	0.028761	unitless			eqn (21)
deg. of saturation	μ	0.4662	unitless			eqn (10)
specific volume	v	14.08 ft <sup>3</sup> /lbm <sub>a</sub>				eqn (26)
		13.90 ft <sup>3</sup> /lbm				using (1+γ) factor and eqn (26)
		13.78 ft <sup>3</sup> /lbm				using ideal gas law
specific enthalpy	h	35.69 BTU/lbm <sub>a</sub>				eqn (30)
<b>Outgoing for adiabatic saturation/evaporation</b>						
pressure	p	14.7 psia				
temperature	t	71.65 F	22.0 C	531.32 R		
relative humidity	φ	1.00	unitless			
sat. pressure	p <sub>ws</sub>	0.3893 psia				eqn (4)
water vap. pres.	p <sub>w</sub>	0.3893 psia				eqn (22)
humidity ratio	W, γ	0.016921	lbm <sub>w</sub> /lbm <sub>a</sub>	118.45 grains/lbm <sub>a</sub>		eqn (20)
sat. humidity ratio	W <sub>s</sub>	0.016921	unitless			eqn (21)
deg. of saturation	μ	1.0000	unitless			eqn (10)
specific volume	v	13.76 ft <sup>3</sup> /lbm <sub>a</sub>				eqn (26)
		13.53 ft <sup>3</sup> /lbm				using (1+γ) factor and eqn (26)
		13.39 ft <sup>3</sup> /lbm				using ideal gas law
specific enthalpy	h	35.69 BTU/lbm <sub>a</sub>				eqn (30)
<b>Differences</b>						
temperature	Δt	-15.6 F				
relative humidity	Δφ	0.52	unitless			
enthalpy	Δh	0.00	BTU/lbm <sub>a</sub>			
humidity ratio	ΔW, Δγ	0.003512	lbm <sub>w</sub> /lbm <sub>a</sub>	24.58 grains/lbm <sub>a</sub>		
<b>Evaporation system parameters</b>						
Wind speed	v	4.6	mi/hr	6.69	ft/s	
Height	h	35.0	ft			
Width	w	35.0	ft			
Xsec area	A	1225	ft <sup>2</sup>			
Incoming wet air vol. flow	Q	8192	ft <sup>3</sup> /s	4.9E+05	ft <sup>3</sup> /min (cfm)	
Dry air mass flow	m <sub>a</sub>	582	lbm <sub>a</sub> /s			
Evaporation rate	m <sub>e</sub>	2.04	lbm <sub>w</sub> /s	122.57	lbm <sub>w</sub> /min	
Liq. water density	ρ	62.3	lbm/ft <sup>3</sup>			@ 70F
Evaporation rate	Q <sub>e</sub>	0.033	ft <sup>3</sup> /s	14.72	gal/min	883 gal/hr

Station ID	Yellow (in)	Clear (in)	White ID	Pad - Dry (g)	Pad - Wet (g)	White (in)
B2	nd	nd	nd	nd	nd	nd
B6	nd	nd	nd	14.3	14.3	nd
B10	nd	nd	nd	13.9	13.9	nd
D4	nd	nd	nd	14.1	14.1	nd
D6	nd	nd	nd	14.2	14.2	nd
D8	nd	nd	nd	14.2	14.2	nd
D10	nd	nd	nd	14.4	14.4	nd
F2	nd	nd	nd	14.3	14.3	nd
F4	0	nd	nd	14	14	nd
F6	0	nd	nd	14	14	nd
F8	0	nd	nd	14.2	14.2	nd
F10	0	nd	nd	14.4	14.4	nd
G7	0	nd	nd	nd	nd	nd
G8	nd	nd	nd	nd	nd	nd
G9	0	nd	nd	nd	nd	nd
H4	0	nd	nd	14.1	14.1	nd
H6	0	nd	nd	14	14	nd
H7	0	nd	nd	nd	nd	nd
H8	0	nd	nd	14.2	14.2	nd
H9	0	0.02	nd	nd	nd	nd
I7	0	nd	nd	nd	nd	nd
I8	0	0.04	nd	nd	nd	nd
I9	0	0.05	nd	nd	nd	nd
J2	0	nd	nd	14.1	14.1	nd
J4	0	nd	nd	13.7	13.7	nd
J6	0	nd	nd	14.1	14.1	nd
J7	0	nd	nd	nd	nd	nd
J8	0.1	0.15	nd	14	88.9	nd
J9	0.4	0.42	nd	nd	nd	nd
K7	0	nd	nd	nd	nd	nd
K8	0.1	0.12	nd	nd	nd	nd
K9	0.4	0.45	nd	nd	nd	nd
L4	0	nd	nd	14.3	14.3	nd
L6	0	nd	nd	14	14	nd
L7	0	nd	nd	nd	nd	nd
L8	0.1	nd	nd	14.4	71.2	nd
L9	0.4	nd	nd	nd	nd	nd
M7	0	nd	nd	nd	nd	nd
M8	0.1	nd	nd	nd	nd	nd
M9	0.3	nd	nd	nd	nd	nd
N2	nd	nd	nd	14	14	nd
N4	0	nd	nd	13.9	13.9	nd
N6	0	nd	nd	14.1	14.1	nd
N8	T	nd	nd	14	34.7	nd
P4	nd	nd	nd	13.7	13.7	nd
P6	nd	nd	nd	14	14	nd
P8	nd	nd	nd	13.6	16.3	nd
R2	nd	nd	nd	nd	nd	nd
R6	nd	nd	nd	14.1	14.1	nd
R10	nd	nd	nd	14.4	15.7	nd

Station ID	Yellow (in)	Clear (in)	White ID	Pad - Dry (g)	Pad - Wet (g)	White (in)
B14	nd	nd	nd	nd	nd	nd
D12	nd	nd	nd	14.3	14.3	nd
D14	nd	nd	nd	nd	nd	nd
F12	0	nd	nd	14.4	14.4	nd
F14	nd	nd	nd	14.5	14.5	nd
G10	0	nd	nd	nd	nd	nd
G11	0	nd	nd	nd	nd	nd
G12	0	nd	nd	nd	nd	nd
G13	nd	nd	nd	nd	nd	nd
H10	0	T	nd	13.8	13.8	nd
H11	0	nd	nd	nd	nd	nd
H12	0	nd	nd	14.4	14.4	nd
H13	nd	nd	nd	nd	nd	nd
H14	nd	nd	nd	14.3	14.3	nd
I10	0.1	nd	nd	nd	nd	nd
I11	0.1	nd	nd	nd	nd	nd
I12	0	nd	nd	nd	nd	nd
I13	nd	nd	nd	nd	nd	nd
J10	0.7	nd	nd	14.1	154.4	nd
J11	nd	nd	nd	nd	nd	nd
J12	0.1	nd	nd	14.2	67.8	nd
J13	nd	nd	nd	nd	nd	nd
J14	nd	nd	nd	14	14.3	nd
K10	0.5	nd	nd	nd	nd	nd
K11	1	nd	nd	nd	nd	nd
K12	0.2	nd	nd	nd	nd	nd
K13	nd	nd	nd	nd	nd	nd
L10	1	0.81	nd	14.4	155.4	nd
L11	0.9	nd	nd	nd	nd	nd
L12	0.4	nd	nd	14.3	140.3	nd
L13	nd	nd	nd	nd	nd	nd
L14	nd	nd	nd	14.1	22.7	nd
M10	0.6	nd	nd	nd	nd	nd
M11	0.4	nd	nd	nd	nd	nd
M12	0.2	nd	nd	nd	nd	nd
M13	nd	nd	nd	nd	nd	nd
N10	0.3	nd	nd	14.1	151.6	nd
N12	0.2	nd	nd	13.7	75.3	nd
N14	nd	nd	nd	14	23.7	nd
P10	nd	nd	nd	14.1	54.2	nd
P12	nd	nd	nd	14.3	29.5	nd
P14	nd	nd	nd	nd	nd	nd
R14	nd	nd	nd	nd	nd	nd

Appendix G – Data and analysis for Turbo-Mist field test on 7/24/03

27 No. 45 cores with D6 orifice plates		24-Jul-03			
27		Number of spray nozzles		0.000457 yr	Duration of test
45		Cores		0.1667 day	
D6		Orifices		4.00 hr	
7/24/03 11:00	37826.4583	Start of test		240 min	
36736.2 gal	m <sup>3</sup>	T1-Nozzle flow totalizer		14400 sec	
26.1 gal/min	m <sup>3</sup> /hr	Nozzle flowrate - indicated		6253 gal	23.7 m <sup>3</sup> Spray volume
328910 gal	m <sup>3</sup>	T2-Bypass flow totalizer		22590 gal	85.5 m <sup>3</sup> Bypass volume
94.6 gal/min	m <sup>3</sup> /hr	Bypass flowrate - indicated			
106 psi	Pa	P1		26.1 gal/min	5.92 m <sup>3</sup> /hr Spray flowrate
102 psi	Pa	P2		94 gal/min	21.4 m <sup>3</sup> /hr Bypass flowrate
102 psi	Pa	P3		21 in <sup>2</sup>	0.0135 m <sup>2</sup> Pad area
7/24/03 13:00	37826.5417	Midpoint		0.1458 ft <sup>2</sup>	
39820.1 gal	m <sup>3</sup>	Nozzle flow totalizer		3.35E-06 acre	
25.7 gal/min	m <sup>3</sup> /hr	Nozzle flowrate - indicated		480 volts	Voltage
340020 gal	m <sup>3</sup>	Bypass flow totalizer		35 amps	Current
94.7 gal/min	m <sup>3</sup> /hr	Bypass flowrate - indicated		29.1 kW	Power
103 psi	Pa	P1		82.5 F	28.0 C Temperature
103 psi	Pa	P2		62%	62% Relative humidity
101 psi	Pa	P3		3.0 mph	1.35 m/s Wind speed
7/24/03 15:00	37826.625	End of test		264.06 deg	264.06 deg Wind direction
42989.2 gal	m <sup>3</sup>	Nozzle flow totalizer		26.05 gpm	Spray
25.7 gal/min	m <sup>3</sup> /hr	Nozzle flowrate - indicated		14.70 gpm	Fallback
351500 gal	m <sup>3</sup>	Bypass flow totalizer		<b>11.36 gpm</b>	<b>Evaporation</b>
94.6 gal/min	m <sup>3</sup> /hr	Bypass flowrate - indicated		44%	
103 psi	Pa	P1		29.1 kW	Power
101 psi	Pa	P2		0.08 \$/kW-hr	Energy cost
101 psi	Pa	P3		<b>0.003 \$/gal</b>	<b>Cost</b>
3 in		Pad width		0.056 \$/gal	Direct heating cost
7 in		Pad length		<b>6%</b>	<b>Relative cost</b>

Adiabatic saturation / swamp cooler calculation using ASHRAE (1985) equations					
<b>Constants</b>					<i>source</i>
univ. gas const.	R	1545.33 ft-lbf/(lbmole-R)			
molecular wt. air	M <sub>a</sub>	28.9645 lbm/lbmole			from eqn (24)
air gas constant	R <sub>a</sub>	53.35 ft-lbf/(lbm-R)			
<b>Incoming air stream</b>					
pressure	p	14.7 psia			
temperature	t	82.454 F	28.0 C	542.124 R	24Jul03 Test
relative humidity	φ	0.62	unitless		
sat. pressure	p <sub>ws</sub>	0.5569 psia			eqn (4)
water vap. pres.	p <sub>w</sub>	0.3464 psia			eqn (22)
humidity ratio	W, γ	0.015010	unitless	105.07 grains/lbm <sub>a</sub>	eqn (20)
sat. humidity ratio	W <sub>s</sub>	0.024491	unitless		eqn (21)
deg. of saturation	μ	0.6129	unitless		eqn (10)
specific volume	v	13.99 ft <sup>3</sup> /lbm <sub>a</sub>			eqn (26)
		13.79 ft <sup>3</sup> /lbm			using (1+γ) factor and eqn (26)
		13.66 ft <sup>3</sup> /lbm			using ideal gas law
specific enthalpy	h	36.26 BTU/lbm <sub>a</sub>			eqn (30)
<b>Outgoing for adiabatic saturation/evaporation</b>					
pressure	p	14.7 psia			
temperature	t	72.29 F	22.4 C	531.96 R	
relative humidity	φ	1.00	unitless		
sat. pressure	p <sub>ws</sub>	0.3979 psia			eqn (4)
water vap. pres.	p <sub>w</sub>	0.3979 psia			eqn (22)
humidity ratio	W, γ	0.017302	lbm <sub>w</sub> /lbm <sub>a</sub>	121.12 grains/lbm <sub>a</sub>	eqn (20)
sat. humidity ratio	W <sub>s</sub>	0.017302	unitless		eqn (21)
deg. of saturation	μ	1.0000	unitless		eqn (10)
specific volume	v	13.78 ft <sup>3</sup> /lbm <sub>a</sub>			eqn (26)
		13.55 ft <sup>3</sup> /lbm			using (1+γ) factor and eqn (26)
		13.41 ft <sup>3</sup> /lbm			using ideal gas law
specific enthalpy	h	36.26 BTU/lbm <sub>a</sub>			eqn (30)
<b>Differences</b>					
temperature	Δt	-10.2 F			
relative humidity	Δφ	0.38	unitless		
enthalpy	Δh	0.00	BTU/lbm <sub>a</sub>		
humidity ratio	ΔW, Δγ	0.002292	lbm <sub>w</sub> /lbm <sub>a</sub>	16.04 grains/lbm <sub>a</sub>	
<b>Evaporation system parameters</b>					
Wind speed	v	3.0	mi/hr	4.43	ft/s
Height	h	35.0	ft		
Width	w	35.0	ft		
Xsec area	A	1225	ft <sup>2</sup>		
Incoming wet air vol. flow	Q	5426	ft <sup>3</sup> /s	3.3E+05	ft <sup>3</sup> /min (cfm)
Dry air mass flow	m <sub>a</sub>	388	lbm <sub>a</sub> /s		
Evaporation rate	m <sub>e</sub>	0.89	lbm <sub>w</sub> /s	53.32	lbm <sub>w</sub> /min
Liq. water density	ρ	62.3	lbm/ft <sup>3</sup>		@ 70F
Evaporation rate	Q <sub>e</sub>	0.014	ft <sup>3</sup> /s	6.40	gal/min
				384	gal/hr

Station ID	Yellow (in)	Clear (in)	White ID	Pad - Dry (g)	Pad - Wet (g)	White (in)
B2	nd	nd	nd	nd	nd	nd
B6	nd	nd	nd	nd	nd	nd
B10	nd	nd	nd	nd	nd	nd
D4	nd	nd	nd	nd	nd	nd
D6	nd	nd	nd	14.3	14.3	nd
D8	nd	nd	nd	14.7	14.7	nd
D10	nd	nd	nd	14.2	14.2	nd
F2	nd	nd	nd	nd	nd	nd
F4	nd	nd	nd	14.2	14.2	nd
F6	nd	nd	nd	14.5	14.5	nd
F8	0	nd	nd	14.0	14.0	nd
F10	0	nd	nd	14.4	14.4	nd
G7	0	nd	nd	nd	nd	nd
G8	0	nd	nd	nd	nd	nd
G9	0	nd	nd	nd	nd	nd
H4	nd	nd	nd	14.1	14.1	nd
H6	0	nd	nd	14.1	14.3	nd
H7	0	nd	nd	nd	nd	nd
H8	0	nd	nd	14.2	21.2	nd
H9	0	0.07	nd	nd	nd	nd
I7	0	nd	nd	nd	nd	nd
I8	0	0.1	nd	nd	nd	nd
I9	0.2	0.20	nd	nd	nd	nd
J2	nd	nd	nd	15.0	15.0	nd
J4	0	nd	nd	14.3	14.3	nd
J6	0	nd	nd	14.3	28.3	nd
J7	0.1	nd	nd	nd	nd	nd
J8	0.3	0.37	nd	13.4	116.8	nd
J9	0.8	0.74	nd	nd	nd	nd
K7	0	nd	nd	nd	nd	nd
K8	0.3	0.3	nd	nd	nd	nd
K9	0.8	0.75	nd	nd	nd	nd
L4	0	nd	nd	14.1	14.1	nd
L6	0	nd	nd	14.2	20.4	nd
L7	0	nd	nd	nd	nd	nd
L8	0.1	nd	nd	14.7	100.4	nd
L9	0.4	nd	nd	nd	nd	nd
M7	0	nd	nd	nd	nd	nd
M8	0	nd	nd	nd	nd	nd
M9	0.2	nd	nd	nd	nd	nd
N2	nd	nd	nd	14.3	14.3	nd
N4	0	nd	nd	14.4	14.4	nd
N6	0	nd	nd	14.4	14.4	nd
N8	0	nd	nd	14.3	35.7	nd
P4	nd	nd	nd	13.7	14.0	nd
P6	nd	nd	nd	14.4	14.4	nd
P8	nd	nd	nd	14.4	14.4	nd
R2	nd	nd	nd	nd	nd	nd
R6	nd	nd	nd	14.1	14.1	nd
R10	nd	nd	nd	14.0	14.0	nd

Station ID	Yellow (in)	Clear (in)	White ID	Pad - Dry (g)	Pad - Wet (g)	White (in)
B14	nd	nd	nd	nd	nd	nd
D12	nd	nd	nd	14.5	14.5	nd
D14	nd	nd	nd	nd	nd	nd
F12	0	nd	nd	14.0	14.2	nd
F14	nd	nd	nd	14.5	14.5	nd
G10	0	nd	nd	nd	nd	nd
G11	0	nd	nd	nd	nd	nd
G12	0	nd	nd	nd	nd	nd
G13	nd	nd	nd	nd	nd	nd
H10	0	0.05	nd	14.4	53.3	nd
H11	0.1	nd	nd	nd	nd	nd
H12	0	nd	nd	14.3	50.0	nd
H13	nd	nd	nd	nd	nd	nd
H14	nd	nd	nd	14.6	14.6	nd
I10	0.3	nd	nd	nd	nd	nd
I11	0.4	nd	nd	nd	nd	nd
I12	0.1	nd	nd	nd	nd	nd
I13	nd	nd	nd	nd	nd	nd
J10	1.1	nd	nd	14.4	158.9	nd
J11	nd	nd	nd	nd	nd	nd
J12	0.2	nd	nd	14.5	143.5	nd
J13	nd	nd	nd	nd	nd	nd
J14	0	nd	nd	14.6	27.0	nd
K10	1.2	nd	nd	nd	nd	nd
K11	1.1	nd	nd	nd	nd	nd
K12	0.2	nd	nd	nd	nd	nd
K13	nd	nd	nd	nd	nd	nd
L10	0.6	0.68	nd	14.5	149.7	nd
L11	0.7	nd	nd	nd	nd	nd
L12	0.2	nd	nd	14.6	129.5	nd
L13	nd	nd	nd	nd	nd	nd
L14	0	nd	nd	14.4	24.1	nd
M10	0.2	nd	nd	nd	nd	nd
M11	0.4	nd	nd	nd	nd	nd
M12	0.1	nd	nd	nd	nd	nd
M13	nd	nd	nd	nd	nd	nd
N10	0	nd	nd	14.6	65.2	nd
N12	0.1	nd	nd	14.6	77.9	nd
N14	0	nd	nd	14.5	20.1	nd
P10	nd	nd	nd	14.2	18.2	nd
P12	nd	nd	nd	14.4	26.1	nd
P14	nd	nd	nd	14.2	16.2	nd
R14	nd	nd	nd	14.3	14.3	nd

Appendix H – Data and analysis for Turbo-Mist field test on 8/11/03

30 No. 45 cores with D8 orifice plates 11-Aug-03

30		Number of spray nozzles	0.000327 yr	Duration of test
45		Cores	0.1194 day	
D8		Orifices	2.87 hr	
8/11/03 12:08	37844.5056	Start of test	172 min	
43236.4 gal		m <sup>3</sup> T1-Nozzle flow totalizer	10320 sec	
40.1 gal/min		m <sup>3</sup> /hr Nozzle flowrate - indicated	6738.2 gal	25.5 m <sup>3</sup> Spray volume
352000 gal		m <sup>3</sup> T2-Bypass flow totalizer	-351917.3 gal	-1332.2 m <sup>3</sup> Bypass volume
82.4 gal/min		m <sup>3</sup> /hr Bypass flowrate - indicated		
102 psi		Pa P1	39.2 gal/min	8.90 m <sup>3</sup> /hr Spray flowrate
96 psi		Pa P2	-2046 gal/min	-464.7 m <sup>3</sup> /hr Bypass flowrate
100 psi		Pa P3	21 in <sup>2</sup>	0.0135 m <sup>2</sup> Pad area
8/11/03 13:25	37844.559	Midpoint	0.1458 ft <sup>2</sup>	
46245.1 gal		m <sup>3</sup> Nozzle flow totalizer	3.35E-06 acre	
39.7 gal/min		m <sup>3</sup> /hr Nozzle flowrate - indicated	480 volts	Voltage
358380 gal		m <sup>3</sup> Bypass flow totalizer	35 amps	Current
82.7 gal/min		m <sup>3</sup> /hr Bypass flowrate - indicated	29.1 kW	Power
100 psi		Pa P1	85.1 F	29.5 C Temperature
96 psi		Pa P2	63%	63% Relative humidity
98 psi		Pa P3	2.4 mph	1.09 m/s Wind speed
8/11/03 15:00	37844.625	End of test	181.50 deg	181.50 deg Wind direction
49974.6 gal		m <sup>3</sup> Nozzle flow totalizer	39.18 gpm	Spray
39.3 gal/min		m <sup>3</sup> /hr Nozzle flowrate - indicated	25.21 gpm	Fallback
366080 gal		m <sup>3</sup> Bypass flow totalizer	13.97 gpm	Evaporation
82.7 gal/min		m <sup>3</sup> /hr Bypass flowrate - indicated	36%	
100 psi		Pa P1	29.1 kW	Power
94 psi		Pa P2	0.08 \$/kW-hr	Energy cost
96 psi		Pa P3	0.003 \$/gal	Cost
3 in		Pad width	0.056 \$/gal	Direct heating cost
7 in		Pad length	5%	Relative cost

Adiabatic saturation / swamp cooler calculation using ASHRAE (1985) equations					
<b>Constants</b>					<i>source</i>
univ. gas const.	R	1545.33 ft-lbf/(lbmole-R)			
molecular wt. air	M <sub>a</sub>	28.9645 lbm/lbmole			from eqn (24)
air gas constant	R <sub>a</sub>	53.35 ft-lbf/(lbm-R)			
<b>Incoming air stream</b>					
pressure	p	14.7 psia			
temperature	t	85.1 F	29.5 C	544.77 R	11Aug03 Test
relative humidity	φ	0.63	unitless		
sat. pressure	p <sub>ws</sub>	0.6065 psia			eqn (4)
water vap. pres.	p <sub>w</sub>	0.3829 psia			eqn (22)
humidity ratio	W, γ	0.016635	unitless	116.45 grains/lbm <sub>a</sub>	eqn (20)
sat. humidity ratio	W <sub>s</sub>	0.026765	unitless		eqn (21)
deg. of saturation	μ	0.6215	unitless		eqn (10)
specific volume	v	14.10 ft <sup>3</sup> /lbm <sub>a</sub>			eqn (26)
		13.87 ft <sup>3</sup> /lbm			using (1+γ) factor and eqn (26)
		13.73 ft <sup>3</sup> /lbm			using ideal gas law
specific enthalpy	h	38.70 BTU/lbm <sub>a</sub>			eqn (30)
<b>Outgoing for adiabatic saturation/evaporation</b>					
pressure	p	14.7 psia			
temperature	t	74.91 F	23.8 C	534.58 R	
relative humidity	φ	1.00	unitless		
sat. pressure	p <sub>ws</sub>	0.4344 psia			eqn (4)
water vap. pres.	p <sub>w</sub>	0.4344 psia			eqn (22)
humidity ratio	W, γ	0.018940	lbm <sub>w</sub> /lbm <sub>a</sub>	132.58 grains/lbm <sub>a</sub>	eqn (20)
sat. humidity ratio	W <sub>s</sub>	0.018940	unitless		eqn (21)
deg. of saturation	μ	1.0000	unitless		eqn (10)
specific volume	v	13.88 ft <sup>3</sup> /lbm <sub>a</sub>			eqn (26)
		13.63 ft <sup>3</sup> /lbm			using (1+γ) factor and eqn (26)
		13.47 ft <sup>3</sup> /lbm			using ideal gas law
specific enthalpy	h	38.70 BTU/lbm <sub>a</sub>			eqn (30)
<b>Differences</b>					
temperature	Δt	-10.2 F			
relative humidity	Δφ	0.37	unitless		
enthalpy	Δh	0.00	BTU/lbm <sub>a</sub>		
humidity ratio	ΔW, Δγ	0.002304	lbm <sub>w</sub> /lbm <sub>a</sub>	16.13 grains/lbm <sub>a</sub>	
<b>Evaporation system parameters</b>					
Wind speed	v	2.4	mi/hr	3.58	ft/s
Height	h	35.0	ft		
Width	w	35.0	ft		
Xsec area	A	1225	ft <sup>2</sup>		
Incoming wet air vol. flow	Q	4381	ft <sup>3</sup> /s	2.6E+05	ft <sup>3</sup> /min (cfm)
Dry air mass flow	m <sub>a</sub>	311	lbm <sub>a</sub> /s		
Evaporation rate	m <sub>e</sub>	0.72	lbm <sub>w</sub> /s	42.96	lbm <sub>w</sub> /min
Liq. water density	ρ	62.3	lbm/ft <sup>3</sup>		@ 70F
Evaporation rate	Q <sub>e</sub>	0.011	ft <sup>3</sup> /s	5.16	gal/min
				310	gal/hr

Station ID	Yellow (in)	Clear (in)	White ID	Pad - Dry (g)	Pad - Wet (g)	White (in)
B2	nd	nd	nd	nd	nd	nd
B6	nd	nd	nd	nd	nd	nd
B10	nd	nd	nd	nd	nd	nd
D4	nd	nd	nd	nd	nd	nd
D6	nd	nd	nd	14.7	14.7	nd
D8	nd	nd	nd	14.3	14.3	nd
D10	nd	nd	nd	14.4	14.4	nd
F2	nd	nd	nd	nd	nd	nd
F4	0	nd	nd	14.7	14.9	nd
F6	0	nd	nd	14.5	15.5	nd
F8	0	nd	nd	14.3	19.3	nd
F10	0	nd	nd	13.8	21.3	nd
G7	0	nd	nd	nd	nd	nd
G8	T	nd	nd	nd	nd	nd
G9	T	nd	nd	nd	nd	nd
H4	0	nd	nd	14.1	18.2	nd
H6	0.1	nd	nd	13.6	47.3	nd
H7	0.2	nd	nd	nd	nd	nd
H8	0.2	nd	nd	14	75.6	nd
H9	0.2	0.2	nd	nd	nd	nd
I7	0.5	nd	nd	nd	nd	nd
I8	0.9	0.85	nd	nd	nd	nd
I9	1	0.85	nd	nd	nd	nd
J2	nd	nd	nd	14.8	14.8	nd
J4	nd	nd	nd	14.3	25.8	nd
J6	nd	nd	nd	14	125.7	nd
J7	1.2	2	nd	14.3	119.1	nd
J8	2.2	nd	nd	nd	nd	nd
J9	3	2.7	nd	nd	nd	nd
K7	0.5	nd	nd	nd	nd	nd
K8	1	0.9	nd	nd	nd	nd
K9	1.5	1.45	nd	nd	nd	nd
L4	0	nd	nd	14.3	19.4	nd
L6	T	nd	nd	14.2	38.9	nd
L7	0.2	nd	nd	nd	nd	nd
L8	0.5	nd	nd	14.5	117.9	nd
L9	1	nd	nd	nd	nd	nd
M7	0.1	nd	nd	nd	nd	nd
M8	0.2	nd	nd	nd	nd	nd
M9	0.5	nd	nd	nd	nd	nd
N2	nd	nd	nd	14.1	14.1	nd
N4	0	nd	nd	14.1	14.1	nd
N6	0	nd	nd	14.4	18.8	nd
N8	0.2	nd	nd	14.3	72.1	nd
P4	nd	nd	nd	14.4	14.4	nd
P6	nd	nd	nd	14.1	25.6	nd
P8	nd	nd	nd	nd	nd	nd
R2	nd	nd	nd	nd	nd	nd
R6	nd	nd	nd	14	14	nd
R10	nd	nd	nd	14.2	14.9	nd

Station ID	Yellow (in)	Clear (in)	White ID	Pad - Dry (g)	Pad - Wet (g)	White (in)
B14	nd	nd	nd	nd	nd	nd
D12	nd	nd	nd	nd	nd	nd
D14	nd	nd	nd	14.5	14.5	nd
F12	nd	nd	nd	14.6	17.4	nd
F14	nd	nd	nd	14	14.3	nd
G10	T	nd	nd	nd	nd	nd
G11	0.1	nd	nd	nd	nd	nd
G12	T	nd	nd	nd	nd	nd
G13	nd	nd	nd	nd	nd	nd
H10	0.15	0.11	nd	14.8	69.6	nd
H11	0.15	nd	nd	nd	nd	nd
H12	T	nd	nd	14.7	29.4	nd
H13	nd	nd	nd	nd	nd	nd
H14	nd	nd	nd	13.9	13.9	nd
I10	0.4	nd	nd	nd	nd	nd
I11	0.2	nd	nd	nd	nd	nd
I12	T	nd	nd	nd	nd	nd
I13	nd	nd	nd	nd	nd	nd
J10	1.8	nd	nd	14.1	141	nd
J11	nd	nd	nd	nd	nd	nd
J12	0	nd	nd	14.5	15.9	nd
J13	nd	nd	nd	nd	nd	nd
J14	nd	nd	nd	14.6	14.6	nd
K10	0.8	nd	nd	nd	nd	nd
K11	0.2	nd	nd	nd	nd	nd
K12	0	nd	nd	nd	nd	nd
K13	nd	nd	nd	nd	nd	nd
L10	0.5	0.5	nd	13.9	141.6	nd
L11	0.15	nd	nd	nd	nd	nd
L12	T	nd	nd	14.1	16.7	nd
L13	nd	nd	nd	nd	nd	nd
L14	nd	nd	nd	14.4	14.4	nd
M10	0.2	nd	nd	nd	nd	nd
M11	0.2	nd	nd	nd	nd	nd
M12	0	nd	nd	nd	nd	nd
M13	nd	nd	nd	nd	nd	nd
N10	0.1	nd	nd	14.4	60.9	nd
N12	0	nd	nd	14.4	19.7	nd
N14	nd	nd	nd	14	14	nd
P10	nd	nd	nd	14.3	20.3	nd
P12	0	nd	nd	14.3	14.4	nd
P14	nd	nd	nd	nd	nd	nd
R14	nd	nd	nd	nd	nd	nd