

The Collection Efficiency of a Massive Fog Collector

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ABSTRACT

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Very large (48 m^2) fog-water collectors are being used on the coastal mountains in northern Chile to generate water. The microphysical characteristics of the high elevation fog (camanchaca) have been examined and the collection efficiency of the collectors measured. The camanchaca exhibits characteristics of clouds, reflecting its source as a marine stratocumulus deck. Droplet mean volume diameters (MVD) in ten cases ranged from 10.8 to $15.3 \mu\text{m}$. Droplet concentrations were typically 400 cm^{-3} with fog liquid water contents ranging from 0.22 to 0.73 g m^{-3} .

The large fog-water collectors consist of a double layer of mesh made from a 1-mm wide flat polypropylene ribbon. The theoretical collection efficiencies of a 1-mm wide ribbon, for droplets with the observed MVD, at wind speeds from 2 to 8 m s^{-1} , are 75 to 95%. The field measurements of the collection efficiency of the mesh at the centerline of a large collector gave values of ~66% ($3.5\text{--}6.5 \text{ m s}^{-1}$; $11 \mu\text{m}$ MVD). This is in good agreement with the theoretical value for a single ribbon once the areal coverage of the mesh is taken into account. At lower windspeeds, the measured collection efficiencies dropped to ~26% (1.9 m s^{-1} ; $15 \mu\text{m}$ MVD). A simple parameterization of the mesh collection efficiency allowed some properties of meshes to be examined, e.g. the mesh shows a marked decrease in droplet collection as the ribbon width is increased while maintaining a constant percentage areal coverage.

The measured water output from the large collector was 2.9 times lower than predicted using the measured amount of water removed at the centerline and the wind speed 6 m upstream. This implies a large-collector efficiency of only ~20%. This low value may result from a lowering of wind speed as the fog approaches the mesh, a reduced collection efficiency away from the centerline, and water losses in the system.

RESUME

Dans les montagnes côtières du nord du Chili, on se sert, pour obtenir de l'eau, d'immenses capteurs d'eau de brouillard (48 m^2). On a examiné les caractéristiques microphysiques du brouillard de forte altitude (camanchaca) et mesuré l'efficacité de captage. Le camanchaca présente des caractéristiques de nuages, en reflétant la source sous forme de plate-forme de stratocumulus marin.

Dans dix cas, le diamètre de la masse moyenne (DMM) des gouttelettes s'est situé entre 10,8 et 15,3 μm . La concentration type des gouttelettes était de $400/\text{cm}^3$, la teneur en eau du brouillard allant de 0,22 à 0,73 g/m^3 .

Les grands capteurs d'eau de brouillard consistent en une double couche de filet en ruban plat de polypropylène de 1 mm de large. La capacité théorique de captage d'un ruban de 1 mm de large, pour des gouttelettes du DMM observé, par un vent soufflant de 2 à 8 m/s, est de 75 à 95%. Sur le terrain, les mesures de la capacité de captage du filet à la ligne médiane d'un grand capteur ont donné des valeurs d'environ 66% (3,5 à 6,5 m/s; DMM de 11 μm). Une fois qu'on tient compte de la couverture surfacique du filet, ce chiffre correspond bien à la valeur théorique afférente à un seul ruban. A des vitesses plus basses du vent, la capacité mesurée de captage est tombée à environ 26% (1,9 m/s, DMM de 15 μm). Le simple établissement des paramètres de la capacité de captage du filet a permis d'examiner certaines propriétés du filet. Par exemple, le filet recueille beaucoup moins de gouttelettes quand la largeur du ruban s'accroît, la couverture surfacique en pourcentage étant constante.

La production mesurée d'eau du grand capteur a été 2,9 fois plus basse que la production prévue d'après la quantité mesurée d'eau enlevée à la ligne médiane et à la vitesse du vent à 6 m en amont. Le grand capteur aurait donc une capacité de captage de seulement 20% environ. Cette basse valeur résulte peut-être de la baisse de la vitesse du vent quand le brouillard s'approche du filet, d'une baisse de la capacité de captage quand on s'éloigne de la ligne médiane, et des pertes d'eau de l'installation.

INTRODUCTION

The demand for fresh water is currently a major political, social and economic issue in the world. Predictions are that the problems will continue to grow more serious as populations increase and conventional water supplies are depleted or contaminated. Faced with a growing demand and a depleting supply, we have to be prepared to explore unconventional sources of water. The high elevation coastal fogs along the west coast of South America are one such source.

A high-pressure area is present in the Pacific Ocean off the west coast of South America throughout the year. The trade wind inversion produced by subsidence in the anticyclone is found along the coasts of Peru and northern Chile at heights that gradually decrease towards the south. Typical heights are in the 600 m to 1200 m range. The inversion caps the vertical development of the extensive fields of marine stratocumulus found over the ocean (Schemenauer et al., 1988). The cloud decks are typically 100 m to 400 m thick and do not produce rain, though occasional drizzle is experienced. The stratocumulus decks are blown onshore by a prevailing southwest wind along the northern coast of Chile. Where the coastal mountains are at an appropriate height, they intercept the clouds resulting in persistent periods of fog. These high elevation fogs are called camanchacas.

Kerfoot (1968), Goodman (1982) and Schemenauer (1986) have reviewed the literature on fog water collection by vegetation and small collectors. They concluded that in certain areas the interception of fog water can provide an important input to the ecosystem. A history of such work in northern Chile led

to the establishment in 1987 of The Camanchaca Project. It is a combined research and operational project designed to investigate the meteorological conditions leading to the formation of the camanchaca, the microphysical properties of the camanchaca, the optimum collector design and construction, and the delivery of water to a village of 330 people 6 km away. The main funding agency is the International Development Research Centre in Ottawa, Canada. The scientific participants are the University of Chile, the Pontifical Catholic University of Chile and the Atmospheric Environment Service of Environment Canada. The collector and pipeline construction is supervised and carried out by the Corporacion Nacional Forestal in the 4th Region.

The choice of optimum sampling locations is made by conducting preliminary experiments on relative fog collection using small collectors (Schemenauer et al., 1987; Cereceda et al., 1988). This has resulted in the siting of fifty large 48-m² collectors (atrapanieblas) and the generation of substantial amounts of water (Schemenauer and Cereceda, 1988; Schemenauer, 1988). This paper will describe the results of in-situ measurements designed to determine the collection efficiency of the atrapanieblas. Knowledge of the collection efficiencies is essential for optimizing collector design and for minimizing water costs.

THE FIELD SITE

The field site is 60 km north of the city of La Serena in north-central Chile. The main experimental location is on a ridge at 780 m (29°26'S 71°15'W). The ridge extends in a north-south direction for about 5 km and is flanked on either end by 1100-m mountains. It is 6 km from the coast of the Pacific Ocean where a small fishing-village, Chungungo, is located.

Meteorological stations have operated continuously since November 1987 at 780 m and 720 m recording a standard set of meteorological parameters as well as the flowrates from the collectors. During the 2-week intensive field programs in 1987 and 1988, continuous meteorological data were also collected at elevations of 30 m and 1100 m and frequent radiosonde ascents were made.

INSTRUMENTATION

Each of the 50 atrapanieblas is 12 m long and 4 m high. The base of the mesh varies from 1 m to 2 m above ground depending on the undulations of the terrain. The actual collector studied in this paper is illustrated in Fig. 1. It is on the crest of the ridge with a few eucalyptus trees at a distance of 25 m or more on the downwind side. The collecting material is a double layer of black polypropylene mesh (Fig. 2) that is made in Chile. The mesh is a triangular weave of a flat fiber about 1 mm wide and 0.1 mm thick. The fiber is woven into a mesh with a pore size of about 1 cm. The double layer of mesh can cover

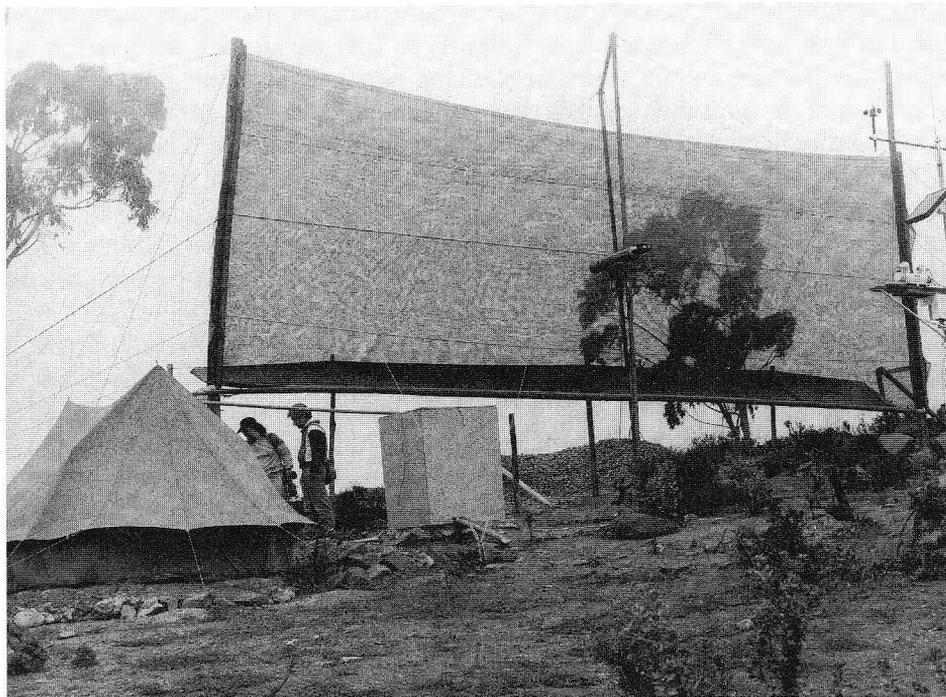


Fig. 1. A $12 \times 4 \text{ m}^2$ fog-water collector on the ridge at El Tofo, Chile. The PMS FSSP probes are in the center and the meteorological tower is on the right.

up to $\sim 70\%$ of the surface area of the collector depending on how the fibers overlap. A complete set of meteorological measurements is made 6 m in front of the atrapaniebla at the centerline height (3.5 m).

Measurements of the characteristics of the fog-droplet sizes and concentrations were made with two Particle Measuring Systems Forward Scattering Spectrometer Probes (FSSPs). Both FSSPs were equipped with aspirators to pull the droplets through the measuring section at a constant 25 m s^{-1} . One FSSP was mounted immediately in front of the atrapaniebla but moved 0.5 m horizontally off center. The second FSSP was mounted behind the atrapaniebla but 0.5 m horizontally off center in the other direction. Measurements were made at 3 heights from just below the center of the atrapaniebla to just above, with each position separated by 0.5 m. Both FSSPs underwent electronic checks and bead calibrations before, during and after the two-week field projects and in addition were operated side by side at times to compare the spectra. The droplet sizes and concentrations were recorded each second. Normally the probes were operated with a nominal channel width of $2 \mu\text{m}$ for each of the 15 channels. Occasionally this was changed to nominal channel widths of 0.5, 1 or $3 \mu\text{m}$ to examine parts of the droplet spectrum in more detail.

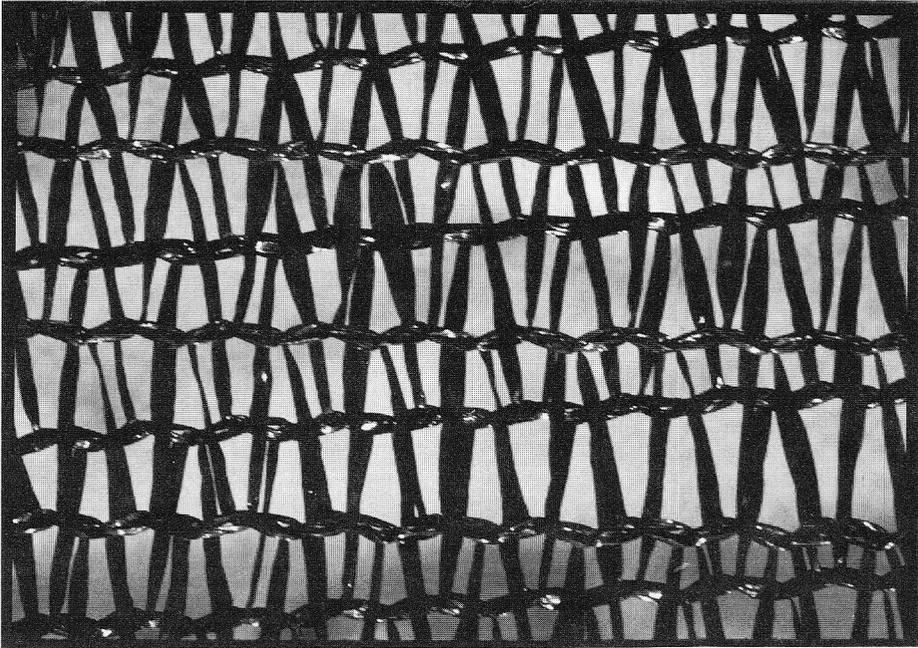


Fig. 2. The Rashell mesh as used in the Camanchaca Project. A double layer is shown. The fiber is 1 mm wide and 0.1 mm thick.

DROPLET-SIZE DISTRIBUTIONS

The camanchaca droplet-size distributions almost always had a single peak with a mode in the 10 to 14 μm range. Maximum droplet sizes only rarely exceeded 30 μm and droplets of this size were contributing little to the fog liquid water content (LWC).

Table I presents the droplet mean volume diameters (MVD) and concentrations from the front FSSP for ten cases. The MVD varied from 10.8 to 15.3 μm reflecting different cloud base heights or updraft velocities and thus different growth times for the droplets. The droplet concentrations on the other hand, except for the 1987 case, remain fairly close to 400 cm^{-3} . Examples of the droplet spectra are shown in Figs. 3 and 4. Fig. 3 shows the spectra from the front and back FSSPs for the 12 November 1987 case. The droplet concentrations are dramatically reduced on the rear side of the mesh for all sizes except the very largest. Few large droplets occurred either in front of or behind the mesh. The average concentration in front of the mesh was 231 cm^{-3} and behind the mesh 73 cm^{-3} . Fig. 4 is a similar plot for the first case of 9 November 1988. The reduction in droplet concentrations is not so marked as in the previous case but it is similar in that the largest reductions take place in the mid-

TABLE I

The collection efficiency of the mesh for 10 sets of measurements near the center of the collector; the sample duration (t), liquid water content (LWC), efficiency (E_m), droplet mean volume diameter (MVD), droplet concentration and wind speed are given

Date	Position number	t (s)	LWC (g m^{-3})		E_m (%)	Front spectrum		Wind (m s^{-1})
			front	back		MVD (μm)	conc. (cm^{-3})	
12 Nov. 87	3	20	0.31	0.098	69	12	231	6.5
4 Nov. 88	3	100	0.31	0.099	68	11.5	383	3.5
4 Nov. 88	3	100	0.22	0.071	67	10.8	301	3.5
4 Nov. 88	3	100	0.32	0.10	68	11.1	406	3.5
9 Nov. 88	4	300	0.68	0.50	27	14.4	477	1.9
9 Nov. 88	4	300	0.72	0.45	37	14.6	435	2.6
9 Nov. 88	4	300	0.73	0.46	36	14.9	419	2.6
9 Nov. 88	5	300	0.66	0.38	43	14.6	408	3.2
9 Nov. 88	5	300	0.73	0.36	51	15.3	384	3.1
9 Nov. 88	5	300	0.68	0.31	55	15.2	366	3.4

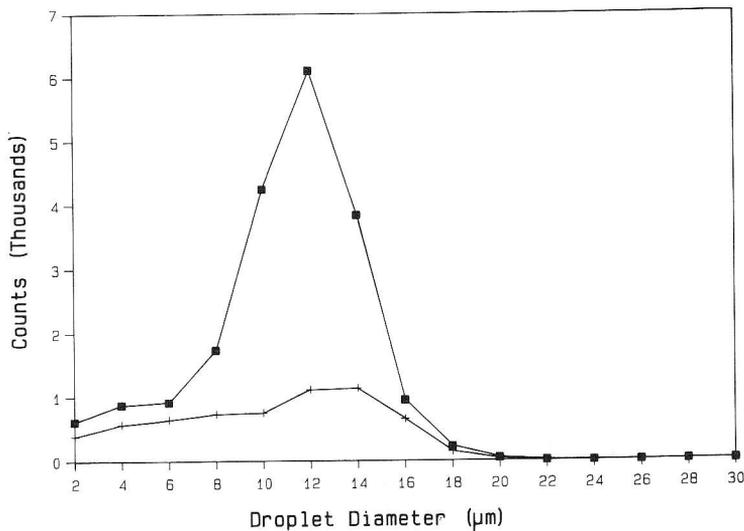


Fig. 3. The fog droplet-size distribution in front of the mesh (squares) and behind the mesh (crosses) on 12 November 1987.

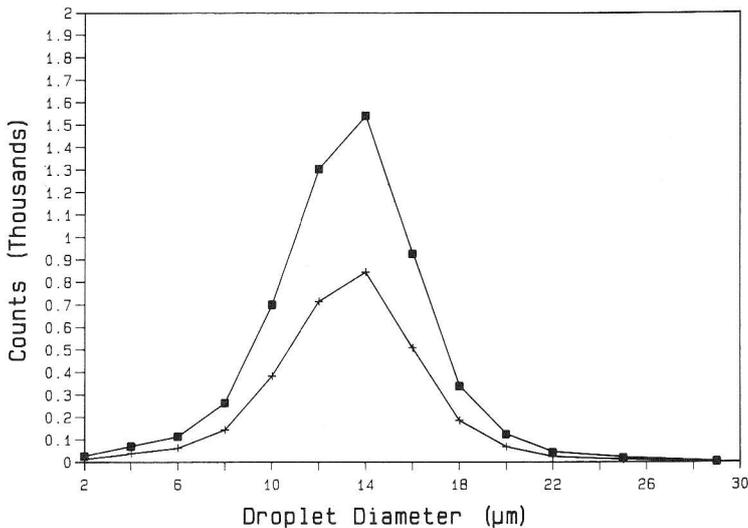


Fig. 4. The fog droplet-size distribution in front of the mesh (squares) and behind the mesh (crosses) on 9 November 1988.

size ranges. The average droplet concentration on the front FSSP was 477 cm^{-3} and on the rear FSSP 291 cm^{-3} .

FOG LIQUID WATER CONTENT

The fog LWC measurements in front of and behind the atrapaniebla are given in Table I. The incoming camanchaca had LWC values from 0.22 to 0.73 g m^{-3} for the ten cases. These values are typical of the lower or mid-levels of cumulus (Schemenauer and Isaac, 1984) and are considerably above what Jiusto (1981) reports for marine or continental surface-based fogs. This is reasonable, given that the camanchaca results from marine stratocumulus cloud decks being advected over the ridge by the sea breeze. The fact that the LWC in the camanchaca can be 0.7 g m^{-3} or higher is of major importance in establishing the water availability on the mountain. LWC values this high or higher are supported by adiabatic LWC calculations on days with low (1000 mb) and warm (20°C) cloud bases.

Fig. 5. shows how the LWC was distributed as a function of size for the case of 12 November 1987. It is very highly concentrated near the peak in the droplet spectrum around $12 \mu\text{m}$. Droplets $< 8 \mu\text{m}$ and $> 18 \mu\text{m}$ diameter were con-

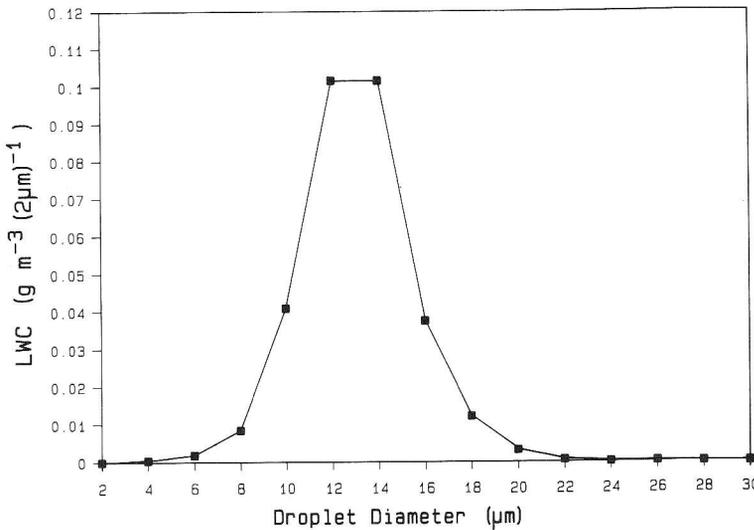


Fig. 5. The distribution of liquid water content in front of the mesh as a function of droplet diameter for the case of Fig. 3.

tributing very little to the camanchaca LWC in this case. This clearly indicates that any fog-water collector in use at the site will have to be particularly efficient in removing droplets in the 10 to 16 μm diameter range.

MEASURED MESH EFFICIENCY

The efficiency (E_m) of the double layer of nylon mesh in removing the camanchaca LWC is presented in Table I for each of the 10 cases. E_m is simply the difference between the front and back LWC values expressed as a percentage of the front LWC. There is considerable variation in the values, from 26% to 69%. It should be clearly noted these values refer to the overall measured efficiency of the mesh and not to the value for a single ribbon or a single droplet size. The most likely meteorological variable to be influencing the collection efficiency is the wind speed, and in Fig. 6 the collection efficiencies for the first four cases in Table I are plotted versus this parameter. It appears that there is only a slight dependency on wind speed, from 3.5 to 6.5 m s^{-1} , for the 11- μm MVD droplets. The six cases of 9 November 1988 from Table I are plotted in Fig. 7. For wind speeds of 1.9 to 3.4 m s^{-1} , and 15- μm MVD droplets, there is a strong dependency of collection efficiency on wind speed. The collection efficiencies for the 11- μm MVD case are probably good to $\pm 5\%$ since a side by

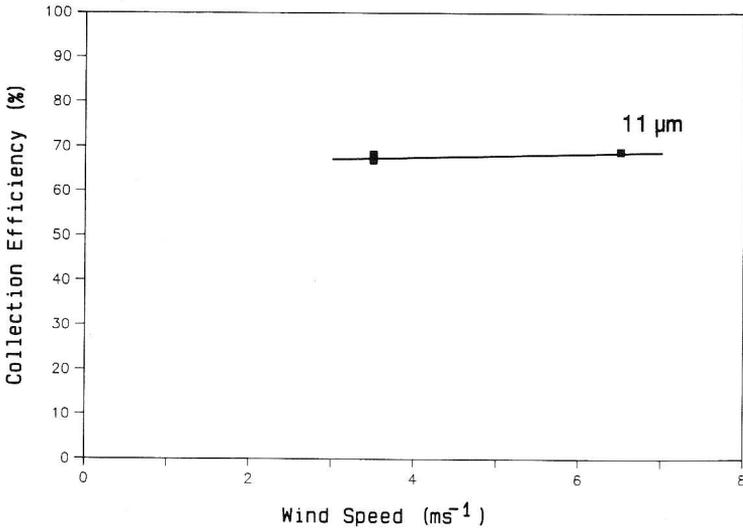


Fig. 6. The measured collection efficiency of the mesh at the center of the large collector as a function of wind speed for the four cases from Table I with droplet MVD of $\sim 11 \mu\text{m}$.

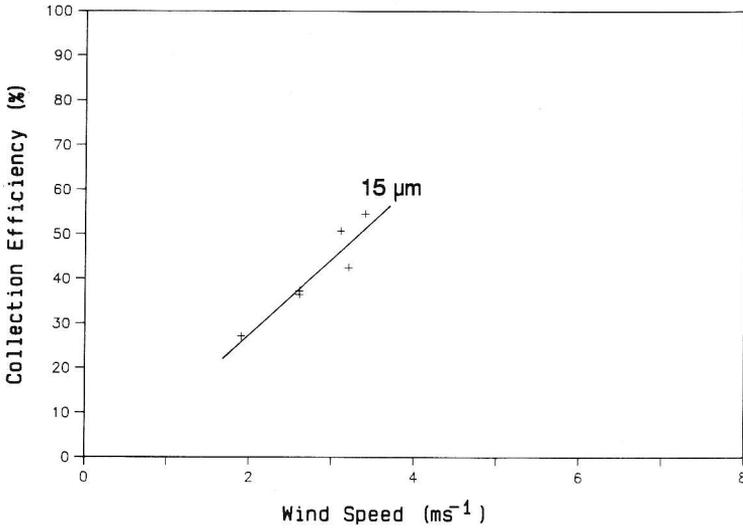


Fig. 7. The measured collection efficiency of the mesh at the center of the large collector as a function of wind speed for the six cases from Table I with droplet MVD of $\sim 15 \mu\text{m}$.

side intercomparison of the two probes was done under these conditions. This was not possible for the $15 \mu\text{m}$ case and thus the least squares fit to the data points could ultimately have to be shifted $\pm 10\%$ when another data set is available. The linear regression equations for the two sets of data are:

$$E_m = 66.3 + 0.41 w_s; N=4; \text{MVD} = 11 \mu\text{m} \quad (1)$$

$$E_m = -6.9 + 17.3 w_s; r=0.94; N=6; \text{MVD} = 15 \mu\text{m} \quad (2)$$

where E_m is the collection efficiency in percent and w_s the wind speed in meters per second. The equations are only valid for the wind-speed ranges noted above.

The collection-efficiency calculations in eqs. 1 and 2 are valid for a range of wind speeds that is representative of the site. Fig. 8 shows a typical diurnal variation in wind speed. The sea breeze is very strong in the afternoon with typical peak values of 5 to 8 m s⁻¹. At night the air is sometimes calm but more typically the winds are 1 to 2 m s⁻¹ from the east. In the case shown, the three peaks in wind speeds between 00h30 and 09h30 were associated with shifts in wind direction from east to west.

The measured centerline mesh efficiencies are reasonably high and indicate a strong dependence on wind speed at low speeds. It is not clear if there is a dependence on droplet size since the data were collected in different wind-speed ranges. This will be discussed further below. The maximum achievable large-collector efficiency is given by the percentage area covered by the ribbon if the ribbon itself has a collection efficiency of 1. In the case of the atrapaniebla, this value is < 76%, since each layer of mesh can cover a maximum of ~38%. The actual field values are not far off this theoretical maximum. This implies that the ribbons themselves indeed have a high collection efficiency.

The field data support the concept of siting the collectors in locations with higher wind speeds and, as we will see below, the theoretical calculations result

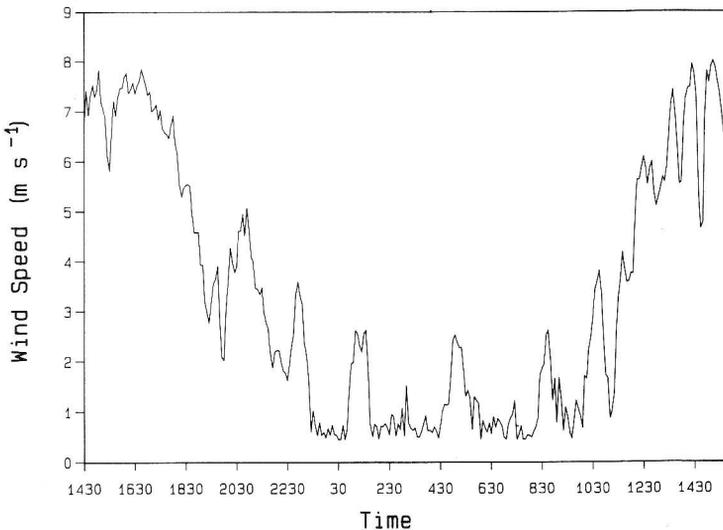


Fig. 8. The diurnal variation of wind speed on the ridge at El Tofo starting at 14h30 local time on 12 November 1987 and ending approximately 15h30 on 13 November 1987.

in higher collection efficiencies for larger droplet sizes. This implies working on the crest of a ridgeline or in a notch in the ridgeline and at altitudes well above the base of the cloud deck generating the fog.

COLLECTOR FLOWRATES

Using the collector area (48 m^2), the measured amount of LWC removed from Table I, and the wind speed, it is possible to calculate the expected output from the atrapaniebla. This is compared in Table II to the measured output for seven cases. The three cases on 4 November 1988 have been omitted because the fog event was just starting and the output flow had not stabilized.

In every case in Table II the calculated flowrate is higher than the measured flowrate from the atrapaniebla. On average, the calculated value is 2.9 times too high. It is probable that the upstream wind speeds overestimate the speed at the surface of the mesh. It is also possible that the collection efficiencies across the mesh are lower than at the centerline. The wind-speed values used in Table II come from measurements for the same time periods as for the LWC data but they were made 6 m upstream of the atrapaniebla. Some reduction in wind speed would be expected as the air approaches the atrapaniebla. This will result from the obstruction to the main flow and the drag of the mesh. There will also be changes in the angle of attack of the wind over the surface of the mesh. Until detailed wind measurements can be made in the vicinity of an atrapaniebla, and more extensive collection-efficiency measurements are available, the empirical factor (2.9) will have to be used to characterize the difference between measured and calculated flowrates. This does not affect eqns. 1 and 2 which correlate the measured collection efficiency to the upstream wind-speed measurements.

Water losses in the collection system are felt to be low for the atrapaniebla

TABLE II

A comparison of the calculated and measured flowrates from the 48-m^2 atrapaniebla

Date	LWC removed (g m^{-3})	W_s (m s^{-1})	Flowrate	
			calc. ($\text{cm}^3 \text{s}^{-1}$)	meas. ($\text{cm}^3 \text{s}^{-1}$)
12 Nov. 87	0.21	6.5	65.5	18.5
9 Nov. 88	0.18	1.9	16.4	5.1
9 Nov. 88	0.27	2.6	33.7	12.1
9 Nov. 88	0.27	2.6	33.7	17.1
9 Nov. 88	0.28	3.2	43.0	24.2
9 Nov. 88	0.37	3.1	55.1	14.7
9 Nov. 88	0.37	3.4	50.4	20.7

studied. Certainly no more than $\sim 10\%$ of the collected water could be lost due to design problems or leaks in the trough and pipes. This therefore cannot be the explanation for the large difference noted above between the calculated and measured values. Similarly, an error in the flowmeter measurements ($\pm 5\%$) or wind speed ($\pm 5\%$) cannot explain the difference.

THEORETICAL CONSIDERATIONS

In this section, the computed collection efficiencies for ribbons from Langmuir and Blodgett (1946) are applied to determine the effectiveness of the collectors. The theory assumes potential flow about an isolated ribbon and considers only inertial impaction. Meshes and filters are frequently viewed as an assemblage of interacting but separate collectors (Spielman, 1977). However, the description of these interacting flow fields around such assemblages and the parameterization of their effects have not been properly addressed.

First we examine the collection of individual ribbons. Fig. 9 shows the collection efficiency of a ribbon for wind speeds of 2 and 8 m s^{-1} and for droplet sizes of 11 and 15 μm as a function of ribbon width. The results are what one would expect from inertial impaction (Langmuir and Blodgett, 1946). As the ribbon width increases, wind speed (droplet velocity) decreases or droplet size decreases, all of which decrease the droplet inertia, the efficiency decreases and the droplet tends to move with the air flow around the ribbon. A 1-mm wide ribbon, however, collects 11- and 15- μm diameter droplets very efficiently (90 to 95%) when the wind speed is 8 m s^{-1} .

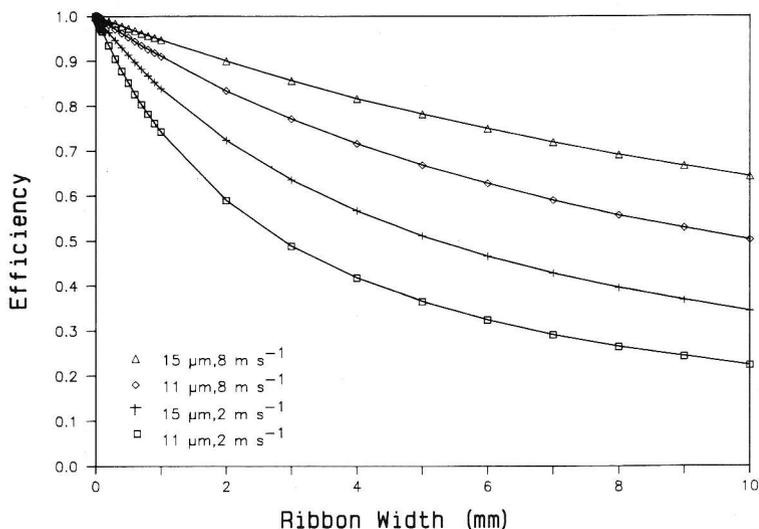


Fig. 9. The collection efficiency of a flat ribbon for wind speeds of 2 and 8 m s^{-1} and for droplet sizes of 11 and 15 μm as a function of collector width (after Langmuir and Blodgett, 1946).

In Fig. 10, the collection efficiency is multiplied by the width of the ribbon to compute the amount of water that a single ribbon might be expected to be able to collect. Even though the efficiency drops off with ribbon width, the collection area increases faster with the result that water collection increases with increasing ribbon width. Note, however, that beyond a certain width, the collection approaches a limit.

Fig. 10 shows that, if you could only put up one ribbon, a 10-mm wide ribbon would generate more water than a 1-mm wide ribbon in the fog conditions on El Tofo. The effect is more pronounced at high wind speeds (8 m s^{-1}) than low wind speeds (2 m s^{-1}) and for larger droplets ($15 \mu\text{m}$) than smaller droplets ($11 \mu\text{m}$). If you put the same *area* of ribbon in a fog though, ten 1-mm wide ribbons would generate more water than one 10-mm wide ribbon. Fig. 10 helps explain why eucalyptus trees, with long leaves 1 to 2 cm wide, are good fog water collectors on El Tofo. The trees reach heights of 15 m or more and the leaves are exposed to fog droplets travelling with higher wind speeds than are measured near the surface. This is a regime in which wide collectors perform effectively.

The computation can be extended to consider multiple ribbons in a mesh. The configuration of the ribbons forming the mesh is not specified and therefore the results are only grossly correct. The mesh could be a single layer or two layers that are touching. An assemblage of ribbons is assumed which forms some sort of matrix; this assemblage is parameterized by the fraction of the collector cross-sectional area that is obscured by the collecting surface. Fig. 11 shows the results for a mesh that covers 50% of the collector's cross-sectional

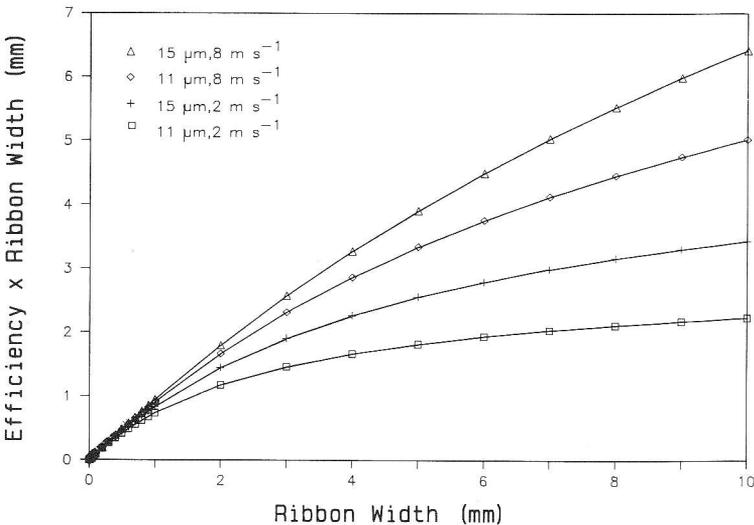


Fig. 10. The product of the collection efficiency (E) and the ribbon width (D) as a function of ribbon width for two droplet sizes and two wind speeds.

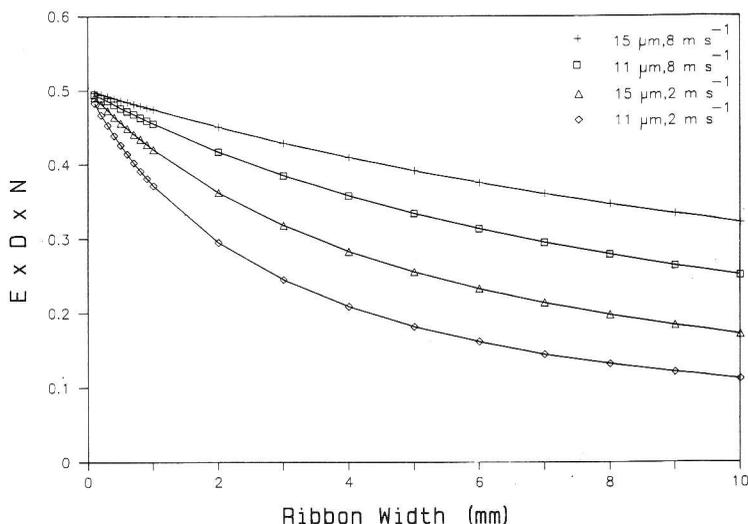


Fig. 11. The product of the collection efficiency (E), the ribbon width (D) and the number of ribbons (N) (to maintain 50% areal coverage) as a function of ribbon width.

area. A single strand of 1-mm ribbon in a 1-cm triangular configuration (such as the Rashell mesh in Chile) obscures about 38% of the area. A double layer would obscure < 76% of the area since some overlap of strands is inevitable. Therefore, 50% coverage is not an unreasonable assumption. Fig. 11 shows that if the number of ribbons is such that an areal coverage of 50% is maintained, then the amount of water collected by a mesh decreases with increasing ribbon size. Therefore, many small ribbons in a mesh are more effective than a few large ribbons for collecting water. As the collector size (ribbon width) gets very small, the collection efficiency approaches 1 and N gets very large. The mesh with 50% coverage will then remove 50% of the fog droplets approaching it. Though, for a ribbon width equal to zero, the collection would be zero. For the case of an atrapaniebla with a 50% coverage of 1-mm wide fibers, Fig. 11 predicts that the mesh will collect ~ 11% more 15- μm diameter droplets than 11- μm diameter droplets when the wind is 2 m s⁻¹.

One should be very careful in applying this figure, in that the ribbon geometry within the mesh and the detailed flow fields at the ribbon have been ignored. The parameterization of droplet collection by meshes is, however, an important subject and will receive continued attention.

Fig. 12 is an adaptation of the collection efficiency versus ribbon-width data in Fig. 9. In Fig. 12, the collection efficiency of a 1-mm wide ribbon, for 11- μm diameter droplets, is shown as a function of wind speed for two cases. A very simple way of thinking of the large collector (atrapaniebla) is as a cross-sectional area which has a certain fraction covered by 1-mm ribbons. The product

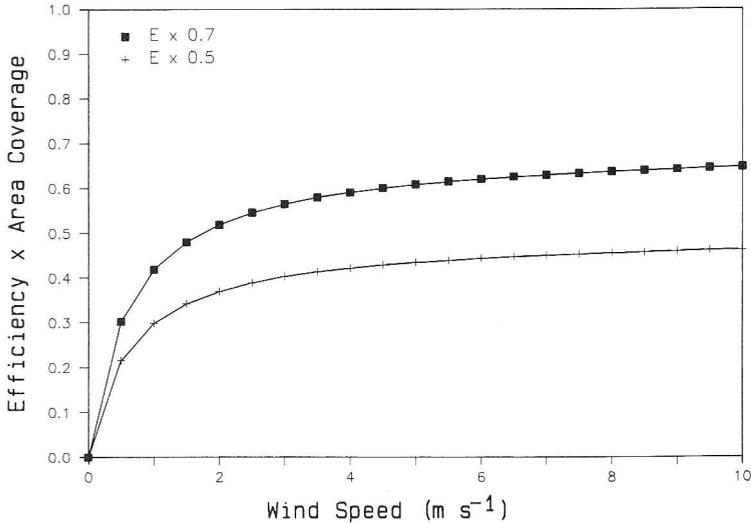


Fig. 12. The product of ribbon collection efficiency and mesh areal coverage (50% and 70%) as a function of wind speed.

of the theoretical ribbon collection efficiency (E) and the fraction of the large collector covered (A) should therefore give an approximation of the efficiency of the large collector (E_{LC}). This is shown in Fig. 12 for 70% and 50% coverage. E_{LC} rises rapidly from 0 to $\sim 2 \text{ m s}^{-1}$ and then levels off with only a small increase in value from ~ 3 to 10 m s^{-1} . The latter part of the curve looks very similar to the measured values of E_m for $11\text{-}\mu\text{m}$ MVD droplets in Fig. 6. The measured values of E_m for $15 \mu\text{m}$ MVD droplets at low wind speeds (Fig. 7) fall off rapidly as the speed decreases, in qualitative agreement with Fig. 12. But the drop in measured E_m occurs at higher wind speeds than is expected. As a first approximation, nevertheless, one can think of the center of the atrapaniebla acting as a set of 1-mm wide ribbons covering 70% of the cross-sectional area. The actual percentage area covered (Fig. 2) is probably less than 70% but it is difficult to estimate since the double layer of mesh is flexible and forms a non-planar collector which bends in moderate winds. The percentage area covered may in fact be different in different parts of the atrapaniebla and at different wind speeds.

It is encouraging that the trends of the measured mesh results are consistent with the theoretical ribbon results and that the parameterized mesh calculations provide some insight. However, more studies, either at the site or in a wind tunnel, are needed to better parameterize the collection of fog water by the mesh in order to optimize the collector design.

CONCLUSIONS

The camanchaca (high elevation fog) along the north-central coast of Chile exhibits characteristics similar to small cumulus and stratocumulus. Measured liquid-water contents were 0.22 to 0.73 g m⁻³, substantially above that found in surface-based fogs. Droplet concentrations were typically 400 cm⁻³ again more characteristic of clouds than of surface-based fogs. In the ten cases studied, droplet MVD ranged from 10.8 to 15.3 μm . Maximum droplet sizes rarely exceeded 30 μm .

The collection efficiency at the center of a 48-m² polypropylene mesh fog-water collector has been demonstrated to be strongly dependent on both wind speed and droplet mean volume diameter. Values as high as 65 to 70% were measured for 11- μm MVD droplets when the wind speeds were between 3.5 and 6.5 m s⁻¹.

Use of the measured centerline collection efficiency and the wind speed measured 6 m upstream, results in a calculated large-collector output that is 2.9 times higher than the measured output. This implies that the actual average wind speed at the mesh surface may be lower by a factor of 3 due to blockage effects of the large collector or that the collection efficiencies across the mesh are lower than at the centerline. The implied efficiency of the collector as a whole is about 20%, i.e. it removes about 20% of the fog water approaching it.

Theoretical calculations of the collection efficiency of an isolated 1-mm wide flat ribbon provide results which agree with the measured field values in demonstrating higher collection efficiencies for larger droplets and higher wind speeds. Numerical modelling of the collection efficiency of a non-planar, two-layered, densely packed mesh is an extremely difficult task. However, a simple parameterization provided insight into the role fiber width plays in the collection efficiency of a mesh with a constant percentage areal coverage. Ultimately, more extensive field measurements, coupled with wind-tunnel data, should enable one to better parameterize the collection efficiency of the mesh and possibly to improve the efficiency of the collectors.

The ultimate goal of The Camanchaca Project is to generate large quantities of fog water for use in coastal villages in Chile. As we have seen in this paper, the output of the collectors is going to vary depending on the wind-speed regime and the droplet sizes and fog LWC at each site. Atrapanieblas such as those being used at the El Tofo site may be applicable at most other locations with similar meteorological conditions, however, operations in extreme conditions such as very high or low wind speeds may require modifications to the meshes.

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