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Droplet separators for evaporative towers: efficiency estimation by PDA

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Abstract

A Phase Doppler Anemometry system has been set up to characterize the behaviour of different arrangements of static impactors that are used as drift eliminators to intercept and remove residual water droplets entrained in the hot air flow released by an evaporative tower. The investigated evaporative tower has a square section of 60x60 cm, that is the standard size for modular separation elements; it was tested while working with or without the droplet separators; for each test condition, the residual water droplets entrained by the air flow and expulsed by the tower are detected few centimetres above the tower exhaust and are characterized by the PDA system that can measure the velocity and diameter of each droplet. Many parameters describing the droplet population over the whole exit section, (number, mean velocity and diameter) can be obtained. The distribution of the droplets is calculated as a function of their diameter, and represented as a percentage of their total number and of their total volume. The velocity-diameter plot of the same droplets shows other aspect of the population. Droplets with same diameter show a spread velocity distribution due to the high turbulence of the exhaust air flow. Droplets with larger diameters have smaller mean velocity, since the gravitational downward force is not negligible compared to the aerodynamic upward drag from the air flow. Few very large droplets have even negative velocity: they are interpreted as droplets that, after the expulsion, are falling back downward. The use of an LDV-PDA system allows to detect such droplets and to discard them from the separation efficiency calculations. The efficiency can be calculated by direct comparison of the number of water droplets that are detected in the exhaust air flow, both globally or for any specific class of droplet size. Global results can be calculated on the basis of the number or of the volume of the droplets. The accuracy of the efficiency estimation is also studied. Two main aspects are considered. The first is that the PDA measurement volume dimension variation with the detected droplet size: it has negligible effect on the result per classes of diameters, but the effect on the global efficiency is present and will be discussed. The second aspect is the presence of droplets that are falling downward in the upward air flow: their presence should be considered and corrected for. The results of this paper are useful when comparing them to other measurements obtained with techniques that are not able to detect the droplet velocity.

Introduction

Evaporative cooling towers [1] are a common part of many industrial and chemical plants; they represent a relatively simple, cheap and reliable mean of removing low-grade heat from cooling water to the atmosphere. Hot water from the plant circuits is sent to the cooling tower, the cold water exits the cooling tower and is sent back to the plant. An external water source is used to replenish the water lost to evaporation. Drift eliminators are devices used to capture water droplets entrapped in the air stream that otherwise would be an additional water loss to the atmosphere. Their aim is threefold: to reduce unwanted and useless water consumption, to reduce the emission of mist that in certain location could represent a risk for vehicle circulation, (e.g. in the vicinity of an airport), and to respect the legislation of many countries facing the risk of proliferation and spreading of pathogens agents [2], like the Legionella Pneumophila.

Different realizations of drift eliminators are used in the industry, most of them relying on droplet separation by impact onto a surface: the impact is obtained by the sudden deviation of the air flow that can not be followed by the water droplets because of their inertia, and are centrifuged away. The combination of the flow speed and deviation, together with the flow passage shape and dimension, determines the minimum size of the droplet that will impact. Smaller droplet can follow the flow deviation and keep existing, this could be not a problem if such smaller droplets do not exist, or their quantity and size is negligible. The flow deviation causes a pressure drop across the eliminators, that is compensated by the presence of the fan.

Background

Since many decades various studies can be found in the literature reporting simulation of different separator geometries and their effects and efficiency on the separation of droplets of different size [3, 4], but experimental measurements are more unusual, and more often limited to global separation performances. The most important general conclusions are that [4]: the circulating water rate has little effect on the drift level, while the air velocity increases the drift level, due to a combined affect of much higher water load in the flow with a slightly better performance of impactor. If complete and accurate experimental data are necessary, with details of the eliminators behaviour for different droplet diameters, the instrumentation required to perform such studies is quite complex, expensive, and difficult to be operated on a real size evaporative tower.

Results agree on the following values to be expected [4, 5]: droplet size from a large evaporative tower range from tens of microns as average drift size, with hundreds of microns as largest detected size. Smaller droplets with few micron size can be formed by recondensation

Evaporative tower experimental set-up and working conditions

The tower was placed outside of the laboratory, under a canopy standing at 10 meters above to protect the measurement instruments from possible rain. It was close to a storage building 3.5 meters tall, with flat accessible roof, over which some instrumentation could be placed and operated, while the other instruments were inside the laboratory.

The tested tower is a counter flow forced draft tower. It has a square section of 60 x 60 cm (0.36 m^2 area section) and is 4.3 meters tall. Inside the tower – from bottom to top – there are the water basin, the air inlet, the filling media, the hot water inlet and the drift eliminator section with the droplet separators stands. To facilitate the experimental campaign, the tower is also equipped with a variable speed fan, various thermometers and hygrometers, a regulation valve and a flow-meter on the water circuit, a visual level indicator in the water basin.

The tested drift eliminator are standard products available on the market (Driconplus, produced by Cotor SrL, Italy); their impact surfaces are flat baffles, with a 45° angle to the air flow direction, and a small 90° deflector located on the discharge side where the flow impacts on the surface.

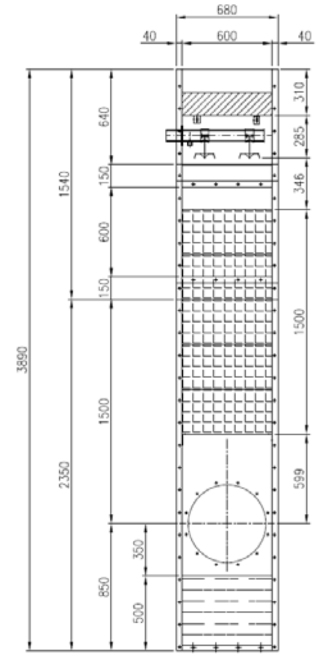

Figure 1 Scheme of the evaporative tower

The parallel impact surfaces are hold by two side supports, forming a module that allows lateral side by side coupling, and vertical stacking in layers, oriented to opposite directions so that the impact surfaces of two layers form a 90° angle that deflects the air flow.

Figure 2 drift eliminators: three stacked layers of modular separators

Different arrangements were tested, by using the same type of separators, named type A, stacked on one, two or three layers named respectively A1, A2 e A3.

Table 1 Nominal working conditions at full load

air average speed	3.5 m/s
Air volume flow	1.26 m^3_{air}/s 4500 m^3_{air} /h
Air mass flow	1.5 kg_{air} /s
Water volume flow	10.8÷11 m^3_{water} /h
Water mass flow	3 kg_{water} /s
Water to air mass flow ratio:	2 kg_{water}/kg_{air}
Water mass flow to tower section surface ratio:	$30\ \frac{m^3_{water}}{h\,m^2}$

The nominal working conditions of the tower are characterized by maximum water and air flow; the values are in the Table 1.

Measurement techniques, set-up and tuning

The water flow was set manually by a regulation valve present on the water circuit, and measured by a rotameter; its full scale was 25 m^3/h, with accuracy better than 1% of the full range. At the nominal working condition of 11 m^3/h, the resulting accuracy was about 2%.

The water consumption was measured by a visual level indicator with a transparent scale positioned on the side of the water basin. The full scale was 25 cm, with typical accuracy around 1 mm when the tower was not working, worst while working because of the vibrations. With the basin section of 60x60 cm the accuracy corresponding to 1 mm of level is 0.36 kg of water. Measurements were always read with the tower not working and internal tubing drained. For some long test sessions that required more water than the basin capacity, known volumes of water were added during working to avoid interruptions.

Ambient temperature and humidity were monitored by a digital portable instrument.

The air flow resulted to be the most difficult to measure on this set-up. The integration of the air velocity profile at the fan inlet was unreliable because of strong asymmetries and instabilities, with the air velocity directed outwards in some points due to the fan induced swirling air and its interaction with the fan motor holders. It was not possible to install a long straight duct to get more homogeneous profile due to lack of space and to the problem of introducing a supplementary unwanted pressure loss.

Better results could be obtained from the average velocity profile measured at the tower upward exit with a fan anemometer, but only without drift eliminators and without circulating water: in this case the velocity profile was more regular, with some irregularity due to the presence of the water duct and of its holder.

When operating the water circuit, the air flow distribution changes slightly: the water jet splashing on a distributor plate formed a sort of water sheet that is a local obstacle to the air flow. In this situation, without drift eliminators, the air velocity cannot be measure by the fan anemometer due to the presence of too many droplets in the flow.

When the drift eliminators were placed on, they introduced an additional pressure drop. The air velocity was deviated from its main upward direction by the separator surfaces, and its absolute velocity increased due to the reduced effective flow section; additionally, two regions showed different velocity near two walls of the exhaust: a peak were the inclined flow impacted and was deviated vertically by the wall itself, and a lack up to negative values, that means a downward flow, close to the opposite wall from which the flaw was drawing away. These border effects were more important for the tower under test due to its close section, but should be negligible for much larger towers.

Finally the best results of air mass flow measure, with drift eliminators installed and water circuit operated, were obtained by calculation from the evaporated basin water: a mass balance between air and water flows, together with the measured values of the air temperature and humidity at the inlet, by considering it saturated at the outlet, gives the air mass flow.

LDV and PDA instrumentation

The combined LDV + PDA system was set-up to measure the velocity and diameter of the droplet entrained by the exhausted air flow. The main problem of these measurements was that when the drift eliminators are installed, only few particles, hopefully none, are present in the flow. In such a condition, a back scatter LDV system has more probability to detect the particles than a PDA [6, 7].

In the back scatter LDV system, the measurement volume is the whole ellipsoid formed by the two laser beams intersection region; the LDV system can measure the velocity of the particles crossing this whole region.

The PDA receiving optics are mounted on a side and visualizes a slice of the LDV volume, so the PDA can only measure the particles crossing this reduced region, with the advantage that it can measure not only the droplet velocity but also its diameter, under the hypothesis that the droplets are spherical.

The strategy used was to implement both systems at the same time, by using commercial hardware.

Table 2 LDV and PDA set-up

Laser: argon-ion, used on the green line (514.5 nm), for axial velocity component and diameter measurement
Bragg cell frequency (frequency shift): 40 MHz
Beam separation at the frontal lens: 38 mm
Nominal beam diameter ($1/e^2$) at the frontal lens: 1.35 mm
Transmitting (and LDV receiving) optic focal length: 600 mm
LDV nominal measurement volume size 290×290×9000 μm
LDV and PDA velocity range: -5 ÷ 15 m/s
PDA Receiving optic scattering angle: 70º
PDA Receiving optic focal length: 600 mm
PDA Sensor aperture: mask B (see Dantec Hardware manual)
Diameter range: up to 900 μm (the presence of droplet up to 1200 μm can be ascertained)
Spherical validation acceptance range: ±10%

The laser source is a continuous Melles Griot 43 series Argon-ion laser used at its maximum power of 300 mW. The optic hardware is made by Dantec [7], and comprises a Bragg cell and beam splitter system, a Fiber LDV transmitting optic with integrated back-scatter receiving optic, a Fiber PDA receiving optic, a 58N70 Detector Unit with three photomultipliers, a forth additional external photomultiplier, a 2D BSA P60 Flow and Particle Processor, and a PC with the acquisition software. The optics was mounted on a traverse system positioned on the building roof close to the tower upper exhaust, for remote positioning of the measurement point in the exhaust flow.

With the PDA system, the droplet vertical velocity component is measured a first time by the acquisition channel 1 (1st photomultiplier and 1st FFT processor board); the channels 2 and 3 are used together with channel 1 to measure and verify the particle diameter. The fourth photomultiplier and the processor 4th board, normally used to measure the second velocity component, were here used to measure again the vertical velocity component of the droplet seen by LDV back-scatter receiving lens integrated in the transmitting optics. In the following text, they will be called PDA-velocity (or LDA-1 by the Dantec software, from Laser Doppler

Anemometry board 1) and LDV-velocity (or LDA-4).

In theory, the LDV system should detect all the particles detected by the PDA system, plus many other particles visible only to its optic. This was observed during the experiments and LDV data were used to have better estimates of air velocity, mostly when the PDA could detect no data at all, while the LDV could still detect some data from particle probably of submicrometric dimensions.

LDV and PDA thermal drift and biased averages issues

The response of a PDA system could change also because the laser power and the photomultipliers efficiency could have a thermal drift. For this reason our system was thermally stabilized before each test session, never operated for more that three hours consecutively, or 4 hours per day, and its response, checked before and after each test by measuring the data rate obtained from a known nebulizer used as reference, resulted to be quite stable.

For each tested conditions, average values were obtained by collecting measures over 25 different positions located at the tower exhaust along a regular square grid; in each position the measurements lasted from 2 to 5 minutes depending on the experimental conditions.

For both LDV and PDA techniques the dimension of the measurement volume depends also on the particle size itself [6, 8, 9], since small particles are less visible and can be detected only when traversing the central region of the measurement volume, where the laser intensity is stronger. A consequence is that the measurement volume dimensions are not know a priori, and hence there is not a know proportion to relate the results to the full section of the measured flow, in this case the tower section. What can be directly compared are the populations of droplets with the same diameter, or more precisely in the same diameter class, measured in two different tests by the same instrumentation. A post processing calibration procedure is often possible; it allows the determination of the correlation between measurement volume dimension and droplet size, thus allowing its correction in the average algorithm by different weighting. In absence of such correcting weighting, the average results of LDV and PDA are normally biased towards the values of the larger particle.

Droplet sphericity and PDA data validation

Theoretically, it is expected that the droplet shape deviates from spherical [11] for Weber number larger than 1 ($We = \rho_{air} v_{rel}^2 D_{dropl}/\sigma_{water}$). In the tested experiments the largest droplets measured less than 1 mm: their Weber number in air remains under the critical value for relative velocity up to 7.5 m/s. If it is considered the largest detected droplet, 850 microns, that also had the minimum velocity, -1 m/s (downwards), in the air stream with mean velocity of 3.5 m/s upwards, its Weber number is around 0.25, far below from the critical value. In fact the droplet non-sphericity has never been a problem.

The droplet sphericity could be appreciated also in the PDA measurements: the signal phase plot [6, 7] presented most of the droplets in the central region of the spherical acceptance range, close to the ideal line of the dominant refraction scattering order use to measure their diameter. Due to the presence of very large droplets, the gaussian beam effect and the slit effect are likely to be strongly present [8] and in fact many signals (up to 10%) laid along the sphericity line of the reflection scattering order. All these signals could be rejected by using the mask B in front of the PDA receiving optics [7]: with its asimmetrical apertures the signals from different scattering orders are clearly separated allowing correct validation and sizing.

The LDV signal quality has always been exceptional, with validation often at 100%, thanks to the extremely sparse droplet distribution in the air flow.

Experimental results:

Velocity distribution and Velocity-Diameter correlation without drift eliminators

The graph of figure 3 shows the time averaged upward velocity in each point of the measurement grid. The velocity distribution is quite flat, with a slight peak due to the asymmetry of the mechanical supports and water ducts inside the tower. This is the droplet average velocity, so also large and slow droplets are included. To estimate the air velocity, only the smaller droplet should be accounted for.

The plot on figure 4 shows the correlation between the droplet diameter (micron, vertical axis) and the outgoing upward velocity (m/s, horizontal axis). The data from the 25 positions of the measurement grid are merged and processed together to give an overview over the whole exit section. Each dot represents one detected droplet. Below 200 micron, droplet velocity does not depend on its diameter; this means that for these droplets the drag by the air flow is dominating Larger droplet have smaller velocity, since the gravitational downward force is not negligible compared to the aerodynamic upward drag from the air flow. Few very large droplets have negative velocity: they are droplet that after expulsion, are falling back downward. These droplets are not considered in the outgoing droplet counting of the following figure 5 and 6.

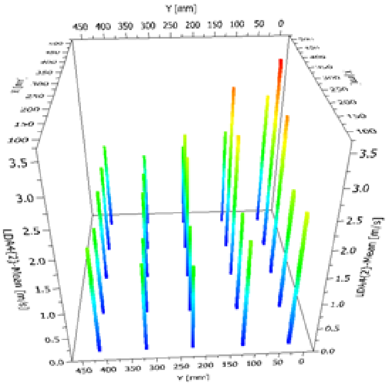

Figure 3 Upward vertical velocity component over the tower exit. Time averages over 2 minutes at each grid position, grid step 10 cm.

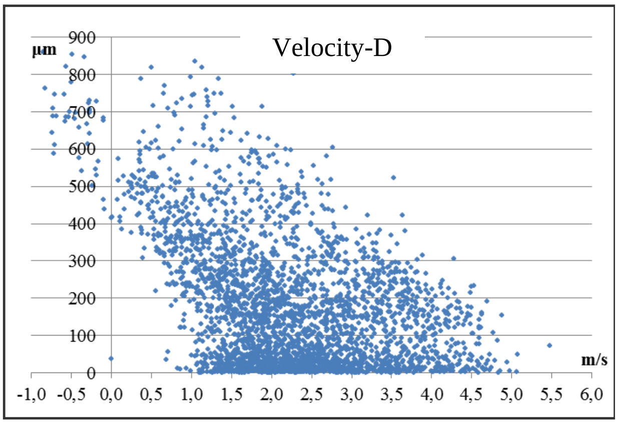

Figure 4 Velocity-diameter correlation: each dot is a single droplet. The dataset is the same used for the averages of the figure 3; total acquisition time 50 minutes.

Droplet distribution, without and with one layer of drift eliminators

The chart in Figure 5 and 6 shows the droplet distribution measured by the PDA over the whole exit section, binned for diameter classes. The yellow data are the percentage on the number of droplets, the blue data show the volume of liquid contained in the droplets of each class, as a percentage of the total droplet volume. The diameter indicated in the horizontal axis is the maximum of each class bin. No PDA bias correction is applied up to now.

Figure 5 shows that without drift eliminators; the most numerous class is the one with the smallest diameter, meaning that the small droplets are the majority of the population. The volume computation shows that few large droplets can contain a large percentage of the total water, since the volume is the third power of the diameter. On the contrary, a very large number of small droplets could represent a negligible percentage of the water volume. The arithmetic mean diameter is 123.7 micron, which confirms the dominance of small droplets.

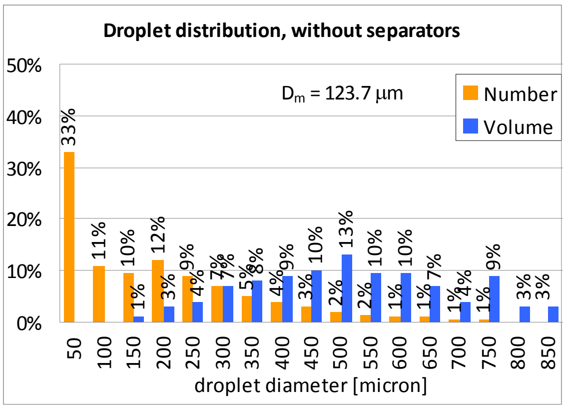

Figure 5 Detected droplet distribution, nominal working conditions, no separators, no PDA bias correction

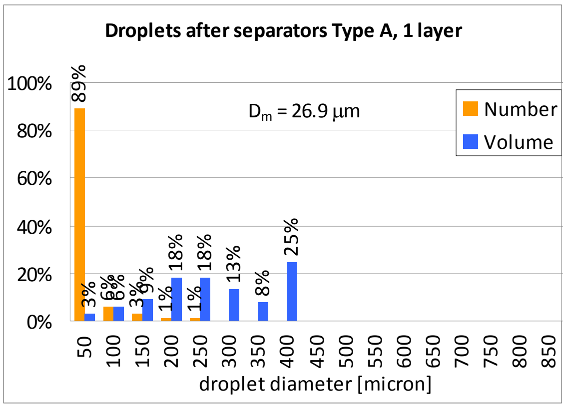

Figure 6 Detected droplet distribution, nominal working conditions, one layer of separators, no PDA bias correction

The chart of figure 6 shows the same results obtained with 1 layer of drift eliminator modules. The horizontal axis is now limited to 400 microns, since no larger droplets were detected. In the presented example the smaller class contains the largest part of the detected droplets (89%), but their volume is just 3% of the total. The few large droplets in the 400 micron diameter class are the more relevant in terms of volume. The arithmetic mean diameter is shown, 26.9 micron.

Data processing

Separation efficiency per classes of diameter.

The drift eliminators efficiency is evaluated by calculating the percentage of removed droplets by difference between the number of droplets detected with and without drift eliminators. In this situation the bias effect of the PDA is not affecting the results, since comparisons are made for the same class of diameter, which are affected by the same bias. Only for the smallest diameter classes, a slight bias effect could be present because the difference between the smallest and largest droplets belonging to the same class is wide. For the cases with two layers of separators, during 125 minutes of acquisitions only four droplets were detected; three of them in the smaller diameter class, and one in the 250 micron class. With three layers of separators, no droplets were detected in 125 minutes of measurements.

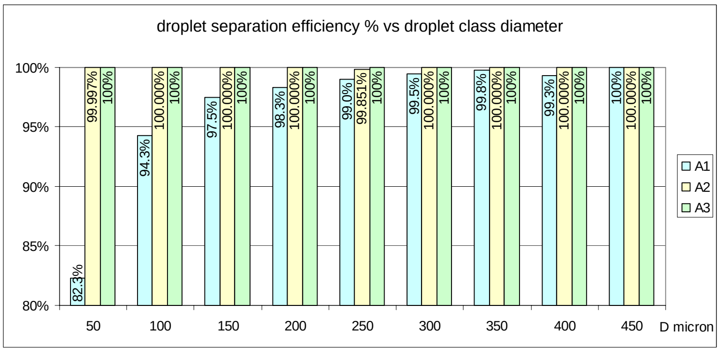

Figure 7 Separation efficiency per class of diameters, with 1, 2 or 3 layers of separators (A1, A2, A3 respectively).

The formula used to calculate the separation efficiency in each class of diameter is the following:

$$\eta_{separation\_Dclass} = 1 - \frac{N_{Dclass\_with\_separator} / t_{acquisition\_with\_separator}}{N_{Dclass\_without\_separator} / t_{acquisition\_without\_separator}} \qquad \text{(eq. 1)}$$

The acquisition duration t of each experiment is used to normalize the data that are expressed as droplets/second through the measurement volume; for droplets with the same diameter the measurement volume has the same size, although not known, and therefore two droplet classes spanning over the same range can be compared directly.

Total separation efficiency: processing.

As just stated, with two or three layers of separators nearly no droplets could be detected, and the efficiency of the separators was nearly 100%. For this reason in the following paragraph only the data from the one layer separator will be discussed.

The total separator efficiency comparison from PDA data can be performed both on the number of droplets and on their volume; other instruments can often perform only one among the two averages.

Negative velocity droplets data can be handled in different ways. It should be considered that after expulsion the droplets are falling back toward the evaporative tower, but in case of strong lateral wind they would fall outside of it. With the data of figure 4, the mass of the downward directed droplets is 15% of the total detected mass; for the case with one layer of separators, this mass is 20% of the total, so not negligible in both cases.

One option is to compute the downward falling droplets mathematically with their negative velocity, so with a negative contribution to the outgoing water mass flow. Practically it means to consider that they are falling back, compensating for a similar outgoing droplet. It is correct for the mass balance of drifted water, but it is wrong for the impact separators since its efficiency is artificially increased by the contribution of the gravity separation.

The option to simply neglect their presence is more correct as regard the separator efficiency computation, and is normally applied in the present work. It represent what would happen with lateral wind blowing on the tower and dragging away those droplets before thay can fall backwards.

The option of processing them with positive contribution mindless of their negative velocity would increase the outgoing mass flow, with an error similar to that committed when using an instrument, like radar or imaging or diffraction sizing instruments, that are not able to measure the particle velocity.

To correct the bias effect of the PDA system the One-Directional Cross-Sectio Method was used; for more details and a review of different methods see e.g. [6, 10]: the mesurement volume size can be accounted for by applying a correction weight to each droplet or droplet class; the correction weight is obtained from data post processing,

The formula used to calculate the total separator efficiency, with and without PDA bias correction options, is the following:

$$\eta_{separation\_global\_NV} = 1 - \frac{\sum D^{NV}_{droplets\_with\_separator} / t_{acquisition\_with\_separator} * W_D}{\sum D^{NV}_{droplets\_without\_separator} / t_{acquisition\_without\_separator} * W_D} \qquad \text{(eq. 2)}$$

Where for Number separation efficiency NV=0, for Volume separation efficiency NV=3.

The factor W_D is the weight function of the droplet or class diameter, note that for W_D =1 the formula turns that where the bias correction not applied. The value of W_D should represent the inverse of the PDA measurement volume dimension section, that is the surface section through which are passing the droplets detected by the PDA optics. It has the shape obtained when an ellipsoid (the two laser beams intersection) of variable diameter (the region of visibility of the droplets), is cut as a slice of constant width (the projection of the PDA optics slit), and projected along the droplet trajectory. For a flows with a dominant direction, if all constant terms are simplified, the only variable parameter is the detected laser beam diameter. Its value is a function of the detected droplet diameter *D*, and can be experimentally found as the *Burst Length*, that is the product of each droplet velocity component absolute value |*V*| times its *TransitTime TT* as recorded by the PDA processor. A mathematic fit of all the detected |*V*|**TT* gives a good estimate of the W_D factor [9]; the envelop of the function | *V* |* *TT* (*D*) would be more correct in theory, but more affected by possible errors due to overestimation of few single values of the *TransitTime*. By using the data obtained without separators, since they are more numerous thus improving statistics, a good fitting function for the *Measurement Volume Dimension* for the tested situation was $MVD = 210 + 7 \bullet D^{0.5} = 7 \bullet (30+D^{0.5})$, where *MVD* and *D* are expressed in microns. The simplified formula $W_D = 1/(30+D^{0.5})$ could be used in equation 2, or the weight could be a normalized weight by choosing a reference droplet. In the present case 100 micron was chosen as the diameter of the droplet with unitary weight, leading to the expression $W_D = (30+100^{0.5})/(30+D^{0.5}) = (40)/(30+D^{0.5})$; following this choice the diameter weight W_D ranged from a minimum of 0.67 for droplet of 900 microns to the maximum of 1.33 for the smallest ones, showing the range of the bias effect.

Total separation efficiency: results.

This paragraph reports the final and most meaningful results of the study.

All data were processes in 4 different ways:

1) Bias correction was not applied (W_D=1), and negative velocity droplet were discarded. This is considered a basic processing, easy to perform, and correct as regard mass flow.
2) Bias correction was applied (W_D=1), and negative velocity droplet were discarded. This is useful to appreciate the effect of the PDA bias.
3) Bias correction was applied (W_D=1), and negative velocity droplet were added to the outgoing mass flow like if they were being ejected. This is the error committed by instruments that are not able to detect the droplet direction
4) Bias correction was applied (W_D=1), and negative velocity droplet were subtracted from the outgoing mass flow to account for that they are falling back into the tower.

The separation efficiency of one layer of drift eliminators was calculated, both for the number of droplets and for their volume. At the same time also the volume distribution and the average diameters of the droplet population were calculated. The results are reported in table 3 and figure 8

Table 3 Processing results: average diameters and overall separation efficiency

Processing		No drift eliminators				With droplet separators A1					
Bias correction	negative velocity	D_{10}	D_{20}	D_{30}	D_{32}	D_{10}	D_{20}	D_{30}	D_{32}	**Volume separation**	**Number separation**
no	discarded	170.7	235.4	285.4	419.5	25.8	48.4	75.3	182.5	99.77%	87.49%
yes	discarded	147.7	212.5	263.2	403.9	23.2	43.4	68.7	171.9	99.74%	85.17%
yes	added	152.8	221.7	276.5	430.3	24.0	46.1	73.3	185.1	99.72%	84.90%
Yes	subtracted	142.5	202.6	247.9	371.5	22.4	40.3	63.0	153.6	99.76%	85.43%

Discussion

PDA Bias effect

The effect of the bias correction, when comparing the first two series on figure 8, shows that the volume distribution function is only slightly affected by this problem, the relative importance of smaller droplet is increased, the opposite for the larger ones. The first two result row of table 3 shows that after bias correction the average diameters are decreased by 10÷15%, and volume and Sauter diameters by 4÷8%. The number separation efficiency after bias correction is slightly worst, 85.2% instead of 87.5%, because the separation of small droplet is less efficient, and the bias correction is increasing the importance of their already large number, but since those droplets have very small mass, the volume separation efficiency is minimally affected by their increase.

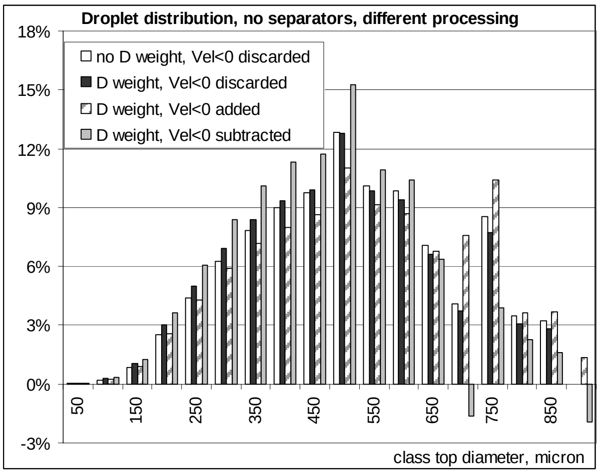

Figure 8 Droplet volume distribution, without separators, processed with four different procedures.

Negative velocity droplet effect

The hypotheses and the consequent algorithms used to process the droplet falling down toward the tower exit in this experimental campaign were affecting the results strongly and in an unexpected manner.

In the figure 8, whose data are the same of figure 4, it is evident that some classes with large diameter contains only few droplets, that are carrying a large volume of water. The class from 850 to 900 microns behaves in a strange way because it contains only one droplet, that accounts for the 2% of the total detected water volume, The decision to discard that droplet, or to add or subtract it to the total water flow influences the total results. Its negative percentage in the last processing is due to the fact that its mass is being subtracted from the total. Other classes show similar strong variations depending on this processing. The fact that the total should always be 100% implies that if some classes are negative, all the positive classes have slightly higher values. Under the hypothesis of no coalescence, negative classes should not exist if all droplets could be detected, or if the statistical basis could be so large to have always, in any class, a sufficient number of droplets.

Conclusions

A PDA system was set-up an successfully used with a real size evaporative tower to measure experimentally the efficiency of drift eliminator systems. The measures evidenced the presence of droplet with downward velocity, it means droplets that after expulsion are falling back toward the tower air exhaust. The data processing effect were analysed to evidence its effect on the results. The PDA bias effect, that is a known issue of this instrument, can be easily corrected with post-processing; this correction is decreasing by some 10% the average diameters of the droplet population. The way downward falling droplet are treated and processed is also affecting the results. The behaviour observed and presented in this work were not found in the literature and are an original contribution to the understanding of measurement techniques and their limits. The results could be very helpful when dealing with instruments that are not able to detect droplet velocity and are therefore affected by the error evidenced in this work and quantified for this particular experimental installation.

Acknowledgements

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