

Increasing Cooling Tower Water Efficiency

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Abstract

In 2008, California Institute of Technology used 764,064,005 liters of water. Cooling towers at the central and satellite plants consumed 319,951,956 liters of water through evaporation and blowdown, contributing to over forty per cent of overall water usage on campus. In this Water Efficiency Project, the amount of water loss due to evaporation and blowdown each month has been studied and has demonstrated that on average, 83 per cent of water loss is due to evaporation and the rest due to blowdown. This project aims to improve overall water efficiency of cooling towers by examining two applicable systems that can recover vapor and reduce blowdown. An ozone treatment reduces the use of chemicals and thus decreases the blowdown rate. A vapor recovery system consisting of a circular fiber filter on top of cooling towers absorbs and condenses water vapor coming out of the cooling towers. A feasibility experiment showed that approximately 10 per cent of evaporated water could be recovered using this method. Further research should be carried out to study corrosion problems from the ozone treatment, and the type of the fiber filter that should be installed to optimize water vapor absorption without obstructing airflow.

Introduction

Water is one of the most vital resources on the Earth, but is becoming increasingly scarce. Numerous attempts to conserve water and reduce water pollution have been made by all kinds of organizations, from the federal government of the United States to research universities such as California Institute of Technology. Caltech currently employs various water-efficient technologies in an attempt to reduce its water consumption level through its Water Efficiency Project. In 2008, Caltech used 764,064,004 liters of water. Over half of the water was consumed through Caltech's own central and satellite utility plants. Each plant operates induced draft cooling towers with four cells. The cooling towers are used to lower the temperature of the water from condensers. A large fan pulls up cool and dry ambient air from below, and warm water sprayed near the top (Fig. 2) cools from evaporation and heat transfer to the cooler air. Warm, saturated air comes out of the cooling tower into the atmosphere (Fig. 1).



Figure 1 | Satellite Plant Cooling Towers

Eighty per cent of water used by Caltech's central and satellite plants is lost from the cooling towers. One factor of the water loss from cooling towers is evaporation. Concentration of chemicals (ions, acids, and so on) that are either originally present in water or added to increase cooling efficiency and reduce microbes increases after each cycle due to evaporation. As the concentration increases, ions might cluster together and form solids, the number of bacteria may increase significantly, thus

decreasing overall cooling efficiency. Therefore, the concentration of solids should be maintained below a certain limit. Blowdown is used to adjust the concentration by bleeding and refilling cooling water. This process results significant water loss in cooling towers and also results water pollution.

Increasing water efficiency of Caltech's cooling towers can lower overall water consumption significantly. Facilities employees currently attempt to decrease blowdown rate by controlling pH setup point – cooling water pH at which blowdown valve opens. The pH level of cooling water increases as water evaporates and the chemical concentration increases. Setting higher pH tolerance level – up to a point at which cooling efficiency of cooling towers does not decrease significantly – increases the number of cycles of cooling water per blowdown.

Ozone treatment of cooling water is another possible solution to reduce blowdown. Ozone, a relatively unstable molecule composed of three oxygen atoms, acts as a strong biocide by oxidizing living organisms. Traditional chemical treatment to control microbes and prevent scaling requires frequent bleedoff of cooling water because of increase in concentration of chemicals due to evaporation. This further requires frequent refill of treatment chemicals. An alternative to the traditional chemical treatment is ozone treatment. As an effective microbial controller, ozone can replace chemicals to control microbes.

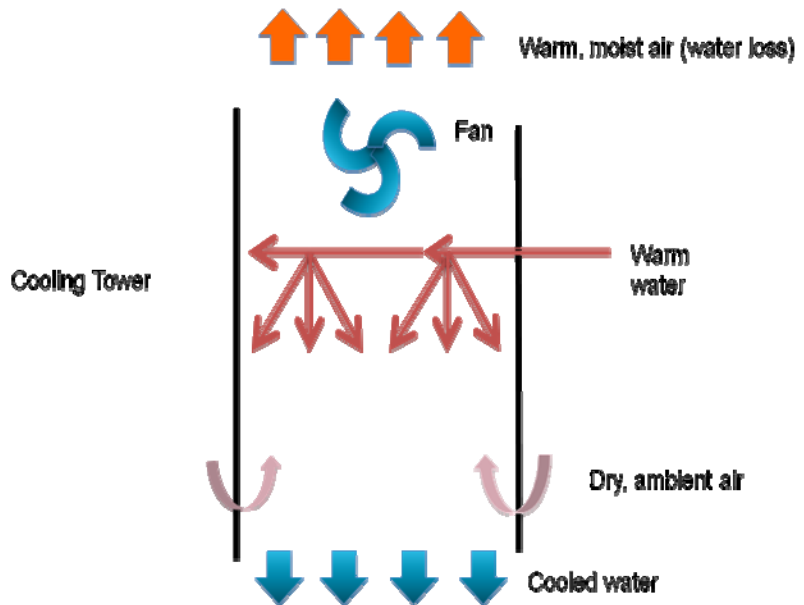


Figure 2a | Cooling Tower Mechanism



Figure 2b | Warm water spray inside the central plant cooling tower

Ozone treatment, an alternative to traditional chemical treatments, can improve water efficiency substantially according to R.J. Strittmatter, et al¹. Ozone treatment for cooling water has several advantages over traditional controls: less or no use of chemicals (toxic and non-toxic), water conservation due to less blowdown (as less or no chemicals are used, the concentration level is much lower). However, there are several concerns about ozone treatment, including the impact on corrosion, effectiveness, and lack of general guidelines. The experiments by Strittmatter, et al show that ozone has a negligible impact on corrosion at typical use levels, does not increase mineral scales, controls fouling, and is excellent for microbial controls. Caltech had previously examined applicability of ozone treatment in its cooling towers, but did not introduce the treatment due to corrosion problems.

Besides reducing blow, the amount of water used on campus can be reduced by reducing the amount of evaporative losses. Attempts to recover evaporation loss can be found in two Korean patents. Kyung Seok Kang uses hollow fiber membrane filter modules to recapture cooling water vapor² and Hoogeun Lee uses honeycomb, pleated or web-like fiber filters to absorb water vapor coming out of cooling towers³. However, the amount of vapor that can be recovered from such systems is not indicated

The ultimate goal of the Water Efficiency Project is to find applicable mechanisms which improve overall water efficiency of cooling towers. For this summer, a cooling tower prototype – a humidifier – and two different types of filters were installed and tested how much vapor dismissed from the humidifier can be absorbed by each filter.

Results

1. Water Usage Data Analysis

Data analysis on cooling tower water usage and its relation with cooling degree days was performed. Central cooling tower and satellite cooling tower's monthly make-up and blowdown levels are recorded in Utility Plant's monthly reports. The reports show that the cooling water make-up and blowdown levels are low during winter and increase during the summer (Fig. 3).

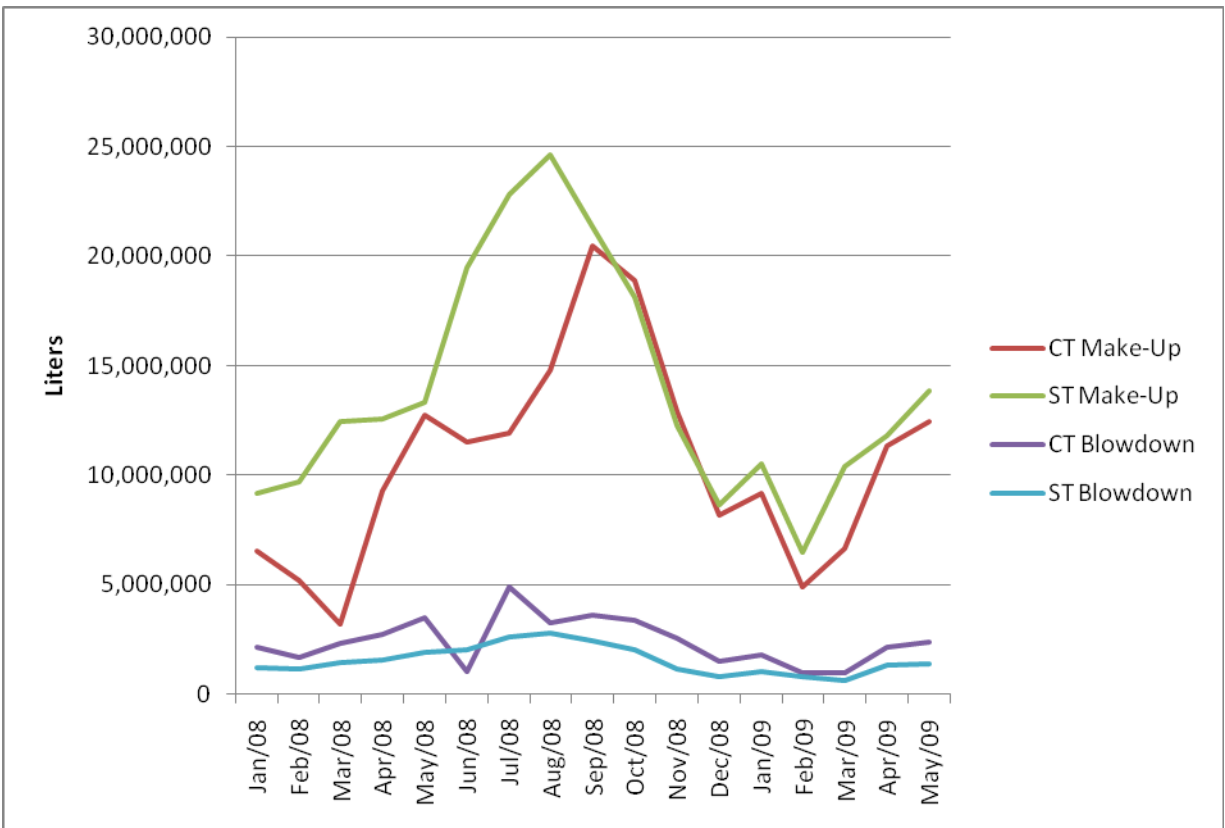


Figure 3 | Central and satellite plants' cooling tower water make-up and blowdown each month from January 2008 to May 2009. Note that the Satellite plant consumed noticeably more water before September 2008. Central plant's cooling towers did not operate as much as Satellite plant's as old chillers were being replaced by new ones. CT: Central Plant Cooling Tower. ST: Satellite Plant Cooling Tower

A quantitative measure of how much cooling is needed each month is obtained in a form of monthly Cooling degree days (CDD) data from the weather station ID KCAPASAD5 (North Wilson Avenue, Pasadena, CA). Total cooling water make-up (central and satellite) correlates with cooling degree days each month (Fig. 4).

	Total MU (L)	Total BD (L)	Tot Evap Loss (L)	Evap Loss (%)
1-08	15,681,702	3,326,936	12,354,766	78.78
2-08	14,855,822	2,798,660	12,057,162	81.16
3-08	15,661,875	3,733,099	11,928,776	76.16
4-08	21,863,949	4,283,935	17,580,014	80.41
5-08	26,068,764	5,368,045	20,700,720	79.41
6-08	30,981,472	3,100,954	27,880,518	89.99
7-08	34,708,885	7,476,796	27,232,089	78.46
8-08	39,378,625	6,009,274	33,369,351	84.74
9-08	41,802,806	6,060,792	35,742,014	85.50
10-08	37,020,676	5,407,563	31,613,113	85.39
11-08	25,162,689	3,682,414	21,480,275	85.37
12-08	16,764,691	2,264,479	14,500,212	86.49
1-09	19,689,875	2,837,459	16,852,415	85.59
2-09	11,335,177	1,759,709	9,575,468	84.48
3-09	17,027,879	1,602,960	15,424,919	90.59
4-09	23,111,629	3,468,847	19,642,782	84.99
5-09	26,247,090	3,743,130	22,503,960	85.74

Table 1 | Total water make-up (MU), blowdown (BD) and evaporation loss by central and satellite cooling towers from January 2008 to May 2009. The percentage of evaporation loss is quite significant – between 76 and 91 per cent – each month.

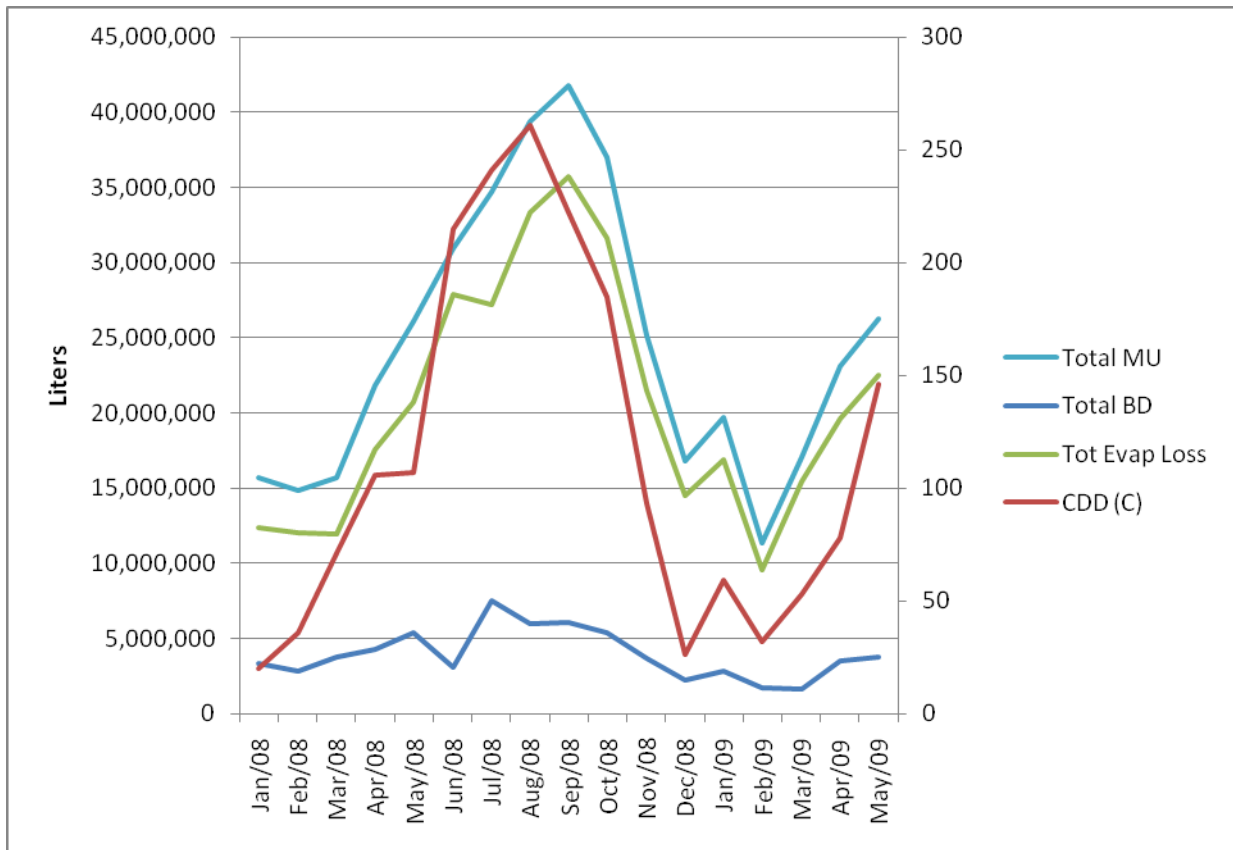


Figure 4 | Total water make-up (MU), blowdown (BD) and evaporation loss by central and satellite Cooling Towers and Cooling Degree Days (CDD). Water consumption by the cooling towers generally follows the trend of CDD as expected. However, it is noticeable that the water consumption during the summer break (June, July and August) does not increase as sharply as the CDD do.

Figures 3 and 4 show that cooling water is lost more through evaporation than through blowdown. Numerical data of total make-up, blowdown and evaporative loss show that only 9 to 24 per cent of make-up water is lost through blowdown (Table 1).

2. Vapor Recovery Experiment

In order to estimate how much vapor can be absorbed by different filters and parameters, a simple experiment was designed using an ultrasonic humidifier (Fig. 5) as a cooling tower prototype.

Supply rate of vapor from the humidifier was calculated by dividing the difference of water remaining in the tank of the humidifier by amount of time passed.

Time Passed	Water Initial (ml)	Water After (ml)	Difference (ml)	Rate (ml/min)
137 min	1000	738	262	1.912
308 min 20 sec	2000	1302	698	2.264
739 min 1 sec	2000	355	1645	2.226

Table 2 | Amount of water emitted by the ultrasonic humidifier over different periods of time

Table 2 shows that 1.9 to 2.2 g of vapor was emitted by the humidifier per minute. This variation, with changing temperature and humidity levels in the laboratory, the source of error is estimated to be around 15 per cent.

Two different types of filters– fiber filter (Fig. 6) and pleated air filter (Figs. 7,8,9) – are installed on top of a humidifier and the amount of time passed and according amount water (in grams) absorbed by each filter is measured. For fiber filter pad, variations in thickness and area were imposed. For pleated air filter, different orientations were used.

Temperature of vapor coming out of the humidifier – 23.5°C on average – was measured in order to compare with the temperature of vapor from cooling towers – estimated to be between 24°C and 30°C from cooling water temperature going into and coming out of Caltech’s cooling towers.

Attempts to measure air flow on top of the humidifier and after going through each filter was not successful as the flow was not constant without a



Figure 5 | VICKS Ultrasonic Humidifier



Figure 6 | Clockwise from left upper corner: fiber filter 1, 2, 3, and 4. Filters 1, 2, 3 are of same size. Filters 1 and 2 are about 1 cm thick. Filters 3 and 4 are of same thickness, about 2 cm thick

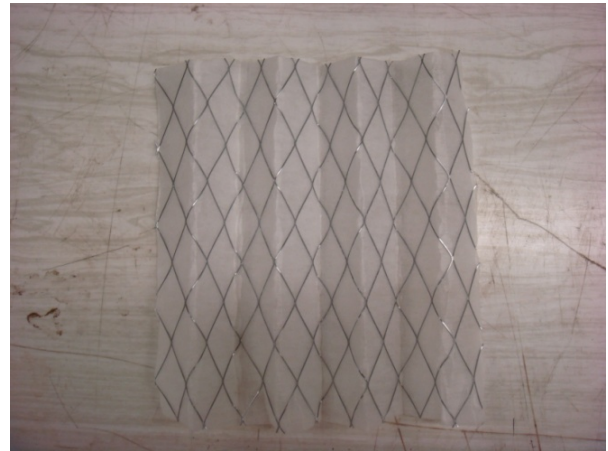


Figure 7 | Pleated air filter in horizontal orientation

filter on top, and filters in horizontal orientation obstruct most of the air flow.

Figure 10 shows a relationship between the amount of time and the amount of vapor absorbed by fiber filter 1. Vapor absorption is linear with time before saturation and concaves down afterwards.



Figure 8 | Single walled pleated air filter in vertical orientation



Figure 9 | Multiple walled pleated air filter in vertical orientation

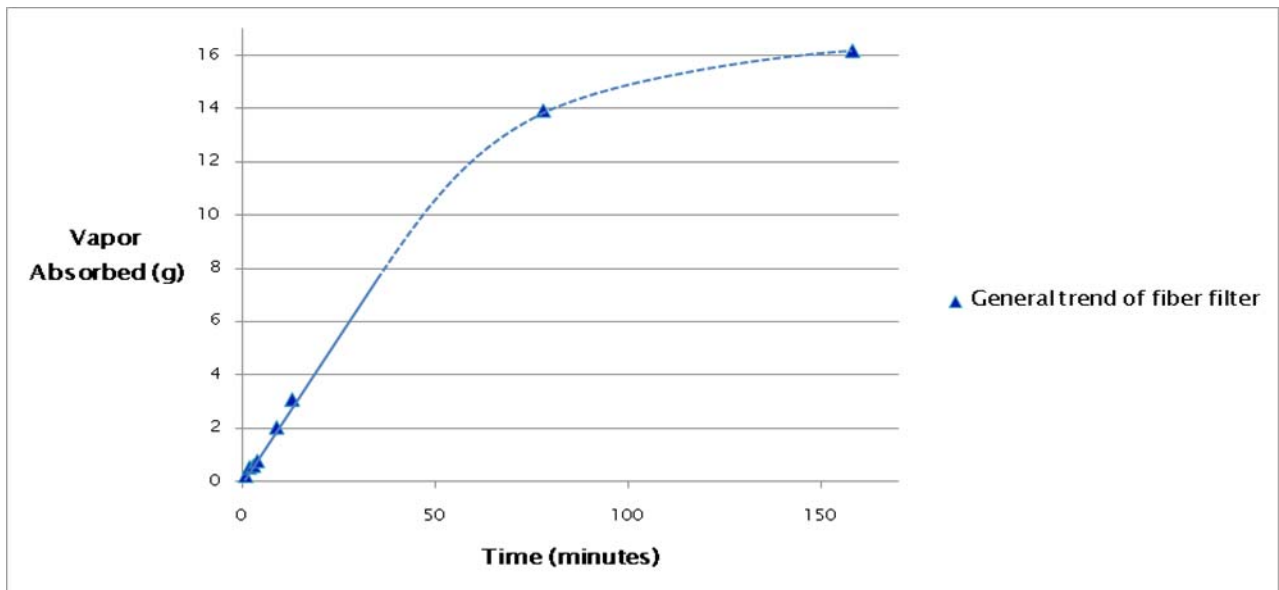


Figure 10 | Vapor absorption versus time of fiber filter 1. The relationship is linear (solid line) before saturation and concave down (dotted line) as the filter gets saturated.

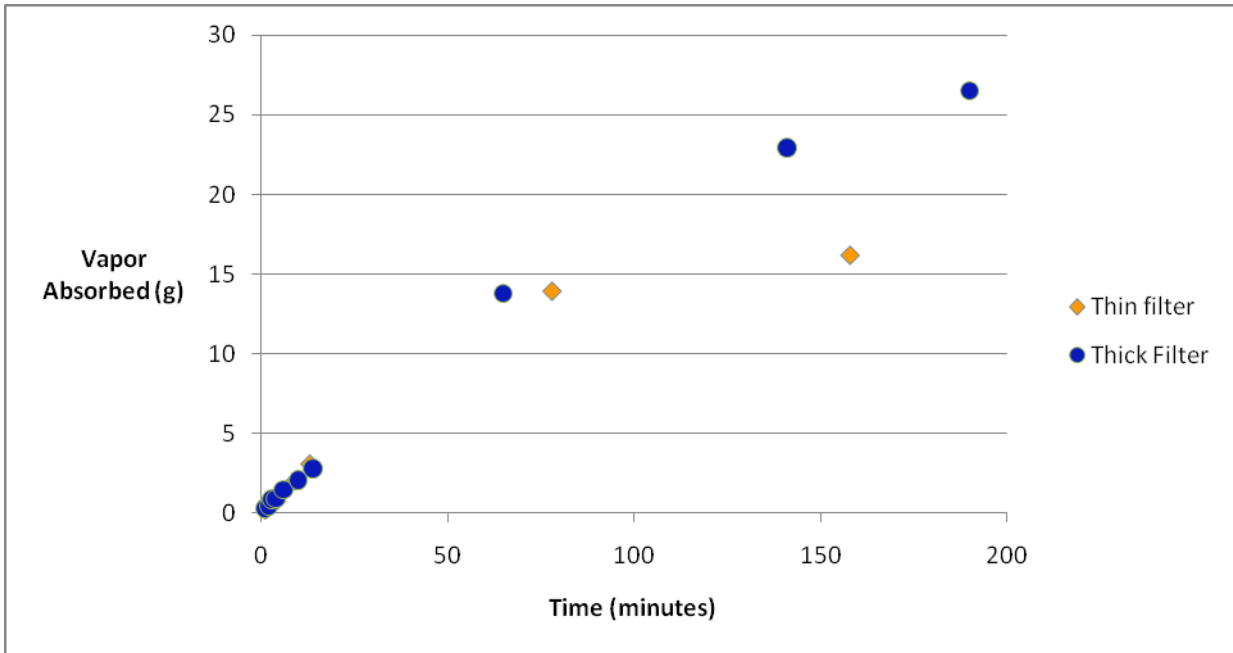


Figure 11 | Vapor absorption versus time of thin and thick fiber filters

Figure 11 shows that the vapor absorption by thin and thick filters is almost identical before saturation. The slope of both curves is approximately 0.2 g/min in the linear region. However, vapor absorption of thick filter concaves down more slowly than that of thin filter, indicating higher saturation level. The thin filter seems to begin deviating from the linear relation around 10 grams of water while the thick filter seems to deviate around 20 grams of water. Hence, the filters may become saturation when they have absorbed 10 g of water per 1 cm of filter.

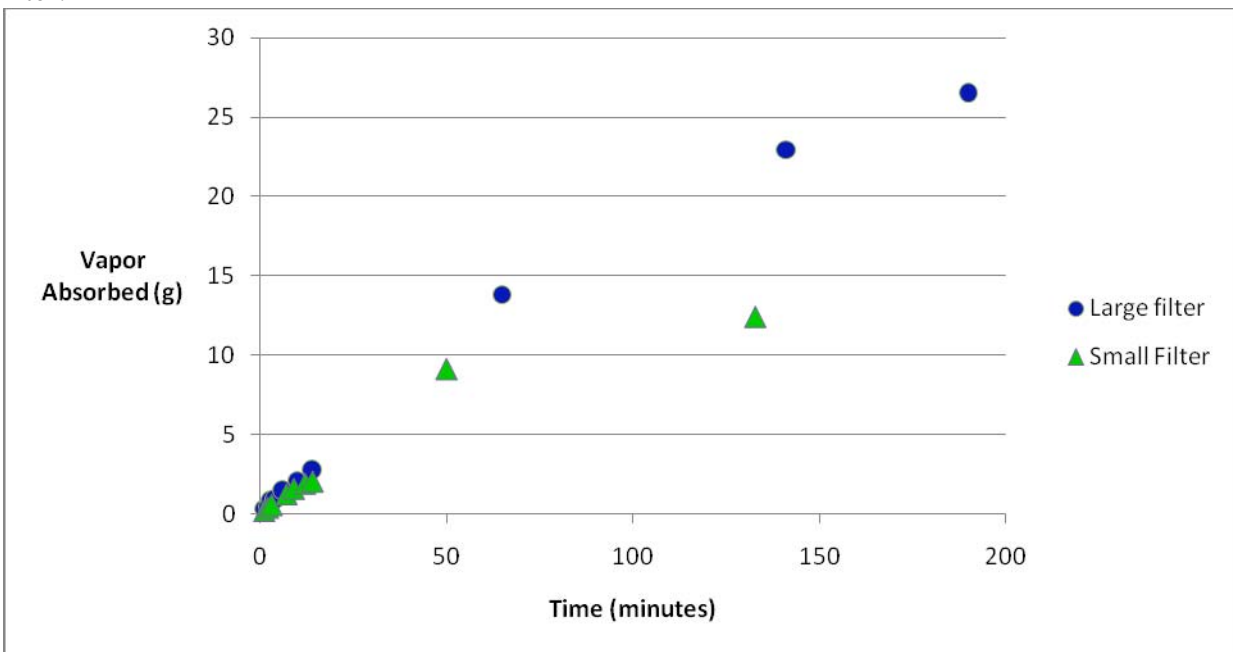


Figure 12 | Vapor absorption versus time of large and small filters

There is no significant difference in vapor absorption between small and large filters before saturation. Figure 12 shows that vapor absorption of large filters concaves down more slowly than that of small filters, indicating higher saturation level.

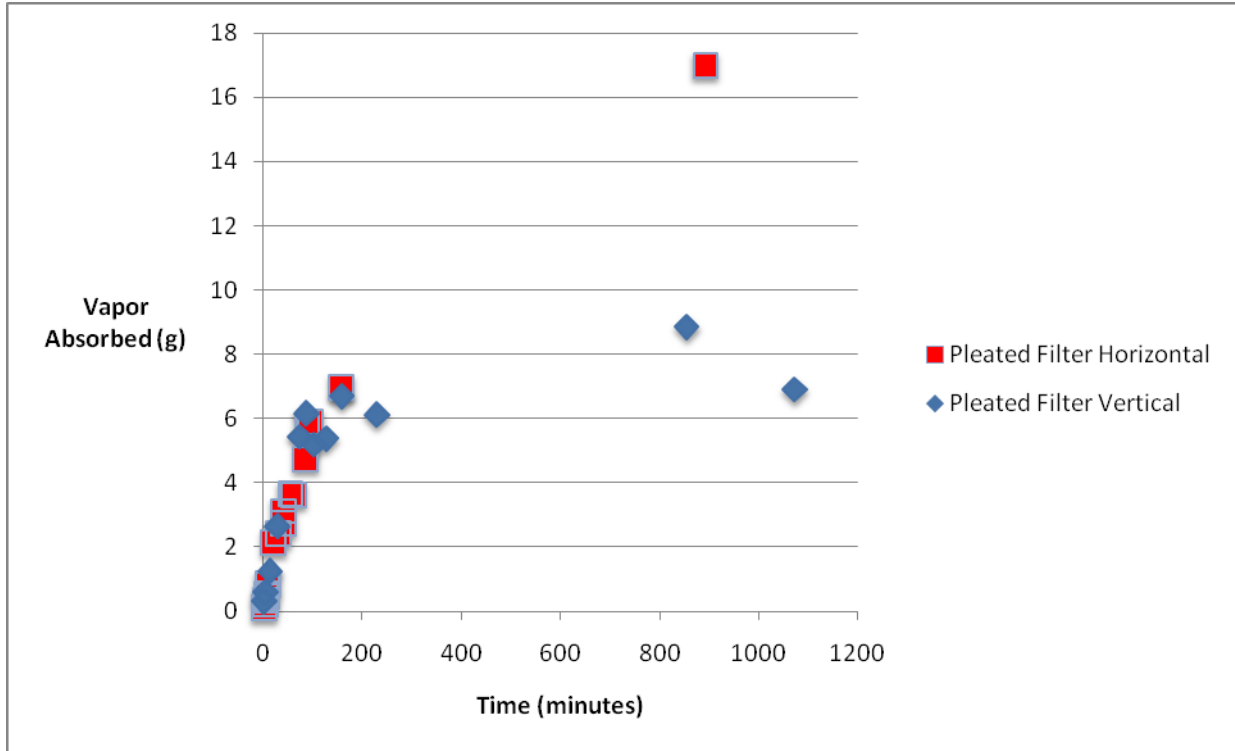


Figure 13 | Vapor absorption versus time of horizontal and vertical pleated air filters

There is no significant difference in vapor absorption between vertical and horizontal filters before saturation. Although there is not enough data points – no points between 4 hours and 14 hours – to draw a conclusion, vapor absorption of horizontal filter concaves down more slowly than that of thin filter, indicating higher saturation level. Since both horizontal and vertical filters have same filter size, differing saturation levels seem to be due to filters' orientations.

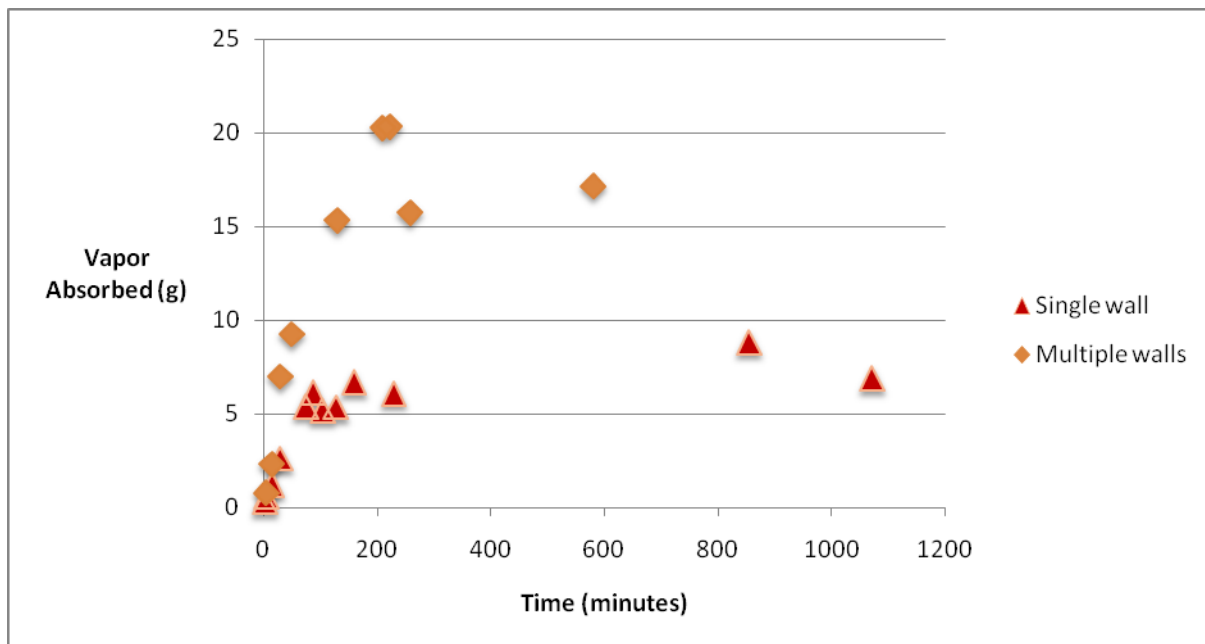


Figure 14 | Vapor absorption versus time of single and multiple concentric vertical pleated air filters

The data presented in figure 14 demonstrate that the results are similar for the single walled and multiple walled filters before saturation. Vapor absorption of multiple walled filter concaves down more slowly than that of single walled filter, indicating higher saturation level.

Figures 10, 11, 12, 13, and 14 show that vapor absorption is linear with time until saturation, thickness and area do not scale proportionally with vapor absorption, vertical orientation results lower saturation than horizontal orientation, and multiple walled filter absorbs much faster than single walled one.

From the data points, around 10 per cent of vapor emitted from the humidifier was captured by the fiber filters and between 3 and 6 per cent by pleated air filter before getting saturated. Applying to Caltech's cooling towers, such filters can save around 16 million liters per year.

Discussion

Caltech cannot use seawater for cooling purposes due to its location – over thirty miles from the ocean – and fresh water is becoming scarcer every year. Cooling towers recycle their cooling water while keeping high cooling efficiency, yet takes up forty two per cent of Caltech's total water consumption. Recovering a small amount of vapor dismissed from Caltech's cooling towers by use of fiber filters can improve overall water efficiency significantly. Further research should be carried on to find optimal thickness, area, and orientation of filter – extensive parameter study. Efficient ways to extract condensed vapor from saturated filters and practical application to cooling towers should be studied thereafter.

Methods

Acquisition of Cooling Water Data. Daily readings of central utility plant (cooling) tower and satellite plant (cooling) tower blowdown, water softeners, central plant's condensate tank make up, chilled water, chilled water expansion tank, and demineralizers are recorded at between 23:00

and 24:00 in Central Utility Plant Operation Log. The amount of water make up for SP cooling tower is same as the amount of water softeners produced from SP, and the amount of water make up for CUP cooling tower is the amount of condensate tank make up, chilled water, water going into chilled water expansion tank and amount of demineralizers subtracted from water softeners produced from CP.

Acquisition of Cooling Water Data. Central Utility Plant WaterLab provided Monthly Chemical Usage Report. Each report shows the amount of chemicals (inhibitor, dispersant/surfactant, biocides, antifoam and bromine) used for CUP, SUP, and IMSS cooling towers.

Acquisition of Cooling Fan Speed and Temperature Data. The speeds of four cooling fans of CUP, supply temperature (supplying to condensers from cooling towers) of CUP, and supply and return (returning from cooling towers to condensers) temperatures of SP are recorded every minute by computer. Averaging into hourly, daily, weekly, and monthly data was performed by Matlab 2009a. Daily, weekly, and monthly Cooling degree days (CDD) data of weather station ID KCAPASAD5 (North Wilson Avenue, Pasadena, CA) are obtained from www.degreedays.net.

Experiment tools. VICKS Ultrasonic Humidifier V5100NS (cooling tower prototype), Marineland Rite-Size Bonded Filter Pad (fiber filter), Flanders extended surface area Pleated Air Filter (pleated air filter), OHAUS PRECISION Standard Model TS120S (scale), Dwyer Model 471 Digital Thermo Anemometer.

References

1. Strittmatter, R. J., B. Yang, et al. (1992). "Application of Ozone in Cooling Water Systems." 17.
2. Homel Co., Ltd. Kang, K.S, inventor; Recovery System for Cooling Water at Cooling Tower, Capable of Reducing Water Consumption by Improving Recovery Ratio of Vapor and Mist. Korea Patent 10-0756384. Aug. 31, 2007.
3. Lee, Hoogeun. Cooling Water Recovery System Using Fiber Filter and its Operating Methods. Korea Patent 10-0473388. Feb. 16, 2005.