American Scientific Research Journal for Engineering, Technology, and Sciences (ASRJETS)
ISSN (Print) 2313-4410, ISSN (Online) 2313-4402
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http://asrjetsjournal.org/

Foaming in Seawater Backpressure Tower

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Abstract

According to the literature, a small to moderate amount of foaming usually takes place in cooling water systems. However, in this case study, foam was found to overflow the sidewall of the tower and reach the equipment of the plant located around the tower. In order to protect the sea life, the proposed solution is based on mechanical foam control. For a more efficient defoaming, we are proposing to increase the height of the sidewall of the tower by 2.1 m in order to avoid overflow and have enough time for the spray hollow cone nozzle to destroy the foam. A controlled amount of anti-foaming agents based on Silicone and Acrylate Copolymers could be added if any foam is remaining after the mechanical control.

Keywords: cooling water system; mechanical foam control; spray hollow cone nozzle.

1. Introduction

Foam is an essential and central step of many industrial processes. For example, liquid foams are an important stage of gas/liquid contacting processes such as distillation and flotation of minerals. Foams made with aqueous surfactant solutions are also extensively utilized for detergency purposes, while foams made with protein solutions are the base of many food products. Other applications of liquid foams include cosmetics, firefighting, oil recovery, and others. On the other hand, uncontrolled foam formation can affect productivity in a wide range of industries. It causes particular problems in the wastewater, pharmaceutical, and food & beverage sectors. Small amounts of foam do not necessarily need to be treated although the presence of foam may cause more serious costly and time-consuming problems. These technical issues include environmental pollution, potential product contamination, loss of product through excessive foaming, downtime and clean-up costs if foams spill over from the process. Excess foam can also severely limit product throughput in a process and can result in damage to equipment including pumps, filters and valves.

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The most noticeable form is foam floating on surfaces. It is easy to monitor and relatively easy to handle. However, surface foam may cause problems with liquid levels and result in overflow leading to pools of oils around the equipment, which is a safety concern [2].

2. Formation of foams

The existence of foams is enabled when two non–miscible fluids are in contact, and the contribution of this contact to the energy of the system is proportional to the area of the contact surface (surface energy). The proportionality factor is called the surface tension. If some energy is furnished to the system, the exceeding energy can be trapped in the form of surface energy and the contact surface between the phases increases [3]. Liquid foams are dispersions of gas bubbles in a liquid containing surface-active species. The latter absorbs at the gas–liquid interface and is responsible both for the ability of a liquid to foam and for the stability of the resulting foams. A measure of the surface activity is the decrease in surface tension upon adding the surface-active component to a pure liquid [4]. Foams are broadly divided into 'wet' and 'dry', depending on the proportion of liquid contained in them. In a wet foam (where the liquid volume fraction is typically between 10% and 20%) the bubbles are approximately spherical, while in a dry foam (where the volume fraction of liquid is less than 10%), the bubbles are more polyhedral in shape [5]. There are many ways in which foams can be produced, including [3]:

a. Nucleation of gas bubbles in a liquid which is supersaturated;

b. Shaking or beating a liquid;

c. Blowing gas through a thin nozzle into a liquid;

d. Blowing gas into a liquid through a porous plug.

The Laplace pressure is known as the pressure difference between the inside and the outside of a curved surface that forms the boundary between a gas region and a liquid region [6]. The pressure difference is caused by the surface tension of the interface between liquid and gas. The Laplace pressure is determined from the Young–Laplace equation given as [7]:

$$\Delta P = P_{in} - P_{out} = \gamma(\frac{1}{R_1} + \frac{1}{R_2}) \quad (1)$$

where R1 and R2 are the principal radii of curvature and γ as is the surface tension. Although signs for these values vary, sign convention usually dictates positive curvature when convex and negative when concave. According to the Laplace equation, since the radius of curvature of smaller bubbles is smaller than that of larger bubbles, the pressure of smaller bubbles is greater than that of larger bubbles; therefore, the gas will enter into larger bubbles from smaller bubbles. Thus, the small bubbles will become smaller and smaller and the large bubbles will become larger and larger. As a result, all the bubbles will finally disappear [8]. Due to the application of biodegradable detergents and the proper operation of wastewater treatment plants, it was thought that the occurrence of foam on surface waters was eradicated. However, the formation of foam in freshwater ecosystems such as rivers and lakes has been reported in the literature [9]. In this context, the presence of foam is linked to point source emissions [10] as well as natural occurring surfactants derived from algae and plants [11]. Moreover, surface-active foaming materials including particles, polymers, specific absorbed cations or anions from organic salts also cause foaming at extremely low concentrations [9]. A second precondition for foam formation is a source of gas bubbles that must be injected at a higher rate than the rate at which the liquid between the bubbles can drain away [12]. In aquatic ecosystems, mechanical impact is needed to introduce air bubbles into the water, which can be caused by cascades or hydraulic structures such as weirs, dams, spillways and discharge pipes, due to stormy conditions and the pounding of waves, in areas of strong currents or in areas, where fresh and salt-water mixes [9]. Sea foam, ocean foam, beach foam, or spume is a type of foam created by the agitation of seawater (Figure1), particularly when it contains higher concentrations of dissolved organic matter (including proteins, lignins, and lipids) derived from sources such as the offshore breakdown of algal blooms [13]. These materials can serve as surfactants or foaming agents. Moreover, as seawater is agitated by breaking waves, these surfactants under turbulent conditions trap air, forming bubbles that stick to each other through surface tension.

Figure 1: Seawater foaming [14]

3. Mechanical Foam Control

Foam is undesirable because it can cause overflow in vessels, create slippery and unsafe working conditions, interfere with processing, damage materials, and cause tanks to drain and dry slowly. The first step for controlling foaming is to find out whether a mechanical or chemical problem causes the foaming. Various methods to achieve mechanical foam control have been developed, including injectors, ejectors, and orifices, where an occasional sudden pressure drop causes the bubble to burst; surface scrapers in evaporators to break and separate foams from heating surfaces; and revolving disks, impellers, and stirrers, where the shear stress is increased by rapidly alternating pressure fields. When moving parts of these devices contact the foam, the centrifugal forces imparted to bubbles destroy them [15]. As shown in Figure 2, controlling foam can also be accomplished by spraying liquid onto the surface of the pool, vessel or reservoir, and allowing the droplets of the spray to impact the foam bubbles, causing them to break.

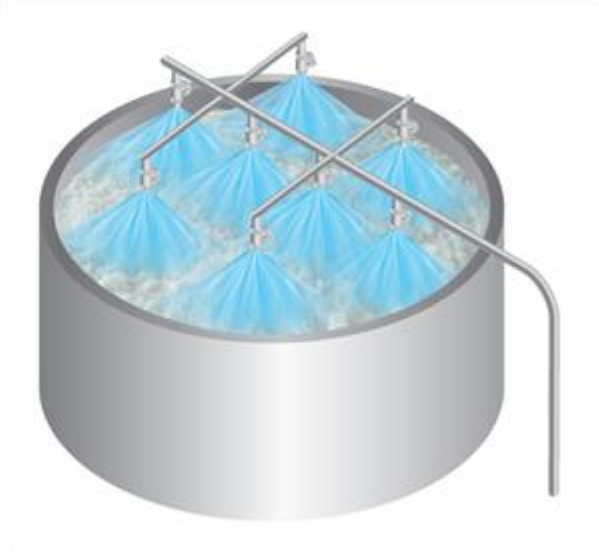

Figure 2: Foam Control by Spray nozzles [16]

Mechanical foam breakers are preferred to overcome the disadvantages associated with the chemical antifoam agents (eg, reduced mass transfer rate, reaction inhibition, and toxicity). However, mechanical foam breakers may involve high operating cost, complicated design, and possible shear damage to the product [17].

4. Physical Foam Control

The Physical foam control methods are another type of mechanical de-foaming technique. High-frequency Ultrasonic waves induce system pressure oscillation rapidly, whereby foam bubbles having high internal pressure compared to pressure in the surroundings apply shearing to the liquid films and collapse bubbles. Ultrasonic foam control is attributed to acoustic pressure, undirected radiation pressure, induced vibrations in the bubbles, high internal pressure in foam bubbles, cavitation and turbulence due to waves pressure oscillation [18]. The thermal physical foam action is referred to as several mechanisms including the evaporation of liquid films that generate foam, expansion of the restricted gas in bubbles due to increasing the gas temperature, decreasing the surface tension by decrease surface viscosity etc. The electrical methods are based on applying an electrical current to the system that leads to change the polarity and charge stability, which causes foam collapse [19].

5. Chemical Foam Control

Mechanical devices alone are generally not totally effective, and their action is enhanced by simultaneously using chemical antifoam agents at the lowest possible concentration [20]. Antifoam chemicals can prevent foam from forming and defoamers break down existing foam. The universal characteristic of any antifoam is the fact that it is surface active, but highly insoluble in water. It has to be formulated so that it will be dispersed as tiny droplets. The surface-active nature of the material causes it to spread very rapidly onto any air-water interface that it encounters. This is especially the case if that interface already is covered by the types of surface-active materials that tend to stabilize foams [1]. There is an extremely diverse set of chemical formulations that can be effective either to prevent foam or to destroy it once it has formed. For example, oil based defoamers have an oil carrier. The oil might be mineral oil, vegetable oil, white oil or any other oil that is insoluble in the foaming medium, except silicone oil. An oil based defoamer also contains a wax and/or hydrophobic silica to boost the performance. Typical waxes are ethylene bis stearamide (EBS), paraffin waxes, ester waxes and fatty alcohol waxes [21]. These products might also have surfactants to improve emulsification and spreading in the foaming medium. On the other hand, Silicone-based defoamers are polymers with silicon backbones. These might be delivered as an oil or a water-based emulsion. The silicone compound consists of a hydrophobic silica dispersed in a silicone oil. Emulsifiers are added to ensure that the silicone spreads fast and efficiently in the foaming medium. The silicone compound might also contain silicone glycols and other modified silicone fluids [22]. These are also heavy-duty defoamers and are good at both knocking down surface foam and releasing entrained air. Silicone based defoamers are also suitable in non-aqueous foaming systems like crude oil and oil refining. The most common antifoam additive used in detergent oils is based on silicone in the form of polydimethylpolysiloxane (Figure 3).

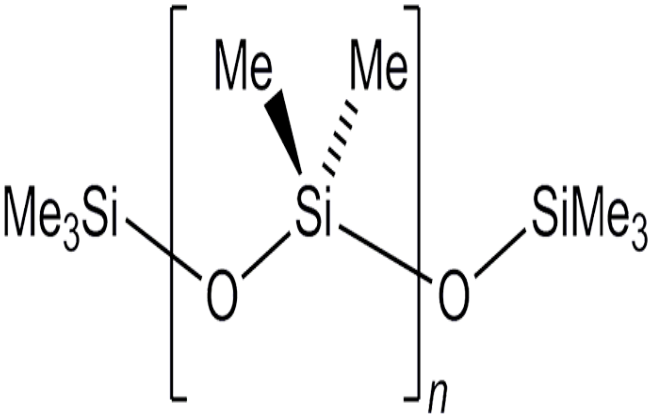

Figure 3: Chemical structure of Polydimethylpolysiloxane (PDMS) [23]

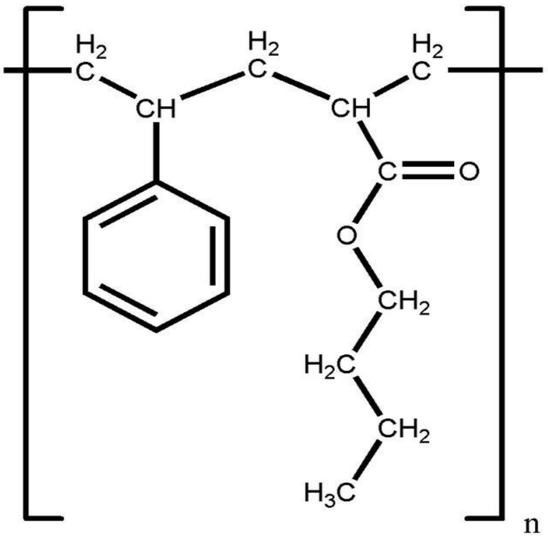

Figure 4: Chemical structure of styrene-butyl acrylate copolymer [24].

As shown in Figure 4, Alkyl polyacrylates are also suitable for use as defoamers in non-aqueous systems where air release is more important than the breakdown of surface foam. These defoamers are often delivered in a solvent carrier like petroleum distillates.

Most studies show no incompatibility between silicone and acrylates and their effects seem to be additive [25]. Figure 5 represents the mechanism by which antifoam additives work is well known. The defoaming process is based on reducing the film strength of the air bubbles at the oil/air interface. First, antifoam contacts a bubble at its film and spreads around the bubble. As it spreads, the shearing force thins the bubble wall until it ruptures.

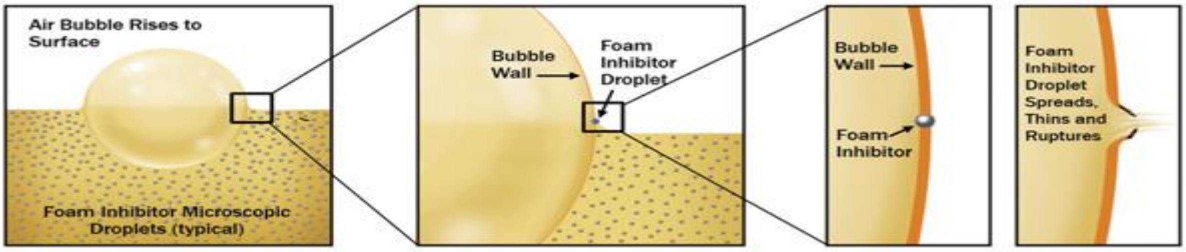

Figure 5: Mechanism of antifoam additives [26].

It then reduces the forces between the bubbles and therefore the area of the foam will be reduced. Finally, the foam bubbles are combined and reach a point where they are large enough to float safely to the water surface and leave the liquid surface and collapse.

6. Literature review

Foaming during the oil refinery process causes many issues and can be challenging to troubleshoot. Determining the root cause of the problem involves accurate testing to determine appropriate solutions. For example, in oil separator in a crude oil refinery, the causes of foam were found to be impurities, other than water, in crude oil that are impractical to remove before an inlet stream reaches the separator [27]. The presence of a foam layer in the separator resulted in false level readings, generally false highs, from traditional level control instrumentation. The false high-level readings result in the actual levels being too low, causing gas carry-under or poor oil and water quality. Separation efficiency decreased by 50%, and oil and water carry-over caused gas compressors, shutdowns. For the mechanical solution, the authors proposed a foam breaker packs were mounted after the inlet device and extend across the gas phase to promote the breakdown of foam. Demisters, such as vane packs, were also proposed to separate entrained liquids from a gas stream. For the chemical treatments, antifoaming agents were utilized to prevent or reduce the amount of foam produced, while defoamers were dosed into existing foam to promote breakdown. As shown in the previous section, there are different antifoam chemicals used in various liquids. However, when it comes to the refinery process, antifoams are usually based on hydrocarbons, organic chemistry, or silicone. Fatty alcohols, esters, and polyols form organic anti-foams. However, silicone antifoaming agents are efficient since they are available in the form of silicone fluids, hydrophobized or substituted fluids, or emulsions. Defoaming agents contain natural or mineral oils, silicone or silicone-free active substances, oil-free components, and polydimethylsiloxane (PDMS) [20]. As shown in Figure 6, defoaming using rotary devices is a technology with various manifestations. Deshpande and Barigou [28] have tabulated a useful summary of the many published empirical studies of defoaming using various rotary devices. Most of the reported studies are at laboratory scale, concerned with controlling the foam of dilute aqueous surfactant solutions in sparged vessels of <0.5 m diameter. The simplest rotary devices include various turbines, vaned discs, and paddles that are applied directly to a rising foam column.

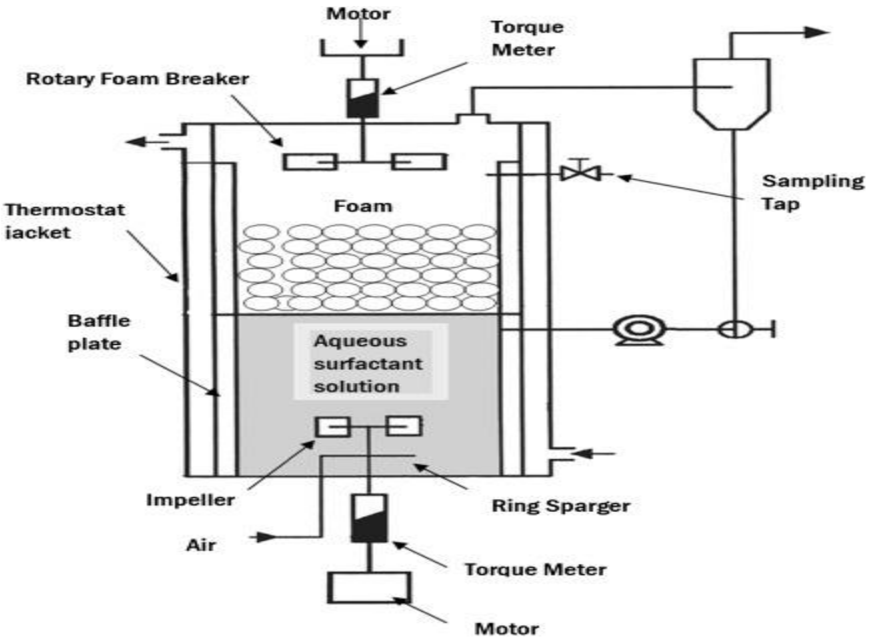

Figure 6: Lab scale rotary foam breaker [29].

However, A.G. Bick and his colleagues [30] claim that there is no indication that these nonchemical technique can prevent foam formation in the first place. According to the authors, chemical agents may be replaced in a process simply by incorporating a rotating nozzle with a controlled angular velocity. By minimizing the interaction of successive drops, foam formation is minimized—even for fluids with high foamability. Their lab-scale findings shows that larger scale models may enable the reduction or elimination of anti-foaming and defoaming additives in some industrial processes.

7. Case study of seawater backpressure tower foaming

7.1. Description of the technical problem

Similar to the technical problems described in the literature, in the chemical plant under investigation, foam appears in the cooling system of the process using seawater as the cooling purpose. The process contains two intake basins from the seawater and it has five pumps. The seawater return line has three backpressure towers of different heights to maintain the system filled in case of total pump failure. In this case study, foaming occurs in the first backpressure tower, which is located in the seawater return line. In Figure 7, the foaming problem location is indicated by a red star. The presence of impurities is usually the cause of foaming occurring and stabilizing. The resultant foaming problem causes pollution in the sea.

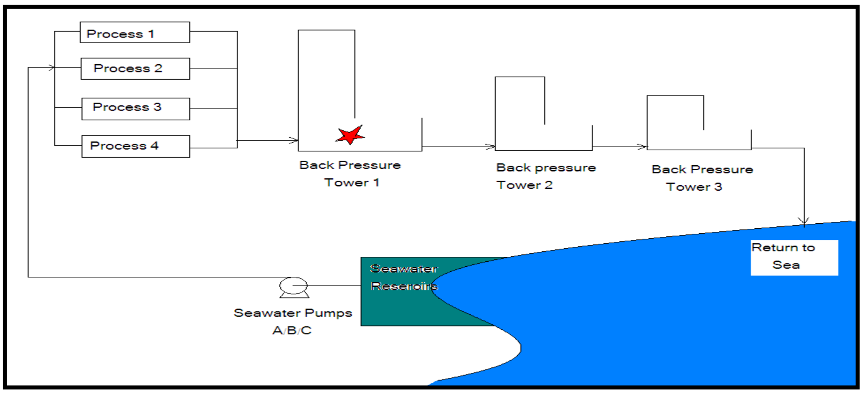

Figure 7

As shown in Figure 8, in the backpressure Tower #1, the foam overflows the wall of the station to reach the equipment in the chemical plant. In the actual situation, Hypochlorite and Chemical Hatacide are utilized as anti-foaming agents.

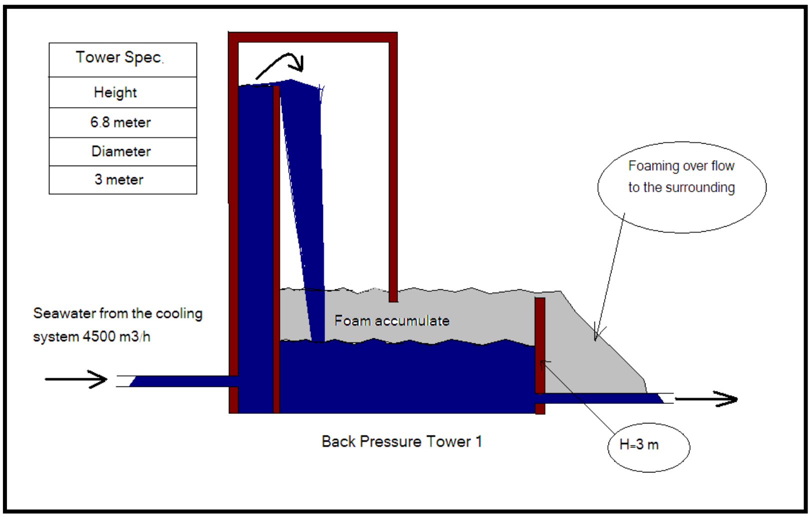

Figure 8: Foam overflow from backpressure #1

7.2. Proposed solutions

Oceans cover 71 percent of the planet and are home to important species and ecosystems that we rely on for food, livelihood, climate regulation and more. Therefore, in order to protect the sea life around the chemical plant under investigation, our proposals are mainly based on mechanical solutions. As shown in Figure 9, in order to minimize the environmental impact of foaming, we first propose to construct a permanent concrete barrier to skim the foam and then use spray nozzles to knock down the foam and prevent build up.

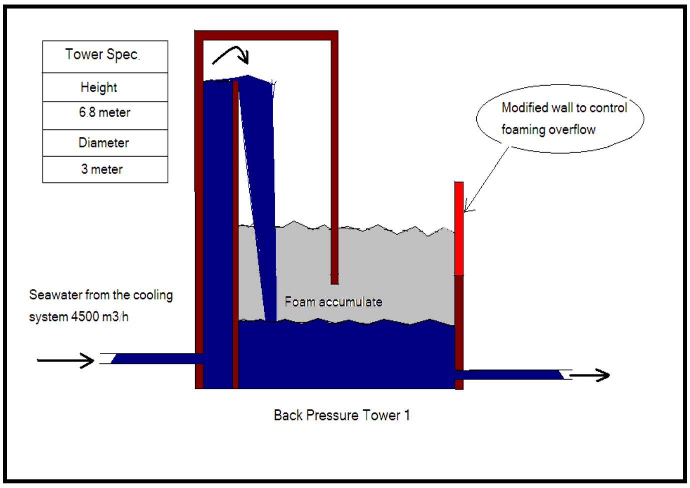

Figure 9: Back Pressure Tower with the modification.

The height of the new side wall is based on the following simple estimation. First, the diameter of the tower is 3 meters. Therefore, the cross sectional area of the tower is equal 7.069 m^2. For the actual wall of the tower, the height of the sidewall is equal to 3 meters. Therefore, the volume of the bottom section of the Tower is equal to 21.21 m3 and the corresponding residence time (RT) is equal to:

$$\text{RT} = \frac{V}{flow\ rate} = \frac{21.21}{4500} = 0.0047\ hr. \tag{2}$$

Now, assuming that an increase of 70% of the residence time of seawater in the tower will allow the foam to be broken up using spray nozzles, the new residence time will be equal to (0.0047 x 1.7) 0.008 hour. The needed volume of the tower will be equal to:

$$\text{V}= (\ t\ x\ flow\ rate\ = 0.008\ hr\ X\ 4500\ \frac{m^3}{hr} =)\ \ 36.05\ m^3 \tag{3}$$

The resulting new height (h) is equal to:

$$\text{h} = \frac{V}{A} = \frac{36.05}{7.069} = 5.1\ m \tag{4}$$

When selecting foam control nozzles there are a number of engineering factors to consider. First, as foam will be generated over an area, any suppressing spray would need to act upon the whole area in a relatively uniform manner. For this situation, the spiral nozzle would be a good choice for foam control as it can produce a full cone spray pattern with a spray angle of up to 170 degrees [16]. As shown in Figure 10, the spray pattern is formed by impacting the fluid onto a protruding helix after exit from the spray orifice. The liquid then shears off the helix, breaking into droplets and forming the spray pattern. Spiral cone nozzles are often used to produce a full cone pattern but this is actually made up of concentric overlapping hollow cone patterns, so with careful crafting of the spiral geometry the concentric patterns can be made to completely converge giving a single hollow cone.

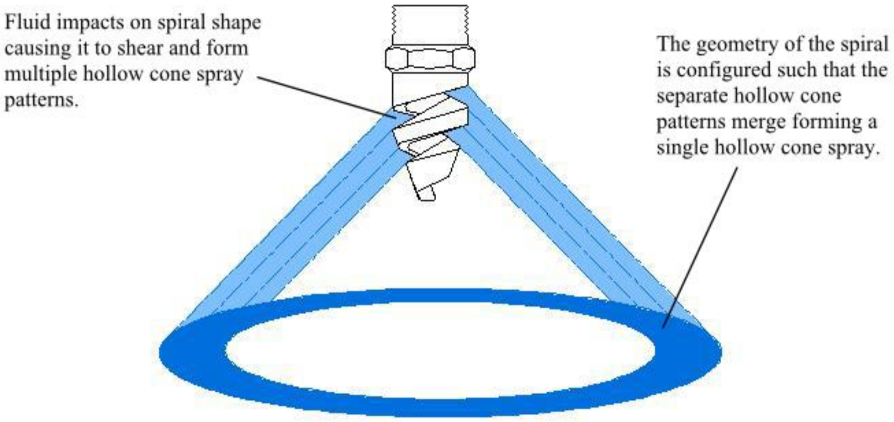

Figure 10: Schematic representation of a Spiral Hollow Cone Nozzle [16].

Secondly, most processes that create foam are from pools of viscous, sticky or lumpy fluids. This operating environment means that nozzle clogging is often a problem. To solve this problem, nozzles of the spiral design are naturally clog resistant [16]. Moreover, successful foam suppression requires a balancing act between having spray size sufficiently fine to give a large number of bubble bursting droplets whilst keeping the droplet size large enough to actually burst the bubbles. Furthermore, foam bubbles will often vary significantly in size and hence the droplets size required to burst the bubble will vary. As such a spray with a broad spectrum of droplet sizes may be more effective than one with a narrow droplet size spectrum. For this case, the spiral nozzles contain a broad spectrum of droplet sizes [16]. Finally, Sprays used to control foam build up need to be carefully dosed. Too much spray being delivered can have an adverse effect as it may actually agitate the fluid below causing more foam to be created. Of course, too little foam control spray will mean a failure to prevent foam build up. The Company “The Spray Nozzle People” proposes the following recommendations [16]:

a. Very light foams require 4-10 litres per minute per m^2
b. Light foams require 11-20 litres per minute per m^2
c. Medium foams require 21-50 litres per minute per m^2
d. Heavy foams require 50+ litres per minute per m^2

Finally, for the chemical treatment of the remaining foam, a monitored amount of anti-foaming agents based on Silicone and Acrylate Copolymers could be tested by the company.

8. Conclusion

Cooling towers are, by design and operation, susceptible to foaming. The water in the plant under investigation is treated with a variety of organic chemicals, some of which could have surface-active properties. Heat exchanger piping leaks could also contaminate the cooling water with process fluids, which may include surfactant-type chemicals and/or may promote bacterial and algal growth. Hence, a small to moderate amount of foam, depending on water chemistry, takes place in many cooling water systems. However, in this case study, foam overflows the sidewall of the tower and reaches the equipment of the plant located around the tower. According to the literature, the mechanical control methods are preferable to overcome the disadvantages associated with antifoam chemical agents. However, mechanical devices alone are generally not very effective, and their action is enhanced by simultaneously using chemical antifoam agents at the lowest possible concentration. Based on this finding, we are proposing to increase the height of the sidewall of the tower by 2.1 m in order to avoid overflow and have enough time for the spray hollow cone nozzle to destroy the foam. As proposed in the literature, a controlled amount of anti-foaming agents based on Silicone and Acrylate Copolymers could be added if any foam is remaining after the mechanical foam control.

Acknowledgement

The authors wish to thank Higher Colleges of Technology, UAE for supporting this technical investigation.

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