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18th Informatory Note on Refrigeration Technologies

Evaporative Cooling and *Legionella*
A Risk which can be Prevented by Using Good Practices

Legionella pneumophila, the causative agent of legionellosis, is found in aqueous environments. The sources of contamination are hot water distribution systems (showers, etc.), evaporative cooling systems such as wet cooling towers and evaporative condensers and all devices generating small, breathable, hot water droplets. The sectors concerned are industry, commercial (hotels, office buildings and shopping centres, etc.), health (hospitals) and residential. Unitary air conditioners, and more generally all types of equipment that use air-cooled condensers, cannot be a source of legionellosis.

Legionella and legionellosis

Legionella is a family of bacteria, commonly present, in low concentrations, in natural and man-made aquatic environments. Most are not virulent; however, *Legionella pneumophila* causes legionellosis, which has two distinct clinical forms: Legionnaire's disease – a form of pneumonia (lethal in 10-20% of cases) – and Pontiac fever – an easily treated flu-like illness.

Proliferation

Legionella bacteria develop in ground and surface water and mud. They grow in slime or biofilms, which are layered groups of microbial populations that protect bacteria from inactivation agents and provide nutrients. Under certain circumstances their concentration may increase significantly. The main physicochemical and environmental parameters inducing *Legionella* proliferation are water stagnation, temperatures of about 25-45°C and chemical characteristics such as a pH between 5.5 and 8.5, high turbidity and high presence of organic materials.[1] Certain materials represent aggravating factors: for example plastics, wood and certain metals support the growth of *Legionella*, as they support the development of biofilms.[2]

Transmission

Most data on transmission are derived from disease outbreaks and epidemics, which suggest that, in most cases, transmission to humans occurs when water containing the organism is fragmented into breathable droplets (1-5 µm) and inhaled by a susceptible person.[3] Factors influencing susceptibility are age and health: older people and people who smoke, people with chronic respiratory disorders or people using immunosuppressive agents are more susceptible. Contamination usually occurs within a radius of 1 to 1.5 km. Water is essential for the survival of the bacteria; if the air is dry, the water will evaporate and *Legionella* will die.[4] In the lungs, the transmitted *Legionella* are engulfed by cells of the immune system (macrophages), but manage to grow within these, finally overwhelming the host's immune system. The incubation period is 2 to 10 days and treatment with antibiotics is usually effective if the disease is diagnosed early. By symptoms alone, it is difficult to distinguish Legionnaire's disease from other types of pneumonia.

Legionellosis: cases and outbreaks

Outbreaks of legionellosis have received much media attention; however, very often the disease appears as single, isolated cases. The first major outbreak of legionellosis, which led to the discovery of the bacteria, occurred in 1976 in Philadelphia, USA, at a convention of the American Legion, where 200 people contracted an unknown form of pneumonia and 40 died. There have been many outbreaks since. Based on data provided by the European Working Group for *Legionella* Infection (EWGLI)[5], 734 cases of onset were declared by 31 European countries in 2005. For example, Germany declare no cases, whereas Spain declared 26 cases, Holland declared 133 cases, France declared 156 and the UK 170. There are very few statistics for Japan and South-East Asia, although in Singapore 65 cases were reported in 2000.[6] In the USA, the Centers for Disease Control and Prevention (CDC) estimate that 10 000 to 15 000 persons contract Legionnaire's disease each year; however, only 10% of the cases are declared.[7] Evidently, homogenization of the rules for recording and counting cases of legionellosis is an issue that needs to be addressed.

A chain of events and mistakes must occur for a legionellosis outbreak to take place: a source of *Legionella* must be present and it must be amplified, disseminated and transmitted to a susceptible host. The latter phases can be influenced by poor engineering design and maintenance practices.

This note will concentrate on the main equipment which uses evaporative cooling: cooling towers and evaporative condensers.

Cooling towers and evaporative condensers

Operating principles

The vapour-compression refrigeration cycle is commonly used in industry, air conditioning or refrigeration in order to cool air, water or process fluids. It generates heat from the condensers, which is rejected to the environment either to water or air. The lower the temperature of rejection, the lower the energy consumption is. Hence, the temperature of the water or the air utilized to cool the condenser should be as low as possible. Evaporative cooling is a process which makes it possible to cool the water used as a medium in the condenser to a lower temperature. There are 3 main categories of evaporative cooling devices:

- open-circuit cooling towers (*Figure 1*) are evaporative heat transfer devices in which atmospheric air cools warm water, with direct contact between the water and the air by evaporating some of the water;

- closed-circuit cooling towers (*Figure 2*) are similar to conventional open-circuit cooling towers. The difference is that the warm water to be cooled is contained inside a coil assembly. The warm water inside the coils is cooled by a separate water stream that is sprayed over the coils while air is blown or drawn by fans. Again, some of the sprayed water is vaporized, contributing to the cooling phenomenon.

  Hybrid towers combining both technologies (closed and open-circuit cooling towers) also exist.

  These three types of towers are usually called wet cooling towers.

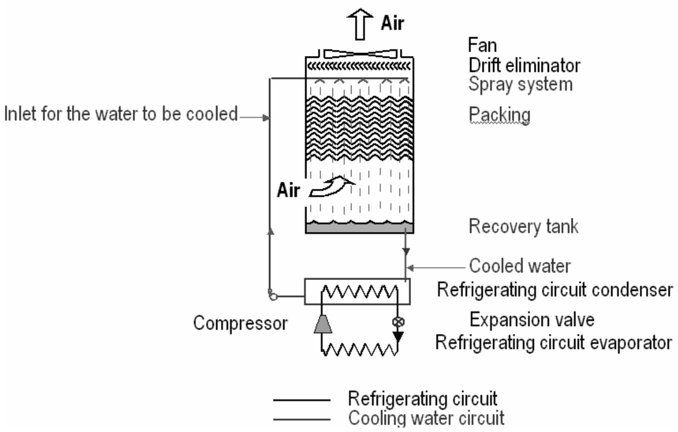

Figure 1. Open-circuit cooling tower

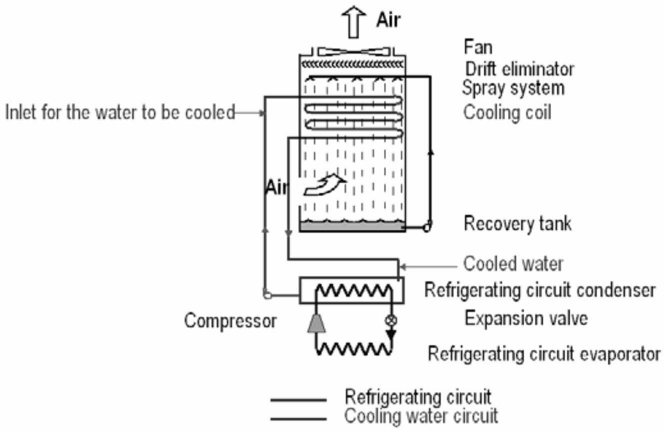

Figure 2. Closed-circuit cooling tower

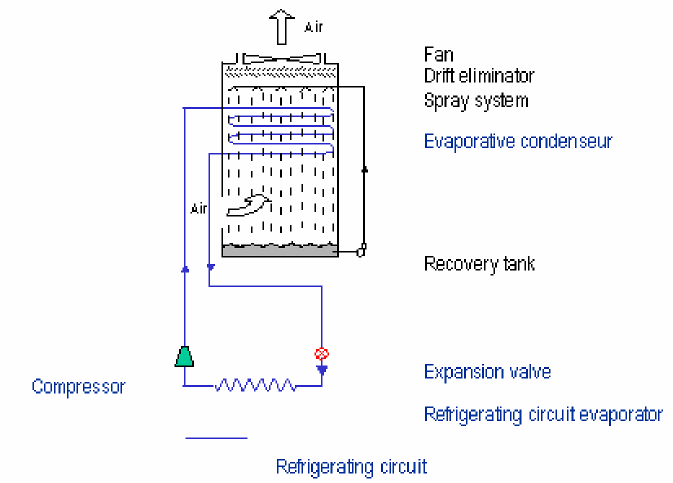

Figure 3. Evaporative condenser

- evaporative condensers (*Figure 3*) are similar to closed-circuit cooling towers. The difference is that rather than water, refrigerant inside the coil assembly is directly cooled and condenses;

There is also another type of cooling tower – called a dry cooling tower – using an air-cooled condenser. Since water is not sprayed into the air, there is no risk of transmission of *Legionella*. However, dry cooling towers have lower cooling capacities than wet cooling towers when one considers the same heat-transfer surface; for this reason, they are generally restricted to relatively small-capacity refrigerating plants.

Benefits associated with wet cooling towers and evaporative condensers

Evaporative cooling – used in wet cooling towers and evaporative condensers – has a number of environmental and economic advantages such as lower energy consumption in comparison with air condensers.

Operation of evaporative cooling devices is based on the following principles:

- the vast majority of the heat being rejected thanks to the very high latent heat of vaporization of water (vaporization of water absorbs heat);
- the evaporative cooling process is based on the wet-bulb temperature of the ambient air, whereas air-cooling systems is based on the dry-bulb temperature. The wet-bulb temperature is generally 8-12°C lower than the dry-bulb temperature. Each degree decrease in the temperature of rejection reduces energy consumption by 1-3%. Hence, evaporative cooling systems make it possible to achieve energy savings of up to 20%, compared with the energy required for an air-cooled condenser;
- the water is recirculated, which leads to a 95% reduction in water consumption compared with water cooling in which the water is lost. Nevertheless, the draining off of water, which maintains an acceptable mineral concentration in the system, is responsible for raised water consumption.

Finally, evaporative cooling enables reduced CO_2 emissions, lower water consumption in comparison with lost-water condensers, and high thermal efficiency to be achieved, with costs remaining attractive.

Risks associated with wet cooling towers and evaporative condensers

Open-circuit cooling towers and to a lesser extent closed-circuit cooling towers and evaporative condensers (due to a smaller volume of water and a shorter circuit), have the potential to develop infectious concentrations of *Legionella*. They can provide favourable conditions for growth and dissemination of the bacteria, as the water temperature in a cooling tower is usually around 29-35°C and organic material and other debris can easily accumulate in cooling towers. These may serve as nutrients and diverse biofilms may also be present on the system surfaces. Furthermore, water droplets are generated in these systems and present a potential risk for *Legionella* distribution. In order to remove these droplets, drift eliminators are incorporated. However, despite great progress, some small droplets (less than 5 µm) may still leave the unit in the stream of saturated exhaust air (see *Figures 1* and *2*).[8]

Wet cooling towers have been implicated as primary or secondary sources in many legionellosis outbreaks and studies have shown that *Legionella* are often present in such installations. However, well-maintained cooling towers with appropriate control and management elements have never been implicated in legionellosis outbreaks. As seen above, evaporative condensers present a much lower risk than wet-cooling towers and are practically risk-free in Northern latitudes where the wet-bulb temperature rarely exceeds 22°C.

Minimizing the risk by design and maintenance

Design and installation

At the design and installation stage for evaporative cooling systems (cooling towers and evaporative condensers), a number of factors should be considered:

- easy and safe access to the cooling systems should be available in order to take samples;
- the system design should facilitate regular maintenance and cleaning;
- the cooling tower should be located as far as possible from fresh air intakes; the system should not be located in areas that could contribute sources of organic material, such as kitchen exhaust fans; the direction of the prevailing wind should be considered and it should not be located upstream of any outdoor public areas; future constructions should also be considered;
- drift eliminators should be installed in order to reduce the loss of water droplets carried out in the exhaust air from a cooling tower.[9] Highly effective drift eliminators, which reduce carryover to below 0.001%, are currently available.[4] These should be installed in such a way so as to facilitate ease of inspection, cleaning and maintenance;
- measures should be taken to treat the water within the system; this water treatment programme should be able to control scale, fouling, corrosion and microbiological growth and located in a convenient position for inspection and maintenance.

Maintenance

An effective preventive maintenance programme is essential to control *Legionella* in evaporative cooling systems. Such programmes include monitoring and treating microbial levels in water systems, regularly inspecting the various components of the cooling system (air intakes, evaporative air coolers and fans), periodically monitoring the effectiveness of the water treatment programme which is overseen by a qualified water expert and recording all maintenance operations in a follow-up logbook.

Although the risk cannot be completely eliminated, as *Legionella* is ubiquitous in aqueous environments, there are a number of key requirements, both technical and managerial, which, if properly implemented, will minimize the risk of *Legionella* infection. All persons involved in the operation and maintenance of the installation must be well trained and aware of their duties. Responsibilities must be identified, as indicated by the Barrow-and-Furness case in the UK, involving 4 deaths, where council workers faced a charge of manslaughter, because UK law states that the employer has a clear obligation to maintain the water services in safe condition.[10] A risk assessment and management programme must define the measures implemented to ensure safe operation and in the case of emergencies; it should be updated every 2 years and all operations must be recorded to ensure visibility.

Voluntary and compulsory prevention tools

Taking into account the public health issues of an outbreak of legionellosis, it is necessary to reinforce preventive actions through raising awareness of the problem in the industrial, commercial and service sectors.

Good practice guides

Many good practice guidance booklets, giving practical advice on the risk of *Legionella* from all potential sources and how to avoid this risk have been developed. Appropriate guides should be made available to all installation owners, operators, designers, installers and maintenance personnel. The American Good Practice Guidelines, first published by ASHRAE in 1981 and updated in 2000, are widely used as a reference. These guidelines provide environmental and operational guidance that contributes to the safe operation of building water systems including cooling towers and evaporative condensers in order to minimize the risk of *Legionella* infection. However, certain studies have found that compliance with these good practice guides is often poor. For example in the UK, the Health and Safety Executive surveyed over 600 premises between 1997 and 1999 and found that although cleaning and monitoring were carried out regularly, water management was poor, access to the tower was difficult and responsibilities were ill-defined.[4]

Regulations

Following outbreaks, it is often seen that although good practice guides are available, they are not followed strictly, and this has often led to the introduction of specific regulations. These regulations often cover compulsory declaration, maintenance and recording of all operations for installations involving cooling towers. In France and Spain, where outbreaks occurred later than elsewhere, regulations concerning design and particularly maintenance of installations have been introduced, including stricter water analyses, compulsory declaration for all cooling towers, an important feature of visibility and responsibility designation for all operations undertaken.[6] Other countries, in which many cases occurred**,** implemented regulations earlier. For example, Australia adopted, in 1988 and 1989 respectively, a code and a standard on the management of cooling towers, which was made partially compulsory by law in 1991.[11]

Conclusion

Legionella, although ubiquitous in most aqueous environments, does not usually give rise to infection even though outbreaks of legionellosis are quite common worldwide. Epidemics often occur when a number of small errors appear at the same time and, for many cases, the precise source is unknown. Open-circuit cooling towers and, to a lesser extent closed-circuit cooling towers and evaporative condensers, are a potential source of *Legionella* contamination and they can act as amplifiers and disseminators of the bacteria. However, well-maintained and regularly controlled cooling towers and evaporative condensers present an extremely low risk. In many countries, guidelines and regulations exist and help minimize the risk associated with such devices. All evaporative cooling devices should follow the guidelines available and a manager responsible for the water hygiene and maintenance of the installation should be appointed. Design, operation and maintenance procedures that minimize the risk should be implemented. These must include an effective drift eliminator, a water management and biocide dosing programme, and regular maintenance and cleaning of the system. Nevertheless, this type of device remains attractive economically thanks to its high-energy efficiency.

IIR recommendations

The risk associated with evaporative cooling devices – and, in particular closed-circuit cooling towers and evaporative condensers – which provide significant energy savings, is very low and well-maintained installations present hardly any risk at all. Cooling towers and evaporative condensers require regular cleaning and bactericidal treatment. This implies the following recommendations:

- an inventory of all the installations, according to a pre-established typology, should be drawn up and continuously updated;
- all persons involved in the design, operation and maintenance of the installations should be trained specifically and should strictly follow the available good practice guides;
- owners and operators should be encouraged to control the installation and must be made aware of their responsibilities;
- regulations should be considered to address the issue of *Legionella* where widespread application of good practice is not occurring. Furthermore, regulations and good practice guides should be internationally harmonized;
- an international database should be created and updated regularly to help countries understand and prevent the risk of *Legionella*. The EWGLI database is a good starting point but should be adapted and improved on. International cooperation is necessary in order to share knowledge and experience, standards, guidelines and regulations and good practice;
- more research must still be carried out on *Legionella*, so that disease-causing doses and limits can be defined and also to ensure sources are identified for the large number of cases for which the source is unknown.

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