Precooling Mass Concrete with Liquid Nitrogen

Automated system leads to increased use of the technology

by John Gajda and Francisco Sumodjo

The practice of precooling mass concrete is probably not as old as you think. The first reported use was at the Norfolk Dam, AR, in the early 1940s, where ice was used to replace a portion of the batch water.[1] The ice reduced the initial temperature of the concrete by about 10°F (5.6°C) due to the energy absorbed as the ice melted. Since then, using ice to precool concrete has become common.

But precooling concrete using ice has limitations. Because batch water only makes up about 5 to 10% of the mass of concrete mixtures, replacing most of the batch water with ice generally can reduce the initial concrete temperature only by about 20°F (11°C). If chilled water is used instead of ice, the reduction in the initial concrete temperature is typically only about 2 to 3°F (1 to 2°C).

Fig. 1: Night construction of the new Oakland Bay Bridge, San Francisco, CA, using an LN cooling system

About 30 years ago, liquid nitrogen (LN) was first used to precool concrete. LN is far colder and occupies a smaller volume than ice, making it more convenient to transport and store. Initially, LN was used to cool the concrete ingredients prior to mixing; LN was sprayed on coarse and fine aggregates, and LN vapor was injected into cement storage silos and bubbled through water to make ice slurry for use as batch water.

However, these practices led to problems with concrete batching operations and concrete quality, were inefficient and costly, and achieved only about a 20°F (11°C) reduction in the initial concrete temperature (similar to that of replacing most of the batch water with ice). LN was later injected into the mixing drum at the batch plant or in the concrete truck, but this process was initially used sporadically.

In recent years, however, LN has become increasingly popular. LN-precooled concrete was used on large projects such as the Texas State Hwy. 45 Turnpike Project[2]; the new San Francisco-Oakland Bay Bridge[3] (Fig. 1); the new Benicia-Martinez Bridge[4]; and the new Hoover Dam Bridge.[5]

The increased use of LN is largely because of the introduction of the automated CryoCrete™ system, developed by Air Liquide Industrial U.S. LP (Fig. 2). This system allows for the safe and efficient precooling of concrete in the drum of a concrete truck or a batch plant. It was used on the aforementioned projects and is being used at many other projects, including dams, buildings, bridges, power plants, and spillways.

With the increasing popularity of LN precooling, concerns arose regarding its effect on the fresh and hardened

Liquid Nitrogen (LN)

The earth's atmosphere consists of about 78% nitrogen. LN is atmospheric nitrogen that has been cooled to a very low temperature, sufficient for it to condense (convert from a gas to a liquid). Under typical conditions, LN boils (converts from a liquid to a gas) at a temperature of −321°F (−196°C). During this conversion, its volume expands by approximately 700 times.

In certain weather conditions, LN precooling can generate a ground fog, so cooling equipment should be located where it does not obstruct visibility for other operations. Personnel working with LN must be properly trained and equipped with safety equipment,[7] as improper handling can result in the displacement of oxygen in the air and direct contact with LN can instantaneously freeze unprotected skin.

A video showing the LN injection equipment and process can be viewed at **www.youtube.com/watch?v=mG-8hZfxeYE**. Although the video shows the concrete truck backing up to the A-frame and lance, trucks drive through the A-frame in most installations.

Night cooling with LN at a batch plant and generation of ground fog

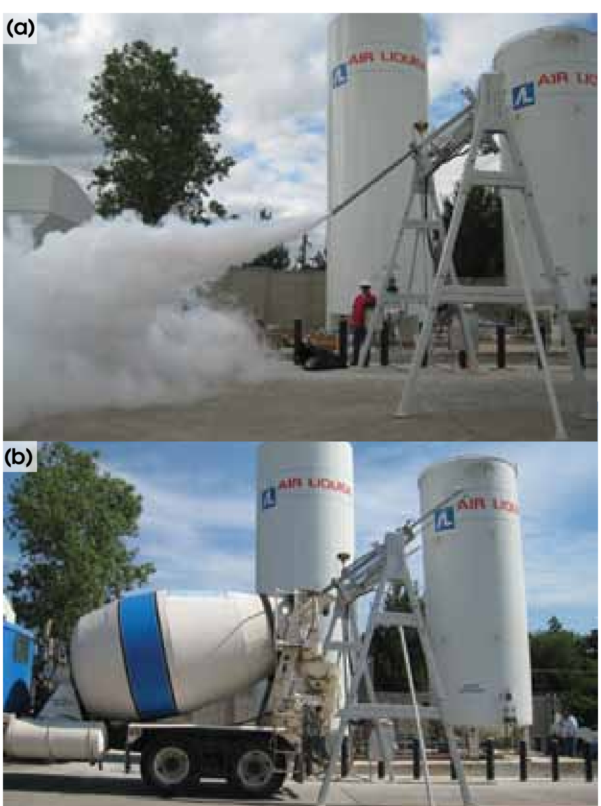

Fig. 2: The CryoCrete™ automated LN cooling system developed by Air Liquide Industrial U.S. LP: (a) during injection testing and (b) just before cooling of a load of concrete in a truck

properties of concrete. Research conducted for the Texas Department of Transportation by the University of Texas at Austin showed that LN has a minimal impact on the properties and performance of the concrete.[6,7] Concrete performance was tested in terms of slump, setting time, yield, compressive strength, splitting tensile strength, elastic modulus, drying shrinkage, rapid chloride permeability, and hardened and fresh air void systems.

The amount of precooling required—and the associated cost—typically determine whether LN is used for full or partial precooling. LN precooling is used when the concrete needs to be cooled more than 20°F (11°C), when ice is not available, or when ice is more expensive than LN. Precooling with LN has the following advantages:

- **Repeatability:** A batch of concrete can be cooled multiple times with LN, including when concrete warms too much due to delays prior to placement;
- **Mobility**: The process can be performed at the batch plant, at the construction site, and even during transport on barges.[8] A small generator provides enough power for the CryoCrete™ system;
- **Utility**: LN can and has been used to cool concrete to as low as about 35°F (2°C);
- **Consistency**: LN accurately changes the temperature of the concrete without changing the composition or characteristics of the concrete. Admixture batching is not affected; and
- **Efficiency**: Only one trained operator is required.

A typical on-site LN cooling system consists of a cryogenic vessel, a pressure regulating system, an automated injection lance, a control panel, a trained operator, and an infrared thermometer.

The cryogenic vessel is supported by a concrete pad and holds 6000 to 13,000 gal. (22,700 to 49,200 L) of LN. The actual size of the vessel depends on the distance from the LN production facility, the amount of concrete to be cooled, and the scheduling of the concrete placements. The pressure regulating system is built onto the cryogenic vessel. The automated injection system consists of a stainless steel lance mounted on an A-frame, which allows the lance to be extended in and out of the rotating drum of the concrete truck.

Prior to LN injection, the drum of the concrete truck must be at full rotation speed to disperse the concrete for efficient and uniform cooling. A reasonable estimate is that about 1.5 gal. of LN are needed to cool 1 yd^3 of concrete by 1°F (about 13 L of LN are needed to cool 1 m^3 of concrete by 1°C). Cooling rates are typically in the range of 2 to 5°F (1 to 3°C) per minute.

The actual required amount of LN and the cooling rate depend on a variety of factors. Damage to the concrete truck can occur if the LN is improperly sprayed into the drum (which can occur if the injection system isn't automated or lacks a retractable lance), the cooling rate is too high, a partial load of concrete is cooled, or the drum is rotated too slowly.

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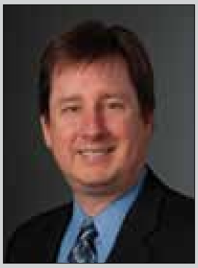

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