Kraft Curing Systems GmbH, 49699 Lindern, Germany

Direct-Fired Vapor Curing Technology for 'Green Tunnels'

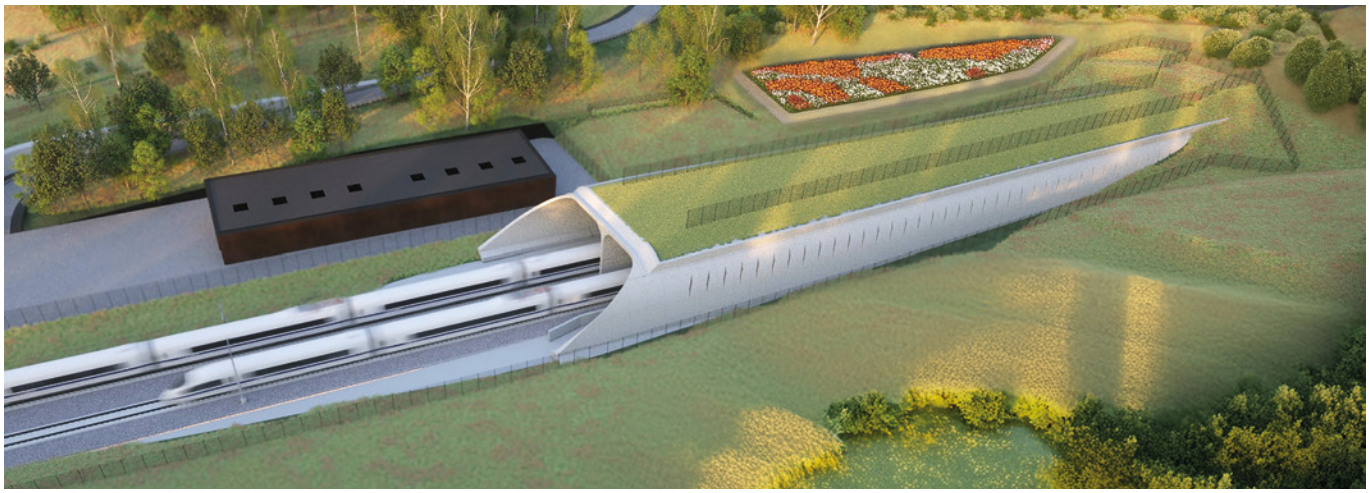
■ Daniel Rafter, Kraft Curing Systems GmbH, Germany

Having been awarded the contract to manufacture and deliver three cut-and-cover tunnels with the longest comprising of over 5,000 individual elements, Derbyshire based Sateba UK turn to Kraft Curing Systems GmbH to provide a unique solution. The brief is to reduce production cycle times by providing accelerated hardening of the uniquely-shaped precast tunnel segments. A two-step curing cycle allows the casting forms to be returned to use promptly while ensuring the element strength development can be controlled over a prolonged period, in line with stringent strength and quality standards.

With a tight deadline to work to, Sateba couldn't wait until their custom-designed 150 m long production hall was completed before casting activities commenced. By late 2021 a temporary outdoor casting area was completed with ten casting forms in a line. With the cold winter period approaching a system was needed to maintain reduced cycle times, and thereby maintaining casting output without compromising the quality of the finished elements. Kraft suggested that the best method in terms of effectiveness and capital cost was to utilize direct-fired vapor which is produced by the well-proven Kraft Vapor Generator. Vapor is a mixture of steam, combustion products and hot air, the ideal mixture for the hardening of concrete products. Without an exhaust flue, virtually all of the heat energy produced in the vapor generators' combustion process can be utilized for curing. This is green steam for green tunnels.

Project Overview

With the forms now in position in the temporary casting yard, it was time for the Kraft team to set to work with the mechanical and electrical installation. With a reduced lead time Kraft was able to deliver a complete vapor curing solution including a containerized vapor generator, vapor distribution piping, under-from vapor diffusers, retractable curing enclosures as well as the innovative AutoCure system to manage the curing cycle. The end-customer requirements called for a primary curing cycle to facilitate rapid demolding as well as a secondary cycle to control the maturity conditions, providing a stable, warm and moist environment for up to 48 hours and providing a controlled cool-down phase. The primary curing cycle could be done using Kraft-provided curing-tarpaulins, with the element still inside the form, with the latent heat of condensation indirectly heating the concrete element through the metal form. The curing requirements for the primary curing cycle called for 50-55 Degrees Celsius for approximately 12 hours with temperature elevation being in the range of 10-15 Degrees Celsius per hour.



Once the 'green tunnels' are installed, the excavated earth is reinstated, with new trees and shrubs planted to integrate the tunnel into the surrounding landscape, fostering connectivity among wildlife habitats along its path."

Once the primary curing cycle is complete the tarpaulin is removed, the form is split and the element is demolded. The still hot element can be transported to the secondary curing area for after-treatment in the secondary curing cycle. The application of vapor this time was to be done inside the Kraft retractable curing enclosures. These tent-like structures collapse to 30% of their total length to allow placement of the concrete elements by the overhead crane.

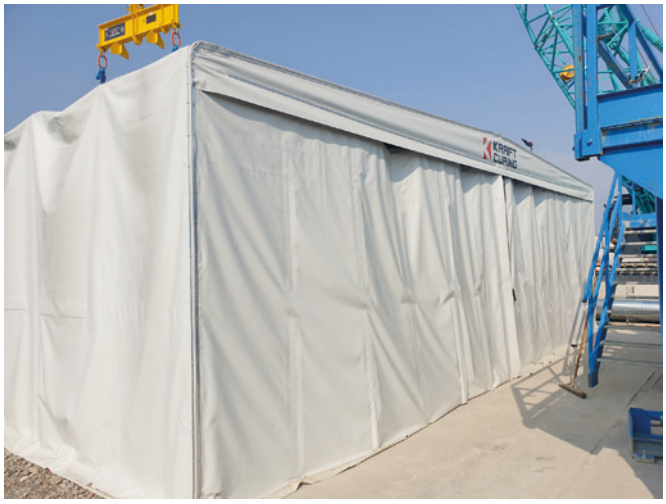
Secondary curing takes place over a period of approximately 40-48 hours, again at 50-55 degrees Celsius. A controlled cool down phase is used to gradually decrease the element temperature to ambient without the risk of thermal shock. Once the secondary curing process has been completed the element can be moved to the stockyard.

In the spring of 2022, the new permanent facility was close to completion. New forms had already been delivered and were being installed in the new building. With casting/curing paused temporarily Kraft returned to the site to begin dismantling the outdoor casting area and transported all materials the short distance to the new building. The design of the vapor piping was such that each section of existing pipe already had a designated position within the new building. The curing enclosures were also partially dismantled and shifted inside. As part of this phase 2 installation, expansion of the curing system layout was required. A further ten enclosures, as well as additional vapor valves, piping and sensors were delivered to supplement the equipment and material already delivered as part of phase 1. Kraft supplied full installation as part of the contract, with an installation supervisor as well as approximately 10 mechanical fitters and two electricians on site ensuring the transition could be completed promptly.

Vapor Distribution & Control

Whether in the outdoor or indoor casting areas, an important factor in any controlled curing system is temperature consistency. Kraft engineers had to work hand in hand with the form

Outdoor temporary casting area allowed the customer to meet the project delivery schedule while awaiting completion of the permanent cast facility.



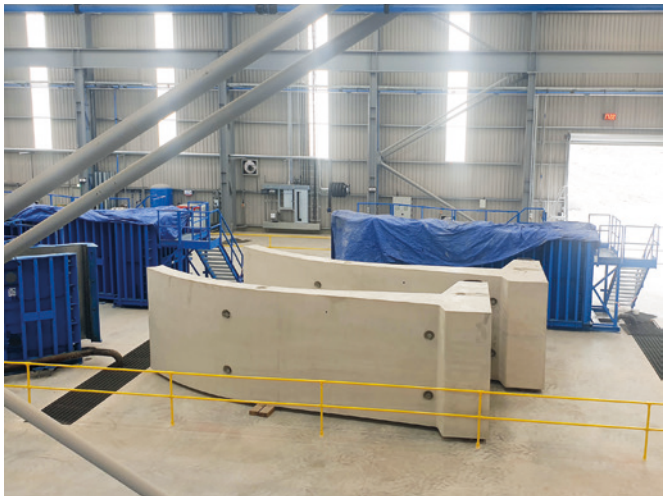
One of the five retractable curing enclosures (tents) initially supplied to the outdoor temporary casting area. The tents could be quickly dismantled and moved to the permanent facility once completed. A further ten tents were supplied as part of phase 2 delivery.

Primary Curing in the Permanent Facility – Pipe trenches keep the production floor free from obstructions. The vapor is always delivered at ground level, directly under the form for best temperature consistency.

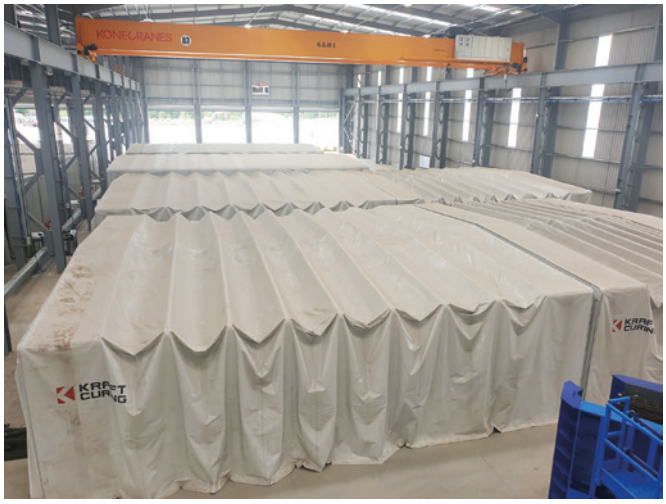
manufacturers and customer to ensure the optimum design for vapor distribution could be provided. Since the vapor is hot and will have a tendency to rise it should be introduced to the curing enclosure as close as possible to floor level to make best use of the heat energy. In the primary casting area, there are several form shapes in use, an individual solution had to be provided in each case, but in general the concept was to use multiple smaller diffusion pipes to deliver vapor across the full length of the form directly under the structure. This also meant that the piping is not obtrusive to casting operations.

Inside the retractable curing enclosures, vapor delivery is provided by three each 2 ½" flexible steam hoses, which can be placed in any position within the enclosure. Special cylindrical diffusers ensure the vapor is distributed horizontally along the floor in a radial pattern from the hose outlet.

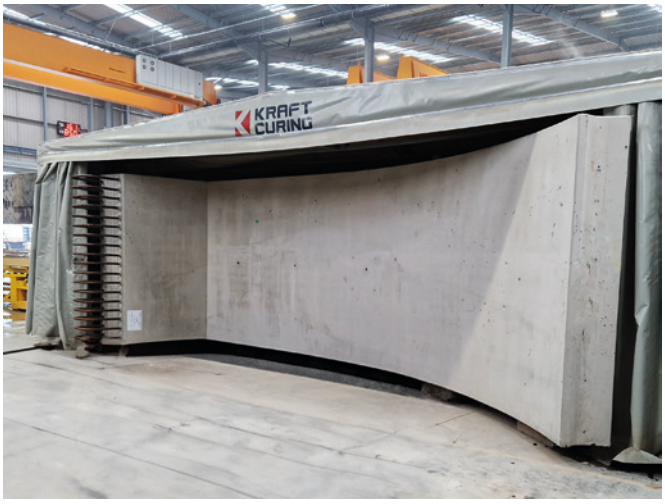
Despite the large quantity of piping required to deliver vapor to such a large production area with more than 40 individual points of use, the piping is not a dominant feature within the production area. Due to the design of the production building, the center-line was almost completely occupied by latticed support columns, this normally dead-space was the ideal placement area for the 8-inch, insulated main vapor header pipe. Several vehicle underpasses or pipe bridges were designed into the pipework to allow traffic to freely pass from one half of the building to another. All vapor control valves were installed on the main line, well out of the way of the work area and any crane activity. The 6-inch branch pipes which supply vapor to each heating zone (enclosure or forms), were placed in pipe trenches along with heavy duty trench covers. In short, the complete vapor distribution system was designed to have as little impact as possible on the daily cast-



The images demonstrate how the carefully thought-out vapor piping layout blends in with the production area to avoid interference with daily operations.



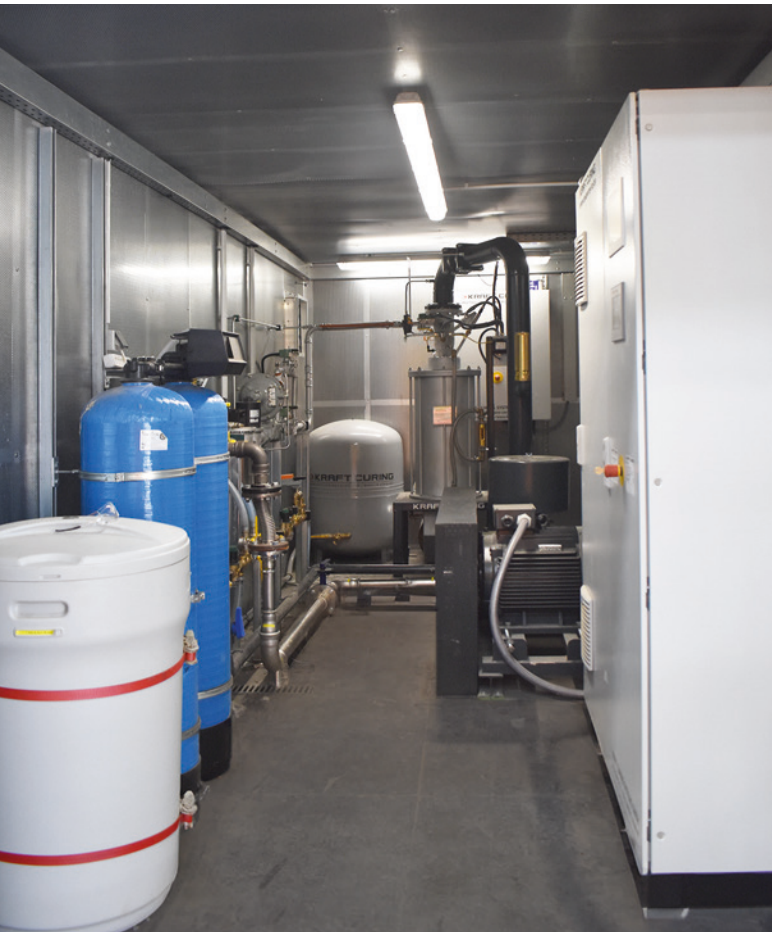
Some of the many retractable enclosures inside the secondary curing area. Each enclosure is capable of containing two concrete elements.



The tents reduce the labor requirement, allowing two elements to be quickly covered for the secondary curing cycle.

ing operations. Other important considerations were piping insulation, vital for preventing heat-loss which could lead to the formation of condensation and vapor losses. The entire piping system is insulated in 80 mm mineral wool insulation with galvanized jacketing. Automatic condensate drains remove any condensate from the vapor line.

In combination with good vapor piping design, a controlled method of vapor delivery is required. Kraft supplied Sateba UK with a comprehensive curing control software referred to as AutoCure. The AutoCure system and PLC measures the concrete temperature directly from a PT100 temperature sensor which is threaded directly into the casting form. The



The Containerized Vapor Curing Unit with Water Treatment System.

sensor protrudes far enough into the form to allow direct temperature against the concrete surface.

The actual temperature value is read directly by the PLC which in turn provides a control signal to the automatic vapor valves. The automatic vapor valves allow supply or shut-down supply of vapor to the respective casting form, regulating the concrete temperature.
The AutoCure program is designed to follow a pre-determined curing curve. Time and temperature parameters can be entered by the customer in order to produce the required curve. As per standard industry practice the curve will be made up of the following phases -preset, temperature ramp phase, temperature soak phase and controlled cool-down. This controlled method guarantees the best results with no compromise to the quality of the finished article. A useful Kraft tool for ongoing quality insurance is the VaporWare system. The VaporWare system is a data recording device which can record and store each individual curing cycle in PDF format. Two copies of the graph are created, one in tamper-proof PDF format usually for the end-client, and one modifiable file which is normally for internal use by the manufacturer.

Retractable Curing Enclosures

The retractable curing enclosures (tents) proved to be the ideal solution, suitable for both indoor and outdoor use and with the ability to be dismantled and relocated quickly. Apart from a level concrete floor, the structures do not require any special foundations. This is a flexible option for the customer, the tents can be easily moved or removed to allow the casting area to be repurposed for different projects. The clever collapsing design allows two elements to be quickly covered, in as little as five minutes, to prepare for the vapor curing cycle. The galvanized steel structure and the vinyl-coated PVC material provide a long service life against the hot, moist curing environment.

Containerized Vapor Generator

The main heart of the curing system consisted of a KC 80-VS low pressure vapor generator. The natural gas fired 2,400 kWh variable-speed vapor generator was supplied pre-installed inside a 20' shipping container. Although natural gas was the chosen fuel source in this project, Propane is also possible. The container serves as a safe, secure and dust-free plant room for the generator and ancillary components. The container is insulated with mineral wool noise reducing insulation and is equipped with lighting, power outlets, ventilation, water-treatment package and an electrical heater and thermostat for frost protection. In the case of Sateba, the container was placed outside the main casting area, although some customers choose to place the container indoors. The container comes with penetrations to allow the gas supply piping, water supply piping, vapor piping and power supply cable to enter the container for connection in a plug and play manner. All systems can be extensively tested as a single entity in the Kraft factory before dispatch to the customer. ■

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