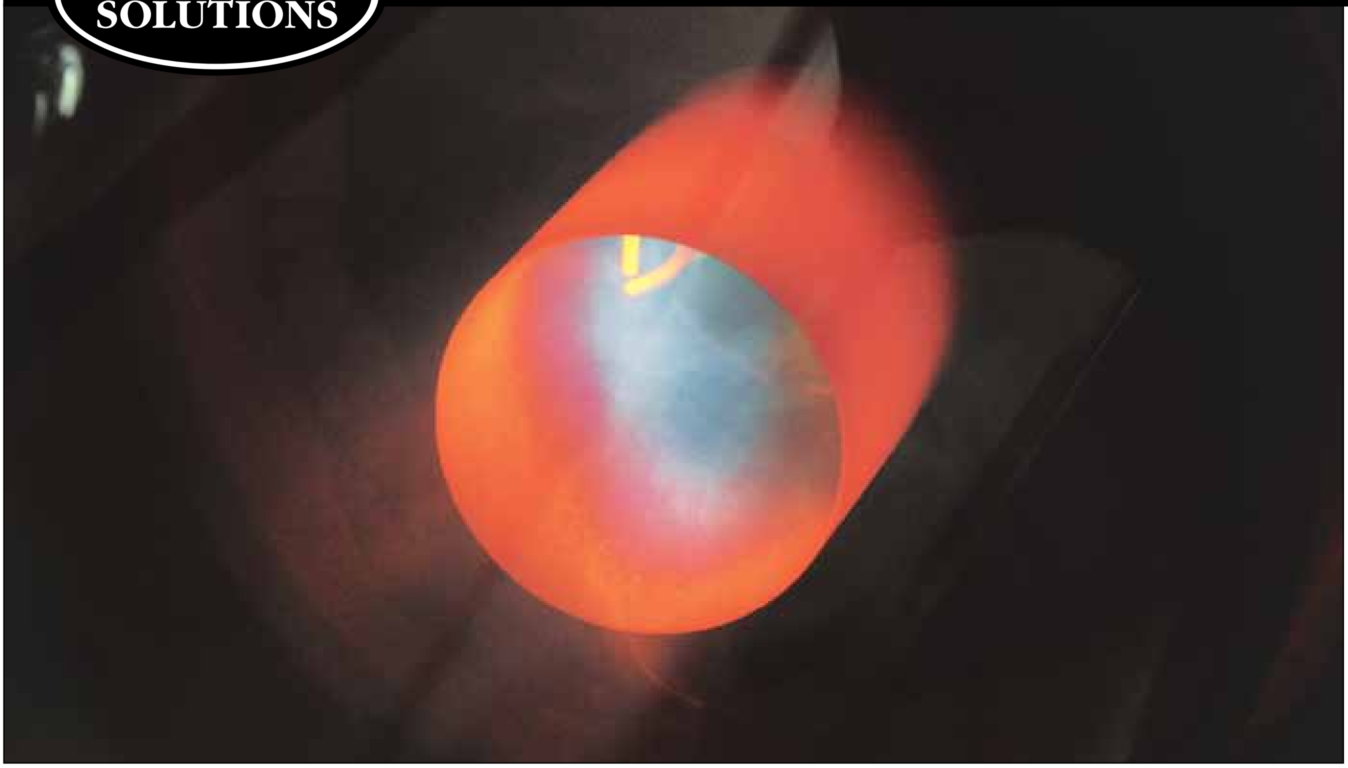
PRACTICAL SOLUTIONS



Blue Flame Afloat

Collaboration between two small European companies yields a compact diesel hydronic heater for marine use that delivers high-efficiency and low-emissions heat.

Text and photographs by Steve D'Antonio

__Above—__A titanium-alloy air sleeve in an efficient hydronic heating unit from Dutch manufacturer Kabola glows red as the diesel fuel burns with a blue flame at 2,600°F (1,427°C). That temperature reduces exhaust gases to a minimum and effectively eliminates soot buildup in the heater.

For boats sailing in the tropics or Mediterranean, cabin-heating systems are a nonissue. But in the colder waters of New England, the Pacific Northwest, Northern Europe, and Russia, recreational boating stretches into the shoulder seasons, and commercial activity carries on through even the coldest months. Heat matters in this large market area, yet onboard heaters are, in too many cases, inefficient afterthoughts. When powerboats are under way, a relatively easy bit of plumbing work can draw excess heat from the engine's cooling system through a cabin radiator; but for vessels at rest, or boats with greater heating needs, an array of solid fuel, propane, and diesel options is available. While it has a reputation as smelly and sooty (especially in older stoves and heaters), diesel has the combined virtues of being less volatile than propane and readily available from main engine and generator fuel supplies. The most efficient of the diesel heaters are hydronic, meaning they comprise a boiler and attached hot-water pipes for heat distribution, much like a standard domestic hot-water baseboard system.

Ultimate efficiency in a hydronic heating system is attained when the diesel fuel that heats the water burns with a blue flame as opposed to the more common yellow flame caused by incomplete combustion, which produces soot particles. The refined engineering of fuel burners to yield a super-clean blue flame isn't new to household-boiler systems, but a partnership between Kabola Heating Systems B.V. (Vianen, Holland) and Scheer Heizsysteme & Produktionstechnik GmbH (Wöhrden, Germany) is the first to apply the technology to small recreational and commercial boats as it is incorporated in Kabola's latest KB series hydronic diesel heaters.

Annals of a Partnership

I'd seen Kabola's red cube-shaped heaters on a number of occasions, particularly on the U.S. West Coast, before I met the North American Kabola distributor, Swedish expat Lars Nilsson, at the Seattle Boat Show a few years ago. I'm a diesel-heat enthusiast, so we talked at length about these units. I liked what I saw; the systems were rugged and simple, with just 10 major parts in the furnace, and they shared many components with well-tested residential and industrial heating systems. Nilsson introduced me to his business partner in MarineTec. Gheorghiu: Costica Gheorghiu, a former merchant mariner and refugee from communist Romania with a story too rich to tell here, who worked hard in the U.S. and sold his share of a Seattle boatyard in 2005. In 2008 his meeting Nilsson at a boat show led to restructuring the Kabola distribution network in North America. Gheorghiu formed MarineTec LLC, with Nilsson as the sales manager. Among others, their premier products remain Kabola furnaces and Solaris, a line of high-end copper-tank water heaters.

A couple of years ago they started talking about a new product: a cleaner, greener (it actually produces fewer hydrocarbon emissions for equivalent heat), more compact, and more efficient diesel furnace than they had ever offered before. The line would ultimately be referred to as the KB series, a name that carries special significance I'll discuss in a moment.

I was intrigued, so in November 2011, during a visit to the Marine Equipment Trade Show in Amsterdam, I took a side trip to learn about the new blue-flame KB model at the plant in Vianen, where Kabola has, in one form or another, been building diesel-fired heating systems since 1947. Over the years the company's product line has evolved from natural-draft radiant-heat furnaces to more sophisticated hydronic models that rely on forced draft and boilers. Up until the KB series, all the company's forced-draft furnaces relied on the familiar yellow flame with a claimed efficiency of 90%–92%. Its premier lines, the B-Tap and HR series furnaces, include the ability to heat domestic water while away from shore power and without running an engine or generator.

Piet Alles and his partner, Arie van Soolingen, started managing Kabola in 2001. They bought the company outright in

The condensing boiler from a Kabola heater was developed in collaboration with well-known domestic-furnace manufacturer Scheer (Wöhrden, Germany).

The KB 20 furnace (KB for Kabola Blue) was created after a 2008 prototype for another model in development failed to reach the market due to problems with a boiler supplier. Turning to Scheer's super-efficient burners allowed for the creation of the new line.

Quantifying Efficiency

The Dutch heating-systems company Kabola and the German company Scheer spend significant effort on measuring the efficiency of their hydronic heating units. Higher efficiency means less fuel consumed to heat a given space, and boat builders and owners can use this measurement, among other criteria, when choosing marine heating systems.

At Scheer's lab, technicians gather information on CO, CO_2, O_2, NO_x and exhaust temperature as well as the furnace's "product," hot water. The efficiency formula they use is similar to the Annual Fuel Utilization Efficiency, or AFUE, system, called SEDBUK (Seasonal Efficiency of Domestic Boilers) in the U.K. It is an average measure of efficiency for assumed season-long use, derived by comparing the Btu content of the fuel versus the Btu content of the product. A unit with 94% efficiency can be assumed to provide, over the course of a heating season, 94% of the Btus of effective heating of the fuel it has consumed.

—*Steve D'Antonio*

A technician at the Scheer plant in Germany assembles a burner unit. The company is known for producing some of the smallest and most efficient boilers, allowing Kabola to reduce the physical dimensions of its KB heater line—a real plus in the tight confines of a boat.

2005. With about 15 employees, they build boiler/heat exchanger units, furnaces, and related hardware in-house, while out-sourcing burners, pumps, and fuel systems, all of which are assembled and tested in Vianen.

They began what they call a "new-every-five" program, which dictated that to remain competitive they would release a substantially new product every five years. In 2008 the HR750 was on the drawing board, but there was a problem with the burner producer that delayed the model's release. At about that time, Alles received an e-mail from Constantin Kinias, the proprietor of German furnace manufacturer Scheer, asking if his firm could purchase products directly from Kabola. His curiosity piqued, Alles did some cursory research of the company, was impressed, and decided to drive the 350 miles (563 km) to Wöhrden in the Schleswig-Holstein region of Germany, to visit Scheer.

He knew that Scheer produced some of the world's smallest *boilers* (the term Europeans tend to call any circulating-hot-water furnace; where Americans often use the term *furnace*, which can be of the forced-hot-air or circulating-hot-water variety) and has a 60-year history of innovation in the production of gas and oil heating systems. In Wöhrden he found a small company with values, ethics, practices, and a skilled work force similar to Kabola's. Kinias and his CEO, Nicole Schroeter (who is also an engineer, originally from East Germany) showed Alles around, answered questions, and compared notes on their products, of which Scheer's crown jewel was their latest creation, an ultra-clean blue-flame diesel-fired burner.

Alles returned to The Netherlands convinced that collaboration would benefit both companies. Then, with his partner he met more formally with Kinias, Schroeter, and Scheer's chief research and development officer, Bernd Meyer. Alles also shared his experiences with Nilsson and Gheorghiu, who were similarly intrigued by the potential for this product in their North American distribution area. Costica in particular has been an important force, encouraging expansion of the product line and improving reliability, documentation, and user-friendliness.

Ultimately, the Scheer principals visited Kabola, bringing with them a blue-flame burner demonstration model. During this visit, Kabola discovered that the Scheer burner would enable them to reduce the depth of the existing HR series furnace by 4″ (102mm), which in the tight quarters of a small yacht could very well mean the difference between a boatbuilder choosing a Kabola or a competitor's furnace. And the size reduction could be achieved while maintaining the same output capacity. Alles and Soolingen scrapped the lagging HR750 project and jumped into a full collaboration with Scheer to build a new furnace with the blue-flame technology—the Kabola Blue (KB) 50 and 75. Today, KB series furnaces range from 23,900 Btu to 136,500 Btu.

The quid pro quo in the business collaboration between the two companies was that Kabola would supply Scheer with complete conventional-burner furnaces for the German marine industry. Scheer also purchases furnaces from Kabola, around which they install their own housing and into which they install their blue-flame boilers for the domestic heating marketplace. Indeed, the collaboration remains so important to both companies that my trip to Kabola led to a visit to Scheer.

The Blue Flame Advantage

After the standard boardroom briefing, Alles, Costica, Kinias, Schroeter, and I headed to Scheer's shop area

***Top right**—Fitted with a glass tube, this demonstration unit reveals how little soot is produced by the furnace's blue flame. The tube's interior remains clear, and white fire-retardant fabric on its exhaust end is unsullied after a start-up and test burn. **Right**—The round combustion chamber in the bottom of the boiler unit is difficult to build but eliminates cool areas that cause inefficient burn. The clean burn also allows the use of smaller boiler tubes (visible here), which further reduces the unit's overall size.*

Readings of exhaust from an operating heater show carbon monoxide levels at a scant two parts per million.

and toured the facility, located in a pastoral setting abutting a horse farm. We made our way through the shop floor, assembly areas, and ultimately to the research and development shop. I was anxious to learn about the burner that allows diesel fuel to burn in a blue flame at 2,600°F (1,427°C) compared to the roughly 1,800°F (982°) of a yellow diesel flame.

A few key elements are required for operating an oil burner in a blue-flame condition. Much like a gasoline or diesel engine, atomization of fuel must be extremely thorough, allowing more of the fuel molecules access to oxygen, and it also must occur virtually at the moment of ignition. (Most readers have likely never seen the inside of an internal-combustion engine's combustion chamber during operation; while carrying out carburetor adjustments using a glass spark plug, I have observed that when all is right, the flame is indeed blue.)

Without complete, or near-complete atomization, diesel fuel burns incompletely, producing the yellow flame common in conventional diesel and oil furnaces and kerosene heaters (as well as cold or poorly tuned diesel engines), along with a certain amount of smoke and soot. While it is initially a symptom of an incomplete burn, soot can further harm efficiency of a heating unit by clogging boiler tubes, especially the smaller ones used in the KB series. (These smaller tubes, which allow the overall unit to be more compact, are only possible thanks to the clean-burning blue flame.) The more thorough combustion achieved in the blue-flame environment also reduces production of polluting nitrogen oxides and carbon monoxide. Once the unit heats up, in less than a minute, CO production falls to less than 4 ppm, and often to zero (multiple instrumentation connected to the units in the development lab clearly showed this). The threshold established by the U.S. Occupational Safety and Health Administration (OSHA), for air that can be breathed, is 50 ppm as an eight-hour time-weighted average concentration.

From the standpoint of limiting the unit's physical footprint, the KB offers yet another advantage; its blue flame length is about 4″ shorter than the yellow flame, which means the corresponding combustion chamber can, as previously mentioned, also be smaller. The KB combustion chamber is circular, which is more difficult to manufacture but reduces the likelihood of cool areas that hamper combustion, reduce efficiency, and produce soot.

How It Works

The details that enable the blue-flame burner to function include high-pressure fuel injection up to 300 psi (2.1 N/mm^2) through an extremely small nozzle orifice whose spray pattern is between 60° and 80°, depending upon the model in which they are installed (larger combustion chambers can benefit from a wider spray pattern). The nozzles, made especially for Scheer by a company in New Jersey, include a unique anti-dribble valve that prevents post-shutdown dribbling and smoke production. These, along with a conventional furnace blower that moves air through the chamber, and a comparatively large ignition spark gap of 0.6″/15.2mm (it's typically 0.16″–0.24″/4.1mm–6.1mm), allow for ultrafine atomization and near-complete combustion with a flame temperature of over 2,600°F.

At start-up, and for the next two to three minutes, fuel within the nozzle is electrically preheated to further improve atomization. Once the unit is up to temperature, fuel that enters the combustion chamber is naturally preheated via the air sleeve. Fuel and air pumps in the burner assembly are made especially for Scheer, incorporating their design requirements to achieve these goals. These pumps are a departure from previous designs, which used a single motor to drive the fuel-injection pump and the fan. With these motors now separate and independent, the fan motor is considerably lighter and less power hungry, and its speed is adjustable.

Top—*Part of the secret to a clean burn is the tiny orifice in the spray nozzle through which diesel is injected at 300 psi (2.1 N/mm2) and its anti-dribble valve that prevents post-shutdown smoking and fouling. The atomization of fuel coupled with a conventional furnace blower and a large ignition spark gap (**bottom**) permits a near-complete burn.*

A Question of Voltage

The heating companies Kabola and Scheer utilize a number of conventional off-the-shelf, precertified industrial components that lower cost and improve reliability of the KB line of hydronic heaters. (Scheer and Kabola products carry CE certification, and Scheer's components also meet standards established by TÜV Rheinland, the Technical Inspection Association in Germany.) These include fuel, air, and circulation pumps as well as control mechanisms. As a result, all these items operate on standard *European* power, 240VAC and 50 Hz. At one time, Kabola offered 24V furnaces; however, KB and conventional furnaces are now exclusively 240V, 50 Hz, which are, for units supplied by MarineTec for the North American market, in turn connected to a small European inverter supplied by the company. Fortunately, start-up and operating loads for the KB series are comparatively low at 500 watts and 165 watts, respectively. The logic behind this decision centers on reliability; AC components are more reliable, as the production numbers for the 240V domestic heating components are many times those of the specialized 24VDC marine equivalents.

—*S.D.*

This conventional off-the-shelf blower runs on standard European 240VAC current. A small integral inverter converts shipboard 12V and 24V electricity for the furnace.

As hot as the flame is within the combustion chamber, the KB is so effective at extracting the heat that one can touch the exhaust pipe. The temperature of the exhaust gas is approximately 390°F (199°C).

Further efficiency can be achieved in the furnace by converting it into a condenser boiler, a feature still being tested and not yet available to customers. With an add-on inline heat exchanger installed in the exhaust outlet at the back of the unit, it adds about 6″ (152mm) to the unit's depth. Heating-loop water returning from

Little heat goes to waste. Here, a test unit exhaust is piped through simple plastic tubing through which condensing water is visible.

Top right—*The nozzle, its support ring, and the large-gap igniter assembled in one unit are ready to be installed in the boiler's combustion chamber.* ***Bottom right—****Refinement of the support, or dosge, ring led to creation of the gap seen here; it is engineered to prevent cracking by creating an intentional break that will close as the unit heats up during operation.*

radiators passes through this heat exchanger and absorbs exhaust heat before re-entering the primary boiler unit. So, heat that would have been exhausted is retained in the heating system, and the cooled exhaust gases require less insulation for exhaust ducts (the test model in the shop was connected to plastic exhaust fittings, through which condensing water could be seen). This cooling has an undesirable side effect in that it causes water vapor in the exhaust gases to condense, and that watery condensate contains acid, which means the materials used for this component must be especially corrosion resistant, or nonmetallic. This can be overcome by installing a simple condensate scrubber to effectively neutralize the acid and render the condensate clean enough to drain or pump overboard.

In the research lab I discussed the details of the KB with those involved. The level of fine-tuning and the number of iterations and modifications the design has gone through in the testing stage are impressive. One example is the nozzle support ring, referred to as the *dosge* ring by the folks at Scheer. Made of a copper alloy, it gets extremely hot, much hotter in the KB series than in yellow-flame burners. Early versions exhibited a tendency to crack because of excessive thermal cycling. A redesign included a gap that when cool is quite large; however, upon heating, the ring expands, effectively closing the void and resulting in a more reliable and patented nozzle tube.

Another refinement: the air sleeve—the component that surrounds the flame—is made of a titanium alloy. The patented design incorporates a very thin wall that is extremely responsive to heat, glowing crimson within seconds of start-up. This approach concentrates the flame and enhances combustion characteristics.

The KB's controller software, which itself has gone through several versions during beta testing, also commands the blower to begin operating prior to combustion, "cleaning" the chamber and improving flame characteristics at the moment of ignition, as well as running for a set interval upon shutdown to once again clean the chamber and cool the flame tube. Typically, combustion efficiency can be further optimized through onsite adjustment of the blower speed via a push-button control to take into account installation variables such as exhaust length and restrictions. (To a point, the KB series furnace works well with more rather than less exhaust system back-pressure.) Once the system is optimized, its onboard computer can program the fan speed "zero point" to maintain ideal operation in the future, if, for instance, wind is blowing against the exhaust.

Units operating in the research lab were wired with a variety of sensors and monitored closely by technicians in a nearby room equipped with a bank of computers and measurement equipment. Establishing accurate efficiency figures is of the highest importance to Scheer and Kabola, as a percentage point or two can have a significant impact on heat production and fuel consumption. Their testing indicates that the KB series units achieve

Fan-speed control is an important factor in attaining the KB heaters' efficiency. The software in this control unit can actually adjust the blower to counter wind blowing against the exhaust.

At Kabola's laboratory, refinements and new developments are constantly being tested.

a claimed efficiency of up to 94%.

To study and exhibit the KB's efficiency and flame characteristics, a demonstration burner consists of one of their standard blue-flame burners attached to a long, transparent tube. At the end of the tube is a white fire-retardant fabric to measure soot production. At each start cycle the flame can clearly be seen to roar to life and with virtually no visible soot or smoke. The inside of the glass tube remains clear, and the white pad at its end remains clean.

During my visit I heard snippets of the term *mit deutcher Gründlichkeit*. I speak very little German, so I asked for a translation. Printed for me by Schroeter, the contemporary translation is "with German efficiency;" however, many still prefer the traditional meaning, "with Teutonic thoroughness." In either case, it describes well the products and the approach of these two small companies in bringing the efficiency of blue-flame oil burners to marine heating. PBB

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