

# Thermateq<sup>®</sup>-nology

April 2001

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## Update on Heat Flux Calibration Standard

### Improvements

In the June 2000 issue of this newsletter, we told you that we have adopted a new method for calibrating heat flux transducers. In that communication we described the new method only very briefly. Since then, many customers and others have asked why we changed to the new method, and have requested more detailed information about it.

There are two possible routes to heat flux calibration, both traceable to NIST. One relies on a radiance standard and the other relies on a temperature standard. Until March 23, 2000 Vatec used the method that is traceable to the NIST radiance standard. Our decision to replace this method was based on the fact that it does not irradiate transducers over their full 180° (hemispherical) field of view.

Why is it important to irradiate heat flux transducers over 180°? One reason is that in the great majority of applications the transducer's field of view will not be restricted to less than 180°. Furthermore, any calibration with less than hemispherical irradiation requires that we (1) measure the field of view and (2) assume or measure the functional relationship between angle of view and sensitivity.

Measurement of a field of view for a transducer is a very tricky proposition. The part of the field excluded must make a negligible contribution to the total energy sensed by the transducer. A cooled aperture of precise dimensions is required, and internal reflections must be prevented. These measures are commonly employed in electrical substitution radiometers, where the objective is to reduce error below 1%, and the cost of the instrument may be much higher than that of a heat flux transducer.

The functional relationship between transducer sensitivity and angle of irradiation is extremely complex because it depends on surface roughness and emissivity of the absorbent coating and on the illuminating wavelengths. The apparatus to measure this relationship is very expensive.

How do we irradiate our transducers over a full 180°? We simply plunge them into a cylindrical black body furnace until the entire transducer is immersed in the calibrating radiation. Obviously we can only do this with special small diameter, long-body transducers. Our reference transducers are 1/2" in diameter and 12" long, water cooled, of course. The furnace used for plunge calibrations is a 1" inside diameter electrically heated graphite tube furnace with argon gas

flooding to prevent oxidation of the electrodes. The furnace is double-ended with a center partition which allows us to measure its internal temperature with a NIST-traceable pyrometer while a transducer is being calibrated.

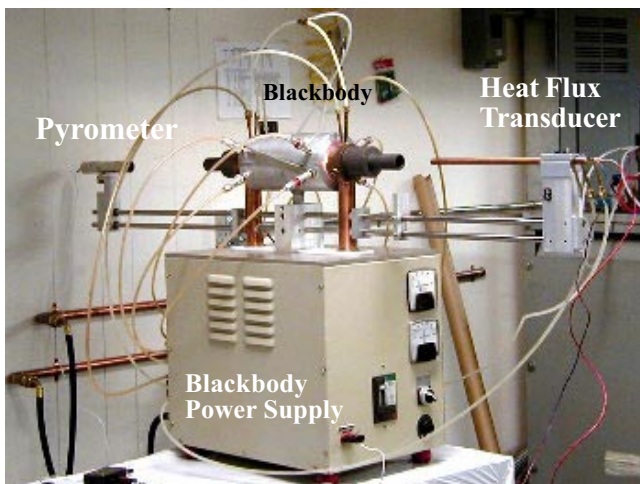
In a typical calibration, the furnace is brought to a temperature representing the heat flux level we want to achieve, with a low flow of argon. When the temperature has stabilized, we

plunge the transducer quickly into the end of the furnace opposite the pyrometer, until its sensing surface is within 1" of the central partition. We record its output continuously during this cycle. After a brief peak which represents a small contribution of convective heat flux from the quick passage through hot argon, the heat flux signal levels off. This is the point at which we make the measurement. After reaching this level the heat flux begins to decrease because the furnace is cooling. This is when we withdraw the transducer.

With the measured temperatures of the furnace and the transducer, we calculate the heat flux represented by the signal, using the Stefan-Boltzmann equation. No correction is made for furnace emissivity because the pyrometer temperature measurement on one end of the furnace is affected by emissivity to the same degree as the heat flux measurement on the other. No correction for emissivity of the transducer is required because we only measure its sensitivity to incident radiation. If an absorbed sensitivity value is required (e.g. for convective applications), it may be calculated using the transducer coating emissivity.

After calibrating a transducer by the plunge method, we use it as a reference in our flat plate heater calibrator. Since we can calibrate reference transducers at up to 300 BTU/ft<sup>2</sup>-sec (340.5 w/cm<sup>2</sup>) much less extrapolation is required in our calibrations than before, when the highest reference rating available was 5 watts/cm<sup>2</sup>. All the instruments used in these measurements are themselves calibrated on a regular basis, so the stability and accuracy of our heat flux calibrations is assured.

For some, this may still not be a sufficiently detailed description of the new calibration method. If you would like to learn more about it, or want to witness actual calibrations, please contact us for more details or for an appointment to visit our office in Christiansburg, Virginia.



## A Customer's Application - University College London

Marios Ioannou and Christopher J.E. Nightingale at University College London recently conducted research titled "Application of Heat Flux Sensors to Detect Liquid Fuel Films within the Cylinder of a Firing SI Engine", published in Society of Automotive Engineers (SAE) journal last year. The authors developed a technique to detect deposition of liquid fuel on the cylinder bore of running IC engines. A key feature of the technique is its ability to avoid lubricating oil affecting the signal indicating the presence of fuel. The technique has been demonstrated on a single-cylinder engine converted to take cylinder heads from recent production 2- and 4-valve, port-injected, V8 engines.

There has been considerable progress made in recent years on the application of heat flux sensors to the measurement of fuel film on the walls of the intake ports of port-injected gasoline engines (see references). The authors saw the potential to use heat flux sensors within the cylinder to reveal information about the deposition of liquid fuel onto surfaces. The objective of this research was to develop such a means of measuring heat flux at the cylinder bore, and to apply it to determine which factors influence fuel deposition on port injected SI engines.

Vatell Corporation's HFM 7 transducers were selected as they had already been proven robust enough to withstand the IC engine environment, and aspects of their performance had been thoroughly investigated (see references). Each sensor was mounted by having a stepped hole in the cylinder bore with a capture nut pushing the flange of the sensor onto the step of the hole through a thin copper washer. The sensor was positioned so that its face was set flush with the arc of the engine's bore.

Figure 1 shows the cylinder block with an indication of how a HFM could be located using a suitable capture nut. It is evident from the figure that the cylinder block had ample provision for coolant passages in order to keep the cylinder bore at a reasonably uniform temperature.

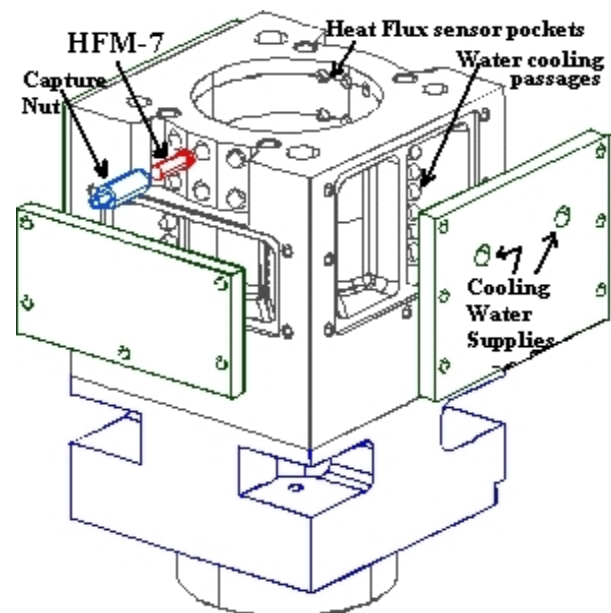
The authors have proven it possible to construct a firing single-cylinder test engine in which heat flux sensors have been mounted in the cylinder bore without being affected by lubricating oil deposited on their surface. The sensors have been located in positions where fuel might be expected to impact on the bore of port-injected SI engines, and the sensors have

given clear signals to indicate when fuel was deposited.

The results of a test program using 2- and 4-valve cylinder heads from recent production, V-8, port-injected engines have led to the following observations concerning fuel deposition on the cylinder bore:

- Fuel deposition occurs in the obvious area, that is near the top of the bore on the side facing the incoming fuel and air mixture.
- More fuel deposition was observed with open valve injection (OVI) than with closed valve injection (CVI)
- Fuel deposition with CVI (2-valve head) was only observed with cold (around 20°C) engine surfaces, and it appeared to be caused by fuel residing in the intake port which was picked up by the initial high-velocity flow of gas into the cylinder, once the exhaust valve head closed. There was negligible fuel deposition with CVI using the 4-valve head.
- Fuel deposition with OVI occurred at all engine temperatures and was due to airborne droplets travelling past the intake valves with an average transport speed around 20m/s. Variation of OVI injection timing over a relatively narrow range, 10° ATDC to 60° ATDC (induction), caused the actual area of impact to move up and down the bore, probably under the influence of changing air flow pattern.
- Comparisons were difficult to make due to the existence of different flow conditions within the cylinder, but there were strong indications that fuel deposition on the cylinder bore was considerably greater with the 2-valve head

Figure 1: Cylinder block design



than with 4-valve head.

- Where flow conditions within the cylinder were the same for the same cylinder head, the technique was capable of giving a qualitative indication of the amount of fuel deposited.

### References:

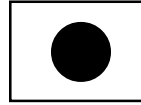
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## Just a Reminder:

We have many of our standard transducers in stock, which means just a few business days for delivery.

We produce a standard line of heat flux transducers that meet 99% of customers' needs. We can also produce custom designed transducers. Our engineers take great pride in being able to develop custom housings and transducers that match the exact requirements. We can even deposit transducers directly on many test objects. Call us today to find out more.

## Our world-wide partners:



Japan - Genorex Corp.  
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## We want to hear from you...

We would love to hear about your heat flux applications.

Also please feel free to contact us about:

- Receiving this newsletter
- Submission to the newsletter
- Products for heat flux sensing

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## Inside:

- Update on Calibration Standard improvement - (page 1)
- A customer's Application - University College London (page 2&3)
- Our world-wide partners (page 3)
- Technical Note: Maximum Heat Flux Level (page 4)

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## Technical Note: How much Heat Flux Can Your Transducer Withstand?

To determine the maximum heat flux that the BF or Episensor can tolerate, one needs to know three numbers: the effective thermal resistance of the transducer, the maximum temperature rating of the transducer, and the temperature of the heat sink onto which the transducer is attached.

The first two quantities can be found on the specification sheet. The thermal resistance of the BF and Episensor is about 8.3 °C/W/cm<sup>2</sup>. However, there will be some thermal contact resistance between the transducer and the heat sink in addition. If the special double-sided

adhesive Vatell supplies for attachment is used, we need to add another 0.5 °C/W/cm<sup>2</sup>.

The maximum temperature of the transducers is 150 °C. For this example, let's assume that we have a water-cooled copper block that stays at 20 °C. We can compute the maximum heat flux as follows:

$$\begin{aligned} \text{Max HF} &= \frac{(\text{MaxTemp} - \text{SinkTemp})}{(\text{ThermalResistance})} \\ &= \frac{(150\text{ °C} - 20\text{ °C})}{(8.3\text{ °C/W/cm}^2 + 0.5\text{ °C/W/cm}^2)} \\ &= 14.8\text{ W/cm}^2 \end{aligned}$$

The critical assumption here is that the surface to which the transducer is applied is an infinitely large heat sink with good thermal conductivity (like a water-cooled copper block).

If you are putting the transducer on a surface that is porous (which would inherently have high thermal contact resistance) or does not carry the heat away from the transducer efficiently, the transducer will heat up much more quickly and so your maximum heat flux will be much smaller.



For more information, please contact Vatell Technical Support