Cylinder outlet temperature vs turbocharger turbine inlet temperature

When wet cleaning turbocharger turbines on 4-stroke diesel engines it is important to maintain the correct turbine inlet temperature. But as Manfred Schumm explains, this can often only be estimated.

Wile cylinder outlet temperature is a central value from which an engine builder can derive information about component material temperatures, the quality of combustion and the power output of the cylinder concerned, for the turbocharger manufacturer – and operator – it is the temperature directly ahead of the turbocharger that is a decisive value.

But why should there, essentially, be a difference between these two temperatures? After all, only the engine’s usually well insulated exhaust pipes lie between the exhaust valve ports of the cylinder head and the turbocharger’s turbine inlet – and the nearest cylinder is often only a few centimeters from the turbocharger.

Well, there is a difference and this is explained below. Suffice it to say at this point that the difference is considerable and the situation is counter-intuitive: measurements on engines in the field have shown that the exhaust gases directly ahead of the turbocharger can be 100 – 140 °C above the temperature indicated by the sensors engine builders fit at the exhaust ports.

This temperature differential (∆T) is an important reference value for engine operators. To get the important operating values mentioned above, engine builders invariably fit temperature sensors at all the cylinders of their engines. By contrast, a temperature sensor is not always fitted ahead of the turbocharger.

Wet Cleaning
This situation can cause difficulties when the engine operator wishes to carry out wet cleaning of the turbocharger’s turbine-side components. This is necessary to remove deposits left when the engine is burning fuels like marine diesel (MDO) or, especially, heavy fuel oils (HFO). Such deposits completely change the carefully designed aerodynamic and thermodynamic behavior of the components in the exhaust gas path, in particular at the nozzle ring, the turbine and turbine housings. In the case of lower quality heavy fuels, these deposits can be very hard to remove, especially in conjunction with exhaust gas temperatures of above 520 °C.

The injection of cold water causes a sudden temperature change in the materials of the turbine-side components and in most cases a noticeable rise in exhaust gas temperature. Injecting water raises the density of the exhaust gases and at the same time extracts heat from the exhaust gases, resulting in reduced energy reaching the turbine. Both effects cause a decrease in turbocharger speed and hence lower charge air pressure, which in turn causes an increase in exhaust gas temperature. To maintain the required engine output in certain applications, e.g. baseload diesel power plants, the loss of engine power is compensated by additional fuel injection.
ABB Turbocharging specifies a series of parameters aimed at minimizing these stresses during wet cleaning. Of these, limits for exhaust gas temperature ahead of the turbine, both before and during wet cleaning, are the most important.

As we have seen, if the engine operator uses the cylinder outlet temperature to set the turbine inlet temperature, it is possible that the actual temperature ahead of the turbocharger will be 100 to 140°C higher than assumed. The result is the excessive thermal stresses mentioned in the turbine housing and at the nozzle ring. And after only a few wet cleaning intervals performed at excessive exhaust gas temperature ahead of the turbine, the visible results could be hairline cracks and even material particles breaking off these components. In addition, the inadmissible stresses involved can cause distortion of flanges and hence lead to fluid leakages (gas and cleaning water).

How do these differences in the measured temperatures occur?

A thermocouple in front of the turbine is permanently in the exhaust gas flow, and at constant engine load it is surrounded by gases with a more or less homogeneous temperature and flow. It is thus capable of measuring the real turbine inlet temperature.

By contrast, the thermocouple after the cylinder is subjected to changing conditions, principally due to the intermittent flow of exhaust gases from the cylinder as the exhaust valve opens and closes. It is thus not constantly surrounded by hot gas.

The cycle of a cylinder on a 4-stroke engine comprises 720° of crankshaft angle – i.e. two revolutions – and depending on timings, the exhaust valve can be open during about 300 of the 720°. This means the sensor is subjected to hot gases for less than half the 4-strokes. No gas is flowing during the remaining period and the sensor cools down.

Another important factor is that valve overlap is used to achieve “scavenging” of the cylinder – i.e. the inlet valve opens while the exhaust valve is still open and much cooler charge air pushes the exhaust gases out of the cylinder. The inevitable mixing of the air and the exhaust gases leads to further cooling of the temperature sensor.

The sensor after the cylinder thus experiences three different situations:
1. Exhaust valve open: hot gas is flowing past the sensor
2. Exhaust and inlet valves both open: a mixture of hot gases and relatively cool air is flowing past the sensor
3. Exhaust valve closed: the sensor is immersed in a relatively cool "scavenging pocket"

These variations combined with the inertia of the sensor lead to a form of “averaging” of the temperature read-out seen by the engine end user.

Which proportion each of the three states mentioned above contribute to the overall conditions around the sensor depends on the position of the sensor, the engine’s valve timings, valve overlap and the scavenging gradient, i.e. the difference between the charge air pressure and the pressure after the cylinder, which in turn is influenced by the turbocharger specification.

It also often occurs that the different cylinder outlet temperatures deviate more or less strongly from one another, which may derive from variations in combustion quality from cylinder to cylinder or interaction between neighboring cylinders via the exhaust gas collector system. This is influenced by the engine’s firing order (pressure wave from one cylinder counteracting the exhaust outflow from another).

Summary

The quintessence is that cylinder outlet temperature is not identical with turbocharger turbine inlet temperature and the effects of wet cleaning turbocharger turbine side components at too high a temperature can be severely detrimental.

The engine end user should try to hit ABB Turbocharging’s recommended temperature range based on turbocharger turbine inlet temperatures 100 to 140 degree higher than cylinder outlet temperature.

Moreover, it may be necessary to adjust exhaust gas temperature by further reducing engine load after the start of wet cleaning due to the effects of the cleaning water described above.

The range 100 to 140°C temperature we quote is based on experience from the field, gathered on several engine types. The band width of 40 degrees is derived from various parameters and influences. It is intended to serve as a guide for engine users for setting a suitably accurate exhaust gas temperature ahead of the turbocharger during wet cleaning when there is no temperature sensor at the turbine inlet.