# Beyond What the Eye Can See[1]

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The availability of devices capable of creating an image of the infrared radiation emitted by an item of process equipment such as the $CO_2$ absorber in an LNG unit has reached the stage where, today, there are free apps that will turn a cellular telephone into an infrared camera. In many cases, the quality of the images may not be sufficient to permit actual process temperatures to be inferred accurately. However, for some engineering purposes even a cell phone equipped with a thermal imaging app may reveal valuable information. For example, gross maldistribution in a packed column can be readily discerned even in a rather low resolution thermal image.

This article looks first at factors that can affect the temperatures actually recorded by a thermal camera, then it compares the temperature profiles extracted from thermal images of three $CO_2$ absorbers in three separate LNG plants with the results from ProTreat® mass transfer rate-based simulation.

**Thermal Imaging**

Infrared (IR) radiation is not visible to the human eye, but every object above absolute zero emits IR. Radiation in the IR range (IR light) is absorbed by glass, so IR camera lenses must be made of materials other than optical or common glasses (so phones must be facial recognition capable). The focussed light is scanned by a phased array of infrared-detector elements. These elements generate a very detailed temperature pattern, or thermogram. It only takes about one-thirtieth of a second for the detector array to obtain the temperature information needed to make the thermogram.

The thermogram is translated into electric impulses which are sent to a signal-processing unit. This consists of a circuit board with a dedicated chip to translate the information from the original elements into data for the visual display. The information appears as various colours depending on the intensity of the infrared emission. The final image is created from the combination of all the impulses from all of the elements.

High temperatures and steep temperature profiles are common in columns absorbing $CO_2$ in LNG plants. Heat of absorption and heat of reaction from $CO_2$ combining with reactive amine solvent generates significant heat. The most common solvent is N-methyldiethanolamine (MDEA) spiked with a lower concentration of piperazine to enhance the reaction rate. Alternatively, aminoethoxyethanol (DGA® or equivalently ADEG®) can and has been used in LNG production. As shown by Weiland and Hatcher (2017), the size and location of the temperature bulge in an amine absorber is a well-defined function of vapor and liquid loads and each phase's heat capacity. If the temperature bulge is not where it should be, is not of the right magnitude or is too broad or too narrow, trouble may be brewing or may have already occurred. Unfortunately, absorbers are only very rarely fitted with thermowells and temperature sensors at positions within the column. Without internal sensors, the simplest way to infer temperatures inside absorbers post-build is via thermal imaging. Thermograms are fairly easy and inexpensive to create, and although they are not as accurate as direct temperature measurement, they can be revealing of real performance and can even expose malfunctioning equipment such as poor liquid or vapour distribution. However, care must be taken in generating thermograms themselves, and especially in their quantitative interpretation.

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**Thermal Imaging Pitfalls**

Perhaps the deepest pitfall in thermal imaging is ascribing too high reliability and precision to numerical results. The thermal image of a tower records the temperature of the IR radiation being emitted from the surface of the shell at every position in the image at the instant the image is taken. However, to translate the colour map into quantitative temperature measurements there are always questions of repeatability, effect of miscellaneous paraphernalia attached to the column, accounting for changing perspective across the height of the column, correcting for the temperature gradient through the tower shell, the effect of wind speed and direction on shell surface temperature, natural variations in the emissivity of the shell's surface, effect of viewing angle, and accounting for sun vs. shade.

*Column Attachments*

There are numerous attachments fixed to column exteriors. Some are grossly obvious such as platforms and ladders, others are more hidden such as small diameter piping, electrical conduit and small blanking flanges. Gross attachments are easier to exclude from measured temperatures but because of limited optical resolution small items are not. Because all surfaces both absorb and emit radiation, column attachments necessarily affect surface temperatures in their vicinity. In other words, they affect the temperature, hence the IR radiation frequency.

*Varying Emissivity, Shaded and Sunny Sides, Wind Effects*

Figure 1 shows a scan of the hot part of an LNG contactor. The locations where measured IR radiation was translated into the indicated temperatures are shown by the + signs. Measurements are in pairs with each pair at the same tower elevation. Members within a pair differ by between 3.2 and 5.9°C. Sometimes the left side is hotter than the right; other times it is reversed. There are numerous possible reasons for such differences, including but not limited to:

- Maldistributed liquid and/or vapour flows
- One side of the column receiving more or less direct sunshine than the other
- Varying emissivity
- Surface cooling by wind blowing across the column

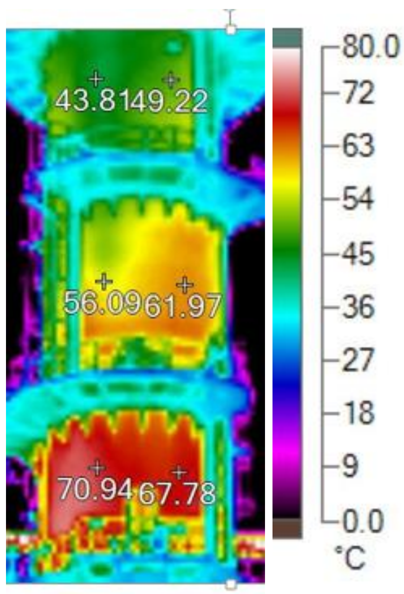


**Figure 1 Thermal Scan of Part of an LNG Absorber**

There is no obvious way to isolate the cause and certainly no way to account for each factor. All one can do is take the variation as indicative of the reliability of the measurements in the particular case. However, surface cooling by wind and temperature drop from vessel wall resistance to thermal conduction can be accounted for, at least approximately.

*Effect of Wind and Wall Conduction*

A tower shell is essentially a vertical cylinder in a crosswind and some attempt can be made to account for the wind's effect on the measured skin temperature. For known wind velocity a first pass estimate is a straightforward calculation, based, for example, on the GPSA Data Book, Figure 8-13 which accounts for convection and radiation from the tower skin to ambient air. Resistance to heat conduction through the tower wall is accounted by the conventional thermal conduction equation where the heat flux is just $k(t_{inner\ wall} - t_{outer\ wall})/L$ where L is the shell thickness and k is thermal conductivity. The two mechanisms combine to relate the skin and tower inside temperatures.

Figure 2 shows a series of lines that exemplify the effect of wind velocity and tower wall thickness on the difference between the tower inside and skin temperatures. In other words, the plots show the offset between the skin temperature which is actually being measured, and the tower internal temperature which is what we want to know. Figure 2 is for 2.5-, 4.0- and 5.0-m (8-, 12-, 16-ft) diameter towers operating at 69 bara (1,000 psia). Corresponding mild-steel shell thicknesses are 105, 165 and 206 mm and the tower inside temperature was taken as 85°C (185°F), typical of the bulge temperature in an LNG plant $CO_2$ absorber. Ambient temperature of 20°C was assumed.

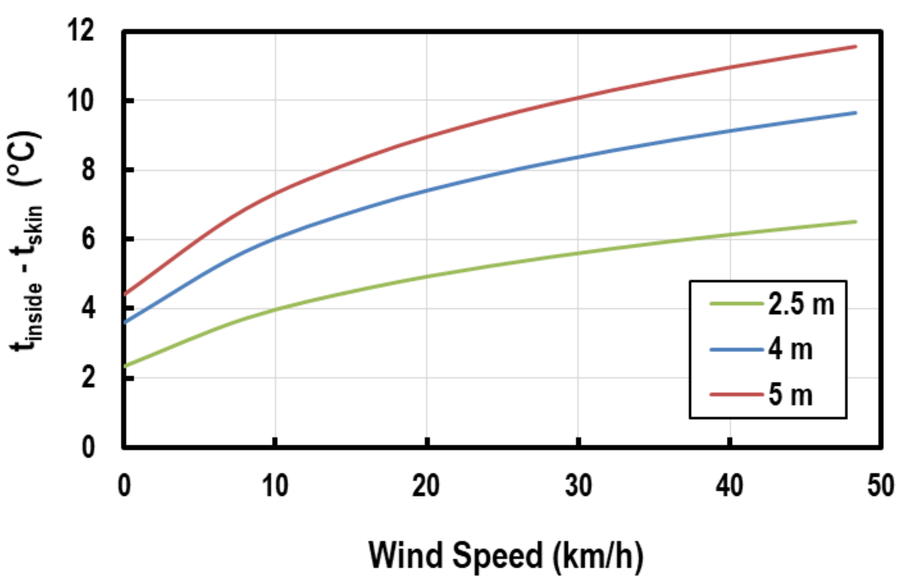


**Figure 2 Effect of Wind Speed and Tower Diameter (Legend) on Temperature Drop across Tower Shell**

Depending on wind speed and tower shell thickness (a function of tower pressure, diameter and material) there can be quite substantial differences between what is measured as the skin temperature and the actual tower internal temperature. The measured skin temperature can easily be 5–10°C colder than the value inside the tower.

There are additional factors that can complicate the translation of a thermogram into a tower temperature *profile* such as relating the elevation on the tower shell to the actual location within the packed beds in the column. It can be less than straightforward to locate the actual top and bottom of multiple (or even a single) packed beds and to locate precisely a point within the packed bed relative to the top or bottom when the length scale used for measurement (the tower diameter as measured by a ruler on paper) is changing along the column from foreshortening, i.e., perspective. If the viewing angle is too shallow, as it is near the edges of the tower, results will be further compromised.

**Temperature Profiles from Thermograms versus Simulation**

The other way to assess temperature profiles in $CO_2$ absorbers used in LNG production is through accurate mass transfer rate-based simulation. The premier software with a proven track record in all gas treating applications is the ProTreat® simulator. The toughest situations involve packed columns containing either random or structured packing; trayed columns are relatively easy to simulate. Packed columns are almost always specified in LNG applications. Here we will look at an example with structured packing, one with a random packing, and one in which temperatures were directly measured with thermocouples located within thermowells positioned inside a bed of random packing.

**Structured Packing**

The tower in this first example is packed with several beds of Mellapak M250.X structured packing. It processes high pressure gas containing nominally 2.8% $CO_2$ using a piperazine promoted MDEA solvent. The temperatures shown in Figure 3 were taken from four repeat images of the tower. The entire series of four images was taken within a very short time span of 33 seconds. The open circles represent the data after correcting for the temperature gradient across the tower shell and the cooling effect of 25 km/h wind.

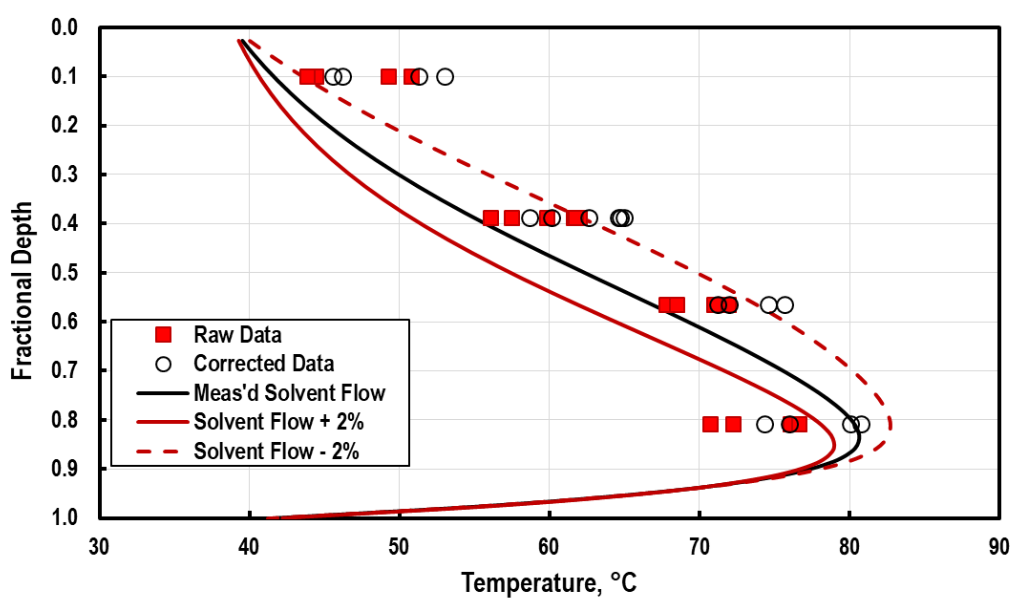


**Figure 3** **Comparison between Measured (■) and Corrected (○) Temperatures and ProTreat® Simulation; Structured Packing**

There is between a 5 and 6°C variation within any set of four measurements at the same elevation, and about a 4°C correction needs to be applied to account for thermal effects across the column wall. Simulations are within a few degrees of the measured data and slightly lower than the corrected temperatures. Despite the thermogram values being scattered, simulation is a fair representation of the trends observed.

Figure 3 also shows considerable sensitivity of simulated temperature profiles to changing solvent flow rate. A ±2% meter error on solvent flow rate would be considered quite good accuracy. However, even this amount of variability causes the simulated temperature profile, and the temperature at the bulge to move from worse agreement to excellent agreement. Knowing temperature profiles can be important because they can be used to pinpoint high corrosion regions and to suggest the potential seriousness of the corrosion. They can also indicate damage to tower internals, and poorly calibrated or misreading instruments. If the simulator can be shown to accurately predict the temperature profile, operator confidence in both field instruments and simulator reliability is enhanced. The simulation tool can then be confidently used for optimisation and in any number of other 'what if' studies.

**Random Packing**

The tower in this example is nominally 5-m diameter, packed with two beds of a metal Intallox® type of random packing and processing very high pressure gas containing nominally 2% $CO_2$, again using a piperazine promoted MDEA solvent. The high gas pressure and large tower diameter resulted in a very substantial tower wall. The thermogram shown in Figure 4 is one of many taken of this tower over a period of less than seven minutes.


**Figure 4 Thermal Scan of Part of Random-Packed Absorber**

Figure 5 shows the temperatures gleaned from the complete set of thermograms (■) together with the temperatures as corrected (○) to account for the gradient through the shell and cooling from an assumed 25 km/h wind. At the temperature bulge (about 80°C) it appears that thermographic repeatability is about ±5°C while at the column top, repeatability is about ±2°C. The ambient heat loss correction at the bulge temperature is about +8°C.

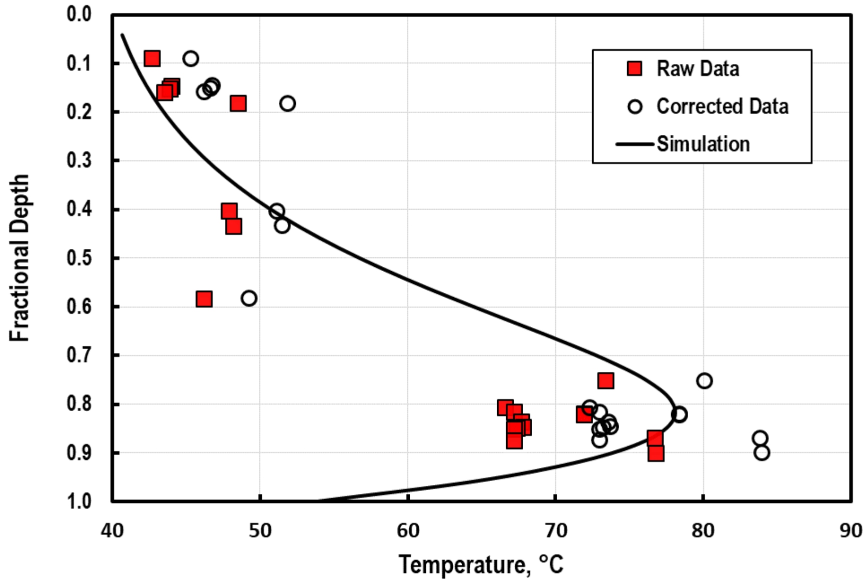


**Figure 5** **Comparison between Measured (■) and Corrected (○) Temperatures and ProTreat® Simulation; Random Packing**

## Thermocouple Measurements

The final case compares simulation with temperatures directly measured by thermocouples within a randomly-packed bed. The absorber is about 4.5-m diameter containing two packed beds and treating 6.3% $CO_2$ gas at 53.5 bara with a piperazine promoted MDEA solvent. The measured (■) and simulated (—) temperature profiles shown in Figure 6 are in excellent agreement. The simulation terminates below the top of the tower because above a fractional relative position 0.09 the column contains three wash trays for recovering vapourised amine rather than packing removing $CO_2$ into the amine solvent.

Given the relatively lower precision of temperatures measured by thermal imaging as shown for example in Figure 5, thermocouples are by far the preferred means to measure temperature. However, in the interest of minimizing capital cost, towers are usually built without thermowells. This is quite unfortunate because even two or three internal measurements at and near where the temperature bulge is expected can provide a wealth of information useful in control and in diagnostics of non-optimally operating absorbers. Thermowells are inexpensive to install during fabrication but prohibitively expense to add later. There is a strong case that the data they can provide justifies the miniscule additional cost for the tower.

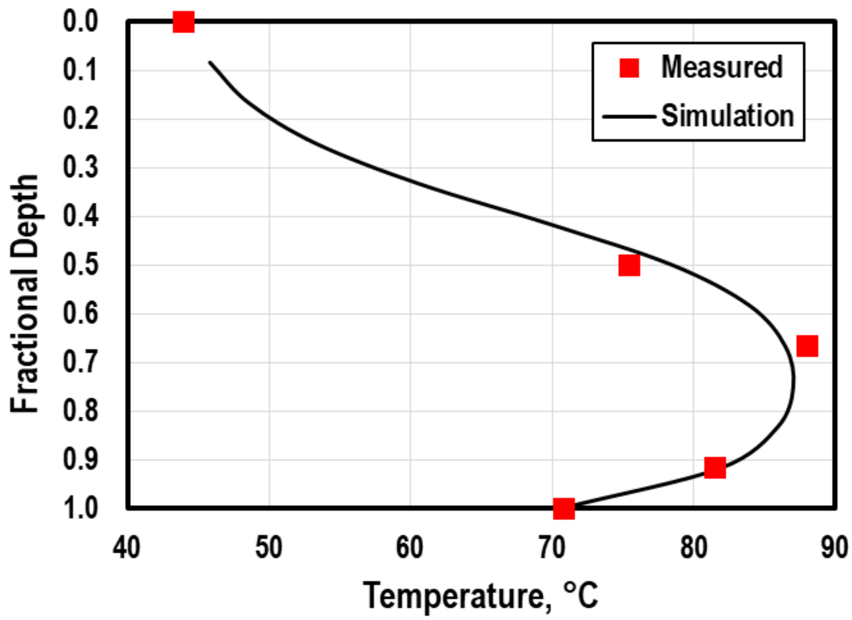


**Figure 6 Comparison between Thermocouple-Measured (■) and Simulated (—) Temperatures**

Knowing what is actually happening inside a $CO_2$ absorber can be of great assistance in diagnosing faulty internals, defective instrumentation, and warning of potentially dangerous corrosion caused by high temperatures. Overall separation performance as revealed by the treated gas composition is not enough, because what is unseen can have dire consequences. A reliable mass transfer rate-based simulator, ProTreat®, will confidently expose how the absorber *should* be operating. A measured temperature profile (preferably using thermocouples) reveals how it is *actually* operating. Even if the difference does not have serious consequences for current unit performance, it may well prove to be significant in terms of the ultimate capacity of the unit, or in terms of unit optimisation.

**References**

Weiland, R. H. and N. A. Hatcher, *Making Sense of Amine Absorber Temperature Profiles*, Hydrocarbon Processing, *22*(2), 47-51, 2017.

GPSA Data Book, Figure 8-13, p. 8-10, Gas Processors Suppliers Association, Tulsa, OK, 2017.