Roberto Jardón

Interview with Dr. **Miroslaw Wrobel** and **Roberto Jardón**

CEO/CTO & Co-Founder of Passero and **Regional Technical Leader** at Cargill BioIndustrial - Power Generation

Photo: Cargill, Passero

Miroslaw Wrobel

Natural Esters: **Insulation Fluids for Green and Reliable Transformers**

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Alan Ross: Hello, I am Alan Ross and this is more than an APC Media interview. It is in fact a big reveal. With us today are two extraordinary experts. One is Miroslaw Wrobel the CEO, CTO, and Co-Founder of Passerro and the other is Roberto Fernandez Jardón, the Technical Leader for Europe and Turkey at Cargill in the Insulating Liquids Division. And that's really what we're here to talk about, natural and synthetic esters. and some of the things that we found out as these gentlemen have worked together and people from Cargill and Passerro have worked together. But first of all, why do we need ester oils? When did their story start? Why did somebody have the idea to make oil out of plants and to put it in transformers?

Roberto Jardón: Well, natural esters were the first natural step, when we were thinking about the development of insulation fluids. We started in the 70s with silicon oil and some other fluids just to breach a gap in fire safety that mineral oil can't deal with. *Synthetic esters started in the 70s as the second generation. But at some point, several additional questions arose: can we make fluid based on bio-based material that also solves the fire safety issues?* In addition to that, it is biodegradable, and it comes from a renewable source. So some very smart guys that were working at Cooper Transformers at that time decided to explore if it could be made to work in the electrical field. And after several years of research, and a lot of different kinds of oils and plants, they came up with a very nice solution that added together all the properties that the transformer manufacturer was willing to have in insulation fluid and additionally having all these fire behavior that they were looking for.

AR So it could be said that safety was an important instigator, particularly fire safety. And since then, Cargill has developed a fire retardant, solution, FR3. But since those early days, we have found there are a lot of other advantages to natural esters as opposed to synthetic ones. And there is a difference between the two. We're going to get a little bit into it. Miroslaw. Let me ask you this question: What do we know about natural esters from a laboratory data standpoint?

Miroslaw Wrobel: We know much already, Alan. Esters will be a very good fluid, for instance in urban areas where we have a transformer close to people's homes, and that is for two reasons. Firstly, due to their fire-retardant properties. The flash point of natural esters is much higher than with mineral oil. Secondly, unlike crude oil derivatives, it's not toxic, and that is very important. We already know that the ester can handle the overload of the transformer much better than mineral oil. If you think about all the electrification levels we want to achieve in the future, like electric cars, and everything else that has to be electric and digital, just think about the amount of power that we will need. But changing out all the transformers in urban areas would be extremely difficult. So why not just change the oil instead?

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AR So, if I understand you correctly, Miroslaw, is that the data we're gathering is showing some really positive, unique values to esters. Anything else you would like to add, Roberto?

RJ Yes, I just want to add to what Miroslaw said. In addition to the higher flash point, esters are also better at handling moisture in the transformer which makes a huge difference. And that was something that was discovered while the FR3 was being developed. The initial tests were conducted in real-life transformers and distribution transformers.
They realized that the paper and the solid insulation aged much slower when immersed in natural ester than in mineral oil. We can discuss that a little. But the main idea is that we are having the same hardware installation around mineral oil and natural ester. And with natural ester, the transformer may last two to three times longer. And there are two ways of approaching this. We can have the transformer working in the same conditions, but longer, or we can explore the transformer working at higher temperatures. Both of these options are very important for handling overloads and this change in the energy consumption profile that Miroslaw was talking about.

AR Yes, absolutely. In the case of esters, we're finding that the law of

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unintended consequences was getting much more benefit, especially today. The demand for medium-sized transformers has gone crazy. Two years ago, we had a supply chain issue. Today we have a demand curve issue. The demand curve is going through the roof. So retrofitting old transformers can keep them lasting longer while you wait for a replacement.

MW We are considering the feasibility of switching isolating oil from mineral to biodegradable. There is a deep need to know how the oil is behaving and if our diagnostic and monitoring method is still fit for our purpose to gather the new information. For the last 100 years, we have been using transformers with mineral oil. The biggest question now is whether we can we apply all those standards to the ester oils, and whether we can expect the same behavior of green oil isolating systems. Mineral oil insulation has many disadvantages, but we take this into account and we try to counteract this with technical solutions like the berms under the transformers, and the constant replacement of the oil. But all of these "fixes" create costs and if the need for the transformers and the electrical power will grow as much as we think, these costs will go through the roof. Changing to ester oils will be the best way to bring these maintenance costs down.

We have over 160,000 data sets from Cargill and we go with the data in all different dimensions, and compare it with the isolating oil data. And I have to tell you, it is absolutely astonishing! The readings are almost perfect! Until now the huge nightmare of the mineral oil isolating transformer has been the acids and water inside it, degrading it and causing problems. These don't play *any* role with Cargill's FR3 and other esters. Instead of degrading, the BDV values are almost on the high because in a natural ester, the water reacts with the acids, hydrating them.

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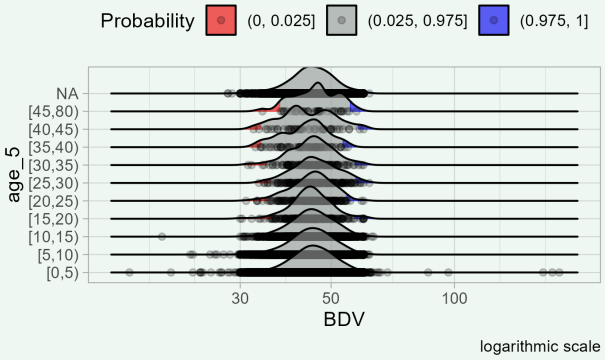
So now you have less acid in the transformer, which means that the paper and the solid cellulose material stay stable for much longer.

RJ Exactly, that is an excellent point! Natural esters have proven to be not just reliable, but virtually maintenance-free. So what they discovered during the tests over the last years is that the higher moisture tolerance of the esters *extracts* the water from the solid insulation that is naturally generated because of the heating of the transformer. It *consumes* that water by reaction with the molecules of the natural ester. And as Miroslaw was saying, we keep the insulation dry to slow down the aging. But this consumption of water also generates free fatty acids that unlike in mineral oil, are mild and non-reactive. This means that they are *not generating a sludge*. So the very important thing to understand is that we can monitor the same things with mineral-oil-filled and ester-filled transformers, but the meaning of these parameters is different for mineral and natural.

MW Exactly! Another example is the temperature model of the transformer through which we calculate the flash point. It doesn't really work for natural esters, because the ester behavior and the heat dispersion are completely different than in mineral oil. So, you can't use those parameters. You have to use something else. Another point is the different viscosity of the oil. The heat capacity is higher than with mineral oil and this means that you can *transform more energy* out of the core. Even better: You can make a smaller, more compact transformer. This means less copper and just generally fewer materials inside the transformer, which is great.

But we will probably have to have to think about different sensors to put on the ester transformer than on the mineral oil ones. DGA for mineral oil is one of the most important things to monitor. Large transformers have something like eleven DGA gases and the behavior of gases in ester-filled transformers is different. Here other factors like the flash point temperature the distribution of the temperature from the core and the viscosity are much more important. A vital aspect of the different viscosity of natural esters is, for example, the lubrication of the windings. Because if you have just paper-insulated windings and the oil is too thick to go through the windings, you will have just a dry removal of the paper inside.

RJ That is a very good point, Miroslaw. With natural esters, especially when there is constant contact with oxygen, we can see long-term how the viscosity of the fluid may increase. Of course, it takes a lot of time, but this is a parameter that is not a routine test for mineral oil transformers but should be a routine test for natural esters because it's an important parameter. Another important thing is to differentiate the *meaning* of these occurrences for the two different insulators. We mentioned acids, which are very dangerous for mineral oils and it is something that needs to be monitored constantly. But for natural esters, it just means that they are working as they're supposed to. It's important to bring this knowledge to the people, to explain the *different meanings* of the tests and how they reflect not only the status of the fluid itself but the complete transformer.



To keep the numbers in the same style as in TTM Issue 24 - "Diagnostic Basics and Laboratory Data Sets", we also put the full age of the transformer with ester. However, note that the total amount of aged ester transformers in the following vintages is only [35,40) => 83, [40,45) => 61, [45,80) => 58. Another point is the compatibility of the BDV measurements. "The mineral oil is typically measured using IEC 60156 and the FR3 ester using ASTM 877. So 50kV with ASTM 877 makes about 80-90kV

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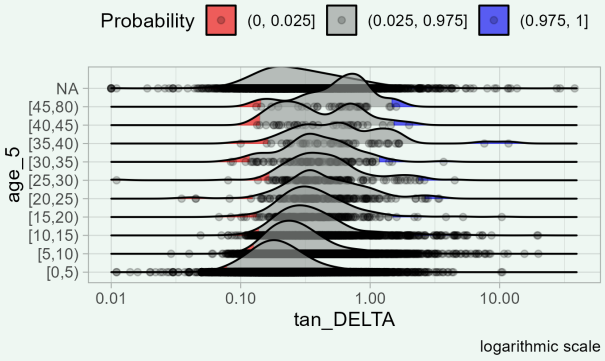
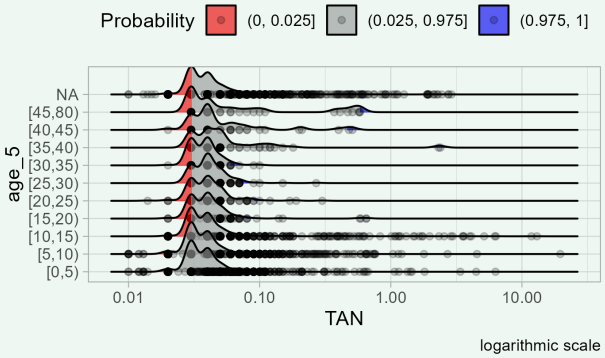
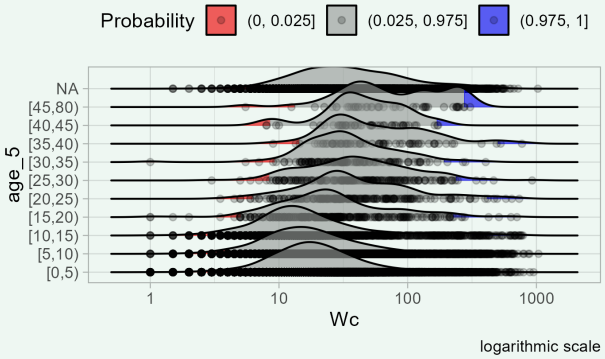
MW Oh absolutely. For instance, you can really overload an ester-filled transformer without serious consequences. If you try this with a mineral oil transformer, you can do this once or twice, and the third time you have a big explosion. You can exploit ester-filled transformers all you want and they will keep coming back for more. However, that still doesn't mean that we don't need some system to monitor the transformer, to tell them when it's enough. But the systems and the parameters used can't be the same as those used for the mineral oil.







RJ And this is exactly what will enable utilities to deal with these different loads and strains on the network efficiently. And connecting with the smart meters that we talked about in the beginning, having the thermal behavior, the thermal image of the transformer, by measuring different points of the temperature inside the transformer with fiber optics can give you an idea of exactly to what extent you can exploit that transformer. For example, if you are having an ambient temperature of ten degrees and a ten MBA transformer under those circumstances, maybe can reach 12 - 13 MVAS without exceeding the temperature limits. And this gap is bigger in

natural esters than in mineral oil. So having the right material with the right monitoring can increase not only the reliability of the installation but the complete resilience of the network. That is something that we need to address urgently also in future network developments.

AR I think people are slowly realizing that transformers are the heart of the power system and how crucial they are because of it. And so what you both and your companies are working on, is quite brilliant. I'd like you to end with this question: Miroslav mentioned the operator, the owner of the transformer. Imagine you're riding an elevator together, he asks you what he should do and you have two minutes.

MW If you have a transformer, that runs with a sustainable and constant load, you don't need to do anything. If you have a transformer that deals with peak loads and peak comparison to the grid, photovoltaic, wind energy, etc. you *need to use ester* and you *need to measure parameters* like viscosity, temperature, and interfacial tension. If you have a transformer with a fault and are in a country with minus degrees Celsius like North Europe, or Canada, you have to keep an eye on the viscosity because it is not as straightforward as with mineral oil.

AR So now, Roberto, it's your two minutes.

RJ Natural ester is a natural and smart choice for transformers. First, you are having a transformer that is fire resistant, that has a fluid that is non-toxic and biodegradable. So in case of any spill or any issue, you will not cause damage to nature. You can explore your transformer at higher loads without jeopardizing the life span of the transformer. You are keeping the insulation dry, which reduced the risk of dialectic discharge or bubbling inside the transformer, reducing the risk of dialectic failures. So you are having a more reliable asset that makes your network more resilient to any change. Additionally, you are going to have the same footprint of the transformer will handle more power, meaning that you don't need to make any upgrades in the substation.

AR Brilliant! I think we made a good case for the benefits of biodegradable esters as the future of liquid insulation. Is there any other point that you think we've not covered?

MW The most important part is just how the oil behaves in cold temperatures. If we keep an eye on that and perhaps adjust the technology a little, everything is doable and the transformer will work without problems. What some experiments with FR3 have shown is, that ester is much better if you have cooling with not laminar, but turbulent flow, because through the turbulent flow, you have more surface contact and you can take more energy out of the core. As I already mentioned before, the heat capacity of esters is much higher than that of mineral oil. So, you can make a compact transformer, but you have to make sure that you pump the oil through the transformer.

And of course, as I mentioned before, we need to adjust the monitors and what they monitor. We at Passerro are currently working on specific sensors for this. It will be something like the Trafostick we already have for mineral oil. At the moment, we can only monitor from the outside of the transformer, but we are extrapolating data from the core. We are still six to nine months away from working out the last kinks but after that we will have the sensor running just right and utilities will be able to just stick it on the transformer and let it be. And if something should go wrong, they will have the information and will be able to act. This will save lots of monitoring and maintenance time because with the increasing number of transformers, we won't be able to take care of all of them simultaneously.

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AR Roberto, what are your closing thoughts?

RJ I would like to cotton onto what Miroslaw said about the importance of this change in the shifting paradigm. We are adding a lot of harmonics in the system from E-chargers, photovoltaic or even wind farms, and even though these harmonics go through the network and reach the transformers, they have several implications. One of them is the harmonic currents, meaning that additional heating may happen on the coils, basically. And the second point is the voltage harmonics that may lead to partial discharge inside the

Photo: Cargill

transformers. And this is something that we have seen in mineral oil transformers and that has been solved by retrofilling them with FR3, because the dielectric properties of FR3 regarding the partial discharge in temperature of voltage are higher than mineral oils. For this change and for this additional challenge that the transformers need to face, FR3 will still be the best solution.

AR One of the things I walk away with from this interview is that we can't take the same parameters that we've looked at for mineral oil and apply them to FR3. We have to apply new parameters. But in every instance, we actually get a higher resiliency and a higher reliability. And those are the two big issues for power systems today. We need to take those better standards and apply them and know that we can operate our transformers much better. They can withstand all of these harmonics, all of these changes. The inverter-based system that we're moving to, power in, power out, you're going to have to have transformers that can withstand all of that, and filling them with sustainable, biodegradable esters will be the way forward. If I were buying a transformer now, I would firewire all around the coil so that I get constant data and I would fill it with Cargill's FR3, and I'd just sit back and be happy and my bosses would love me for reducing labor time and costs.

This has been a great discussion and revelation, gentlemen. Thank you so much for being here today.

RJ Thank you, Alan.

MW Thank you.