Webinar Script

Introduction – Slide 1 (Title)

On behalf of the International Copper Association and all its affiliates and copper centers around the world, I would like to welcome everyone to this Webinar. My name is John Hipchen and I will be the presenter.

As representatives of the copper industry, our goal today is to make you aware of emerging trends, to help you understand what is driving these changes and to explain the technology behind them. We also want to show you energy efficient options that will help meet the demands being placed on our industry. Our member companies who produce copper tubes can provide even more information about specific tube products and supply solutions. And toward the end of this presentation, we will post the microgroove.net website where you can find more detailed information.

Slide 2

The type of coils we will be talking about today are round copper tube, flat fin coils.

Slide 3

And they are used in a number of applications that cover residential, commercial and industrial settings. These coils can be condensers, evaporators, water heating coils and a number of other heat exchanger uses. Round tube, flat fin coils have been around for over 100 years and there are good reasons why they are still in use today. But, as we will see, they are being successfully modified to fit modern demands.

Many of us are already familiar with the increasing requirements for energy efficiency and the push to use refrigerants that are less damaging to our atmosphere. In an effort to lower costs, many design engineers are also under demands for smaller, more compact systems that save on materials and refrigerants. Over the next 60 minutes we are going to discuss these demands for efficiency and cost savings, and we are going to look at how smaller diameter, MicroGroove copper tubing can help meet these demands with minimal investment or change to our well established manufacturing practices.

Slide 4

This photo is taken out of a current catalog of heat exchangers and it is a good example of the changes we are going to discuss today. The new design in this picture shows smaller diameter tubes that not only provide 35% more passes which will result in considerably more heat transfer, but you will notice that the tubes are arranged in a staggered pattern which will again, improve the efficiency of this coil. And this is a good representation of the trend we want to discuss in more detail.

Slide 5 - Benefits

Specifically, we are going to show how reducing the diameter of copper tubes can improve heat transfer resulting in more energy efficient, smaller and lighter coils…bringing about all of these benefits to the manufacturers and distributors of air conditioning and refrigeration systems. Keep in mind that each of these benefits is not only associated with meeting energy and refrigerant regulations, but each benefit also means cost reductions or cost efficiencies that help all of us in an increasingly competitive market.

Slide 6 – Time Line

As I mentioned, the standard round tube-plate fin coil has been in use for over 100 years. In the 1980’s, tubes with internal grooves and enhancements were developed. Because these internal modifications were found to have such a big impact on efficiency, they quickly became common in the market. The name “MicroGroove” today refers to these internal enhancements. But “MicroGroove” is a newer name and it also means smaller diameter tubes. Over the past 10 years, we have seen a trend toward internally enhanced smaller diameter tubes, and on this timeline we noted that coils with MicroGroove tubes have been in commercial use since approximately 2005.

Slide 7 – OEM Manufacturers

And we know that all of these OEM manufacturers are currently producing systems with small diameter MicroGroove tubes.

Slide 8 – Technology Drivers; Factors Influencing the Trend Toward Small Diameter

There are a number of factors behind the move toward small diameter tubes and they range from government mandates on energy efficiency such as increased SEER ratings, to the phasing out of R22 refrigerant and the higher pressures that are associated with replacements for the R22. R22 replacements include 410a which is currently being used in residential air conditioning systems. The coefficient of performance, or COP, is another rating that design engineers are paying more attention to and the drive to increase COP's is yet another factor behind trends toward smaller diameter tubes.

Slide 9 – Regulation Timeline

About 20 years ago, government regulations became a larger factor in the design of air conditioning and refrigeration equipment when the Montreal Protocol took effect in January of 1989. Since then, it has undergone 7 revisions. The Montreal Protocol mandated a phase-out plan for CFC's (which are chlorofluorocarbon) refrigerants by 1995. This covered refrigerants like R-12 that are no longer used. HCFC refrigerants (Hydro chlorofluorocarbons) were allowed as transitional replacements until HFC refrigerants are fully implemented. HFC stands for Hydro fluorocarbon and this family of refrigerants does not have chlorine, chlorine being the problem element which has been linked to the depletion of our ozone layer. R-22 was a transitional HCFC refrigerant and today we see this being replaced by HFC's like 134a, 404a and 410a. It is typical for HFC refrigerants to operate at higher pressures than CFC or HCFC refrigerants. R744 is the name for CO2 as a refrigerant and systems that use CO2 have even higher operating pressures. In Europe, a directive that is often referred to as the "F-Gas" regulations ban the use of 134a in new automotive platforms starting in 2011. The Kyoto Protocol was adopted in December of 1997 and went into effect in 2005. The Kyoto Protocol adds to the phase-out of CFC covered by the Montreal Protocol and focuses on greenhouse gases and HFC's. To quickly summarize this slide, government mandates related to energy efficiency and refrigerant use have pushed air conditioning and refrigeration manufacturers toward new coil designs that have to be more efficient and handle higher pressures.

Slide 10

Before we get into the technology of ACR coils and the technical reasons behind the trend to small diameter tubes, we want to emphasize just how complicated this subject is. We have refrigerant that is moving through coils and as it does, the refrigerant changes phase from vapor to liquid, or vice versa. In the process, we have heat being transferred from the refrigerant through the tubes to the fins and ultimately into the air. And finally, we have the air that is moving across the fins and the heat that is being dissipated into that air. In all of these segments, we have dynamic processes occurring so the math behind the design of a coil can be lengthy and complicated. For the purposes of this discussion, we will concentrate on technical concepts and we will use images to make our points. We plan to avoid any heavy math today, however, we could go into that level of detail in a separate meeting where we would have sufficient time to do so.

Slide 11 – Thermal Resistance

So let's review the path that heat takes and the mechanisms involved as it moves from the refrigerant inside of a tube, through the tube wall, into the fins and finally into the air. This slide illustrates heat flow in a similar manner as electricity, with areas of resistance. Starting on the right, inside the tube, refrigerant carries heat and moves that heat into the tube wall. Conduction transfers that heat through the tube wall where it either continues to move into the fins or the heat can be transferred into the air moving across the tubes by convection. The heat that has been transferred into the fins is eventually transferred into the air by convection. So we see areas where both convection and conduction are the mechanisms at work transferring heat. Now let's take a close look at exactly what happens to the refrigerant flowing through the tubes because that is where all of this heat transfer begins.

Slide 12 – Development of Boundary Layers

Whenever fluid moves through a tube, the fluid closest to the tube wall behaves differently than the fluid in the center of the tube. The fluid next to the tube wall sets up a boundary layer where heat transfer becomes more difficult. And this applies to the hydraulic motion of fluid, as well as the way heat moves from the center of the tube to the tube wall. So heat transfer engineers refer to both hydraulic and thermal boundary layers. To simplify, fluid closest to the tube tends to move slower than the fluid in the center. Even in turbulent flow, a laminar sub-layer forms and heat moves slower through these boundary layers than it does in the faster-moving fluid toward the center of the tube. Boundary layers act as an insulator and interfere with the heat transfer that we want.

Slide 13 – Reduction of Boundary Layers

The internal enhancements in MicroGroove tubes, in other words the grooves and proprietary patterns that tube manufacturers put on the inside tube wall, reduce this boundary layer and increase heat transfer through the tube wall. Here we can see the boundary layer in a smooth tube develop and it does not dissipate or go away. In a tube with MicroGroove enhancements, you can see the boundary layer begins to develop, but it breaks down as it moves over the grooves.

Slide 14 – MicroGroove Features

The exact configuration of the internal grooves and patterns is based on a long history of technical development and design, and is backed up by both experimental and field performance data. And the data clearly shows significant advantages to MicroGroove tubes.

Slide 15 – Boundary Layer Theory

The additional mixing of the refrigerant that occurs inside the tube because of these grooves increases the amount of refrigerant that comes in contact with the tube wall. The positive effect on heat transfer from these internal enhancements has been known for a long time and applied commercially for over 20 years. And, when combined with small diameter tubes, we have even more advantages that we want to look closer at. But before we do, let's look for just a minute at how air flows through a round-tube coil.

Slide 16 – Air Flow Around Tubes

Air must flow around the tubes as it passes through a coil and as it does, the air stream is broken up and heat is transferred into the air. The number of tubes and the location of the tubes, as you can imagine, will have an impact on the air pressure that is lost going through the coil.

Air forms the same type of boundary layers as refrigerant does, and in many respects it can be dealt with the same as any fluid. Just as we saw with microgrooves inside of the tubes, outside, the tubes break up any boundary layers that the air tends to form as it flows through the coil. The more tubes we use, the more we break up the boundary layer on the air-side, and more heat transfer will result. But in many cases, more tubes mean a higher air-side pressure drop. So there is a balance at some point where a coil uses an optimal amount of air to achieve the heat transfer that the system requires. Remember also, that heat is being dissipated by the fins and the fins have slots or louvers again, to break up air boundary layers and improve heat transfer.

Now, let's discuss the geometry related to a reduction of tube diameter and while we do, keep in mind the fluid dynamics that we just looked at and the advantages of microgrooves.

Slide 17 - Geometry and Surface Area Advantages

When we compare tubes of different diameters, the first thing we might notice is that it will take several smaller diameter tubes to equal the surface area of a larger diameter tube. At first glance, we might think this is a disadvantage but we actually have some important benefits here, a big one being an increase in the surface area to volume ratio and that equates to more heat transfer. And, with this increase in heat transfer, we don't need to match the volume or surface area of the larger tube to get the same amount of cooling. Another benefit that we haven't mentioned yet is that in a smaller diameter tube, we can hold the same pressure as the larger diameter tube but we can do it with thinner tube walls. So, when we reduce tube diameters, we can actually reduce the weight of the materials being used and in turn, reduce costs.

Slide 18 – Increased Heat Transfer with Less Material
And, as we continue to reduce tube diameters, we continue to gain surface area in relation to the amount of refrigerant we have in the tube. And we can continue to reduce tube wall thicknesses while still meeting the same pressure criteria as the larger tubes. Or, from another angle, we can handle higher pressures in small diameter tubes with the same tube wall thickness. The bottom line, is that we can do a whole lot more with considerably less material.

Slide 19 – Surface Area / Volume
To demonstrate this further, we are looking at a plot of surface area over volume. As we go from 9 – ½ mm diameter, all the way down to a 3 mm diameter tube, you can see that the amount of surface area that is available in the same volume increases dramatically. And that is why the heat transfer coefficient is so much higher in smaller diameter tubes…because there is more surface area available to transfer that heat.

Now let's start talking about what happens to the entire coil when we substitute smaller diameter tubes.

Slide 20 – Coil Design Factors
For the person designing coils, there are a number of factors that can be considered. And all of these factors will have an impact on things that people who buy these coils are interested in, like how big they are, how much energy they use and how much they cost. So there are options when it comes to designing coils and we want to look closer at some of these options to see exactly what the effects are on performance.

Slide 21 – Coil Design Factors
So, let's adjust these parameters; (1) the total length of the tubes, (2) the amount of surface area, and (3) the volume of refrigerant.

Slide 22 – Coil Design Factors
The effects we are interested in when these parameters change are (1) the overall performance of the coil as measured by the amount of heat that can be transferred, (2) the weight of the coil because that correlates directly with material cost, and (3) the heat transfer coefficient or coefficients if we remember the thermal resistances in the earlier slide. For this discussion, we will reduce the diameter of the tubes. Without getting into a lot of numbers, let's look at a chart that shows the effect of changes to these parameters:

Slide 23 - Constant Tube Length
This chart shows different scenarios, and in each case, we are reducing the diameter of the tubes. And, in each scenario, you can see that one of the parameters is held constant. Let's look first at what happens when we hold the total length of tubes constant but reduce the tube diameter. What we are talking about here is not the length of each individual tube. If we add up the lengths of all the tubes we get a total tube length and that is what we are referring to. If we match the total tube length, we see a decrease in surface area, volume and weight. The heat transfer coefficient increases but the drop in surface area is such that the system can not match the original performance, so that performance drops. This would amount to considerable cost savings due to the low refrigerant charge and reduced materials, but depending on the application, that drop in performance would probably not be acceptable.

Constant Performance – Same Slide (23)

In the second column, the performance is constant but in order to achieve that, the total tube length was increased. We have considerably less surface area than the original coil and also much less volume, less weight and a higher heat transfer coefficient. This scenario shows a coil that matches the performance of the original, but is smaller, lighter, has a lower refrigerant charge, and very important to a lot of people, it will have a much lower cost.

Constant Surface Area – Same Slide (23)

In the third column, the surface area is held constant which means the total length of the tubes will increase and if we use the same tube wall thickness, as we did in this chart, it works out that the weight is about the same. But I want to point out that when we match the surface area with smaller diameter tubes that have typical reduced wall thicknesses found in supplier's product catalogs, we actually see a reduction in weight. The volume will decrease and the heat transfer coefficient increases, again due to the tube efficiency. In this scenario, performance increases considerably and costs are reduced because there is less refrigerant.

Constant Volume – Same Slide (23)

In the last column, the volume is held constant which means the total length of the tubes is increased much more than the other scenarios, the surface area increases and so does the weight and heat transfer coefficient. However, in this scenario the performance goes up dramatically. Although a cost increase would be expected in this scenario because these coils will use more materials, that cost is buying a big increase in performance.

Slide 24 - Technology Drivers

Now that we have looked at some theory behind the benefits of microgrooves and small diameter tubes, let's remember the factors that are driving our market right now.

As design engineers grappled with all of these changes, they realized that there are benefits of smaller diameter MicroGroove tubes that had not yet been fully exploited and that these benefits could solve a lot of the problems they were dealing with. Specifically, the increase in surface area to volume ratio from MicroGroove tubes had a big impact on the heat transfer coefficient. Plus, smaller diameter tubes could stand higher pressures with thinner tube walls.

Slide 25 – Design Options

And this gives the people that design coils some options: (1) First of all, coils can be designed to take up the same amount of room but have considerably higher performance and handle higher pressures. And this is important if pressures produced by the compressor have gone up to meet new SEER ratings. Or, another option is to design coils that take up less room and still have higher performance than coils with larger diameter, conventional tubes. Coils can be designed with smaller diameter MicroGrooves to match the performance of an existing coil but take up much less space and due to thinner tube walls, material costs and refrigerant charge would be lower. Or, coils can be designed with a lower air-side pressure drop. All of these options are valuable, depending on the goals of the project, and all options have the potential to reduce costs. There are yet more options available, but this gives you an idea of the design flexibility that results from MicroGroove tubes.

Slide 26 - Coil Manufacturing

Now let's talk about manufacturing coils with smaller diameter MicroGroove tubes.

Slide 27 – Tubes and Fins

Shown as simply as we can, a typical coil is made of tubes and a series of flat plates.

Slide 28 – Tubes Inserted into Fins

The tubes are inserted through the plate fins.

Slide 29 – Fin Collar

Fin spacing is maintained by the size of the collar that is formed around the holes for the tubes. Fins can be stacked prior to the placement of the tubes and the collars around the tube holes will hold the fins at equal spacing.

Slide 30 – Tube Expansion Provides Tube-to-Fin Contact
The tubes are then expanded in diameter and this binds them to the fins mechanically.

Slide 31 – Coil Ready for U-Bends
This expansion of the tubes produces the contact between the tube and fin which is critical to the transfer of heat. In this photo you can also see the louvers in the fins. Remembering our discussion on boundary layers, these louvers increase heat transfer by breaking up the air and eliminating the formation of boundary layers. You will also notice that the tube ends are flared for U-bend fittings.

Slide 32 – U-Bends Determine Refrigerant Circuit
The U-shaped fitting are brazed onto the tube ends and this determines the exact circuit that the refrigerant will travel through the coil. The brazing material is often supplied as a solid ring that slips onto the joint during assembly, and that ensures that a consistent amount of material is used in each joint. This is a well established process, very reproducible and very robust.

Slide 33 – Benefits of Manufacturing Coils with Small Diameter MicroGroove Tubes
This method of manufacturing coils continues to set the industry standard for corrosion resistance and reliable service life. Since this process remains largely unchanged for small diameter MicroGroove tubes, engineers and technicians throughout the industry are familiar with the practices and also the costs associated with it.

Now let’s take a look at actual situations where small diameter MicroGroove Tubes were used and the resulting data that was generated.

Slide 34 – Research Consortium
In China, a small diameter copper tube research consortium was formed. And their results have served as a foundation for the development of residential air conditioning products that are more economical and use less material than traditional technology with conventional tubes. Wenson Zheng, Frank Gao and Kerry Song from the International Copper Association’s Shanghai Office coauthored four research papers on small-diameter copper tubes in cooperation with two Chinese Universities. They collaborated with the School of Energy & Power Engineering at Xi'an Jiaotong University on heat-exchanger design projects. And they collaborated with the Institute of Refrigeration and Cryogenics at Shanghai Jiaotong University, on the condensation of refrigerant-oil mixtures in small diameter tubes.

Slide 35 – OEM Reports
In addition to research papers and projects at universities, air-conditioning and refrigeration OEMs recently published three papers on small-diameter copper tubes. Researchers from Chigo Air Conditioning reported on the performance of small-diameter copper tubes in an evaporator for residential air conditioners. Researchers from Midea Refrigeration Appliances reported on small-diameter inner-grooved copper tubes in a split air-conditioning system. And researchers from LU-VE in Italy presented geometry for the next generation of condensers with an ultra-low refrigerant charge. All of this information can be found at www.microgroove.net.

Now let’s take a closer look at exactly what they found and why small diameter copper tubes provide so many advantages over conventional technology. The next few slides use data from the Research Consortium and this data shows the effects of small diameter tubes in real numbers.

Slide 36 – Local HTC Increases as Tube Diameter Decreases
We mentioned that the heat transfer coefficient in the tube increases as the tube diameter decreases. In this experiment, the heat transfer coefficient is measured for 5 mm and for 4 mm MicroGroove tubes. The heat

transfer coefficient is reported in watts per square meter Kalvin and is plotted against mass flux reported as kilograms per square meter second. You can see the higher heat transfer coefficient for the 4 mm tube tracking about 15 to 20 per cent above the 5 mm tube.

Slide 37 – HTC for Smooth and MicroGroove Tubes (5 mm)

The effect of the grooves and internal tube enhancements on the heat transfer coefficient can be seen here, measured in 5 mm tubes at three different mass flux rates. Remember that the grooves break down the insulating boundary layer that we talked about and mix refrigerant as it moves through the tube. The effect on the heat transfer coefficient when compared to a smooth internal tube surface is rather significant, as seen in this data. It is interesting here that as the mass flux increases, there is a positive effect on the smooth tube regarding the heat transfer coefficient. But there is a much more significant effect on the MicroGroove tube.

Slide 38 - Refrigerant Pressure Losses

One thing that we must be aware of is that it takes more pressure to move fluid through small diameter tubes than it does through larger tubes. If the hydraulic pressure is measured before and after fluid moves through a tube, a pressure loss or pressure drop is measured. And this pressure loss is plotted here, measured in a core with 7 mm tubes and one with 5 mm tubes. At three different flow rates, a slightly higher pressure loss can be seen in the smaller diameter tube. Pressure losses can be easily reduced with an increased number of branches. In fact, if the number of branches is increased, the tube length per branch can be decreased providing extra options to the heat transfer engineer.

Slide 39 – MicroGroove vs. Micro Channel

Comparisons are often made between round copper tubes and aluminum micro channel tubes. Be careful that the copper tubes in the comparison you are looking at are MicroGroove. As you have already seen here, just comparing copper tubes with smooth internal surfaces to enhanced internal surfaces shows big effects. Comparing conventional, larger diameter, smooth copper tubes to aluminum microchannel tubes will also show favorable results for the micro channel. However, when the comparison is made to smaller diameter copper MicroGroove tubes, the copper tube is not only competitive but often superior.

Slide 40 – Tube Geometry Improves Heat Transfer

Comparison studies often cite a high air-side pressure drop as a disadvantage for copper tubes. However, we must remember that both the tube geometry and the fin design are responsible for the air-side pressure drop. With copper tubes, there are a number of options, such as; (1) the number of tubes, (2) how the tubes are arranged or the tube geometry, (3) and lastly all the parameters that go into the fins such as the fin pitch, louvers, louver angles, etc. Micro channel tubes allow only one path for the air, and therefore the only parameters that are left to deal with air flow and the air-side pressure drop are those related to the fin design.

On the refrigerant side, remember that the circuitry of the copper microgroove tubes can be modified to adjust refrigerant pressure drops. A big advantage for MicroGroove tubes is the lower refrigerant charge. Aluminum micro channel tubes are all joined at a manifold that can take a considerable amount of refrigerant to fill. Let's look at a report by an Italian company named LU-VE that was presented this year at a workshop on refrigerant charge reduction at a conference in Stockholm, Sweden.

Slide 41 - Case Study by LU-VE S.p.A., Italy

In an effort to optimize an existing condenser with conventional 9.52 mm tubes, this Italian company designed new coils keeping the performance the same…right around 20 kW.

Slide 42 – Case Study Continued

As I mentioned, their existing coil had 9.52 mm tubes and in the trial designs, they used aluminum multi channel tubes and 5 mm copper Microgroove tubes.

Slide 43 – Case Study Continued

In this row, you can see that they were able to reduce the refrigerant charge in the aluminum tube design to about 51% of the refrigerant used in the existing design. But the 5 mm copper tube design only used about 44% of the refrigerant in the original design, further reducing the refrigerant charge another 16 or 17%.

Slide 44 – Case Study Continued
If we look at the size of the header required in the aluminum design, we can see a diameter of 38 mm, which the company reported as the minimum diameter they could use to ensure proper tube-to-header joints and refrigerant flow.

This is a good example of the advantages that copper microgroove tubes offer over conventional designs.

Engineers have continued to work with MicroGroove tubes and today they are seeing additional options that have not been tested yet, but have the potential to change air conditioning and refrigeration coils even further.

Slide 45 – Benefits of MicroGroove Tubes
In conclusion, I would like to review these basic benefits related to smaller diameter copper MicroGroove tubes. Small diameter microgroove tubes allow for energy efficient designs. They allow manufacturers to use less material and less refrigerant. These are proven, durable products with a history of success behind them. Small diameter Microgroove tubes allow engineers the flexibility to design for a wide variety of operating conditions. And this is a manufacturing process that is proven, economical, robust and familiar to the entire industry. And finally, this process is supported by a supply chain that is very well established with manufacturing and distribution centers world-wide.

Slide 46 – Game Changer Ad
For more information, you can visit our website at microgroove.net.

Slide 47 – Thank You
Thank you for your attention. Can we answer any questions?