
MAGNET
SECRETS
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Introduction

Welcome to ***Magnet Secrets***.

Magnetic fields are amazing. They are the invisible energy manifestation projected from a magnet. Just moving a copper wire through a magnetic field generates electricity in the wire. But the opposite is also true. Running electricity through a wire that is placed in a magnetic field forces the wire to move. These three forces, magnetism, electricity, and physical motion, are bound together to make electric motors and electric generators do what they do. This simple set of discoveries from the 1830's has evolved to make the whole "modern era" possible.

Currently, magnets and magnetic fields are used in hundreds of technologies. The list is very long, but a few of the more obvious examples including audio and video recording, computer memory, navigation systems (including the compass), electric power generation, electric cars, and holding notes to your refrigerator! What is common to all of these applications is that they take advantage of the large physical or electrical force interactions I mentioned earlier.

But there is another side to magnets and magnetic fields that is subtler. Most of you know that magnets have a special relationship with the element Iron. Unlike other elements, Iron is attracted to a magnet. Iron can even be turned into a temporary magnet if electricity is applied to a wire wrapped around the Iron. Since Iron's response to magnetism is so much stronger than any other element, we usually think that it is a unique event, and that other elements have "no response" to magnetic fields. While this is the general perception, it is not a scientific fact.

The truth is, most elements respond to magnetic fields, even though these reactions are considered "weak" when compared to Iron. Still and all, some of these "weak" reactions can be just as useful as some of the stronger actions. Over the last 40 years, a great deal of research has been done to study these weaker reactions to magnetic fields. Some of these findings are quite remarkable, and well documented.

This manual is designed to introduce you to some of the more significant aspects for the subtle uses of magnetic fields. It includes patents, government reports, news articles, and University Studies, all in support of the fact that magnetic fields can and do influence water, fuel, and other liquids in economically significant ways. Next, it shows you which inexpensive magnets to purchase to save you money. And finally, it shows you exactly where and how to install them to get the best results to lower your energy costs.

Welcome to ***Magnet Secrets***

Table of Contents

Content Page

Disclaimer

The ***Magnet Secrets*** manual is a guide for home owners who wish to increase the energy efficiency of their home. It consists of numerous suggestions for home owner's to "do-it-yourself".

Statements suggesting any specific energy savings or money savings are based on the benefits obtained by using magnets in ways suggested by University studies and other private research. Due to the fact that different homes have different energy efficiency conditions, and different home owner's have different skills regarding home improvement projects, YOUR RESULTS MAY BE DIFFERENT than those of others.

A&P Electronic Media, and the authors of this manual, cannot be held liable for the specific level of energy savings you may receive, and no specific claims of energy savings are guaranteed. Also, A&P Electronic Media, and the authors, cannot be held liable for any damage that may occur during your attempt to implement these recommendations in your home.

While all of these recommendations have been implemented in a safe and effective manner by others, you bear 100% of the responsibility for implementing them in a safe and effective manner in your home.

As you move forward to implement these energy saving recommendations, there are a number of considerations you should be aware of:

1. Modifications to your home may effect your home-owners insurance
2. Modifications to your appliances may effect the manufacturer's warranty
3. There may or may not be tax benefits for your improvements. Please seek the help of a tax professional to help you determine if you are eligible.

To maximize your success, it is up to you to use common sense when needed and seek professional help when required.

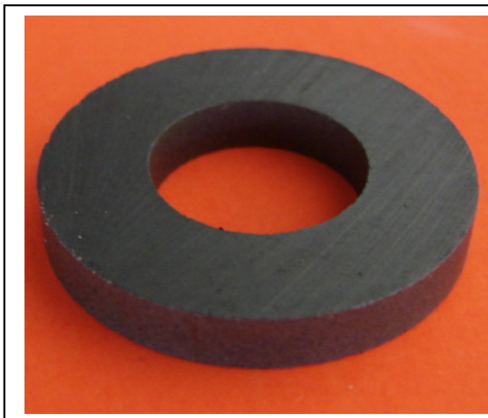
Section One: Using Magnetic Fields

Chapter One: The Method that Works

You've seen the claims. Magnets can increase the gas mileage in your car, soften your water, de-scale your hot water heater, and even make your air conditioner run more efficiently. The question is: are these claims true? This booklet is designed to cut through the myths and give you the answers.

A simple Google Search on the term "magnetic water systems" yields a staggering 12 million hits! Obviously, its a hot topic. Hundreds of companies are selling magnets at inflated prices and claiming dozens of remarkable benefits. There are thousands of "satisfied customers" out there and almost as many articles by skeptics saying that magnetizing water and other liquids just doesn't work! So, who's right? Well, they BOTH are!

Patent offices, all over the world, have been issuing patents on magnetic treatment of water and other fluids for decades. Each new "inventor" has his or her own new way to apply the magnetic fields to the fluid to gain the claimed benefits. Most methods work to one degree or another. The question is: WHAT METHOD WORKS BEST? If there really are a host of benefits from applying magnetic fields to liquids, what is the easiest and cheapest way to get the best results?



"Donut" Shaped Ring Magnet

Remarkably, I was introduced to a process that works extremely well by it's inventor, in 1981. I was living in Santa Barbara, California at the time and studying advanced physics with Bruce DePalma. Bruce discovered that just pouring juice or wine through the hole of a donut shaped magnet could dramatically alter and re-blend the taste of these beverages. The effect was so remarkable, we did extensive "research" on wine! Inexpensive wines could be made to taste much more like expensive brands, while excellent wines could be ruined completely! Quite often, the taste was re-blended in rather complex ways. It also changed the texture of the liquids as they rested on the palette. Many of the beverages seemed "softer", and water poured through the magnetic ring was less "sticky" between the fingers.

Granted, all of these effects were subjective, but they were NOT SUBTLE. The effects showed up consistently and quite often, the enjoyment of the beverages was greatly enhanced by the process. The other interesting thing was, when beverages were poured through the magnetic ring with the poles reversed, beverages always got worse. Tastes moved to far less agreeable blends, and the feeling on the palette was more astringent, like the liquid was "less wet" somehow. Also, pouring a liquid through the ring in one direction did not reverse the effect of pouring it through in the opposite way. Both effects were dynamic, and non-reversible.

Simple "party magnets", made up of a funnel and a ring magnet mounted in a plastic cup, were tested and over 80% of the people could taste the difference in their favorite beverage when it was subjected to the magnetic field. They were also a great "conversation piece".

We came to the conclusion that "something was definitely happening" when liquids were poured through the hole of a donut shaped magnet. But in those days, we really didn't know much about "WHAT" was happening, or "WHY".

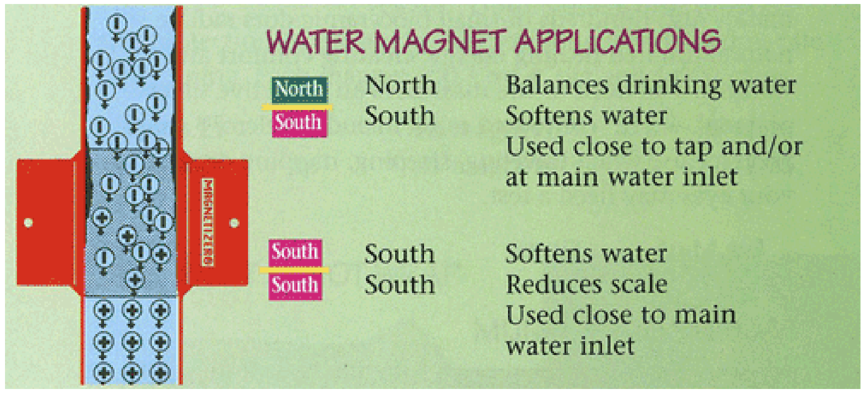
Bruce filed for patents in Europe and the US on the special configuration for "magnetic treatment" of liquids. The European Patent (WIPO) was published in September of 1981. The US Patent did not issue, to the best of my knowledge. The complete text of Bruce DePalma's patent is reprinted in Section Two of this book.

Standard Magnetic Configurations

28 years ago, treating liquids with magnetic fields seemed like a novel idea. Today, there are hundreds of companies selling magnets to treat water and fuels, like gasoline. Most people believe that if you just slap a magnet onto a pipe, that you should be able to get the benefit of "magnetic treatment". It is this author's opinion that this lack of detailed knowledge in this field is what has lead to so many bad results and skeptical reports.

Magnetic Poles Facing Pipe

Most of the cheap magnets for treating liquids just place a strong magnet on a pipe carrying water or fuel, and orient the magnet so its POLE FACE is pointing at the pipe. Then another magnet is placed on the other side of the pipe with the opposite POLE FACE pointing at the pipe. If the magnets are strong enough, even this simple arrangement can produce some effects. This placement of magnets on a pipe produces a magnetic field orientation where the lines of force run **across the flow** of liquid in the pipe.



Some companies sell magnetic water treatment systems so that their magnets can be placed in the mounting frame so they may either oppose each other or attract each other, and that slightly different benefits can be expected from these different magnetic configurations.

From research that I have done in this field, I would say that over 98% of magnets sold to treat water or fuel with magnetic fields, use these cross-flow configurations. I would also say that these configurations produce far weaker results than the method developed by Bruce DePalma.

DePalma's Method

Unlike all of the other methods where the liquid flows across the magnetic field, Bruce DePalma found that when the liquid flows PARALLEL to the lines of force in the magnetic field, the benefits are strengthened.

In fact, DePalma found a number of conditions that seemed to maximize the benefits. These benefits were described in his patent and are summarized here:

1. the liquid should flow parallel to the magnetic lines of force
2. the magnetic field strength should remain constant during the magnetic treatment
3. the liquid should flow through the magnetic field by entering at the North Pole and exiting at the South Pole to maximize the softening effects
4. the fluid should flow straight through the magnetic field, and turbulent flow should be avoided during magnetic treatment
5. the beneficial effects are apparently conferred to the liquid regardless of the speed of its passage through the magnetic field, and
6. similar effects were produced by generating the magnetic field with either permanent magnets or a coil operated by Direct Current.

The following images are taken from the WIPO Patent issued to Bruce DePalma. Fig-1 illustrates the ring magnets around the pipe, shown in a cut-away view, Fig-5 shows the flow of fluid from North to South while staying parallel to the lines of force, and Fig-3 shows the set-up for using an electromagnet to produce the same effects.

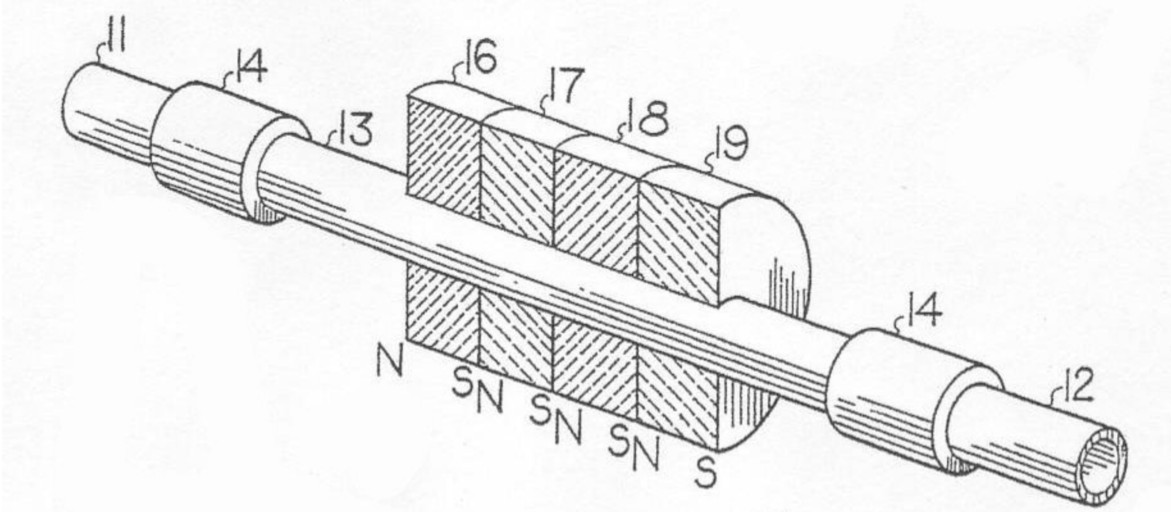


Fig-1

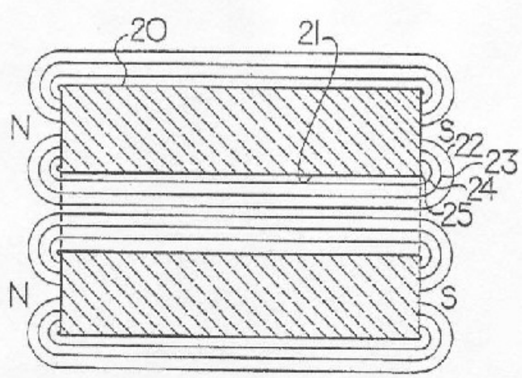


Fig-5

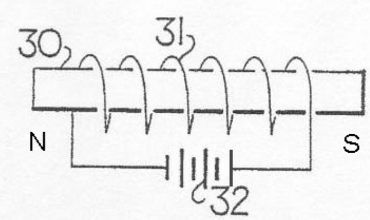


Fig-3

So, these illustrations and claims lay out the magnetic configurations that DePalma found produced the best results, and were the basis of his WIPO Patent of 1981.

Chapter Two: Supporting Evidence

Remarkably, in 1998, the Department of Energy of the US Government, issued a 32 page **Federal Technology Alert** discussing the use of magnetic fields for controlling the hardness of water and the deposition of minerals in pipes and heaters. The purpose of this report was "to speed the adoption of energy-efficient and renewable technologies in the Federal Sector". This means that the Department of Energy had researched this information, determined that it was accurate, and was encouraging other government departments to adopt the use of these technologies to save the government money! This publication was titled ***Non-Chemical Technologies for Scale and Hardness Control***. (A complete copy of this report is included in Section Two of this book.)

This federal report lays out the history of the development of this technology and its rise to effectiveness and reliability. But the most interesting section is the brief discussion of the specific application methods. On pages 5 and 8 of this report, diagrams are used to illustrate how magnetic fields are to be applied to water flowing in pipes to produce the beneficial effects of "water softening" and "mineral de-scaling". Three of these diagrams are reproduced here.

In this first diagram, the drawing indicates water flowing through a pipe, indicated by the arrow, from left to right. This water carries both (+) ions and (-) ions along with it. As it flows, it enters the magnetic field at the North Pole, flows parallel to the lines of force, and exits the magnetic field at the South Pole. For all intents and purposes, this is the method developed by Bruce DePalma.

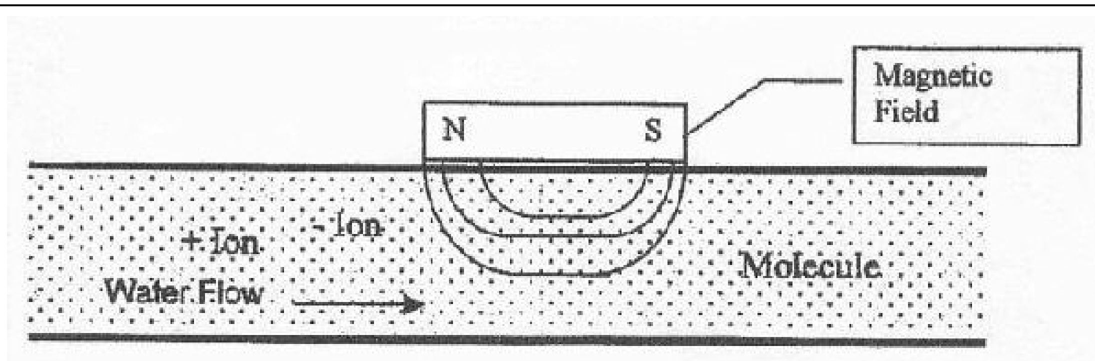
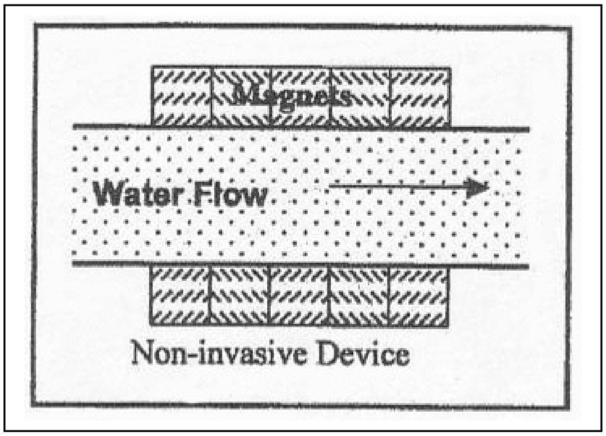
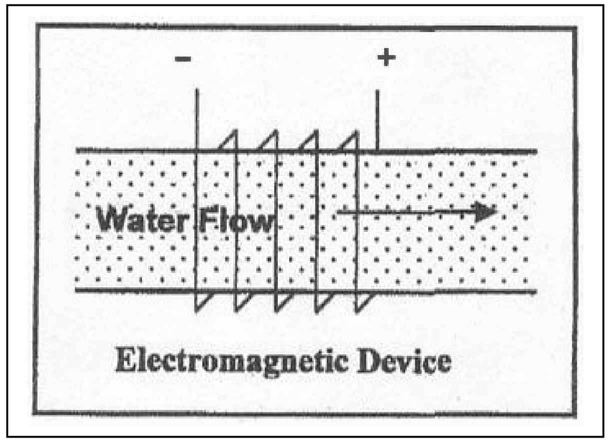


Figure 1. Diagram of General Magnetic Device Construction

In the next image, you can see a diagram depicting water flowing through the center of a stack of ring magnets (shown in a cut-away view), like in the DePalma images. And finally, in the last image, you see a fluid flowing through an electric coil wrapped around a pipe, again, just like in the DePalma patent diagrams.





So here we have a Federal Report describing how to obtain the benefits of magnetic water treatment, illustrating the exact methods developed by Bruce DePalma 16 years earlier.

In my estimation, it is no co-incidence that the US Federal Government, and the Department of Energy in particular, has published a report specifying that magnetic fields can be used to "soften water" and to remove mineral deposits from pipes and heaters. This specific method of applying magnetic fields to liquids is recognized and reported to be the preferred method.

In spite of this recognition, most manufacturers of Magnetic Treatment devices still do NOT use this magnetic configuration!

So, what does the Federal Technology Alert say about the possible cost and energy savings of using this technology? Well, first, they clearly state that anything that interferes with the flow of heat from a heating element to the water, in a water heater or a boiler, reduces the efficiency of that system. They go on to say that minerals from the water that plate onto the inside of pipes act as an "insulating layer" and therefore interferes with the transfer of heat. Normally, this insulating layer of minerals, or "scale" must be removed by some sort of maintenance cycle on a periodic basis, and that this maintenance labor costs money.

The report says that magnetic treatment of water can reduce or eliminate the costs associated with the periodic maintenance of scale removal, or the costs associated with using chemicals to remove the scale. They go on to say that magnetic treatment is the most cost effective method for this application, and calculate a reduction in maintenance costs of up to 100%.

Next, they also say that the energy savings are even more significant, since the thicker the scale is on the inside of the pipes, the more energy is needed to heat the water. In Table 1, to the right, these figures are shown. The Table shows that the energy efficiency of an older water heater with just an 1/8th of an inch of scale in the pipes can be made **25% more efficient** if that scale could be removed by treating the water properly with magnetic fields.

Table 1. Example Increases in Energy Consumption as a Function of Scale Thickness

Scale Thickness (inches	Increased Energy Consumption (%)
1/32	8.5
1/16	12.4
1/8	25.0
1/4	40.0

Obviously, this represents a huge cost reduction and is well worth doing. It will also allow your water heater to run for many more years, almost maintenance free.

More Evidence

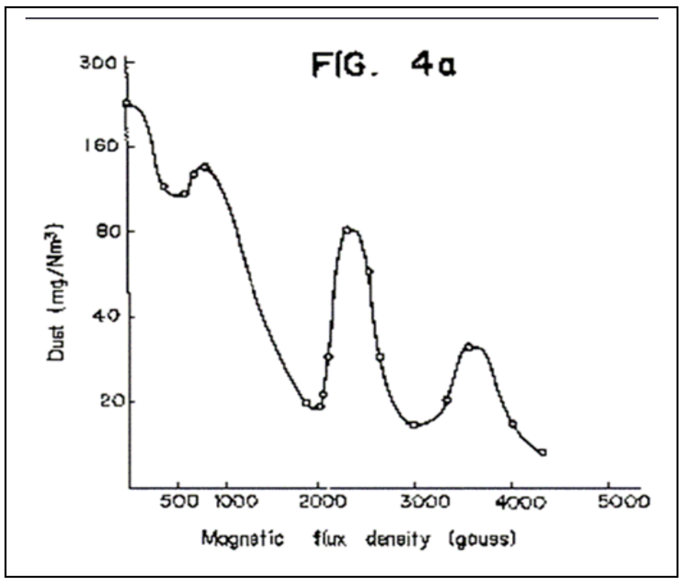
Recently, a short, but extremely important article was published in **Infinite Energy** magazine, titled ***Is There a Credible Basis for Magnetic Devices to Represent Green Technology***. This article was authored by Ron Kita and appeared in the January 2009 issue. Ron Kita is a multiple patent holder in the field of magnetic treatment of liquids, and a former research director for a major company in the industry. In a field with few experts, Kita must be considered one of the few. (A complete copy of this article is included in Section Two of this book.)

In his article, Kita sites numerous patents, University studies, and prominent researchers. His examples strongly support the idea that magnetic fields can produce useful, measurable changes in the molecular structure of both solids and liquids. These examples include the following:

1. **Reducing mineral scale in water heaters and boilers.** One citation refers to the work of Professor Simon Parsons, of Cranfield University in the UK, who found that calcium crystals dissolved in water, exposed to a magnetic field, changed from the cubic structure responsible for scale formation into a spherical structure which does not form scale. Some of these effects were seen to persist for up to 200 hours after magnetic treatment (over 8 days).
2. **Reducing iron rust in water.** This citation refers to US Patent #4,935,133, by Yutaka Himara of Japan, which shows how to remove red rust from water by using magnetic fields. The process involves using magnetic fields

to convert the red, soluble form of rust Fe_2O_3 into one of the black, non-soluble forms of iron oxide, either FeO or Fe_3O_4. Once the new, non-soluble iron compound settles out, it can be removed from the water by using either a filter or another magnet.

3. **Normalizing the pH of water.** This reference shows that water in cooling towers or other systems that circulate water can benefit by magnetic field treatment because excess hydronium or hydroxyl ions tend to be become bound up, leading to the water approaching a pH of 7.0. This effect is most likely to appear when the native pH of the water is between 6.2 and 7.8 to begin with. In large systems, this can still be a commercially useful effect. In support of this idea, I once helped a friend set up a hot tub in her backyard. The water in most hot tubs tends to become too alkaline, requiring the weekly addition of an acidic agent. By magnetizing the water in the circulating system, I was able to produce a near perfect pH in the water at all times. In fact, the water had just a slight tendency to become too acidic, requiring the addition of a little Baking Soda about once a month!
4. **Increasing the combustion efficiency of hydrocarbon fuels.** This citation refers to US Patent #4,188,296, by Etuo Fujita of Japan, which shows a number of complex interactions between magnetic treatment of fuel and combustion efficiency. In the graph to the right, labeled FIG. 4a, some of this data is reproduced here. It shows that the benefits of magnetic fuel treatment can be very "non-linear", rising and falling dramatically with changes in magnetic field strength. This probably explains why so many people say that magnetic treatment of fuel doesn't work. What this series of tests shows is that a near maximum benefit point occurs just before 2000 gauss, represented by the first major dip in exhaust particulate, which is a relatively weak field. This refutes both the idea that "stronger fields work better" as well as "there is no benefit at all". The truth is found in knowing all the facts and the benefit is found by creating a tuned system.



5. **Increasing the efficiency of refrigerators and heat pumps.** In this citation, Kita references two US Patents (#6,662,569 and #7,340,919) as well as the work of Professor Samuel Sami of the University of Moncton, in Canada. Information in this field is some of the most recent with regard to

magnetizing fluids for commercial benefit. Two articles published by Professor Sami report a number of remarkable discoveries with regard to magnetizing heat pump refrigerants. One of the first effects noted was that the boiling point of the refrigerant could be effectively lowered by its passage through a magnetic field. This allowed the refrigerator or air-conditioner to run more efficiently because the evaporators wouldn't freeze up as much. He also found that the lubricants mixed with the refrigerants tended to stay mixed better when they were magnetized. This allowed more of the lubricants to travel through the compressors so they ran cooler, quieter, and with less wear. Both of these benefits would allow the heat pumps to produce more cooling with less energy used, and also run longer without maintenance. (Both of Prof. Sami's articles are included in Section Two of this book.)

After presenting all of this data, Kita's conclusions are modest. In his closing remarks, he states: "Magnetic devices do not represent a 'magic bullet' for the environment, but they do have utility in improving the quality of our air and water, providing that the limitations of this technology are viewed in a reasonable performance framework." This is reasonable. Magnetic fields can enhance a wide variety of processes, and as long as these benefits are properly understood, claims about them can be both positive and reproducible.

Still More Evidence

One of the best articles ever written on this topic is ***Magnetic Water Treatment De-Mystified*** by Dr. Klaus Kronenberg. In this article, he discusses how applying magnetic fields can change the behavior of water and various mineral scale precipitates, as well as their management in drip irrigation systems, ice makers, steam cleaning equipment, and solar hot water heaters. He also states that "Hundreds of field arrangements have been tested with a number of different water types. Maximum effectiveness was achieved with arrangements where the fields originated from simple, ring-shaped permanent magnets of barium ferrite of a medium grade." So again, the DePalma Method is referenced and stated to be the best for these uses.

Dr Kronenberg is also the author of the article titled ***Microscopic Fuel Tests using Magnetic Fuel Conditioning***. In this article, he discusses how applying magnetic fields can change the behavior of combustible fuels by further breaking down long-chain molecular structures. He therefore concludes that magnetic fuel treatment may be more effective on less refined fuels, such as Diesel fuel for engines or #2 fuel oil, for furnaces.

(Both of Dr. Kronenberg's articles are reproduced in their entirety in Section Two of this book.)

Conclusions

Magnetic fields are capable of producing a wide variety of subtle effects on water and other substances. Many of these effects have been studied extensively by qualified researchers in Government, private industry, and University settings. In the process, a number of significant effects have been identified that can be utilized for commercial and economic benefits. This has lead to the filing and granting of hundreds of Patents on "magnetic treatment" methods, worldwide.

In spite of this mountain of evidence, there are still those who insist that "magnetic treatment" does not work. At this point, it seems clear that reports that state that "magnetic treatment" does not work are simple wrong, or are made by authors who have not seriously investigated the subject.

Chapter Three: Practical Applications

It should be pretty obvious from the information presented in Chapter Two of this book that Magnetic Field Treatment of water and fuel can be effective. There are multiple patents, published articles, and University studies that support this premise. But the question remains, can it be ***practical***? By practical, I mean that the Magnetic Field Treatment system that you install actually works, that it is easy to implement properly, and that it is cost effective. By cost effective, I mean that the cost of implementing the Magnetic Field Treatment processes PAY FOR THEMSELVES with the energy savings within the shortest possible time.

An example of what I am talking about is as follows. Let's say you can increase the efficiency of your fuel oil furnace by 10% by magnetizing the fuel just before it enters the burner. And let's also say that you can find a number of companies that will sell you a Magnetic Treatment System for your furnace that costs $150. Now, if you spend $1,000 per year to heat your home in the winter, and you can save 10% of that, which is $100, then it will take you one and a half winters to pay for your Magnetic Treatment System from the energy savings. This gives you an ROI (return on investment) of one and a half years. Some people would be pleased with this and consider it a good investment. But the fact is, in this scenario, the first year actually costs you more than not doing anything, and the real savings don't start showing up until the THIRD WINTER.

So, for people who need to start saving MONEY right now, this is a tough sell. But there is another way. What if I told you that you could make your own Magnetic Treatment System for less than $20 worth of magnets and be saving both energy and money in the second MONTH of next winter! That's what I mean by COST EFFECTIVE! Well, its true. Thousands of people have done this, and so can you.

Three Projects and Three Rules

So, there are at least three ways to use magnets in your "everyday life" that are practical, easy to understand, and effective. These include 1) magnetizing your house water main, and especially the pipe leading to your hot water heater, 2) magnetizing the fuel line to your furnace and/or the gas line to your non-electric hot water heater, and 3) magnetizing the fuel line in your car. These are the easiest ways to use magnets to save energy and save money at the same time.

In each of these situations, there are a number of "RULES" that must be followed to get the best results. These rules are as follows:

- **Rule 1.** Always align your magnets in the right direction
- **Rule 2.** Always make sure that the pipe carrying the liquid you want to magnetize is NOT made of IRON
- **Rule 3.** Always make sure that you are using the proper number of magnets to produce the desired effects

If you follow these simple rules, you will always get excellent results.

Now, before I show you HOW to do these projects, I'd like to review exactly what we might hope to accomplish with each one, and WHY following the 3 Rules is necessary. Once you have learned this completely, you can probably find other areas of your home and life that can benefit from the proper use of magnets.

Water Main

Magnetizing the water line in your home can produce TWO effects that are beneficial. The first is that the magnetized water can become "softer", keeping dissolved minerals in suspension, and lowering the surface tension of the water so that soaps and detergents work better. It can also "feel" slipperier between your fingers. The second is that it can strip the "scale" deposits out of your hot water heater, which will make heating your hot water more efficient and save you money. It can also help your older hot water heater last longer before replacement.

Furnace Fuel Line

Magnetizing the fuel line leading to your furnace can make your fuel burn more efficiently. This one application, if done correctly, can save you about 10% on the cost of heating your home. For appliances that run on Natural Gas, such as furnaces or water heaters, magnetizing the gas line can reduce gas use by between 5% and 10%.

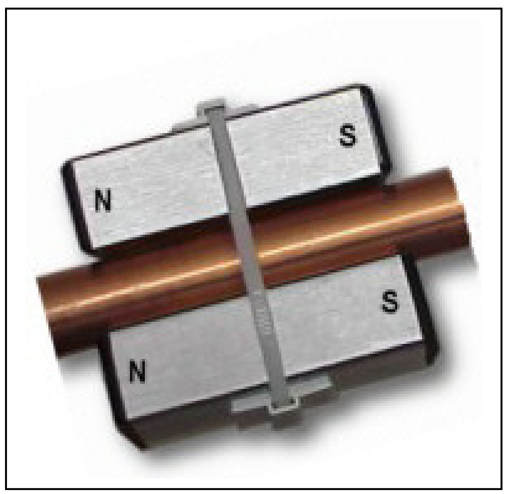
Automobile Fuel Line

Magnetizing the fuel line leading to your car's engine can make your fuel burn more efficiently. Done correctly, this application can increase your fuel economy by between 5% and 10%. While these gains may seem small, with the price of gasoline due to remain high in the future, every little bit helps.

Rule #1

Always align your magnets in the right direction. The reason for this is simple. All of the research shows that fluids have to be "magnetized" properly to get the beneficial effects. Using our preferred method, we want the fluid to enter our device at the NORTH POLE and to exit our device at the SOUTH POLE. If you are building the unit yourself, you have to know which polarity of your magnets is which, and align them correctly. To accomplish this, I recommend you purchase a "magnetic polarity indicator", and I'll show you where to get that shortly.

Rule #2



Always make sure that the pipe carrying the liquid you want to magnetize is NOT made of IRON. Again, the reason for this is simple. Iron conducts magnetism. Everybody knows that. But in this case, we want the magnetic field to get into the liquid INSIDE the pipe. If the pipe is made of Iron, the magnetic field will travel along IN the Iron, and none of the magnetic field will get inside the pipe where our liquid is. So, for our Magnetic Field Treatment to be effective, we have to make sure that we are magnetizing our liquid in a pipe that is NOT made of IRON. **The pipe can be made of copper, brass, bronze, aluminum, plastic, or rubber.**

Rule #3

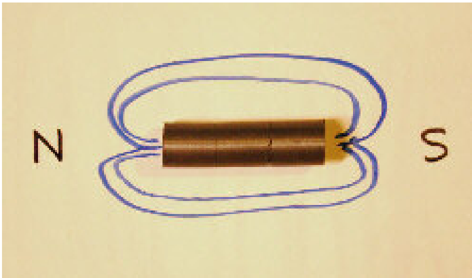
Always make sure that you are using the proper number of magnets to produce the desired effects. Again, the reason is simple. We saw in Chapter Two that some of these magnetic effects are very "non-linear". That means that to get the effect we are looking for may require a little bit of "playing around" with your set-up until the proper magnetic field strength is being applied to your water or fuel to "get the job done". This is not difficult, but it may take a few adjustments after your initial installation. The important thing is to EXPECT THIS and not just give up if your first attempt is not producing the effects you want.

So now I have defined the projects and the processes we will use and why. Now I can get down to specifics!

The Modified "DePalma" Method

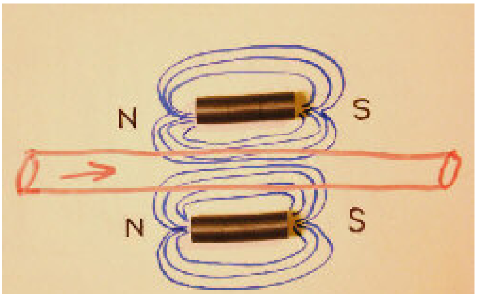
When I was studying with Bruce DePalma in the early 1980's, we always used the donut shaped ring magnets to produce these benefits. And they always worked really well. The problem arises when you want to start using a Magnetic Field Treatment system on a pipe that is already installed and full of liquid. You can't get the ring magnets onto the pipe without actually breaking into the pipe, some how. This is quite often difficult, messy, or extremely inconvenient, and therefore prevents Magnetic Field Treatment from being applied in that situation.

It was determined that the ring magnets where not really necessary, and that ANY CONFIGURATION of magnets that produced parallel lines of magnetic force in the liquid along the direction of flow would create the beneficial effects. Many different configurations were tried, but the simplest method involved using "bar magnets" and just strapping them on the sides of the tube or pipe. A "bar magnet" is usually any permanent magnet that is longer than it is wide, and it is always magnetized along its length. The first image shows this idea.

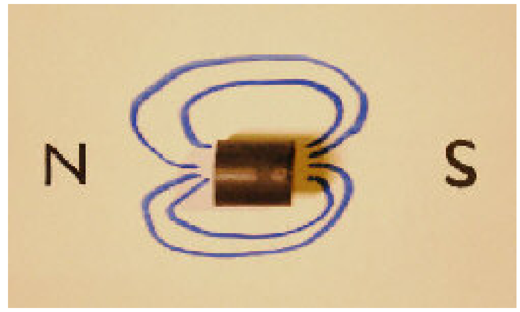


a BAR MAGNET with its magnetic field drawn in to illustrate

The second image shows a view of two bar magnets and how their magnetic fields interact to produce a combined field that intersects inside the pipe, drawn in RED.



By simply strapping two or more of these bar magnets to a pipe, any desired magnetic field strength can be produced, easily and inexpensively. This method of applying magnetic fields to pipes is just as effective as DePalma's original method, but it eliminates all of the problems of using donut shaped ring magnets. By stacking single "cylinder magnets" to make your own "bar magnets" of any length, the process becomes extremely versatile and cost effective.



Single Cylinder Magnets can be stacked to produce your own Bar Magnets of any desired length.

Magnetizing Your Water Line

Pictured to the right is an example of two "home-made" bar magnets on an incoming water main. The copper pipe is just under the floor joists in the basement ceiling, near the area of the clothes washer. Black tape is used to hold two cylindrical bar magnets to the pipe. Once the cylinder magnets were glued together with Super-Glue to make the bars, the entire installation took about 5 minutes.

A simple test can be used to help you determine how many bar magnets to use for your water main. Make up three or four of the bar magnets and bring them to your kitchen sink. Run some water from the sink and adjust the temperature so it is neither cool nor warm, but just about the same temperature as your skin. Then, lightly rub your fingers together in the stream of water, and notice how "slippery or sticky" it feels. Next, tape two of the bar magnets to the faucet, with the South Poles facing toward you, and then rub your fingers in the water again. What you are looking for is the "slipperiest" feeling between your fingers that you can get. It may happen with two, three, or four of the bar magnets on the faucet.

When you find the right number of magnets that produces the slipperiest water, then remove those magnets from the kitchen faucet, and mount that combination of magnets on your WATER MAIN, which is the in-coming COLD WATER LINE.

Since you want to magnetize ALL of the water in your house, you need to place the magnets on the pipe before it branches out to go to a faucet, somewhere in the house. Also, remember Rule #2, and don't mount the magnets on a section of Iron Pipe. The other main consideration is to mount the magnets on your water line as close to your Hot Water Heater as you can, to get the best "de-scaling effect" possible. There is a little bit to learn, but all-in-all, its pretty easy.

Magnetize Your Furnace Fuel Line

Pictured to the right is an example of two "home-made" bar magnets on the incoming fuel line to the furnace burner. Black tape is used to hold two cylindrical bar magnets to the copper pipe. Once the cylinder magnets were glued together with Super-Glue to make the bars, the entire installation took about 5 minutes. Just remember, the fuel enters the magnetic field at the North Pole of the magnets, and exits at the South Pole of the magnets. This arrangement, with two bar magnets made from Ceramic 8 material, is a good place to begin experiments to produce the proper effects.

Magnetize Your Automobile Fuel Line

Pictured to the right is an example of two "home-made" bar magnets on the incoming gasoline fuel line in the engine compartment of a car. Black tape is used to hold the cylindrical bar magnets to the rubber fuel line. Like the magnets on the water line, you can adjust both the number or magnets per bar, and the number of bar magnets in the system to fine tune the system for the highest mileage gain possible. Typically, a 10% mileage gain is considered good.

Other Projects

There are a number of other possible uses for magnets in the home, such as on your refrigerators, freezers, air conditioners, and heat pumps. As stated in Chapter Two, these benefits are well researched. The problem is that the installation of magnets in these appliances is a little more complicated than the ones I have shown here. If you get good results from the first projects, you might want to get adventurous and try these extra projects, as well. The best place to put magnets on a heat pump is directly before the expansion valve.

Magnets have many uses, and I have only emphasized the ones that can save you the most money quickly, and are the easiest ones to implement correctly.

Chapter Four: Resources and Recommendations

If you are interested in implementing these simple projects for **Magnet Secrets**, here is what I recommend.

Permanent Magnets are available from a wide variety of companies, with prices that vary as well. I recommend you buy the magnets you need from a company on the Internet called Applied Magnets.

	
1 in x 5/8 in Ceramic Cylinder Magnet	**Magnetic Pole Detector-Identifier**
Grade C8 [CERAMIC-D6] Grade C8 the strongest ceramic material available BrMax: 3850 gauss Magnetized through the Thickness 5/8”	APPLICATIONS Pole detection of permanent magnets Measurement of stray magnetic fields in packaging Coil testing Post-magnetization polarity checks

The table above shows the two products I recommend. The first product is the "CERAMIC-D6" shown in the first box. If you purchase 30 units at a time, the price per magnet is $2.20 each. The only other thing I recommend is the "Magnetic Pole Detector-Identifier" shown in the second box. It costs $19.99 and will allow you to install your magnets correctly, each and every time, without guessing!

GO HERE FOR THE ABOVE TWO RECOMMENDED PRODUCTS

MAGNET 4 LESS

To purchase these items, just follow this link: MAGNET 4 LESS and follow the navigation to <Ceramic Magnets>> Ceramic Discs and Cylinders>. This will take you to the proper web page at Applied Magnets.

The total cost for these two items is about $86 (US Dollars) but that doesn't include shipping. This will give you all the magnets you need to install ALL OF THE PROJECTS discussed in this E-book, and the tool to do it right.

Once you get your cylinder magnets, you can glue sets of 3 or 4 of them together to make your own "bar magnets". Since the magnets will naturally attract each other, a single drop of Super-Glue is usually sufficient to hold the bars together. Then, you are ready to implement the recommendations in this book.

Final Recommendations

Even though I have given you enough information to begin to use magnets to Save Money and Energy, I highly recommend that you actually READ the documents in Section Two of this book. They are all highly informative, and contain a great deal of information I have not cited. There is so much more to learn.

Also, as you have probably noticed, there are a number of magnetic configurations, other than "The DePalma Method", that have effective uses. Feel free to continue to study this fascinating subject, and maybe even run some experiments of your own.

In the end, magnets and magnetic fields are still a mystery, and science is just beginning to discover the many wonderful things they can do.

Buy Ready-Made Magnets Designed for these Uses

Now that you know how to use magnets correctly, you may still wish to just purchase professionally made products for these purposes. Well, I can help you with that too!

The company that grew out of the original patent by DePalma is now the Industry Leader. For your convenience, here is our Magnet Secrets store that sells these high quality products.

Magnet Secrets Store

Section Two: Historical Documents

World Intellectual Property Organization
Patent Publication Number: WO 81/02529

Title: Magnetic Water Conditioner Apparatus

Inventor: Bruce E. DePalma

Publication Date: September 17, 1981

PCT WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

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Published
With international search report

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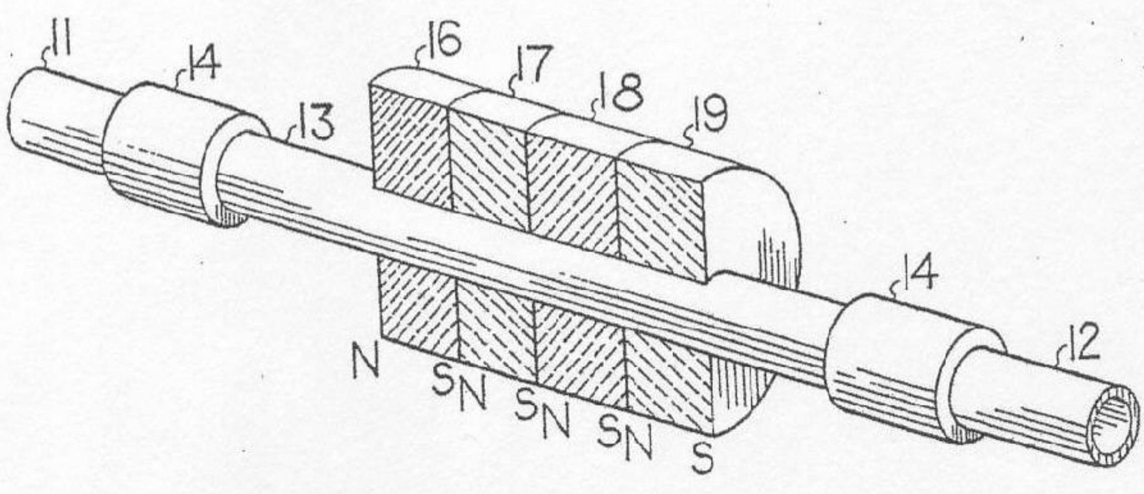

(57) Abstract

Much feed water for boilers and hot water heaters contains minerals which result in boiler scale and deposits in heaters and water pipes. Treatment of such water by causing it to flow through a magnetic field has been effective to greater or lesser degree in preventing boiler scale and deposits in heaters and water pipes. An effective magnetic field for such water treatment has been determined as one wherein the lines of flux are parallel to the water flow. This is provided by apparatus with an axial hole (21) utilizing a permanent magnet or an electromagnet (20). The apparatus has a non-magnetic water conduit (13) fitting tightly within axial hole (21) of the magnet (20). The magnet (20) is axially magnetized and the magnetic structure is arranged to maximize the magnetic flux (22-25) in axial hole (21). A principal use of the apparatus is the magnetic treatment of feed water for boilers and hot water heaters. This is in reducing scale and deposits from minerals in such water.

FOR THE PURPOSES OF INFORMATION ONLY

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Description

Magnetic Water Conditioner Apparatus

Technical Field

My invention relates to the magnetic treatment of mineralized water and has particular reference to an improved geometry of magnets that more effectively treats or conditions water to increase its apparent softness.

Feed water for boilers and hot water heaters has been magnetically treated for decades to reduce boiler scale, heater deposits and water pipe deposits. Feed water has been subjected to various configurations of magnetic fields, both steady fields and alternating fields. This magnetic treatment has been effective to greater or lesser degrees in preventing boiler scale and heater deposits and deposits in water pipes. While the chemistry and electronics of magnetic field effects on dissolved and suspended minerals has not been precisely determined, the magnetic treatment causes the mineral content to remain in suspension rather than deposit out as scale. In the case of boilers the accumulated suspended minerals are continuously or periodically flushed out by flushing the boiler water. This magnetic treatment is generally less expensive than ion-exchange treatment of feed water or additive chemical treatment of feed water.

Background Art

Municipal water systems are generally the source of water for boilers. No boiler can operate efficiently or dependably if its heat transfer surfaces are allowed to foul with scale. Yet, most municipal water systems provide water that contains scale-producing minerals. The major dissolved materials in water are silica, iron, calcium, magnesium, and sodium compounds. Metallic constituents occur in various combinations with bicarbonate, carbonate, sulphate, and chloride radicals. Scaling occurs when calcium or magnesium compounds in the water precipitate and adhere to the internal surfaces of the boiler. These scaling compounds become less soluble as temperatures increase, causing them to separate from solution. The result is overheating of boiler tubes, followed by failure and equipment damage.

This same scaling occurs in the heater and pipes of hot water heater systems. Unless these scaling deposits can be reduced, they result in heater failure and reduced carrying capacity of scaled-up pipes.

Many different types of water treatments are used to reduce the scaling, including sodium zeolite softening, hot lime zeolite softening, split stream softening, demineralizing, and distillation. All of these treatments require extensive capital outlays for various treatment tanks and controls, as well as a continuous supply of chemicals, or in the case of evaporation, a continuous use of fuel.

While the magnetic treatment of water to reduce its apparent hardness has been known for decades, it has not been commercially used for boilers and heaters, because it has been ineffective. I have determined that a properly designed magnetic treatment conditioner or apparatus can be made that is effective for water-softening. The tremendous capital outlays for the usual softening processes may be avoided, as well as the continuous expenditures for chemicals and fuels.

Disclosure of Invention

I have ascertained that the most effective magnetic treatment occurs when the lines of flux are parallel to the water flow.

I have determined that the most effective magnetic field for water treatment is a steady or permanent field as contrasted to a fluctuating field or as contrasted to an alternating magnetic field. I have further determined that the most concentrated field is the most effective. I have devised a magnetic field that is extremely concentrated for the available magnetic material. I have devised a hollow cylindrical permanent magnet that is axially polarized and has a water pipe of non-magnetic material passing axially through the cylinder. Alternatively, I have constructed a direct-current coil of hollow cylinder shape which has a non-magnetic conduit passing axially through it. I have determined further that the conduit must fit these magnetic structures as tightly as possible and that the conduit wall should have minimum thickness for the water pressures being used.

I have discovered that if the water exits from the south pole of the magnetic field it gives the maximum "softening" effect to the water; that is, the maximum suspension of mineral in the water and the minimum of deposits. Conversely, if the water exits from the north pole of the magnetic field the water is "hardened" and tends to deposit out more readily and to react with soap. This may be useful as a defoaming treatment for water. I suspect that this south pole exiting to soften is not universally true and may be limited to a particular geographical area. Perhaps in the southern hemisphere the polarity to soften water will be reversed. Orientation of my magnetic field with the earth's magnetic field does not appear to be important.

I have found that my magnetic treatment improves potability of "softened" drinking water as compared to water treated with chemicals or ion-exchange to render it softer.

Brief Description of Drawings

Various objects, advantages, and features of the invention will be apparent in the following description and claims, considered together with the accompanying drawings forming an integral part of this specification and in which:

Fig. 1 is a three-dimensional view of piping passing through a permanent magnet in vertical section.

Fig. 2 is a three-dimensional view of the magnet and pipe of Fig. 1.

Fig. 3 is a schematic diagram of a direct-current coil passing around a pipe to create a magnetic field in the pipe.

Fig. 4 is a three-dimensional view of the commercial embodiment of the direct-current coil of Fig. 3.

Fig. 5 is a schematic sectional view through the magnets of Figs. 1 and 4 showing the concentration of lines of flux in the center of the conduit through the magnets.

Fig. 6 is a schematic end view of the magnet of Fig. 5 showing the manner in which the lines of flux concentrate in the conduit portion of the magnet.

Best Mode for Carrying Out the Invention

Referring to Figs. 1 and 2, pipes 11 and 12 are connected by a pipe 13 provided particularly in accordance with the invention. The pipe 13 may be secured to the pipe sections 11 and 12 by any suitable means such as couplings 14. Pipes 11, 12, and 13 form part of a continuous conduit for raw water leading to a boiler or to a water-heating system. Disposed about the pipe 13 prior to its coupling to pipe lengths 11 and 12 are a plurality of ring-shaped permanent magnets 16, 17, 18, and 19, which are all axially magnetized, that is, along an axis parallel to the pipe 13. While any suitable permanent magnet material may be used, I presently prefer, for purposes of manufacturing economy, ceramic magnets.

The pipe 13 is made of non-magnetic material and may be metal or plastic or glass or other nonferrous materials, and I presently prefer glass or plastic to eliminate any electrical effects on the water due to dissimilar metals being present. The interior of the conduit 13 should be as smooth as commercially feasible to avoid any turbulence in the flow, and in this connection the couplings 14 should be of such construction as to minimize any turbulence in the flow. Each ring magnet 16, 17, 18, and 19 is oriented with the adjoining magnet or magnets so that there is a continuous magnetic field from north on the left to south on the right as viewed in Fig. 1. This stack of ring magnets develops a magnetic field, which is shown in schematic form in Figs. 5 and 6, wherein a schematic magnet 20 of hollow-cylinder construction has an axial hole 21 through it, and lines of flux 22, 23, 24, and 25 emanate from the ends of the magnet 20 to pass through the hole 21. There it will be noted that the lines of flux 22 emanating from the farthest radial area pass toward the center of the bore 21 and that the next lines 23 emanating from the ends closer to the bore take a path to one side of the center of the bore 21; that the lines 24 that are closer to the bore take a path fairly close to the bore edge and that the lines 25 emanating close to the bore follow the interior of the bore 21.

This distribution of lines of flux is shown schematically in Fig. 6 wherein the outermost lines 22 pass toward the center of the bore 21 and the other lines 23, 24, and 25 that are closest to the bore 21 have their lines of flux away from the center of the bore. The result of this inwardly projecting series of flux lines 22 through 25 is to give a very intense field in the bore 21 so that a maximum intensity of magnetic field will be exerted upon water flowing through a conduit placed in the bore 21 of the magnet 20 of Figs. 5 and 6.

Referring now to Fig. 2, this illustrates in full outline the magnet of Fig. 1 shown in section. Shown in Fig. 2 is a dimension L for the length of the magnet which is designated by the numeral 15. There is also shown a dimension D for the diameter of the magnet 15, and there is shown a dimension C for the outside diameter of the conduit 13 passing through the magnet 15. Depending upon the material from which the magnet is made, the geometry is so chosen as to maximize the lines of flux thru the axial hole compared to the flux lines thru the air on the outside of the magnet. Also the environment of the magnet must be selected not to interfere with this maximization of axial flux.

I have found that for ferrite magnets the magnet length L must be greater than one-fourth of the diameter D for the best water-conditioning. I have also found that if the length of the ferrite magnet is more than about two times the diameter, then there is very little added flux strength because of this added length. The diameter C of the pipe conduit passing through the magnet, which is the same as the inside diameter of the hole through the magnet, of course, has a bearing on these length and diameter dimensions, and these length and diameter ratios apply generally when the conduit dimension C is one-half of D or smaller.

I have also used direct-current coils of hollow-cylinder shape and find that these function effectively to create the desired magnetic field in a pipe passing through the hollow of the cylinder.

Referring to Figs. 3 and 4, a conduit 30 has a coil of wire 31 wrapped tightly about the conduit 30, and this is energized by a battery 32 passing direct current through the coil. The coil generates a steady magnetic field which is identical in all respects to the magnetic field of the permanent magnets and generates lines of flux as illustrated in Figs. 5 and 6. Shown in Fig. 4 is the commercial version of the schematic Fig. 3, wherein the conduit 30 has a multilayer coil 33 wrapped around it and this coil 33 will generate a north pole at the left end as indicated by the letter N and a south pole at the right end as indicated by the letter S. The coil is energized by any suitable source of direct current, and there is shown schematically a direct-current generator 34 driven by a AC-motor 36 or any other suitable motor, which in turn delivers current to the coil 33 through conductors 37 and 38.

I find that it is important that the conduit through the magnets be straight and even in cross section so that there is no turbulence as the water passes through the magnet. The flow of water, therefore, is aligned with the lines of flux as shown most graphically in Fig. 5 as the water passes through the magnet 20. If the raw water carries in it floating particles, these should, of course, be screened out, and the conduit 13 of Fig. 1 could, for example, be made of transparent glass or other transparent nonmetallic material so that any iron or iron oxide particles that collect on the interior of the conduit 13 in the region of the magnet will be clearly visible and can thereupon be cleaned.

For creating apparent softening of the raw water, the water should flow through the magnets from north to south. If it is desired to increase the apparent hardness of the water, then the water should flow through the magnets from south to north. When the flow is from north to south, then the apparent softening also seems to loosen some boiler scale already formed.

The term "apparent softening" is used to denote the effect on the dissolved material. My apparatus does not remove any dissolved material, and a chemical analysis on a dry basis of water treated by my apparatus would be the same as the untreated input water. However, there is a chemical or electronic change in these scale-producing materials so that they do not deposit out as readily as the materials in raw water. The same analysis applies to my water treatment to increase the "apparent hardness", except in this case scaling is increased and the usefulness is for defoaming and other uses of hard water.

I have found that the beneficial effects conferred by magnetic water treatment with my apparatus occur independently of the rate of water flow through the magnet. I have described my permanent magnet with respect to ferrite materials, but it will be apparent to those skilled in the art that any other material may be used and any other configuration other than rings of permanent magnets may be used. For example, ceramic magnets are made in cylindrical shells or two semicylindrical shells that are cemented together for completion of the cylinder. These shells or cylinders are magnetized in an axial direction. If a long solenoid is used, then almost all of the lines of flux will be contained within the axial bore.

I have experimented with ceramic magnets, primarily because they are cheaper by several times than those of alnico, and rare earth cobalts and mixtures with other metals. These ferrite magnets have a smaller flux density than other more expensive magnet materials, but suitable geometrics of ferrite result in very satisfactory flux densities. I have found that the ring-shaped loudspeaker magnets, which are axially magnetized, are readily and inexpensively available and, by stacking, any desired length of cylindrical magnet may be quickly formed that is also axially magnetized. If alnico magnets are used the length must be greater compared to diameter than with ceramic magnets.

I have described my invention with respect to presently preferred embodiments thereof as required by patent statutes. I do not limit myself to these embodiments, however, as they are illustrative only of my invention. I include within the scope of the following claims all variations, modifications, and improvements that fall within the true spirit and scope of my invention.

Claims

1. Apparatus for the magnetic treatment of mineralized flowing water, comprising:
   a) a magnet of cylindrical shape that is axially magnetized and which has an axial hole of uniform cross section;
   b) and a water conduit disposed in the axial hole of the magnet and in a close fit with the magnet hole and formed of non-magnetic material,

   said magnet having a geometry and environment to maximize the magnetic flux in the axial hole.

2. Apparatus as set forth in claim 1 wherein the magnet is a permanent magnet.

3. Apparatus as set forth in claim 1 wherein the magnet is a direct-current coil.

4. Apparatus as set forth in claim 1 wherein the conduit within the confines of the magnet is straight and smooth to minimize water turbulence.

5. Apparatus as set forth in claim 1 wherein the conduit is formed of nonmetallic material.

6. Apparatus for the magnetic treatment of mineralized flowing water comprising:
   a) a magnet of hollow cylinder shape that is axially magnetized with a continuous magnetic field having a north pole at one end and a south pole at the other end;

b) a water conduit axially disposed in the magnet with a close fit and formed of non-magnetic material;

c) and means for flowing mineralized water through the conduit in a selected direction.

7. Apparatus as set forth in claim 6 wherein the means for flowing causes water in the conduit to exit the magnet at the south pole of the magnet to reduce the apparent hardness of the water.

8. Apparatus as set forth in claim 6 wherein the means for flowing causes water in the conduit to exit the magnet at the north pole of the magnet to increase the apparent hardness of the water.

9. Apparatus as set forth in claim 6 wherein the magnet is a permanent magnet of ceramic ferrite material and has a length more than one-fourth of the diameter and less than twice the diameter.

1

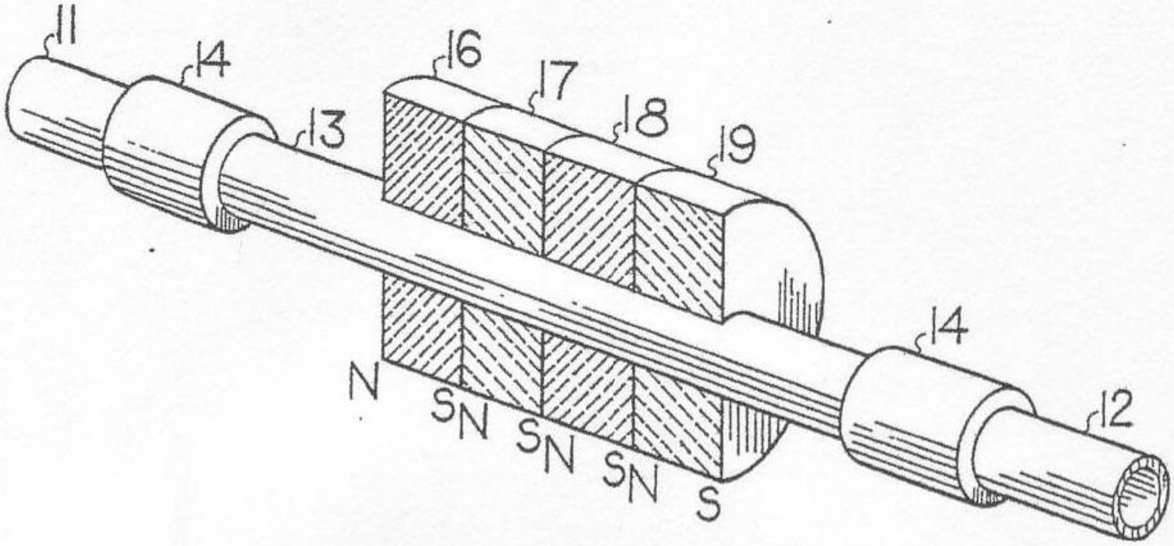

Fig-1

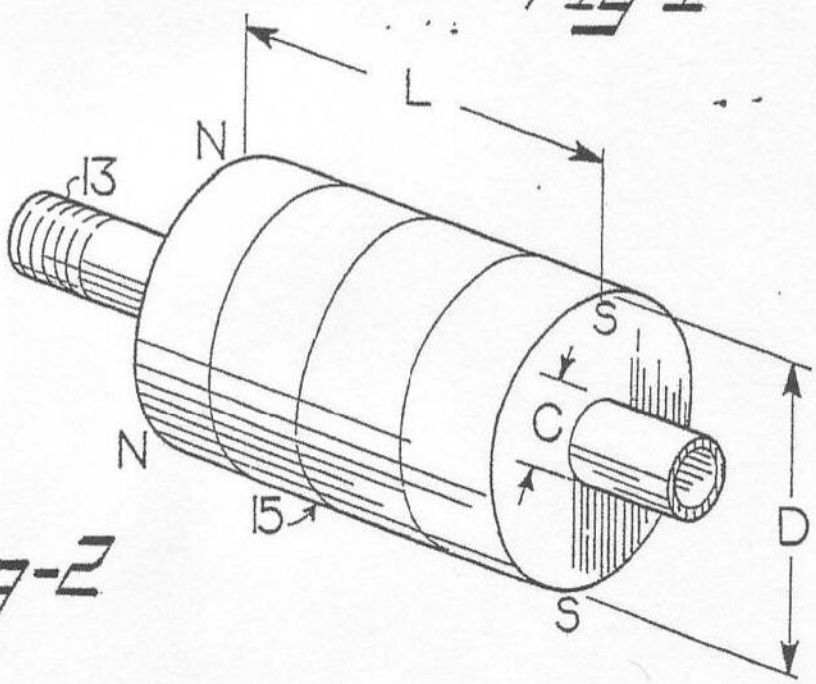

Fig-2

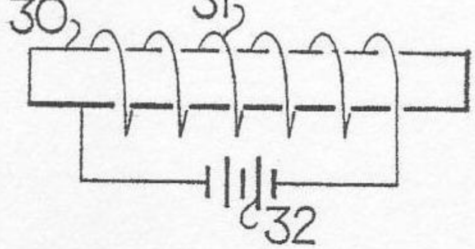

Fig-3

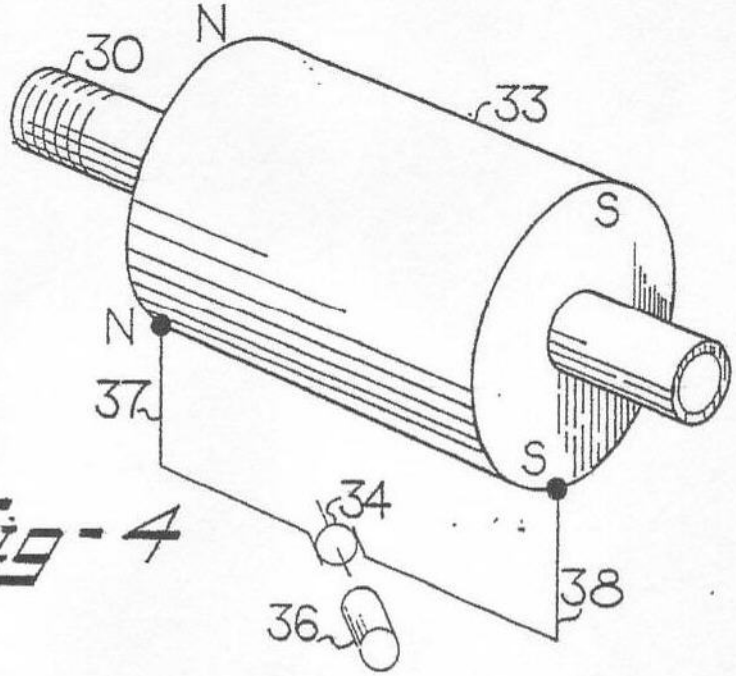

Fig - 4

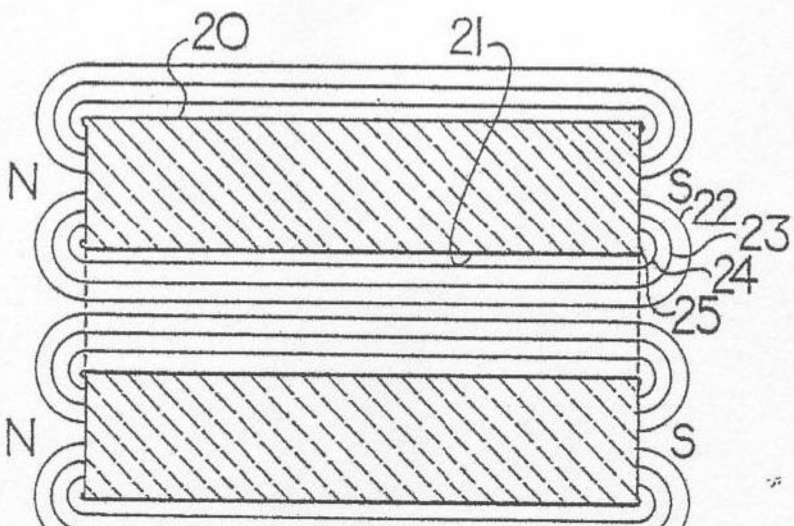

Fig - 5

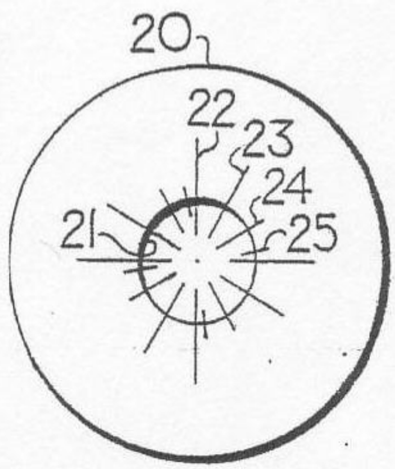

Fig - 6

INTERNATIONAL SEARCH REPORT

International Application No PCT/US81/00304

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [3]

According to International Patent Classification (IPC) or to both National Classification and IPC

Int. Cl.[3] B01D 35/06
U.S. Cl. 210/222

II. FIELDS SEARCHED

Minimum Documentation Searched [4]

Classification System	Classification Symbols
US.	210/222,223

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [5]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [14]

Category *	Citation of Document, [16] with indication, where appropriate, of the relevant passages [17]	Relevant to Claim No. [18]
X	US, A 2,652,925, Published 22 September 1953 Vermeiren	1-9
X	US, A 4,146,479, Published 27 March 1979 Brown	1-9
A P	US, A 4,210,535 Published 01 July 1980 Risk	1-9
A	US, A 4,153,559 Published 08 May 1979 Sanderson	1-9
A	US, A 2,939,830 Published 07 June 1960 Green et al	1-9
A	N The Magnetic Effect, Published 1975, by Davis & Rawls, Jr. Exposition Press. Hicksvill, N.Y. See p. 115-p.120.	1-9

* Special categories of cited documents: [15]

"A" document defining the general state of the art

"E" earlier document but published on or after the international filing date

"L" document cited for special reason other than those referred to in the other categories

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but on or after the priority date claimed

"T" later document published on or after the international filing date or priority date and not in conflict with the application, but cited to understand the principle or theory underlying the invention

"X" document of particular relevance

IV. CERTIFICATION

Date of the Actual Completion of the International Search [2]	Date of Mailing of this International Search Report [2]
15 April 1981	05 MAY 1981
International Searching Authority [1]	**Signature of Authorized Officer [10]**
ISA/US	Theodore A. Granger

Form PCT/ISA/210 (second sheet) (October 1977)

Federal Technology Alert

DOE/EE-0162

Title: Non-Chemical Technologies for Scale and Hardness Control

Date of Publication: January, 1998

Publisher: US Department of Energy

Federal Technology Alert

A publication series designed to speed the adoption of energy-efficient and renewable technologies in the Federal sector

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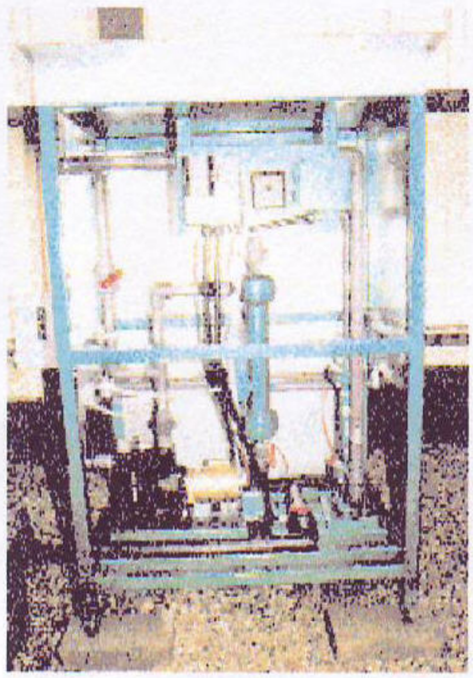
Non-Chemical Technologies for Scale and Hardness Control

Technology for improving energy efficiency through the removal or prevention of scale.



The technology addressed in this *Federal Technology Alert* (FTA) uses a magnetic or electrostatic field to alter the reaction between scale-forming ions in hard water. Hard water contains high levels of calcium, magnesium, and other divalent cations. When subjected to heating, the divalent ions form insoluble compounds with anions such as carbonate. These insoluble compounds have a much lower heat transfer capability than heat transfer surfaces such as metal. They are insulators. Thus additional fuel consumption would be required to transfer an equivalent amount of energy.

The magnetic technology has been cited in the literature and investigated since the turn of the 19^{th} century, when lodestones or naturally occurring magnetic mineral formations were used to decrease the formation of scale in cooking and laundry applications. However, the availability of high-power, rare-earth element magnets has advanced the technology to the point where it is more reliable. Similar advances in materials science, such as the availability of ceramic electrodes and other durable dielectric materials, have led to the electrostatic technology becoming more reliable.

Application Domain

The magnetic or electrostatic scale control technologies can be used as a replacement for most water-softening equipment. Specifically, chemical softening (lime or lime-soda softening), ion exchange, and reverse osmosis, when used for the control of hardness, could potentially be replaced by the non-chemical water conditioning technology. This would include applications both to cooling water treatment and boiler water treatment in once-through and recirculating systems. Other applications mentioned by the manufacturers include the use on petroleum pipelines as a means of decreasing fouling caused by wax build-up and the ability to inhibit biofouling and corrosion.

Energy-Savings Mechanism

The primary energy savings from this technology result from decrease in energy consumption in heating or cooling applications. This savings is associated with the prevention or removal of scale build-up on a heat exchange surface where even a thin film can increase energy consumption by nearly 10%. Secondary energy savings can be attributed to reducing the pump load, or system pressure, required to move the water through a scale-free, unrestricted piping system.

Other Benefits

In addition to energy savings, these technologies offer other potential areas for savings. First, the need for scale and hardness control chemicals can be eliminated or greatly reduced. In a typical plant this savings could be on the order of thousands of dollars each year, when the cost of chemicals, labor and equipment is factored in. Second, periodic descaling of the heat exchange equipment is greatly reduced. Thus process downtime, chemical usage, and labor requirements are reduced. Third, potential savings may result from reductions in heat exchanger tube replacement due to failure. Failure of tubes due to scale build-up, and the resultant temperature rise across the heat exchange surface, will be elimi–nated or greatly reduced in proportion to the reduction in scale formation if the current scale control is not adequate.

Application Screening

As mentioned previously, the technology can be applied wherever hard water is found to cause scale. The magnetic technology, being a physical process as opposed to chemical water softening, is expected to perform best in locations with harder water. Hard water contains a greater number of ions, thus increasing the likelihood of beneficial collisions. The electrostatic technology will be most beneficial in waters of lower hardness. Here the number of ions is lower. Thus the electrostatic field density per ion is greater, which leads to a more rapid neutralization of the surface charge.

In general, there are only a few locations that do not require or would not benefit from some type of hardness control. Hard water is one in which the hardness is greater than 60 mg/L (or ppm) as calcium carbonate. This corresponds to approximately 3.5 grains of hardness per U.S. gallon. The Pacific Northwest states, the North Atlantic coastal states, and the Southeast states, excluding Florida, are locations where naturally occurring soft water is most likely to be found. The balance of the United States could benefit from some type of water treatment to control scale formation, from either one of the traditional technologies, such as lime softening or ion exchange, or the non-chemical technologies discussed in this FTA.

Costs

Cost information was requested from each manufacturer for three different-sized units: 1 gpm (gallons per minute), 100 gpm, and 1,000 gpm flow rates. As is typical of process equipment, cost per unit of treatment decreases with increasing capacity. To treat 1 gpm a typical cost was on the order of \$100, or about \$100/gpm. To treat 1,000 gpm a typical cost was on the order of \$10,000, or about \$10/gpm.

In general, the electronic units were more costly than the magnetic units for an equivalent flow rate. Costs ranged considerably with unit size, with the 1-gpm units ranging in cost up to \$500. For the 1,000-gpm units the range of costs was considerably greater, from \$900 to over \$1,000,000.

Life-Cycle Cost

The technologies will have impacts on four costs: energy costs, water consumption and discharge costs, maintenance costs, and water-softening system-operating costs. The most significant life-cycle cost impact is with energy costs where both costs for water heating and pumping will be reduced. Significant reductions in water-softening costs due to reduction or elimination of chemical consumption will also be realized. Maintenance costs, in the form or reductions in the need for heat exchanger cleaning, are also reduced. Lastly, the water consumption and discharge costs may be reduced by allowing higher cycle of concentration within the system, thus lower make-up water and blowdown volumes.

The Technology's Development

Magnetic and electrical effects on water were first noted at the turn of the 19^{th} century, but the technologies were not commercialized and were basically not heard of until the latter part of the 20^{th} century. The Japanese are conducting considerable research on magnetohydrodynamics as a means of propulsion, and similar research has been conducted in the past in the United States and other industrialized countries. This research has been facilitated by the advent of rare earth magnets, solid state electronics, and advanced ceramic or polymeric materials after World War II. Only after these advances has non-chemical water treatment shown promise and come into more wide-spread use.

Of the manufacturers listed in this FTA, most have come into existence since the advent of the environmental movement in the United States in the early 1970s. Others have histories dating back to as far as just after World War II. This can be attributed both to the advent of cost-effective components (e.g., magnets, electronics) and to the public desire for more "green" or environmentally friendly alternatives to chemical treatment.

Relation to Other Technologies

Use of the non-chemical technologies does not prohibit the use of any other technology or equipment. As mentioned previously, the change from chemical to non-chemical scale control may warrant investigation of other means of corrosion or biofouling control, as these three chemical treatment or control applications are often balanced amongst each other.

Technology Outlook

There is no evidence to suggest that the non-chemical scale control technologies are going to disappear anytime soon. Each has a historical basis of successful installations. Advances in materials science should only serve to improve each of the technologies. More powerful magnets will allow the magnetic devices to become smaller and/or more efficacious. More durable electrodes and dielectric compounds will improve the life of the electrostatic units.

Probably the most significant general trend in water treatment is the move away from chemical-based treatment technologies. This trend has begun at the consumer level, is becoming apparent at the corporate level, and will continue to grow. Increased availability of information on technologies, the environment, and human health will only serve to feed this trend.

Federal Technology Alert

Non-Chemical Technologies for Scale and Hardness Control

Technology for improving energy efficiency through the removal or prevention of scale.

Abstract

The magnetic technology has been cited in the literature and investigated since the turn of the 19th century, when lodestones and naturally occurring magnetic mineral formations were used to decrease the formation of scale in cooking and laundry applications. Today, advances in magnetic and electrostatic scale control technologies have led to their becoming reliable energy savers in certain applications.

For example, magnetic or electrostatic scale control technologies can be used as a replacement for most water-softening equipment. Specifically, chemical softening (lime or lime-soda softening), ion exchange, and reverse osmosis, when used for the control of hardness, could potentially be replaced by non-chemical water conditioning technology. This would include applications both to cooling water treatment and boiler water treatment in once-through and recirculating systems.

The primary energy savings from this technology result from decrease in energy consumption in heating or cooling applications. This savings is associated with the prevention or removal of scale build-up on a heat exchange surface, where even a thin film can increase energy consumption by nearly 10%. Secondary energy

savings can be attributed to reducing the pump load, or system pressure, required to move the water through a scale-free, unrestricted piping system.

This *Federal Technology Alert* provides information and procedures that a Federal energy manager needs to evaluate the cost-effectiveness of this technology. The process of magnetic or eletrostatic scale control and its energy savings and other benefits are explained. Guidelines are provided for appropriate application and installation. In addition, a hypothetical case study is presented to give the reader a sense of the actual costs and energy savings. A listing of current manufacturers and technology users is provided along with references for further reading.

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2

Contents

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About the Technology

The technology addressed in this FTA uses a magnetic or electrostatic field to alter the reaction between scale-forming ions in hard water. Hard water contains high levels of calcium, magnesium, and other divalent cations. When subjected to heating, the divalent ions form insoluble compounds with anions such as carbonate. These insoluble compounds have a much lower heat transfer capability than heat transfer surfaces such as metal. They are insulators. Thus additional fuel consumption would be required to transfer an equivalent amount of energy.

The magnetic technology has been cited in the literature and investigated since the turn of the 19th century, when lodestones or naturally occurring magnetic mineral formations were used to decrease the formation of scale in cooking and laundry applications. However, the availability of high-power, rare-earth element magnets has advanced the magnetic technology to the point where it is more reliable. Similar advances in materials science, such as the availability of ceramic electrodes and other durable dielectric materials, have allowed the electrostatic technology to also become more reliable.

The general operating principle for the magnetic technology is a result of the physics of interaction between a magnetic field and a moving electric charge, in this case in the form of an ion. When ions pass through the magnetic field, a force is exerted on each ion. The forces on ions of opposite charges are in opposite directions. The redirection of the particles tends to increase the frequency with which ions of opposite charge collide and combine to form a mineral precipitate, or insoluble compound. Since this reaction takes place in a low-temperature region of a heat exchange system, the scale formed is non-adherent. At the prevailing temperature conditions, this form is preferred over the adherent form, which attaches to heat exchange surfaces.

The operating principles for the electrostatic units are much different. Instead of causing the dissolved ions to come together and form non-adherent scale, a surface charge is imposed on the ions so that they repel instead of attract each other. Thus the two ions (positive and negative, or cations and anions, respectively) of a kind needed to form scale are never able to come close enough together to initiate the scale-forming reaction. The end result for a user is the same with either technology; scale formation on heat exchange surfaces is greatly reduced or eliminated.

Application Domain

These technologies can be used as a replacement for most water-softening equipment. Specifically, chemical softening (lime or lime-soda softening), ion exchange, and reverse osmosis (RO), when used for the control of hardness, can be replaced by the non-chemical water conditioning technology. This would include applications both to cooling water treatment and boiler water treatment, in once-through and recirculating systems. Other applications mentioned by the manufacturers include use on petroleum pipelines as a means of decreasing fouling caused by wax build-up, and the ability to inhibit biofouling and corrosion.

The magnetic technology is generally not applicable in situations where the hard water contains "appreciable" concentrations of iron. In this FTA, appreciable means a concentration requiring iron treatment or removal prior to use, on the order of parts per million or mg/L. The reason for this precaution is that the action of the magnetic field on the hardness-causing ions is very weak. Conversely, the action of the magnetic field on the iron ions is very strong, which interferes with the water conditioning action.

A search of the Thomas Register™ in conjunction with manufacturer contact yielded eleven manufacturers of magnetic, electromagnetic or electrostatic water conditioning equipment that fell within the scope of this investigation. The defined scope includes commercial- or

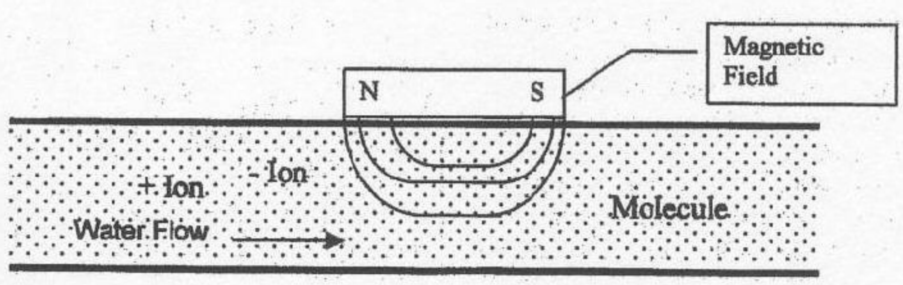

Figure 1. Diagram of General Magnetic Device Construction

industrial-type magnetic, electromagnetic or electrostatic devices marketed for scale control. Devices intended for home use, as well as other non-chemical means for scale control, such as reverse osmosis, are not within the extended scope of this FTA.

Exact numbers of units deployed by these manufacturers are virtually impossible to compile, as some of the manufacturers had been selling the technology for up to 40 years. One manufacturer claims as many as 1,000,000 units (estimated total of all manufacturers represented here) are installed in the field. Where not withheld by the manufacturer because of business sensitivity reasons, customer lists included both Federal and non-Federal installations. Those manufacturers who did withhold the customer list indicated a willingness to disclose customer contacts to legitimate prospective customers.

Literature provided by and discussions with manufacturers described a typical installation for a boiler water treatment scheme as including the device installed upstream of the boiler. Manufacturers vary in their preference of whether the device should be installed close to the water inlet or close to the boiler. Both locations have been documented as providing adequate performance. Generally, the preferred installation location for use with cooling towers or heat exchangers is upstream of the heat exchange location and upstream of the cooling tower. Downstream of the cooling tower but upstream of the heat source was also mentioned as a possible installation location, primarily for the use with chillers or other cooling equipment.

The primary *caveat* on installation of the magnetic technology is that high voltage (230V, 3-phase or above) power lines interfere with operation by imposing a second magnetic field on the water. (This is most noticeable when these electric power sources are installed within three feet of a magnetic device.) This second magnetic field most likely will not be aligned with the magnetic field of the device, thus introducing interference and reducing the effectiveness of the treatment. Installations near high voltage power lines are to be avoided if possible. Where avoidance is not possible, the installation of shielded equipment is recommended to achieve optimum operation. Some manufacturers also have limitations on direction of installation—vertical or horizontal—because of internal mechanical construction.

Energy-Savings Mechanism

The primary energy savings result from a decrease in energy consumption in heating or cooling applications. This savings is associated with the prevention or removal of scale build-up on a heat exchange surface where even a thin film (1/32" or 0.8 mm) can increase energy consumption by nearly 10%. Example savings resulting from the removal of calcium-magnesium scales are shown in Table 1. A secondary energy savings can be attributed to reducing the pump load, or system pressure, required to move the water through a scale-free, unrestricted piping system.

Table 1. Example Increases in Energy Consumption as a Function of Scale Thickness

Scale Thickness (inches	Increased Energy Consumption (%)
1/32	8.5
1/16	12.4
1/8	25.0
1/4	40.0

As was discussed above, magnetic and electric fields interact with a resultant force generated in a direction perpendicular to the plane formed by the magnetic and electric field vectors. (See Figure 2 for an illustration.) This force acts on the current carrying entity, the ion. Positively charged particles will move in a direction in accord with the Right-hand Rule, where the electric and magnetic fields are represented by the fingers and the force by the thumb. Negatively charged particles will move in the opposite direction. This force is in addition to any mixing in the fluid due to turbulence.

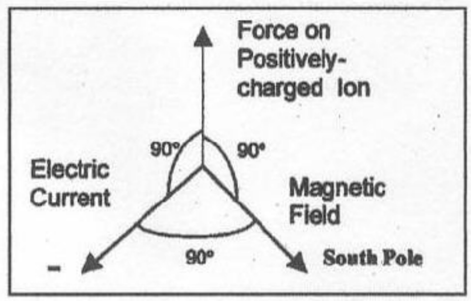

Figure 2. Diagram Showing Positioning of Fields and Force

The result of these forces on the ions is that, in general, positive charged ions (calcium and magnesium, primarily) and negative charged ions (carbonate and sulfate, primarily) are directed toward each other with increased velocity. The increased velocity should result in an increase in the number of collisions between the particles, with the result being formation of insoluble particulate matter. Once a precipitate is formed, it serves as a foundation for further growth of the scale crystal. The treatment efficiency increases with increasing hardness since more ions are present in solution; thus each ion will need to travel a shorter distance before encountering an ion of opposite charge.

A similar reaction occurs at a heat exchange surface but the force on the ions results from the heat input to the water. Heat increases the motion of the water molecules, which in turn increases the motion of the ions, which then collide. In addition, scale exhibits an inverse solubility relationship with temperature, meaning that the solubility of the material decreases as temperature increases. Therefore, at the hottest point in a heat exchanger, the heat exchange surface, the scale is least soluble, and, furthermore due to thermally induced currents, the ions are most likely to collide nearest the surface. As above, the precipitate formed acts as a foundation for further crystal growth.

When the scale-forming reaction takes place within a heat exchanger, the mineral form of the most common scale is called calcite. Calcite is an adherent mineral that causes the build-up of scale on the heat exchange surface. When the reaction between positively charged and negatively charged ions occurs at low temperature, relative to a heat exchange surface, the mineral form is usually aragonite. Aragonite is much less adherent to heat exchange surfaces, and tends to form smaller-grained or softer-scale deposits, as opposed to the monolithic sheets of scale common on heat exchange surfaces.

These smaller-grained or softer-scale deposits are stable upon heating and can be carried throughout a heating or cooling system while causing little or no apparent damage. This transport property allows the mineral to be moved through a system to a place where it is convenient to collect and remove the solid precipitate. This may include removal with the wastewater in a once-through system, with the blowdown in a recirculating system, or from a device such as a filter, water/solids separator, sump or other device specifically introduced into the system to capture the precipitate.

Water savings are also possible in recirculating systems through the reduction in blowdown necessary. Blowdown is used to reduce or balance out the minerals and chemical concentrations within the system. If the chemical consumption for scale control is reduced, it may be possible to reduce blowdown also. However, the management of corrosion inhibitor and/or biocide build-up, and/or residual products or degradation by-products, may become the controlling factor in determining blowdown frequency and volume.

Other Benefits

Aside from the energy savings, other potential areas for savings exist. The first is elimination or significant reduction in the need for scale and hardness control chemicals. In a typical plant, this savings could be on the order of thousands of dollars each year when the cost of chemicals, labor and equipment is factored in. Second, periodic descaling of the heat exchange equipment is virtually eliminated. Thus process downtime, chemical usage, and labor requirements are eliminated. A third potential savings is from reductions in heat exchanger tube replacement due to failure. Failure of tubes due to scale build-up, and the resultant temperature rise across the heat exchange surface, will be eliminated or greatly reduced in proportion to the reduction in scale formation.

Variations

Devices are available in two installation variations and three operational variations. First to be discussed are the two installation variations: invasive and non-invasive. Invasive devices are those which have part or all of the operating equipment within the flow field. Therefore, these devices require the removal of a section of the pipe for insertion of the device. This, of course, necessitates an amount of time for the pipe to be out of service. Non-invasive devices are completely external to the pipe, and thus can be installed while the pipe is in operation. Figure 3 illustrates the two installation variations.

The operational variations have been mentioned above; illustrations of the latter two types are shown in Figure 4:

- Magnetic, more correctly a permanent magnet
- Electromagnetic, where the magnetic field is generated via |electromagnets
- Electrostatic, where an electric field is imposed on the water flow, which serves to attract or repel the ions and, in addition, generates a magnetic field.

Electrostatic units are always invasive. The other two types can be either invasive or non-invasive. The devices illustrated in Figure 3 are examples of permanent magnet devices.

Installation

Most of the devices are in-line—some invasive, some non-invasive—as opposed to side-stream. The invasive devices require a section of pipe to be removed and replaced with the device. Most of the invasive devices are larger in diameter than the section of pipe they replace. The increased diameter is partially a function of the magnetic or electromagnetic elements, and also a function of the cross sectional flow area. The flow area through the devices is generally equivalent to the flow area of the section of pipe removed.

The non-invasive in-line devices are designed to be wrapped around the pipe. Thus downtime, or line out-of-service time, is minimized or eliminated.

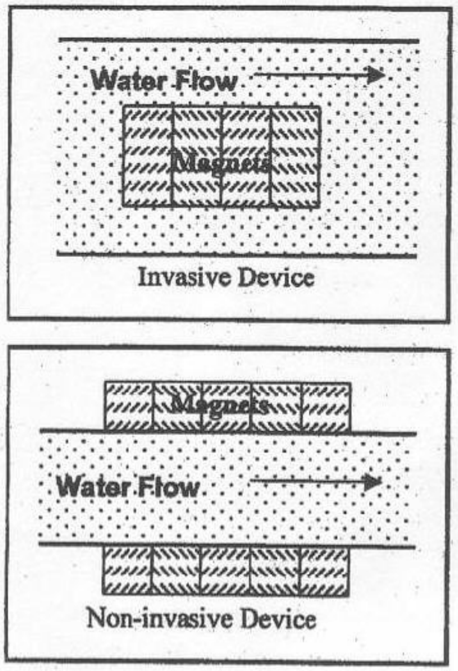

Figure 3. Illustration of Classes of Magnetic Devices by Installation Location

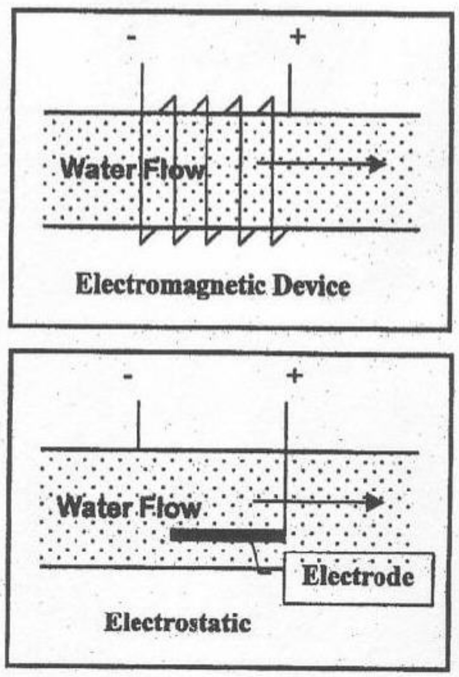

Figure 4. Illustration of Classes of Non-Permanent Magnet Devices

Federal Sector Potential

The potential cost-effective savings achievable by this technology were estimated as part of the technology assessment process of the New Technology Demonstration Program (NTDP).

Technology Screening Process

New technologies were solicited for NTDP participation through advertisements in the *Commerce Business Daily* and trade journals, and, primarily, through direct correspondence. Responses were obtained from manufacturers, utilities, trade associations, research institutes, Federal sites and other interested parties. Based on these responses, the technologies were evaluated in terms of potential Federal-sector energy savings and procurement, installation, and maintenance costs. They were also categorized as either just coming to market ("unproven" technologies) or as technologies for which field data already exist ("proven" technologies).

The energy savings and market potentials of each candidate technology were evaluated using a modified version of the Facility Energy Decisions Screening (FEDS) software tool[(a)] (Dirks and Wrench, 1993).

Non-chemical water treatment technologies were judged life-cycle cost-effective (at one or more Federal sites) in terms of installation cost, net present value, and energy savings. In addition, significant environmental savings from the use of many of these technologies are likely through reductions in CO_2, NO_x, and SO_x emissions.

Estimated Savings and Market Potential

As part of the NTDP selection process, an initial technology screening activity was performed to estimate the potential market impact in the Federal sector. Two technologies were run through the assessment methodology. The first technology was assessed assuming the technology was applied to the treatment of boiler make-up water. The second technology was assessed assuming the technology was applied to both the treatment of boiler make-up water and cooling tower water treatment. The technology screenings used the economic basis required by 10 CFR 436. The costs of the two technologies were different based on information provided by the manufacturers, thus leading to different results.

The technologies were ranked on a total of ten criteria. Three of these were financial, including net present value (NPV), installed cost, and present value of savings. One criterion was energy-related, annual site energy savings. The remaining criteria were environmental and dealt with reductions in air emissions due to fuel or energy savings and included SO_2, NO_x, CO, CO_2, particulate matter, and hydrocarbon emissions.

The ranking results from the screening process for this technology are shown in Table 2. These values represent the maximum benefit achieved by implementation of the technology in every Federal application where it is considered life-cycle cost-effective. The actual benefit will be lower because full market penetration is unlikely to ever be achieved.

(a) This software tool was developed for the Federal Energy Management Program (FEMP), Construction Engineering Research Laboratory (CERL), and the Naval Facilities Engineering Service Center (NFESC) by Pacific Northwest National Laboratory (PNNL).

Laboratory Perspective

The primary question to be answered is "Does the technology work as advertised?" The history of the technologies, as illustrated through primarily qualitative—but some quantitative—assessment in many case studies, has shown that when properly installed, a decrease in or elimination of scale formation will be found. While the evidence supporting the technologies may be thought of as mainly anecdotal, the fact remains that upon visual inspection after installation of these devices the formation of new scale deposits has been inhibited. In addition, in most cases, scale deposits present within the system at the time of installation have been removed.

The key here is *properly installed*. By this it is meant that a manufacturer or their qualified representative is responsible for equipment integration. Unlike many other technologies where much of the knowledge has been reduced to a quantitative model, the non-chemical water treatment industry still relies largely on experience as the means of providing quality installation, service and, consequently, customer satisfaction.

Of particular interest to the manufacturer would be physical parameters such as water flow rate, and water quality parameters such as hardness, alkalinity, and iron concentration. These parameters will help determine the optimum size and the extent of treatment.

The manufacturer may also want to know whether the installation is for use in conjunction with a boiler or a cooling tower, and for once-through or recirculating water systems. These parameters will help determine the optimum location within the system.

Other factors of interest may include whether the cooling or heating system is sensitive to particulate matter, and if so what particle sizes. The device works by initiating the precipitation of scale, thus particulate matter will be present in the treated water. If the system is sensitive to particulate matter there may be a need for a solid separation device such as a filter, a settling basin, a cyclone, or a sump to collect solids and to allow for their easy removal from the system.

Table 2. Screening Criteria Results

Screen Criteria	Results	
	First Screen	Second Screen
Net Present Value ($)	147,518,000.	158,228,000.
Installed Cost ($)	52,819,000.	35,299,000.
Present Value of Savings ($)	200,336,000.	193,527,000.
Annual Site Energy Savings (Mbtu)	4,166,000.	3,761,000.
SO_2 Emissions Reduction (lb/yr)	3,292,000.	427,000.
NO_x Emissions Reduction (lb/yr)	1,028,000.	550,000.
CO Emissions Reduction (lb/yr)	304,000.	128,000.
CO_2 Emissions Reduction (lb/yr)	303,000.	234,000
Particulate Emissions Reduction (lb/yr)	60,000.	29,000.
Hydrocarbon Emissions Reduction (lb/yr)	7,000.	3,000.

Note: First Screen: Boiler make-up water treatment.
Second Screen: Cooling tower water treatment and boiler make-up water treatment.

Application

This section addresses the technical aspects of applying the technology. The range of applications and climates in which the technology can be applied are addressed. The advantages, limitations, and benefits in each application are enumerated. Design and integration considerations for the technology are discussed, including equipment and installation costs, installation details, maintenance impacts, and relevant codes and standards. Utility incentives and support are also discussed.

Application Screening

As mentioned previously, the technology can be applied wherever hard water is found to cause scale. Since the technology is a physical process, as opposed to chemical water softening, it is expected to perform best in locations with harder water. In general, only a few locations do not require or would not benefit from some type of hardness control. Hard water is one in which the hardness is greater than 60 mg/L (or ppm) as calcium carbonate. This corresponds to approximately 3.5 grains of hardness per U.S. gallon. The Pacific Northwest states, the North Atlantic coastal states, and the Southeast states, excluding Florida, are locations where naturally occurring soft water is most likely to be found. The balance of the United States could benefit from some type of water treatment to control scale formation, using either one of the traditional technologies such as lime softening or ion exchange, or the non-chemical technology discussed in this FTA.

Where to Apply

Non-chemical scale control technologies can be used for either boiler scale control or cooling tower scale control. Boiler scale control applications are the majority of the installations, but the control of silica scale in cooling water applications is also possible. Experience has been cited with both retrofit installations and in new installations (see References for a brief listing of applicable reports and publications).

Non-chemical scale control technologies are best applied:

- When the use of chemicals for water treatment is to be minimized or eliminated. Lime, salt and acid for cleaning can be reduced or eliminated.
- When space requirements do not allow installation of lime softening equipment or ion exchange equipment. The non-chemical technologies are generally very space efficient.
- When particulate matter in the water can be tolerated by the process; otherwise solids separation is required.
- When frequent system shutdowns are required for descaling even with a diligent chemical scale control program.
- In remote locations where delivery of chemicals and labor cost makes conventional water softening or scale control methods cost prohibitive.

What to Avoid

There are a few precautions to be noted before selecting the technology:

- This technology is littered with disreputable manufacturers or vendors, the actions of whom have given the technology an undesirable history in the eyes of many. Work with a reputable manufacturer (such as those included herein) through their engineering department or their designated installer. These people have much more experience with the technology than the typical water treatment engineering firm.
- Be aware of process water requirements since these requirements may dictate the need to install solids separation equipment or iron removal equipment in order to maximize the performance of the technology.
- Installation near high voltage electrical equipment or strong magnetic fields is to be avoided since these fields will interfere with the performance of the technology. (Near is relative to the voltage; for 208/220/240V it means within 36 inches; for higher voltages it is proportionally more distant.) Also, check the pipeline for its use as an electrical ground. Stray electrical current in the pipe will have the same effect as installation near a strong electrical or magnetic field.

Installation

Installation issues with these devices are few. The first issue is whether a permanent magnet or one of the electronic devices is chosen. The latter needs a suitable supply of electricity.

The second issue is device capacity, which will dictate space requirements and pipe size. The pipe size generally determines the fittings. Smaller devices, up to approximately 2" pipe size, are available with solder or pipe thread fittings. Larger devices may have flange fittings that would necessitate the installation of matching flanges in the current pipe arrangement.

The third issue is the potential for downtime, which needs to be coordinated with other facility activities. However, this should not be a major impediment since downtime for cleaning and maintenance of cooling towers, or boiler inspection is part of the regularly scheduled activities for most installations.

A fourth issue would arise with the corrosion control chemistry, which will likely need some adjustment under a non-chemical scale control technology. In many cases the layer of scale on heat transfer surfaces is beneficial from a corrosion control standpoint. With this layer not present when using a non-chemical technology, the concentration of corrosion control chemicals may need adjustment in order to provide the proper protection. On the reverse side, many users are claiming the presence of a fine powdery film on the surfaces the treated water contacts. This powder has been attributed to serve as a corrosion inhibitor.

The most significant issue may be whether a solids separation device is needed to remove the particulates formed. Filters, hydrocyclones, and settling basins are all compatible with the technology. The choice among these or other solids separation technologies should be made in conjunction with the manufacturer who will have the best idea of particle size distribution, and thus the relative efficiencies of the separation technologies.

Maintenance Impact

There is a significant, positive impact on maintenance. Field applications have shown the technology to be capable of controlling scale for extended periods of time, months or years, eliminating the periodic cleaning or descaling of process equipment that is typical of conventional, chemical-based scale control technologies. The resources—time, chemicals, and equipment—previously devoted to periodic scale removal from heat exchange surfaces will be made available for other tasks. Note, however, the need for periodic inspection of the heat exchange surfaces is not reduced or eliminated.

The electrostatic devices also require periodic inspection of the electrodes. This scheduled maintenance activity can be performed in conjunction with the heat exchange surface inspection and requires less than a person-day to disassemble and inspect the system.

Equipment Warranties

All of the manufacturers offer some type of warranty on their respective device. The range is from 90 days to as much as 10 years. Another perspective is the potential impact upon warranties for installed equipment. No information was uncovered as part of this effort to indicate any instance where a boiler or cooling tower equipment manufacturer voided a warranty for equipment. However, no specific effort was made to contact manufacturers of boilers and cooling tower equipment to assess specific warranty conditions or policies.

Codes and Standards

Only one code or standard specific to the non-chemical technologies was identified in the course of preparing this FTA: API 960, Evaluation of the Principles of Magnetic Water Treatment, 09/1985, 89 pages. Of course, all applicable plumbing, piping, mechanical, and/or electrical codes and standards would still apply.

Costs

Cost information was requested from each manufacturer for three different-size units, based on flow rate: 1 gpm (gallons per minute), 100 gpm and 1,000 gpm. As is typical of process equipment, cost per unit of treatment decreases with increasing capacity. To treat 1 gpm, a typical cost was on the order of $100, or about $100 per gpm. To treat 1,000 gpm a typical cost was on the order of $10,000, or about $10 per gpm.

In general, the electronic units were more costly than the magnetic units for an equivalent flow rate. Costs also ranged considerably with unit size, with the 1-gpm units ranging in cost up to $500. For the 1,000-gpm units the range of costs was considerably greater, from $900 to over $1,000,000.

Installation costs also varied widely, in conjunction with equipment size. The lower flow rate units will mate with 3/4" to 1" pipe sizes with soldered, flanged or threaded (NPT) fittings. Installation time estimates were on the order of one hour, with additional parts costing less than $10. The larger-size units (1,000 gpm) were typically designed to mate with a 12" to 18" pipe using a flange fitting. Estimated installation time ranged from one to four person-days, requiring less than $1,000 in additional materials.

Weight was an important characteristic in the installation estimate because the permanent magnet units may exceed 1,000 pounds. There is a trade-off between installing a heavier permanent magnet unit requiring no outside power versus a lighter electronic unit for which an electrical connection needs to be made, and possibly electrical lines run to the point of installation. The net effect is expected to be neutral with regard to installation time estimates.

Since these units are typically delivered in the sizes quoted off-the-shelf, there is no design cost by the manufacturer. Facilities engineering and design for calculations and updating plant drawings should amount to less than two person-days for the large units, and less than an hour for the small units.

Utility Incentives and Support

Although no specific incentive programs were identified, the Department of Energy and the Advanced Research Projects Agency have funded research in this area. Some utility or trade associations have supported the electronic technologies with funds and exposure. For example, the American Water Works Association sponsored a conference to discuss the non-traditional treatment technologies. In addition, as California municipalities face water shortages, they have turned to a number of measures to lower water consumption and increase water quality. Many have prohibited the use of water softeners and may offer assistance in funding conversion to low/no salt water conditioning technologies.

Additional Considerations

There are additional considerations to be taken into account. Primary among these is the reduction in chemical use at the facility for water softening. The chemical use reduction may lead to reduced safety, training and reporting requirements.

Electricity consumption will also be reduced. The actual reduction is highly dependent upon the technology employed. Permanent magnets use no electricity, so both the on-site electricity used for chemical treatment as well as the off-site energy required to produce and transport the chemicals will be eliminated. For the electronic units, on-site energy requirements may vary from as little as 10% of the chemical-based treatment system energy consumption—typical, to 10 times the energy consumed by the chemical-based treatment system.

Energy consumption reductions will lead directly to reductions in air combustion emissions. There will also be additional indirect reductions due to decreased transportation of fuels and decreased fuel processing. The latter will also lead to reductions in water use, water pollution, and solid wastes from mining and processing operations.

Technology Performance

The information in this section was compiled primarily from case studies, along with selected contact with users and third party researchers. As mentioned previously, the use of magnetic or electric fields to treat water had its origins near the turn of the 19^{th} century. Commercialization of the technology began after World War II, with the largest advances coming in the last 20 years with the development of rare earth magnets and inexpensive electronic controls.

There are records of installation of the technology in the United States from about 1950. Manufacturers claim to have installations operating satisfactorily for as long as 30 years. No good statistics were available on the total number of installations over this period. However, using the estimates of one manufacturer as a basis, there could be upwards of 1,000,000 units installed in the United States in commercial or industrial facilities, inclusive of all units installed by all manufacturers.

Field Experience

As has been alluded to above, user experience has been positive. Two experiences have been common. First, users have noted a dramatic reduction in scale formation to the point where the need for chemical scale control is eliminated. Second, the prior build-up of scale on heat exchange surfaces has been removed over time. This last process has been noted as taking from 30 days to over a year, depending upon the thickness and composition of the scale.

This is not to say there have not been less than successful installations or applications. The non-chemical technologies may not be universally applicable for scale control, just as any technology may not be a universally applicable solution to the problem it was designed to solve.

The magnetic technologies are not as effective when silica is present in the system. Nor do they work as efficiently when iron is present, as was mentioned above, or when other magnetic minerals are present. The history of the technology is also littered with cases where the magnet field was applied incorrectly or did not have sufficient strength to affect the reaction. This latter was especially true early in the life cycle of the technology when ferrous-based magnets were the norm. High levels of particulate matter will also negatively influence the efficiency of the technology by reducing the collision frequency of the desirable reactions.

Energy Savings

Energy savings result from both reductions in pumping energy input to the system and reduction in fuel consumption. The first aspect has not been well quantified by the users or in any of the case studies. It is thought of as a secondary benefit.

Fuel consumption has been lowered in every situation. The exact savings are a result of a number of factors:

- How effective the chemical scale control program may have been relative to the input water hardness
- How often the heat exchange system was taken down for maintenance and cleaning.

On systems that were descaled frequently or had low scale formation, due to low hardness and/or an effective chemical scale control program, the savings in fuel consumption was lower, often from a few percent to as much as 15%. The lower savings were at an installation using ion exchange softening of moderately hard water (less than 150 mg/L as calcium carbonate hardness). On systems where descaling was infrequent or absent altogether, or where the chemical scale control program was not as effective in controlling scale formation, fuel consumption savings ranged up to 30%. This was found to be the case in an installation using very hard water (hardness in excess of 300 mg/L as calcium carbonate), andd a chemical scale control program, with heat exchanger tubes closing due to scale formation after less than one year. In each case the fuel consumption savings was proportional to the thickness of the scale layer removed.

One important note was that fuel consumption savings often trailed installation of the technology by a significant period due to the fact that the savings is driven by the amount of scale on the heat exchange surface. The accumulated scale will erode over time, resulting in fuel consumption reductions. For this reason, many of the manufacturers recommend installing the technology only after the system has been descaled, thus savings in fuel consumption would be immediate.

Maintenance

As mentioned above, maintenance requirements typically are reduced upon implementation of the non-chemical technology. First, periodic maintenance of the water-softening equipment and chemicals is eliminated. Second, the periodic heat exchanger inspection and cleaning cycle is reduced to an inspection cycle. The handling and storage requirements for the chemicals—lime, soda ash, salt and acid—have been eliminated, as has training for their use, storage and handling. The reduction in these periodic activities frees up the previously time allocated for application to other activities.

There are maintenance activities associated with this technology. For the electromagnetic and electrostatic units, a daily check that the power is on is necessary (a "power on" indicator light is included with most, if not all, units). The electrostatic units need to have the electrodes checked periodically, semi-annually, and the electrodes replaced when noticeably worn or damaged, perhaps every five years. The reader should speak to the manufacturer for details which may vary.

When solids or particulates accumulate in the system, they will need to be removed. Automatic blowdown of the system should control the daily accumulation. If the system is not cleaned prior to installation of the non-chemical technology, the scale in the system will detach and its removal will be necessary. Filters, sumps and hydrocyclones are all effective means of capturing the solids, but each will require periodic cleaning.

Environmental Impacts

There are areas where the technology mitigates environmental impacts. The first is air quality due to emissions reduction associated with decreases in fuel consumption. The second is a corresponding decrease in solid wastes, ash and other fuel combustion residues to be disposed. Of course, this will only be applicable in the situation in which an end user combusts fuels on-site for the production of power. A third area is the reduction in release, or potential for release, of water treatment chemicals stored at a facility. Since chemical consumption will decrease, emissions from storage will also decrease. The wastes associated with disposal and management of used chemical containers will also be reduced.

Case Study

For the case study, a hypothetical facility is used and the application of a permanent magnet device is described. The conditions are based on information gathered during the user interviews and reading of published and unpublished case studies. The purpose is to illustrate the types of data required to prepare a site-specific cost analysis, not to illustrate what any particular user might experience in the way of cost savings.

Facility Description

The facility currently uses extremely hard water (hardness of 350 mg/L as calcium carbonate) and employs lime softening. The process water is used in a recirculating boiler water system with flow of 1,000 gpm or 1.4 MGD (million gallons per day). Makeup and blowdown were estimated at 10% of the flow, or 140,000 gallons per day. The water-softening process removes a significant fraction of the hardness, but not all, leading to semiannual inspections and annual cleaning of the heat exchanger. This frequency is thought to be fairly typical.

Cost for the lime used in the process is estimated at \$10/ton delivered. Cost for natural gas is \$5.80/1000 ft^3. Acetic acid, used for cleaning, costs \$2 per gallon.

Existing Technology Description

The current system is a conventional lime softening plant consisting of lime storage facilities, a slaker where the powered lime is mixed with water, a mixing basin for adding controlled amounts of the lime solution to the water, and a settling basin where the precipitated solids are removed. Downstream of the water treatment facilities is a conventional shell-and-tube heat exchanger used to heat the water for both building heat and process water.

Lime consumption for softening is 48 tons/year. In this case, alkalinity is sufficient so as to not require the addition of soda ash during the softening process. Natural gas consumption for process water heating is 400,000 MBtu/year. Electricity consumption for the softening process was estimated at 3,100 kWh per year. Acetic acid is used during cleaning, approximately 100 gallons per cleaning. Production losses due to system downtime are not being included in this analysis.

(If the system had instead used ion exchange softening, the applicable chemical use information would have been the regenerant, typically salt but possibly acid, and the consumption of ion exchange resin. This last item is calculated as the mass replaced divided by the total volume of water treated.)

Data on lime consumption can typically be found in purchasing records, or also in a water treatment system operator's log. The latter would be more accurate since it would more closely reflect lime used for water softening, whereas the former would list only lime purchases including those for water softening, pH adjustment and other uses.

Natural gas consumption, or other fuel consumption data, can be taken from accounting records, if the only use of natural gas is for process water, or from operation data, (e.g., firing rate data), or calculated from an energy balance for a portion of the production system. The firing rate data or other operation data would be the most accurate but might not always be available.

Electricity consumption information can be calculated from nameplate capacity of the mixing and pumping equipment involved. For this report, it was derived from information compiled by the Electric Power Research Institute. In some cases there may be energy or monitoring data available for the process that would be available as part of the water treatment system operator's records.

New Technology Equipment Selection

A magnetic scale control device will be investigated as an alternative to chemical scale control. The first step was consultation with the manufacturer, including submitting water analysis data and a schematic of the current system showing the proposed location of the equipment to facilitate manufacturer selection and equipment sizing. (A magnetic device was chosen because the preferred installation location was remote, with electrical power not readily available.)

For the proposed location and required flow rate, a unit was identified that would fit the current piping configuration without a need for adapters. The unit cost is $10,000 including shipping. The estimate by the in-house facilities engineering staff calls for three days to install the system, one-half day each for set-up and clean-up, one day to remove a section of pipe to make space for the device (including installing flanges), and one day for installation and leak testing. Three people are required, as well as a device capable of lifting 1,000 pounds in order to position the device and facilitate removal of the old section of pipe.

One of the key elements to sizing these devices is the water velocity through the device. Manufacturers recommend, typically, at least a 7 feet per second water velocity. If the water velocity through a section of pipe is too low, it will be necessary to use adapters to decrease the size of the pipe through the device, thus increasing the velocity. Water velocity in feet per second can be calculated as follows, where *Diameter* is in feet:

$$U = \frac{0.535 * GPM}{\pi * Diameter^2}$$

Savings are expected to result from discontinuance of chemical consumption and decreased energy consumption (10% of process energy and all of the water treatment energy). Inspection will still occur.

Savings Potential

Energy savings can result from two areas. First is the reduction in fuel used in generating heat. Methods for calculating the fuel consumption were discussed above in the technology descriptions. The fuel consumption savings is simply the net difference, in this case estimated equal to 10% of the baseline fuel consumption. (This estimated savings was used to illustrate a case where there was a fairly uniform 1/16" thick layer of scale across a heat exchanger surface. Of course, it is realized that the scale layer, and therefore energy consumption, builds over time and is not an instantaneous effect.) This savings is also equal to the loss in heat transfer efficiency due to scale formation on the heat exchange surface.

Second is the energy savings resulting from decreased pressure drop within the heat exchanger. This is not quantified here, but could be quantified if the pressure drop through the current system was known, along with the energy characteristics of the pump so that reductions in pressure could be related to energy consumption.

Cost savings also result from reductions in chemical use. Chemical softening will be reduced, and likely eliminated, by the use of non-chemical treatment technologies. There will also be a corresponding energy decrease from the shutdown of chemical mixing equipment and water treatment equipment used in the softening process. The estimated chemical savings here was 480 tons per year and the corresponding electricity savings was 31,000 kWh per year.

Table 3 illustrates typical consumption data for the baseline and alternative and the potential annual costs savings. Not shown are water consumption and water discharge, which do not change between the alternatives. Capital cost for the alternative treatment system, estimated at $10,000 at the beginning of the 15-year analysis period, is not shown either. Fifteen years was chosen because it was typical of the life of field units.

Life-Cycle Cost

The full results of the BLCC computations are shown in Appendix B. A discussion of the BLCC software is

Table 3. Annual Costs and Savings

Item	Costs $/unit	Baseline Lime Softening		Alternative Magnetic Treatment		Annual Costs Savings
		Annual Consumption	Annual Cost $/year	Annual Consumption	Annual Cost $/year	
Electricity	0.05/kWh	3,100	155	0	0	155
Natural Gas	5.80/MBtu	400,000	2,320,000	360,000	2,088,000	232,000
Chemicals	10/ton	48	480	0	0	480
Total			2,320,635		2,088,000	232,635

given in Appendix A. The BLCC Comparative Economic Analysis is shown in Figure 5. Installation cost for the magnetic treatment device is estimated at $10,360, calculated as $10,000 for the device and $360 for design and installation labor. Operating costs for the technology are estimated at $2,088,000 per year versus costs of $2,320,635 per year for the conventional lime-softening technology, both exclusive of water consumption and discharge. Life-cycle costs for each of the technologies as calculated by the BLCC software are $27,524,500 for the magnetic technology versus $30,283,500 for the conventional technology. (This includes the cost of water and wastewater disposal of $2,605,292.) This represents a life-cycle cost savings of $2,759,000. The Simple Payback from BLCC is less than one year, and the Adjusted Internal Rate of Return is 50.66%.

The Technology in Perspective

The future of non-chemical water treatment technologies is promising. As public awareness of the environmental effects of chemicals increases there will be an increasing demand to deploy alternative, more environmentally beneficial technologies. As a means of reducing energy consumption and stretching the available personnel resources in the days of ever-shrinking budgets, non-chemical technologies make sense as both cost effective and having demonstrated performance.

The Technology's Development

Magnetic and electrical effects on water were first noticed prior to the turn of the 20th century. Considerable research is being conducted on magnetohydrodynamics by the Japanese as a means of propulsion, and similar research has been conducted in the past in the United States and other industrialized countries. This research has been facilitated by the advent of rare earth magnets, solid state electronics, and advanced ceramic or polymeric materials after World War II. Only after these advances has non-chemical water treatment shown promise and come into more widespread use.

Of the manufacturers listed in this FTA most have come into existence since the advent of the environmental movement in the United States in the early 1970s. This can be attributed both to the advent of cost-effective components (e.g., magnets, electronics) and to the public desire for more "green" or environmentally friendly alternatives to chemical treatment.

Relation to Other Technologies

The use of the non-chemical technologies does not prohibit the use of any other technology or equipment. As was mentioned previously, the change from chemical to non-chemical scale control may warrant investigation of other means of corrosion or biofouling control, as these three chemical scale treatment or control strategies or applications are often balanced amongst each other.

An increase in cycles of concentration was also noted by one user as another water saving measure that was employed. The ability to increase the cycles of concentration was attributed to the stability of scale-forming ions or scale particles in suspension. Water consumption was halved in this multi-pass system.

Technology Outlook

There is no basis to assume that the technologies are going to disappear anytime soon. Each has a historical basis of successful installations. Advances in materials science should only serve to improve each of the technologies. More powerful magnets will allow the magnetic devices to become smaller and/or more efficacious. More durable electrodes and dielectric compounds will improve the life of the electrostatic units.

Probably the most significant trend is the move away from chemical treatment technologies. This trend has begun at the consumer level, is becoming apparent at the corporate level, and will continue to grow.

****
* NIST BLCC: COMPARATIVE ECONOMIC ANALYSIS (ver. 4.4-97) *
****

Project:	**Non-Chemical Scale Control FTA**
Base Case:	**Lime Soft.**
Alternative:	**Magnetic**

Principal Study Parameters:

Analysis Type:	**Federal Analysis—Energy Conservation Projects**
Study Period:	**15.00 Years (NOV 1997 through OCT 2012)**
Discount Rate:	**3.8% Real (exclusive of general inflation)**
Base Case LCC File:	**SOFTEN.LCC**
Alternative LCC File:	**MAGNETIC.LCC**

Comparison of Present-Value Costs

	Base Case: Lime Soft.	Alternative: Magnetic	Savings from Alt.
Initial Investment item(s):			
Capital Requirements as of Serv. Date	$0	$10,360	-$10,360
Subtotal	$0	$10,360	-$10,360
Future Cost Items:			
Energy-related Costs	$27,678,200	$24,908,850	$2,769,350
Water Costs	$2,605,292	$2,605,292	$0
Subtotal	$30,283,500	$27,514,140	$2,769,360
Total P.V. Life-Cycle Cost	$30,283,500	$27,524,500	$2,759,000

Net Savings from Alternative 'Magnetic' compared to Base Case 'Lime Soft.'

Net Savings	= P.V. of Non-Investment Savings		$2,769,360
	- Increased Total Investment	$10,360	
		Net savings:	$2,759,000

Note: the SIR and AIRR computations include differential initial costs, capital replacement costs, and residual value (if any) as investment costs, per NIST Handbook 135 (Federal and MILCON analyses only).

Savings-to-Investment Ratio (SIR)
For Alternative 'Magnetic' compared to Base Case 'Lime Soft.'

$$SIR = \frac{\text{P.V. of non-investment savings}}{\text{Increased total investment}} = 267.31$$

Adjusted Internal Rate of Return (AIRR)
For Alternative 'Magnetic' compared to Base Case 'Lime Soft.'
(Reinvestment Rate = 3.80%; Study Period = 15 years)

AIRR = 50.66%

Estimated Years to Payback

Simple Payback occurs in year 1
Discounted Payback occurs in year 1

ENERGY SAVINGS SUMMARY

Energy type	Units	—— Average Annual Consumption —— Base Case	Alternative	Savings	Life-Cycle Savings
Electricity	kWh	3,100.0	0.0	3,100.0	46,500.0
Natural Gas	MBtu	400,000.0	360,000.0	40,000.0	600,000.0

EMISSIONS REDUCTION SUMMARY

Energy type	——— Average Annual Emissions ——— Base Case	Alternative	Reduction	Life-Cycle Reduction
Electricity:				
CO2 (Kg):	3,005.0	0.0	3,005.0	45,075.1
SO2 (Kg):	10.9	0.0	10.9	163.6
NOx (Kg):	9.1	0.0	9.1	135.8
Natural Gas:				
CO2 (Mg):	21,125.3	0.0	21,125.3	316,879.9
SO2 (Kg):	84.0	0.0	84.0	1,260.0
NOx (Kg):	16,460.0	0.0	16,460.0	246,900.0
Total:				
CO2 (Mg):	21,128.3	0.0	21,128.3	316,925.0
SO2 (Kg):	94.9	0.0	94.9	1,423.6
NOx (Kg):	16,469.1	0.0	16,469.1	247,035.8

Figure 5. Comparative BLCC Analysis

Increased availability of information on the technologies, the environment, and human health will only serve to feed this trend.

Manufacturers

The following is a listing of manufacturers of these technologies compiled from the Thomas Register and those who have contacted FEMP directly. It has been limited to U.S. manufacturers; foreign manufacturers or U.S. affiliates of foreign manufacturers were not included. No effort was made to locate and include manufacturers not listed in the Thomas Register. This listing does not purport to be complete, to indicate the right to practice the technology, or to reflect future market conditions.

Advanced Environmental Products
9450 Schulman #113
Dallas, TX 75243
214/340-1435
Fax: 214/344-2134

Aqua-Floc Inc.
Department T-94
6244 Frankford Avenue
Baltimore, MD 21206
800/368-2513
410/485-7600
Fax: 410/488-2030

Aqua Magnetics International, Inc.
915-B Harbor Lake Drive
Safety Harbor, FL 34695
813/447-2575
Fax: 813/726-8888

Conservonics
30555 Southfield Road #420
Southfield, MI 48076
801/540-3634
Fax: 810/716-7508

Descal-A-Matic Corp.
4855-T Brookside Ct. Suite A
Norfolk, VA 23502
757-858-5593
Fax: 757/853-3321

Electrostatic Technologies Inc.
2223 Guinotte Avenue
Kansas City, MO 64120
816/842-0616
Fax: 816/842-9756

Enecon Corp.
125 Bayliss Road Suite 190
Mellville, NY 11747-3800
800/854-1374

Enertec Inc.
Department TR
306 Railroad Street
P.O. Box 85
Union City, MI 49094
517/741-5015
Fax: 517/741-3474

Hydrodynamics Corp.
1615 W. Abram Street #110
Arlington, TX 76013
817/277-6700
Fax: 817/277-2197

Magnatech Corp.
Superior Manufacturing Division
2015 S. Calhoun Street
P.O. Box 13543
Fort Wayne, IN 46868
800/692-1123
219/456-3596
Fax: 219/456-3598

Progressive Equipment Corp.
419 East 9th Street
Erie, PA 16503
814/452-4363
800/728-6395
Fax: 814/459-3094

Quantum Magnetic Systems Inc.
5224 Blanche Ave.
Cleveland, OH 44127
216/441-9670
Fax: 216/441-9677

Zeta Hydrometals Corporation
4565 S. Palo Verde Road, Suite 213
Tucson, AZ 85714
520/747-4550
888/785-9660
Fax: 520/747-4454

Who is Using the Technology

Federal Sites

Included here are but a few of the installations provided by the manufacturers. For a full listing the reader is advised to contact a manufacturer directly. Some manufacturers expressed concern about printing customer names in a public list such as this Federal Technology Alert but indicated they could provide such customer references to interested potential buyers. Most manufacturers specify having hundreds to almost 10,000 installations. Not all of these sites were contacted during the course of preparing this FTA.

- GSA, Suitland, MD.
- National Aeronautics and Space Administration, multiple locations
- United States Coast Guard, multiple locations
- United States Air Force, Luke AFB, Phoenix, AZ
- United States Army Corps of Engineers, Sacramento District, Sacramento, CA
- United States Environmental Protection Agency, Andrew W. Breidenbach Environmental Research Center, Cincinnati, OH (Rich Koch and Bob Banner, Cleveland Telecommunications Corporation)
- United States Postal Service, multiple locations

Non-Federal Sites

- Arnold Printing, Cincinnati, OH (Hank Majeushi, 513/533-9600)
- Bethlehem Steel, multiple locations
- Chrysler, multiple locations
- Ford Motor Company, multiple locations
- General Electric, multiple facilities
- General Motors, multiple facilities
- Getty Center, Los Angeles, CA
- Inland Steel, 200 locations
- House of the Future, Ahwatukee, AZ (Arnold Roy, The Frank Lloyd Wright Foundation, 602/948-6400)
- John Deere, multiple locations
- John Hancock Center, Chicago, IL
- LTV Steel, multiple locations
- Protective Coatings Inc. (Bob Bernadin and Ron Byers, 219/456-3596)
- National Steel, over 100 installations
- USX, multiple locations
- United States Playing Card Company, Cincinnati, OH (Tom Berens, 513/396-5700)

For Further Information

Associations

No trade associations exist that are specific to the non-chemical water treatment technology manufacturers. The following associations are general water quality associations.

American Water Works Association
6666 West Quincy Ave
Denver, CO 80235
303/794-7711

Cooling Tower Institute
P.O. Box 73383
Houston, TX 77273
713/583-4087

Water Quality Association
4151 Naperville Road
Lisle, IL 60532
708/505-0160

Consultants

Robert A. Marth
340 Central Avenue
Sunnyvale, CA 94086
408/746-0964
Fax: 408-737-0291

T. Craig Molden
Water Service Technology/NWI
P.O. Box 545
Michigan City, IN 46361
219/879-8425
Fax: 219/879-8852

User and Third Party Field Test Reports

The following references represent only a small sample of the published work on these technologies. The references here are intended to give the reader an indication of the history of scientific research on the topic as well as the sponsoring agencies and interested audiences.

Alleman, J. 1985. *Quantitative Assessment of the Effectiveness of Permanent Magnet Water Conditioning Devices*. Purdue University. Sponsored by and protocol by Water Quality Association.

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Baker, J.S., and S.J. Judd. 1996. "Magnetic Amelioration of Scale Formation." *Water Research*, 30(2):247-260.

Benson, R.F., B.B. Martin, and D.F. Martin. 1994. "Management of Scale Deposits by Diamagnetism. A Working Hypothesis." *Journal Environmental Science and Health*, A29(8):1553-1564.

Busch, K. W., M. A. Busch, D. H. Parker, R. E. Darling, and J. L. McAtee, Jr. 1986. "Studies of a Water Treatment Device That Uses Magnetic Fields," In *Proceedings Corrosion/85*, Boston MA.

Dirks, J.A., and L.E. Wrench. 1993. "Facility Energy Decision Screening (FEDS) Software System." PNL-SA-22780. In *Proceedings of the Energy and Environmental Congress*. Minneapolis, Minnesota, August 4-5, 1993.

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Gruber and Carda. 1981. *Performance Analysis of Permanent Magnet Type Water Treatment Devices*. South Dakota School of Mines and Technology. Sponsored by and protocol by Water Quality Association.

Hibben, S.G. 1973. *Magnetic Treatment of Water*. Advanced Research Projects Agency of the Department of Defense.

Marth, R.A. 1997. *A Scientific Definition of the Magnetic Treatment of Water: Its Subsequent Use in Preventing Scale Formation and Removing Scale*. Research Conducted for Descal-A-Matic Corporation.

Parsons, S.A., Bao-Lung Wang, S.J. Judd, and T. Stephenson. 1997. "Magnetic Treatment of Calcium Carbonate Scale — Effect of pH Control." *Water Research*, 31(2): 339-342.

Quinn, C.J., T.C. Molden, and C.W. Sanderson. 1996. "Nonchemical Approach to Hard Water Scale, Corrosion and White Rust Control." In *Proceedings Iron and Steel Engineer*, Chicago IL, September 30, 1996.

Reimers, R.S., P. S. DeKernion, and D. B. Leftwich. 1979. "Sonics and Electrostatics - An Innovative Approach to Water and Waste Treatment." In *Proceedings Water Reuse Symposium*, Volume 2. American Water Works Research Association Research Evaluation, Denver, CO.

Rubin, A.J. 1973. *To Determine if Magnetic Water Treatment is Effective in Preventing Scale*. The Ohio State University, Columbus, OH.

Schmutzer, M. A., and G. W. Hull. 1969. *Examination to Determine the Physical or Chemical Differences Between Untreated and Magnetically Treated Water*. United States Testing Center, Inc. Hoboken, NJ.

Simpson. L. G. 1980. "Control Scale and Save Energy." *The Coast Guard Engineer's Digest*, Volume 20, Number 205, pp. 32-35.

Design and Installation Guides

Many of the manufacturers have guides for internal use or use by their recommended installer or sales agent. Contained in these guides are listings of customers, design and installation notes, warranty information, and answers to many user questions. Most or all of this information may not be available to customers. However, the manufactures do make available sales brochures and summaries of specific applications or case studies. Also included with the units will be owner's manuals and other end user installation and maintenance documentation.

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Appendixes

Appendix A: **Federal Life-Cycle Costing Procedures and the BLCC Software**

Appendix B: **Life-Cycle Cost Analysis Summary**

BLCC Input Data Listing: Lime Softening
BLCC Detailed LCC Analysis: Lime Softening
BLCC Input Data Listing: Magnetic Water Conditioning
BLCC Detailed LCC Analsis: Magnetic Water Conditioning
Comparative Present-Value Costs of Alternative Projects
BLCC: Comparative Economic Analysis

Appendix A

Federal Life-Cycle Costing Procedures and the BLCC Software

Federal agencies are required to evaluate energy-related investments on the basis of minimum life-cycle costs (10 CFR Part 436). A life-cycle cost evaluation computes the total long-run costs of a number of potential actions, and selects the action that minimizes the long-run costs. When considering retrofits, sticking with the existing equipment is one potential action, often called the *baseline* condition. The life-cycle cost (LCC) of a potential investment is the present value of all of the costs associated with the investment over time.

The first step in calculating the LCC is the identification of the costs. *Installed Cost* includes cost of materials purchased and the labor required to install them (for example, the price of an energy-efficient lighting fixture, plus cost of labor to install it). *Energy Cost* includes annual expenditures on energy to operate equipment. (For example, a lighting fixture that draws 100 watts and operates 2,000 hours annually requires 200,000 watt-hours (200 kWh) annually. At an electricity price of $0.10 per kWh, this fixture has an annual energy cost of $20.) *Nonfuel Operations and Maintenance* includes annual expenditures on parts and activities required to operate equipment (for example, replacing burned out light bulbs). *Replacement Costs* include expenditures to replace equipment upon failure (for example, replacing an oil furnace when it is no longer usable).

Because LCC includes the cost of money, periodic and aperiodic maintenance (O&M) and equipment replacement costs, energy escalation rates, and salvage value, it is usually expressed as a present value, which is evaluated by

$$LCC = PV(IC) + PV(EC) + PV(OM) + PV(REP)$$

where PV(x) denotes "present value of cost stream x,"
IC is the installed cost,
EC is the annual energy cost,
OM is the annual nonenergy O&M cost, and
REP is the future replacement cost.

Net present value (NPV) is the difference between the LCCs of two investment alternatives, e.g., the LCC of an energy-saving or energy-cost-reducing alternative and the LCC of the existing, or baseline, equipment. If the alternative's LCC is less than the baseline's LCC, the alternative is said to have a positive NPV, i.e., it is cost-effective. NPV is thus given by

$$NPV = PV(EC_0) - PV(EC_1)) + PV(OM_0) - PV(OM_1)) + PV(REP_0) - PV(REP_1)) - PV(IC)$$

or

$$NPV = PV(ECS) + PV(OMS) + PV(REPS) - PV(IC)$$

where subscript 0 denotes the existing or baseline condition,
subscript 1 denotes the energy cost saving measure,
IC is the installation cost of the alternative (note that the IC of the baseline is assumed zero),
ECS is the annual energy cost savings,
OMS is the annual nonenergy O&M savings, and
REPS is the future replacement savings.

Levelized energy cost (LEC) is the breakeven energy price (blended) at which a conservation, efficiency, renewable, or fuel-switching measure becomes cost-effective (NPV >= 0). Thus, a project's LEC is given by

$$PV(LEC*EUS) = PV(OMS) + PV(REPS) - PV(IC)$$

where EUS is the annual energy use savings (energy units/yr). Savings-to-investment ratio (SIR) is the total (PV) savings of a measure divided by its installation cost:

$$SIR = (PV(ECS) + PV(OMS) + PV(REPS))/PV(IC).$$

Some of the tedious effort of life-cycle cost calculations can be avoided by using the Building Life-Cycle Cost software, BLCC, developed by NIST. For copies of BLCC, call the FEMP Help Desk at (800) 363-3732.

Appendix B

Life-Cycle Cost Analysis Summary

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* N I S T B L C C: I N P U T D A T A L I S T I N G (ver. 4.5-97) *
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FILE NAME: SOFTEN
FILE LAST MODIFIED ON 10-31-1997/13:34:12
PROJECT NAME: Non-Chemical Scale Control FTA
PROJECT ALTERNATIVE: Lime Soft.
COMMENT: Baseline cost calculations

GENERAL DATA:

ANALYSIS TYPE: Federal Analysis—Energy Conservation Projects
BASE DATE FOR LCC ANALYSIS: NOV 1997
STUDY PERIOD: 15 YEARS, 0 MONTHS
SERVICE DATE: NOV 1997
DISCOUNT AND INTEREST RATES ARE Real (exclusive of general inflation)
DISCOUNT RATE: 3.8%
Mid-year discounting convention
Escalation rates do not include general inflation

CAPITAL ASSET COST DATA:

INITIAL COST (BASE YEAR $)	0
EXPECTED ASSET LIFE (YRS/MTHS)	15/0
RESALE VALUE FACTOR	0.00%
AVG PRICE ESC RATE(SERVICE PD.)	0.00%
NUMBER OF REPLACEMENTS	0

NO REPLACEMENTS

OPERATING, MAINTENANCE, AND REPAIR COST DATA:

ANNUAL RECUR OM&R COST ($):	0
ESCALATION RATE FOR OM&R:	2.00%

No non-annually-recurring OM&R costs reported.

ENERGY-RELATED DATA:

NUMBER OF ENERGY TYPES = 2
DOE energy price escalation rates filename: ENCOST7A
DOE region (state code): 2 (OH)
DOE rate schedule type: Industrial
Underlying gen. inflation rate used with DOE rates: 0.00%

		(A)	(B)
ENERGY TYPE:		Electricity	Natural Gas
BASE ANNUAL CONSUMPTION:		3100	400000
UNITS:		kWh	MBtu
PRICE PER UNIT ($):		0.050	5.800
ANNUAL DEMAND CHARGE ($):		0.00	0.00
ESCALATION RATE METHOD:		DOE rates	DOE rates
	1997	0.31	1.12
	1998	-0.47	-0.74
	1999	-0.55	0.00
	2000	-0.63	0.74
	2001	-0.47	1.48
	2002	-0.63	1.09
	2003	-1.04	0.72
	2004	-0.89	0.71
	2005	-0.33	0.71
	2006	-0.25	0.70
	2007	-0.49	0.70
	2008	-0.99	0.35
	2009	-2.16	0.69
	2010	-2.64	0.34
	2011	-2.18	1.03
	2012	0.18	1.02

WATER-RELATED DATA:
UNITS: 1000 gallons

	ANNUAL WATER USAGE		ANNUAL WATER DISPOSAL	
	Units/Yr	Price/Unit	Units/Yr	Price/Unit
@Summer Rates	52560	3.000	5256	5.000
@Winter Rates	0	0.000	0	0.000

WATER PRICE ESCALATION RATES &:

Year	Water Usage Rate(%)	Water Disposal Rate(%)
1997	3.00	3.00
1998	3.00	3.00
1999	3.00	3.00
2000	3.00	3.00
2001	3.00	3.00
2002	3.00	3.00
2003	3.00	3.00
2004	3.00	3.00
2005	3.00	3.00
2006	3.00	3.00
2007	3.00	3.00
2008	3.00	3.00
2009	3.00	3.00
2010	3.00	3.00
2011	3.00	3.00
2012	3.00	3.00

****

* NIST BLCC: INPUT DATA LISTING (ver. 4.5-97) *

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FILE NAME: MAGNETIC
FILE LAST MODIFIED ON 10-31-1997/13:36:02
PROJECT NAME: Non-Chemical Scale Control FTA
PROJECT ALTERNATIVE: Magnetic
COMMENT: Alternativ cost calculations

GENERAL DATA:

ANALYSIS TYPE: Federal Analysis—Energy Conservation Projects
BASE DATE FOR LCC ANALYSIS: NOV 1997
STUDY PERIOD: 15 YEARS, 0 MONTHS
SERVICE DATE: NOV 1997
DISCOUNT AND INTEREST RATES ARE Real (exclusive of general inflation)
DISCOUNT RATE: 3.8%
Mid-year discounting convention
Escalation rates do not include general inflation

CAPITAL ASSET COST DATA:

INITIAL COST (BASE YEAR $)	10360
EXPECTED ASSET LIFE (YRS/MTHS)	15/0
RESALE VALUE FACTOR	0.00%
AVG PRICE ESC RATE(SERVICE PD.)	0.00%
NUMBER OF REPLACEMENTS	0

NO REPLACEMENTS

OPERATING, MAINTENANCE, AND REPAIR COST DATA:

ANNUAL RECUR OM&R COST ($):	0
ESCALATION RATE FOR OM&R:	0.00%

No non-annually-recurring OM&R costs reported.

ENERGY-RELATED DATA:

NUMBER OF ENERGY TYPES = 2
DOE energy price escalation rates filename: ENCOST7A
DOE region (state code): 2 (OH)
DOE rate schedule type: Industrial
Underlying gen. inflation rate used with DOE rates: 0.00%

	(A)	(B)
ENERGY TYPE:	Electricity	Natural Gas
BASE ANNUAL CONSUMPTION:	0	360000
UNITS:	kWh	MBtu
PRICE PER UNIT ($):	.050	5.800
ANNUAL DEMAND CHARGE ($):	0.00	0.00
ESCALATION RATE METHOD:	DOE rates	DOE rates
1997	0.31	1.12
1998	-0.47	-0.74
1999	-0.55	0.00
2000	-0.63	0.74
2001	-0.47	1.48
2002	-0.63	1.09
2003	-1.04	0.72
2004	-0.89	0.71
2005	-0.33	0.71
2006	-0.25	0.70
2007	-0.49	0.70
2008	-0.99	0.35
2009	-2.16	0.69
2010	-2.64	0.34
2011	-2.18	1.03
2012	0.18	1.02

WATER-RELATED DATA:
UNITS: 1000 gallons

	ANNUAL WATER USAGE		ANNUAL WATER DISPOSAL	
	Units/Yr	Price/Unit	Units/Yr	Price/Unit
@Summer Rates	52560	3.000	5256	5.000
@Winter Rates	0	0.000	0	0.000

WATER PRICE ESCALATION RATES &:

Year	Water Usage Rate(%)	Water Disposal Rate(%)
1997	3.00	3.00
1998	3.00	3.00
1999	3.00	3.00
2000	3.00	3.00
2001	3.00	3.00
2002	3.00	3.00
2003	3.00	3.00
2004	3.00	3.00
2005	3.00	3.00
2006	3.00	3.00
2007	3.00	3.00
2008	3.00	3.00
2009	3.00	3.00
2010	3.00	3.00
2011	3.00	3.00
2012	3.00	3.00

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* N I S T B L C C: D E T A I L E D L C C A N A L Y S I S (ver. 4.5-97) *

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PART I - INITIAL ASSUMPTIONS AND COST DATA

Project Name: Non-Chemical Scale Control FTA
Project Alternative: Lime Soft.
Run date: 10-31-1997 13:37:02
Run type: Federal Analysis—Energy Conservation Projects
Comment: Baseline cost calculations
Input data file: SOFTEN.DAT, last modified: 10-31-1997/13:34:12
LCC output file: SOFTEN.LCC, created: 10-31-1997/13:34:19
Base Date of Study: NOV 1997
Service Date: NOV 1997
Study period: 15.00 years (NOV 1997 through OCT 2012)
Discount rate: 3.8% Real (exclusive of general inflation)
Mid-year discounting convention

Note: This BLCC report satisfies the economic evaluation criteria of FEMP requirements for federal energy studies.

Initial Capital Asset Costs (not discounted)

	Total Cost
Total Initial Capital Asset Costs	$0

Energy-Related Costs

Energy Type	Units	Avg Annual Usage	Price+ ($/Unit)	— Avg Annual Cost+ — Energy	Demand	Total P.V. Cost
Electricity	kWh	3,100	$0.050	$155	$0	$1,707
Natural Gas	MBtu	400,000	$5.800	$2,320,000	$0	$27,676,500

+Energy price as of base date (not adjusted for price escalation)

* *
* *

PART II - LIFE-CYCLE COST ANALYSIS
Discount Rate = 3.8% Real (exclusive of general inflation)

Project Alternative: Lime Soft. Run Date: 10-31-1997/13:37:02

	Present Value (1998 Dollars)	Annual Value (1998 Dollars)
Capital Requirements as of Service Date:	$0	$0
Operating, Maintenance & Repair Costs:		
Subtotal	$0	$0
Energy Costs	$27,678,200	$2,454,720
Water Costs	$2,605,292	$231,058
Residual Value of Orig Capital Components	$0	$0
Residual Value of Capital Replacements	$0	$0
Total Life-Cycle Project Cost	$30,283,500	$2,685,779

* *
* *

PART III - EMISSIONS SUMMARY\a

Region: Source Documentation:

Energy Type	Avg Annual Emissions	Life-cycle Emissions
Electricity:		
CO_2 (Kg):	3,005.0	45,075
SO_2 (Kg):	10.9	164
NO_x (Kg):	9.1	136
Natural Gas:		
CO_2 (Mg):	21,125.3	316,880
SO_2 (Kg):	84.0	1,260
NO_x (Kg):	16,460.0	246,900
Total:		
CO_2 (Mg):	21,128.3	316,925
SO_2 (Kg):	94.9	1,424
NO_x (Kg):	16,469.1	247,036

\a Based on emission factors from file USAVG.EMI

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* *
*   N I S T B L C C: D E T A I L E D L C C A N A L Y S I S (ver. 4.5-97)   *
* *

PART I - INITIAL ASSUMPTIONS AND COST DATA

Project Name: Non-Chemical Scale Control FTA
Project Alternative: Magnetic
Run date: 10-31-1997 13:36:46
Run type: Federal Analysis—Energy Conservation Projects
Comment: Alternativ cost calculations
Input data file: MAGNETIC.DAT, last modified: 10-31-1997/13:36:02
LCC output file: MAGNETIC.LCC, created: 10-31-1997/13:36:06

Base Date of Study: NOV 1997
Service Date: NOV 1997
Study period: 15.00 years (NOV 1997 through OCT 2012)
Discount rate: 3.8% Real (exclusive of general inflation)
Mid-year discounting convention

Note: This BLCC report satisfies the economic evaluation criteria of FEMP requirements for federal energy studies.

Initial Capital Asset Costs (not discounted)

	Total Cost
Total Initial Capital Asset Costs	$10,360

Energy-Related Costs

Energy Type	Units	Avg Annual Usage	Price+ ($/Unit)	— Avg Annual Cost+ — Energy	Demand	Total P.V. Cost
Electricity	kWh	0	$0.050	$0	$0	$0
Natural Gas	MBtu	360,000	$5.800	$2,088,000	$0	$24,908,850

+Energy price as of base date (not adjusted for price escalation)

* *
* *

PART II - LIFE-CYCLE COST ANALYSIS
Discount Rate = 3.8% Real (exclusive of general inflation)

Project Alternative: Magnetic — Run Date: 10-31-1997/13:36:46

	Present Value (1998 Dollars)	Annual Value (1998 Dollars)
Capital Requirements as of Service Date:	$10,360	$919
Operating, Maintenance & Repair Costs:		
Subtotal	$0	$0
Energy Costs	$24,908,850	$2,209,113
Water Costs	$2,605,292	$231,058
Residual Value of Orig Capital Components	$0	$0
Residual Value of Capital Replacements	$0	$0
Total Life-Cycle Project Cost	$27,524,500	$2,441,089

* *

Comparative Present-Value Costs of Alternative Projects
(Shown in Ascending Order of Initial Cost, * = Lowest LCC)

Project Alternative	LCC Filename	Initial Cost (PV)	Life Cycle Cost (PV)
Lime Soft.	SOFTEN	$0	$30,283,500
Magnetic	MAGNETIC	$10,360	$27,524,500*

* *
*   N I S T B L C C: COMPARATIVE ECONOMIC ANALYSIS (ver. 4.4-97)   *
* *

Project: Non-Chemical Scale Control FTA
Base Case: Lime Soft.
Alternative: Magnetic

Principal Study Parameters:

Analysis Type: Federal Analysis—Energy Conservation Projects
Study Period: 15.00 Years (NOV 1997 through OCT 2012)
Discount Rate: 3.8% Real (exclusive of general inflation)
Base Case LCC File: SOFTEN.LCC
Alternative LCC File: MAGNETIC.LCC

Comparison of Present-Value Costs

	Base Case: Lime Soft.	Alternative: Magnetic	Savings from Alt.
Initial Investment item(s):			
Capital Requirements as of Serv. Date	$0	$10,360	-$10,360
Subtotal	$0	$10,360	-$10,360
Future Cost Items:			
Energy-related Costs	$27,678,200	$24,908,850	$2,769,350
Water Costs	$2,605,292	$2,605,292	$0
Subtotal	$30,283,500	$27,514,140	$2,769,360
Total P.V. Life-Cycle Cost	$30,283,500	$27,524,500	$2,759,000

Net Savings from Alternative 'Magnetic' compared to Base Case 'Lime Soft.'

Net Savings = P.V. of Non-Investment Savings	$2,769,360
- Increased Total Investment	$10,360
Net savings:	$2,759,000

Note: the SIR and AIRR computations include differential initial costs, capital replacement costs, and residual value (if any) as investment costs, per NIST Handbook 135 (Federal and MILCON analyses only).

Savings-to-Investment Ratio (SIR)
For Alternative 'Magnetic' compared to Base Case 'Lime Soft.'

$$SIR = \frac{\text{P.V. of non-investment savings}}{\text{Increased total investment}} = 267.31$$

Adjusted Internal Rate of Return (AIRR)
For Alternative 'Magnetic' compared to Base Case 'Lime Soft.'
(Reinvestment Rate = 3.80%; Study Period = 15 years)

AIRR = 50.66%

Estimated Years to Payback

Simple Payback occurs in year 1
Discounted Payback occurs in year 1

ENERGY SAVINGS SUMMARY

Energy type	Units	Average Annual Consumption			Life-Cycle Savings
		Base Case	Alternative	Savings	
Electricity	kWh	3,100.0	0.0	3,100.0	46,500.0
Natural Gas	MBtu	400,000.0	360,000.0	40,000.0	600,000.0

EMISSIONS REDUCTION SUMMARY

Energy type	Average Annual Emissions			Life-Cycle Reduction
	Base Case	Alternative	Reduction	
Electricity:				
CO_2 (Kg):	3,005.0	0.0	3,005.0	45,075.1
SO_2 (Kg):	10.9	0.0	10.9	163.6
NO_x (Kg):	9.1	0.0	9.1	135.8
Natural Gas:				
CO_2 (Mg):	21,125.3	0.0	21,125.3	316,879.9
SO_2 (Kg):	84.0	0.0	84.0	1,260.0
NO_x (Kg):	16,460.0	0.0	16,460.0	246,900.0
Total:				
CO_2 (Mg):	21,128.3	0.0	21,128.3	316,925.0
SO_2 (Kg):	94.9	0.0	94.9	1,423.6
NO_x (Kg):	16,469.1	0.0	16,469.1	247,035.8

About the Federal Technology Alerts

The Energy Policy Act of 1992, and subsequent Executive Orders, mandate that energy consumption in the Federal sector be reduced by 30% from 1985 levels by the year 2005. To achieve this goal, the U.S. Department of Energy's Federal Energy Management Program (FEMP) is sponsoring a series of programs to reduce energy consumption at Federal installations nationwide. One of these programs, the New Technology Demonstration Program (NTDP), is tasked to accelerate the introduction of energy-efficient and renewable technologies into the Federal sector and to improve the rate of technology transfer.

As part of this effort FEMP is sponsoring a series of Federal Technology Alerts (FTAs) that provide summary information on candidate energy-saving technologies developed and manufactured in the United States. The technologies featured in the Technology Alerts have already entered the market and have some experience but are not in general use in the Federal sector. Based on their potential for energy, cost, and environmental benefits to the Federal sector, the technologies are considered to be leading candidates for immediate Federal application.

The goal of the Technology Alerts is to improve the rate of technology transfer of new energy-saving technologies within the Federal sector and to provide the right people in the field with accurate, up-to-date information on the new technologies so that they can make educated judgments on whether the technologies are suitable for their Federal sites.

Because the Technology Alerts are cost-effective and timely to produce (compared with awaiting the results of field demonstrations), they meet the short-term need of disseminating information to a target audience in a timeframe that allows the rapid deployment of the technologies—and ultimately the saving of energy in the Federal sector.

The information in the Technology Alerts typically includes a description of the candidate technology; the results of its screening tests; a description of its performance, applications and field experience to date; a list of potential suppliers; and important contact information. Attached appendixes provide supplemental information and example worksheets on the technology.

FEMP sponsors publication of the Federal Technology Alerts to facilitate information-sharing between manufacturers and government staff. While the technology featured promises significant Federal-sector savings, the Technology Alerts do not constitute FEMP's endorsement of a particular product, as FEMP has not independently verified performance data provided by manufacturers. Nor do the Federal Technology Alerts attempt to chart market activity vis-a-vis the technology featured. Readers should note the publication date on the back cover, and consider the Alert as an accurate picture of the technology and its performance at the time of publication. Product innovations and the entrance of new manufacturers or suppliers should be anticipated since the date of publication. FEMP encourages interested Federal energy and facility managers to contact the manufacturers and other Federal sites directly, and to use the worksheets in the Technology Alerts to aid in their purchasing decisions.

Federal Energy Management Program

The Federal Government is the largest energy consumer in the nation. Annually, in its 500,000 buildings and 8,000 locations worldwide, it uses nearly two quadrillion Btu (quads) of energy, costing over $8 billion. This represents 2.5% of all primary energy consumption in the United States. The Federal Energy Management Program was established in 1974 to provide direction, guidance, and assistance to Federal agencies in planning and implementing energy management programs that will improve the energy efficiency and fuel flexibility of the Federal infrastructure.

Over the years several Federal laws and Executive Orders have shaped FEMP's mission. These include the Energy Policy and Conservation Act of 1975; the National Energy Conservation and Policy Act of 1978; the Federal Energy Management Improvement Act of 1988; and, most recently, Executive Order 12759 in 1991, the National Energy Policy Act of 1992 (EPACT), and Executive Order 12902 in 1994.

FEMP is currently involved in a wide range of energy-assessment activities, including conducting New Technology Demonstrations, to hasten the penetration of energy-efficient technologies into the Federal marketplace.

For More Information

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International callers please use (703) 287-8391
Web site: http://www.eren.doe.gov/femp/

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Author: Ron Kita

Public Document

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Is There a Credible Basis for Magnetic Devices to Represent Green Technology?

Ron Kita*

Over the years, numerous articles have been published on magnetic devices and their negative performance aspects. Articles have appeared in publications such as the *Wall Street Journal*, *AARP Newsletter*, *Popular Mechanics* and the like. In most cases, the reporter likely contacts a professor at a local university, who relates that there is no foundation in science for these devices to work; hence such negative articles are bound to arise. Few professors even check their scientific guide, the *CRC Handbook of Chemistry and Physics*. Located within is the "Magnetic Rotary Power Index," which relates the degree of effect that a magnetic field has on a specific hydrocarbon molecule. Also, many professors are not even aware if there are colleges or universities (even their own) engaging in this research.

As a result, names and organizations are never mentioned nor their positive research papers on the positive effects of magnetic treatment reported in the press or on television. A Google search will relate favorable research in magnetics being done by (this is a partial list, of course): Prof. Rongjia Tao, Temple University; Prof. Raymond Cho, Drexel University; Prof. Samuel Sami, University of Moncton; Prof. Ken Busch, Baylor University; Prof. Klaus Kronenberg, California Polytechnical-Pomona; Prof. Arthur Kney, Lafayette College; Prof. Simon Parsons and Prof. Simon Judd, Cranfield University (United Kingdom); Prof. Michael Coey, Trinity College (Dublin, Ireland). Needless to say, there are a number of journal articles, research papers, doctoral theses, patents and the like that are never presented to the public.

Magnetic or electrostatic fields can be utilized to reduce mineral scale from boilers, furnaces, water heaters and heat exchangers and significantly reduce energy cost. As cited by the U.S. Bureau of Mines, a .25 inch layer of mineral scale can reduce heat transfer by 25%, thus increasing energy costs.

Also, it should be noted that the use of ion exchange softeners that discharge brine into the aquifers should not be considered green technology. Magnetics offer a far more environmentally acceptable means for the elimination of hard water deposits.

Magnetics can also be used to improve the efficiencies of air conditioners, refrigerators and heat pumps. U.S. Patent 6662569 represents such a means. In a series of articles published by the *International Journal of Energy Research*, Prof. Samuel Sami (ASME and ASHRAE Fellow) reports that a magnetic field will allow a refrigerant to boil with lower expenditure of energy since a magnetic field is used to disrupt intramolecular forces, and in U.S. Patent 7340919 an electrostatic technique uses the electronic dissimilarity between halocarbon refrigerants and silicon materials such as glass. The triboelectric effect is similar to the magnetic technique with respect to the disruption of forces; however, the magnetic techniques favor refrigerants of high dipole moments and the triboelectric will work on the older non-polar refrigerants.

The magnetic device is a clamp-on device, while the triboelectric device requires an insert to be placed into the liquid phase of the refrigerant line prior to the point of evaporation.

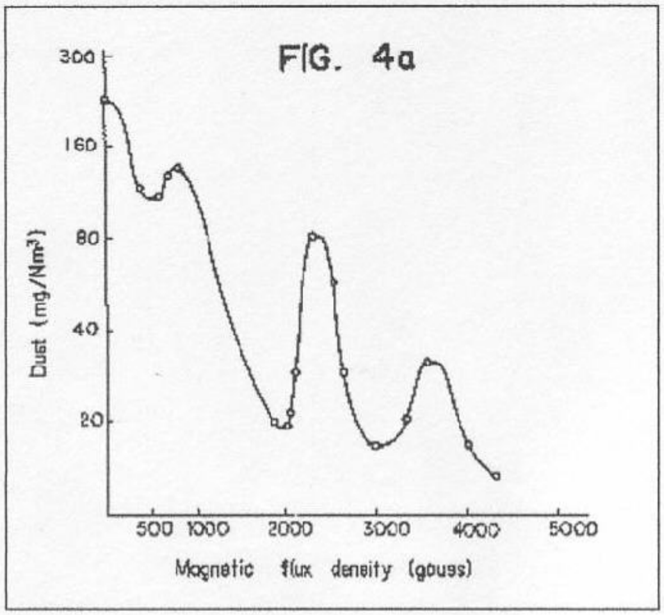
There is an added benefit in using the magnetic device to increase the seasonal energy efficiency ratio (SEER) or coefficient of performance (COP) of such systems. With the newer polar refrigerants, a polar miscible lubricant must be used. There have been some problems in the compatibility between certain lubricants and refrigerants which make them far less than ideally soluble. The lack of solubility prevents the lubricant from being returned to the compressor, thus shortening the life of the compressor.

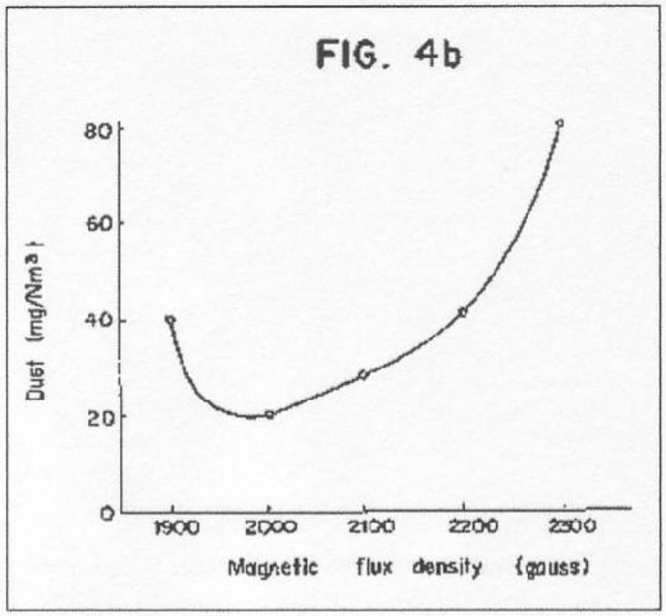
Prof. Sami's research on this topic was published in *Air Conditioning/Heating/Refrigeration News*, which is searchable online (www.achrnews.com). Prof. Sami's *International Journal of Energy Research* papers are available online at www.magnetizer.com/hvac/hvac.htm.

In industrial and commercial air conditioning systems, magnetic devices have been used on the refrigerant lines and on the chiller water going to the cooling tower, thus generating a double advantage. The advantages are in reducing the inefficiencies produced by mineral scale building on the heat exchanger surfaces as well as removing scale on the walls of the tower. Refrigerants that are affected magnetically require less electrical energy.

In the magnetic treating of tower water, it should be noted that the pH of the water tends to stabilize around a neutral pH of 7.0. The pH scale is logarithmic and obviously highly acidic or highly alkaline waters cannot be neutralized by effects, but waters that are in the low to mid-range 6.0 readings or mid to high 7.0 readings can find that the water will tend to stabilize at a pH of 7.0 Non-neutral waters, either of the hydroxyl or hydronium ion species, have ions in excess and by binding up the "excess" ions, water neutrality tends to be established. This effect is most pronounced in recirculation magnetic water systems.

In the patent of Hirama, (U.S. 493515, a magnetic treatment device), he relates the conversion of red iron rust water, FeO, over the black iron rust water, Fe203. Red iron rust water is soluble while black iron rust water is insoluble and precipitable. In the change from FeO to Fe203 there is a change in the oxidation number-valence from +2 for iron in FeO to +3 for the iron valence in Fe203. The black form of iron is passivated and has less of a tendency to corrode, while red iron rusted material can continue to the point of decomposition of the initial structure.





Magnetic fuel treatment is a very interesting phenomena. What is not understood by many is that the effect is a nonlinear effect, which means too high of a magnetic field can result in a diminished effect. This effect was first documented by Fujita in U.S. Patent 4188296; of especial interest is a series of curves that relates the most efficient levels of magnetic field to achieve ideal or stoichiometric combustion. Figure 4a (from the Fujita patent) shows a series of wave-like patterns that decline with increasing gauss levels indicating finer combustion rates, but along the waves are crests that reflect poor combustion. In summary, there are a series of "windows" of ideal treatment. Although it cannot be ascertained, it seems like the series of waves relate that a quantum effect is occurring. In science, many times proportionality is assumed, and in this case the effect is nonlinear and discrete levels of gauss must used to achieve positive results.

Magnetizer U.S. Patent 5829420 was invented to remove some of the capriciousness of magnetic fuel treatment. In this case an electromagnet is used in conjunction with a microprocessor which obtains data from combustion sensors whose data is heuristically evaluated and fed into a microprocessor that energizes the electromagnet to the appropriate level to insure "ideal" combustion.

To achieve green effects in buildings, permanent magnets can be made to specifications that assure that non-carbon dioxide emissions are minimized. Automotive emissions have different combustion environments: autos have high compressions and a relatively short time constraint on combustion, while boilers have ambient air and have far more time to allow complete combustion.

According to the *CRC Handbook of Chemistry and Physics*, natural gas or methane has by is symmetric structure no dipole moment. A Magnetizer was installed in a telephone switching building circa 1990 and a Honeywell Purple Peeper Device was installed to monitor the presence of the flame, which is in the 360 nm spectra. Twenty minutes after the installation, the monitor gave a quality of flame reading from the Purple Peeper of 2.0; prior to the installation the highest reading ever detected was 1.8. The combustion expert at Honeywell was contacted and given the details. Ulrich Bonne of Honeywell commented there must be some mistake, that magnets cannot do that.

The U.S. Patent Office was not willing to grant Simon Ruskin a patent on his magnetic device for the conversion of parahydrogen missile fuel into orthohydrogen for increasing thrust performance of a rocket engine. According to the Federal Register a repository for Ruskins patent appeal, the Patent Office claimed the device was not patentable because the effect was obvious. Ruskin, one of the most prolific inventors, was granted U.S. Patent 3228868 eight years after filing.

Magnets can change the morphology of scale; in fact, the webpage by Prof. Simon Parsons of Cranfield University (www.cranfield.ac.uk/sas/researchthemes/p9408.jsp) shows the effect of a static magnetic field on water: before the crystalline scale structure is cubic, and after a brief exposure to the field the mineral scaling structures become spherical, non-scaling.

Magnetic devices can reduce toxic emissions from boilers, furnaces and the like as well as increase the performance of refrigerants used to cool buildings.

Magnetic treatment of water to decrease scale has been documented by many notable professors, such as Kronenberg, Parsons and Coey.

What is most disturbing is that a paper by Mike R. Powell in *Skeptical Inquirer* is used to debunk magnetic water treatment. A google search of "Mike R. Powell" engineer produces hits that are mainly related to debunking magnetic water studies. There are no "google scholar" papers published by him on any topic. His work at Pacific NorthWest Labs/PNNL/PNWL cannot be documented. No patents are issued to him. Yet, this article in *Skeptical Inquirer* tried to debunk Prof. Coey of Trinity College. Coey is very favorable on magnetic water treatment and has a reputable background. The abstract of his paper, "Magnetic Water Treatment," in the *Journal of Magnetism and Magnetic Materials* (February 2000; 209 (1), pp. 71-74) reads as follows: "Carbonates formed by heating water containing 120 mg (Ca)/liter are characterized by X-Ray diffraction and electron microscopy. Tests on 32 pairs of samples establish at the 99.9 probability level that drawing of water through a static magnetic field (B=0.1 tesla, 10T/m) increases the aragonite/calcite ratio in the deposit. There is an incubation period of several hours, and the memory of magnetic treatment extends beyond 200 hours." See his website: www.tcd.ie/Physics?Magnetism/Profile/mike.php.

Magnetic devices do not represent a "magic bullet" for the environment, but they do have utility in improving the quality of our air and water, providing that the limitations of this technology are viewed in a reasonable performance framework.

About the Author

Ron Kita holds a BS from Villanova (1967). He is an information scientist. He was formerly with Magnetizer Industrial Technology, where he was responsible for basic research and product development. Kita has three co-invented patents and two patent applications under consideration. He has published in *Fronter Perspectives* and the *International Journal of Energy Research*.

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Author: Dr. Klaus J. Kronenberg

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Magnetic Water Treatment De-Mystified

by Dr. Klaus J. Kronenberg, Claremont, CA

Background:

Dr. Klaus J. Kronenberg has a long background in the field of magnetism. He is a Doctor of Physics from the University of Cottingen, Germany. He also earned a Doctor of Natural Sciences from the Technical University, Clausthal, Germany, where he did his Thesis: "Aging and Stabilization of Permanent Magnets". He was connected with Deutsche Edelstahl Werke, Krefeld Germany, where he worked on permanent Magnet-Precipitate in Alnico 5 shown by Electron Microscopy. Upon arrival in the United States, he worked for Indiana Steel Products Co., Valparasio, IN on the Development of Crystal-Oriented Barium Ferrite. Then he went on to General Dynamics, Pomona, CA, where he invented Permanent Magnet Bearings. Among the many awards and recognitions he has received are: Special Award from Alexander von Homboldt-Stiftkung, Bonn, Germany and Guest Professorship from the Ruhr-University Bochum, Germany [Study of Samarium Cobalt]. Recently, he served as an Associate Professor at California State University, Pomona, CA. His Magnetic Water Studies were done with Fluid Magnetics Corp., Dinuba, CA

Are the Waters of the East Different from the Waters of the West?

Slowly, but steadily, physical treatments of water with magnetic fields are becoming known and accepted in the Western World. They have been utilized for at least 25 years, in many countries of the Eastern World, the USSR and Mainland China for instance. There, hundreds of success- reports have been published, most of them admitting the lack of a fully satisfying scientific explanation. These papers describe - often in great detail - the observation of reduced formation of hard lime scale, the elimination of old lime scale deposits, accelerated plant growth, desalination of soils, improvement of concrete, better cleaning, faster drying, better taste and smell of drinking water, changes of freezing modes, beneficial effects on patients with kidney stones, and minute changes in some physical constants of the water, such as viscosity, IR absorption, surface tension, to name just a few.

Many of these reports are authored by scientific teams of universities or government agencies, describing years of experimentation and subsequent routine applications in larger forms. Resulting savings in the use of chemicals, of energy, and of equipment are substantial, according to these reports.

Contradicting these descriptions originating from Eastern countries are a number of reports of tests and checks by teams working in countries of the West. No change of the water was found by magnetic treatment according to some of these reports. Some of these evaluations concede to find some effects when long-time observations were made.

In a number of States within the USA, magnetic water treatment has officially been declared to be a hoax or its advertisement has been outlawed to be fraudulent. How can such discrepancies of opinion exist for tens of years in our small and supposedly communicative, scientific world?

A number of reasons for different opinions are caused by a number of obvious differences in the circumstances prevailing in the respective countries, for instance: The peoples of the Western world insist to be able to understand what they are doing or using. Theoretically unexplained processes have the stigma of black magic or superstition.

The West is used to and takes for granted the unrestricted availability of chemicals for all purposes in reliable quality and purchasing price which is not so in many countries of the East.

The Russians do not have a particularly good reputation in matters of research on water, after the disaster of the claim by Deryagin to have found the "Polywater" in the 1960's. (The history of this scientific misfiring is well presented in FELIX FRANK'S booklet *Polywater*, the MIT Press Cambridge, MA. 1981.)

The Free-Enterprise system permits anybody to take advantage of potentially fast profits with wild claims about an important item, such as water. Many partially informed or irresponsible sales-people give the entire issue a bad name by false promises, such as "No need for chemicals!" The Correct statement would be: "Chemicals become more effective in magnetically treated water, so that one needs chemicals in reduced amounts."

What is Magnetic Water Treatment?
(As described by Russian papers)

A number of conditions are given in the Russian papers about the details of their experiences; here are a few:

1. The water to be treated has to move through a magnetic field not stronger than 1000 to 2000 Oersted.
2. For a certain flow-velocity the effect is a maximum.
3. It usually works better for water of a lower temperature.

4. Some small changes of the physical constants of the water last only for a few minutes.
5. The capability of the water to prevent formation of hard lime scale may last for up to 2 days.
6. Instead of forming hard lime scale ("Slake") clinging to the walls of the container, the calcium carbonate of magnetically treated water forms a soft sludge ("Shlam"), flowing with the water.

Reliable observations of the effects of the magnetic treatment require several weeks. Many attempts to produce faster results have not always been conclusive.

1. The magnetically treated water is able to dissolve formerly deposited lime scale.
2. Soil can be desalinated.
3. Harvests are significantly improved in quantity and quality.

Our own Experiments and Observations

Confronted with the challenging discrepancy between 400+ computer references of papers from the East and a score of opposing, critical surveys from Western countries, we probed into the matter experimentally. We had the facilities of the California State Polytechnic University, Pomona, at our disposal, where the author has been teaching Physics for 10 years, and acoustics at this time. The author had been working in materials research for most of his professional life, permanent magnetism and crystallography being his specialties. He was familiar with the many unsolved puzzles of water by his early works as a physics student in Cottingen, Germany.

Why is there lime scale?

The formation of hard lime scale at the container walls by the $CaCO_3$ content of water is a consequence of the scarcity of nucleation centers in ordinary water. When the concentration of the $CaCO_3$ exceeds the solubility, the solidification can begin only at appropriate starting points most of the time at foreign matter. If no foreign matter is present in the form of particles in the liquid, solidification can start only at the walls of the container. Ordinary water tends to surround any foreign particulate with complexes of 100 to 200 water molecules each. The water molecules agglomerate around every foreign particle in ordinary water. They form cages around them which makes them ineffective as nuclei. Then, the container walls are the only non-water substances available. The resulting crystals are of the dendritic mode. They are characterized by few starting points attached firmly to the wall and extended systems of crystals clinging to one another and to the wall around the starting point. The dendritic crystallization mode is the initiation of the formation of hard lime scale which, if further solidification of the mineral occurs, grows layer over layer on the first set of dendrites.

Early detection of lime scale.

Microscopic observation of the beginning of crystallization in the form of dendrites reveals the tendency for scale formation immediately. We placed drops of water on glass slides and permitted the water to evaporate under observation with magnifications from 50 to 400 times. The microscope was equipped with polarizer and analyzer in order to improve the contrast for the optically active $CaCO3$ crystals. We compared drops of ordinary water as it came from the tap with drops of the same water after it had passed through magnetic fields; the drops were evaporating side by side on the same glass slide under identical conditions.

Magnetic effects?

The area formerly covered with the water is now covered with a lattice of thin dendritic crystals, the rim of the drop is studded with a number of thick, strongly light-polarizing dendritic crystals which had grown each from one point at the glass on the periphery of the drop. These crystals were firmly attached to the glass of the slide; they fractured if one attempted to dislocate them with a microscopic needle. This entire drop periphery contained 124 such prominent crystal systems. The entire drop circumference contained 41 such crystals. So: The number of these crystals which had grown on the glass was reduced by about two thirds by the magnetic treatment of this water. The effectiveness of the treatment, with respect to reduction of such glass-attached crystals, was therefore 67%. Assuming that these crystals are the start of scale formation, the magnetic treatment would have had an effectiveness of 67%.

An economical quantitative method.

This simple method of comparing the microscopic crystal count without and with the magnetic treatment permits within hours a quantitative estimate of the effectiveness of the treatment with regard to scale reduction. The counting is greatly facilitated by the fact that in a circular water drop on a glass slide, almost the entire mineral matter solidifies at the outer circumference of the drop. This was found to be caused by a convection within every circular drop of evaporating water. This convection is caused by the evaporation cooling at the surface of the drop; it transports the heavier substances within the drop radially from the center to the outer perimeter of the drop where they become concentrated and solidified. Furthermore, after counting all crystals of the entire perimeter of many drops it was found that the distribution of the crystals along the perimeter is even enough that the crystal count within a section of only 1/12 of the entire drop is usually representative for the entire drop.

With this straight forward and economical working scheme we investigated the effectiveness of magnetic fields for various flow velocities, for various numbers of magnets, for different pole arrangements and for different waters.

First findings.

The relationship between effectiveness and flow velocity had in almost all cases a maximum for one velocity. The plot of the values had the shapes of resonance curves. Variations of the distances between the magnets confirmed the relation between the flow velocity and the sequence of the fields crossed by the water, as indicated by the two curves.

Magnetic Arrangement.

Hundreds of field arrangements have been tested with a number of different water types. Maximum effectiveness was achieved with arrangements where the fields originated from simple, ring-shaped permanent magnets of barium ferrite of a medium grade. The arrangement was granted a US Patent in 1981*. By "tuning" such a device to a certain water velocity the effectiveness of such a device could be brought close to 100% with 8 ring-magnets. Water which contains a large amount of admixtures shows additional effects if it passes repeatedly through a magnetic device. The admixed algaecides, bactericides, and softening chemicals produce an extended dendritic crystallization over the entire area of the evaporated drop.

The formerly hidden foreign particle becomes available to the over concentrated calcium carbonate, so that the dissolved calcium carbonate diffuses to this particle equally from all sides simultaneously. So, the typical circular disk shape of a seeded crystal appears. If the effectiveness of the magnetic treatment was high, no calcium carbonate needs to wait to diffuse to the container wall in order to solidify. Therefore reduction of the hard scale formation can be understood as an internal seeding effect in the magnetically treated water.

Entropy/Energy

Skeptics might doubt this process to be possible because the former mixture of liquid water and liquid calcium carbonate is being turned into liquid water and separated, solid calcium carbonate. This un-mixing means a lowering of the entropy of the system. Any entropy lowering requires the expense of energy which cannot come from the permanent magnets. The needed energy can only be delivered by the kinetic energy of the flowing water. For this reason, no effect can be expected if the water does not move.

Removal of formerly deposited hard lime scale

Having no restriction for the solidification of the calcium carbonate the liquid water is soon depleted of dissolved calcium carbonate. Having some of the large cage-clusters in pieces the depleted water is particularly active (reduced viscosity and surface tension). If the water streams passed calcium deposits, it replenishes its calcium carbonate content by dissolving stationary solid calcium carbonate. It may be mentioned here, that in many cases of rather thick deposits, the dissolving does not precede piecemeal from the outer layer, as the customary acid washes do. The magnetically treated water rather weakens the bond between the wall and the calcium carbonate, so that the scale breaks off in rather large pieces from the walls on which they had grown. This dissolving process may take several days or even weeks. But under advantageous circumstances only hours may be required to loosen old, hard deposits and render them removable.

Can water have a memory?

According to many reports of success, the water retains its capability of reducing scale for up to 2 days. Critical comments try to make this fact appear to be absurd by calling it a “memory“ of the water for its “magnetic experience.“ We realize that the treated water has its specific scale reducing capability as long as its calcium carbonate is in the solid form of the inert micro crystals.
We have investigated these crystals with high magnification for many different waters and varied treatments. Using the interference colors of the polarized light the thickness of the disk-shaped crystals can be estimated to be from 0.1p. to 2.4p. (About 4 times the wavelength of red light).

Transformation in the solid state.

With hundreds of evaporated drops of different waters under continuous observation before and after various treatments, it is one of the most astounding findings that these dry, seemingly immobile crystals, sitting on the glass slides, keep changing their mode for weeks in their solid state.

Most significant is the transformation of the disk-shaped circular crystal platelets. After about 20 hours they develop holes in their centers and some of their matter turns into thin needles bundled up at the location of the disk. The disk-shape is a meta-stable crystal form of calcium carbonate; it transforms into the more stable form of acicular crystals within days. These needle-shaped crystals then dissolve also, most of them last only 2 or 3 days. That is the reason for the fact that the scale-reducing properties of the treated water last for 2 days only.

More research

Many questions remain for more investigations. The influence of temperature has not been investigated as yet. It can only be assumed to be of essence according to Russian reports. Also, the type of the water from different sources seems to be of importance. Some mountain spring waters require particularly well adjusted magnet sequences in order to be effective. According to findings by geologists about the type of mountain water coming from narrow spaces of defect structures within mineral deposits, such water may have formed only few complexes of a specific size. Therefore the required resonance is a narrow one and therefore difficult to achieve.

The effectiveness of the magnetic treatment may also be influenced by certain mineral contents of the water - such as silicates - which appear to interfere with the magnetic treatment.

Freshly fallen rainwater did not show much effect from the magnetic treatment. It has been found to contain as many seeded disc-shaped crystals as water after the magnetic treatment! It is believed that the raindrops passing on their way down through the electric fields of the clouds may undergo a sort of natural treatment with electric fields.

The actual physical changes of the water.

Another wide open field of questions remains to be investigated; that are the short-lived effects of magnetic fields on the physical constants of the water. These effects are so minute that their measurements are beset with uncertainties. Yet their effects for the usefulness of the water are often of great importance, as for instance the surface tension which determines many parameters of the water quality. A number of experiences are reported from many sides, and some of our own observations with respect to these changes in the physical structure of liquid water will be mentioned in the next section.

Learning more about liquid water.

Assuming that the interactions between magnetic fields and moving water are of the nature which are here proposed, the study of magnetic water treatment opens new avenues for the study of the structure of liquid water. So far, no systematic study has been attempted of this issue. Nobody doubts the overwhelming importance of the use of water for virtually every human endeavor, yet there is no correlation which could oversee all the many separate researches into water by the various users.

(In the 6 volumes of his comprehensive treatise *WATER*, Felix Franks decries this fact and has tried in his lifetime to change this lack of concerted effort.)

The magnetic water treatment issue might be one way to make the few known facts of the physical structure of water more generally available. One important step in this respect is that the general public learns that there are fundamental problems with the physical structure of water.

At this time, even the more sophisticated users and investigators of water think most of the time only in chemical terms of the water. Almost without exception, "testing of water" is considered a chemical analysis. Understanding the nature of the magnetic treatment of water as to be only a phase-change of some components of the water, it is evident that any chemical analysis of the water before and after the treatment cannot possibly show a change. The magnetic treatment does not actually add or remove anything from the water. A standard chemical analysis brings all the substances into an all over dissolved state, thusly undoing the effects of the magnetic treatment. Many negative test results have been published because of this exclusively chemical thinking.

Again, it has to be said that many of these misconceptions have their origin in the misrepresentation of the method by insufficiently trained sales personnel. They try to compare the effects of the magnetic devices with softening chemicals or ion exchangers. So, the water users are disappointed and consider the entire issue a swindle.

What are the Consequences for Future Water Usage For Industries?

Simple magnetic treatment units with their best effectiveness at a fixed water flow rate serve with advantage in such installations which require a constant flow rate. The size of the treatment unit can be selected to fit the exact requirement of the machinery.

Very small units may serve in drip irrigation at every separate outlet with one gallon/hour flow rate, or a larger unit may be used for the entire irrigation system. Ice machines, solar panel, steam cleaners may have a precisely fitted magnetic unit permanently built in. Without it they would plug up within a few weeks of use and would have then to be washed out with acid to remove the accumulated hard lime scale. The built-in magnetic units keep these machines running for many months without an acid wash.

In the case of steam cleaners, an additional benefit results from the lessened surface tension of the magnetically treated water. Oral, unpublished reports of increased cleaning power of detergents confirm the microscopically found change of the water-detergent mixture. Instead of the drop circumference which is usually well defined by the surface tension, the treated water wets the glass surface much better improving the activity of the added detergent.

Another potential application of magnetic water treatment has been looked into for the oil industry. The fossil water which comes up with the oil is extremely heavy with minerals. Its separation from the oil and subsequent replacement under ground can be facilitated by magnetic treatment.

Some preliminary investigation (non-published) was successful for one narrow range of flow rate. The massive dendritic crystal growth has been replaced with a multitude of small, rectangular crystals. Much further investigation is needed to reap the potential benefits from magnetic water treatment for a number of problems of the oil industry. As for instance a better separation of the oil from the water.

*** Note from page 5, under the sub-topic Magnetic Arrangement:**
This reference apparently refers to the magnetic arrangement developed by Bruce DePalma, involving the use of Ferrite Ring Magnets, and granted WIPO Patent publication in 1981. While the author, Kronenberg, refers to a US Patent on this method, no granted US Patent by DePalma on this method has been found.

Published Article

Title: Microscopic Fuel Tests Using Magnetic Fuel Conditioning

Date of Publication: 1991

Publisher: Unknown

Author: Dr. Klaus J. Kronenberg

Public Document

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Microscopic Fuel Tests Using Magnetic Fuel Conditioning

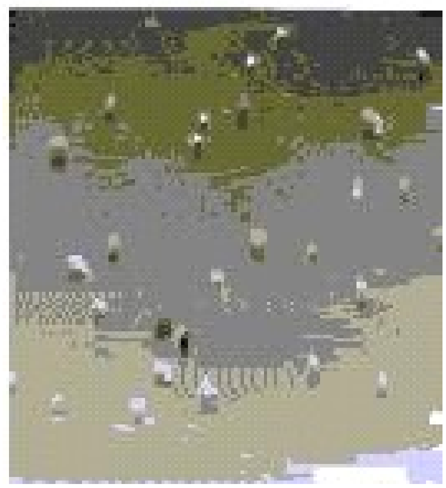
by Dr. Klaus J. Kronenberg (1991)

After 45 years of experience as a physicist, studying magnetics, acoustics and crystallography, Dr. Klaus Kronenberg, in conjunction with other Research efforts, has developed an exciting new theory of magnetic fluid treatment.

Investigations and results:

Empty glass slides were held for several seconds in the exhaust stream of a V-8 gasoline engine using leaded gasoline running at 2000 rpm.

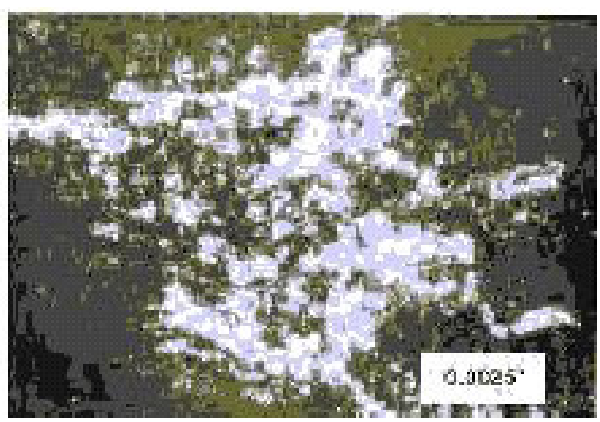
Fig.1 No Treatment.



The droplets at highest magnification show a spherical, structure-less shape.

All slides exposed to the exhaust without Magnetic Treatment showed a multitude of small droplets clinging to the glass. They were distributed over the entire glass slide at even distances. They did not evaporate over days. Their shape became visible in the microscope using polarized light.

Fig.2 No Treatment.

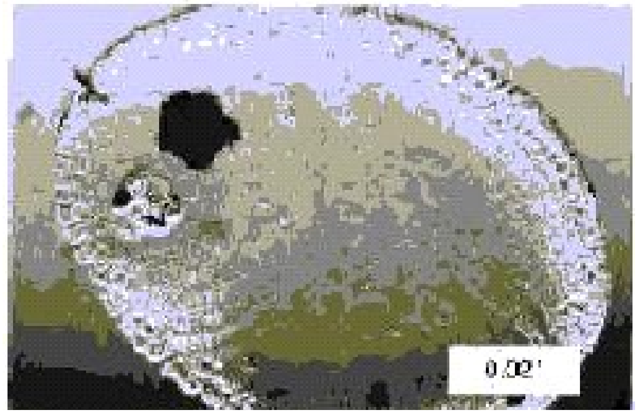


Remains of a solid particle from the exhaust which bounced off the glass slide.

Figure 2 is an example of a shapeless bit of matter clinging to the glass. About 10 such places were found with similar shapeless matter on the glass

Fig.3 Exhaust of Magnetically Treated Fuel.

One of the round spots found on the glass slide exposed to exhaust from Magnetically Treated gasoline.



The slides which had been exposed to the exhaust when the magnetic device was in place on the fuel supply line were also full of the small droplets, but additional material was discovered clinging to the glass. This material formed roundish spots, about 10 to 30 per slide. The details of the round spots were most visible when side-illuminated. Many contained a black particle in them, which was often broken up. All the rims of the round spots were heavily scalloped, exhibiting just enough surface tension to form the roundish appearance of the spot on the glass slide.

Fig.4 Exhaust of Magnetically Treated Fuel.

Stronger magnification and side illumination reveals scalloped shape of the rim of this substance (low surface tension indicated).

The side-illumination reveals the scalloped rim of the spot. The traces of the gradual evaporation within the spot are visible and show that the evaporation ended at the particle.

In order to obtain more information about the nature of the material which formed the rounded spots they were observed with polarized light. Within the roundish spots crystalline shapes appeared with a variety of configurations. Most of the shapes were crystals of a dendritic type. Large numbers of smaller, nearly cubic crystals were also found. All of these crystals are of an optically active material, recognizable on the dark-light contrast within each crystal in the polarized light. The shape of the crystals point toward the crystals having a cubic crystal structure, being most likely a lead compound.

CONCLUSIONS

The consistent results of both test series permit a cautious attempt at explanation. The fact is that the slides covered with exhaust without the magnetic fuel treatment showed only the tiny droplets, but not one single round spot. But, the round spots were found in abundance on the slides from exhaust with magnetic treatment. This makes it almost certain that the magnetic device on the fuel supply line had an effect on the combustion of the fuel in the engine.

The roundish shapes of these spots are evidence of the fact that they must have been splashed onto the glass as a liquid. They must have been in the form of spherical drops in the exhaust. Their sizes imply drops at least 1000 times heavier than the droplets found in the exhaust of the untreated fuel. The dark particles found inside these roundish spots indicate that a solid particle was transformed in the combustion process partly to a liquid. This could have happened in the form of a partial combustion.

Not one roundish spot of a similar size has been found in the exhaust of untreated fuel. This suggests, that such partial combustion of certain larger particles has not been occurring without the magnetic treatment. In the exhaust of untreated fuel we find instead, evidence of some larger solid particles which have left some formless traces after hitting the glass and flying off. They showed no trace of a liquid by a partial combustion.

The investigated fuel is a mixture of many components containing benzene-like ring-molecules. The refining process - heating in the absence of oxygen - had used the internal vibration of the large molecular sheets to have them break up. The molecular fragments were driven off, collected and separated. Their size determined their ability to resist combustion.

The results of our tests with the application of a number of magnetic poles which the fuel had to pass on the way to the engine can be best understood as an additional effect of fuel refining. We suggest that some larger molecular structures remained in the fuel after the normal refinement process, because they withstood the breakup effect by heat. They were then broken up when they passed through the series of alternating magnetic fields. The magnetic effect on molecules is very weak. But it is known that it can be amplified a million fold in the case of resonance. If the time sequence of the alternate magnetic fields encountered by the streaming fuel hits a frequency of the internal vibration of a molecular structure, then a resonance occurs and may break up the structure which had escaped the breakup by the original refining process. This renders the original refining process more complete.

Therefore, we think we can predict that the effect of magnetic fuel treatment will be best for the least completely refined fuel.

Further research is required in order to confirm the findings. Possible differences for different fuels (Diesel), varied rpm's, and varied arrangements of magnetic fields are being explored.

Published Article

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Effect of magnetic field on the performance of new refrigerant mixtures

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SUMMARY

Performance test results of new alternative refrigerant mixtures such as R-410A, R-507, R-407C, and R-404A under various conditions of magnetic field are discussed, analysed and presented. The test results were obtained using an air-source heat pump set-up with enhanced surface tubing under various magnetic field conditions. Performance tests were conducted according to the ARI/ASHRAE Standards.

The test results demonstrated that as magnetic field force increases, compressor head pressure and discharge temperature slightly increase as well as less liquid refrigerant is boiling in the compressor shell. This has a positive effect in protecting the compressor. The effect of magnetic field on mixture behaviour varies from one mixture to another depending upon the mixture's composition and its boiling point. Furthermore, the use of magnetic field appears to have a positive influence on the system COP as well as thermal capacities of condenser and evaporator. Copyright © 2002 John Wiley & Sons, Ltd.

KEY WORDS: new refrigerant mixtures; magnetic–caloric effect; ARI/ASHRAE standards

1. INTRODUCTION

It is well known that certain materials properties and particularly temperature will increase when placed in a magnetic field and, will likewise decrease when the magnetic field is removed. This mainly is caused by the effect of the magnetic field on the entropy and the heat content of material. This phenomenon is known as magnetic–caloric effect. The effect of magnetism and magnetic field on fluids is still considered as not well-known subject. However, it is well established that there are major changes caused by the passage of fluid through magnetic field.

Several magnetic refrigeration devices under development by Astronautics using convention NbTi magnets have been described by Zimm and De Gregoria (1992). The system advantages of incorporating high-temperature super conducting magnets in designs have been discussed. The authors also explained the nature of active magnetic regenerative (AMR) cycle and its requirements in refrigeration.

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Research on magnetic–caloric effect and its application have been discussed by Gschneiddd-ner and Pecharsky (1999) for cooling near-room temperature. The study included the relationship between the nature of magnetic transformation and the temperature dependence of the magnetic–caloric effect and the entropy utilized in the magneto caloric.

The magnetic measurements to evaluate the thermodynamic behaviour of magnetic material have been presented by Foldeaki *et al.* (1995). As reported in this reference, depending on the thermodynamic cycle selected, the isothermal magnetic entropy temperature change or the adiabatic temperature change upon the field application should be preselected as a function of temperature. This paper presented classical magnetic measurements, when evaluated within the framework of the Landau theory.

A magnetic heat pumping can be made according to Brown (1976) using a ferromagnetic material with a curie point and an appropriate thermodynamic cycle. The regenerative magnetic cycle can approach the Carnot cycle efficiency, as reported by Brown.

Furthermore, most refrigeration and air-conditioning systems experience load variation. High efficiency and high performance are greatly in demand. Among techniques employed for improvement, capacity control, optimization of vapour compression systems are the refrigerant liquid and vapour injection. However, it is believed that the magnetic field can be employed as an enhancing technique.

The several studies reported in the literature demonstrated the magnetic field and its capabilities as well as its impact on the thermodynamic characteristics. However, as the EHD technique has shown an improvement of the heat transfer on refrigerant side (Muraki *et al.*, 2001), it is believed that magnetic field could have an enhancement effect on heat transfer properties. Several studies have been reported on the use of magnetic elements in enhancing the performance in many applications such as oil, natural gas furnaces, diesel engines, fuel lines and also in water treatment. To the authors knowledge none has been reported on the use of magnets as a performance enhancer in the refrigeration industry.

Therefore, this paper is concerned with the study and analysis of some refrigerant mixtures behaviour inside enhanced surface tubing air fined heat exchangers under magnetic field at various forces of the magnetic field (Gauss levels). The blends under consideration in this study are; R-507 (R-125/R-143a:50/50%), R-404A (R-125/R-143a/R-134a:44/52/4%), R-410A (R-32/R-125:50/50%), and R-407C (R-32/R-125/R-134a:23/25/52%). All percentages of the afore-mentioned blends are based on weight. The main thrust of this study is to study the enhancement of the heat transfer rates and system coefficient of performance and optimize the use of magnets in refrigeration systems.

2. EXPERIMENTAL APPARATUS AND MEASUREMENTS

Figure 1 shows a schematic diagram of the experimental set-up, which is an air-source vapour compression heat pump, composed mainly of a 3 kW compressor, oil separator, condenser, precondenser, pre-evaporator, adjustable expansion device, capillary tubes and evaporator.

Three magnetic elements with Gauss level of 4000 each have been employed in this study. These magnets were intended for gasoline fuel line of 1/4 in diameter, they were clamped at the refrigerant line of same diameter. The units were single-type with two brackets strapped around the pipe. They were clamped on the refrigerant liquid line at the post-condenser outlet at various distances, before the capillary tube/thermal expansion valve used as flow control device. During

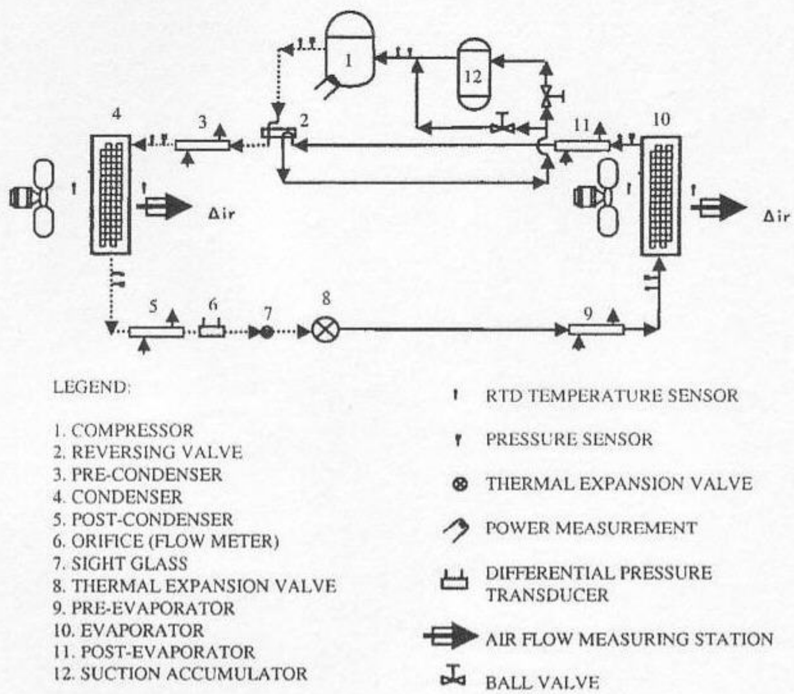

Figure 1. Schematic diagram of the air/air heat pump test facility.

the course of this experimental study, series of three magnets were used totalling 12 000 Gauss levels. The magnets were placed at three locations of the post-condenser outlet at a distance of 0.13, 0.47 and 0.71 m, respectively. This was necessary to ensure that the magnets are placed on the refrigerant full liquid line. This is confirmed by observation through the sight glass. At each position, experiments were conducted with one, two and three magnets placed at 0.01 m spacing between each other. Figure 1 depicts the set-up flow diagram and magnet positions.

The oil content in the refrigerant loop was estimated to be about 1% using gas chromatography. Pressure, temperature and flow rate measuring stations are shown in Figure 1. All pressures were measured using calibrated pressure transducers (0–800 kPa). The accuracy of the pressure transducers was $\pm 2.5\%$. Differential pressure transducers were employed to measure the refrigerant flow rate. Temperatures were measured by RTD temperature sensors which have an accuracy of $\pm 0.5\%$. Humidity measurements were obtained through the accurate recording of dry and wet bulb temperatures.

All recorded measurements were obtained at a variable sink and source air temperature of 21°C entering the condenser. On the other hand, the capillary tubes were adjusted to optimize the system's performance with every tested refrigerant mixture. This simulates the system's performance at different thermal loads and using a variable thermal expansion valve.

A calibrated orifice, installed in the liquid refrigerant line after a liquid receiver, was used to measure the refrigerant mass flow rate. Pressure taps on both sides of the orifice were connected to a differential pressure transducer (0–250 kPa). Air mass flow rate was also measured by a

Pitot tube-type air flow meter calibrated station. The accuracy of the mass flow measurements was $\pm 3\%$ of the nominal flow.

Power supplied to the compressor was measured because it is needed for the heat balance. An AC/DC clamp-on was calibrated for power measurements with an accuracy of $\pm 3\%$. The energy balance of the test unit was within $\pm 3\%$.

Data collection was carried out using a P150 equipped with a data acquisition system with a capacity of 112 channels. This enabled us to record, at a single scan the local properties such as: pressure drops, pressure, temperature, and flow rates as well as power consumption.

All tests of the blends under question were preformed under steady-state conditions and according to ANSI/ASHRAE 37-1978 Standard and ARI-240 Standard. The data collection was scanned every second and stored every 10 s. The experimental values were averaged over a period of 10 s.

The primary parameters observed during the course of this study were: mass flux, heat flux, thermal capacities, power consumed and quality for refrigerants under investigation; R-507, R-404A, R-407C as well as R-410A at various magnetic element conditions. It is important to note that during the course of this study the impact of each magnetic condition was tested separately and measurements were only recorded once the system reached a stable condition.

In order to evaluate the blend's performance, the thermodynamic properties of pure and zeotropic refrigerant mixtures should be known. REFPROP (McLinden *et al.*, 1998) version 6.01 was used to evaluate the mixture's characteristics. Interaction parameters were selected with caution, since their values may influence the outcome of REFPROP prediction of the thermodynamic and transport properties. Interaction parameters are the mixing parameters of refrigerant mixtures.

Test conditions and coil specifications of the heat exchangers used employed in this study are given in Tables I and II. The geometrical parameters of the micro-fin tubes are also presented in Table III.

Table I. Air coils specifications.

Tube outer diameter	3/8″
Rows deep	4
Fin per inch	12
Fin depth	3.46″
Fin height	20″
Fin length	30″
Fin thickness	0.0045″
Rifled tubes	Microfins

Table II. Test conditions.

Temperature of air of the condenser inlet	21°C
Temperature of air at the evaporator inlet	−15 to +8°C
Air flow rate	7.07×10^{-2}–$9.4 \times 10^{-2}\,m^3\,s^{-1}$
Refrigerant mass flow rate	8–40 $g\,s^{-1}$
Condenser pressure	600–1800 kPa
Evaporator pressure	170–450 kPa
Standard relative humidity at condenser inlet	45%

Table III. Geometry of micro-fin tubes, (round tip geometry).

Outside diameter	0.375″
Root diameter	0.344″
Tip diameter	0.331″
Fin height	0.0074″
Pitch	0.016″

3. RESULTS AND DISCUSSION

In the following sections, samples of the system's performance with some new alternative refrigerants under various magnetic fields conditions will be presented, discussed and analysed. The test conditions were: condenser pressure varied between 600 and 1800 kPa, and the condenser refrigerant temperature was between 28 and 38°C. The evaporator pressure ranged from 170 to 450 kPa, and the refrigerant evaporator temperature was between −20 and −6°C. Under these conditions, and at each test, the following parameters have been measured: thermal capacities at evaporator and condenser sides, power consumed by compressor, refrigerant flow rates, coolant flow rates and refrigerant quality at both evaporator and condenser sides.

The aforementioned measured/calculated parameters, such as power consumed and thermal capacities at the evaporator and condenser, are necessary for evaluating the coefficient of performance (COP) under heating and cooling modes. However, only the heating mode was considered in this study.

The COP and heat absorbed/released at system heat exchangers are calculated as follows:

$$\text{COP} = \frac{\text{Heat absorbed/released}}{\text{Compressor power}} \tag{1}$$

and

$$Q_{\mathrm{a/r}} = \dot{m}_f \, C_{p,\mathrm{f}} \, \Delta T \tag{2}$$

$$Q_{\mathrm{a/r}} = \dot{m}_f \, \Delta H \tag{3}$$

where $\dot{m}_{\mathrm{f}}$ and ΔT represent the air mass flow rate, and air temperature difference across the evaporator/condenser coils. $C_{p,\mathrm{f}}$ is the specific heat for airflow and ΔH gives the total air enthalpy difference across the heat exchangers.

Equations (2) and (3) represent the heat exchanger sensible and latent heats, respectively. Equation (3) is employed particularly during cooling load calculation.

As mentioned during the course of this study, only heating tests were conducted. Therefore, only the sensible heat was considered in calculating the thermal capacities as shown in Equation (2).

The results of the various refrigerant mixtures with no magnets were used as a baseline for this study. Upon completion of the baseline results of each refrigerant mixture, under the aforementioned conditions, the compressor and the system was drained and evacuated. Following this step, the system was then recharged with the preferred refrigerant mixture. This procedure was repeated before conducting the series of tests for every single alternative mixture.

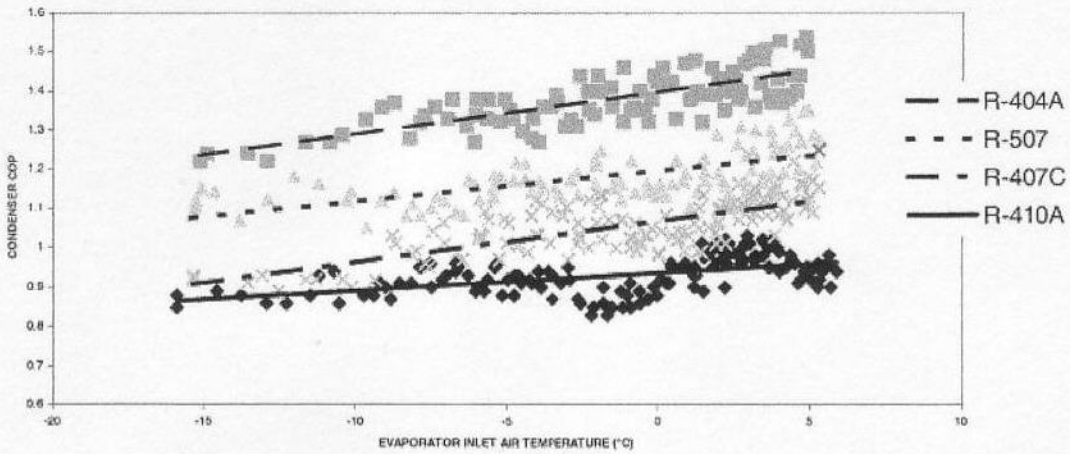

Figure 2. Condenser COP vs evaporator inlet air temperature with no magnets.

In the following, the functional dependence of the following parameters on the refrigerant temperature entering the evaporator will be outlined; input power, thermal heating capacity at the condenser side, pressure ratio, condenser pressure, evaporator thermal capacity and COP.

During the experimentation, the sink's air temperature was kept constant at 21°C, and relative humidity was also kept at 45%. The source coolant temperature varied from −15 to 5°C at the evaporator inlet. The dry and wet bulb temperatures of the source and sink were within the ASHRAE and ARI Standards.

Samples of the results obtained during these runs and used as baseline data with no magnets were plotted in Figure 2 at various entering air temperatures to the evaporator. As expected, the results plotted in this figure show that the COP heating, increases at higher entering air temperature at the evaporator side. The results also demonstrate that R-404A has the highest COP among the mixtures under investigation.

In order to study the influence of the number of magnets on the behaviour of the refrigerant mixtures and the system performance samples of the test, results were plotted at various conditions in Figures 3–12. On the other hand, it appears from the sample results displayed that the magnets accelerated the increase of the COP compared to the no magnets results. Furthermore, R-404A appears to show the highest performance at lower evaporation temperatures and this is mainly due to its significant latent heat at low temperatures.

It is quite clear from Figure 4 that the evaporator COP was enhanced with different percentages depending on the type of mixture and its boiling point. This has a positive and significant impact on the cooling capacity as well as the efficiency of the system performance. It is quite clear from the data in Figure 4 that R-507 behaviour is significantly influenced by the magnetic field force (Gauss levels) and power of the magnets. On the average, it appears that higher Gauss levels enhanced the evaporator COP by 20% depending upon the refrigerant mixture boiling point. It is believed that the magnetic effect or field changes the polarity of oil which is a hydrocarbon from negative charge to positive charge. This results in entertaining the oil and being carried away from the heat transfer surface, thus enhancing the heat transfer rate and coefficient of heat transfer. Thus, the consequent effect on the COP has been caused by this

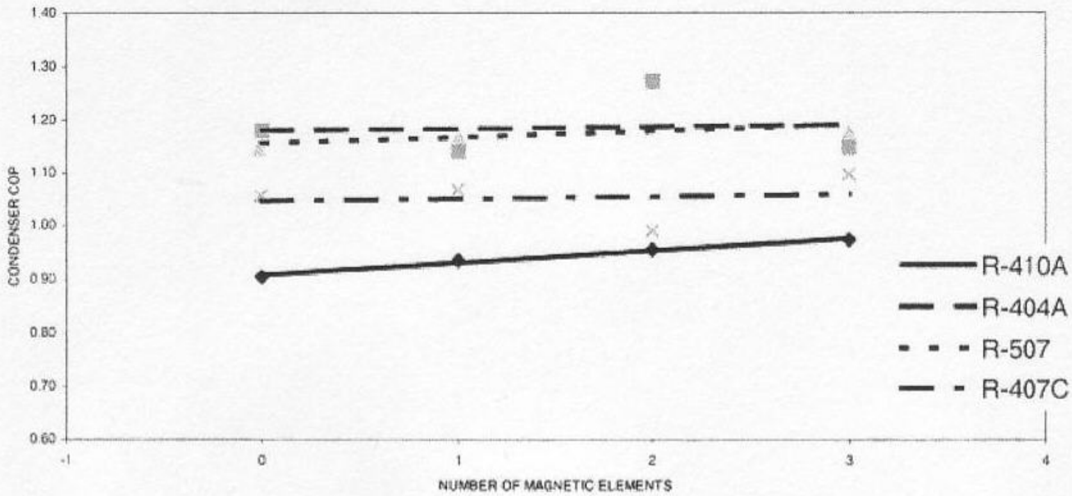

Figure 3. Condenser COP vs number of magnetic elements at constant temperature (0°C).

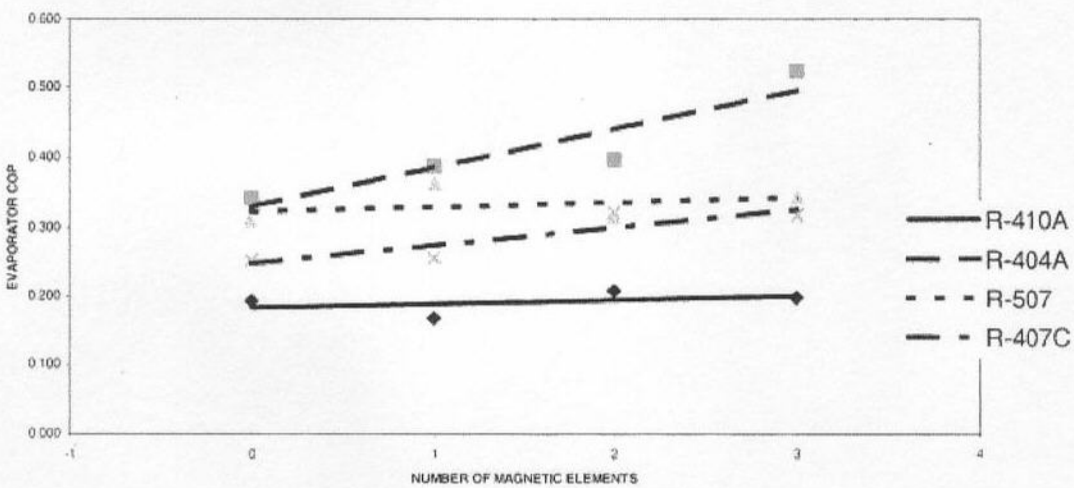

Figure 4. Evaporator COP vs number of magnetic elements at constant temperature (0°C).

phenomenon. It was also shown that higher Gauss levels increase thermal capacities. Previous studies have shown that oil entertained in the refrigerant flow results in degrading the heat transfer rates (Sami *et al.*, 1993).

Furthermore, since the condenser's COP is an important parameter in evaluating the cycle performance, and is calculated as function of the compressor power, Figure 5 has been constructed to show the impact of the magnet Gauss levels on the power consumed. It appears that the magnets reduce slightly the power consumption of the compressor. Also higher Gauss levels results in decreasing the power consumption. The decrease of the power consumption appear to be around 8%. It is believed that increasing Gauss levels decreases the compressor

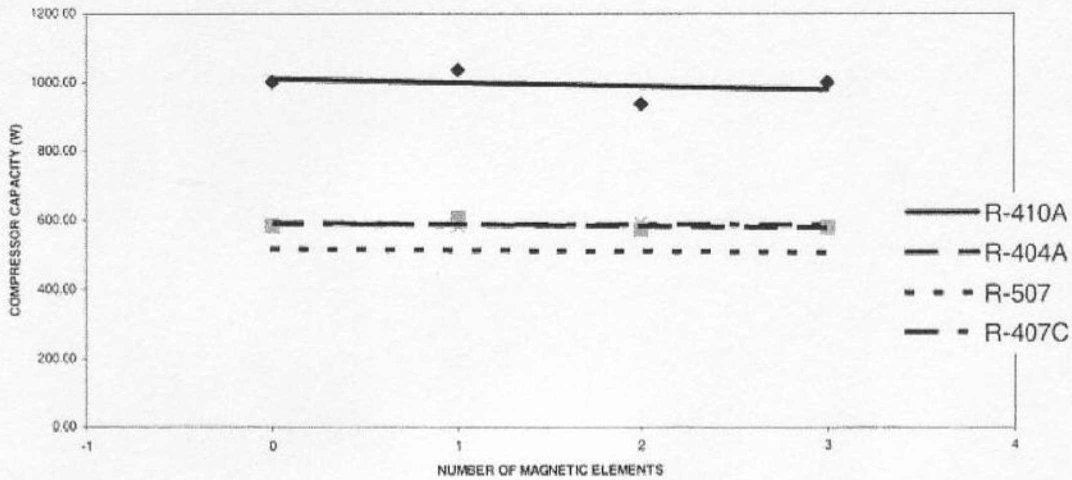

Figure 5. Compressor capacity vs number of magnetic elements at constant temperature (0°C).

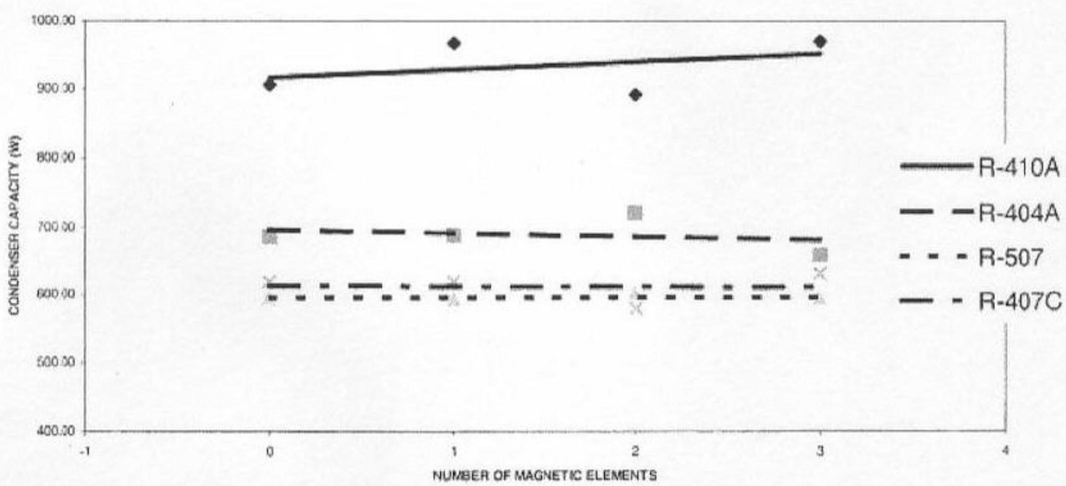

Figure 6. Condenser capacity vs number of magnetic elements at constant temperature (0°C).

power and therefore enhance the COP. This is a result of efficient boiling and condensation and less liquid being boiled at the compressor shell. It is interesting to note that the mixtures with higher latent heat seem to exhibit slower decrease in the power consumption.

In order to understand the impact of the magnetic field on the condenser capacity, Figure 6 has been plotted for the refrigerant mixture in question. Slight increase in the condenser capacity was observed. However, R 410-A showed the highest increase in capacity with the increase of Gauss levels.

Figure 7 shows the evaporator capacity under various Gauss levels. The data presented in this figure clearly demonstrated the enhancement of the evaporator capacity with the increase in the

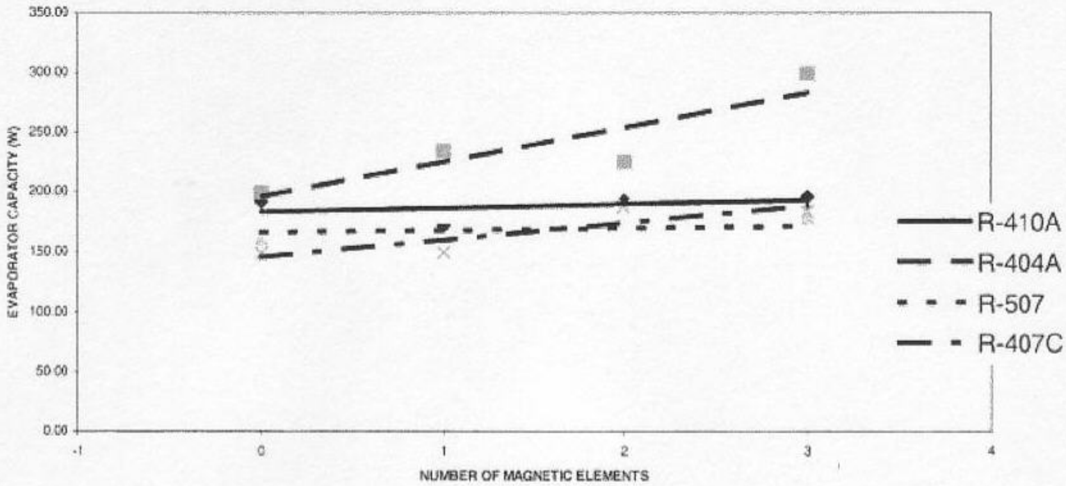

Figure 7. Evaporator capacity vs number of magnetic elements at constant temperature (0°C).

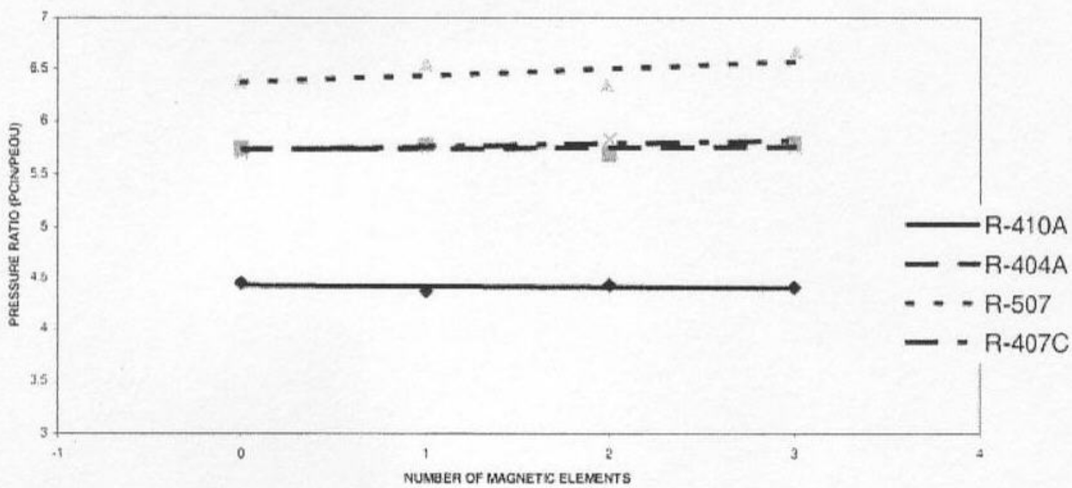

Figure 8. Pressure ratio vs number of magnetic elements at constant temperature (5°C).

number of magnetic elements used. It also appears that the R-404A experiences the highest enhancement among the refrigerant mixtures under investigation. This is mainly due to the low boiling temperature of the mixture and the high latent heat at the test temperature.

The pressure ratio represents the ratio between the discharge and the suction pressure across the compressor. Figure 8 displays results observed with various magnetic element. The results show that the pressure ratio has been slightly increased with the increase in the number of magnetic elements. This is expected since less liquid refrigerant is being boiled in the compressor shell and therefore, this results in increasing the pressure ratio. This trend has been observed with other refrigerant mixtures under investigation.

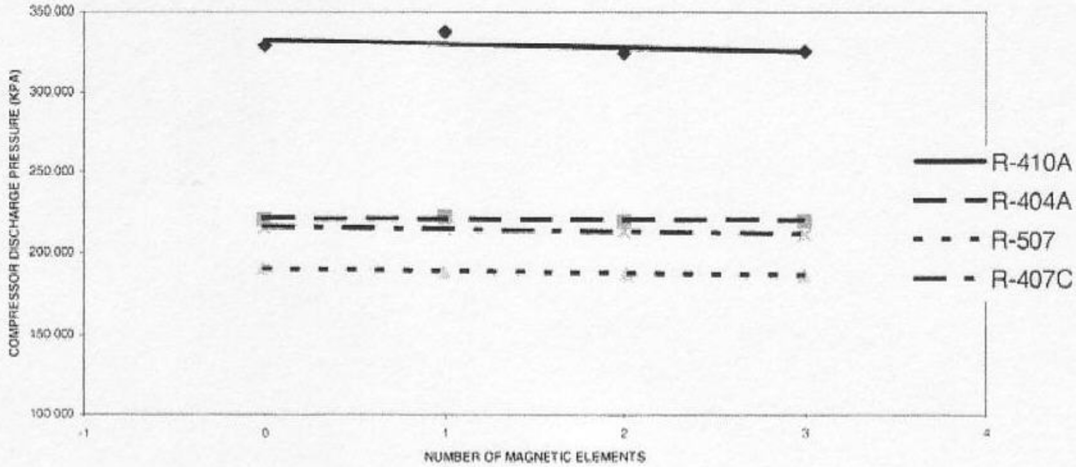

Figure 9. Compressor discharge pressure vs number of magnetic elements at constant temperature (0°C).

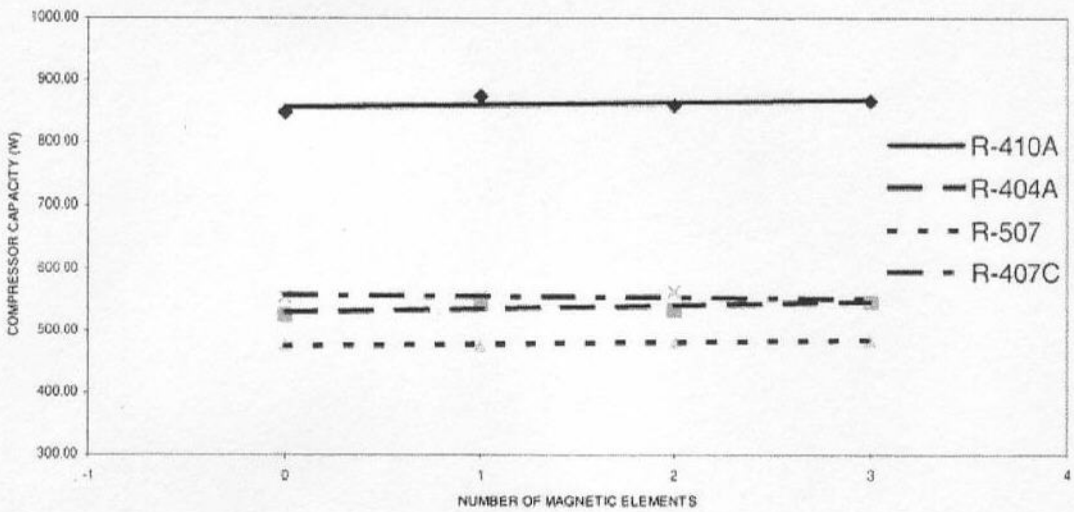

Figure 10. Compressor capacity vs number of magnetic elements of constant temperature (−15°C).

The compressor head pressure and discharge temperature are important parameters to be considered when selecting an alternative mixture, therefore, Figure 9 has been constructed to study these parameters. Figures 4–6 gives clear evidence that as the magnetic field force increases COP of the condenser and evaporator increase. However, it also appears that higher Gauss levels slightly decrease the discharge pressure. It is suggested that this is a result of less liquid refrigerant being carried into the compressor chamber. Furthermore, these results clearly indicate that R-410A has superior compression properties compared to the other blends under investigation.

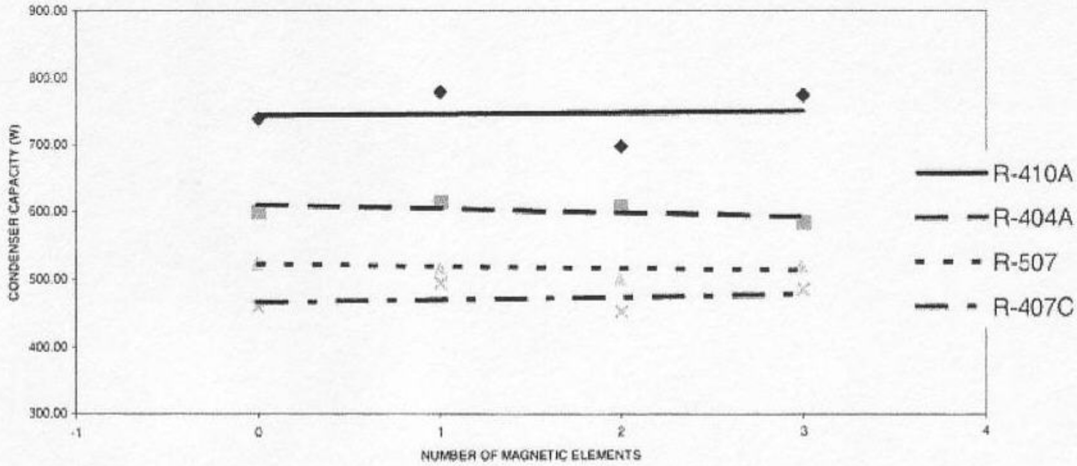

Figure 11. Condenser capacity vs number of magnetic elements of constant temperature (−15°C).

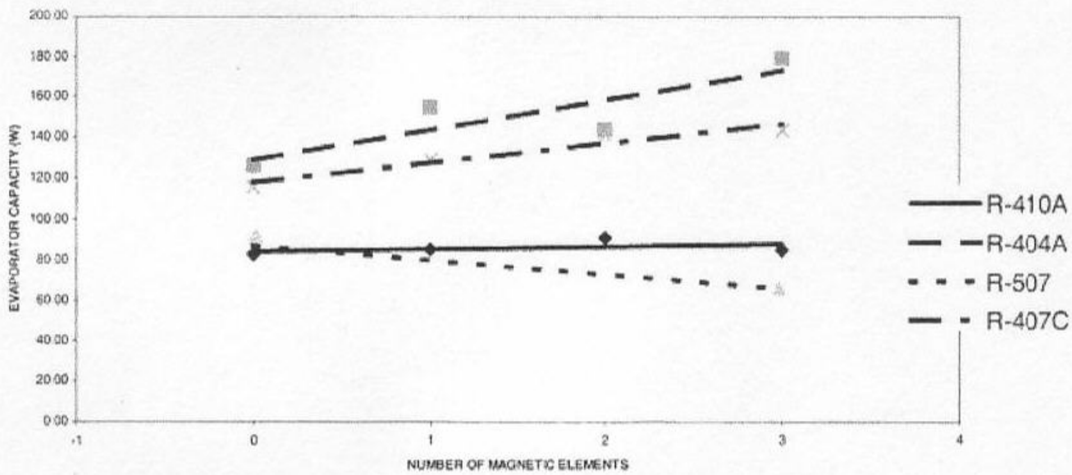

Figure 12. Evaporator capacity vs number of magnetic elements of constant temperature (−10°C).

Based on the above results and the additional information presented in Figures 4–6, it appears from Figure 10 that lower evaporation temperatures seem to slightly increase the compressor capacity with higher Gauss levels. This is quite expected since higher Gauss levels enhance the evaporator capacity and therefore, reduce refrigerant liquid boiling in the compressor shell. Figure 11 also demonstrates that higher magnetic fields results in enhancing the heating capacity of the system even at low evaporation temperatures. This figure also shows that the refrigerant mixture in question respond similarly to the increase of the magnetic field force. Figure 12 displays sample results on the impact of magnetic field force on the cooling capacity of the evaporator. Refrigerant mixture exhibit almost the same behaviour with increase of magnetic field levels however, it appears that R-507 experienced slight decrease in the evaporator capacity.

4. CONCLUSIONS

During the course of this experimental study, the performance characteristics of some new proposed substitutes under various magnetic field levels have been investigated, analysed and compared to that of no magnet condition. The test results under heating conditions demonstrated that increasing the magnet capacity has a positive effect on the COP. The study showed that the effect of magnetic field on the mixture behaviour varied depending upon the mixture's composition and its boiling point.

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Influence of magnetic field on two-phase flow convective boiling of some refrigerant mixtures

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SUMMARY

In this paper, an experimental study on the influence of magnetohydrodynamic (MHD) on heat transfer characteristics of two-phase flow boiling of some refrigerant mixtures in air/refrigerant horizontal enhanced surface tubing is presented.

Correlations were proposed to predict the impact of MHD on the heat transfer characteristics such as average heat transfer coefficients, and pressure drops of R-507, R-404A, R-410A, and R-407C in two-phase flow boiling inside enhanced surface tnbing. In addition, it was found that the refrigerant mixture's pressure drop is a weak function of the mixture's composition.

It was also evident that the proposed correlations for predicting the heat transfer characteristics were applicable to the entire heat and mass flux, investigated in the present study. The deviation between the experimental and predicted value using new and improved correlations for the heat transfer coefficient and pressure drop were less than $\pm 20\%$, for the majority of data. Copyright © 2005 John Wiley & Sons, Ltd.

KEY WORDS: heat transfer; MHD; boiling; refrigerants mixtures

1. INTRODUCTION

The effect of magnetism and magnetic field on fluids is still considered as a not well known subject. However, it is well established that there are major changes caused by the passage of fluid through magnetic field.

Several studies reported in the literature demonstrated the magnetic field and its capabilities as well as its impact on the thermodynamic characteristics. However, as the electrical hydrodynamic (EHD) technique has shown an improvement of the heat transfer rate on refrigerant side (Sami and Aucoin, 2003), it is believed that magnetic field could have an enhancement effect on heat transfer properties.

The literature revealed that in addition to what has been reported by Sami *et al.* (1996, 1998, 2000, 2003), Wang *et al.* (1998) investigated nucleate boiling on several commercially available enhanced and smooth tubes using working fluids R-22, R-123, R-134a, R-407C and R-410A in

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water/refrigerant geometry. His work concluded that heat transfer coefficients of R-410A and R-22 are comparable. Other results have been reported on two-phase flow characteristics inside smooth tube by Wijaya and Spatz (1995) using R-22 and R-410A.

Numerous studies on the fluid flow and heat transfer of refrigerant mixtures inside horizontal smooth tubes by Sami and Aucoin (2003) and Khartabil *et al.* (1988), Heide and Schenk (1996), Krauss *et al.* (1996), Tanka and Sotani (1998), Webb *et al.* (1971) reported no remarkable effect of the mixture's composition on the flow pattern of condensation. However, none has been cited in the literature on influence of Magnetic Hydrodynamic (MHD) field on the heat transfer characteristics of refrigerant mixtures (Yata, 1998; Sami and Kita, 2005).

The present research work has been undertaken to better understand the impact of magnetic field on the boiling fluid flow and heat transfer characteristics of some new alternative refrigerant mixtures inside enhanced micro-fins surface tubing under various levels of magnetic flux: R-410A (R-32/R-125:50/50%), and R-407C (R-32/R-125/R-134a:23/25/52%). All percentages of the aforementioned blends are based on weight.

2. EXPERIMENTAL APPARATUS AND MEASUREMENTS

Figure 1 shows a schematic diagram of the experimental set-up, which is composed of an air/refrigerant vapour compression heat pump with 3 kW compressor.

Various magnetic elements with gauss level of 4000 each have been employed in this study. These magnets were clamped at the refrigerant lines, single-type with two brackets strapped

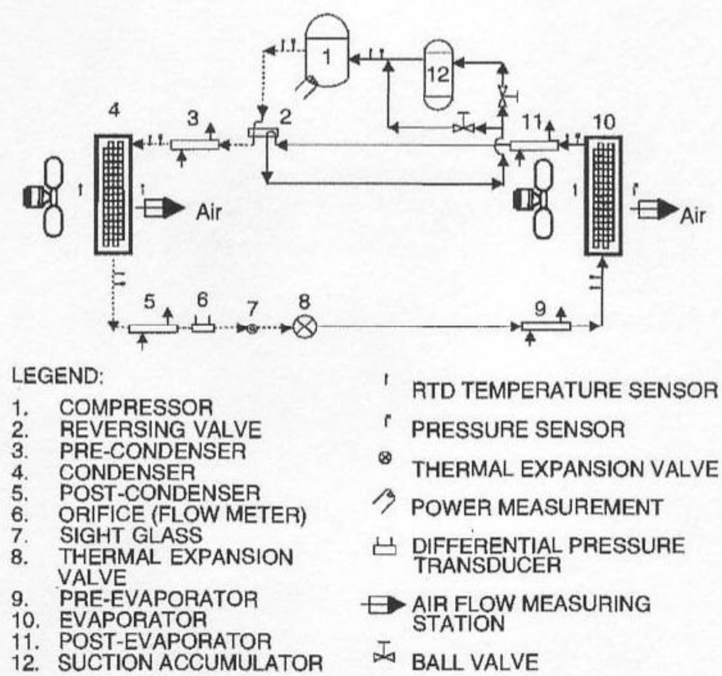

Figure 1. Schematic diagram of air/air heat pump test facility.

around the pipe. They were clamped on the refrigerant liquid line at the post condenser outlet at various distances, before the capillary tube/thermal expansion valve used as flow control device and at the low vapour pressure line leading to the compressor. The permanent magnets were placed at different locations of the outlet of post condenser. This was necessary to ensure that the magnets are placed on the refrigerant full liquid line. The full liquid line is defined as a section of the pipe where the flow is sub-cooled liquid. At each position, experiments were conducted with one, two and three or more magnets placed at 0.01 m spacing between each other. Figure 1 depicts the set up flow diagram and magnet positions.

2.1. Test facility

A test facility was constructed to study the refrigerant mixture boiling under liquid injection conditions. The facility was capable of producing saturated vapour at the evaporator outlet for boiling studies. The experimental set-up is an air/refrigerant vapour compression heat pump and is composed mainly of a 3 kW compressor, oil separator, condenser, pre-condenser, pre-evaporator, adjustable expansion device equipped with a series of capillary tubes with control valves, and a test evaporator. The oil content in the refrigerant loop was estimated to be about 1% using gas chromatography.

2.2. Test section

The experimental set-up test section was composed of a micro-fin finned evaporator coil. The geometry of the coils is presented in Tables I and II, whereas Table II gives details of the micro-fins geometrical parameters. Furthermore, Table III gives the test conditions and information on the key parameters of the system. Pressure, temperature and flow rate measuring stations are also shown in Figure 1.

The accuracy of the pressure transducers was $\pm 2.5\%$. Differential pressure transducers were employed to measure the refrigerant pressure drop. Temperatures were measured by RTD sensors with an accuracy of $\pm 0.5\%$ of full scale.

Table I. Air coils specification.

Tube outer diameter	0.375 in (0.9525 cm)
Rows deep	4
Fins per inch	12
Fins depth	3.6 in (8.884 cm)
Fins height	20 in (50 cm)
Fins length	30 in (76 cm)
Fins thickness	0.045 in (0.114 cm)
Rifled tubes	Micro-fins

Table II. Geometry of micro-fin tubes (round tip geometry).

Outside diameter	0.75 in (0.525 cm)
Root diameter	0.44 in (0.738 cm)
Tip diameter	0.31 in (0.407 cm)
Fins height	0.074 in (0.0188 cm)
Pitch	0.016 in (0.0406 cm)

Table III. Test conditions.

1	Temperature of air at the condenser inlet	21°C
2	Temperature of air at the evaporator inlet	−15°C to +8°C
3	Air flow rate	7.07×10^{-2} to $9.4 \times 10^{-2}\,m^3\,s^{-1}$
4	Refrigerant mass flow rate	8–40 $g\,s^{-1}$
5	Condenser pressure	600–1800 kPa
6	Evaporator pressure	170–450 kPa
7	Standard relative humidity at condenser inlet	45%

The accuracy of the mass flow measurements was ±3% of the nominal flow. Air temperatures data at inlet and outlet of the evaporator and condenser were stable experienced no fluctuations and therefore, a typical response time of RTD was sufficient and considered accurate for such an application.

In order to close the energy balance power supplied to the compressor and fans was measured with an accuracy of ±2.5%.

2.2.1. Water loop. Water was circulated through the inside of the condenser tube to cool down the superheated refrigerant entering the condenser. The water loop was composed of pump, control valves, flow meter, and heat exchangers. The heat exchangers were used to provide accurate control of the water temperature before entering the condenser.

2.2.2. Anti-freeze loop. The anti-freeze solution was employed to remove heat from the refrigerant mixtures under investigation. The flow of anti-freeze was circulated through various components; subcooler, reservoir with immersed heater, water heat exchanger. The anti-freeze loop was capable of producing 3 ton of refrigeration at −18°C.

2.2.3. Data collection. Data collection was carried out using a P-130 equipped with a data acquisition system having a capacity of 112 channels. This enabled us to record with a single scan, local properties such as pressure drops, pressures, temperatures, flow rates, heat flux and power. All tests were performed under steady state conditions. The channels were scanned every second and stored every 10 s. The measured values were averaged over a period of 10 s.

In order to develop the proposed correlations describing the two-phase flow boiling heat transfer characteristics, the thermodynamic properties as well as transport properties of pure and zeotropic refrigerant mixtures should be known. The REFPROP version 6.01 Reid *et al.* (1987) and McLinden (1998) was used to evaluate the characteristics during phase change of the mixtures under investigation. On the other hand, interaction parameters were selected with caution to avoid influencing the transport properties of refrigerant mixtures (Sami and Poirier, 1998).

2.2.4. Test procedure. The results of the various refrigerant mixtures with no liquid injection were used as baseline for this study. Upon completion of the baseline results of each refrigerant mixture, under the aforementioned conditions, the compressor and the system were drained and evacuated. Following this step, the system was then recharged with the preferred refrigerant mixture. This procedure was repeated before conducting the series of tests for every single alternative mixture. Same type oil was used during experimentation.

During the experimentation, the sink air temperature was kept constant at 21°C, and relative humidity was also kept at 45%. The source coolant temperature varied from −15 to 5°C, at the evaporator inlet. The dry and wet bulb temperatures of the source and sink were within the ASHRAE and ARI Standards.

2.2.5. Saturated refrigerant conditions. The anti-freeze temperature at the test section was adjusted until the desired saturation conditions are achieved. The saturation temperature is controlled by the inlet anti-freeze temperature and flow as well as the immersed heater in the anti-freeze tank.

During the boiling testing the refrigerant mixture saturation temperature was compared with two temperatures refrigerant mixture probes in the test section. Saturation condition was considered achieved if the temperatures agree within ±0.5%.

2.2.6. Uncertainty of the results. The convective boiling heat transfer coefficient is determined from the test section heat balance, temperature difference and other thermal resistances. Earlier experience with our instrumentation and current study showed that the uncertainty in the refrigerant side heat transfer coefficient was ±7.5% and overall heat transfer coefficient was ±10.8%. For further details the reader is advised to consult references Sami and Poirier (1998) and Sami and Grell (2000).

3. MODELLING OF HEAT TRANSFER CHARACTERISTICS

In the following sections, the results of the heat transfer characteristics such as pressure drops, heat transfer coefficients at different conditions will be presented aud discussed.

3.1. Heat transfer

The following equations have been employed to calculate the heat transfer coefficients from the data stored during each particular test at equilibrium conditions.

The heat transfer rate in the evaporator test section can be determined from the heat balance of the airflow;

$$Q_a = \dot{m}_a(H_{ain} - H_{aout}) \tag{1}$$

where H_{aout} and H_{ain} are the total enthalpies of airflow leaving and euterius the evaporator, respectively.

The vapour quality at the exit of the test section was calculated from an energy balance of

$$x_{out} = x_{in} + \frac{Q_a}{\dot{m}_r h_{fg}} \tag{2}$$

the system and the refrigerant properties were determined at saturation conditions in the test section.

The total heat transferred to the refrigerant is

$$Q_{rt} = \dot{m}_r h_{fg} \Delta x \tag{3}$$

where Δx is the quality change in the test section.

The overall heat transfer coefficient based on the outside surface area of the test section is

$$U = \frac{Q_{rt}}{A_o \mathrm{LMTD}} \tag{4}$$

where LMTD is the logarithmic mean temperature difference based on the inlet/outlet of air/refrigerant flows. The calculation of the LMTD is based on the nonlinear enthalpy variation with temperature. Furthermore, the LMTD was calculated for one straight section of the test section. No integration of LMTD values was needed, since only one section of the heat exchanger was considered in this study.

Assuming no fouling and R_{wal} is the thermal resistance in the copper wall of the tube, the refrigerant heat transfer coefficient h_r can be calculated as follows:

$$\frac{1}{h_r - A_i} = \frac{1}{UA_o} - \left(\frac{1}{h_a A_o} + R_{wal}\right) \tag{5}$$

where h_a is the air heat transfer coefficient and is calculated using the Wilson plot technique as described in Khartabil *et al.* (1988). R_{wal} is the wall resistance evaluated using the actual thickness and the outside diameter of the tube.

During the course of this study for data resolution purposes, the enhanced surface tube has been treated as a plain tube with an equivalent diameter. Using the equivalent diameter is consistent with the approach suggested by Sami and Poirier (1998) and Khartabil *et al.* (1988) for the enhanced surface tubing heat exchangers.

The reliability of the testing facility has been checked out by comparing the correlations reported by Collier (1981). Excellent agreement was obtained. Interested readers are advised to consult Sami and Desjardins (2000) for similar results on single phase, and two-phase flows of pure and/or refrigerant mixtures.

4. RESULTS AND DISCUSSION

4.1. *Boiling characteristics*

Samples of the experimental boiling data have been plotted in Figures 2–5, where the boiling heat transfer coefficient is plotted versus mass flow rate and the Reynolds number for various refrigerant mixtures. As expected, the data showed that the boiling heat transfer coefficient increases with the increase in the Reynolds number and the mass flow rate. The data clearly indicated that the boiling heat transfer coefficient was significantly influenced by the application of magnetic field. The heat transfer coefficient was enhanced using the magnetic field with some refrigerant mixtures as shown in Figures 2 and 3. However, some refrigerant mixtures did not respond to magnetic treatment equally. This is quite evident for certain flows and Reynolds number was less than 80 000. The impact of magnetic field on the heat transfer coefficient as well as the thermophysical properties was demonstrated via the various plots of Reynolds number and heat transfer coefficients.

It also appears from the data presented in Figures 2–5 that the magnetic field had a positive effect on the heat transfer coefficient of refrigerant mixtures with less gliding temperatures and moderate boiling temperatures such as R-404A and R-410A. In particular Figure 4 has shown that the magnetic field was insignificant at lower mass flow rates less than $0.02\,\mathrm{kg\,l\,s^{-1}}$. On the

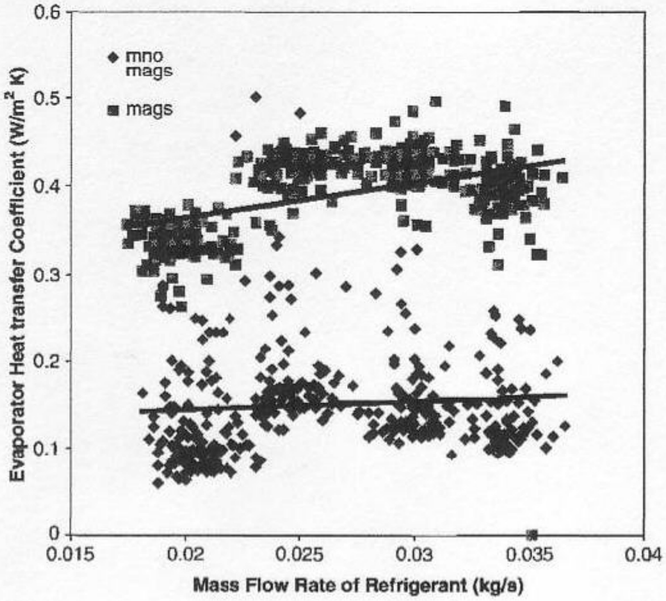

Figure 2. Display of boiling heat coefficient of R-404A versus mass flow rate.

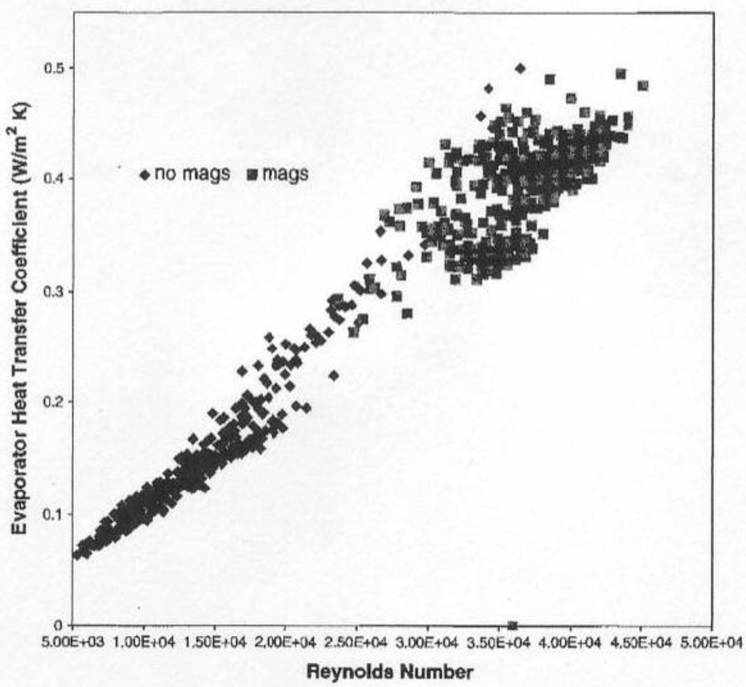

Figure 3. Heat transfer coefficient for R-404A at various Reynolds numbers.

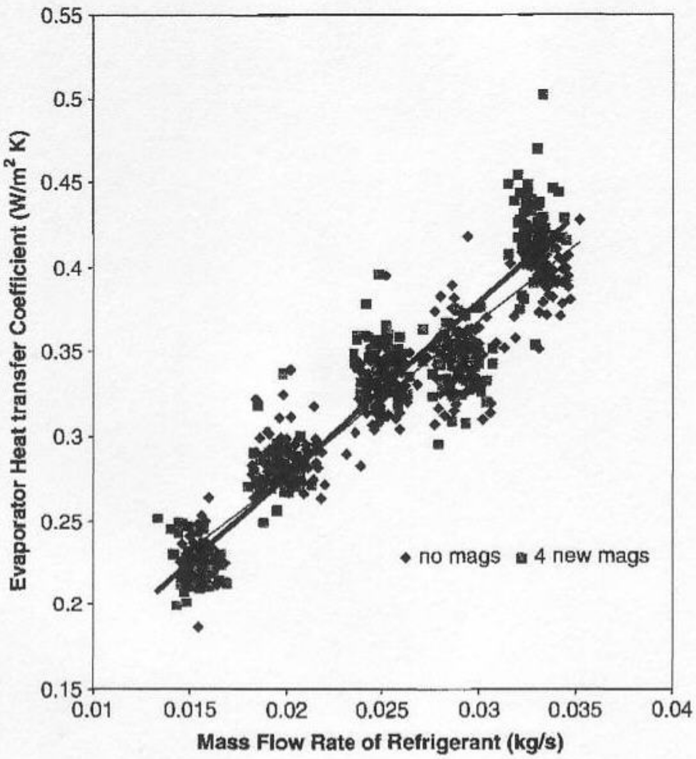

Figure 4. R-410A HTC versus mass flow rate.

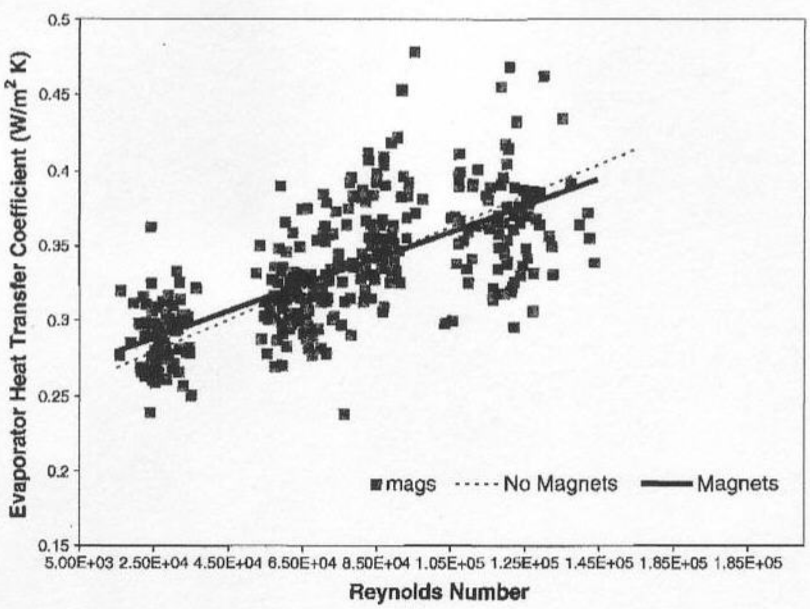

Figure 5. HTC of R-407C versus Reynolds number.

other hand, the results demonstrated that as flow rates increased the magnetic impact became evident.

The data displayed in the above-mentioned figures showed that the heat transfer coefficient was influenced by the Reynolds number, magnetic field power and the boiling point of the refrigerant mixture.

After detailed analysis of the convective boiling two-phase flow data, the following form proposed by Sami and Song (1996) is considered. Figure 7 showed the proposed correlation for R-410A:

$$\mathrm{Nu_e} = A(\mathrm{Re}^2 \cdot \mathrm{K_f})^{0.3} + B \tag{6}$$

where

$$\mathrm{Nu_e} = \frac{hD_b}{k},\ \mathrm{Re} = \frac{GD_b}{\mu}, \mathrm{K_f} = \frac{\Delta X h_{fg}}{L*g}$$

And finally, Equation (6) takes the following form:

$$\mathrm{Nu_e} = AY + B \tag{7}$$

Figure 7 had been constructed in an attempt to validate the proposed correlation, where values of measured heat transfer coefficients and nondimensional heat transfer coefficient predicted by the proposed correlation were compared with experimental ones for R-407C as a sample of the experimental data. The data plotted in these figures showed that the correlation is applicable to

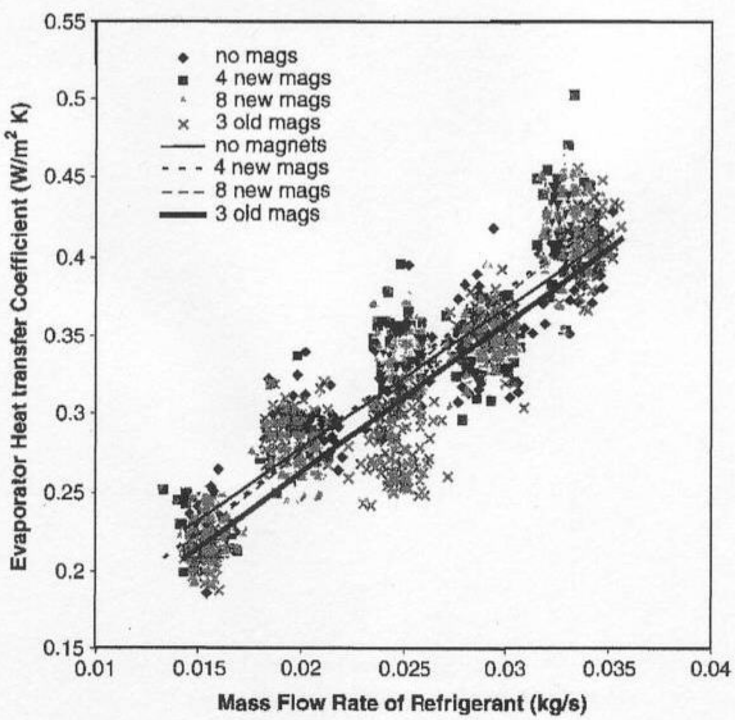

Figure 6. R-410A HTC versus mass flow rate.

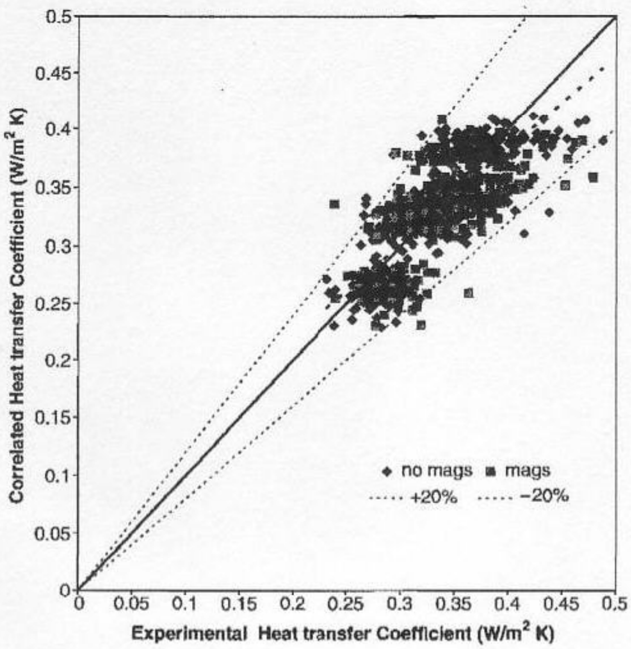

Figure 7. R-407C correlated versus experimental heat transfer coefficient.

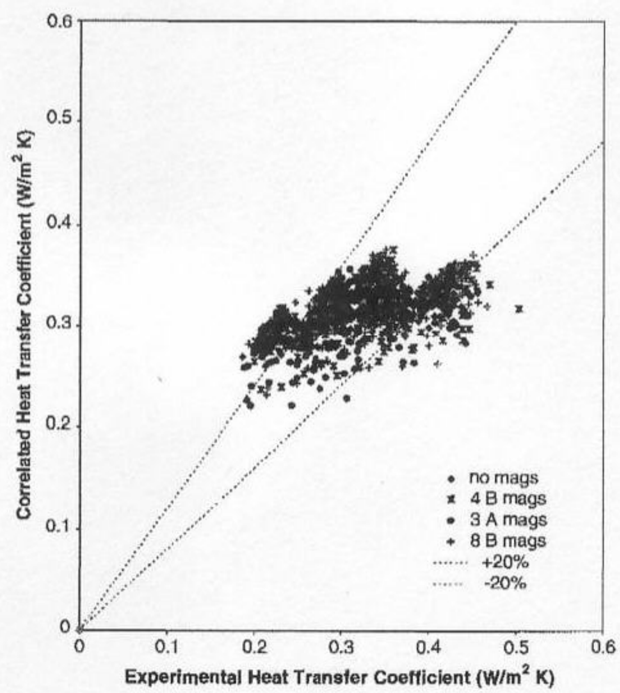

Figure 8. R-410A correlated versus experimental heat transfer coefficient.

the entire heat and mass flux, investigated in the present study for the proposed blends under question. The average deviation between the experimental and predicted values was less than $\pm 20\%$, for the majority of data. Similar deviations have been observed with the other refrigerant mixtures under investigation.

Another attempt has been made to validate the experimental data for R-410A and was presented in Figure 8. Other samples of R-507 are shown in Figure 9 where it appears that the average deviation between the experimental and predicted values was less than $\pm 20\%$, for the majority of data.

No attempts have been made to compare the proposed boiling correlations to existing ones, since to the authors' knowledge, none were reported in the literature under liquid injection test conditions.

Equation (7) clearly showed as presented in Figure 10 that there was a functional dependence of boiling heat transfer on the transport properties; and particularly thermal conductivity and viscosity of the refrigerant mixtures as well as other parameters. However, a sensitivity analysis demonstrated that the thermal conductivity and viscosity were the most crucial to the prediction of the boiling characteristics (Sami and Desjardins, 2000; Sami and Grell, 2000). Those thermophysical properties were significantly influenced by the MHD (Sami and Kita, 2004).

The proposed correlations in Equation (6) and their inherent dependence on the magnetic power have been plotted in Figures 6–10, where as the Nusselt numbers calculated after the experimental data obtained for the refrigerant mixtures in question was plotted against various numbers of magnets with different Gauss power. The comparison between the measured forced

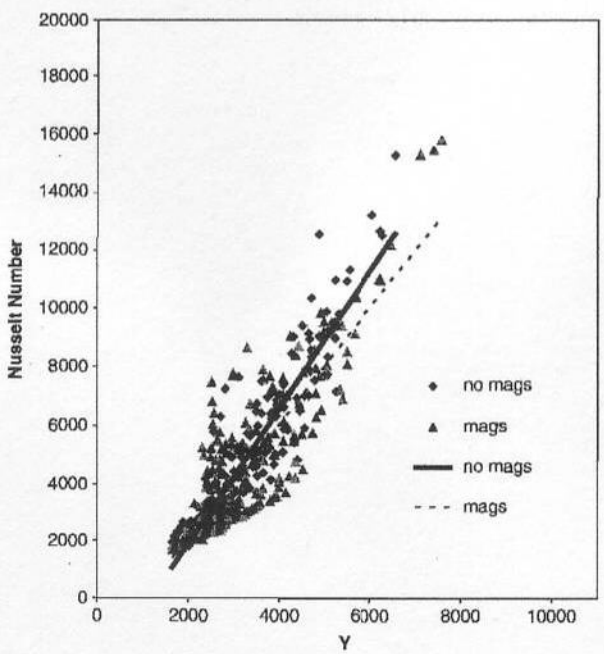

Figure 9. R-507 Boiling Nusselt number correlations.

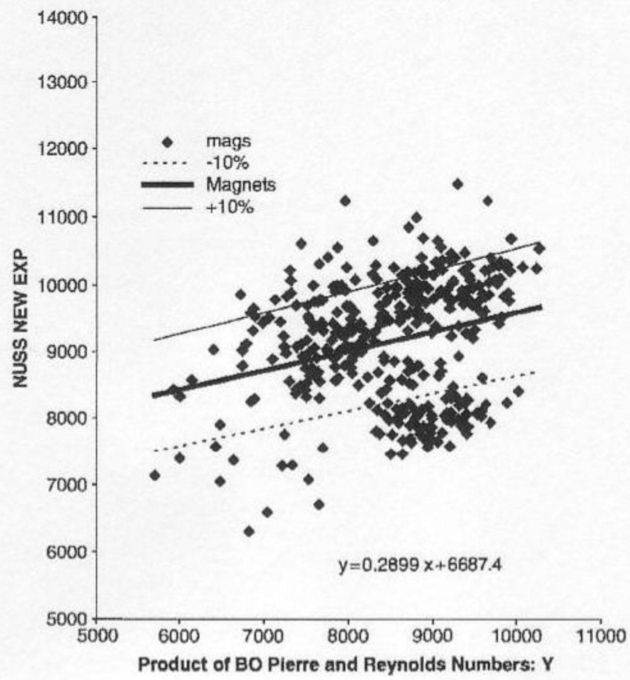

Figure 10. Validation of the data for R-401A.

convection boiling heat transfer coefficients showed that the data displayed was applicable to the entire heat and mass flux range for the proposed blends under question.

5. CONCLUSIONS

The boiling heat transfer coefficient characteristics of some alternatives refrigerant mixtures such as R-404A, R-407C, R-507, and R-410A have been studied in air/refrigerant under magnetic field conditions. The data revealed that magnetic treatment is beneficial to the heat transfer coefficient depending upon the Reynolds number and the boiling point as well as the type of refrigerant.

In addition, the proposed heat transfer coefficient correlations were found to be applicable to the entire heat and mass flux, in the present study under the gas/liquid injection conditions. The deviation between the experimental and predicted under liquid injection was less than $\pm 20\%$ for the majority of data.

NOMENCLATURE

A = heat transfer area (m^2)
D = diameter of tube (m)

D_e = equivalent diameter based on the bore diameter ($D_e = D_{oi} - D_{bo}$) (m)
D_{bo} = fin height (m)
D_{oi} = outside diameter (m)
G = mass flux ($kg\,m^{-2}\,s^{-1}$)
h = heat transfer coefficient ($kW\,m^{-2}\,K^{-1}$)
h_{fg} = latent heat of vaporization ($kJ\,kg^{-1}$)
H = total air enthalpy ($kJ\,kg^{-1}$)
K = thermal conductivity of liquid ($kW\,m^{-1}\,K^{-1}$)
L = length (m)
$\dot{m}$ = mass flow rate ($kg\,s^{-1}$)
P = pressure (kPa)
Q = heat input (kW)
R_{wal} = wall thermal resistance ($K\,kW^{-1}$)
T = temperature (°C or K)
U = overall heat transfer coefficient ($kW\,m^{-2}\,K^{-1}$)
x = quality based on mass (dimensionless)
Z = characteristic length (m)

Greek letters

μ = viscosity of liquid (Pa s)
ρ = density ($kg\,m^{-3}$)

Dimensionless numbers

K_f = Bo Pierre boiling number ($\Delta x h_{fg}/gL$)
Nu = Nusselt number (hD_e/K)
Nu_e = Nusselt number for evaporation (hD_b/K)
Re = Reynolds number (GD_e/μ)
Re_L = Reynolds number for boiling ($\rho_l.u_{vin}.L/\mu$)

Subscripts

a = air
ac = acceleration
av = average
b = bore
e = equivalent
en = entrance
ex = experimental
i = inside
in = inlet
L = liquid
m = measured
o = outside
out = outlet

r	= refrigerant
rt	= transferred to refrigerant
tp	= two-phase
v	= vapour
wal	= wall

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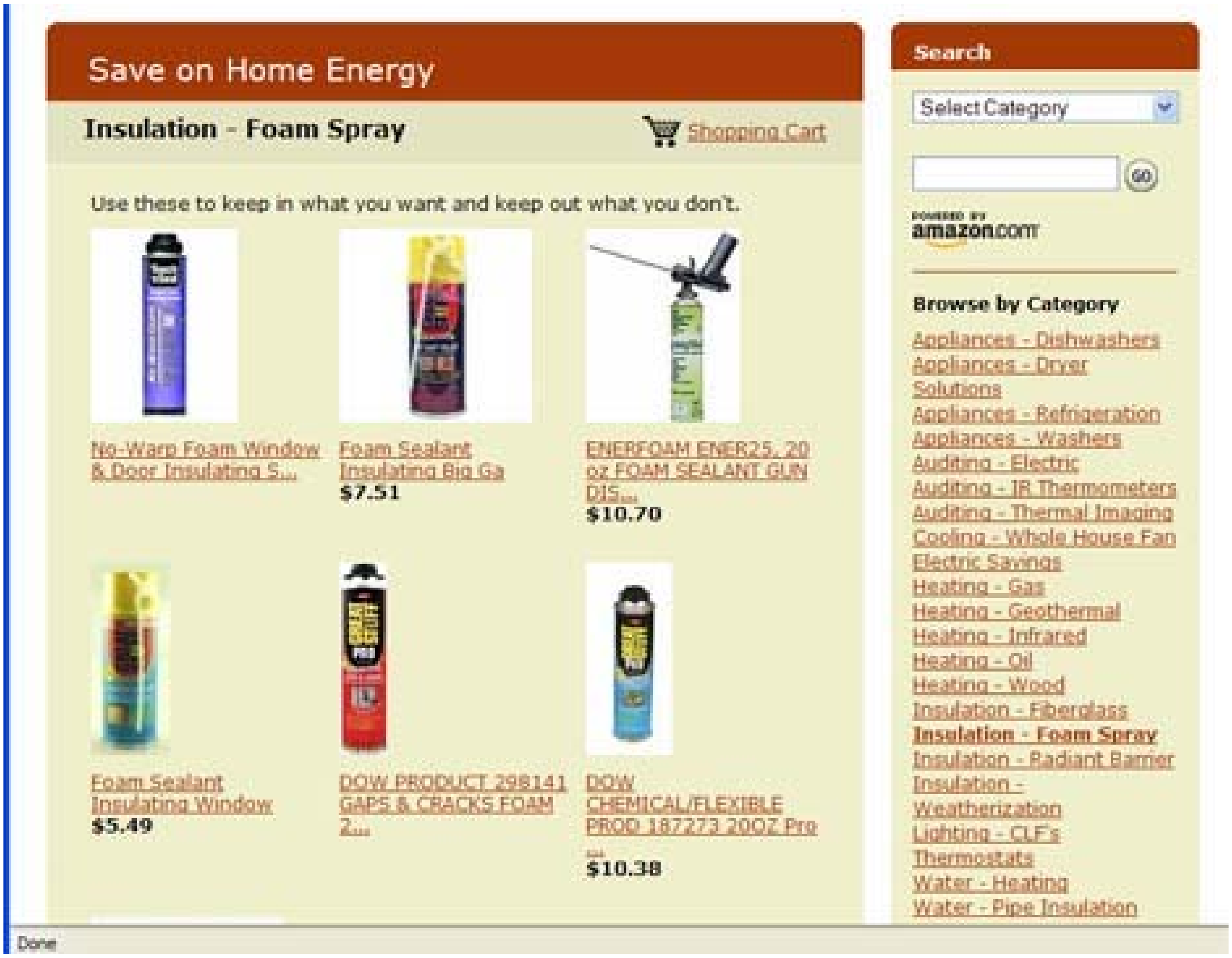

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