Key Considerations When Planning to Upgrade Existing Vacuum Furnaces

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Abstract

Today's competitive environment requires that you do more with less – to make equipment last longer and run more efficiently. With the industry becoming more demanding, there has never been a better time to ask the question: "Where, and in what, do I invest my money with aging equipment?"

This paper offers a close-up look at what is possible when weighing different options for upgrading an aging vacuum furnace, focusing on the many factors that go into choosing the right upgrades and repairs for both your equipment and process requirements.

Introduction

The roof is half off. There are no doors on the kitchen cupboards. And you're not quite sure what happened to your front lawn. To top it off, you've spent three times the amount expected – and you're not even close to done. Simply put, it's a home renovation nightmare.

Tackling a home renovation project is much like caring for your vacuum furnace. And starting the process without all the details can lead to a situation that quickly spirals out of control.

For any project or large undertaking – again, picture a home renovation – cost is a factor that must be considered. The first step is determining how much you can spend. Then it involves pricing out the kitchen, the bathroom, a new roof and so on. From there, you determine what you can actually do based on where you can get the most bang for your buck. In other words, what you can do to have the biggest impact while working within your constraints and understanding needs versus wants.

Caring for an aging piece of equipment is no different. The purchase of thermal processing equipment is a long-term investment. You should expect to get decades out of your equipment if maintained properly. That said, at some point you will have to ask the question: "Do I buy new equipment or put significant money into my aged equipment?"

The following questions will help guide you through this decision-making process:

- What are realistic expectations for the life of the furnace and its main components?
- What are your expectations for hot zone quality and performance?
- What do you need out of your controls system?
- Are there new developments or changes in technology that can improve the equipment's function, help you meet your customers' changing requirements or even aid you in growing your business?
- What is your plan for consistently maintaining your equipment?

Of course, these are just a few things to consider. It is also important to know the fair market prices for a vacuum furnace and its subsystems. Through the context of industry-gathered data and fair average timelines, this paper examines the factors you should weigh when determining where, and in what, to invest your money. It also covers some of the different options for upgrading older equipment, including hot zone replacement, controls upgrade or replacement, chamber vessel maintenance or replacement and, from a broader perspective, general equipment upkeep.

The Cost of a New Furnace

When you have an aging piece of equipment, it is hard to make an informed, well-thought-out decision without all the facts. After all, you have to determine if you budgeted enough money to properly take care of your equipment (and at the proper intervals), or if it is even worth maintaining your older equipment versus buying new. To provide some perspective on the many decisions ahead of you, Table 1 illustrates some of the fair market price ranges for a vacuum furnace and several costlier components.

Table 1. Fair market price ranges for a new vacuum furnace with a 36" x 36" x 48" work zone and its subsystems.

Equipment Type	Fair Market Range
New vacuum furnace (36" x 36" x 48" work zone)	$425–700K
Graphite hot zone replacement	$50–100K
Full controls	$50–100K
Partial controls	$10–40K
Vessel	$75–100K
Motor	$10–30K
Pumping system	$15–25K

The typical life span of a vacuum furnace is approximately 25-35 years. When purchasing equipment that you expect will have a long life, you will no doubt find yourself faced with major overhauls that can be costly and require proper budget planning. Good planning and proper equipment upkeep can help prevent you from reaching a point of no return – a point where you are investing more time, energy and money in the outdated equipment compared to the cost of a new furnace (Fig. 1).

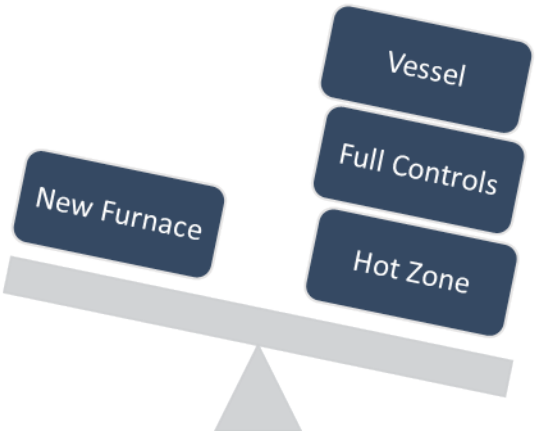

Figure 1 – Scale representing the potential investment for purchasing new versus repairing an older furnace.

So the question is, "How much is too much to invest in aging equipment?" While the answer to this question is different from one company to the next – and some may make the decision based on the amount of capital they have available – you have to consider the likely return on investment for new versus repairing used.

Step one then is to evaluate your actual needs. Do you need a furnace that always has the newest features and technology in order to keep up with industry standards? Everyone wants reliable equipment, but do you need 95% uptime with 24/7 production, or does your production rate allow for 70-80% uptime while running a single shift? Do you plan to take the furnace out of production on a regular basis for minor repair and preventative maintenance, or is floor-to-floor time the dominant factor influencing how you operate the furnace?

Based on your answers, you will know what replacements and upgrades are most important to you and how you will need to plan for them. You might even set a threshold where, once you reach it, you start to consider purchasing new versus maintaining.

One method for setting this threshold is to perform a life-cycle cost analysis (LCCA). It takes into consideration all the costs of acquiring, owning and disposing of a piece of equipment [1]. According to Dan Herring, "The key factor to consider when looking for a heat-treat furnace is understanding the True Equipment Cost (TEC), which equates to the initial investment plus the total cost to maintain (over time) divided by equipment life expectancy" [2].

The purpose of performing an LCCA (or TEC) is to estimate the overall costs of alternatives and to select the option that ensures the equipment provides "the lowest cost of ownership consistent with its quality and function" [3]. What one might find, though, is that "an industrial product procured at the lowest initial cost may not necessarily be the one which also costs the least sum of money in the long run" [1].

Determining Where to Invest

Most companies have a budget, and on a yearly basis, they do their best to plan for capital expenditure (capex) and maintenance spending. For example, if you have $30,000 for the entire year, you are going to look for ways to make that money cover the entire furnace for the year and give you the most value.

You might purchase hot zone replacement parts to keep it operating, new seals for the furnace along with proper oil changes, a motor balance, a rebuilt pump on the shelf and critical spares to keep the furnace up and running. While you are not going to need $30,000 *every* year for critical spares, you will need to set aside money for maintenance, as well as part replacement and repair.

Now, let's say you have a significant budget for repairing an older furnace. You still have to consider if spending your hard-earned money on an older piece of equipment is the right decision. Take an old classic car, for example. Are you rebuilding it because there is sentimental value? Or, is there a point at which the amount of time, energy and money being put into it no longer aligns with your goals?

It is reasonable to conclude that if you are replacing most of your major subsystems, a new furnace is very likely a better investment. If you are relocating an old furnace and there are rigging and moving costs, this would further bolster that position.

So what are the big hitters that you need to evaluate and plan for when developing your capex budget? Let's start with your hot zone. Although several factors determine the life of your hot zone, you will likely need to fully reline or completely replace the hot zone every 5 to 8 years. The controls system will also likely need a refresh, or maybe even replacement, at around 15 years. The vessel, though, might only need to be replaced once at 25 years (if at all). Other major items for overhaul or replacement include motors, variable reactance transformers (VRT) and pumps – all of which likely fall into a capex budget.

Figure 2 illustrates the average rate of equipment replacement within the industry for three of the most expensive items on a furnace. Again, it should be noted, there are multiple factors that weigh into how often you should rebuild or replace these systems, such as type of processes, frequency of use and specific industry requirements.

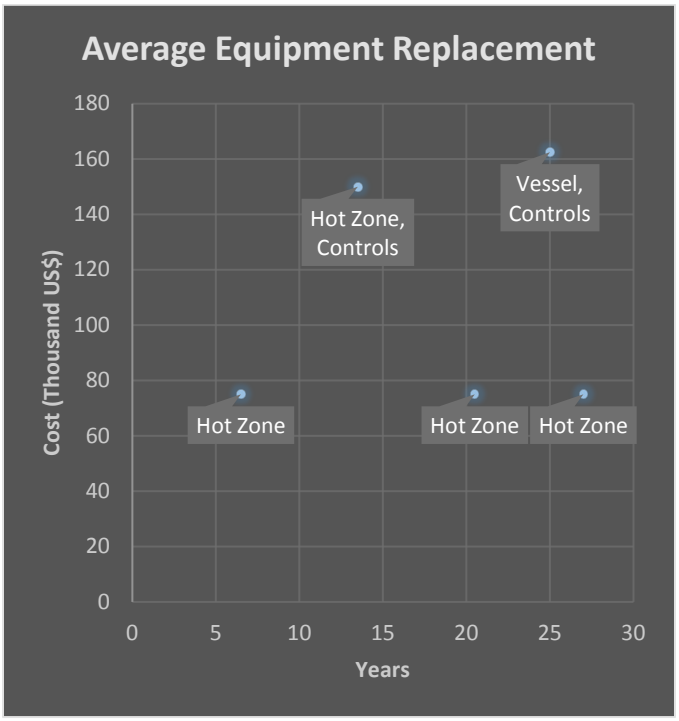

Figure 2 – The average replacement period/cost for major vacuum furnace components.

Everyone wants to maximize the life of their equipment, but in order to do so one must follow best practices. However, if water quality is poor, the chamber walls are clogged and thinning, the hot zone is destroyed or aged beyond repair, the pumps haven't been maintained, the controls are dated and unreliable and the motor has never been rebuilt or maintained, then major work – and major investment – will be needed sooner rather than later. Yet if you have executed a plan to maintain your equipment, you will likely never be in a position where all major components need replacement at the same time.

So how do you avoid getting to this point? By following best practices, caring for the equipment and spending smart.

Hot Zone Replacement

The heart of any furnace is the hot zone, and there are several factors that affect when and why your hot zone should be replaced. For example, are you considering replacing the hot zone because of part contamination? Or is it because the insulation has degraded to the point that heat loss is a real problem (maybe so much so that you are seeing heat distorting or damaging your hot zone's frame)?

Is it because you want the latest design so you can achieve commonality with your other furnaces? Or because you replace it at a specified interval, no matter what, since that's what you have always done? No matter the reason, you will need to replace the hot zone over the life of the furnace.

Although there are differing viewpoints regarding when the condition of the hot zone warrants replacement, there are several factors that can create wear-and-tear and have a heavy influence on the life of your hot zone.

Knowing When It's Time to Replace

While preventative maintenance can help extend the life of your hot zone, it may be time to consider replacing it when it no longer operates near peak performance. Several factors affect the life span of a hot zone, including:

1. Leaks – oxygen in the furnace will discolor or oxidize your parts and cause the hot zone to quickly degrade.
2. Cleanliness – contamination in the furnace can cause part discoloration and hot zone degradation.
3. Pressure – high-pressure gas quenching, by nature, creates a turbulent atmosphere in the furnace; therefore, the higher the pressure and larger the gas turbine cooling motor, the greater potential for deterioration.
4. Temperature – operating the furnace near its maximum operating temperature will cause accelerated wear on the hot zone.
5. Total operating time – the more cycles the furnace runs, the more frequently the hot zone will need maintenance [4].

Indications of the hot zone wearing away include excessive hardware breakage; heating elements showing signs of pitting, deterioration or breakage; distortion and overall wear on the hearth rails; and evidence of the insulation breaking, warping or eroding to the point the insulating values have been significantly compromised.

If your insulation is compromised to the point you see the interior plenum wall or frame, you are radiating significant heat to the frame and likely causing permanent damage. Signs of damage include cracking, warping and discoloration to the frame – all of which will require repair or replacement.

Certain factors during your process cycle also serve as warning signs of a degrading hot zone, including loss of temperature uniformity, extended cycle times due to heat loss or excessive contamination, longer pumpdown times, more energy consumption (i.e., electricity) and discoloration of your parts or hot zone.

Controls Upgrade and Replacement

Determining if a controls upgrade or replacement is the right option is also based on general expectations and needs. As you try to decide, key questions to consider include:

- Will an upgrade give you better data acquisition, traceability and accuracy?

- Will an upgrade give you better data to improve the quality of parts and meet industry standards that demand more information?
- Will it allow your equipment and overall operations to be smarter and more efficient?
- Will an obsolete controls system and/or components put you at risk?

Overall, there is basic data that you need to allow the furnace to operate properly and provide safe function of the equipment. Beyond that, there are several options that allow you to be much more precise with the amount and type of data you collect, the frequency at which you collect this data and the manner in which it is stored and retrieved.

So where do you start in determining if a controls upgrade is right for you versus maintaining the current controls system to avoid a major investment?

Range of Controls Options
Available controls upgrades and replacements often depend on the vintage of the vacuum furnace and your requirements. Because of the pace of technology, components start to become obsolete after just a handful of years. Even controls systems that are ten years old can be an issue and not supported by the OEM (original equipment manufacturer) [5].

A minimal upgrade may be available with a more recent PLC (programmable logic controller) if a processer fails and there is a direct replacement. You might also need to upgrade just the software or OIT (operator interface terminal) platform, or go from paper to a digital recorder. Other minor component replacements would include basic hardware inside the cabinet, including wire, fuses and contactors. All of the above are relatively low-cost solutions to keep your controls system up and running with the opportunity for some minor upgrades.

Alternatively, if you have a furnace that is 20-25 years old, you are likely better off looking at a more comprehensive partial controls upgrade, or replacement of the entire control cabinet. At this age, the vast majority of components are obsolete and the technology is definitely behind the times for most industries.

Overall, it's important to remember that there's always new technology on the horizon and older technology that will eventually become obsolete. So ask yourself, "What do I really need?" Then based on those needs, consider the available options to determine which solution will truly provide the desired short- and long-term results. If you are asking this question on a regular basis, you are less likely to be caught off guard with a major unplanned expense for a controls upgrade.

Chamber Maintenance and Repair

The vacuum furnace chamber is a large investment. If maintained properly, you shouldn't have to replace it. When deciding to repair or replace, there are several factors to take into account:

- Are there leaks you've been chasing that you simply cannot weld and fix with confidence?
- Are the chamber walls clogging and thinning from poor water chemistry to the point it can no longer be safely repaired?
- Are there significant hot spots from lack of water flow on the chamber itself?
- Is it a high-pressure chamber that has exceeded its duty cycle limits?

Chamber repair is possible if you've performed proper upkeep and maintenance, but one of the keys to maximizing the chamber life is a proper water system.

The Role of a Quality Water Supply
Water is necessary and critical for the protection and operation of your vacuum furnace, and it is required for several areas of the furnace. The jacketed space within the vacuum chamber walls and the heat exchanger require the largest amount of water flow. The water keeps the vessel's inner wall safely below the typical maximum temperature of 300 °F (148 °C) [6].

Proper flow, pressure and water treatment will prevent high temperatures from causing extensive damage to your furnace. Poor water quality that is untreated is one of the main culprits for major deterioration of a carbon steel chamber through buildup and corrosion of both the interior and exterior vessel walls. A solution for carbon steel corrosion is a stainless steel vessel. Although this design has a benefit of reduced erosion, build-up can – and will – still occur within the chamber walls if there is poor water quality.

Having a quality water supply is a simple way to increase the chamber's life span. As such, the water supply should meet these requirements (at a minimum):

"- Hardness: 7 grains/gallon (maximum)
- Calcium carbonate level: 3-100 ppm
- pH: 7.0-8.0
- Suspended solids: < 10 ppm
- Conductivity: 300 micro mho/cm" [7].

We recommend that you use treated water on a closed-loop system to help extend the life of your furnace chamber.

General Maintenance Strategy

Part of planning ahead is understanding that vacuum furnaces can experience significant wear-and-tear in a few ways throughout their life. The most extreme is the occurrence of a catastrophic event. This could be the failure of a motor; a thermocouple that is not fully inserted, allowing the furnace to run above its standard operating temperature; melting a work

load inside the furnace; or an operator error during loading/unloading of the furnace.

In addition, a recent Deloitte study found that "poor maintenance strategies can reduce a plant's overall productive capacity between 5 and 20 percent" [8]. This makes the regular performance of preventative and predictive maintenance even more essential. Especially since both play a long-term role in the life span of your equipment and are often the difference between a proactive and a reactive response.

A preventative maintenance (PM) plan generally includes regular inspection, equipment servicing, repair and replacement. Overall, PM programs allow companies to schedule downtime in advance, and they help provide predictable annual maintenance costs.

Predictive maintenance, on the other hand, applies analytics to detect a risk of failure, thus helping prevent the failure before it occurs. For example, Ipsen's PdMetrics® predictive maintenance software platform connects to sensors on the furnace to gather data, analyze it and provide real-time diagnostics for any upcoming maintenance needs [9]. The integration of predictive maintenance helps furnace users plan ahead – whether that means scheduling personnel to perform maintenance or ensuring the required furnace parts are in stock.

Maintenance Best Practices

If you are employing a maintenance strategy, you might be spending a little more on service or the critical parts you're keeping on the shelf. However, this also keeps you better prepared in case of component failure, which will end up costing more than the maintenance needed to prevent the failure.

As an OEM, we have found that PM checklists allow you to better track all the items you should be inspecting on a regular basis. Some of the essential maintenance activities you should perform include:

- Changing the oil in the vacuum pumps at regular intervals (dependent on the cycle, process and overall furnace utilization)
- Replacing dynamic seals, such as door seals and poppet valve seals (every year)
- Calibrating instrumentation on a regular basis
- Checking the motor for proper balance and operation on a regular basis
- Evaluating the hot zone and checking for debris, discoloration and proper fit up of hot zone components on a daily basis

Replacement Parts

When considering buying a new furnace or replacing major components, an important question to ask is, "What spare parts should I be keeping on the shelf to reduce unplanned downtime?" The answer should consider the life span (in hours or heat cycles), criticality, lead-time and shelf life of components, as well as the cost of downtime.

Often, you want high-turnover items in stock for immediate replacement. Such items are components that tend to fail after *x* amount of hours or are prone to mechanical failure due to operator error. Other components that are good practice to have on hand include elements for the hot zone, oils for the pump, wires, washers, hot zone hardware and seals for the whole furnace. If you have several furnaces of the same model and design, you may even consider keeping a spare hot zone or motor on the shelf.

When weighing return on investment versus uptime and planned downtime, being proactive about the way you do maintenance is often the intelligent, cost-effective choice.

Conclusions

A new heat-treating system and its main components are a major investment, and you should expect to get decades out of them. To make the most of this investment, though, you not only need to choose the right upgrades and repairs for your equipment, but also have a plan for maintaining the equipment.

Remember the house that was in disarray? That could just as easily be your furnace.

Imagine for a moment that your furnace's hot zone is completely destroyed. The chamber has hot spots because it is clogged, and you can feel the heat radiating off it from five feet away. The control cabinet is 30 years old, you have no recipe storage and you can no longer find the parts you need on eBay. Add in neglected pumps, a furnace that leaks like a sieve and a melting transformer. Needless to say, things are not looking good and it is time to invest in something new.

Or, that scenario you are picturing could be completely different. If you have given priority to running the equipment the right way over just running the furnace, you might find a hot zone that is in decent shape and only needs a partial rebuild. The chamber is running on a good water system and has minimal hot spots. While the control cabinet is 20 years old, the guts are still good, meaning you can get by with a partial controls upgrade. You have also planned ahead and have critical spares on the shelf.

Do not allow that home renovation nightmare. You can purchase the most robust piece of equipment in the world, but if you don't do the upkeep and follow best practices, it doesn't matter how well it's built – you're not going to get the full potential out of it.

The key to making sure your furnace stays healthy involves being smart about your investment, planning ahead for your maintenance and doing the basics on a daily basis. Of course, you don't have to do this on your own. Take advantage of furnace trainings like Ipsen U, which are taught by technical

experts – and don't be afraid to ask for help and insight. Their expertise can be a big support when navigating through this decision-making process.

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