DRYVac™

A 21ST CENTURY APPROACH TO VAPOR RECOVERY

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By

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EXECUTIVE SUMMARY

Three and a half decades ago the Congress of the United States mandated the installation of hydrocarbon vapor emission control systems in loading terminals to reduce air pollution. Many technologies were attempted, but only one survived. It is known today as the "Vapor Recovery System". It is a short-cycle, adsorption-absorption regenerable process. It also generates a return on investment; returning several times its initial value in its lifetime. While it works, system designers have failed to keep pace with advances in computer technology, electronics, instrumentation, and compressor design. The reputation of vapor recovery suffered as a result. Some terminals switched to combustion systems, losing the economic advantage of vapor recovery in favor of simplicity. Now, however, an up to date vapor recovery system is available that offsets these objections; a system that achieves significantly higher rates of return. It is simpler, requiring far less maintenance. It is smarter, managing itself. And, it is much more efficient, using as much as 60% less operating energy. It is more reliable than any other vapor control technology, keeping terminals up and running longer. And every system comes with its own dedicated Pentium computer displaying all data on a color monitor placed where operators can see it, and making it extremely user-friendly. It is called DRYVac™, a system that is rapidly becoming the technology of choice for large and small terminal owners throughout the world.

The following technical paper explains why.

INTRODUCTION

In 1970, the US EPA mandated the application of hydrocarbon vapor emission control in most loading terminals in the USA. Vapor recovery became the method of choice in medium and larger terminals because the technology promised a return on the capital investment. This trend grew to encompass Europe, and is now spreading globally.

In the 1970s, many approaches to vapor control were tried. By 1980, the technology of choice was the short cycle, pressure swing, activated carbon adsorption-absorption system. This system is still offered today. While it has been essentially unchanged up to this point, it is now undergoing significant advancements.

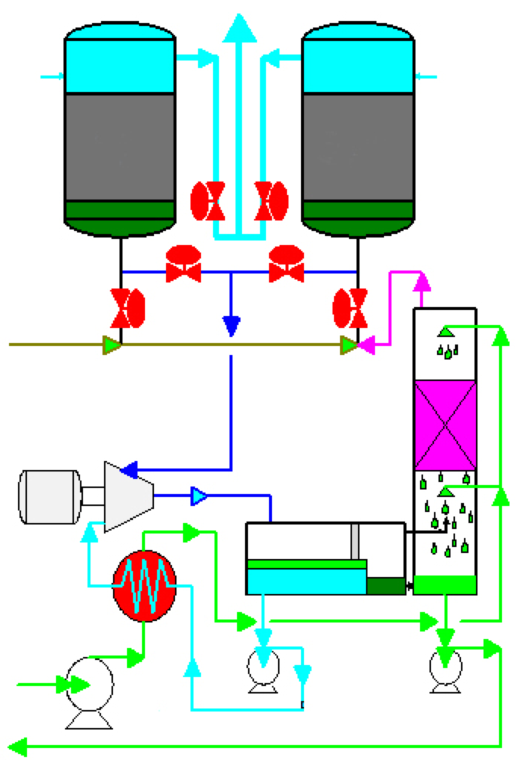
The advancements have produced a new system employing a more modern approach. It is called DRYVac™. It is smaller and better because of the application of 21st century electronics, an advanced compression technology, the latest industrial and Pentium computer platforms, carefully developed dedicated software, and 35 years of application experience.

This paper investigates the new DRYVac™ system to identify its differences and to explain what makes it today's system of choice by many of the world's most successful oil companies.

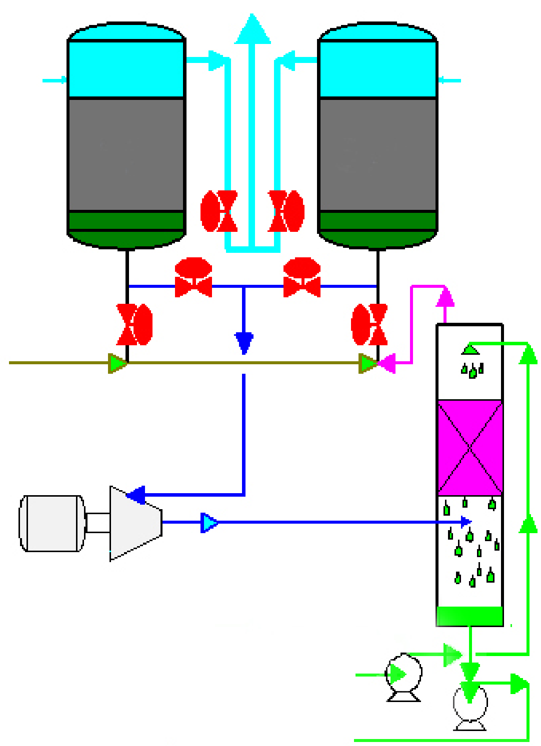
DESIGNS: OLD VERSUS NEW

The basic design of the vapor recovery system was established in the 1970s through trial and error in the field. Since the process was brand new, and the EPA demanded results, there was neither time nor money for any meaningful laboratory experiments. All early work was based on little-known suppositions and on the science of adsorption, desorption, and absorption. By the end of the decade, over 500 carbon adsorption vapor recovery systems were in place, thus allowing designers to obtain the specifics necessary to properly design new systems. However, this technology remained essentially unchanged until the DRYVac™ System was developed.

A comparison of the typical vapor recovery system design in 1980 and the new DRYVac™ System today reveals the outward changes that have been made to improve the system using the dry compressor and other 21st century technologies.



WET SYSTEM FLOW DIAGRAM



DRY SYSTEM FLOW DIAGRAM

VAPOR COMPRESSOR TECHNOLOGY

For many decades, the use of liquid ring compression systems has dominated flammable/ vapor compression. These compressors are subject to severe corrosion and

erosion as shown in this graphic, and therefore lose capacity throughout their comparatively short life. Only a brand new liquid ring compressor is capable of achieving a very deep vacuum. As wear and tear take their toll on internal tolerances, the ability of the liquid ring pump to achieve very deep vacuum levels drops. Since this is quite detrimental to the efficiency of the entire vapor recovery process, other solutions were sought.

By the mid-1990s, primarily due to the above mentioned problems with liquid ring compressors, a few vapor recovery designers began to investigate the use of dry-screw type compressors for their applications.

Some were tried as "field experiments" to test the viability of the dry-screw design. Most of these field dry-screw experiments met with disappointing performance and/or premature compressor failure. One did not.

The first successful application of a viable dry compression system came about as the result of one of these failed field tests in the latter half of the 1990s. At that time, no dry compressor manufacturer had designed a dry-screw compressor specifically for vapor control applications. Therefore, manufacturers had no knowledge of the differences between compressing air and compressing flammable vapors. With no other choice, off-the-shelf compressors were used in these early applications.

In this application, ten (10) Kohl dry-screw compressors were installed in a very large marine terminal vapor control application. At start-up, these compressors were found to be quite deficient in their actual performance field tests compared to their published capacity data. These tests proved that the Kohl compressors underperformed significantly. This underperformance had the effect of rendering the entire system ineffective.

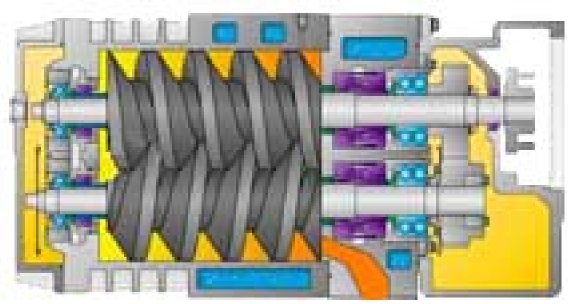
These underperforming compressors were unable to completely regenerate the activated carbon, allowing hydrocarbons to build up on the carbon over time until the entire system failed from excessive hydrocarbon emissions. It goes without saying that the owner was totally dissatisfied with this condition, and demanded a remedy. Several options were considered, each very difficult financially.

The first option considered was the addition of another three Kohl compressors to make up the difference between the published performance data and the actual performance. The control software would have required modification and the footprint of the system would have required enlarging to accommodate the three additional compressors. Finally, three more compressors would have required additional electrical service in a terminal already short of excess electrical capacity. A new substation would have cost over a half-million dollars. This proved to be the deciding factor against this option.

The next option was to find a substitute compressor that would actually perform in accordance with its published data. A global search for a suitable supplier was initiated. Tests were performed, and in the end only one manufacturer, Busch (Germany), was found to meet the all of the performance criteria.

Busch considered dry bearings but opted for oil wetted bearings to improve lubrication and extend bearing life. The grease seals used on other Busch compressors were exchanged for mechanical seals to provide a more positive seal and to extend seal life. Explosion tests were conducted and the pump casting was designed to absorb such forces. Busch agreed to develop a dedicated compressor for vapor control applications, and was selected as the preferred supplier.

In the final analysis, Busch provided a line of dry compressors designed specifically for the rigors of vapor control service.



BUSCH DRY-SCREW VACUUM COMPRESSOR

Repeated performance testing for the ten-compressor application assured that ten of these Busch compressors could directly replace the poorly-performing Kohl compressors. Ten Busch compressors were installed and the problem was solved. The overall system is performing as designed to this day, some eight years later.

DRY VAPOR SYSTEM DESIGN CHANGES

The advent of successfully applied dry-screw compressors allowed vapor recovery system designers to eliminate the components associated with decades of wet applications. Eliminated by default were:

- The liquid ring compressor,
- The seal fluid (glycol-water mix),
- All seal fluid piping,
- The seal fluid circulating pump and controls,
- The seal fluid flow controls,
- The seal fluid heat exchanger,
- The seal fluid separator and associated controls,
- The vapor-liquid demister,
- The activated carbon,
- All seal fluid quality testing and related supplies, and
- Premature vacuum pump failures due to erosion and corrosion.

Eliminating the above vastly simplified the concept of a generic vapor recovery system. With these gone, the design of vapor recovery systems could be approached from a new perspective; a 21st century approach.

By the start of the 21st century, computerized control had become the norm for efficient process control in all modern refinery complexes, petrochemical plants, pharmaceutical facilities, and the manufacturing industry in general. And yet, of the over 750 vapor recovery systems in the world, not one single system was being actually controlled by the process logic used throughout industry. This needed to change.

The design of any valid process logic begins with a thorough understanding of the process. The variables that affect the performance of the process must be identified. The acceptable and unacceptable ranges of these variables must be identified. Intelligent instruments must be used to measure these variables and transmit them to a sufficiently powerful process logic controller (PLC).

PLC software must be written to accept input from the data gathering instruments, and to process that data into meaningful adjustments to the process to keep the entire process fully optimized. When a variable drifts out of its acceptable range, the software must recognize this condition, and make the necessary process adjustments to correct it. The PLC is a stand-alone intelligent process controller.

At the same time, a method to communicate all of this conditional data to operating personnel is considered a must to keep the operating staff informed of all conditions at all times. The 21st century communication method of choice is a large format human-machine interface (HMI). This is typically a PC based 17" (or larger) computer monitor display. The PC is programmed to accept dedicated and unique process outputs from the PLC in real time, and to display those outputs on the monitor in various selectable screens. The Main Screen is a flow diagram of the entire process system and displays the key process conditions in real values in real time. By selecting a key process component, the screens change to display the historical process parameters of that component, starting typically with the most recent over a few hours of time in trended graphical format. It is possible to expand or narrow the time frame to get a view over longer time or to zero in on data or condition changes taking place in a very short time.

The process itself is controlled entirely by the PLC. The process system will function without the PC based HMI so long as the PLC is operational. The HMI is a "window" into the process.

The monitor is almost always in color, and may also be touch screen. Its software development is often more complex that the software for the PLC. It is programmed to display all of the measured process variables and to display them in an intelligent, understandable format to any and all operations personnel and other observers. It may also be used to communicate this information to all interested off-site personnel via the internet, an intranet, satellite, or a dedicated telephone line and modem.

To recap, the dry vapor recovery system design eliminates a large portion of the decades-old regeneration system. These obsolete components are replaced with 21st century automation instruments, flow and temperature controls, a powerful process logic computer with dedicated software, and a monitoring display with its dedicated software. The dry system controls itself in every aspect of its operation, as is explained in more detail in the next section.

PROCESS CONTROL LOGIC

If "intelligent operation" is defined as the capability of a system to manage itself in virtually every regard, the DRYVac dry system meets that definition through its process software and PLC.

The goal of the software development exercise for the DRYVac™ System was to 1) eliminate emissions and then 2) to conserve energy throughout the process. No other vapor recovery software has ever been written with these priorities in place.

The properly sized vapor recovery system will virtually eliminate emissions. Hundreds of systems accomplish this throughout the world every day. However, none of those systems are designed to eliminate hydrocarbon emissions AND optimize process control to conserve energy.

For decades, the conventional wisdom was that vapor recovery systems had to be designed to operate like other short-cycle plants; back and forth on timed cycles. For vapor recovery systems, 15 minute cycles were established as the criteria for design and operation based on 1975 studies of typical truck loading times. In the 30 years since that time, the basic design theory has not changed … until now.

The DRYVac™ system is the first system ever designed to accurately measure the mass of hydrocarbons entering the system as a standard. By measuring the mass of hydrocarbons, the PLC knows at any given time the amount of hydrocarbons adsorbed, and the amount that can be adsorbed. The rate of hydrocarbon entry is constantly compared with the time to reach the predetermined maximum, and then compared with the condition of the other carbon vessel or vessels. If the other carbon vessel(s) have previously been regenerated, and are in stand-by waiting for the next cycle change, the on-line bed remains on line. If the other carbon vessel is being regenerated, the PLC calculates the remaining regen time and compares it with the predicted duration for the on-line carbon vessel to reach its adsorption limit. The system adjusts itself accordingly, and the process is optimized based on the preferential criteria (emission elimination).

In order to meet the second preferential criteria (energy reduction) the system monitors the exact mass of hydrocarbons into the system as described above, and allows the on-line carbon vessel to remain on-line as long as possible up to a preset limited number of hours. If the products loaded are lean, such as distillates like diesel or jet fuel, the on-line bed remains on line even longer. However, the PLC software takes note of this leaner loading profile, and increases the maximum regeneration vacuum level to pull the heavier hydrocarbons off of the carbon, extending its life significantly compared to wet systems which do not have the ability to create the high vacuum levels needed to accomplish this.

The software is designed to completely regenerate a carbon vessel in from approximately 8 to 16 minutes, depending on the actual mass and concentration of hydrocarbons adsorbed during the last on-stream cycle.

At the beginning of each regeneration cycle, the carbon vessel to be regenerated contains a large mass of air and hydrocarbons in the vessel void space and in the pore space between the carbon particles. When the flow control valves close, the PLC confirms their closed position, and the carbon vessel is completely isolated from the inlet vapor stream. At this point the dry compressors are started. The drivers (electric motors) on the dry compressors are speed controlled using the PLC software and variable frequency drives (VFDs).

Each compressor is started individually to conserve starting energy. The starting speed is very low, also to conserve operating energy. The PLC controls the start-up process initially. Once the compressors are running, the PLC begins to slowly increase their rotating speed. During this time, the large mass of air and hydrocarbons in the carbon vessel is being removed. At a fraction of their maximum, the speed control of the compressors is transferred from the PLC to a pressure transmitter. This transmitter is located in the recycle line between the absorber column and the vapor inlet line, upstream of a fixed orifice plate designed to create backpressure on the absorption column during this large mass flow portion of the regeneration cycle. Increasing the backpressure on the absorption column reduces the actual velocity of vapor flow in the column, increasing its absorption efficiency and reducing the mass of recycled vapors flowing into the on-line carbon vessel.

As the mass flowing from the regenerating carbon vessel increases, the pressure in the absorber also rises. When this pressure reaches the optimum level, the pressure transmitter in the recycle line slows the compressor rotating speed to maintain the optimum speed and the optimum pressure in the absorber. As the mass leaving the regenerating carbon vessel begins to fall, the pressure also begins to fall. The pressure transmitter senses this falling pressure and increases the compressor speed until it reaches maximum. The pressure transmitter controls the compressor speed throughout the remainder of the regeneration cycle, and during the purge air portion.

Since the vacuum level achieved during regeneration is the most direct indicator of regeneration status of the carbon, the maximum vacuum level is used to signal the completion of actual carbon regeneration. In the event the actual regeneration time is short, and if the currently loaded mass is low, the software allows the newly regenerated bed to be shut in under high vacuum at the conclusion of the regeneration cycle, after the bed is polished with purge air, and all flow control valves remain closed. This tests the flow control valves to confirm that they are sealing bubble-tight. This shut-in condition lasts for ten minutes, at the end of which time the HMI reports the results to the operating staff. In the event a leak is detected, the HMI indicates this to the operating staff so the leaking valve can be adjusted, repaired, or replaced as necessary.

In the event that loading is heavy, or inlet hydrocarbon concentrations are high, such as when motor gasoline is being steadily loaded in all loading bays, the software may determine that the carbon vessels need to cycle from one to the other as soon as the basic regeneration cycle is completed. In this case, the vacuum test is automatically bypassed. This is dictated by the root design priority to first prevent emissions.

At the end of the deep vacuum portion of each regeneration cycle, a small amount of air is allowed to enter the top of the carbon vessel. This air is pulled through the carbon by the compressor(s), stripping remnant hydrocarbons from the carbon particles in the process. This air stream is referred to as "purge air", since it purges remnant hydrocarbons from the carbon bed. The amount of purge air is varied by the software depending on the inlet hydrocarbon mass and concentration during the last on-line cycle. Varying the purge air limits the compressor run time to only that actually needed, conserving even more operating energy.

The PLC also measures the hydrocarbon concentration in the effluent air stream. It compares this outlet hydrocarbon concentration with the hydrocarbon mass flowing into the system in real time, calculates the actual hydrocarbon mass flow out of the system, and reports this value in milligrams per liter of product loaded on the HMI. This precise concentration is displayed on the HMI in any configuration the client desires. It is typically displayed on the Main Screen of the HMI in terms of 1) an instantaneous value as a measure of overall system performance in that instant of time, and 2) as a six-hour rolling average, since most operating permits are based on a hydrocarbon concentration not exceeding some value (i.e. 10, 35, or 80 mg/L) over a six hour average. This emissions data, like all data gathered by the PLC, is recorded stored in the PC of the HMI. A large hard drive is supplied in the PC portion of the HMI to provide many months of historical data. This data is useful in monitoring long-term trends in the overall operation of the loading terminal and its vapor recovery system.

To recap, software identified as "ESP™" self-manages the entire vapor recovery system to achieve the lowest level of hydrocarbon emissions while operating at the most optimized energy level.

Since the selection of activated carbon is critical to the overall long-term system performance, it seems prudent to understand the history of activated carbons used in vapor control, and the evolution of its selection and application to date, as follows.

ACTIVATED CARBON

In the earliest days of carbon adsorption vapor recovery system design, very little empirical data was available to support the claims of the various carbon suppliers. Again, field testing was the development platform of the time, so many types and grades of activated carbon were tried. Wood based carbon showed greater adsorption capacities but had frequent overheating episodes, while coal based carbon was less adsorptive and tended to be slightly less susceptible to overheating. Both of these had a tendency to "dust" under normal vapor recovery conditions. The fine carbon dust was harder to flow through. It created an excessive pressure drop within the carbon vessel, causing truck mounted relief valves to relieve during loading. Dusting shortened the effective life of either of these two types of carbon in vapor recovery service.

In the search for a solution to these problems, formed carbon was investigated. In the long run it was thought to be too costly, and further use of formed carbon was essentially abandoned.

Over the next two decades carbon suppliers spent their development dollars finding ways to maintain the adsorptive characteristics of the more active carbon varieties while limiting their tendencies to overheat. This help to reduce the number of heat-ups as time wore on.

By the mid-1990s, the entire industry was growing weary of carbon heat-ups in vapor recovery applications. Industry seemed willing to go to great lengths to avoid them. As a result, many economically viable vapor recovery applications were switched to other less economically favorable combustion technologies to avoid the issue of carbon bed heat-ups and the related terminal downtime. The reputation of vapor recovery began a decline.

At the same time, an industry-wide consolidation of loading terminals was progressing in full force. Some terminals merged, while others were simply eliminated. The result was fewer terminals with larger and larger loading rates. The ability to load more and more product put a strain on both existing recovery and combustion-based vapor control systems. Many of these systems were simply too small to perform properly. Some, however, were large enough that simple changes, like exchanging high pressure-drop carbon for low pressure-drop carbon, rendered them effective again.

A fresh look at formed carbon produced an ideal carbon that is low in pressure drop, low in activity, and yet high in density. This new "FloMax™" carbon is the retrofit carbon of choice for most vapor recovery system owners today.

And best of all, not one single bed of FloMax™ carbon has ever had a temperature excursion event.

To recap, the activated carbon used to adsorb hydrocarbons in vapor recovery systems has evolved from the status of a virtual unknown, to a scientifically formed constant, making all vapor recovery systems fitted with it operate safely and consistently.

CONCLUSIONS

Much significant advancement has been made in the evolution from the original wet vapor recovery system to the 21st century dry vapor recovery system. The new system is smaller, simpler, and much smarter than older systems. The DRYVac™ System is completely self-managed based on instrument input to sophisticated software. The new system uses dry-screw compressors which save at least 30% of the normal operating cost. The dedicated software and the use of VFDs for compressor speed control reduce costs by even more, up to 60% in many cases. Combine these developments with the low pressure-drop FloMax™ carbon, the 21st century PLC, PC-based HMI, and our very intelligent software programs, and it is not surprising that the DRYVac™ system is now being accepted as the standard of the industry.

ACKNOWLEDGEMENTS

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Mr. Tim Hammond is president of TESCO, Inc., a Midwest USA service and sales firm. Tim is a native of Tulsa, Oklahoma. After he received his college degree, he worked for Maintenance Services, Inc. (later acquired by Matrix Services), in the liquid terminal industry for many years before founding TESCO in 1993. TESCO is headquartered in Indianapolis, Indiana.