INTRODUCTION

The oil industry is often accused of being mired in its own traditions and paradigms. The phase, "We've always done it this way!" permeates a great deal of what we do, often to our detriment. Facility design is no different, whether in a production processing plant, gas treating facility, waterflood, or SWD plant.

In 2015 we still frequently build facilities without drawings, without considering proper sizing practices, and without any applied engineering, often based on what we did the last time, right or wrong. And while traditionally each new facility will stay essentially unchanged for the next thirty years or so, most pre-planning is still often neglected. Perhaps it's finally time to change this pattern!

In 2015 we have new opportunities to do a better job in every sector of the oil industry. As the price of oil plummeted in late 2014, a new desire to be better at what we do needs to take place to help offset shrinking revenue streams. We need to do better!!

The 21st century is the era of master template designs, and of the "plug and play" concept. These allow new facilities to adapt from the high flow rates of IP to the intermediate flows of a maturing field, and again in the last phase of the natural decline. This is new in the 21st century. It was prompted by the need to address long-term operations in the huge shale oil plays where very large scale drilling programs and production operations are forecast for fifty years or more. It makes one ask, "Why haven't we thought this far ahead before?" Best of all, plug and play make sense!

In the past we processed production as we received it. Today, most process engineers agree that a goal of "steady state processing" is worth the effort necessary to achieve it. In 2015 we can strive for and achieve "steady state" process considerations, and in so doing we can minimize the capital investment in new facilities. In 2015 we can design and select the right equipment with the right internals to do the right job at the best cost and get it in the shortest time.

In 2015 we can cost effectively automate facilities to maximize efficiency. We can author operating software to create a smarter workplace environment while making facilities and employees more predictive and far more profitable.

In 2015, and in the years to come, the paradigms of the past are finally giving way to a new generation of truly modernized facilities, at last! This paper makes an effort to promote and support such a design effort.

AVOIDING THE PARADIGMS

Paradigms are the legacy of the past 150 years. Edwin Drake drilled the world's first cased oil well in 1859 using a cable tool drilling rig. The paradigm of that cable tool technology stayed with us for over 50 years, finally giving way to the concept of rotary drilling and the famous Hughes Tool tri-cone drilling bit. The paradigm of drilling by turning the entire drill string stayed with us another 80 years, and can still be found in use today, even though most 21st century wells are drilled using a downhole progressing cavity drilling "motor" to turn the drill bit without having to turn the entire drill string!. Each of these technologies bettered the last. Drake's well took over 14 months to drill … to a depth of just 69'! By 1980 rigs using Hushes' technology were drilling 500' per day! Today we often make 1500' or more in a single day thanks to the advent of the bottom hole drilling motor! Each of these was a major breakthrough, bringing with it huge industry-wide advances and, of course, more oil and cash flow.

From the industry's rudimentary beginnings in 1859 facilities purchased for each new well site tended to stay there until the well dried up and was abandoned. The original equipment had to function under the new-well conditions, and for the ever-declining life of the well. Initial production volumes were large and mostly oil while final volumes were small and often mostly water. There was little thought given to the predictably changing conditions, or to optimizing operations throughout the life of the well. This became the norm, and eventually, another of our entrenched paradigms. This paradigm created inbred inefficiencies which cost each well owner millions of dollars over the life of nearly every well. In fact, the only normal change on most well sites was to downsize the pumping unit as the well declined.

Waterflooding, begin commercially in 1948, reversed this trend, and forced changes in facilities as heretofore declining water volumes reversed. As water volumes increased, smaller pumping units had to be swapped out for larger ones. The decline trend reversed as wells made more and more total fluid in response to active waterflooding. Water rapidly became the predominant produced fluid in most 20th century oilfields. Yet, most of the process facilities remained unchanged, using equipment designed for an industry producing mostly oil. The reason? Probably because of that now-infamous paradigm … "we've always done it that way".

SELECTING THE RIGHT EQUIPMENT

In the past three "standard" lease equipment types stood out as those most often used. They were:

1. *The Gunbarrel*
2. *The vertical separator*
3. *The vertical heater treater*

These three types of equipment completely dominated the industry then, and continue to dominate it today!

The Gunbarrel

The Gunbarrel, an atmospheric vessel (tank), was developed in the late 1800s when the industry produced very little oil compared to the amount of oil produced, was designed to separate small amounts of water from large volumes of oil. While reasonably efficient at accomplishing this when used as conceived, it is very poor at separating small amounts of oil from large amounts of water because of its oil-focused process design. Yet, even today, it remains the atmospheric separator of choice by many facility designers … because "we've always done it that way".

In today's high water cut conditions, a condition exactly opposite of the original Gunbarrel design condition, it is no surprise that Gunbarrels do not perform the oil-water separation function efficiently. Most of us now realize that selecting a Gunbarrel to do the job of separation today is clearly the wrong choice. It's mostly the age old paradigm ("we've always done it that way") that pushes us to select the Gunbarrel, even though today's conditions are the reverse of what they were when Gunbarrels actually worked.

Who knew? After each boom and bust cycle the industry tends to send the brain trust packing! This results in a widespread lack of knowledge. And so, we perpetuate the mistakes of the past in the areas of oilfield process equipment design and function. Not good!!

The Vertical Separator

Vertical separators were developed in the early days of 20th century when it was recognized that natural gas could become commercialized for use in industrial and home heating and gas lighting. The equipment design mindset of the day was that "anything vertical is better", another lasting paradigm. As we reached a more enlightened era in the middle of the 20th century more and more of the industry's larger companies began to invest in R&D. From this effort it became obvious that in all but very foamy crudes, horizontal separators outperform vertical separators at least 3:1. Even with a 300% process advantage, because of the age-old paradigm, the industry will still purchase many more vertical separators in 2015 than it does horizontals … because "we've always done it that way."

The Vertical Heater Treater

With the widespread introduction of electricity in the earliest days of the 20th century came the advent of welding technologies, and the ability to fabricate high integrity pressure vessels. The first heated vertical separator was introduced in the early days of the Great Depression, in the early 1930s. The term "Heater Treater" was coined since this vessel was designed to heat crude oil to lower its viscosity so the water of emulsion would separate more readily from it, thus "treating" the crude oil to pipeline/refinery specifications (typically 99.5% pure crude oil). After World War II the R&D departments of most of the larger companies began to realize the deficiencies of the vertical heater treater, and the horizontal heater treater made its debut. By 1950 it was obvious that the typical horizontal heater treater is at least three times as efficient at heating and "treating" crude, yet in 2015 more ten times more vertical heater treaters will be installed than horizontals, again, because of the legacy and paradigms of the past. Chief among these is the paradigm, "because we've always done it that way," which continues to be a major motivator in the oil and gas industry even in 2015!

A Late Comer … The FWKO

Separating oil from water in the high water cut environs became a necessity as older fields 'watered out" and as secondary recovery water injection projects became the norm in the late 1940s and 1950s. High water cuts are still typical of many of today's oilfield operation, forcing facility designers to focus on free *water removal using free water knockouts (aka FWKO). Since the FWKO was developed in the "modern era "after 1950, most are horizontal to take advantage of the greater process capacity. These water-oil separators are designed to separate small amounts of oil from large volumes of water (the opposite of the Gunbarrel), and they do so reasonably well. However, these FWKOs only are simple bulk separators, usually leaving some water in the oil phase effluent, and some oil in the water phase effluent. And, since the water is the higher volume fluid processed, small amounts of oil left in the water translate to quite significant reductions in potential oil revenue to the owner/operator.*

In 2015 most produced water is hauled or pipelined to third-party salt water disposal (aka SWD) plants. These plants average about 0.25% oil recovery from the water they process. In 2015, most SWD plants recover between 0.2 and 1.0% oil, depending on how well they are designed. Today, with oil at around $60/barrel, each 0.25% oil recovery in a nominal 15,000 BWPD SWD plant is worth about 821,250 dollars per year to its owner. This implies that good SWD designs can be quite valuable … perhaps nudging us away from that age-old paradigm!

FACILITY DESIGN EMPHASIS … OIL OR WATER?

While many oil producers consider their core competency to lie in the area of producing crude oil, most produce far more water than oil in 2015. On average the industry produces more than 90% water compared with their 10% or less oil. This should prompt a refocus focus! However, oil recovery from water is often overlooked because of the paradigm that we are an "oil" industry, even though the lost oil revenue more than justifies any refocusing effort.

The fact is that most oilfield process equipment was designed in the "oil era" when more oil than water was produced. The design criterion was to remove the basic sediment and water from crude so the crude oil could be sold to at the premium price. However, the continued use of oil-focused equipment in a predominately water producing environment is illogical if not financial damaging. It's a tough habit to break … and another paradigm we need to put to rest once and for all during 2015.

One such effort is the HWSB© Skim Tank. It is a 21st century system with a 1st century technology, designed for high water cut applications, and it works. It is today's Gunbarrel replacement, designed entirely for high water cut applications. Tracer surveys conducted on Gunbarrel after Gunbarrel show retention time (hydraulic efficiencies) of less than 5%! These very low efficiencies, more often in the 0.5% to 3.0% range, don't measure up to the 72% efficiency of the HWSB^{TM}. The polishing zone in each HWSB^{TM} is it quite efficient hydraulically, approaching ideal "plug flow" conditions. Since the emphasis of design is the water phase rather than oil dehydration, nearly all oil is separated and captured, making it available for sale.

Properly designed and applied, the 21st century HWSB$^{©}$ Skim Tank separates virtually all oil from water. In most applications it pays for itself in a few weeks by dramatically increasing oil recovery! Carryover becomes a thing of the past. Designed with the focus on water clarification, the aqueous phase of the vessel outperforms other systems available today.

Another technology is commonplace in separation applications throughout industry worldwide. It is the use of Lamella coalescing plates. The use of parallel plates for enhanced separation has been around for centuries. In the 21st century an adaptation of the age-old Lamella technology has been configured into three-dimensional matrix plates, not only in the oil and gas industry, but in all industry globally. In 2015 most automatic cars washes use this technology to separate sediment from wash water so it can be recycled again and again. This technology is being used today in our industry in glycol dehys, FWKOs, heater treaters, separators, and even frac tanks used for flowback water treatment, capturing all flowback oil on site.

While hundreds of like technologies exist for use in the 21st century, one more worth mentioning is the DAF. DAF is an acronym originally coined for "dissolved air flotation". Efforts to simplify the original DAF technology have leg to a sister technology also called "DAF", but which literally means "dispersed gas flotation". While the dissolved gas method is more efficient, the dispersed method is less costly. It is also less forgiving in cases where upsets occur, common in the oil industry. The dispersed process requires smaller footprints, making it ideal of offshore oilfield applications where footprint costs soar. However, when a producer of oilfield water desires to clarify varying qualities of produced oilfield waters, the dissolved air (or gas) flotation technology remains dominant.

Clearly, selecting the right technology is one of the keys to designing effective facilities in the 21st century.

PLUG AN D PLAY

The concept of changing out lease process equipment as conditions change is neither new nor unique, yet in the real world it is rarely done. There are exceptions, of course, like the example above of changing pumping units to fit the most current conditions. But most often even today, exchanging Gunbarrels, Heater Treaters, FWKO's, and Separators however simply isn't done. Nevertheless, this concept is changing!

In many of the well-known 21st century oil shale plays operators are applying the plug and play concept. They are purchasing multiples of larger process equipment geared for early-on IP processing during the initial months of higher volume production. Then, as the wells settle down to a more stable decline rate, the larger higher volume equipment is replaced with scaled-down equipment which may stay in place for the next 50-75% of the life of the facility, and the larger equipment is sent to the next new well. Finally, the scaled-down equipment is moved to better suited locations and is replaced with the smallest process equipment sized for the final life of the facility.

This process allows the operator to mix and match his equipment inventory with his actual process needs through the processing life of each facility.

STEADY STATE PROCESSING

Perhaps the most overlooked issue in modern facility design is the issue of "steady state" processing. Oilfield operations are treated as if they are steady state, where flow rates are relatively consistent. However, when they are not, it is clear that all too often too little time and attention are paid to the processing conditions needed to create a more steady state process.

Steady state processing is the optimum. In steady state process design the process equipment is as small as it can be which keeps the cost of the process equipment at the absolute minimum. As flow rates deviate, process equipment must be more carefully designed to accommodate the highs while functioning efficiently during the lows. This leads to over-designing, and inefficiencies. It also adds to the equipment and its operating costs, often doubling or tripling them. And, when overlooked, it leads to process upsets which result in contaminated oil and water. In 2015 the value of contaminated oil may be reduced by up to 25% at the time of sale! This translates to millions of dollars in penalties. In 2014 alone over 20,000 truckloads of crude oil were rejected by pipelines for being off spec. The lost revenue to the sellers cost them over $52 million!

In 2015 over 3 billion barrels of produced oilfield water will be disposed of in deep wells fed by SWD Plants. As this stream arrives at the SWD Plants it averages 0.25% oil, representing an oil stream of 7.5 *million barrels of oil worth 450 million dollars. Off-spec oil will cost SWD plant owners at least up to $65 million in 2015 alone.*

Off spec oil is defined as oil that does not meet the quality criteria for entry into the nation's pipeline infrastructure feeding oil into the US refinery network. This specification is generally in the 0.3% BS&W to 0.5 BS&W range. BS&W is defined as "basic sediment and water"; sediment defined as inert solids like formation fines, remnant drilling mud (clays), corrosion by-products (rust, iron sulfide, etc.), and scale (precipitated calcium carbonate, calcium sulfate, and others.

A major cause of these contaminants in recovered crude oil from SWD Plants is the method used to recover the oil. Most SWD Plants give too little credence to the discipline of process design. Many use process equipment designed for other processes, equipment that is often not suited to SWD Plant processing, like the Gunbarrel. And nearly all SWD Plants refuse to address the basic issue of process design; actual inlet flow rate. Instead, the typical SWD Plant is built without a formal design effort, often copied from a neighboring facility. It moves oil containing water through it as rapidly as possible with little or no regard or concern for the separation process. Often the fluids are moved inside the plant using high-shear centrifugal pumps which can literally homogenize the oil and water eliminating the majority of the potential oil-water separation. The result is that a significant portion of the otherwise recoverable oil does not separate and is not recovered. And, what little is recovered is all too often off-spec.

The gravity separation process may be a mystery to many facility owner/operators. It is considered a black art. The reality of separation is that it is a physical phenomenon, governed by basic laws of physics which were developed, quantified, and proven even before the world's first oil well was drilled!

The dominant physical law in the field of separation is Stokes' Law. When SWD and production processing plants are designed in accordance with Stokes Law they are each considerably more efficient at separating and capturing today's valuable crude oil, treating it to a level quality standard consistent with today's specifications. This results in a significant increase in cash flow to the owners which often doubles or triples the net after-tax profitability of these properly designed plants.

In order to accomplish efficient separation in any plant the first issue is to strive for "steady state" processing. Steady state assures that the process vessels operate consistently and within their designed/engineered operating parameters. Rates can be varied within a reasonable band in production facilities and in SWD plants to assure that the maximum processing flow rate is not exceeded. When this is accomplished the separation process is optimized.

In all SWD plants designed and operated in the desired steady state condition the oil recovery process is maximized, water quality improvement is maximized, and solids settling is assured, each in the process vessel designed for that purpose. The results are a huge increase in cash flow and a significant reduction in operating costs. As water quality improves all well work on the disposal well is diminished accordingly,

What's the Norm?

The norm in production processing is relative steady state flow. However, in trucked in SWD plants the norm is highly erratic and unpredictable flow rates from zero to ten times the daily disposal rate or more.

In production processing plants steady state is quite likely. Wells produce at relatively constant rates, feeding production into the facility at reasonably constant flow rates. This allows the production process equipment to be sized for such rates, and operated within a narrow band of flow rates to achieve decent *separation. The only normal deviations are with well cycling using pump-off controllers, or when a single well or group of wells is shut down. Otherwise, the daily throughput is relatively consistent within a factor of 1:2.*

In SWD plants where water is hauled to the plant by truck, the rates vary almost beyond belief. During nighttime hours when very few trucks operate the flows into a SWD plant will be small and infrequent. However, at the break of day trucks head out and pick up their first load of water, all arriving at the SWD plant in a narrow time band. Several trucks may offload at one time, each at rates exceeding the normal daily disposal rate. For instance, in a 15,000 b/d SWD plant where the disposal well takes 15,000 barrels each 24 hours, six trucks may offload simultaneously in ten minutes at a flow rate of 112,320 b/d! Two hours later the flow may diminish to zero, only to return to an exceedingly high rate a few hours later. This makes creating steady state flow in the typical SWD plant quite challenging … but far from impossible.

All that is needed is enough water holding capacity to absorb the high inflows while the process and disposal rates remain constant and in steady state.

Achieving Steady State

As mentioned above, creating a steady state process condition in production operations is considerably more straight forward than it is in any SWD plant operation. Where varying flows are created using ESPs with pump-off controllers, VFDs can smooth out their flows. Avoiding the temptation to meter fluids out of separation vessels using "snap-acting" level controllers can dramatically improve steady state processing and separation efficiencies.

In SWD plants the keys to steady state processing, where oil recoveries and associated cash flows are maximized, demands a new level of design focus. Encouraging pipeline tie-ins with water producers helps a great deal, particularly when the operators operate their water transfer systems in steady state using tank level transmitters with throttling pumps operated with VFDs rather than the older method of allowing tanks to fill up and then pumping them out, turning the pump on and off using a high-low level detecting Murphy switch. The transfer of water through a properly fed pipeline connection is ideal, and where the supply tank batteries are clustered, is becoming the norm. The SWD plant designed for pipeline feed will always be much smaller, simpler, and less costly than it's trucked in water counterpart.

When wells are remote, water must be trucked. In this case the SWD plant must be designed with "buffer tanks" which have the capacity to store all the water that cannot be disposed of during each large-scale offload event. Since most truck offloading will occur in three significant "waves" of truck traffic (morning, noon, and later afternoon), the buffer tank capacity must be sufficient to allow all trucks to offload in each wave. Whether the owner ops for a series of smaller shop fabricated tanks, or one large field erected inlet water buffer tank, the capacity must be calculated considering the number of trucks delivering water into the plant in each wave, versus the volume of water disposed of during the typical daylight hours of operation. This dynamic is very real, and must be considered when sizing the buffer capacity. Once the buffering volume is sufficient, the SWD plant can operate day in and day out accepting most of the daily throughput in the daylight hours, processing and disposing of it 24 hours a day in steady state (at a constant rate).

CONCLUSIONS

With falling oil prices the cost of every wasted dollar increases dramatically. Through attention to detail we have the opportunity to improve cash flow by putting the paradigms of the past behind us and by paying more attention to the way we design and operate our surface facilities. More use of properly *designed and more efficient horizontal separation equipment is a start. Add to this the use of the "plug and play" concept and we can correctly match process equipment to process conditions, optimizing separation efficiencies and cash flow. Automation can and should play a much larger role in daily operating decisions so the workforce can work smarter instead of harder/longer. And processing in steady state can produce financial results unfamiliar to most.*

2015 will be a year of transition. It is full of opportunity for those with the courage to demand that we all do the very best we can.

ABOUT THE AUTHOR AND HTC

Bill Ball is the founder and owner of HTC, Inc. He has a long history of oilfield separation system design experience, which when coupled with his hands-on oilfield experience and career portfolio, make him one of the industry's leading separation authorities today. After his university studies his career started in a 1,000,000 b/d waterflood operation where he was responsible for the evaluation and performance improvement all surface facilities. Through this hands-on effort, he learned the modifications that help improve process efficiency, and those that do not. In the decades since Bill has accumulated a lifetime of knowledge and experience in oilfield separation. He holds several patents in the field.

The culmination of this work is the DFSD™ De-sanding, Flow Splitting, and De-gassing tank, the HWSB™ Skim Tank Gunbarrel replacement for all high water cut applications, and the "HEGB™ High Efficiency Gunbarrel". These unique designs achieve the highest level of hydraulic and separation efficiency known to exist in any design. In combination they form the foundation of HTC's ProFit™ SWD Plant Design Package currently considered to be the most cost effective SWD Plant Design available. In overview, each produces results that achieve unparalleled quality in the effluent streams.

Today, HTC, Inc. is one of the industry's leading low-cost surface facilities design firms. Bill's team of seasoned veterans specialize in salt water disposal (aka SWD) plant, flowback water treatment plants, two and three phase separation systems, and crude oil processing and dehydration/desalting plant designs worldwide. HTC affiliates blanket every field of engineering discipline making HTC a full service firm capable of complete turnkey designs.