The Voraxial® Separator – A New Technology for Separation of Oil and Solids from Produced Water

John A. DiBella, Enviro Voraxial Technology, Inc.
Dan Samela, PhD, PE, Enviro Voraxial Technology, Inc.

INTRODUCTION

Enviro Voraxial® Technology, Inc. (EVTN) has developed and patented the Voraxial® Separator. The Voraxial Separator is a new technology designed to separate large volumes of fluids or a combination of fluids and solids based on their different densities. The Voraxial Separator was first introduced to the Produced Water Industry three years ago with tests on an Offshore Platform. Although the technology was put into service on a short time schedule, the potential benefits of the technology for offshore service were demonstrated at that time.

Since that time significant technology changes have been incorporated in the Voraxial Separator to improve the Separator's performance and function. Technology changes implemented by EVTN allow the Voraxial Separator to operate at a higher maximum rotational speed. At the higher maximum speed, the Voraxial Separator produces a "G" force four times higher and a flow rate about two times higher in the same footprint. In addition to the improved performance, the technology changes have resulted in a significant increase in Separator reliability.

There are several features of the Voraxial Separator that are significant in the Produced Water Industry. The Voraxial Separator can be operated as a stand-alone device or as a pretreatment unit. Test data is available to demonstrate the separation performance as a Stand-alone unit or as a pretreatment unit. The Voraxial Skid operating at an Onshore facility in Europe produced an average oil removal efficiency for the Voraxial Separator of 93% with a peak efficiency of 98%. As a pretreatment unit on this project, the Voraxial Separator contributed to a system efficiency of over 99% removal of Produced Water. In another example, the Voraxial Separator was used for a pretreatment on a Produced Water System in Trinidad and averaged a removal efficiency of over 91%. The Voraxial was also tested on its ability to handle gas slugging. The Voraxial was able to reform the vortex and perform the same quality separation without any adjustments or modifications.

In addition to the separation performance of the Separator, it has been demonstrated that the performance is not affected by changes in flow over a wide range, or by changes in the influent concentration over a wide concentration range. Another unique feature of the Voraxial Separator that the market is embracing is the fact that the Separator produces quality separation without any pressure loss. The Voraxial Separator performs like an axial flow pump with an open, low shear impeller and provides its own motive force.

This paper describes the Voraxial Technology, describes recent technology improvements, presents performance data, and discusses present and future activities.

VORAXIAL® TECHNOLOGY

For those not familiar with the Voraxial® Technology, a brief description follows. EVTN's Voraxial Separator is a continuous flow turbo machine that produces a high centrifugal force and generates a vortex to separate a mixture of fluids or a combination of fluids and solids by their different densities. The heavier elements are drawn to the outside of the vortex while the lighter materials are drawn toward the center, forming the central core of the vortex. The outer stream contains the heavier particles while the lighter elements are found in the inner core. A specially

designed manifold is utilized at the exit of the separation chamber to collect the separated streams. The Voraxial separation principle is illustrated on Figure 1.

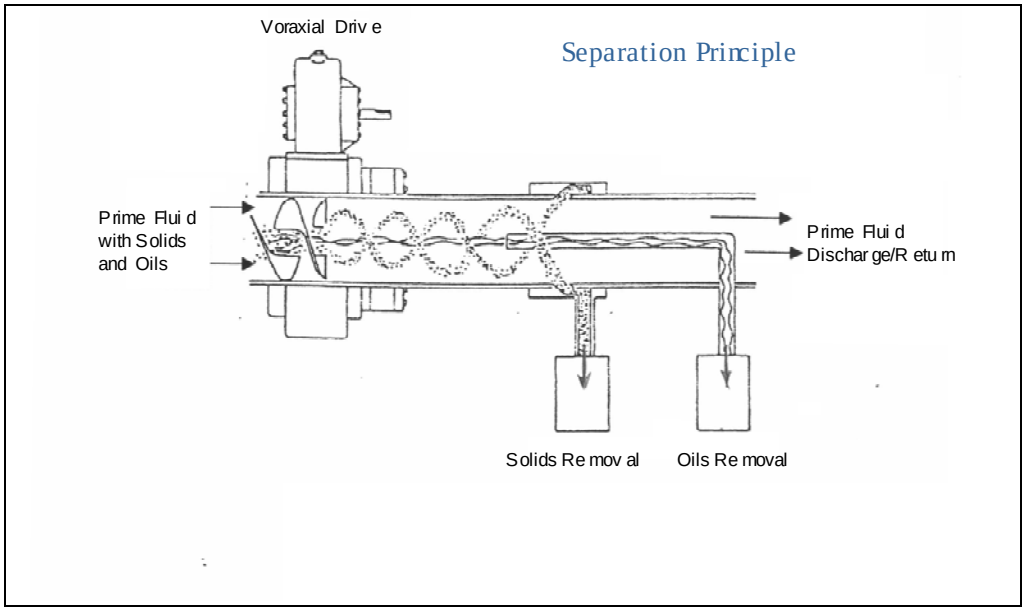

Figure 1 – Voraxial® Separation Principle

Figure 1 shows 3-way separation; liquid/liquid/solid separation. The Separator can also be configured for 2-way separation: liquid/liquid or liquid/solid separation. As shown, the primary fluid with oil and solids enters the separator. The hydraulically designed impeller creates cyclonic flow which forces the heavier solids to the outside of the stream, while the lighter oil particles are drawn to form the central core or vortex. At the exit of the separation chamber, the separated streams are collected and the primary fluid is released for discharge or further treatment. If there is any gas entrained in the fluid stream, the gas, being lighter than water will combine with the vortex and exit through the Light Manifold where the lighter fluids such as oil, are removed..

The Voraxial Separator has one inlet manifold, although there can be several branches leading to the inlet. As noted above, the Voraxial Separator releases the fluid in two (2) or three (3) outlet manifolds, depending on the particular application. The Separation Chamber is located between the Voraxial Separator impeller and the Separation Manifold. The Separation Chamber is where the actual separation takes place.

To produce efficient separation, the Voraxial Separator is capable of generating a high “G” force. Depending on the model utilized and the operating speed, the separator can produce a “G” force of over several thousand.

The Voraxial Separator is scalable and can be fabricated to process any amount of flow. EVTN presently manufactures four (4) Voraxial Separator models. These models are listed on Table 1 along with nominal flow rates.

Table 1 - Voraxial® Separator Models

Voraxial Model	Separation Chamber Diameter (Inches)	Nominal Flow (USGPM)
1000	1	5
2000	2	15 - 60
4000	4	100 - 500
8000	8	1000 - 5000

The flow rates listed on Table 1 are nominal rates for typical hydraulic conditions encountered. The units can operate outside these ranges, depending on the Voraxial Separator operating speed, and inlet and outlet hydraulic conditions. With an external motive force (high pressure or upstream pump), the Separators can operate outside these ranges.

A Voraxial 4000 Separator is shown on Figure 2. As shown on this figure, the Separator configuration has a very small footprint (the separation chamber has a 4" diameter), while processing high flow rates (over 17,000 BPD).

As noted, the Voraxial Separator does not need a pressure drop to perform separation. The Voraxial Separator actually performs similar to an axial flow pump (high flow, low pressure increase) with an open, low shear impeller. As long as the Separator is flooded, it can handle a wide range of slugging flows

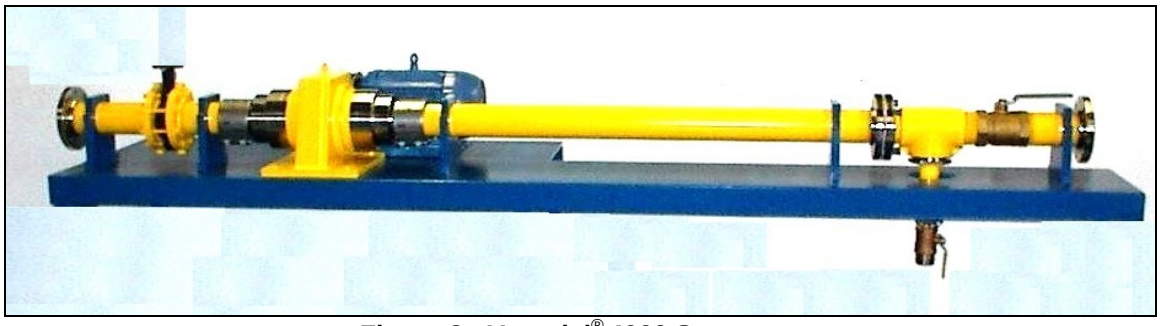

Figure 2 - Voraxial® 4000 Separator

There are many benefits for the use of a Voraxial Separator for the separation of produced water. Benefits include:

- No pressure drop – can operate at low pressure and provides a pressure increase
- High "G" force
- Treatment of a wide range of flows – including slugging flows
- High performance over a wide influent concentration range
- Handles fluctuation in flow rate without any adjustments
- Handles fluctuation in influent concentration without any adjustments
- Separation of 3 components simultaneously
- High flow, low energy – high flow per Hp
- Compact unit – small footprint
- Low shear impeller – oils are not emulsified as the mixture flows through the Separator
- Non-clogging – open impeller
- Variable speeds to optimize separation for different applications
- East of installation and operation

TECHNOLOGY IMPROVEMENT

The technology improvements made are associated with modification to the Rotor Assembly of the Voraxial Separator. EVTN found that there were many potential benefits with the use of gas seals and implemented a design and test program to evaluate their application with the Voraxial Separator. Various design changes were required to the Voraxial Separator Rotor Assembly to provide higher speed. The non-contacting double gas seal provides for extended seal life, reduced power consumption, and elimination of a wet seal lubrication system. The non-contacting, dry running technology provides high performance sealing.

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The non-contacting gas seals can operate at much higher speeds than the mechanical seals used previously. The re-designed Rotor Assembly allows the Voraxial® Separator to operate in the range of 6000 to 7000 rpm as opposed to 3000 rpm for the older models. The gas seals can be designed for even higher speed and EVTN is presently pursuing this option.

The re-design of the Rotor Assembly and the use of gas seals provide many benefits associated with operation at higher speeds. The most important improvement in performance resulting from higher speed is the increase in the "G" force developed by the Voraxial Separator. With the higher rotational speed, the upgraded Voraxial Separators now produces a maximum "G" force four times higher than that of the older models (The Model Voraxial 4000 produces a "G" force of over 2000).

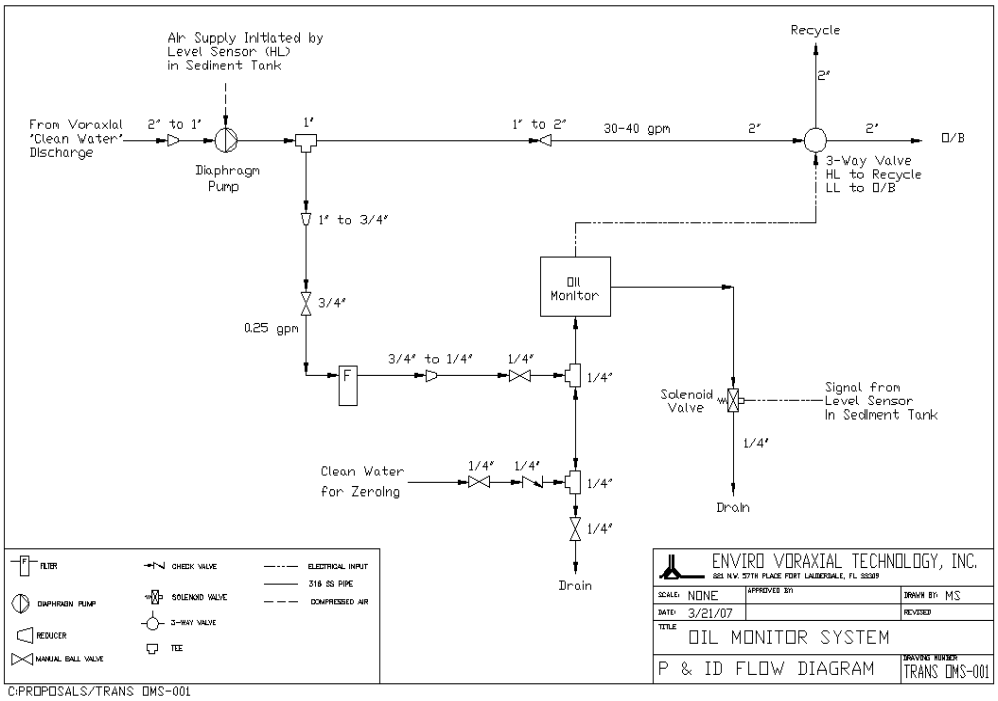
Operating experience with the upgraded Voraxial has shown that the Separator can provide liquid/liquid/solid/gas separation; the fourth component being gas entrained in the produced water. In 4-way separation, the gas is separated and removed from the process fluid by the Light Manifold where the lighter fluids, such as oil, are removed.

In addition to the many improvements in Separator performance and function, the use of gas seals has resulted in significant improvement in Separator reliability and a decrease in maintenance requirements. The non-contacting gas seals operate with minimal friction resulting in longer durability. Gas seals have a long and successful operating history in industry. The mechanical seals used on the older Voraxial Separators had a shorter life-span and more maintenance due to wear on the seal rings.

PRESENT ACTIVITIES

As noted previously, EVTN offers its Voraxial® Separators as a stand-alone unit, as a retrofit or pretreatment to existing separation systems or as a total turnkey solution, depending upon the type of separation requirements needed by the customer. Since the Voraxial is a compact separation device, a complete system can be configured around the Voraxial that is also compact and economical. One type of skid, a two-stage Voraxial Skid incorporates the primary Voraxial for bulk oil and solids removal. The "clean water" then proceeds to a coalescer to improve the separation of oil in the second Voraxial by increasing oil droplet size. If oil concentrations less than 5 ppm are required, EVTN can also supply a Polishing Unit after the second Voraxial Separator. We are able to construct compact skids because of the high volume/small footprint of the Voraxial and its ability to provide efficient separation without the need for a pressure drop.

EVTN has several different configurations of the Voraxial Skid operating in the market. EVTN can include different types of equipment onto the skid to meet each customer's specific fluid separation issues or discharge requirements. A Deckwater Drainage System is operating on a Transocean Rig. A typical arrangement for a Voraxial Separator Deckwater Drainage System is shown on the figure below. This arrangement includes a skid mounted Voraxial Separator, a coalescer, a solids filter, a discharge pump and a oil/water monitor. A skim tank is provided to recover separated oil. The Voraxial Separator and associated equipment used depends on the run-off characteristics of the fluid and the design flow rates. The system can be designed for a wide range of flows



EVTN has another Voraxial Skid conducting oil/water/solids separation for a waste-to-energy plant. Although it is not in a produced water application, the Voraxial is performing the same function. The flow rate varies from 25 to 40 gallons per minute and the influent oil concentration also varies. The Voraxial is performing efficient separation without any adjustments.

Another variation of the Voraxial Skid is being installed for a pond cleanup application. This Skid is comprised of a skimmer, a pump, a Voraxial Separator and a tank for the oil discharge.

Regarding Produced Water, EVTN completed a test of a Voraxial 2000 Produced Water Skid at an onshore oil production facility. The facility discharges approximately 150,000 BPD. The Voraxial 2000 Separator which processes approximately 2000 BPD was tested to measure the efficiency of oil recovery. Due to the characteristics of the fluid stream and the customers design requirements, a two-stage Produced Water Skid was used for this application. The high flow, small footprint Voraxial Separator allows for construction of a compact skid to meet a variety of requirements.

The two-stage system included a Voraxial 2000 Separator, a coalescer, a second Voraxial 2000 Separator, and a polishing unit. The first stage Voraxial 2000 Separator provided for bulk removal of solids and oil, the coalescer was provided to improve the separation of oil in the second Voraxial 2000 Separator by increasing oil droplet size. A final step, if needed, was provided to polish the discharge to meet stringent re-injection standards.

The Skid equipment includes:

1. **Voraxial® 2000 Separator** (removes bulk solids and free oil)
2. **Coalescer**, (increases the size of small oil droplets for secondary separation)
3. **Voraxial® 2000 Separator** (removes free oil discharged from the Coalescer)
4. **Polishing Unit** (removes any remaining oil emulsions)

The Skid system is designed for flow from the first Voraxial Separator to the Coalescer to the second Voraxial Separator, and then to the Polishing Unit. However, the skid is configured with

bypass lines so that all equipment can be used or bypassed, based on the wastewater quality and the treatment requirements. One Voraxial Separator will always be utilized.

A view of the Voraxial 2000 Separator Skid is shown on Figure 3. The two Voraxial 2000 Separators can be seen as the yellow equipment in the figure. The small size of the Voraxial Separators is apparent.

Figure 3 – Voraxial 2000 Separator Skid

The Voraxial Separator Skid is provided with an air-operated Diaphragm Pump which, if needed, can increase the pressure of the feed flow to allow for coalescer and polisher pressure increase as operation proceeds, and contaminants buildup. The pump can be bypassed if sufficient pressure is available in the feed flow. The pump was bypassed throughout the test series.

The Polishing unit is designed to remove any fine emulsions remaining in the fluid stream after treatment in the Voraxial Separator. Two Polishing units are mounted on the Voraxial Separator Skid; one operating and one on standby. The Polishing Units can also be bypassed and were throughout the majority of the test series.

Design specifications for the Voraxial Separator Skid are listed below.

Design specifications

Nominal Flow Rate	25 to 50 GPM
Design Pressure	250 psi
Design Temperature	250 F
Construction materials	316 SS
Pipe size	2 inch
End Connections	150# RF Flanges
Valves	316 SS Ball valves
Instruments	Pressure gauges
Electrical	400 V, 3 Phase, 50 Hz
Voraxial Separator Power	3 Hp each Separator
Nitrogen or Air Requirements	5 SCFH each Separator
Diaphragm Pump Air Requirements	100 scfm
Maximum Rotational Speed	6800 RPM
Maximum “G” Force	1300
Approximate Weight (empty)	2500 kg
Dimensions (Lx Wx H)	3500 x 1800 x 3000 mm (L x W x H)

The test skid is shown on Figure 4. The Skid is approximately 10 ft. long by 4-1/2 ft. wide by 6 ft. high. The Produced Water feed line can be seen entering the skid on the lower right-hand side. The discharge line is behind the skid and is not in view in this figure. The “first” Voraxial Separator is the upper Separator on the skid, and is partially hidden by the Gas Control Panels for the gas seals. The flow in the first Separator goes from right to left.

The exit manifold for the Separator is visible on the left side of the skid. The flexible hose exiting the manifold is for solids discharge, but was not used during this test. The “second” Voraxial Separator is the lower separator in the figure, and the flow goes from left to right. A Coalescer can be seen on the bottom of the skid.

The air operated Diaphragm pump is on the lower right-hand side of the skid. The pump was not used during this test. The Produced Water Feed Pump and the Voraxial Separators provided the motive force to circulate the Produced Water. Sample lines and pressure gauges were provided downstream of each piece of equipment.

Test Results

Testing was conducted over a seven day period. A total of 33 runs were made, although not all of the samples collected were analyzed by the Onsite laboratory. Many of the inlet samples were not analyzed because the range of inlet concentrations were known. Some of the discharge samples with the Polisher operating were not analyzed. For those samples analyzed, the results show that discharge samples with the Polisher on-line had very low concentrations (<5ppm).

All sample results reported were analyzed by the Onsite Laboratory. Photos were also taken of various samples collected. The photos provide additional evidence that separation results were excellent.

Figure 4 – Voraxial 2000 Separator Skid Test Setup

Prior to running the test, a clear plastic tube was installed on the first Voraxial Separator to view the vortex produced, and to demonstrate the separation taking place. Figure 5 shows the vortex produced by the Voraxial Separator under flow conditions.

Figure 5 – View of Voraxial Separator Vortex

The figure shows a straight vortex produced by the Voraxial Separator. This figure clearly shows that the separation of oil from the Produced Water was very good. This type of vortex is indicative of excellent separation being performed.

A summary table of the raw data is shown on Table 2. This table includes 25 of the raw data points. All runs with the discharge data analyzed are included in the table. Several of the runs with the polisher operating were not analyzed for discharge concentrations and are not included in the table. In addition to the equipment configuration (equipment on-line), flow, and sample concentrations, this table illustrates the separation efficiency achieved during the run when inlet and discharge concentrations are available. The efficiency is the percent of influent oil removed by the Voraxial Separator or skid equipment.

A review of the data in Table 2 shows that the inlet oil concentration to the skid varied from 1,190 ppm to a high of 17,200 ppm. The average inlet oil concentration was 2,362 ppm. The discharge concentration for the majority of the runs was less than 40 ppm. The highest discharge concentration was 126 ppm for run 11, with no Coalescer operating. This run was conducted during an experimental adjustment of the valves. With the Polisher on-line, the discharge concentrations were all less than 5 ppm

Table 2
VORAXIAL SKID TEST DATA

Run #	On Line	Flow (gpm)	Inlet Oil (ppm)	Voraxial Clean Water Oil (1) (ppm)	Clean Water Discharge (2) (ppm)	Voraxial Efficiency (%) (3)	Skid Efficiency (%) (4)	Efficiency With Polisher (%)
A1	VCVP	44	3,490	N/A	1			99.96
A2	VCVP	44	3,000	N/A	2			99.93
1	VCV	44	2,070	143	15	93.1	99.3	
2	VCV	44	2,120	264	29	87.5	98.6	
3	VCV	44	N/A	329	93			
5	VCV	44	N/A	2,910	40			
6	VCVP	44	N/A	N/A	3			
7	VCV	44	N/A	139	48			
9	VCV	44	N/A	240	42			
10	VCV	44	N/A	185	116			
11	VV	46	N/A	164	126			
13	VCV	45	N/A	N/A	35			
15	VCV	44	1,190	191	99	83.9	91.7	
16	VCV	45	1,280	127	33	90.1	97.4	
17	VCV	31	1,410	122	34	91.3	97.6	
18	VCV	31	N/A	148	43			
19	VCV	31	17,200	610	36	96.5	99.8	
20	VCV	31	2,760	77	30	97.2	98.9	
21	VCV	31	7,510	129	39	98.3	99.5	
22	VCV	31	2,710	128	42	95.3	98.5	
23	VCV	30	1,980	126	28	93.6	98.6	
24	VCV	26	1,920	123	30	93.6	98.4	
25	VCV	26	1,401	104	26	92.6	98.1	
26	VCV	26	1,729	84	23	95.1	98.7	
27	VCV	26	1,494	97	19	93.5	98.7	

Notes: Data Analyzed by the Onsite Laboratory
N/A – Not Analyzed,
(1) – Refers to the Clean Water PPM after the first Voraxial Separator

(2) - Refers to the Clean Water discharge from the second Voraxial Separator or the polisher when used
(3) - Refers to the separation efficiency of the first Voraxial Separator
(4) - Refers to the separation efficiency of the Skid without polishers

The flow rate varied from 26 to 46 gpm during the test without any adjustments to the valve settings. Based on the results, the flow rate had no affect on performance**.** This is a characteristic of the Voraxial Separator, which has good performance over a wide range of flows. It can be stated that the Separator skid also performs well over a wide range of flows. The data also shows that the discharge concentration is not sensitive to fluctuations in the influent concentration. Runs 19 and 21 have very high concentrations (17,200 and 7,510 ppm, respectively. However, the discharge concentrations are both less than 40 ppm. This is another characteristic of the Voraxial Separator and that of the skid.

As can be seen on Table 2, excellent separation performance for Produced Water was obtained. Photos taken of samples also verify the excellent performance. This is illustrated on the figures that follow. A photo of samples for run 1 is shown on Figure 6. This run had a skid efficiency of 99.3% (refer to Table 2). This excellent separation is verified by the photo. The figure shows the outlet Oil samples collected for the first and second Voraxial Separators, and for the "Clean" discharge sample. The Clean sample was analyzed as 15 ppm.

Similar results are shown on Figure 7. Figure 7 is a photo of samples collected for run 2. The oil out samples have a heavy oil layer on top of the fluid, while the Clean sample is clear. The Clean sample was analyzed at 29 ppm.

Several discharge samples were not analyzed; however, photos of the samples show that results were good. Figure 8 shows a Polisher Out sample for run 12 (not analyzed). The visual samples show that performance was excellent.

Figure 6 – Run 1 Samples

Figure 7 – Run 2 Samples

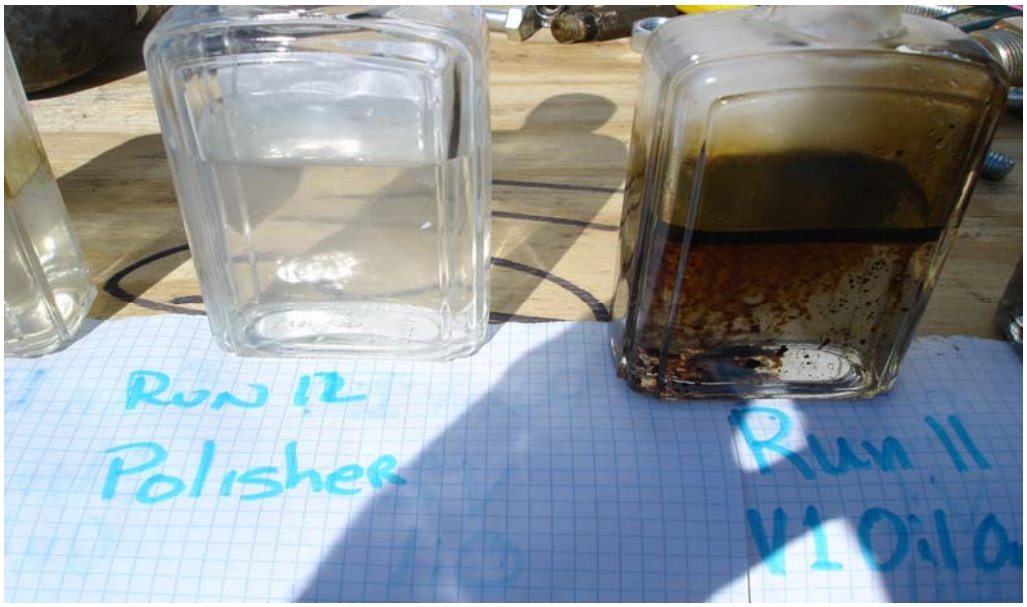


Figure 8 – Run 12 Sample From Polisher

In summary, excellent separation was obtained by the Voraxial 2000 Separator Skid. The Skid, with all units operating, produced oil removal efficiencies as high as 99.9%. Effluent concentrations were less than 5 ppm. A Voraxial 2000 Separator alone produced an average oil removal efficiency of 93%, with a peak efficiency of 98.3%. The results for the skid operating without a Polishing Unit averaged over 98% removal of Produced Water. These results are summarized on Table 3.

Table 3
Efficiency Results

Equipment Configuration	Average Oil Removal Efficiency
First Voraxial only	**93%**
Voraxial – Coalescer – Voraxial	**98%**
Full Skid	**99+%**

In addition to the excellent separation performance, the Voraxial Skid also demonstrated that the performance was not affected by changes in flow (over a range of approximately 2 to 1) or influent concentrations (over a range of approximately 17 to 1).

EVTN completed a produced water separation on a platform in Trinidad. A Voraxial 4000 Separator was installed for pretreatment of produced water feeding a Holding Tank. Data collected during the past month is shown on Table 4.

Table 4
Pretreatment of Produced Water

Flow (BPD)	Inlet TPH (ppm)	Voraxial Outlet TPH (ppm)	Voraxial TPH Removal (%)	V203 Outlet TPH (ppm)	System TPH Removal (%)
4000	1197	-	-	326	73
4500	1151	97	92	45	96
NR	778	368	53	39	95
6000	1617	354	78	98	94
6000	787	242	69	80	90
6500	958	314	67	105	89
NR	786	292	63	87	89
6500	879	375	57	90	90
6500	993	370	63	63	94
6500	682	178	74	61	91
7000	1533	247	84	37	98
7000	715	91	87	44	94
7000	635	217	66	67	89
6000	524	106	80	71	86
6000	696	183	74	56	92
6000	626	191	69	54	91
6000	433	326	25	76	82
6000	733	117	84	67	91
6000	471	83	82	27	94

NR – Not Recorded

The Voraxial Separator was very efficient as a pretreatment to the customers produced water system. Without the Voraxial Separator, the efficiency of treatment for removal of Total Petroleum Hydrocarbons (TPH) was 73%. With the Voraxial Separator as a pretreatment device, the system has over 91% removal efficiency. It is important to note that the larger model Voraxial 4000 Separator also demonstrated that its separation performance was not affected by changes in flow (over a range of approximately 65%) or influent concentration (over a range of approximately 4 to 1).

EVTN has several other applications either ongoing or in the planning stage for produced water treatment (onshore, offshore and oil sands applications), refinery wastewater treatment, slop oil treatment and liquid/solid separation. Some of the applications include a Voraxial for tar sand separation, a Voraxial for oil cleanup from a pond and a Voraxial 4000 Separator for liquid/liquid/solid separation. The Voraxial is being used in other industries as well including oil/water/sand separation in the waste-to-energy industry, oil/water separation in the mining industry and oil/water separation in the manufacturing industry.

EVTN is scheduled to deploy additional Voraxial Separators (both Voraxial 2000 and Voraxial 4000 models) and Voraxial 2000 Skids, in the upcoming months. The Voraxial Separators and Skids are being requested as a total solution and as a pretreatment for bulk oil/sand separators. The Voraxial will do both liquid/liquid and liquid/liquid/solid separation. Within the refinery industry, EVTN is in discussions to install the Voraxial Separator upstream of an API Separator to conduct bulk oil and sand separation. This would decrease the load on the API Separator and increase its efficiency. Within the Produced Water market, EVTN is working on multiple applications both onshore and offshore. EVTN is also being approached by other manufacturers to combine the Voraxial with their equipment and chemicals. The combination provides the industry with a compact solution.

SUMMARY

This paper has reviewed the Voraxial® technology, technology improvements implemented by EVTN in the past year, the resulting Voraxial Separator performance improvements, and Separator applications for produced water, as well as several other applications.

The technology improvements allow the Voraxial Separator to operate at a higher maximum rotational speed. At the higher maximum speed, the Voraxial Separator produces a “G” force four times higher and a flow rate almost two times higher in the same volume or footprint.

In addition to the improved performance, the technology changes have resulted in a significant increase in Separator reliability. In summary the Voraxial Separator has improved in several areas.

The improved Voraxial Separator:

- Produces a Higher “G” force (300% increase)
- Has higher separation efficiency
- Has higher reliability/lower maintenance costs
- Produces a higher process fluid pressure increase (has an improved pump curve)
- Treats a higher flow with the same footprint
- Treats the higher flow with a lower energy consumption per flow rate
- Separates 4 components simultaneously

In addition to the separation performance of the Separator, it has been demonstrated that the performance is not affected by changes in flow over a wide range, or by changes in the influent concentration over a wide concentration range. A unique feature of the Voraxial Separator is the fact that the Separator produces quality separation **without any pressure loss**.

Interest in the Voraxial Separator has increased significantly. The Voraxial Separator is now being deployed and/or installed at various offshore and onshore applications. These applications include produced water separation, deck water drainage, refinery applications, liquid/solid separation, mining, and manufacturing applications. EVTN is also engaged in discussions regarding heavy oil removal. The Company is developing relationships with service companies to further increase the awareness and projects for the Voraxial Separator.