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An Energy Cost Comparison – Vacuum & Gravity Sewer Systems
Thursday, May 30th, 2013

Presented by
Jeff Gilbert, P.E.
Dan Burden, Ph.D., P.E.
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Presenters

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WadeTrim

Moderator:
Bob Drake
Editor-in-Chief, CE News & RAI
ZweigWhite
Wade Trim’s Involvement w/Vacuum Sewers

- Florida Keys Design Experience
  - Key Largo Wastewater Treatment District, Area C
  - Middle Plantation Key, Islamorada
- Owner’s Representative – Islamorada Wastewater Program (DBO)
Jeff Gilbert, P.E.

• B.S. Civil Engineering

• Florida registered professional engineer

• Worked for last 6 years in Key Largo and Islamorada as part of the state mandated wastewater improvement program

• Design and construction experience with vacuum sewer technology in the Florida Keys

• Resident engineer for Village of Islamorada’s Wastewater Improvement Program
Dan Burden, Ph.D., P.E.

- Ph.D. and Master in Civil Engineering
- Florida registered professional engineer
- 25+ years of consulting experience in FL
- Program Manager for Sarasota County Septic Tank Replacement Program
- Technical Review Committee Member for Islamorada Wastewater Program (Present)
Learning Objectives

• Basic understanding of sewer collection technologies
• Operational theory of gravity and vacuum sewer systems
• Major components used in designing a sewer collection system
• Evaluation of power usage at a conventional wastewater lift station and a vacuum pump station
• Comparison of power usage and identification of energy savings
Presentation Outline

• Study Purpose
• Sewer Collection Technologies
• Design & Construction Components
• Study Location
• Comparative Methodology
• Analysis Results
• Conclusions
Study Purpose

- Provide accurate power costs for future vacuum projects and O&M budgets
- Compare vacuum power costs against Water Environment Federation (WEF) published data
- Determine if vacuum sewers require more or less energy for operation than a gravity sewer system in a similar sized service area
Part 1 – Jeff Gilbert, P.E.

- Vacuum Sewer System Components
- How A Vacuum Sewer Works
- Gravity Sewer Collection Systems
Vacuum Sewer System Components

Valve Pits

Vacuum Mains

Vacuum Station
How a Vacuum Sewer Works – At the House

(1) House to pit via gravity lateral

(2) Interface valve opens and the contents are sucked out

(3) Differential pressure propels sewage toward vacuum station
How a Vacuum Sewer Works – In the Vacuum Main

Sawtooth profile keeps open passageway on top of pipe

When nearby valve(s) open, flow moves toward vacuum station

Flow comes to rest & temporarily accumulates at the low points
Vacuum Main Profile

Vacuum main drops 1 ft every 500 ft then a 1 ft lift is used to return the main to the original invert.

Minimum 0.2% slope towards the vacuum station.
How a Vacuum Sewer Works
– At the Vacuum Station

(1) Vacuum pumps cycle on and off 16”–20” Hg

(2) Wastewater enters the collection tank

(3) Sewage pumps transfer the contents to WWTP
Vacuum Station

SEWAGE PUMPS
Sends sewage to gravity main, force main, or WWTP

VACUUM PUMPS
Cycle to maintain vacuum

COLLECTION TANK
is liquid and vacuum reservoir
Vacuum Pumps
Sewage Pumps & Collection Tank
Vacuum Chart Recorder

Continuous Monitoring of the System

7-day Chart Recorder
Touch Screen and Run Meters

Interface touch screen
Pump run-time meters (vacuum & sewage pumps)
Vacuum Station – Various Building Styles

- Ponte Vedra Beach, FL
- New Bern, NC
- Englewood, FL
- Martin Co, FL
WEF Manual of Practice FD-12

Manual contains about 120 pages on vacuum sewers

- Planning
- Design
- Construction
- O&M
- System Management
- Sample Regulations
Vacuum Sewer Misconceptions

• Vacuum pumps do not operate continuously. They cycle on/off for an approx. 3 minutes (see illustration w/ chart)

• Infiltration/Inflow is not a common occurrence

• A vacuum leak will not take an entire system down
Gravity Sewer Basics

• Minimum pipe velocity 2 fps required

• Corrosion control and protection needed due to H₂S gas production

• Pumping stations are required

• Manholes are required at 300-500 ft (typical)

• Manhole designs need to address inflow/infiltration
Gravity Sewers – Lift Station Design

Lift stations – Hydraulic structures which are used to transport wastewater

Key components:
- Wet well
- Pumps
- Motors
- Controls
- Power
2 Types of Lift Stations

- **Submersible Lift Stations** (small to medium in size)
  - Generally smaller in size, < 700 gpm
  - Duplex pumps, usually constant speed
  - Wet well detention times < 20-30 mins

- **Dry Pit Lift Stations** (medium to large in size)
  - Larger stations, usually a master lift station
  - Variable speed pumps typically used
  - Wet well detention times usually < 15 mins
  - Standby generator system
Lift Station Illustration

Typical Gravity Sewer & Lift Station Profile
Typical Gravity Sewer System

- **Advantages:**
  - Allows for handling of grit and solids
  - By maintaining a minimum velocity, the production of $\text{H}_2\text{S}$ and methane gases can be reduced

- **Disadvantages:**
  - Minimum slope requirements result in deep excavation
  - Pumping stations are required
  - Manholes are usually a source of inflow/infiltration
  - Potential for manhole overflows during power failures (lift stations)
Gravity Sewers – Design & Construction

• Construction can be disruptive due to the depth of construction, multiple lift stations, and dewatering requirements.

• Manholes required at set intervals, pipe intersections, changes in pipe direction and changes in pipe slopes.

• Infiltration and inflow always a concern.

• Buoyancy considerations.

• Renewal and replacement costs associated with manholes & lift stations (corrosion problems).
Part 2 – Dan Burden, Ph.D., P.E.

• Comparative Study
• Study Location
• Methodology
• Data Analysis
• Results
# Gravity vs. Vacuum Sewers

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Gravity Sewer</th>
<th>Vacuum Sewer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipe Size</td>
<td>8 to 42 inch</td>
<td>4 to 10 inch</td>
</tr>
<tr>
<td>Minimum Slope</td>
<td>0.40 ft/100-ft (8” dia)</td>
<td>0.20 ft/100-ft independent of pipe dia</td>
</tr>
<tr>
<td></td>
<td>0.037 ft/100-ft (42” dia)</td>
<td></td>
</tr>
<tr>
<td>Manholes</td>
<td>4-ft min. diameter; Spaced every 300-600 ft; Coatings required</td>
<td>Manholes not required</td>
</tr>
<tr>
<td>Construction Depth</td>
<td>Range from 3.0 to 6.5 feet below surface</td>
<td>Shallow (30-48 inches below surface), saw-tooth profile</td>
</tr>
<tr>
<td>Energy Costs</td>
<td>???</td>
<td>???</td>
</tr>
</tbody>
</table>
Vacuum & Gravity Sewer Comparisons
Vacuum & Gravity Sewer Comparisons

• Vacuum sewers are typically installed in the right-of-way, require shallow trenches with minimal disruption; and less environmental impact

• Gravity sewers are installed along roadway centerlines; can result in short term road closures due to the depth of construction and dewatering requirements; and require more pavement restoration
Which is More Energy Intensive?

Compared to a gravity lift station, a vacuum station has vacuum pumps in addition to sewage pumps. So the answer is obvious if the gravity layout does not require a lift station at all or if only 1 lift station is required.

But, when multiple lift stations are required to do the same job as 1 vacuum station, the answer is not so obvious.
When Multiple Stations are Required – Which Technology is More Energy Intensive: Gravity or Vacuum?

Even though vacuum has fewer pumps, does the additional power required for the vacuum pumps result in more power for vacuum?

Or, does the pumping and re-pumping associated with gravity result in more power for gravity?
Gravity Main – Some Simple Math

**Problem:** Determine the depth required for a lift station using an 8-inch diameter gravity sewer for a total distance of 11,000 linear feet based on the following assumptions:

1. Minimum slope = 0.40% min slope for 8” (4 ft/1,000 ft)
2. 3-foot minimum cover
3. Ground elevation = 5.0 ft NGVD

**Solution:**

5.0 – (3.0 minimum cover) – (4/1,000)*(5,500) = 5-3-22 = -20 ft NGVD

*Using a lift station every 5,500 LF, would result in an elevation fall of -17 ft.*
Vacuum Main – Some Simple Math

Min slope = 0.20% min slope (1 ft/500 ft); Lifts used to regain elevation

Following this general pattern of 1 ft of fall in 500 ft followed by a 1 ft lift allows the trench depth to stay within a foot of the starting depth throughout (3 to 4 ft typical)

With a 6” diameter vacuum main, it is possible to use (20) - 1 ft lifts and still stay within AIRVAC’s design criteria for static loss

This equates to a total line length of 10,000 ft (20 lifts every 500 ft = 10,000 ft)
In flat terrain, a single, large centrally located vacuum pump station (VPS) can serve an area roughly 3 to 4 square miles.
To serve the same 3 to 4 square mile service area with gravity sewers would require a total of 7 lift stations.

7 Lift Stations

- 4 small sized LS (each Q/4);
- 2 medium sized LS (each Q/2); and
- 1 Master LS (Q)
## Sewer Pump Station Comparison - Typical

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Gravity Sewers</th>
<th>Vacuum Sewers</th>
</tr>
</thead>
<tbody>
<tr>
<td># Stations Required</td>
<td>7 Lift Stations</td>
<td>1 Vacuum Station</td>
</tr>
<tr>
<td># Vacuum Pumps</td>
<td>None</td>
<td>2 or 3 (10 – 25 Hp/ea)</td>
</tr>
<tr>
<td># Sewage Pumps</td>
<td>14 (Hp varies)</td>
<td>2 (Hp varies)</td>
</tr>
<tr>
<td>TOTAL</td>
<td>7 Pump Stations &amp; 14 Pumps</td>
<td>1 Pump Station &amp; 5 Pumps</td>
</tr>
</tbody>
</table>
Comparative Energy Study

Objectives:

1. Evaluate existing power usage at conventional wastewater lift stations
2. Compare lift station power data with AIRVAC vacuum pump stations
3. Document the energy savings achieved with the use of a vacuum pump station
Study Location

- Stock Island, Florida is located at 24°34′12″N 81°44′15″W.
- Approx. 1 square mile of land.
- Population = 4,000 (est).
- Approx. 1,855 housing units.
- Sewer utility on Stock Island is owned and operated by Key West Resort Utilities Corporation.
Why KWRU Was Chosen for this Study

• Ideal candidate for comparative evaluation
• Two different collection systems operated by same utility
  • Conventional gravity sewers w/ multiple lift stations
  • Vacuum sewer system
• Both systems are similar in size (# connections)
• Both systems have been in operation for 10+ years
• Good operating records available from the utility
Conventional Gravity Sewer System (9 L.S.)

WWTP
Why Stock Island Was Chosen for This Study

• Sewer lateral inspection requirements for new connections has reduced observed inflow/infiltration into the Stock Island collection system.

• KWRU routinely conducts salinity monitoring in its system to detect where potential I/I problems may exist and can be remedied.

• Salinities > 2-3 ppt will usually indicate a significant I/I problem.
## Key West Resort Utility – Stock Island, FL

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Gravity</th>
<th>Vacuum</th>
</tr>
</thead>
<tbody>
<tr>
<td>System type in operation</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td># Pump Stations</td>
<td>3 large 6 small</td>
<td>1</td>
</tr>
<tr>
<td>Operational 10+ years?</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td># ERC’s</td>
<td>928</td>
<td>1,309</td>
</tr>
<tr>
<td>Power records</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Methodology

- Lift Station Pump Information
- Lift Station Pump Run Times
- Vacuum Station Pump Run Times
- 3-year Data Period Used
- Actual Data Records:
  - January 2010 thru April/May 2012
- Data Extrapolation:
  - 2\textsuperscript{nd} half of 2012
## Typical Power Bill

**Billing Summary**

<table>
<thead>
<tr>
<th></th>
<th>Present</th>
<th>Previous</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Account Number</strong></td>
<td>6636391-00</td>
<td>6636391-00</td>
</tr>
<tr>
<td><strong>Name</strong></td>
<td>KW RESORT UTILITY CORP</td>
<td>KW RESORT UTILITY CORP</td>
</tr>
<tr>
<td><strong>Service Address</strong></td>
<td>6630 FRONT ST.</td>
<td>6630 FRONT ST.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Meter Number</th>
<th>Read Dates</th>
<th>Billing Dates</th>
<th>Meter Readings</th>
<th>Multiplier</th>
<th>Usage</th>
<th>Units</th>
<th>Power Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>ELECTRIC: 0000055353</td>
<td>12/07/2010 - 11/12/2010</td>
<td>12/07/2010 - 11/12/2010</td>
<td>RE 66650 - 06645</td>
<td>1</td>
<td>5</td>
<td>kWh</td>
<td>1.00</td>
</tr>
<tr>
<td>ELECTRIC: 0000055353</td>
<td>12/13/2010 - 12/07/2010</td>
<td>12/13/2010 - 12/07/2010</td>
<td>RE 00018 - 00000</td>
<td>1</td>
<td>18</td>
<td>kWh</td>
<td>1.07</td>
</tr>
</tbody>
</table>

All payments are due upon receipt. Payments received after 2:00 p.m. will be processed the next business day. A 5% penalty will be assessed on current amounts not paid by the "Past Due On" date. Any unpaid previous balance on your bill may cause immediate disconnection of service.

<table>
<thead>
<tr>
<th>Rate</th>
<th>Usage Charges</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.138300</td>
<td>23</td>
</tr>
<tr>
<td>0.001600</td>
<td>23</td>
</tr>
</tbody>
</table>

If you have any questions, please call Keys Energy Services at (305) 295-1000, or visit our website: www.KeysEnergy.com

**Message:** WISHING YOU A BRIGHT HOLIDAY SEASON, AND A PROSPEROUS NEW YEAR! HAPPY HOLIDAYS FROM KEYS ENERGY SERVICES!
### Lift Station Information
- # pumps (duplex, triplex station)
- Voltage
- Full load amperage
- Annualized run times
- Power usage (calculated)
- Power costs (calculated)
- Based on $0.1383 kW/hr costs in the Keys

<table>
<thead>
<tr>
<th># Pumps</th>
<th>Voltage</th>
<th>Pump #1 Amps</th>
<th>Pump #2 Amps</th>
<th>Total kW Usage</th>
<th>Annualized Pump Run Time (hrs)</th>
<th>Annual Power Cost</th>
<th>Monthly Average Power Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>230</td>
<td>22.6</td>
<td>20.8</td>
<td>9.982</td>
<td>5,351</td>
<td>$7,387</td>
<td>$616</td>
</tr>
</tbody>
</table>
Typical KWRU Residential Connections
# KWRU System Connections

<table>
<thead>
<tr>
<th>KWRU Lift Station Name</th>
<th>Equivalent Residential Connections (ERCs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laundermat</td>
<td>24</td>
</tr>
<tr>
<td>Pines &amp; Palms</td>
<td>24</td>
</tr>
<tr>
<td>LS-3</td>
<td>61</td>
</tr>
<tr>
<td>Boyd</td>
<td>78</td>
</tr>
<tr>
<td>LS-4</td>
<td>80</td>
</tr>
<tr>
<td>LS-1</td>
<td>92</td>
</tr>
<tr>
<td>LS-2A</td>
<td>121 (298)</td>
</tr>
<tr>
<td>ForceMain</td>
<td>160 (240)</td>
</tr>
<tr>
<td>GolfCourse</td>
<td>288</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>928</strong></td>
</tr>
</tbody>
</table>
Lift Station Power Costs

KWRU Lift Station Power Costs (2010 - 2012)

- **Annual Power Cost ($)**
- **KWRU Lift Stations**

Bars represent:
- 2010 Power
- 2011 Power
- 2012 Power
VPS Power Costs

Stock Island Vacuum Pump Station Power Costs
(Total ERCs = 1,309)

Annual Power Cost ($)

- Sewage Pumps
- Vacuum Pumps
- Sewage + Vacuum Pump Cost

- 2010
- 2011
- 2012
VPS Power Cost = $11.21/ERC (based on 1,309 ERCs)

L.S. Power Cost = $20.57/ERC (based on 928 ERCs)
## Cost Comparison Results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>WEF MOP No. FD-12 Published Results</th>
<th>KWRU Vacuum Pump Station</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monthly Power Costs ($/kWh/EDU)</td>
<td>$1.66 - $3.34/EDU</td>
<td>$1.71/EDU</td>
</tr>
<tr>
<td>Power Rate</td>
<td>$0.10/kWh</td>
<td>$0.1383/kWh</td>
</tr>
<tr>
<td>Installation Date(s)</td>
<td>1970 – 2001</td>
<td>2002</td>
</tr>
</tbody>
</table>

![Annual Power Cost ($/EDU)](chart.png)
Results

Stock Island Gravity System

- Multiple small lift stations w/ only 2 large stations in the system
- Most gravity systems have multiple large stations (5-10)
Results – Stock Island VPS

- Located adjacent to WWTP; meaning less power consumption required for sewage pumps

- Average runtime is 3.28 hrs/day for sewage pumps (Sept 2010)

- Sewage pump flow (VPS) accounted for approx. 162,400 gals of treated flow (approx. 50% of the total system flow – 330,000 gpd through the WWTP)
Conclusions

• Vacuum sewers are more energy efficient when compared with conventional gravity sewer systems for similar service areas

• Results compare favorably with WEF Manual results

• Possible federal and/or state program financial incentives for energy conservation
Acknowledgements

• Chris Johnson, Key West Resort Utilities Corp.

• Bobby Bellino, Key West Resort Utilities Corp.

• Greg Wright, Key West Resort Utilities Corp.

• Rich Naret, P.E., Bilfinger Airvac Water Technologies
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