Understanding Economic Optimization of DRA in Crude Pipelines
Dennis Arensman1

1 Enterprise Products

ABSTRACT

Economically optimizing DRA within a crude pipeline is simple when using an optimization program, however it is challenging and important to understand how the optimization works. This paper will address a methodology of how DRA and power are optimized to minimize economic costs. Then an analysis will look into how velocity, fluid viscosity, DRA performance, pump spacing, pipe size, cost of electricity, and cost of DRA affect economic optimization results. Finally, this paper discusses several key factors that affect decisions such as building new stations or laying new pipelines versus increasing DRA injection rates into existing assets.

APPROACH

Energy is consumed in order to move a barrel of oil. DRA decreases the amount of energy that is required to move that barrel of oil. A price associated with both energy consumption to transport a barrel of oil and DRA utilized to reduce the energy consumption. The goal of optimizing DRA usage is to minimize the total cost to move each barrel of oil from origination to destination.

This paper looks at the shape of the power consumption curve, DRA cost curve, and combined power consumption and DRA cost curves. These curves show the cost on the y-axis and the DRA injection rates on the x-axis. Viewing the graphs provide a quick way to determine optimal DRA injection rate. Physical limitations of the pipeline, DRA skid, and pumps are also considered within this paper as part the economic optimization process.

This paper aims to demonstrate how DRA optimization works and key factors that affect optimization. Examples shown within this paper will be limited in scope in order to ensure clarity of the demonstrated concepts. Adding complexity to the examples would result in solutions that are unique to the case set up. Numbers are not included within this paper since the aim is to teach general concepts and not provide solutions to unique cases.

This paper will analyze different parameters by taking the same base hydraulic pipeline model and changing one parameter at a time. The effects of changing the parameter on the DRA performance will be considered negligible. This is done to limit the interactions caused by changing individual parameters and because different DRA types vary in response to parameter changes.

DRA Optimization

Economic optimization of DRA requires finding the minimum cost of transporting a barrel of oil from origination to destination. Costs to transport a barrel of oil include the cost of pumping the oil, cost of added chemicals, cost of personnel monitoring the pipeline, maintenance costs, and so on.

Personnel salaries, maintenance costs, repair costs, and similar type costs are set monthly or onetime costs. These onetime and monthly costs will occur regardless of what happens within the pipeline. Therefore they do not need to be considered as part of DRA economic optimization.

Costs directly affected by utilizing DRA within a pipeline are the cost of the DRA injected into the pipeline and the cost of power consumption. Therefore, only the cost of DRA injected into the pipeline and power consumption cost need to be considered as part of this analysis.

Pump power calculation is shown in Equation 1.

Equation 1

\[ P = \frac{Q \times H \times SG}{\text{conversion factor} \times \text{eff}} \]

Changes in flow rate, head, specific gravity, or efficiency will affect power. The conversion factor in Equation 1 is determined by the units of power, flow rate, and head used in the equation.
Electric cost can then be calculated by using Equation 2.

**Equation 2**

\[
Power\ Cost = (Cost\ of\ Electricity) \times (P)
\]

Changes in the cost of the fuel source and changes in power consumption will affect power cost.

DRA performance curves are normally described by Equation 3. These curves provide information about how much reduction in head loss or pressure loss to expect within a pipe segment. Equation 3 assumes that change in pressure due to friction is much larger than change in pressure due to elevation.

**Equation 3**

\[
\text{% Drag Reduction} = \frac{\Delta P_{\text{without DRA}} - \Delta P_{\text{with DRA}}}{\Delta P_{\text{without DRA}}} = 1 - \text{% Drag Reduction}
\]

Reduction in head loss for a pipe segment due to DRA injection can then be calculated using Equation 4 – assuming the segment is filled with DRA at a constant DRA concentration. Considering DRA performance in this form helps explain the magnitude of head loss reduction based on DRA performance.

**Equation 4**

\[
\frac{\Delta P_{\text{with DRA}}}{\Delta P_{\text{without DRA}}} = \frac{\Delta \text{head}_{\text{with DRA}}}{\Delta \text{head}_{\text{without DRA}}} = 1 - \text{% Drag Reduction}
\]

Combining Equation 1 and Equation 4 result in a system power requirement equation, as seen in Equation 5. This equation shows the reduction in system power requirements that can result from the use of DRA.

**Equation 5**

\[
P = \frac{Q \times \Delta H_{\text{without DRA}} \times (1 - \text{% Drag Reduction}) \times SG}{\text{conversion factor} \times \text{eff}}
\]

Equation 6 shows how to calculate DRA Usage cost.

**Equation 6**

\[
\text{DRA Usage Cost} = (\text{Cost of DRA}) \times (\text{DRA Usage})
\]

Adding the Power Cost and DRA Usage Cost together provides the total cost to transport a barrel of oil which will vary due to optimization of DRA use in the pipeline. These equations are simple algebraic calculations. It is the details and assumptions behind the data used in these calculations that makes cost calculation extremely complex.

In this paper a simple economic analysis will be utilized. DRA will be assumed to have a flat cost per gallon, unless otherwise mentioned. Thus, DRA cost will be linear with the addition of more DRA as shown in Figure 1. Power will be assumed to have a flat cost per unit power, unless otherwise mentioned. All pumps will also assume that they can operate with an infinitely variable frequency drive, unless otherwise mentioned. Thus, power cost decreases inversely to the DRA performance as shown in Figure 2.

Adding the DRA cost curve and power cost curve together with total cost per barrel on the y-axis and DRA injection concentration on the x-axis results in the graph shown in Figure 3. The resulting curve in this simplified example is a perfect J-curve. The optimal DRA injection rate is the point where the combined economic cost is minimized. Hydraulic models will need to double check if the pipeline is physically able to operate at the optimal DRA injection rate.

Figure 4 shows a pressure profile of a pipeline with two different DRA injection rates. DRA injection rate “A” results in the pipe over pressuring at the resulting flow rate; whereas DRA injection rate “B” stays within the MOP of the pipeline. Looking at Figure 4 indicates that DRA injection rate “A” is the Optimal DRA injection rate for economics. This means that if the pipeline is being designed for this flow rate, then it will never be able to operate with the economically optimal DRA injection rate. Stated another way, DRA will be injected into the pipeline in order to make the flow rate and not to optimize the cost of operating the pipeline.

**Optimization Parameters**

This section analyzes how different parameters affect the optimization process. Some parameters affect only one aspect of the DRA optimization process and are easy to understand their effect on the optimization process. Other parameters are entwined with several aspects of the DRA optimization process and simplifications need to be made in order to gain an understanding of how those parameters affect the DRA optimization process.

**DRA Type**

Not all DRA performs equally. This is good because it allows DRA to be utilized in a large variety of flow scenarios and with a variety of products. The shape of the curve can change so that the initial slope varies as shown in Figure 5, the slope can level out at a vary %DR as shown in Figure 6, or both the initial slope and the maximum %DR can vary as shown in Figure 7. Differences in degradation rates and unravel distances also occur with different types of DRA.

All these variations affect the overall system power requirement. In a system with an ideal pump, then power requirements (and thus power cost) will change inversely to the DRA performance curve as shown in Figure 8. The initial slope of the DRA performance curve has a significant effect on the economic optimization at lower velocities within pipelines. The maximum %DR is important for pipelines operating at high velocities.

**DRA Cost**

Price per unit of DRA is negotiated between DRA vendor and user. The pricing structure may have a flat cost, a tiered pricing structure, or a number of other pricing structures.
Linearly increasing the price per unit of DRA linearly increases the slope of DRA cost as DRA injection rate increases as shown in Figure 1. Increasing the cost of DRA with a flat pricing structure will result in the optimal DRA injection rate reducing as shown in Figure 9. Figure 9 also demonstrates that different pipeline parameters may require a certain amount of DRA in order for the pipeline to safely operate. Safety considerations require may require DRA inject rates to be higher than economically optimal DRA injection rates.

A tiered pricing structure for DRA leads to opportunities to decrease transportation costs by increasing DRA injection rates - assuming the correct conditions are present as shown in Figure 10. Economic analysis should be conducted to determine when this condition occurs to assist in decisions to increase DRA injection rates.

Power Cost

Gas power contracts are based on the consumption of gas within a specified time interval. Electric power contracts have an additional level of complexity. First, the total amount of electrical power drawn from the power grid within a specified time period is charged within an electric bill. Second, there is a demand charge for the largest magnitude of power drawn from the power grid within a specified period of time. The demand charge for a rarely used pump may constitute the majority of the electric bill for the pump. For this reason, using DRA to avoid use of the station may result in overall cost savings.

Similar to DRA cost, power cost is negotiated between pipeline companies and power companies. The pricing structure may be a flat cost, tiered structure, or a number of other pricing structures. Increasing power cost will increase the optimal DRA injection rate as well as increasing the total cost to transport a barrel of oil.

Pump Spacing

DRA usage allows pumps to be spaced farther apart while maintaining the same flow rate. Wider spacing of pumps can reduce the number of DRA injection skids required on a pipeline. DRA eventually degrades as it flows down the pipeline. So increasing pump spacing may result in increased DRA injection rates required at each DRA skid to counteract DRA degradation.

Control pressures at each pump may decrease if pump spacing increases. Adding a control valve in between pump stations would allow the control pressures to remain at the required level. However, control valves could also shear the DRA and a new DRA skid would be required downstream of the control valve. This will increase the total volume of DRA injected into the pipeline and may decrease the optimal DRA injection rate. Alternatively, increasing DRA injected into the pipeline would lower the discharge pressure requirements. Increasing DRA rates to match a physical limitation of the pipeline may result in more DRA injected into the pipeline than is economically optimal.

Velocity

Equation 7 shows the Dracys-Weisbach equation for head loss within a pipe. Velocity is tied to power consumption within a pipeline where power consumption is proportional to velocity squared time the friction factor. This means that increasing velocity within a pipeline is a major contributor to increasing power cost to transport a barrel of oil.

Equation 7

\[ \Delta h / L = f_D \left( \frac{1}{2g} \right) \times \left( \frac{v^2}{D} \right) \]

Increasing velocity within a pipeline can increase the degradation rate of DRA. DRA performance is assumed to be unaffected by changes of velocity within this paper. Figure 11 shows how velocity affects the shape of the J-curve analysis within an idealized system. The overall transportation cost increases as velocity increases. The ideal DRA injection rate also increases as velocity increases within the pipeline.

Pipe MOP

Pipeline MOP is a practical limitation that should be considered when analyzing DRA optimization. Pipeline systems may exist where the economically optimal DRA injection rate causes the system to operate above the MOP of the pipeline, see Figure 4. When this occurs DRA needs to be injected above the optimal concentration to allow the pipeline to operate safely.

DRA presents unique operating scenarios where the system can become limited due to the economic cost of transporting a barrel of oil rather than a hydraulic limitation. Transportation cost analysis should be performed during pipeline design as well as hydraulic studies to avoid situations where the design flow rate is not economically feasible even though the design flow rate is hydraulically feasible.

Higher MOP should be considered within pipelines if high velocities are required within the pipeline. Increasing the MOP of a pipeline also allows pump stations to be spaced farther apart which can reduce the number of locations DRA needs to be injected into the pipeline.

Pipe Diameter

Pipe diameter affects fluid velocity and DRA performance. Larger diameter pipes are able to move flow rates at lower velocities than smaller diameter pipes. Thus, increasing pipe diameter can decrease the overall cost to transport a barrel of oil. Smaller diameter pipes may still be selected due to the initial capital cost of large diameter piping compared to small diameter piping. Increasing a pipe too much may result in an optimal DRA injection rate of 0 ppm as shown in Figure 12. Sudden reductions in pipe diameter may cause DRA shearing which will remove any benefits of the DRA downstream of the pipe constriction.
**Fluid Properties**

Fluid properties such as viscosity, density, temperature, etc. are closely tied to DRA performance while also having an effect on the hydraulic of the pipeline. These parameters are not possible to predict how changes in these parameters will affect the overall optimal DRA injection rate.

For example, increasing the viscosity of a fluid will generally reduce the performance of DRA. This will reduce the optimal DRA injection rate. However increasing the viscosity of a fluid will also increase the power required to transport a barrel of oil. The increased power will have the effect of increasing the optimal DRA injection rate. Different fluids and DRA vary in their interactions and will therefore result in different system behaviors.

**Pumps**

Pumps have a significant influence on power costs. The efficiency curve, driver type, fuel type, head limitations, and flow rate limitations influence the shape of the power cost curve.

A fixed speed pump will require a control valve downstream of the pump to ensure the discharge pressure is within the MOP of the pipeline. A pipe may only need 50% of the maximum head of a pump, but the fixed speed pump is required to operate at its set speed and throttle the remainder of the consumed power. Economic optimization curves with fixed speed pumps can have flow rates where extra DRA injection is used to prevent pumps from operating. Conversely the economic optimization curves can also have flow rates where reduced DRA injection is used because the pump is required to produce a set amount of head.

Pumps with VFDs are able to produce economic DRA curves that are closer to the idealized curves presented within this paper. VFDs have limitations for their minimum speeds. Cases may still arise where the VFD is unable to allow a system to perform at the economically optimal DRA injection rate because the VFD would be required to operate below minimum speed.

Gas turbine driven pumps are able to control their fuel consumption. The controlled fuel consumption allows the pumps to vary their speed and thus the produced pump head. Gas turbines may encounter similar limitations to VFDs.

Pump efficiency curves show how a pump will perform at different flow rates. Flow rates near the best efficiency point (BEP) of the pump will have the highest efficiencies. Efficiency will decrease as flow rates move away from the BEP. The shape of the pump efficiency curve will influence the power consumption as shown in Figure 13. The influence on power consumption will extend to the power cost curve as shown in Figure 14.

Fuel type consumed by the pump influence the motor efficiency and the cost of power. Head limitations may cause excessive DRA requirements at high flow rates. Flow rate limitations may become the bottleneck of the pipeline if DRA allows the pipeline to operate at flow rates higher than the maximum design flow rate.

**DRA Skid Limitations**

DRA skids are sized for expected DRA usage. Pumps are used to inject DRA from a storage tank into the pipeline. The pump on the DRA skid is subject to minimum and maximum flow rate limitations. These limitations can prevent the pipeline from operating at the optimal DRA injection rate.

**Conclusions**

Understanding how different parameters affect DRA optimization is beneficial when making decisions that affect pipeline economics. Combining the electric costs and DRA costs for a pipeline will create a j-curve which can then be used to determine the optimal DRA injection rate. Some cases may have physical limitations that prevent a pipeline from operating at the minimum transportation cost for a system. By understanding how different parameters affect a pipeline, it is possible to know how varying the operation of a pipeline will affect the economics without running a model.

**References**


**Author Biography**

**Dennis Arensman**, Dennis is a Senior Pipeline Systems Planning Engineer at Enterprise Products Partners L.P. He has worked in the energy industry for 5 years. Dennis holds a Bachelor of Science Degree in Mechanical Engineering from the University of Houston and a Master’s of Science Degree in Petroleum Engineering from Texas A&M University.
FIGURES

Figure 1 – DRA Cost versus Volume of DRA Injected with Fixed DRA Cost

Theoretical DRA Cost vs Gallons of DRA Used

Figure 2 – Ideal Power Cost Relationship to DRA Performance Curve

Electric Cost vs DRA Injection Rate

- Power Cost
- DRA Performance

DRA Injection Rate, PPMv

Power Cost, $/volume

DRA Performance, %DR
Figure 3 – Combined DRA Cost and Power Cost

Figure 4 – Case Where DRA Concentration is Required to be Higher than Optimal Concentration for Desired Pipeline Flow Rate
Figure 5 – DRA with Different Initial Slopes and the Same Maximum %DR

DRA with Different Initial Slopes

Figure 6 – DRA with the Same Initial Slopes and Different Maximum %DR

DRA with the Same Initial Slope and Different Maximum %DR
Figure 7 – DRA with Different Initial Slopes and Different Maximum %DR

Figure 8 – Power Usage vs DRA Injection Rate for 2 Different DRA Performance Curves
Figure 9 - Example of Optimal DRA injection rates vs Pipeline Velocity at different DRA prices

**Optimal DRA Injection Rate vs Velocity**

- Very Low Cost
- Low Cost
- Medium Cost
- High Cost
- Very High Cost

Min Required DRA Line

Figure 10 – Example of Tiered DRA Pricing Creating Opportunities to Decrease Transportation Cost by Increasing DRA Injection Rate

**Example of Tiered Pricing Affecting DRA Injection Decisions**

Combined Power and DRA Cost
Figure 11 – Graph of Power and DRA Costs vs DRA Injection Rates at Various Velocities

Total Cost vs DRA Injection Rate With Various Velocities

- Very Low Velocity
- Low Velocity
- Medium Velocity
- High Velocity
- Very High Velocity

DRA Injection Rate

Figure 12 – Total Cost vs DRA Injection Rates for Various Pipeline Diameters

Comparison of Transportation Cost vs DRA Injection Rate at the Same Velocity

- Smallest Diameter
- Small Diameter
- Medium Diameter
- Large Diameter
- Largest Diameter

DRA Injection Rate
Figure 13 - Pump Efficiency Effect on Power Consumption

Example of Pump Efficiency Effect on Power Consumption

- Flat Pump Efficiency
- Variable Pump Efficiency
- Power - Flat Pump Efficiency
- Power - Variable Pump Efficiency

Flow Rate

Figure 14 - Pump Efficiency Effect on Power Cost

Example of Pump Efficiency Effect on Power Cost

- Power Cost - Flat Pump Efficiency
- Power Cost - Variable Pump Efficiency