An Analysis of Power Requirement and Cost of The Dakota Access Pipeline and Rail Transportation

Sarah Liu

The City College of New York

Professor Prathap Ramamurthy

ME 35600 Fluid Mechanics

26 November 2023

Abstract

In the proposal of the Dakota Access Pipeline, the uptick in opposition struck upon the need of the analysis of the overall impact of the pipeline to the environment as well as the economic impacts. This report serves the sole purpose of breaking down the costs and carbon emission of the two options. In this analysis, in order to determine the more economic option to transport crude oil at a rate of 91,000 m^3/day, power consumption of an added pipeline as well as using rail transportation is calculated to determine carbon emissions and costs to run. For the purpose of this analysis only the operations of the transportation of the life cycle analysis are considered to simplify the comparation. Specific design requirements of the pipeline account for additions of valves and flanges added to overall head loss which is accounted for in the calculations.

Methodology

To start off the calculations of carbon emissions of the proposed Pipeline, several design requirements must be considered.

$$D = 750\,mm\,Diameter\;of\;the\;pipeline$$

$$Material\!:\;Stainless\,Steel$$

$$Flange\;every\;100\,m$$

$$Valve\;every\;100\,km$$

For the calculations involved with both the railroad and pipeline, the properties of the crude oil transported as well as the required operating data are given below.

$$\rho = 850\,\frac{kg}{m^3}\,\textit{density of crude oil}$$

$$\nu = 4E-6\,\frac{m^2}{s}\;\textit{Kinematic viscosity of Crude Oil}$$

$$L = \;1900\,km$$

For calculating the carbon emissions, power requirements are calculated, considering both major and minor head losses. Total Power is calculated with the equation:

$$P = \rho g Q \Sigma h_f$$

Where Σh_f represents the summation of the major head loss and all minor head losses due to the flanges and valves.

Major head loss is calculated with the equation:

$$h_f = f\,\frac{LV^2}{2Dg}$$

Where only the friction coefficient and velocity are unknown. Velocity can easily be calculated from the Volumetric flow rate defined above by using:

$$V = \frac{Q}{\frac{\pi}{4}D^2}$$

Converting the volumetric flow rate into correct units and plugging into the equations yields a Velocity of $V = 2.384\ \frac{m}{s}$. To calculate the friction coefficient, the Reynold's number (Re) must first be calculated. Re can be found with the equation:

$$Re = \frac{VD}{\nu}$$

Plugging in the Velocity previously found and the kinematic viscosity and diameter, we yield a Re of 447009.25. This Reynold's number also validates that the fluid flow is turbulent, although it could also be assumed. This conclusion can lead us to using the Moody Chart to easily reference friction Factor based on the Reynold's Number and the relative number. We can calculate the relative roughness by referring to the roughness of the material of the pipe. Stainless steel has a roughness of around 0.002. The relative roughness is found simply by dividing the roughness by diameter. The relative roughness is calculated as 2.67E-6. The yielded f is 0.01275.

Note that f can also be calculated through the implicit Colebrook equation or the explicit Haaland equation. Plugging all known values into the head loss equation we yield:

$$h_f = \frac{(0.01275 \cdot 1.9E6 \cdot 2.384^2)}{2 \cdot 9.81 \cdot 0.75}$$

$$h_f = 9356.556\, m$$

To calculate the minor loss, Resistance Coefficient can be found with the resistance coefficient table. Such value is summed up for each valve and flange and a total head loss can be calculated with the equation below:

$$h = h_f + \frac{v^2}{2g}(\Sigma\kappa)$$

$$h = 102926.38\, m$$

To now calculate power consumption due to the pipeline

$$P = 850 \cdot 1.053 \cdot 102926.38 \cdot 9.81$$

$$P \approx 90.37\, MW$$

In the calculations of the power requirement of a railroad alternative, the basis requirement of the railroad is set. The most common Crude Oil railroad transportation is the US DOT-111 tank cars. Such requirements are given:

$$Gas\ milege\text{:}\ 1.5\ \frac{km}{L}$$

$$Capacity\text{:}\ 131\ m^3$$

With this information, we can calculate the train car required to transport $91{,}000\ m^3$ of crude oil.

$$N = 7\ train\ cars$$

These train cars must rely of diesel fuel to run, and such information can be recovered to calculate power requirements:

$$Calorific\ value:\ 45.5\ \frac{MJ}{kg}$$

$$\rho(diesel) = 866\ \frac{kg}{L}$$

(World Nuclear association)

Now to calculate the total fuel requirements we start by calculating the liter of fuel needed for the 7 train cars and convert into the correct units.

$$V = \frac{L}{Gas\ milege} \cdot N$$

$$V = \frac{(1900\ )}{1.5} \cdot 7 \cdot \frac{1}{24\ \cdot 3600}$$

$$V = 0.1026\ \frac{L}{s}$$

The power requirements of the railcars are calculated below with the given information:

$$P = \rho C_v V$$

$$P = 866 \cdot 45500 \cdot 0.1026$$

$$P = 4.04\ MW$$

Cost comparation:

According to the *US Bureau of Transportation Statistics*, the cost of transporting oil for pipeline is $5 per barrel and railroad transportation is $10-15 per barrel. The cost of transporting the two methods for the total proposed $91{,}000\ m^3$ volume of oil per day.

Pipeline: $2.36 mil/day

Rail: $5.73 mil/day

Carbon emissions calculations:

$$266.5\ CO_2\ emissions\ g\ per\ KWh$$

Rail: 4.04 MW-day = 96,960 KWh

$$CO_2\ emissions:\ 25.84\ Mg$$

Pipeline: 90.37 MW-day = 2,168,880 KWh

$$CO_2\ emissions:\ 578\ Mg$$

(Volker Quaschning)

Analysis

From the results of the calculations, we can see that the pipeline power requirements are 22 times that of railroad transportation. The cost of the pipeline is far less than the railroad in the day-to-day operations. It is also important to note that these calculations consider only the power of transportation operations, neglecting the full Life cycle requirements including construction and maintenance costs.

Conclusion

As stated above, such calculations in this report are far limited in the total needed information of the comparative analysis for the DAPL and a railroad. Much of the calculation is also limited to more ideal conditions, ignoring the safety, physical damages to the land, how prone the method will be to accidents, as well as environmental analysis of the land such transportation would be placed into. Such impacts of the Pipeline are done with a full Life Cycle analysis conducted in full and referenced in the power calculations (Liqiao H., et al.) However, from the calculations, it can be concluded that an added pipeline is far more power intensive and therefore causes more environmental impact than a railroad in terms of carbon emissions. The cost of the pipeline operation is far less than that of the railroad by only operations. It should however be noted again that such cost neglects the high amount of cost for construction as that number is estimated to be $7.5 billion *(U.Colorado Boulder)*.

References

Bureau of Transportation. (2012). Retrieved from https://www.bts.gov/archive/publications/national_transportation_statistics/table_01_61. Accessed November 25, 2023.

Carla F., Mark M., Nicholas P., Kate F. (2018). Social Cost and Material loss: The Dakota Access Pipeline. *University of Colorado Boulder.* Retrieved from tps://www.colorado.edu/program/fpw/sites/default/files/attached-files/social_cost_and_material_loss_0.pdf. Accessed November 25, 2023.

Liqiao H., Qi L., Jinyue Y., Yongtu L., Haoran Z. (2021). Carbon Footprint of Oil Products Pipeline Transportation. *Science Direct.* Retrieved from https://www.sciencedirect.com/science/article/abs/pii/S0048969721019768.Accessed November 25, 2023.

Volker Quaschning. (2022). Specific carbon dioxide emissions of various fuels. Retrieved from https://www.volker-quaschning.de/datserv/CO2-spez/index_e.php. Accessed November 26, 2023.

World Nuclear Association. (2022). Heat Values of Various Fuels. Retrieved from https://world-nuclear.org/information-library/facts-and-figures/heat-values-of-various-fuels.aspx. Accessed November 25,2023.