MATLAB codes were developed in order to determine the decrease in the amount of CO2 emissions ($∆CO\_{2})$ using a hybrid geothermal system vs. a natural gas system or coal based system for steam generation at required conditions and for a hot water-based geothermal system vs. a natural gas system or a coal based system for hot water generation. The steam-based hybrid geothermal system requires a surface pump, a subsurface pump, a boiler, and a heat pump. The hot water-based geothermal system requires a subsurface pump, a surface pump, and a heat pump. The amount of CO2 generated by operating the geothermal plant is dependent on how much electricity is needed for the utilities in the surface plant as well as the source of the electricity. In our calculations, we used a natural gas combined cycle with an efficiency of 64% as the source of electricity for the geothermal surface plant equipment.[1] The amount of CO2 produced by the geothermal energy systems will be compared to a heating and cooling system that is entirely based on natural gas or coal (CO2 produced by the original system). The heating value of natural gas used was 39 MJ/m3. The amount of natural gas needed was calculated using the power requirement, the heating value of natural gas and the density of natural gas (0.90 kg/m3). It is assumed that 2.75 kilogram of CO2 was produced per kilogram of natural gas used.[2] Equation 1 is used to get the $∆CO\_{2}$ values.

$∆CO\_{2}=\frac{CO\_{2} produced by the orginial system-CO\_{2} produced by the new system}{MMBtu produced }$ (1)

In order to determine the amount of CO2 produced by the natural gas boiler alone, the volume of natural gas needed to supply the boiler was taken and multiplied by the density of natural gas to get the mass of natural gas needed. In order to calculate the amount of steam produced by the boiler, the volume of natural gas was multiplied by the heating value of natural gas and an assumed efficiency to produce the steam of 85%. In order to calculate the amount of CO2 produced, it was again assumed that 2.75 kilogram of CO2 was produced per kilogram of natural gas used.[2]

In order to determine the amount of CO2 produced by burning coal in order to produce hot water or steam, the current CO2 emission per MMBtu that was produced by the MEA plant in 2015 will be used which is 94.65$\frac{kg}{MMBtu}$.[3]

Tables 1 and 2 show that a horizontal well configuration is more environmentally beneficial than a vertical well configuration. It can also be seen that supplying the entire campus with a hybrid geothermal system to support WVU’s heating and cooling need is more environmentally beneficial than just using a natural gas based or coal based steam heating and cooling system.

*Table 1. Amount of CO2 emissions reduced by steam-based hybrid geothermal system with heat pump compared to natural gas boiler and coal.*

|  |  |  |
| --- | --- | --- |
|  | Natural Gas $\frac{kg CO\_{2} reduced}{MMBtu}$  | Coal $\frac{kg CO\_{2} reduced}{MMBtu}$  |
| Scenario 1 Horizontal  | 2.4265 | 23.2803 |
| Scenario 2 Horizontal  | 2.0713 | 22.9155 |
| Scenario 1 Vertical  | 1.9754 | 22.8349 |
| Scenario 2 Vertical  | 1.7457 | 22.5929 |

*Table 2. Amount of CO2 emissions reduced by steam-based hybrid geothermal system without heat pump compared to natural gas boiler and coal.*

|  |  |  |
| --- | --- | --- |
|  | Natural Gas $\frac{kg CO\_{2} reduced}{MMBtu}$  | Coal $\frac{kg CO\_{2} reduced}{MMBtu}$  |
| Scenario 1 Horizontal  | 3.0870 | 23.9232 |
| Scenario 2 Horizontal  | 3.2025 | 24.0412 |
| Scenario 1 Vertical  | 2.8501 | 23.6918 |
| Scenario 2 Vertical  | 3.0231 | 23.8648 |

 In Table 3, it can be seen that using a flow rate of 40 kg/s per configuration is more environmentally beneficial when comparing it to using a flow rate of 80 kg/s. This is because the amount of subsurface pump power required increases with the production flow rate from the well. It can also be seen that the water to steam ratio does not have much effect on the environmental impact when comparing systems of the same flow rate and alternate energy supply (coal or natural gas).

*Table 3. Amount of CO2 emissions reduced by hot water-based geothermal system based on peak energy usage values and a horizontal well configuration.*

|  |  |  |  |
| --- | --- | --- | --- |
| Flow Rate from Each Configuration | Water/ Steam Usage | Natural Gas $\frac{kg CO\_{2} reduced}{MMBtu}$ | Coal $\frac{kg CO\_{2} reduced}{MMBtu}$ |
| 80 kg/s | 60/40  | 42.4903 | 70.3877 |
| 75/25 | 41.8561 | 69.7535 |
| 85/15 | 41.6466 | 69.5439 |
| 40 kg/s | 60/40  | 48.2839 | 76.1813 |
| 75/25  | 48.0007 | 75.8981 |
| 85/15  | No. of wells are above the allowable value range | No. of wells are above the allowable value range |

Overall, a hot water-based geothermal system is more environmentally beneficial than a steam-based hybrid geothermal system when considering the amount of CO2 that would be reduced when comparing it to a natural gas or coal system. When comparing steam-based hybrid geothermal systems, the systems without a heat pump are more environmentally beneficial.

**References**

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