Integration of energy storage infrastructures into electrical grids represents a crucial milestone in the transition towards energy systems with high penetration of renewables. However, the high cost of the currently available technologies is a significant barrier for their implementation on the industrial scale. High temperature thermal energy storage systems, in combination with bottom steam cycles, are being investigated as potential cost-effective alternatives to traditional large-scale energy storage technologies. In this study, the performance of a rock bed high temperature energy storage unit is experimentally investigated. The rock bed has a storage capacity of 450 kWh$_{th}$, was built to store heat at 600°C and is characterized in terms of thermal efficiencies. Charge and discharge cycles were performed for different operating conditions and the temperature distribution across the bed was analyzed. A particular focus was set on the study of the impact of buoyancy forces on the temperature gradient inside the bed and on the storage unit efficiency. Different charging powers, flow concepts and rock bed configurations were discussed to optimize storage operations and led to an improvement in efficiency of the charging phase of 17%. A thermal round trip efficiency of around 68% was estimated for the best configurations and different improvement approaches were discussed for future research.