Oxygen-supply system design optimization [1]

Set-up

The operation of a Basic Oxygen Furnace (BOF) is based on cycles. Each cycle consists of a low oxygen demand interval in which raw materials are introduced to the furnace, and a high oxygen demand interval in which the raw material is processed. The low demand interval is 0.4 hours, and the high demand interval (t_1) is 0.6 hours, giving a total cycle time (t_2) of 1 hour. Due to equipment limitations, the oxygen production rate (F) is held constant throughout the cycle. Any excess oxygen produced during the low demand period is compressed and stored, to be withdrawn as needed during the high demand period. The objective of this problem is to design an oxygen-supply and storage system that meets the oxygen demand of the furnace over the entire cycle while minimizing cost. Figure 1 shows the BOF system.

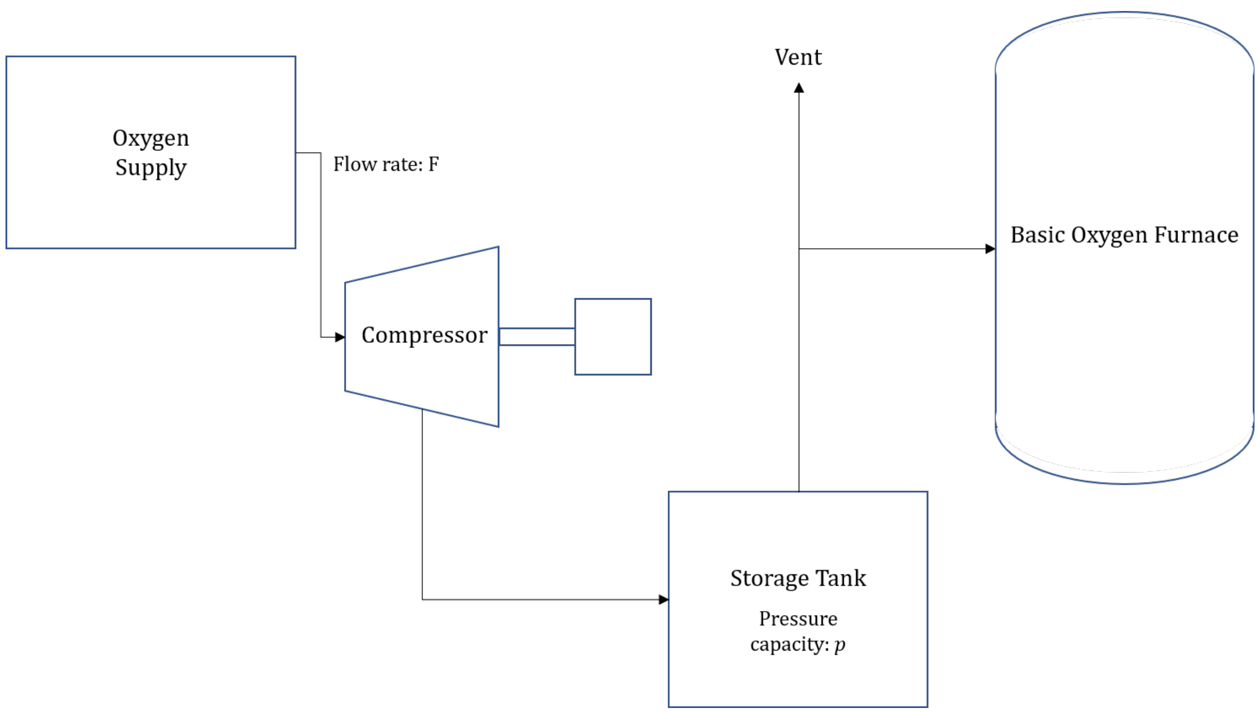

Figure 1: Oxygen Supply System

The two design variables for this system are the maximum storage tank pressure (p) in psia and the oxygen production rate (F) in tons/hour. The following are given constants. The low oxygen demand rate (D_0): 2.4 tons/hour, the high oxygen demand rate (D_1): 37 tons/hour, The gas constant (R): 670.6 ($ft^3 psia/(HP - HR)$)), Temperature (T): 530 degrees Rankine, the compressibility factor 0.98 (z), unit conversion factor (k_1): 14005.8, compressor efficiency (k_2): 0.75, and the oxygen delivery pressure (p_0): 200 psia.

These values are used to calculate the compressor design capacity (H), and the storage tank design capacity (V). These intermediate values are then used to calculate the total cost of the system, as shown below.

Cost Functions

The annual cost of the BOF system is found using Equation (1). Here d is an annual cost factor for the compressor and storage tank and N is the number of cycles in one year of operation.

$$Annual\ Cost = C_1 + d(C_2 + C_3) + NC_4 \tag{1}$$

C_1 is the oxygen plant annual cost, and is given by:

$$C_1 = a_1 + a_2 F \tag{2}$$

C_2 is the capital cost of the storage vessel:

$$C_2 = s_1 s_2 V^{s_3} \tag{3}$$

C_3 is the capital cost of the compressor:

$$C_3 = 0.2 b_1 b_2 H^{b_3} \tag{4}$$

C_4 is the compressor power cost and is given by:

$$C_4 = 0.001 b_4 t_1 H \tag{5}$$

Where a_1, a_2, s_1, s_2, s_3, b_1, b_2, b_3, b_4 are cost parameters.

Table 1: Cost parameters for the oxygen supply and storage system [2]

symbol	value	units
a_1	60.9	dollars/hour
a_2	5.83	dollars/hour
b_1	2.5e-5	dollars/hour
b_2	680	$(HP)^{-c_3}$
b_3	0.85	dimensionless
b_4	6.0e-3	dollars/(HP-HR)
s_1	3.0e-5	dollars/hour
s_2	660	$(cubic feet)^{-b_3}$
s_3	0.9	dimensionless
d	5	dimensionless
N	8000	dimensionless

Intermediates

The maximum amount of oxygen stored (I_{max}) in the tank during the cycle can be calculated as:

$$I_{max} = (D_1 - F)(t_2 - t_1) \tag{6}$$

The compressor design capacity is given by:

$$H = \frac{I_{max}}{t_1} \frac{RT}{k_1 k_2} \ln \frac{p}{p_0} \tag{7}$$

Constraints

The maximum tank pressure lies under the constraint:

$$p >= p_0 + 1 \tag{8}$$

To meet the required oxygen demand the production rate must meet the following constraint:

$$F >= \frac{D_0 t_1 + D_1(t_2 - t_1)}{t_2} \tag{9}$$

References

[1] A Ravindran, Gintaras Victor Reklaitis, and Kenneth Martin Ragsdell. *Engineering optimization: methods and applications*. John Wiley & Sons, 2006.

[2] Frank C. Jen, C. Carl Pegels, and Terrence M. Dupuis. Optimal capacities of production facilities. *Management Science*, 14(10):B573–B580, 1968.