1. Introduction

The air separation unit (ASU) is one of crucial elements of the oxy-fuel power unit. The combustion process of fuel in modified atmosphere, where nitrogen is replaced by carbon dioxide, needs large amounts of high-purity tonnage oxygen. For power units, of the net electric power of hundreds megawatts, the ASU of thousands tons of oxygen per day are required. Presently, such a quantities may be obtained only by cryogenic air separation. The effectiveness of cryogenic oxygen production is thus one of the crucial parameters impacting the overall oxy-fuel plant efficiency. The main goals of the present paper are thus identification of components of the ASU cycle which are responsible for largest irreversibilities, as well as, quantitative evaluation of potential of their improvement. The case study has been based on a large capacity, three-column ASU and one-column ASU as a reference. The analyzed ASU produces gaseous oxygen at 95% purity and near ambient pressure, as required by an oxy-fuel coal-fired power unit.

2. Simulation model

The ASU plant has been modeled in detail on AspenPlus software. For all subsystems, like air compressors, heat exchangers, throttling stations and distillation columns, exergy balances have been formulated and solved. Absolute and relative exergy losses occurring in main components of the system have been calculated. The relative losses
have been normalized taking the overall work consumption of the ASU system as basis. Such an approach enables for determination of the contribution of each component to the total system irreversibility.

Two simulation models have been developed: one- and three-column type ASU. The structures of both plants have been adopted from [1] and [2]. Aspen Plus simulation schemes have been presented in Figures 1 and 2.

Model of one-column ASU consists of:
- three stage air compression with inter-stage cooling,
- cryogenic heat exchanger,
- air condenser (reboiler of distillation column)
- throttling valve
- distillation column,

while in case of three-column ASU, the model consists of:
- three distillation columns,
- four stage compression with inter-stage cooling,
- two cryogenic heat exchanger,
- two condensers - reboilers for low pressure column,
- throttling valves,
- expander.
The potential of ASU effectiveness improvement has been evaluated by change of crucial parameters, defining effectiveness of particular devices, to its marginal values ensuring lowest possible irreversibility, e.g. compressor efficiencies have been fixed to 100% and minimal temperature differences in heat exchangers have been fixed to 0. The computational process have been repeated independently for each crucial part of ASU enabling determination of an impact of singular device irreversibility on the exergy loss distribution among all ASU components. The assumptions related to analyzed cases have been presented in Table 1.

Table 1. Case studies assumptions

<table>
<thead>
<tr>
<th>ASU type</th>
<th>Case</th>
<th>Minimal temperature difference in cryogenic heat exchanger</th>
<th>Minimal temperature difference in inter-stage cooler</th>
<th>Compressors polytrophic efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>one-column</td>
<td>base case</td>
<td>5</td>
<td>5</td>
<td>0.85</td>
</tr>
<tr>
<td></td>
<td>case 1</td>
<td>3</td>
<td>5</td>
<td>0.85</td>
</tr>
<tr>
<td></td>
<td>case 2</td>
<td>2</td>
<td>5</td>
<td>0.85</td>
</tr>
<tr>
<td></td>
<td>case 3</td>
<td>1</td>
<td>5</td>
<td>0.85</td>
</tr>
<tr>
<td></td>
<td>case 4</td>
<td>0</td>
<td>5</td>
<td>0.85</td>
</tr>
<tr>
<td></td>
<td>case 5</td>
<td>0</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>case 6</td>
<td>0</td>
<td>2.5</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>case 7</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>three-column</td>
<td>case 8</td>
<td>5</td>
<td>5</td>
<td>0.85</td>
</tr>
</tbody>
</table>

3. Results

The exemplary results in form of calculated exergy losses have been presented in Figure 3. The exergy loss $\Delta \dot{X}$ has been defined as a sum of exergy destruction $\delta \dot{X}$ (internal loss caused by irreversibility) and external loss $\dot{X}_{out}$ (waste exergy crossing the system boundary), as stated in Equation 1.

$$\Delta \dot{X} = \delta \dot{X} + \dot{X}_{out} = \dot{X}_{in} - \dot{X}_{outP}$$

while:

$$\delta \dot{X} = \dot{X}_{in} - \dot{X}_{out}$$

where:

$\dot{X}_{in}$ - exergy entering the component, W,

$\dot{X}_{out}$ - exergy leaving the component, W,

$\dot{X}_{outP}$ - exergy of products leaving the component, W,

$\dot{X}_{outA}$ - external loss of exergy from the component, W.

All the exergy losses have been calculated assuming the same product (oxygen) stream (1 kg/s), purity (95%) and pressure (101.3 kPa).
The obtained results indicate, that the largest exergy losses occur in cryogenic heat exchangers. As expected, adding of additional distillation columns (upgrading to three pressure levels) and integration of heat exchange between distillation columns, lead to substantial increase of exergetic efficiency. The potential for further improvement is however reduced. There is still some reserve in heat exchange integration and distillation processes. It is worth to note, that the exergy loss in air compression train is strictly related to irreversibilities occurring in other components and affecting the required compressed air pressure.

**Literature**


**Acknowledgments:**
This work has been prepared in framework of the task of research: “Development of oxy-combustion technologies for pulverized-coal and fluidized bed boilers integrated with carbon dioxide capture” funded by the Polish National Center for Research and Development within the strategic program of research and development: “Advanced energy generation technologies”.  
Co-author of this paper (Grzegorz Nowak) is a scholar in SWIFT project POKL.08.02.01-24-005/10 which is co-financed by European Union within European Social Fund