Integration challenges of Air Separation Unit with thermal power plant

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Air separation technologies – current state

Table 1. Comparison of air separation methods

Technology & development stage	O_2 purity, %	Capacity, tons per day	Possible by-produckts, Quality	Energy demans, kWh/ton O_2	Driving force	Start-up time
Cryogenic Matured	99+	up to 4 000*	Nitrogen, Argon, Krypton, Xenon, Very good	200 [1]	electricity	hours/ days
Adsorption Matured	95+	up to 300	Nitrogen, Bad, ca 11% O_2	500 [2]	electricity/ heat (70 – 90 ºC)	minutes/ hours
Membrane (polymer) Matured	~40	up to 40	Nitrogen, Bad	– [3]	electricity	minutes
Membrane (ITM) R&D phase	99+	laboratory scale	Nitrogen, Bad	400 [4]	electricity/ heat (800 ºC)	hours

* – from a single train
[1] – data from existing installation
[2] – laboratory-based estimation
[3] – not applicable due to low oxygen purity
[4] – literature data

Possible coupling ASU unit with thermal power plant

The energy required for separation of oxygen must be obtained as the expense of part of the energy produced in the energetic block using oxygen combustion technology. Exhausted gases that result from the combustion of pure oxygen have high concentration of carbon dioxide. In order to sequestrate those gases must be first compressed what is the resulting expenditure of energy associated with the work of compression. The energy expended on these two processes results in a significant decrease in the efficiency of the power unit.
In order to improve the economics of engagement the ASU with thermal power plants it is necessary to appropriate design method of their engagement:

- Reduction of energy consumption of oxygen separation process associated with a lowering of the purity to 95%
- Use of waste heat from power units.
- Use of waste products from the process of oxygen separation from air, such as nitrogen.

The resulting nitrogen can be used for such purposes as inertisation of different tanks or silos, drying of coal and biomass.

Oxy-combustion technology

The concept of oxy-combustion is to use oxygen instead of air for the combustion process in order to achieve a high concentration of CO2 in the flue gas. Table 2 shows the current production of electricity and its potential demand for oxygen if all coal power plant uses oxy-combustion method.

Table 2. Current oxygen electricity production in the world.

	European Union	USA	World
Average energy production [GWh/month]	257 160	337 313	1 884 916
Percentage of total carbon energy	52 %	37 %	42 %
Daily oxygen demand [tons] [1]	3 362 000	3 154 000	19 792 000
Amount of energy needed to produce the required amount of oxygen [GWh/month] [2]	88 640	83 163	521 817
Percentage by which the total energy production would have to be raised [3]	34,47 %	24,65 %	27,68 %
Additional quantity of carbon dioxide resulting from the production of energy to produce oxygen [tons/day] [4]	3 047 000	2 859 000	17 937 000
Percentage increase in daily production of CO_2 [4]	66 %	66 %	66 %

[1] – on the assumption that all coal power plants use the oxy-combustion method
[2] – calculated on the basis of today's global average energy consumption of oxygen production – 877 kWh / ton O_2
[3] – in order to maintain current energy demands
[4] – on the assumption that energy to power the ASU is derived entirely from coal sources

Lignite drying by dry nitrogen stream produced in ASU

To simulate the effect of drying lignite by stream of dry nitrogen to increase the efficiency of electricity generation, the following assumptions have been made:

- electric power of the power unit 100 MW
- efficiency of the power unit 35 %
- relative humidity of the lignite 42,1%
- relative humidity of nitrogen from the ASU 0 %
- relative humidity of nitrogen after lignite drying 100 %
- the lignite corresponds to one of the national coal.

For the assumed power block there were specified the fuel stream and the stream of oxygen required in the oxy-combustion technology. The net calorific value of coal was calculated using the Mendeleev formula. A nitrogen flow was determined by the stream of oxygen and the composition of the air. The drying process influenced the decrease in moisture content of the coal and, indirectly, the share of other ingredients.

Table 3. Influence of the waste dry nitrogen temperature for improving the thermal block parameters by drying lignite (initial coal moisture content: 42.1%)

Nitrogen temperature, ºC	Lignite humidity after drying, %	Increase of calorific value, %	Reducing of lignite use, t/day	Reducing of lignite use, %
10	40.7	3.0	74	2.9
20	39.3	6.0	143	5.6
30	36.8	11.5	261	10.3
40	31.8	22.3	462	18.3
50	21.1	45.6	793	31.3
55	10.5	68.7	1 030	40.7

Use of heat from power plant

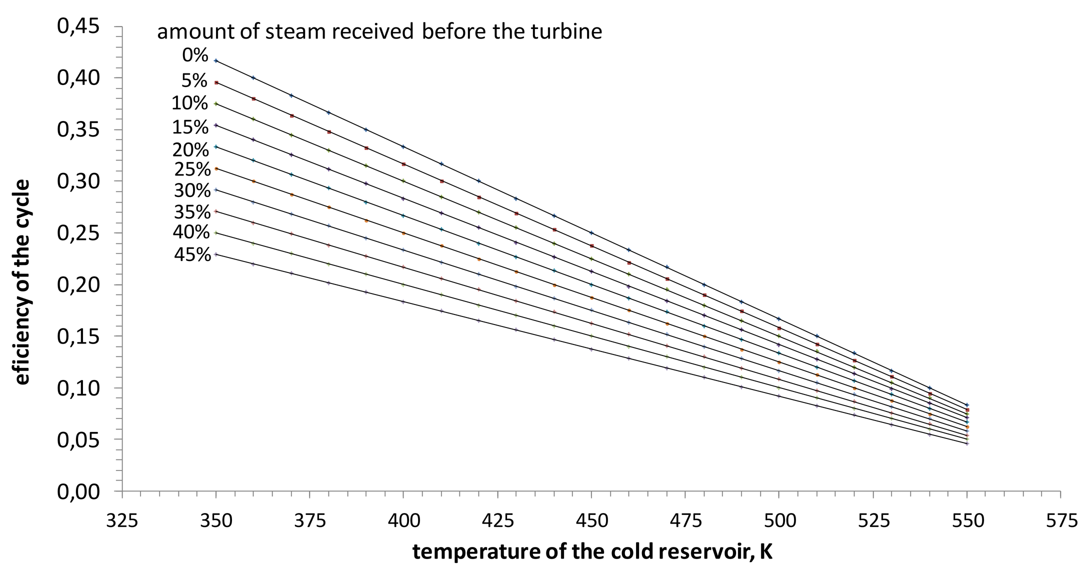

Fig 1. Carnot cycle efficiency, depending on the temperature of the cold reservoir and the amount of steam received before the turbine. Temperature of the hot reservoir – 600K.

In order to perform air separation by the TSA method, it is necessary to provide heat to the adsorption bed in the regeneration step. Obtaining this heat from thermal power plant involves the reduction of the thermal cycle efficiency by either increasing the temperature of so-called cold reservoir of the circuit (waste heat), or by receiving part of the superheated steam before the turbine

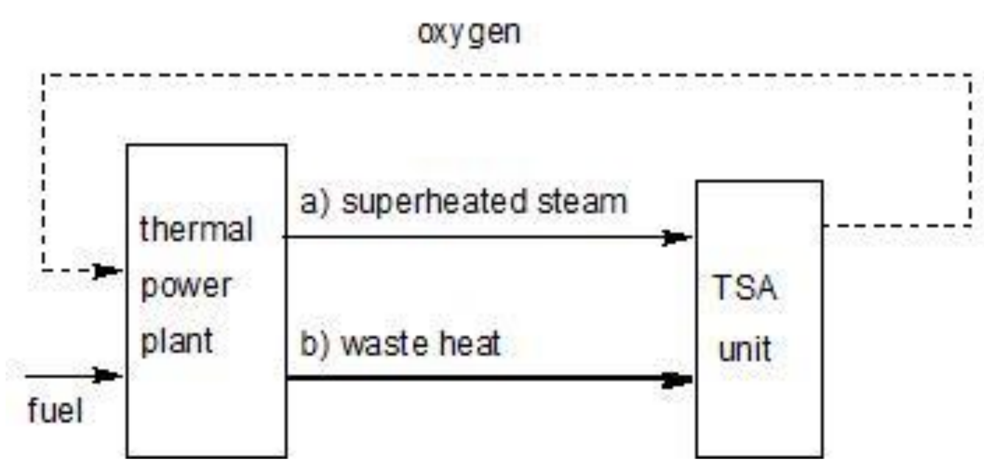

Fig 2. Possible coupling of TSA oxygen separation unit witch thermal power plant by a) receiving part of the superheated steam before the turbine or by b) receiving waste heat on a higher level of temperature

Conclusions

There are three main mature technologies of oxygen separation from the air: cryogenic, adsorption and polymer membrane. A choice of a particular oxygen separation method depends on the required scale of oxygen production and its purity. Cryogenic separation method is the best suitable for high capacities. It also guarantees high purity of both oxygen and waste gasses. Adsorption methods can produce oxygen in much smaller capacities than cryogenic ones. Oxygen obtained from polymer membrane has no sufficient purity. In case of oxy-combustion, the main criterion is electrical capacity of the plant. Second criterion refers to the purity of obtained oxygen that should not be lower than 90%. The optimal purity for oxy-combustion is about 95%. For oxy-combustion thermal power plants with electrical capacity exceeding 25 MWe, cryogenic separation is the optimal method. In order to increase the efficiency of oxy-combustion the low humidity nitrogen which is produced by cryogenic air separation can be used to pre-drying of the power plant fuel. If all coal power plants in the world make use of the oxy-combustion method, it would be necessary to increase the global total energy production at about 27,7 % to cover today's demands for electricity. In addition, the amount of produced CO2 would increase by 66 %.

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