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General Design Consideration of Cryogenic Air Separation Unit for Esfahan Steel Company

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ABSTRACT

Cryogenic air separation unit is integral part of many industrial manufacturing plants like steelmaking, glass, chemical and petrochemicals industries where high purity argon, oxygen and nitrogen are required. Argon, nitrogen and oxygen quality, its production cost and its energy consumption are important parameters in any cryogenic air separation plant design. In this paper, the importance of parameters which used in designing the cryogenic air separation plant are evaluated. Here, in this paper, ESCO, referred to Esfahan steel company in designing cryogenic air separation unit. Products purity is the main issue in every cryogenic air separation plant design. Pressure and temperature variation must be well controlled within cryogenic air separation unit. The annual steel production of ESCO is about 2.5 Mt pre year and it is planned to increase its production to 3.2 Mt by end of 2016. ESCO requires about 300×10^6 Nm^3/y (34300 Nm^3/h) of oxygen for its present steel production. ESCO needs an additional 84×10^6 Nm^3 (9600 Nm^3/h) oxygen for its proposed 0.7 Mt crude steel production increase.

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1. Introduction

The main constituents of air are nitrogen (78%), oxygen (21%), argon (0.9%) and remaining is carbon dioxide some inert gases. Air impurities are dust, hydrocarbon, water vapor and etc. depend on environmental conditions. Oxygen, nitrogen and argon are used in petrochemical and petroleum refineries, steelmaking, welding, medical treatment, electronic industries, food industries and various other industrial and research applications according to their inherent properties [1]. An air separation unit is an integral part of many industrial manufacturing plants like found in the steelmaking, glass, chemical and petrochemicals industries [2].

Gas purity and flow rate are the main issue in Gas purity and flow rate are the main issue in every air separation plant design for steelmaking plant. For lower volume and purity, the pressure swing absorption and membrane separation (non-cryogenic air separation unit) might be the right choice. Cryogenic air separation units (ASU) are adopted where high purity and large volume of gases are needed. The varying boiling temperatures of the air constituents are the basis for their separation in cryogenic state. The technology of the cryogenic air separation unit has matured during the last 100 years since it is an energy intensive process. Although, an ASU uses air as a raw material but it consumes a tremendous amounts of electrical energy. Therefore, electrical energy is also considered as a raw material. An ASU is operated at cryogenic temperatures of -170 to -195 °C. Tight energy integration is required for an ASU in order to adjust to changing product demand. The cost of liquid air components is strictly depended on its energy consumption, process design, process operation, manufacturing approach and techniques. All the technical efforts are so far done in reducing plant energy consumption and improving quality of cryogenic ASU products [3].

The cryogenic air separation process has been traditionally adopted for oxygen production in the steel industry. Oxygen purity is one of the key issues. High purity oxygen (above 99.5%) is an essential for basic oxygen steel production application. Purity of oxygen also improves steel quality in electric steel production. Market competition has forced steel authorities to reduce expenses and improve quality. Steel production is an energy intensive industry and needs to improve energy efficient production processes. Steel quality is also improved by improving qualities of raw materials. Cryogenic ASU is a part of an integrated steel plant, which is an energy intensive and product quality management based unit. Therefore, oxygen quality, its production cost and energy use are important in the steel-making industry.

In this paper, the importance of the various parameters that are used in the design of the air separation plant are evaluated. We refer to Esfahan steel company (ESCO) in our discussion in designing air separation unit. Esfahan steel company is the third largest steelmaking plant in Iran, which opened in 1971 with annual capacity of 600,000 Mt. Steel products of ESCO are beams, angles, round bars and channels (constructional steel products) with a production capacity of 3.6Mt. ESCO uses a blast furnace-oxygen convertor method for steel production. ESCO market share of steel production is 95% for iron bars, 20 % for crude steel, 30% for rebar production. ESCO is planning to have new oxygen plant for its steel production [4].

For every ton of steel, on average approximately 120 Nm^3 oxygen is required for the conventional steelmaking procedure [5]. The annual steel production of ESCO is about 2.5 Mt per year and is planned to have production of 3.2 Mt by end of 2016. ESCO requires about $300\times10^6 Nm^3/y$ (34300 Nm^3/h) of oxygen for its current steel production. ESCO needs an additional $84\times10^6 Nm^3$ (9600 Nm^3/h) oxygen for its proposed 0.7 Mt crude steel planned production increase.

For every ton of steel, 80-120 Nm3 of nitrogen (99.99%) is also consumed as a protective gas in various processes involved in steelmaking.

Argon gas is also consumed in steelmaking at about 3 to 4.5 Nm3 per ton of steel as a blowing and protective gas [5].

ESCO has planned to have a cryogenic ASU with 25000 Nm3/h oxygen production capacity for its future plant development. This is about 36 ton/h (864 ton/d). The cryogenic air separation unit is widely used since it is economical in large scale environments and meets the purity requirements of steel plant. This scale of cryogenic ASU is considered to be of medium size and sizes of cryogenic ASU has increased from 100 to 4000 t/d over the years. Basically, ASU is economical for consumption of 100 t/d and above. For a low tonnage consumer, ASU cannot compete due to distillation column scaling down difficulties and small compressor efficiency. Important parameters for technology selection are volume and purities required, customer location, industrial gases usage pattern and infrastructure feasibilities.

2. Process Evaluation

The two main processes for air separation into its components are classified by either cryogenic or non-cryogenic separation systems [6]. The first criteria is to determine the purity and necessary volume of gases. For larger volume gaseous products (above 100t/d), with 95% and above purity, liquid industrial gases and argon recovery, then the process adopted would be cryogenic air separation. ESCO's required volume of oxygen is about 25000 Nm^3/h (864 t/d). The right choice of technology for ESCO is an onsite cryogenic ASU. To design a cryogenic ASU for ESCO, there are various user requirements which has to be known by the vendor. The design of a cryogenic air separation process cycle depends upon users requirements like

How many products are required?

What is the delivery pressure and flow rate of the products?

What should the purities of the products be?

What is cycle load of the products?

What is priorities/ evaluation criteria of the user?

What is the product's flexibility from user point of view?

Appropriate design of cryogenic ASU plant in any industry is required to provide the above information by the user to the designing company. By appropriate adjusting of steps involved in functioning of cryogenic ASU, user's requirements can be maintained.

General steps involved in the functioning of any generic cryogenic ASU are:

1. Compressing air to 5 to 8 bar depending on desired products pressure
2. Cooling of compressed air to remove much of air moisture
3. Further cooling of compressed air below mechanical refrigeration temperature
4. Removal of air impurities like carbon dioxide, residual water vapor, hydrocarbons, dust and etc.
5. Bring air temperature near to cryogenic temperature by use of heat exchanger and waste gas streams
6. Refrigeration of the air by a series of expansion/compression cycles to get to the cryogenic distillation temperature.
7. Separation of the air components in the distillation column at the cryogenic temperature of its components (two high and low pressure distillation columns are used in series, in order to have oxygen as product). Nitrogen is drawn from the top and oxygen drawn from the bottom of each distillation column. Oxygen purity is improved in a second low pressure column. Argon has similar boiling temperature to oxygen and remains as impurity in oxygen. For high purity oxygen, argon is removed at a point in the low pressure column where its concentration is in maximum level in oxygen. Pure argon is produced in an auxiliary unit from crude argon.

8. To produce refrigeration at cryogenic temperatures in streams to compensate for heat leak into the cold box. This is executed by reducing the pressure of streams. This removes energy from gas streams and reduces its temperature more than it would in a simple expansion valve.

Here some design aspects of cryogenic ASU for steelmaking plant are reviewed.

3. Required Products

It is important to know how many gaseous products are needed since the basic technology is decided on the required number gaseous products. If the technology choice is cryogenic separation even though number of products are directly influenced design and cost of ASU plant. Argon generally fractionates between oxygen and nitrogen in an ASU plant and is economically produced as a co-product with oxygen. If it is desired to have argon as a third product then an additional distillation column is added to the ASU to separate argon from nitrogen and oxygen rich streams. The choice is between production of nitrogen and oxygen, where plants for production of nitrogen are less complex and use lower electrical energy than plants with only production of oxygen gas. ESCO uses a blast furnace-oxygen convertor method for steel production therefore all three industrial gases oxygen, nitrogen and argon are required. In a blast furnace-oxygen convertor, oxygen is the main gas used in steelmaking.

In general, only a pure nitrogen producing plant is less complex and low energy consuming than a pure oxygen producing plant. Having both nitrogen and oxygen in a co-production plant requires more capital and operational investment. This type of co-producing plant is more energy intensive than a single component producing plant. Separating air components into their liquid form is also required, which doubles the amount of energy per unit of delivered products [7].

4. Delivery Pressure and Flow Rate of Products

In a steelmaking plant oxygen availability must deliver 120 $Nm^3$for every ton of steel in conventional steelmaking. The rate of delivery should be 200 to 710 (or above) Nm^3 per minute at pressure of above 1.5 to 15 bar. Pressure and the flow rate of oxygen should be varied in order to attain sonic and supersonic velocities in the blast furnace.

Large gaseous volumes are only generated from cryogenic air separation units. The cryogenic air separation process is the most adopted process for medium to large scale steel production unit. There are peak hours, seasons and or shut down periods in a round-the-clock steel plant operations. Variation in the supply of industrial gases in a steel plant must have been considered and hence making and storing gases in liquid form need additional equipment and engineering design sophistication. This doubles the required energy per unit of gas delivery. For 50 t/d delivery and above, the most preferred and economically sound method is cryogenic ASU. An ASU plant is almost exclusively use for 100 t/d delivery of industrial gases.

For every ton of liquid oxygen about 3 tons of liquid nitrogen and smaller amounts of argon (as a byproduct) are produced. The ESCO required volume of oxygen is about 25,000 Nm^3/h (864 t/d). The volume of produce nitrogen is about 75,000 Nm^3/h (2,592 t/d). This amount of liquid nitrogen is certainly more than the requirement of ESCO. A plan should be considered for liquid nitrogen storage and supply to other industries. It is estimated about 282 t/d argon is also produced. It should be planned in such a way to keep a portion as back-up liquid gas storage for 2-4 days.

In a cryogenic ASU plant, excess nitrogen is inevitability produced since there is four times as much as nitrogen than oxygen in air composition. Some of the excess nitrogen is used to cool incoming air but for the rest additional liquefiers at plant need to be considered.

In common ASU's, oxygen is produced slightly above atmospheric pressure in a cryogenic distillation column. In the double column cycle, 6 bar compressed air is cooled to near its dew point and feeds into the bottom of column at high pressure. Nitrogen evaporates first and rises to top of the column. By use of a re-boiler/ condenser the top column vapor nitrogen is condensed against incoming liquid oxygen. Condensed overhead nitrogen is divided into two reflux streams, partially to return to the high pressure column and partially to the top of low pressure column. High pressure column oxygen is sent to an intermediate stage of the low pressure column and oxygen accumulates at the bottom of low pressure column [8].

As the pressure of delivery gases are increased, cost of ASU plants is also increased. It is important to have trade-offs among parameters like capital cost, process simplicity, required gaseous products pressure and so on. Compressing oxygen and nitrogen to the required pressure can be expensive. In a GOX process, oxygen is removed from the bottom of the low pressure column as vapor and used to cool entering air. In a high pressure product, oxygen should further compressed.

It is well understood that low pressure ASU products are less expensive in terms of operating and capital cost. Gaseous oxygen and nitrogen can be produced in different process cycles from above atmospheric pressure at up to 8 bar pressure without using compressor.

In order to meet a steelmaking plant's high pressure oxygen requirement, a pumped LOX cycle is generally utilized to produce oxygen at an elevated pressure directly from the cold box instead of using oxygen compressor. A portion of liquid oxygen is pumped from low pressure column at an elevated pressure and warmed against a high pressure air feed to an ambient temperature.

5. Purities of Products

Purity is also one of the key factors in industrial plant evaluation. For a product purity above 95%, cryogenic ASU is adopted. Non-cryogenic technologies produce oxygen and nitrogen to a maximum of 95% purity and hence non-cryogenic technologies may be economical for gaseous products of 90 to 93% purity. The level of output purity has its own impact on the cost of process energy consumption. At a higher energy consumption, purity of ASU products can be improved. Therefore, purity of ASU products has one of the factors that are considered for cost of energy consumption. For a conventional ASU with a 99.5% oxygen purity about 0.35 kWh energy is consumed per Nm^3 of oxygen. Optimal purity of oxygen is increased as pressure increases. Purity of oxygen is determining factor in power consumption of ASU plant.

From other point of view, argon has boiling point between oxygen and nitrogen with a lesser relative volatility than nitrogen. This makes a major difference in separating pure oxygen (above 97%) from impure oxygen (less than 97%). In other words for 97% and above oxygen purity, all nitrogen should be stripped out of the low pressure column and then argon can separate from oxygen. In a simple double column ASU, the number of separating stages is increased from 35 to 60 to improve purity of oxygen from 95 to 99.6%. Increasing the number of separating stages in the distillation column for oxygen recovery must be compensated by increasing the discharge pressure of the air compressor to the distillation column. Therefore, careful optimization is required for each specific design case.

6. Air Quality

For the safe design of an ASU the quality of air must be known. Air conditions and air trace components should be recorded and provided to ASU supplier. Air impurities can cause process problems like reaction, plugging and corrosion. Carbon dioxide, Sulfur dioxide, water vapor, N_2O and NO_x cause plugging due to liquefaction in the system. Sulfur dioxide and HCL cause corrosion in system. All hydrocarbons, ozone and NO_x react with system components. A seasonal survey of air condition can give the appropriate air quality information to a supplier for proper ASU design since a four season climate conditions exist in most plant locations. Measuring air impurities and quality should done over a long term period but accurate analysis of air quality and compositions can be difficult. Quality of air may also change due to changes in neighboring areas or changes in wind the condition and direction. A correct estimation of air quality requires long term site survey (considering neighboring areas, any intermittent or normal vents, wind direction and speed). Care must be taken with any direct air measurements. Furthermore, care must be taken to have a long enough test of air quality and compositions with precise and high sensitivity instruments. A site survey may not be practically sound in many cases as it is a time consuming procedure. In this case for design propose, higher values are considered for conservative design basis.

The water vapor content of the inlet air varies with atmospheric temperature and elevation above sea level. In an ASU plant the byproduct streams of oxygen, nitrogen and argon are produced at any purity either in gaseous or liquid form [9].

7. Power Used

The main aim of designing any cryogenic ASU is to minimize operating costs which include cost of electricity and other operating parameters. Cost of electricity is the main issue in ant cryogenic ASU. One possible way is to go for oversize plant of the required production capacity in order to meet major customer demand by producing only during off peak hours since electricity cost in off peak hours is reduced to one third of its price during peak hours.

In this case, we should consider an ASU plant with capacity of 864 t/d oxygen with above 99% purity. The average kWh electrical energy cost is considered to be about 6 cents ($0.06) based on a peak hour's tariff rate including tax and other expenses.

The most important performance parameter in design and operation of any cryogenic ASU is the overall oxygen specific energy which is the ratio of total power consumption in kW to total oxygen production Nm^3/hr.

Practically, it may vary from unit to unit of same capacity. Castel [10] forecasted the oxygen specific energy for cryogenic ASU based on technological forecasting reach of 0.28 ~ 0.3 kWh/Nm^3 in 2010 using extraplotted method. Castel's forecast was later confirmed by Pafaffand Kather [11] and proposed 0.25 to 0.28 kWh/Nm^3 oxygen specific energy for any up to date ASU plant.

According to the Linde engineering group, the energy consumption in a conventional ASU plant is about 0.35 kWh/ Nm^3 (245 kWh/t) of liquid oxygen with 99% purity. This number in an advanced optimized ASU plant is about 0.25 kWh/ Nm^3 (175 kWh/t) of liquid oxygen with 95% purity. According to Air Liquid group improved ASU plant, oxygen specific energy consumption is about 0.23 kWh/ Nm^3 (160 kWh/t). Oxygen specific energy consumption (kWh/Nm^3) has been improved from 0.65 to 0.25 kWh/Nm^3 since 1960 as production capacity of plants have also been increased.

According to our calculation, it is logical to consider oxygen specific energy consumption (kWh/Nm^3) as 0.38 since it is planned to have a stock or second hand refurbish cryogenic ASU after 2003. If ASU technology is taken from the Linde group, Air Liquid Co. and Air Products group, it is possible to have an oxygen specific energy consumption below 0.3 (kWh/Nm^3). On the other hand, fixed capital investment will be higher and most important point is that it may not possible to have direct deal with these leading ASU manufacture.

Based on 0.38 kWh/Nm^3 oxygen specific power (0.38 kWh energy is required for every 1 Nm^3 of oxygen production), 9500 kWh of energy is required for 25000 Nm^3 oxygen.

A total of 228,000 kWh energy will be consumed for 864 t of oxygen per day. The total energy consumption per year will be 83,220,000 kWh. Total energy required and estimated cost of energy required are given in Table 1.

Table1: Energy consumption based on theoretical (0.38 kW/Nm^3) oxygen specific power

Required capacity of oxygen	Energy consumption for oxygen production based on theoretical 0.38 kWh/Nm^3)oxygen specific energy consumption	Cost of energy $0.06/kWhr
25,000 Nm^3	9500 kWh	$570
36 t/h	9500 kWh	$570
864 t/d	228,000 kWh per day	$13680
315,360 t/y	83,220,000 kWh per year	$4,993,200

It is estimated the oxygen production cost per ton will turn up to be about $15.83. Most of the energy is consumed by the compressor and the expander in a cryogenic ASU plant.

The estimated energy cost for one ton of oxygen is about $15.8. In reality, these values can be checked against real values which are obtained from a working plant to find out the power loss. Comparison of theoretical oxygen specific power consumption with obtained oxygen specific power consumption from any plant gives a degree of cost effectiveness. By utilizing a proper controlling system in an ASU plant, one can push the ASU plant oxygen specific power consumption to the theoretical value.

Liquids production should be planned to operate at hours that electricity price is lowest (overnight, weekends, not in peak hours). A close cooperation should be arrange between the ASU plant management and the electricity supplier during peak hours in summer months. Improving the expander efficiency of any cryogenic ASU unit can be directly linked to oxygen production efficiency. It is estimated that every expander refrigeration kW decrease there can be a saving of 5 kW of electricity.

Using a type of predictive control model, one can maximize high pressure product production in high pressure distillation column and total product recovery while reducing operating cost. A suitable predictive control model can keep the right balance among operating parameters of an ASU plant to minimize power consumption (90% of operating cost) at maximum product rate [12]. Therefore, correct evaluation of plant parameters can help to maximize plant life and asset profit potential.

Power consumption can be minimize in basic double column cryogenic ASU by

1. To reduce pressure drop in heat exchanger by increasing its size
2. To reduce temperature difference between boiling oxygen and condensing nitrogen by increasing reboiler condenser size
3. Reducing pressure drop in two distillation column by using structured packing
4. Less pure oxygen to reduce number of separating stages in distillation column
5. Appropriate design of basic components ASU like compressor, air purifier, heat exchanger, distillation column.

8. Cost Estimation

All improvements made to the cryogenic air separation unit were, so far, to reduce cost and improve reliability and flexibility [8]. From the point of view, the challenge for any industry is to manage peaks and drops of the macro-economic situation in order to make right investment decision. It is globally understood that to make an investment at the bottom of an economic cycle is better than those at top if done in a carefully conceived, developed and well-executed manner.

For an operating cost estimation, direct costs should be calculated first. Items that come under the direct cost is power cost, cooling water cost, payroll overhead cost (20 -27% of payroll cost), supervision cost (15% of direct labor cost), plant maintenance cost (3-7 % of investment), operating supplies (20 -25% of plant maintenance cost).

Indirect cost should be taken as 40% of direct labor, plant maintenance and the operating supplies cost.

Fixed cost are taxes and insurance (2-3% of investment cost) and depreciation cost (6-10% of investment cost).

Total annual operating cost is the sum of the direct cost, indirect cost and fixed cost. The production cost of oxygen ($/ton of oxygen) is the ratio of the total annual operating cost to annual production of oxygen.

Production cost of oxygen ($/ton of oxygen) = (total annual operating cost) / (annual production of oxygen)

A discounted cash flow (DCF) is used as a valuation method to estimate the attractiveness of an investment opportunity. DCF analysis uses future free cash flow projections and discounts them to arrive at a present value estimate, which is used to evaluate the potential for investment.

The profit return of total capital investment of a plant is calculated by taking the ratio of capital investment (P) to return profit (R) from giving relation (1) where n is the life of plant and the interest rate total investment per year

$$P/R=[(1+i)^n-1]/[i(1+i)^n] \quad (1)$$

Return profit (R) is then

$$R=P[i(1+i)^n]/[(1+i)^n-1] \quad (2)$$

Net profit (N) is

Net profit (N) = Return profit (R) - Depreciation cost (6-10% of investment cost)

Gross profit (G) is the profit a company makes after deducting the costs associated with making and selling its products, or the costs associated with providing its services. Considering governmental income tax is from 25 to 50% of net profit (here is assumed 50% governmental income tax)

$$\text{Gross profit}\,(G)=2\times\text{Net profit}\,(N) \quad (3)$$

Sales (S) is calculate as;

Sales (S) =Gross profit (G) + total annual operating cost

Selling price of oxygen ($ / ton of oxygen) = Sales (S) / annual production of oxygen

Now, it can back calculate to find out Net profit (N) of oxygen sales in a year

Total Sales (S) = annual oxygen production (t/y)× selling price of oxygen ($ / ton of oxygen)

Gross profit (G) = Total Sales (S) - total annual operating cost

Net profit (N) = Total Sales (S) - total annual operating cost - Gross profit (G) - Income tax revenue

Total positive cash flow (F) = depreciation cost (6-10% of investment cost) + Net profit (N)

Operating cash flow is important because it indicates whether a company is able to generate sufficient positive cash flow to maintain and grow its operations, otherwise it may require external financing.

There are alternative methodologies that can supplement the discounted cash flow (DCF) approach to analyze the projected economic situation.

9. Safety Aspects

ASU plant operation has some hazards that are associated with gases being ventilated into the atmosphere, such as:

-
- Asphyxiation (nitrogen and argon)
- Enhanced fire risk (oxygen)
- Cold and low visibility (cryogenic gases and liquids)
- Hot gases (e.g., compressor inter-stage relief/discharge gas vents)

These hazards must be controlled at the plant site. The gas exit velocity of warmed gases is also important at the warm-end of an ASU. Noise and odor levels should be at permitted acceptable levels.

10. Conclusion

Although oxygen production by cryogenic distillation of air is a commercially matured process, there have been many improvements over the time that has resulted in significant reduction in the specific oxygen production power and the trend is expected to continue in the future. ESCO has planned to have a cryogenic ASU oxygen of 25000 Nm^3/h capacity for its future plant development. This is about 36 ton/h (864 ton/d). The most important performance parameter is the overall oxygen specific energy which is the ratio of total power consumption in kW to total oxygen production Nm^3/hr. The overall oxygen specific energy is considered to be 0.38 for a refurbish cryogenic ASU plant which match oxygen requirement. It is estimated the oxygen production cost per ton will turn up to be about $15.83. Cryogenic ASUs become cost effective at the level of about 200-300 tons/d oxygen. Most efficient and reliable unit are above 500 to over 2,000 ton /d. Refurbish cryogenic ASU mechanical characteristic should be able to accommodate system efficiency variation with system flexibility in acceptable range. Ambient temperature and pressure and temperature fluctuations are major source of instability in ASU plant caused by front end of cleaning system sequencing. Design for high peak efficiency in ASU plant may easily scarify flow rates change ability in compressor and expander. Therefore for an excellent paper design efficiency, one must run the plant on single point. It becomes extremely difficult to accommodate pressure and temperature fluctuation in such plant therefore ASU plant should always run below paper design efficiency in order to accommodate pressure and temperature fluctuation.

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نکات کلیدی در طراحی واحد جداسازی برودتی هوا برای ذوب آهن اصفهان

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چکیـــــده

واحد جداسازی برودتی هوا جزء لاینفک بیشتر صنایع فولاد، شیشه، شیمیایی و پتروشیمی است که همواره مقدار متنابهی اکسیژن، ازت و ارگون مایع با خلوص بالا مورد نیاز است. برای صنایع، کیفیت (خلوص) اکسیژن، ازت و ارگون، هزینه تفکیک و مایع کردن اجزاء هوا و مصرف انرژی از عوامل تاثیرگذار بر انتخاب و طراحی واحدهای جداسازی برودتی هوا هستند. در این مقاله اثرگذاری این عوامل بر روی طراحی واحد جداسازی برودتی هوا مورد بررسی قرار گرفته است. طراحی موجود با در نظر گرفتن پیش نیازهای لازم برای یک واحد جداسازی برودتی هوا برای ذوب اهن اصفهان است. خلوص مورد نیاز اکسیژن، ازت و ارگون مایع از نکات کلیدی در طراحی است. کنترل مستعمر و موثر تغییرات فشار و درجه حرارت در برج تقطییر واحد جداسازی برودتی هوا برای ماندن در ناحیه تعادلی لازم بسیار مهم است. تولید سالانه ذوب اهن در حدود ۲/۵ میلیون است و در نظر است میزان تولید را به ۳/۲ میلیون تن در سال برسانند. در حال حاضر برای این میزان تولید در حدود ۳۰۰×۱۰^۶ مترمکعب در سال اکسیژن مایع استفاده میکند و در حدود ۸۶×۱۰^۶ متر مکعب در سال مازاد بر مقدار فعلی نیاز دارد.

واژگان کلیدی: جداسازی برودتی هوا، نکات طراحی، خلوص، شدت جریان