

# Linde and Claude System Second Law Comparison for Liquefaction of Air

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## Abstract

The study deal with the anComparative analysis of two cryogenics system Linde Hampson and Claude. Thesecond law efficiency and the output which in form of liquefaction mass air are compared and through comparison result of systems it conclude that by joining extra accessories in system make a system efficient in output result but in other hand making system large , its cost and as well as useful energy destruction of overall system are degraded which seen in from of low second law efficiency. Two system giving same atmospherics input condition and varying compressor pressure considered. Final results show the output of Claude system is more than the Linde while seconde efficiency of ofLinde is 18% more than the Claude at 300 bar compressor pressure.

## Nomenclature

$W$ =work

$Q$ =Heat input

$\eta_I$ =First law efficiency

$\eta_{II}$ =Second law efficiency

$h$ =Enthalpy

$s$ =Entropy

$X$ =Dryness fraction

$T$ =temperature

$P$ =Pressure

$m$ =mass

$\epsilon$ =Effectiveness of heat exchanger (approx. 80%)

$\eta_{comp}$ =Efficiency of compressor (approx. 80%)

$\eta_{expander}$ =Efficiency of expander (approx. 80%)

$C$ =Specific heat capacity fluid or gas

$W_t$ =Work of reversible isothermal compression

$W_{comp}$ =Shaft work supplied to compressor per unit

mass

## 1. Introduction

Cryogenics is a field of acquiring very low temperature, the temperature which sufficient to

liquefy most of gases but generally the temperature below  $-150^{\circ}\text{C}$  is considered in range of cryogenics. In early centuries the throttling effect of cooling and various expansion device attract the scientist toward achieving low temperature but oxygen use in medical science and its storage factor turn 18 centuries scientist to attain low temperature which can liquefy air and in turn harness the oxygen from that liquefaction. In end of 18 centuries various research are done cryogenics field but first scientist which got success is Linde and after that lots of scientist liquefy various gas on their scale. Various systems of cryogenics come in light in which Linde and Claude is widely used as system for liquefaction of air.

The system is made but how much they are efficient in industrial point of view is become matter of concern. Various method are employs to minimize the cost without affecting the production rate are investigated in various mathematical techniques and simulation technique is widely used. In all this a best method second law exergy analysis of system which is based on the second law of newton of energy destruction.

Exergy analysis is basically defined as the how much part of energy we can fully utilize in our work. Useful part of energy is called exergy while unused part is anergy. First law efficiency simply defined as the ratio of output to the input of energy while Second law efficiency deal with the exergy and defined as the ration of exergy output to the exergy input.

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$$\eta_I = \frac{\text{Output energy}(W)}{\text{Input energy}(Q)}$$

$$\eta_{II} = \frac{\text{Exergy output}}{\text{Exergy Input}}$$

Lots of research are done to optimize and to increase the second law efficiency of system. And for this lots of new techniques are experimentally studied. Yang et al. [1] performed a comparative study on the trans critical carbon dioxide refrigeration cycles with a throttling valve and with an expander, based on the first and second laws of thermodynamics. Ignacio L’opezPaniagua [2] find New Simple Method for Estimating Exergy Destruction in Heat Exchangers. Yongliang Li [3] study An optimal design methodology for large-scale gas liquefaction. Antungalovic [4] do detail Analysis of Exergy Destruction of an

Evaporator or/and a Condenser. The main cause of low Second law efficiency directly link to the irreversibility of system so for which is just a form of exergy losses in any system. Irreversibility is the reason why the exergy received by the cold fluid and that released by the hot fluid are not equal. In fact, the total exergy loss in an exchanger is another characteristic of its exergetic behavior commonly referred to in the literature [5,6],and only part of the exergy loss can be avoided in practice [7]

**2. Thermal analysis of Linde system**

Linde system is first system which is use for liquefaction of air. In Fig 1(a).This system consist a compressor, heat exchanger, throttle valve and a separator. The air or gas which is used to liquefy is circulate in this closed cycle with perfect insulation to avoid large losses to occur due to system and outer surrounding temperature difference.Fig 1(b) show the temperature entropy diagram for Linde system.

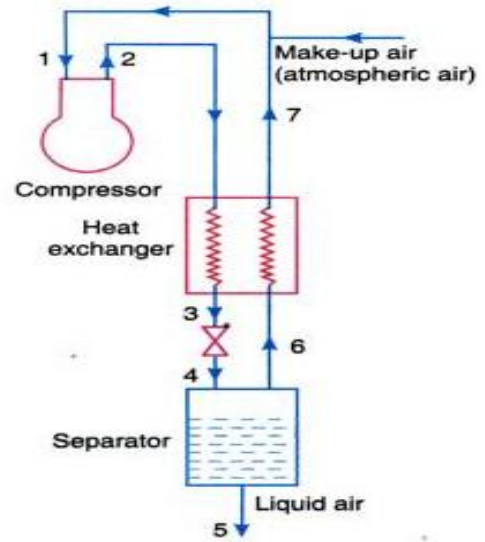


Fig: 1(a). Linde system for Liquefaction for gases

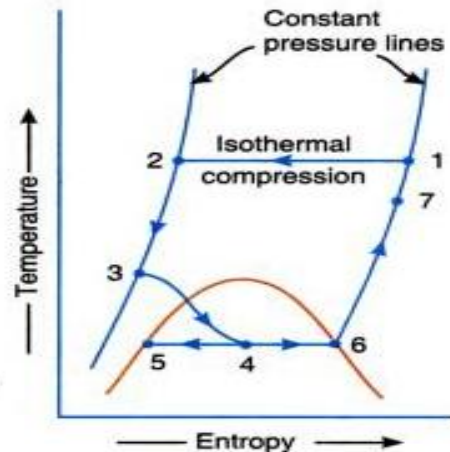


Fig: 1 (b). Tempertaure vs entropy of Linde system

$$\eta_{comp} = \frac{W_t}{W_{comp}} \tag{1}$$

$$W_t = mRT \ln \frac{P_2}{P_1} \tag{2}$$

$$W_{comp} = h_2 - h_1 - T_1 (s_2 - s_1) \tag{3}$$

$$W_{reversible} = W_{actual} - T_0 s_{gen} \tag{4}$$

$$W_{actual} = \frac{W_{comp}}{x} \tag{5}$$

$$W_{reversible} = h_5 - h_1 - T_0 (s_5 - s_1) \tag{6}$$

Heat Exchanger

$$m_2(h_2 - h_3) = m_6(h_1 - h_6) \tag{7}$$

$$m_2(h_2 - h_3) = (m_2 - m_5)(h_1 - h_6) \tag{8}$$

$$: m_6 = (m_2 - m_5) \tag{9}$$

$$\varepsilon = \frac{c_h(T_2 - T_3)}{c_{min}(T_2 - T_6)} \tag{10}$$

Throttling process:

$$h_3 = h_4 \tag{11}$$

Heat Balance of the separator

$$m_2 h_4 = m_5 h_5 + m_6 h_6 = m_5 h_5 + (m_2 - m_5)(h_6) \tag{12}$$

Second law analysis :

$$\eta_{II} = \frac{W_{rev}}{W_{actual}} \tag{13}$$

COP (coefficient of performance):

$$COP = \frac{h_2 - h_1}{h_2 - h_1 - T_1 (s_2 - s_1)} \tag{14}$$

### 3. Thermal analysis of Claude system

Claude system not only used for liquefaction of air but other gas also can be liquefy with this system also .Fig 2(a) show a block diagram of Claude system having two heat exchanger ,two separator and two throttle valve with an expander. Fig 2 (b) shows temperature entropy diagram.

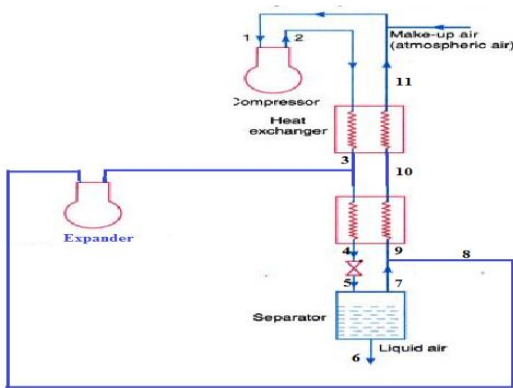


Fig: 2(a). Claude system for Liquefaction for gases

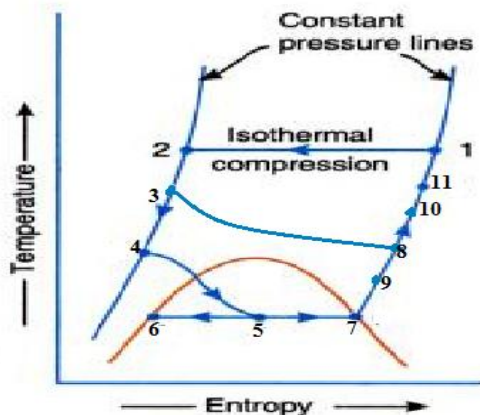


Fig: 2(b). Temperature vs entropy of Claude system

$$\eta_{comp} = \frac{W_t}{W_{comp}} \tag{15}$$

$$W_t = mRT \ln \frac{P_2}{P_1} \tag{16}$$

$$W_{comp} = h_2 - h_1 - T_1 (s_2 - s_1) \tag{17}$$

$$W_{reversible} = W_{actual} - T_0 S_{gen} \tag{18}$$

$$W_{Total} = W_{comp} + W_{Expander} \tag{19}$$

First heat exchanger:

$$m_2 (h_2 - h_3) = (m_2 - m_6) (h_1 - h_{10}) \tag{20}$$

Expander:

$$\frac{T_8}{T_3} = \left(\frac{P_8}{P_3}\right)^{\left(\frac{\gamma-1}{\gamma}\right)\eta_{expander}} \tag{21}$$

$$W_{Expander} = h_8 - h_3 \tag{22}$$

$$(m_4 - m_6 + m_8) h_9 = m_8 h_8 + (m_4 - m_6) (h_7) \tag{23}$$

Second Heat exchanger:

$$m_4 (h_3 - h_4) = (m_2 - m_6) (h_{10} - h_9) \tag{24}$$

Throttle valve:

$$h_4 = h_5 \tag{25}$$

Heat Balance of the separator

$$m_4 h_5 = m_6 h_6 + (m_4 - m_6) (h_7) \tag{26}$$

Second law analysis:

$$\eta_{II} (\%) = m_6 \left( \frac{h_7 - h_6 - T_0 (s_7 - s_6)}{W_c} \right) \times 100 \tag{27}$$

COP (coefficient of performance):

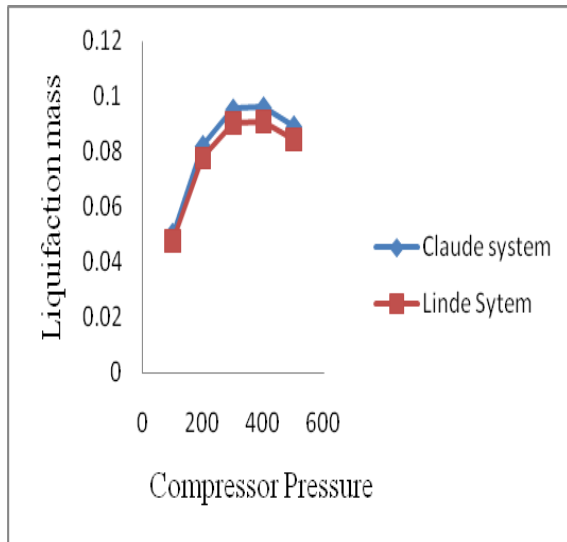
$$COP = \frac{h_2 - h_7}{h_2 - h_1 - T_1 (s_2 - s_1)} \tag{28}$$

Table: 1.

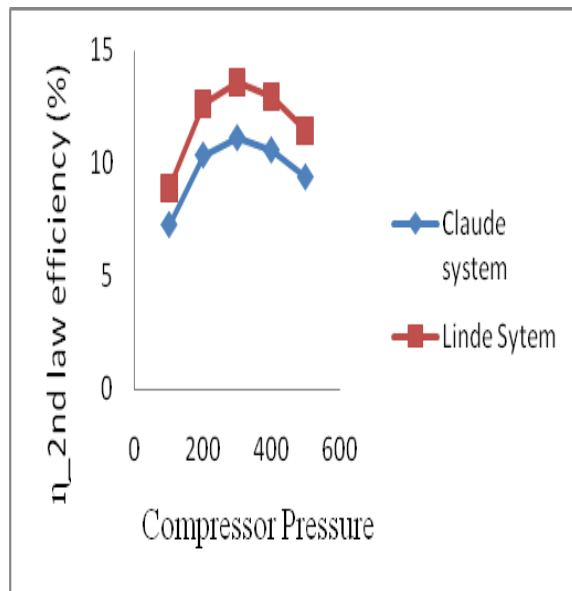
Linde System (Air)			
COP	$\eta_{2^{nd}}$ law (%)	m_Liq mass	P (Comp Pre)
0.5612	8.891	0.04751	100
0.487	12.64	0.0778	200
0.4501	13.58	0.09048	300
0.4253	12.92	0.0911	400
0.4063	11.43	0.08433	500

**Table: 2.**

ClaudeSystem (Air)			
COP	$\eta_{2^{nd}}$ law (%)	m_Liq mass	P (Comp Pre)
0.5568	7.271	0.05007	100
0.4836	10.35	0.08203	200
0.4471	11.12	0.09533	300
0.4225	10.58	0.09603	400
0.4036	9.383	0.08913	500



**Fig: 2.5**Liq mass vs compressor pressure



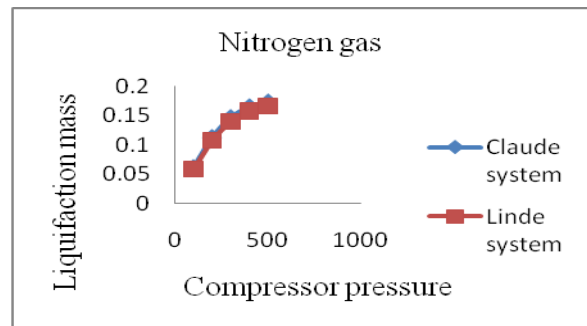
**Fig: 2.6.** Second law efficiency (%) vs compressor pressure

**Table: 3.**

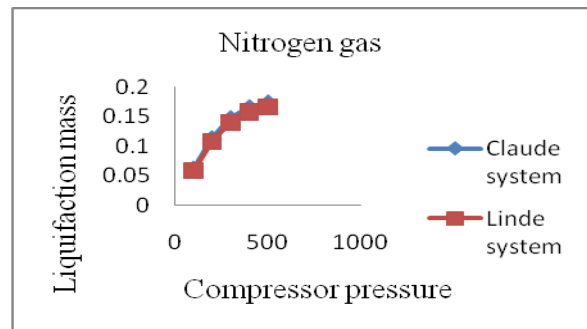
Claude System (N)			
COP	$\eta_{2^{nd}}$ law (%)	m_Liq mass	P (Comp Pre)
0.5679	6.818	0.04781	100
0.4921	9.851	0.07971	200
0.4543	10.87	0.09531	300
0.4287	10.67	0.09914	400
0.4091	9.795	0.09534	500

**Table: 4.**

Linde System (N)			
COP	$\eta_{2^{nd}}$ law (%)	m_Liq mass	P (Comp Pre)
0.5721	8.521	0.04539	100
0.4954	12.3	0.07564	200
0.4571	13.57	0.09048	300
0.4314	13.32	0.09408	400
0.4116	12.2	0.0903	500



**Fig:-**



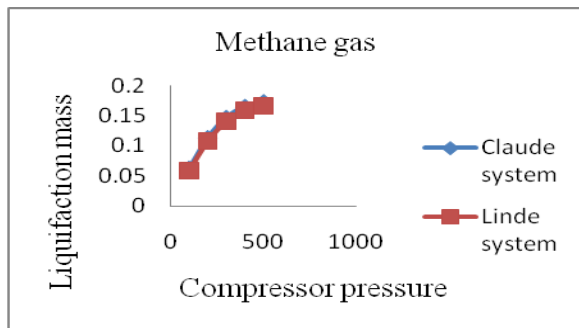
**Fig:-**

**Table: 5.**

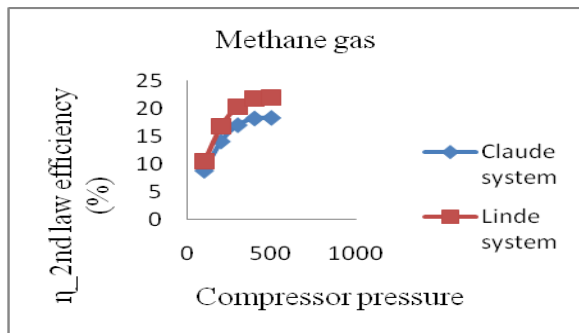
Claude System (CH4)			
COP	$\eta_{2^{nd}}$ law (%)	m_Liq mass	P (Comp Pre)
0.5765	14.78	0.1164	100
0.5114	23.56	0.2091	200
0.4784	26.27	0.2492	300
0.4547	26.21	0.2615	400
0.4355	25.11	0.2617	500

**Table: 6.**

Linde System (CH4)			
COP	$\eta_{2^{nd}}$ law (%)	m_Liq mass	P (Comp Pre)
0.5829	17.43	0.1105	100
0.5161	27.8	0.1991	200
0.4825	31.24	0.2392	300
0.4585	31.31	0.2523	400
0.4392	30.08	0.2531	500



**Fig:-**

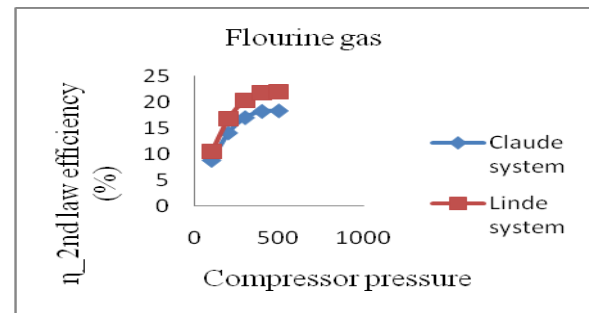
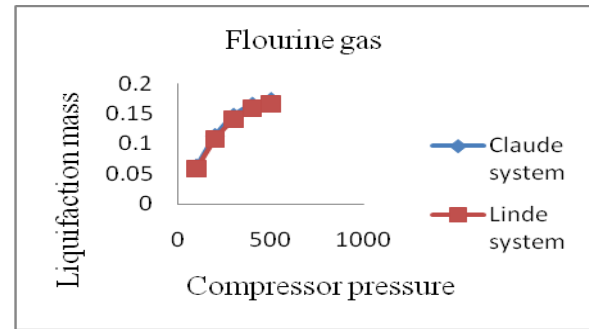


**Fig:-**

**Table: 7.**

ClaudeSystem (F)			
COP	$\eta_{2^{nd}}$ law (%)	m_Liq mass	P (Comp Pre)
0.5608	6.713	0.04466	100
0.489	10.57	0.08062	200
0.4541	13.01	0.1069	300
0.4311	14.22	0.123	400
0.4137	14.6	0.1316	500

**Table: 8.**



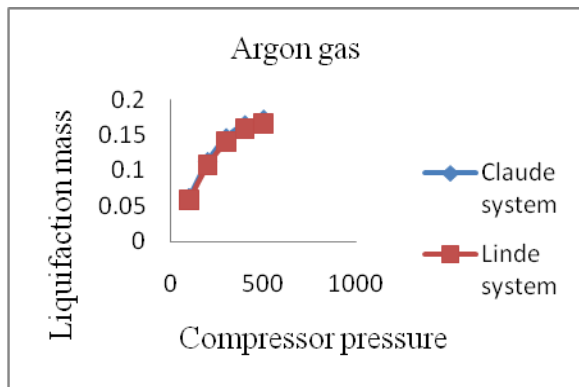
**Fig:-**

**Table: 9.**

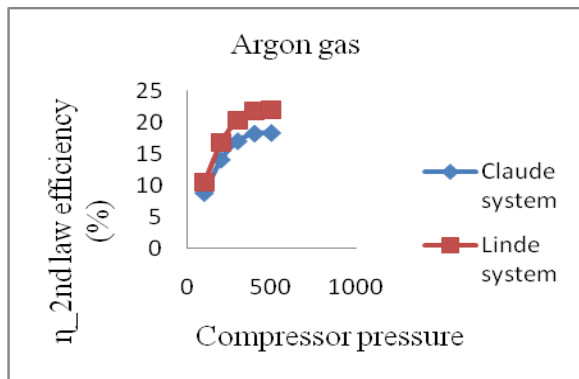
Claude System (Ar)			
COP	$\eta_{2^{nd}}$ law (%)	m_Liq mass	P (Comp Pre)
0.3923	9.83	0.06649	100
0.343	15.62	0.1209	200
0.3191	18.82	0.1565	300
0.3032	20.07	0.1757	400
0.291	20.12	0.1835	500

**Table: 10.**

Linde System (Ar)			
COP	$\eta_{2^{nd}}$ law (%)	m_Liq mass	P (Comp Pre)
0.3955	11.1	0.06352	100
0.3454	17.61	0.1154	200
0.3212	21.24	0.1497	300
0.3051	22.7	0.1684	400
0.2928	22.79	0.1761	500



**Fig:-**



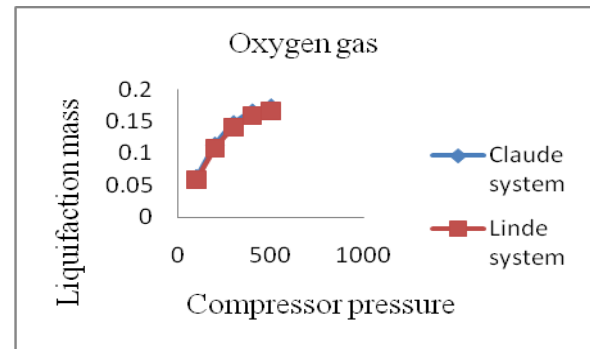
**Table: 11.**

Claude System (O2)			
COP	$\eta_{2^{nd}}$ law (%)	m_Liq mass	P (Comp Pre)
0.5395	8.732	0.06136	100
0.4719	14.01	0.1125	200
0.4392	16.97	0.1465	300
0.4174	18.17	0.165	400

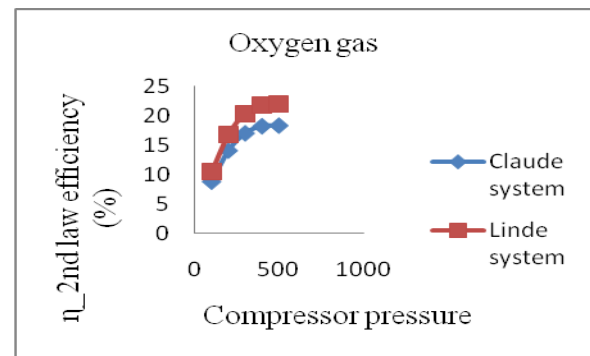
0.4007	18.28	0.173	500
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**Table: 11.**

Linde System (O2)			
COP	$\eta_{2^{nd}}$ law (%)	m_Liq mass	P (Comp Pre)
0.5441	10.47	0.05851	100
0.4755	16.77	0.1072	200
0.4422	20.34	0.1399	300
0.4202	21.83	0.158	400
0.4033	22.01	0.1659	500



**Fig:-**



**Fig:-**

#### 4. Results and discussion

For the analysis and comparison between two system Linde and Claude for liquefaction of air the inlet condition for both system is kept constant and compressor pressure are vary Computational numerical technique is used to get the following results.

1. In fig 5 the liquefaction mass of air is higher in Claude as compared to linde system ,so output of claude is more than the linde.The compressor pressure is not directly proportional to

liquefaction mass ,liquefaction mass is higher in range of 300 to 400 bar compressor pressure ,further increase in pressure degrade the quantity of liquefaction mass in both system

2. In fig 6 show that the second law efficiency of Linde system is more than the claude system and compressor pressure in range of 300 to 330 bar show highest efficiency for both system.

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## 5. Conclusion

1. Linde system having less energy losses than claude system showing higher second law efficiency than claude system.
2. Output wise the claude system is better than linde system.
3. Compressor pressure range 300 to 350 show good result in both system at constant slandered atmospherics inlet conditions