# Study on Performance of Cyclone Separator on Vapour Compression Refrigeration Systems

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***Abstract*** **:**

Carrying of Liquid particles within gas flow on vapour compression refrigeration systems can cause serious problems in process plant and operation. Cyclone separator is a simple, compact, low weight, low cost and high efficiency separator. This paper is focused in study the performance of cyclone separator for separating liquid particles in vapour compression refrigeration system. Mathematical models and computer program (MATLAB) have been used to study the performance, settling velocity and cut-point diameter. The results shown that: the performance for the cyclone separator increases as the mass particles and inlet velocity increased. In addition, the collection efficiency of the cyclone increased linearly as the mass of particles and inlet velocity increased. Moreover, the collection efficiency increased as the cut-point diameter decreased.

**Keywords:** *Cyclone separator, settling velocity, cut-point diameter, collection efficiency.*

## I. Introduction

The consumption and diversity of frozen products has increased considerably in developed countries due to the advantages compared to fresh products. Due to this, there is an increasing interest for freezing installations and equipment such as ice plants. An ice plant is a complete installation uses vapour compression refrigeration system for production and manufacturing of ice [1].

In the industrial process, separation of multiphase fluids is fundamental to protect other process equipment (e.g. pumps and compressors) from damage. In addition, separation also improves the performance of downstream equipment, since certain equipment handle multiphase streams poorly [2].

Cyclone separators has been regarded as one of the simplest and cheapest type of separators on account of their high efficiency, adaptability, and relative economy in power. Cyclone separators have been widely used in different industrial processes [3].

N. Mikheev et. al [4] have utilized cyclone separator for separation of gas-liquid mixture with high flux density. Detailed flow structure in the separator has been obtained from numerical study. Experimental research allowed estimation of separation efficiency and flow resistance coefficient of the separator.

R. Ramachandran and P. Sivakumar [5] have conducted a research in design and development of cyclone separator. The work aimed to optimize and reduce the pressure drop and for a given collection efficiency of the cyclone separator. Several models are proposed to study and the optimum model is selected as the best suited for cyclonic separation.

In vapour compression cycles, the refrigerant completes its cycle in the evaporator. Liquid particles can flow with the gas stream to the compressor and create critical thermal stress on the compressor which causes failure in the internal parts of compressor and decreasing the overall performance of the vapour compression refrigeration system. The Main purpose of this paper is to study the performance, and separation efficiency of the gas-liquid separator in industrial vapor compression refrigeration plants using cyclone separator. The study also aims to investigate the factors that affect the performance of the separator.

## II. Methodology and Materials

The cyclone design procedure outlined by Cooper and Alley (1994), hereafter referred to as the classical cyclone design process, was developed by Lapple in the early 1950s. The classical cyclone design process (the

Lapple model) is perceived as a standard method and has been considered to be acceptable [6].

### A. Settling Velocity

It's generally assumed that particles on entering the cyclone quickly reach their settling velocity. Particles sizes are so small that Stokes law is considered valid. For centrifugal separation, the radial settling velocity of the cyclone is given by the following

$$V_{tr} = \frac{\omega^2 \, r \, D_p^2 \, (\rho_l - \rho_g)}{18 \, \mu_g} \quad (1)$$

$$\omega = \frac{V_i^2}{r} \quad (2)$$

### B. Number of Effective Turns

Number of effective turns in a cyclone is the number of revolutions the gas spins while passing through the cyclone outer vortex. A higher number of turns result in a higher collection efficiency.

$$N = \frac{1}{h}\left(l + \frac{z}{2}\right) \quad (3)$$

### C. Cut-Point Diameter

The cut-point of a cyclone is the aerodynamic equivalent diameter (AED) of the particle collected with 50% efficiency. Therefore, as the cut-point diameter increases, the collection efficiency decreases. The cut-point diameter is calculated as follows

$$D_{pc} = \left[\frac{9 \, \mu_g \, W}{2\pi \, N \, V_i \, (\rho_l - \rho_g)}\right]^{0.5} \quad (4)$$

### D. Collection Efficiency

Collection or fractional efficiency is defined as the fraction of particles of a given size collected in the cyclone, compared to those of that size going into the cyclone.

Based upon the cut-point diameter:

$$\eta_c = \frac{1}{1 + \left(D_{pc}/D_j\right)^2} \quad (5)$$

Operational data is collected from a local ice plant which uses ammonia as a refrigerant (Alsafi Ice Factory) located in Port Sudan, Sudan for analysis. A model of the cyclone separator is proposed and then used for study. Various readings of the particle diameter and gas-liquid mixture entering velocity are proposed to test the two separators under numerous situations. MATLAB is utilized for running several calculations.

For theoretical research regarding the cyclone separator utilization instead of the gravity settling chamber the cyclone dimensions are based on Lapple conventional cyclone [7].

**Table 1**: Design parameters for a Lapple cyclone.

| | |
|---|---|
| Body diameter | 1 m |
| Height of inlet | 0.5 m |
| Width of inlet | 0.25 m |
| Length of body | 2 m |
| length of cyclone cone | 2 m |
| Diameter of gas exit | 0.5 m |

## III. Results and Discussion

The most important parameters that used to determine the performance of the cyclone separator are the inlet velocity of cyclone, the radial settling velocity, the cut-point diameter and the separation efficiency. The graphs in figures 1 - 7 showed the cyclone separator's performance variation. The charts below are obtained from the tables in appendix (A).

Figure 1 and 2 show the relationship between the gas inlet velocity and the settling velocity of the cyclone separator versus the variation of the particle diameter and the suction pressure of the compressor. Figure 1 shows the variations of radial settling velocity of the gas development inside the cyclone versus the inlet velocity at different values of particles diameter from d = 60 to 100$\mu m$ at 2.2 bar. A Linear correlation exists between settling velocity and the inlet velocity for all particles cases.

From the Figure 1 it can be observed clearly that as the inlet velocity increased the settling velocity of the cyclone separator also increased. As shown in the Figure 1, the fastest rate of radial settling velocity is occurred in the maximum particle diameter of 100$\mu m$, this is due to the increasing of inlet velocity to the cyclone which leads to more centrifugal forces for the separation to occur.

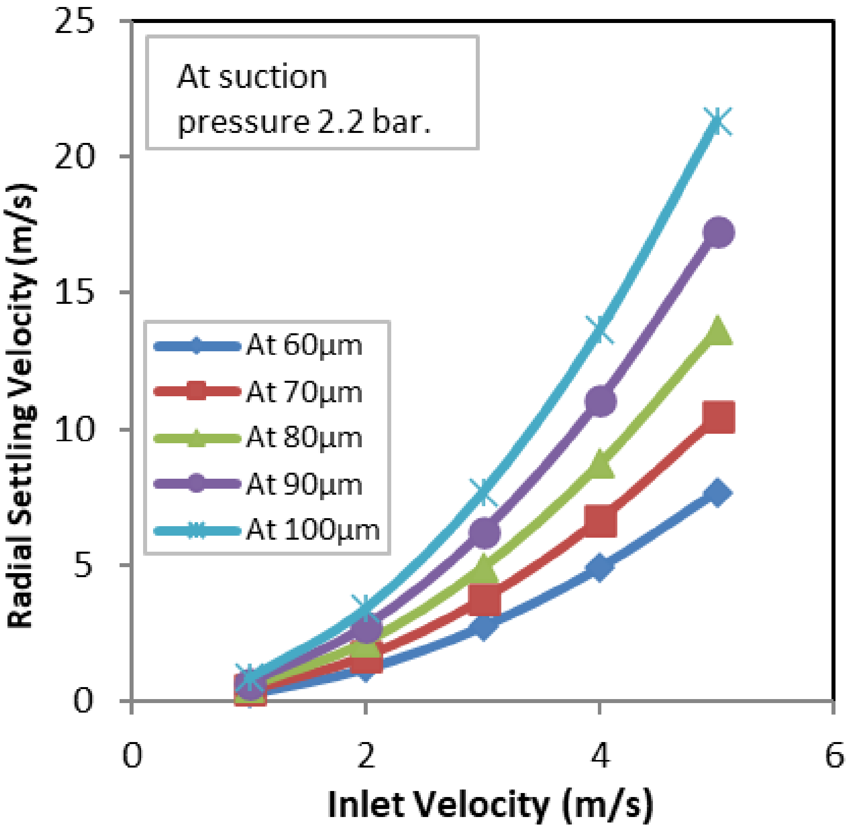


**Figure 1:** Effect of the inlet velocity on the radial settling velocity of the cyclone separator with variation of the particle diameter.

Figure 2 shows the variation of radial settling velocity versus inlet velocity for particle diameter of 80$\mu m\mu m$ at pressure range of 0.5 to 2.2 bar. The gradient of the radial settling velocity-inlet velocity plot reflects the influence of inlet pressure of the gas on the redial settling velocity inside the cyclone. As shown in the Figure 2, radial settling velocity and inlet velocity showed a linear relationship between them, as the inlet velocity increased, the radial settling velocity increased for all different pressures. The maximum value of radial settling velocity obtained at the inlet velocity of 5 m/s at inlet pressure of 0.5 bar.

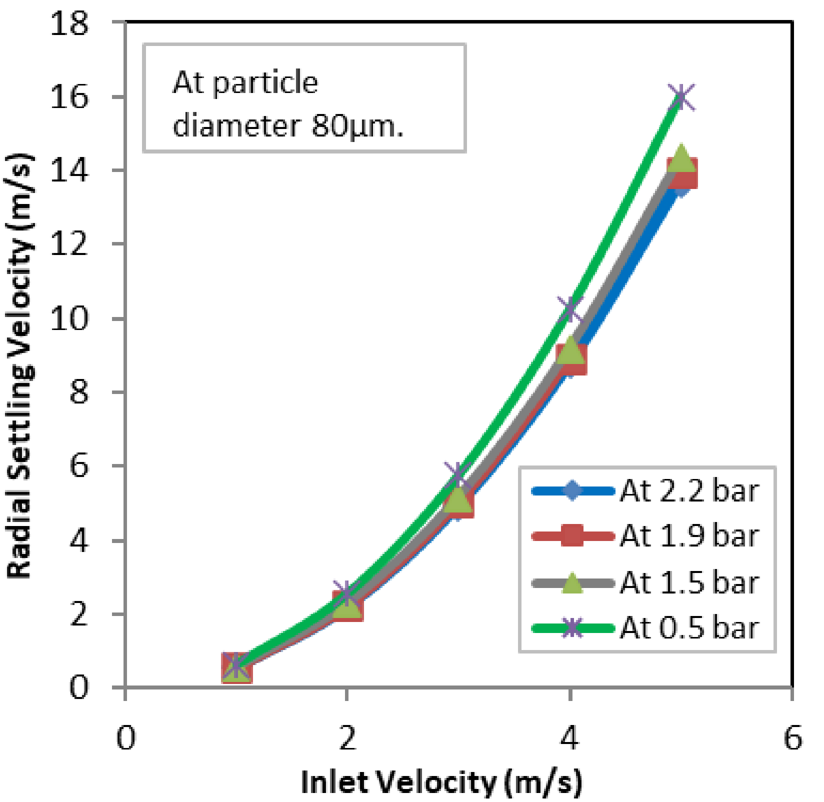


**Figure 2:** Effect of the inlet velocity on the radial settling velocity of the cyclone separator with variation of the suction pressure.

Figures 3 and 4 show the relationship between the gas inlet velocity and the collection efficiency of the cyclone separator with the variation of the particle diameter and the suction pressure of the compressor. It can be observed that from Figure 3 for different values of the particle diameter at 2.2 bar, as the inlet velocity increases the collection efficiency of the cyclone separator also increases. As stated before, the increase in the inlet velocity to the cyclone results in more centrifugal force for the separation to occur. The maximum efficiency of the cyclone obtained at velocity 5m/s for all diameters. For the diameter of the particle 100$\mu m$ the efficiency of the cyclone separator reached 99%.

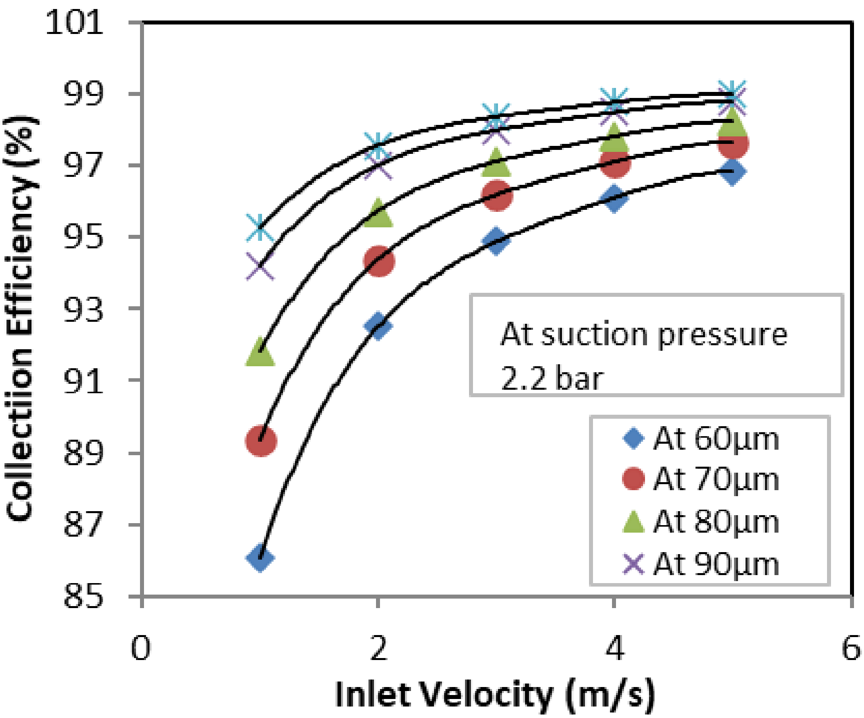


**Figure 3:** Effect of the inlet velocity on the collection efficiency of the cyclone

separator with variation of the particle diameter.

The effect of the inlet pressure on the cyclone efficiency has been illustrated in the Figure 4. As mentioned previously in Figure 3 the cyclone efficiency increased as the inlet velocity increased. Figure 4 shows the variation of cyclone efficiency versus the inlet velocity of the particle diameter of 80$\mu m$ at range of inlet pressure of 0.5 to 2.2 bar. As shown in the Figure 4 as the inlet pressure increased the cyclone efficiency decreased while the efficiency of the cyclone increased as the inlet velocity increased. The maximum efficiency obtained at the inlet pressure of 0.5 bar. The minimum inlet pressure indicates that the refrigerant at the liquid state that means it is very easy to convert to gas at the compression stroke and the work done will minimized.

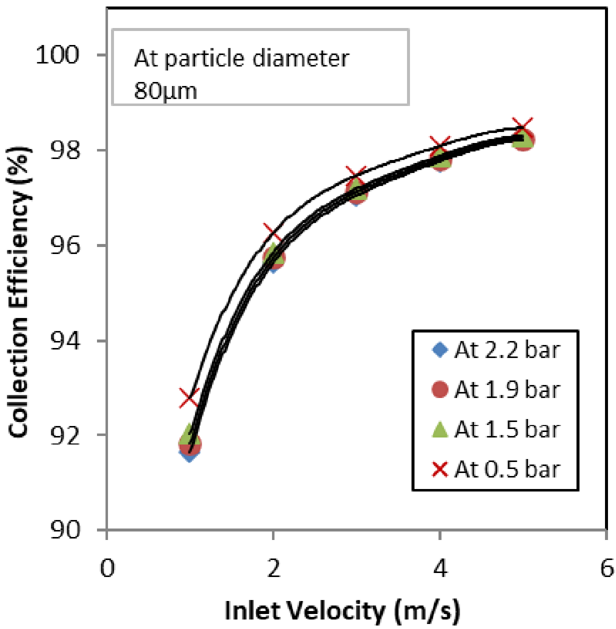


**Figure 4:** Effect of the inlet velocity on the collection efficiency of the cyclone separator with variation of the suction pressure.

Figure 5 shows the relationship between the inlet velocity and the cut point diameter of the cyclone separator. It can be noted that as the inlet velocity of the cyclone increases the cut point diameter decreases. As been stated in the previous chapter, the cut point diameter is an index for measuring the performance of the cyclone separator.

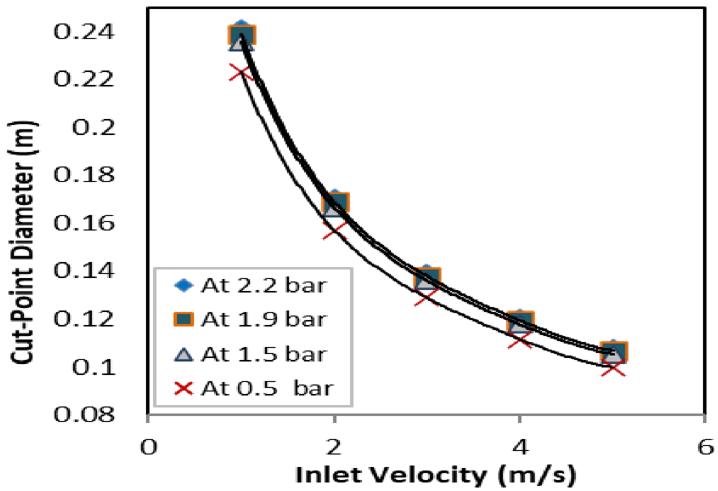


**Figure 5:** Influence of cyclone separator inlet velocity on the cut-point diameter.

Figure 6 and 7 show the relationship between the cut-point diameter and the collection efficiency of the cyclone separator at pressure 2.2 bar and variation of the particle diameter at range of 60-100$\mu m\mu m$. It can be noted that as the cut point diameter decreases the collection efficiency of the cyclone separator increases for all different diameter of particles. The minimum efficiency obtained by the diameter of 60$\mu m\mu m$, while the maximum obtained by the particle diameter of 100$\mu m.\mu m$.

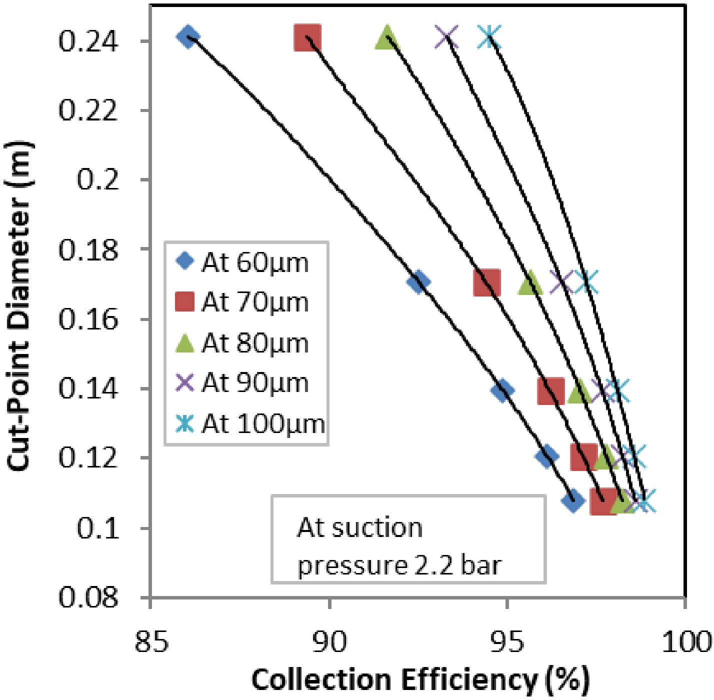


**Figure 6:** Influence of cut-point diameter on cyclone separator collection efficiency with variation of the particle diameter.

Figure 7 shows the variation of cut-point diameter and the collection efficiency for particle diameter of 80$\mu m\mu m$ at pressure ranges of 0.5 bar to 2.2 bar. As shown in Figure 7 the collection efficiency of the cyclone separator increases as the cut-point diameter decreases at all different pressures ranges. The maximum efficiency of the cyclone separator obtained at the suction pressure of 0.5 bar.

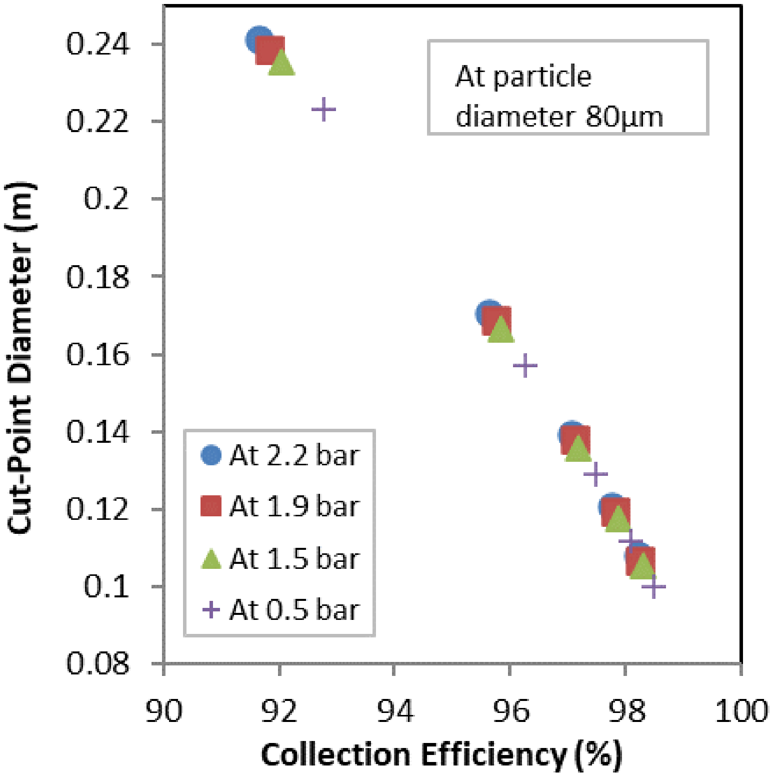


**Figure 7:** Influence of cut-point diameter on cyclone separator collection efficiency with variation of the suction pressure.

**Conclusion:**

1. As the inlet velocity increases, the settling velocity of cyclone separator increases.
2. The increase in inlet velocity has a positive effect on performance of cyclone separator.
3. Cut-point diameter decrease has a positive effect on settling velocity and the collection efficiency of the cyclone separator.
4. Formation of bigger particles results in better performance for the separator.

**Nomenclature:**

$D_j$ : jth particle diameter (μm)

$D_p$ : Particle diameter (μm)

$D_{pc}$: Diameter of particle collected with 50% efficiency (µm)
g: Acceleration of gravity (m/s$^2$)
$h$: Height of inlet duct (m)
$l$: Height of inlet duct (m)
N: Number of effective turns
r: Cyclone radius (m)
$V_i$: Cyclone inlet velocity (m/s)
$V_t$: Settling velocity (m/s)
$V_{tr}$: Radial settling velocity (m/s)
W: Width of cyclone inlet (m)
$z$: Length (vertical) of cyclone cone (m)
$\eta_c$ : Collection efficiency (%)
$\mu_g$: Gas viscosity (kg/m.s)
$\rho_g$: Gas density (kg/m$^3$)
$\rho_l$: Liquid density (kg/m$^3$)
ω: Angular velocity (rad/s)

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